RCAF DEFENCE ECONOMICS

CANADIAN ARMED FORCES

FORCES ARMÉES CANADIENNES

National Defence Défense nationale

Canada

RCAF
DEFENCE
ECONOMICS

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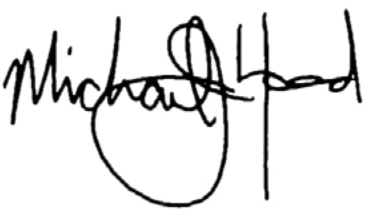
Foreword

RCAF Defence Economics brings together topical issues, concerns and analysis methodologies, culminating in a one-source reference, focusing on the very dynamic, complex and intricate arena of defence economics and resource management. The subject matter is pertinent to all military environmental domains; however, this handbook has been written as a resource from a Royal Canadian Air Force (RCAF) perspective. As Commander, it is my responsibility to evolve the RCAF enterprise within the institution of the Department of National Defence (DND) consistent with its mission and vision. Continually weighing and balancing complex global and domestic actualities involve a progressive persistence necessary to adapt and remain current, vital, and within the dimensions of our strategic direction—*Strong, Secure and Engaged*. This book elucidates insights and illustrates the complexities and interwoven nature of the book's theme, recognizing that the limited and politically discretionary resources of the DND generate a true challenge in the fundamentals of defence priority.

The Royal Canadian Air Force Aerospace Warfare Centre (formerly CFAWC) has commissioned a book on the challenges and opportunities of managing RCAF resources. The book is intended to offer a cogent survey of key resource management methods and applications in an accessible language for both officers and scholars interested in defence economics and operational research and analysis techniques. Although the focus is on the Air Force, the chapters in this book are selected to cover topics that have applicability to the wider public sector investment decisions and resources management. Since the global financial crisis, defence and other discretionary government programs have faced a series of downward revisions in their respective budgets. The Air Force, one of the most capital intensive of the armed forces, is acutely aware of these pressures and cognizant of the need for scientifically rigorous analysis to make critical investment decisions. This edited volume provides a comprehensive survey of resource management techniques intended to help both public officials and Air Force officers identify spatially optimal basing of aircrafts and military capabilities, choose a portfolio of capabilities that effectively counters security risks, and boost the efficiency and effectiveness of military forces.

RCAF Defence Economics offers a comprehensive survey of resource management methods intended to transform the RCAF and the wider public service into efficient and effective 21st century organizations. The book includes a synthesis of economic principles, operational research and decision theory wedded to a selection of real-world applications. Today, nations face the usual competing demands for public provision of goods and services in a limited resource environment combined with a threat environment that disrupts traditional notions of security and sovereignty. The chapters in this volume offer a valuable set of tools to navigate the political landscape and to meet calls to increase transparency and accountability, providing a resource to assist the Air Force and the Armed Forces in helping to guarantee peace and security. The handbook is primarily intended for military staffs, civil servants, and graduate students in management, economics, operational research and political science. As such, each chapter is a self-contained treatment of a particular aspect of resource management. The reader should be able to understand the research question (the policy issue to be addressed or the decision required), the theoretical model or the general approach used, the analysis (be it quantitative or qualitative), the results, the decision or policy prescriptions, and finally, issues to consider for future studies. In some cases, technical and mathematical discussions have been relegated to an appendix. It is important to emphasize the accessibility of each chapter to a diverse readership. This book is intended to both address a literate gap related to the Canadian Air Force and to provide a needed Canadian perspective in defence literature.

RCAF Defence Economics did not come together under the ownership of a single author. It was structured to include multiple authors selected for their academic and experience backgrounds in specialized areas subject to the disciplines of defence economics. Therefore, each chapter of this book is uniquely authored by senior accredited professors and scientists as a well-crafted compendium on the art and science of Canadian defence resource management. Initiated by Dr. Fetterly and Dr. Solomon, who observed a conspicuous lack of literature in this field, this book furnishes and sets the academic standard as the RCAF economics resource.



Michael J. Hood
Lieutenant-General
Commander Royal Canadian Air Force
2016-2018

CH01

Introduction

Ross Fetterly and Binyam Solomon

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Background

Defence resource management is a key factor in Royal Canadian Air Force (RCAF) outcomes. Business planning, the annual allocation for flying rates across fleets, investment in air force personnel training and infrastructure, as well as the effective administration of resources all have the potential to enhance operational output. Central to RCAF resource management is the concept that decisions need to be made from among a number of alternatives in order to meet a desired end state. As a consequence, this places considerable responsibility, accountability, and authority on RCAF leadership to make those decisions. Indeed, in a public-sector environment, where the customs of public-sector management imply that "administrators have a degree of discretion and that they are expected to make choices among alternatives"[1] and where the long-term nature of the environment can span several decades in some cases, the importance of effective resource management is paramount. Further complicating resource-allocation decisions is the balancing of constant near-term demands for resources in training, readiness, and operations with longer-term demands, such as initiating the options-analysis process to replace a specific fleet that may need to be replaced in a decade and a half.

All defence resource-management decisions are made in an international security environment that is constantly changing in terms of speed, scope, threat, and consequence. This brings an ever-changing dynamic to RCAF resource management, where decisions and changes need to be made within processes, such as the federal government budget cycle and the Treasury Board capital-equipment-procurement-approval process. What makes this process unique for the RCAF is the technical nature of air forces, their extensive use of multiple advanced aircraft fleets, the high cost of maintaining and operating those fleets, as well as the considerable annual cost to train aircrew and the air trade technicians who maintain the aircraft fleets. This publication on resource management in the RCAF will highlight the importance of resource management in the air force and emphasize the need for leaders and managers at all levels to effectively manage their resource allocations.

In the current, highly turbulent threat environment, the ability for air forces to deploy capabilities rapidly is critical. This impacts RCAF internal resource allocation for training, readiness, and interoperability. For instance, the experience of the Canadian Armed Forces (CAF) in Afghanistan strongly reinforced the importance of equipment to institutional success. As a result, focusing on resource allocation in a manner that is responsive to change is a key enabler of long-term institutional success. This is particularly the case in defence, where the unanticipated nature of emerging conflicts "forces the entire defence enterprise to reorient and restructure institutions, employ capabilities in unexpected ways, and confront challenges that are fundamentally different from those routinely considered in defense calculations."[2]

In 2017, "rather than witnessing the spread of stable liberal democracies worldwide, which develop the capacity to provide for the security and economic needs of citizens, we are seeing the large-scale movement of populations to zones of peace and prosperity."[3] Whereas safety and security in contested areas remain challenges, resolving regional conflicts has become increasingly difficult. In this environment, predictability and simplicity [can be viewed as] a "forlorn hope."[4] In addition, local security or economic problems can have global impacts. Yet even in Europe and North America, which have provided significant international leadership and stability, the past three decades have witnessed the growth in inequality within Western democracies[5] that now needs to be addressed by national governments. This is already placing a premium on the ability of defence departments to demonstrate substantive outcomes using the financial resources provided to them by national governments. How defence departments demonstrate strong outcomes depends on decisions by those national governments regarding future fiscal-year funding allocations.

RCAF Resource-Management Challenges

The RCAF is in the midst of an extended, uncertain, and challenging period, where both emerging operational requirements and shifts in resource demands are likely to surprise us on a frequent basis, bringing a constant diversity of unexpected challenges. This fluid, dynamic, and non-linear environment poses distinct and different challenges for RCAF resource planners. In a defence milieu where resource scarcity has become a precondition in defence planning, defence resource management needs to be fully staffed with capable leaders from a diversity of backgrounds and experience. Resource challenges in the RCAF that are likely to remain permanent fixtures as the security environment evolves include:

- budget pressures;
- increasing operating costs;
- costs incurred from operating ageing equipment;
- recruiting challenges with Canadian youth;
- providing cost-effective training to aircrew and air maintenance personnel; and
- investing in and maintaining RCAF infrastructure.

The risks that the RCAF faces today are distinct in that they are more systematic and global than in the past, while also being more unpredictable and interrelated. Although the RCAF is a well-managed and established long-term organization, historically, it has been a better executor than innovator. Yet, the experience of the RCAF in Afghanistan demonstrated its ability to innovate when faced with operational challenges. The challenge now, however, is to incorporate innovation into the core of RCAF culture and doctrine. Furthermore, as the RCAF is an expeditionary air force, it is generally more of a capital-intensive organization than territorial air forces are. In a business environment where innovation is being democratized, a culture of innovation in the RCAF is essential to continued operational achievement. In this environment, successful outcomes "will depend on an inclusive, collaborative, and internally and externally networked culture, to draw in ideas"[6] from external sources and counter peer competitors.

Furthermore, technological advances in military aircraft frequently demand new investment and upgrades. This drives the need to generate original and creative thinking to keep the institution effective and relevant. Viewed from this perspective, the RCAF needs to be much more proactive in its resource-management approach by placing itself at the leading edge of disruptive trends in order to keep pace with potential adversaries. Developing and supporting divergent thinkers in the RCAF could help support generating a broader perspective on resource-management issues in the RCAF.

Following the decade-long Afghanistan expeditionary mission, the Department of National Defence (DND) and CAF shifted their joint focus to the institution, institutional reform, and governance. This period of reflection and reform strengthened internal governance significantly in a very deliberate and focused manner and was necessary after an extended period where operations predominated. The aim of this institutional shift to governance was, first, to improve internal decision making and resource allocation/management and, second, to demonstrate to central agencies and the government that defence resources were well managed. As a consequence, the centre of gravity in defence administration is becoming the effectiveness of resource management. From the RCAF's perspective, it now needs to demonstrate on a continual basis that it has optimized its resource allocation and effectively executed its business plan.

The RCAF is, as are all other elements of the defence establishment in Canada, faced with the constant watermark of fiscal realities. While the RCAF does not have control over when it will have to face external challenges, the air force knows the rate at which its existing weapon systems are wearing out. With the continual rapid advancement of technology, leveraging advanced systems will depend to a considerable extent on these new technologies. Indeed, while technology is a primary factor driving change in the RCAF, continuously adopting new technology is creating an explosion of data. To an increasing extent, the RCAF environment is becoming driven by data, which represents a near-term challenge. With serious gaps in our resource-management-business-intelligence capacity, the RCAF needs to augment information availability so that decision makers at all levels have the capacity to make better resource-management decisions. This is currently being addressed at the institutional level, which will benefit the RCAF once implemented. Viewed from that construct, the RCAF now has the ability to adapt to a changing security environment that will be shaped by the effective allocation of resources.

A number of chapters in this publication are written by defence scientists, illustrating the importance and utility of applied research. This research can be done to improve or enhance existing equipment and direct future requirements or force generation of aircrew and air trades. Research and publication are also within the domain of the Canadian Forces Aerospace Warfare Centre. Yet, scholarship and publications on resource management within the RCAF are, unfortunately, limited. The objective of this book is to contribute to the literature on this subject and be a resource for RCAF and CAF personnel, defence officials, central agencies, academics, and Canadians.

Outline

As the title of the book implies, defence resource management is both an art and a science. Money and, more specifically, the monetization of various aspects of social interaction have allowed economics to be quantitative and relatively scientific. However, not all aspects of military outcomes and effects are quantifiable.

Some public-sector economic solutions arrived at after careful analysis of available data may lead to outcomes that are unpalatable politically. As a policy-relevant discipline, economics needs to translate principles into practical applications. An economics and resource-management book must provide logically consistent principles (science) and skilfully translate these principles into reality (art). This transformation of science into art requires accessible language and a practitioner's touch.

Defence resource-management practitioners and experts working in academia and research organizations as well as senior military officers contributed to this book. Some of the chapters use quantitative data to arrive at a particular resource-management challenge (Chapters 2, 5, 6, and 12). Others provide a critical review of a particular case study to highlight and recommend courses of action (Chapters 12–14). The unifying structure of the chapters is the transition from strategic and external factors to the operational and tactical challenges that influence RCAF resource management.

Introduction and strategic issues

Which external factors influence the RCAF resource domain? This introduction and Chapters 2–4 outline these factors and provide a broad overview of the book. In Chapter 2, Dr. Binyam Solomon (Defence Research and Development Canada [DRDC] Senior Scientist and Adjunct at Carleton University) traces the relationship between the Government of Canada's (GC's) own resource management and its influence on CAF and the RCAF. Competing demands for scarce federal funding put significant pressure on CAF and the environments to show value. The chapter also presents a simple resource-allocation model that forecasts some of the RCAF's likely responses to external "shocks" in the form of strategic review or doctrinal shifts.

Chapter 3, by Colonel Ross Fetterly (former RCAF Comptroller and Adjunct Professor at University of Ottawa and Royal Military College [RMC]), outlines the resource-allocation challenge and formulates the key research question addressed throughout the book. Specifically, given the historical consistency of the broad and strategic defence priorities in Canada, some force structures within the RCAF are likely to endure. However, globalization, the security environment, and technology are all impacting force-planning and force-management strategy. The RCAF also needs to consider political and institutional effects, which manifest themselves in the form of changing government mandates, the median voters' preferences, and international relations. These changes have a material impact on how defence and the environments are structured, managed, and evaluated.

Viewed from force-development and planning perspectives, Chapter 4, by Dr. John Steele (Defence Scientist at DRDC), presents capability-based planning (CBP) at the CAF level and its implications for the RCAF's own force-planning outcome. A well-functioning CBP ought to be agnostic about the who and the how of the provision of military effects. Consequently, the RCAF needs to be aware that some of the military effects that it currently provides may potentially be sourced by other environments or even by civilian and foreign sources.

Institutional drivers and resourcing strategies

The GC, through its central agencies, provides guidelines, procedures, and mandates that influence or constrain the resource-allocation strategies of line departments such as DND/CAF. For example, the government employs three distinct line departments when purchasing military equipment. One line department is responsible for monitoring and assisting key industrial sectors. Most aerospace and defence firms fall into this category. Another organization is responsible for all government procurement and ensures that financial and contracting rules and regulations are followed to satisfy accountability and transparency requirements. DND/CAF, of course, is the department that requires military equipment to fulfil its and the government's military outcomes. The next three chapters address these GC demands and their consequences on CAF's and the RCAF's resource-management strategies.

In Chapter 5, Dr. Bohdan Kaluzny (DRDC Scientist) develops an F-35A unit-recurring-flyaway cost model to illustrate the application of an independent estimate and analysis tool. Reporting costs in a rigorous, transparent, and replicable manner to parliamentarians is a natural consequence of accountability and transparency initiatives. Effective resource management also requires such tools to fully understand the cost, benefits, and affordability of the portfolio of military capabilities.

The Life Cycle Cost Framework[7] outlined by the GC provides direction on how to formulate, calculate, and report the full cost of military equipment. Dr. Kaluzny's work also provides information on the DND/CAF reporting requirements. Similarly, the work of Dr. P. E. Desmier (Senior Defence Scientist and Director of Materiel Group Operational Research) contributes to the development of tools with a special emphasis on operating and sustainment costs.

In Chapter 6, Dr. Desmier uses standard time-series statistical techniques to forecast future sustainment costs for the next-generation fighter that will replace the current CF18 fleet. The key consideration in this forecasting model is the use of the ratio between the acquisition costs of the existing platform and the acquisition costs of the new platform to predict the evolution of sustainment costs. This novel approach is applicable to any platform, as long as historical sustainment costs of analogous systems exist.

In Chapter 7, Dr. J. Craig Stone (RMC and Canadian Forces College professor) provides an assessment of the key industry players in the provision of capital equipment to the RCAF. The aerospace industry's structure, areas of specialty, and overall economic and financial health provide clues to how the RCAF chooses resourcing strategies. The broader and healthier the industry, the more flexibility it confers on the RCAF when choosing among alternative sourcing strategies.

In Chapter 8, Richard Shimooka (Research Fellow at CDA [Conference of Defence Associates] Institute) considers various government procurement strategies that often seem to be mutually exclusive. Can the government design a policy that will nurture domestic capacity, respect international trade regulations, and provide competitive prices that are affordable for the military services?

Force generation and related issues

In the last section of the book, the chapters address force-generation issues with the help of general operational-research techniques or case studies. Chapter 9, by Lynne Serre (Defence Scientist with Director General Military Personnel Research and Analysis) provides modelling and simulation techniques to assess various attrition trends in CAF in order to inform annual planning of intake and production of military personnel. The modelling and simulation tool provides planners with information on attrition drivers, gaps in military intake, as well as recruitment and retention strategies.

For the RCAF, pilot training is the most crucial and complicated process. In addition to recruitment and retention challenges (given the civilian demand for the specialty), choosing among training formats is equally demanding. In Chapter 10, Dr. Stuart Grant (DRDC Senior Scientist) provides an interesting overview of the role of simulation within the suite of training tools available for pilot training. The key insight of the chapter is the assessment of the benefits of simulation. While ample information and data exist on the costs and valuation of inputs, the benefits of simulation are not fully analysed or understood. The chapter provides important methods and approaches for weighing the costs and benefits of simulation.

The final three chapters provide case studies on select RCAF activities or initiatives to describe the practical use of resource-management strategies. In Chapter 11, Colonel Fetterly collaborates with Christopher Penney (DRDC scientist) to evaluate the effectiveness of strategic air-transport and search-and-rescue capabilities. These are arguably the most visible of the RCAF's capabilities and the most amenable for quantitative analyses. The chapter tackles important issues such as in-year pressures and mitigating strategies, resourcing decisions related to force generation and force employment, as well as key RCAF cost drivers.

In Chapters 12 and 13, the pilot-training program and alternate service delivery (ASD) strategy are jointly examined. The RCAF has a solid history of designing and managing ASD or of outsourcing activities. NATO Flying Training in Canada (NFTC) is one of the main ASD strategies managed by the RCAF and the focus of the last two chapters of the book. Chapter 12, by Dr. Charles J. Hunter (DRDC), describes and applies the NFTC resource-allocation model, which provides predictions on student-load limits given a specified set of resources (e.g., teaching personnel, equipment, maintenance, etc.). The model also includes features such as concurrency (scheduling of multiple activities), seasonal daylight-flying limitations, and real-weather training-day effects.

While we can use the model to plan and make student-loading decisions, Lieutenant-Colonel Jonathan Clow (Air Staff) investigates the contract design, award, and monitoring aspects of the NFTC in Chapter 13. NFTC is run by a contractor, Bombardier Inc., and includes a mix of government-furnished personnel and equipment to conduct the training. The chapter critically examines this complex program and the associated performance monitoring issues and challenges.

Conclusion

The global strategic environment is currently bringing about non-linear and disruptive change, while shifting to an uncertain multipolar world. A traditional evolutionary approach to change in a time where strategic planning needs to provide the context will challenge the RCAF to seize emerging initiatives. The RCAF's current focus on innovation is a strategy geared towards positioning the RCAF for future opportunities.

With technology advancing rapidly and warfare shifting to a hybrid and multidomain environment, the RCAF needs to exploit innovative approaches to research-and-development strategies and business-planning activities. This book provides ideas and insights that support transformation initiatives which will help the RCAF reshape and position itself for the future.

Ross Fetterly retired in 2017 from the Canadian Forces after a 34-year career as the Royal Canadian Air Force's Director of Air Comptrollership and Business Management. He previously served as the Military Personnel Command Comptroller, and in other senior positions with the Department of National Defence Assistant Deputy Minister (Finance). He is currently a Fellow with the Canadian Global Affairs Institute. Retired Colonel (Col) Fetterly completed a tour in February 2009 as the Chief CJ8 at the NATO base headquarters at Kandahar airfield, Afghanistan, where he was responsible for finance, contracting and procurement. Col Fetterly was employed as the deputy commanding officer of the Canadian contingent in the United Nations Disengagement Observer Force in the Golan Heights in 2000–01. He has served as an Air Force Squadron Logistics Officer and as a Finance Officer at military bases across Canada. He is an adjunct professor at the Royal Military College of Canada (RMC) Department of Management and Economics, and a Senior Fellow with the Centre for Security Governance. Dr. Fetterly has a B.Comm (McGill), M.Admin (University of Regina) and an MA and PhD in War Studies from RMC. His PhD fields of study included defence economics, defence policy and defence cost analysis.

Binyam Solomon is Senior Defence Scientist at Defence Research and Development Canada and an Adjunct Research Professor at Carleton University. He is currently on assignment as the special advisor to the Deputy Parliamentary Budget Officer. Previous appointments include co-editor of the journal, Defence and Peace Economics (2013–18), Chief Economist, Department of National Defence, and acting Chief Scientist at the Centre for Operational Research and Analysis. He has published extensively in economics, statistics and defence topics. His research interests include political economy, defence management, peacekeeping economics and time series methods. Solomon holds a PhD in Defence Economics from the University of York, United Kingdom.

Abbreviations

ASD	alternate service delivery
CAF	Canadian Armed Forces
CBP	capability-based planning
DND	Department of National Defence
DRDC	Defence Research and Development Canada
GC	Government of Canada
NFTC	NATO Flying Training in Canada
RCAF	Royal Canadian Air Force
RMC	Royal Military College

Notes

1. Douglas Bland, *Issues in Defence Management* (Kingston: Queen's University School of Policy Studies, 1997), 15.

2. Nathan Freier, *Known Unknowns: Unconventional Strategic Shocks in Defense Strategy Development* (Carlisle, PA: Strategic Studies Institute, 2008), vii.

3. Jennifer Welsh, *The Return of History: Conflict, Migration, and Geopolitics in the Twenty-First Century* (Toronto: House of Anansi Press, 2016), 136.

4. Bernd Horn, "No, But Yes. Military Intervention in the New Era: Implications for the Canadian Armed Forces" (Calgary: Canadian Defence and Foreign Affairs Institute, 2015), 3.

5. Thomas Piketty, *Capital in the Twenty-First Century*, trans. Arthur Goldhammer (Cambridge, MA: The Belknap Press of Harvard University Press), 2014.

6. The Conference Board, "CEO Challenge 2017: Leading through Risk, Disruption, and Transformation" (New York: The Conference Board, Inc., 2017), 6.

7. Canada, Treasury Board Secretariat, "Next Generation Fighter Capability: Life Cycle Cost Framework," accessed January 25, 2018, https://www.canada.ca/en/treasury-board-secretariat/services/reporting-government-spending/what-we-are-doing/next-generation-fighter-capability-independent-review-life-cycle-cost-framework.html.

CH02

The Political Economy of the Royal Canadian Air Force

Binyam Solomon

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Introduction

The Royal Canadian Air Force (RCAF) is a complex organization with many facets that make it an ideal subject of study for defence economics and resource management. From a national-security perspective, the RCAF is the first line of defence, as implied in *Air Force Vectors*: "Defending Canada in the current strategic and political environment requires capabilities that allow surveillance **and** control of the entirety of the Canadian airspace, coast and maritime approaches."[1] [emphasis in original]

The RCAF is also the instrument of Canada's bilateral commitment to defend North American airspace alongside the United States (US). Further, the RCAF is responsible for space, which is increasingly becoming the next frontier for conflict and resources.

Economically, the RCAF and air transportation are crucial elements for both defending and linking remote locations. The aerospace industry in Canada and elsewhere receives considerable attention from governments as a source of innovation and strategic industrial capacity. Given this special attention by governments, the aerospace industry is also adept at lobbying.[2] The labour used to produce air effects is highly specialized and in great demand outside the military. Consequently, the cost for training and retaining labour is significant compared to other environments such as the Canadian Army (CA).

In terms of capital, the RCAF utilizes sophisticated and technically complex military aircraft. When procuring or asking for funding for such equipment, the RCAF faces increased public and political attention, but without a commensurate awareness and understanding of the cost risks associated with such purchases. As noted earlier, governments are interested in the aerospace and related high-technology industries for their potential as job creators and an engine of innovation. The RCAF capability requirements face the trilemma of domestic industrial policy, limited funding, and national-security exigencies.[3]

There are a number of defence-economics questions worth exploring. Given the important role aviation plays in the defence of the North American airspace, does it command a large portion of defence funding? Is the RCAF a franchise monopoly? Since there are no competing organizations that can provide maritime, land and air effects, there are no incentives to innovate or conduct efficiency improvements.[4] In addition, there are no profit incentives that can entice the RCAF or other environments to continuously search for productivity improvements.

The lack of a signal both from price and profit does not necessarily limit the application of economics-based policy prescriptions. The articulation of the RCAF's resource challenges in terms of economics provides the necessary framework to define and explain the problem and to structure the analysis and solution space within the budgetary and political constraints. The purpose of this chapter is to explore and analyse the strategic-level resource challenges that the RCAF faces through economics and resource-management tools.

Such an assessment would be incomplete, however, without an understanding of the Government of Canada's and the Department of National Defence's (DND's) fiscal and economic environments.

As a result, the chapter begins with a brief overview of these higher institutions. The next section looks at RCAF manning requirements and then critically examines RCAF resource allocation by reviewing its labour demand. Ideally, inputs such as labour provide clues about the optimality of the production process if linked to a quantifiable (monetized) measure of air effects. In the absence of such data, we use a model of labour requirements to examine the RCAF resource-allocation strategy. Appendix A provides technical details about the labour-demand model and the associated statistical measures. The RCAF strategy is further explored through a qualitative and quantitative assessment. In particular, we look at research issues posed by RCAF senior leaders over the last decade and at indirectly observed intent. The last section provides a conclusion and points to future research directions.

The Fiscal and Economic Environments

One of the anonymous reviewers for Chapter 4, Capability-Based Planning and the Royal Canadian Air Force commented that "CBP [capability-based planning] for the Air Force in isolation of the other services [sic] is no different in concept than CAF [Canadian Armed Forces] CBP in isolation of [its] allies, OGDs [other government departments], NGOs [non-governmental organizations], etc."

The reviewer is, of course, reminding us of the important linkages among CAF's environments when formulating force-development strategies. Similarly, discussing resource management in the RCAF needs to be contextualized as part of the Government of Canada's decision space. We begin this chapter by providing a brief overview of the Canadian government's resource-management challenge.

As a small open economy, Canada relies on international conventions as well as bilateral and multilateral economic and security arrangements.[5] Thus, when balancing the need for national security with that of a health- or social-safety net, the federal government has to consider the international environment. The geography and population dispersion also complicate the balancing act. The country covers more than nine million square kilometres, yet the majority of the population lives within driving distance of the US border. Regardless, the federal government, both directly and through provincial transfers, supports the necessary infrastructure for citizens located in remote regions of the country.

A democratically elected government also attempts to address certain popular initiatives to maintain broad appeal and electability. Often these initiatives will have long-term fiscal effects, constraining future allocation of scarce resources. For example, Hart and Dymond[6] point out that in the 1960s, the Canadian federal government pursued a socially activist agenda to redistribute income and help poorer regions. By the 1970s, the government of the time felt that the state ought to advance science and technology, urban affairs, environment and international development.[7] To facilitate these expansive policies, the government created departments, ministries of state, and over 100 new agencies, boards and commissions.[8]

As shown in Figure 1,[9] the federal debt level steadily increased in the 1970s until its peak in 1997 at $750B in real dollars.[10] The steady decline since then is largely attributable to the more restrained (from a social activism and budget perspective) approach and reliance on market-based solutions of successive governments. The comparable data are only available to 2008 and do not include the recent government's expansive approach to combat the great recession.

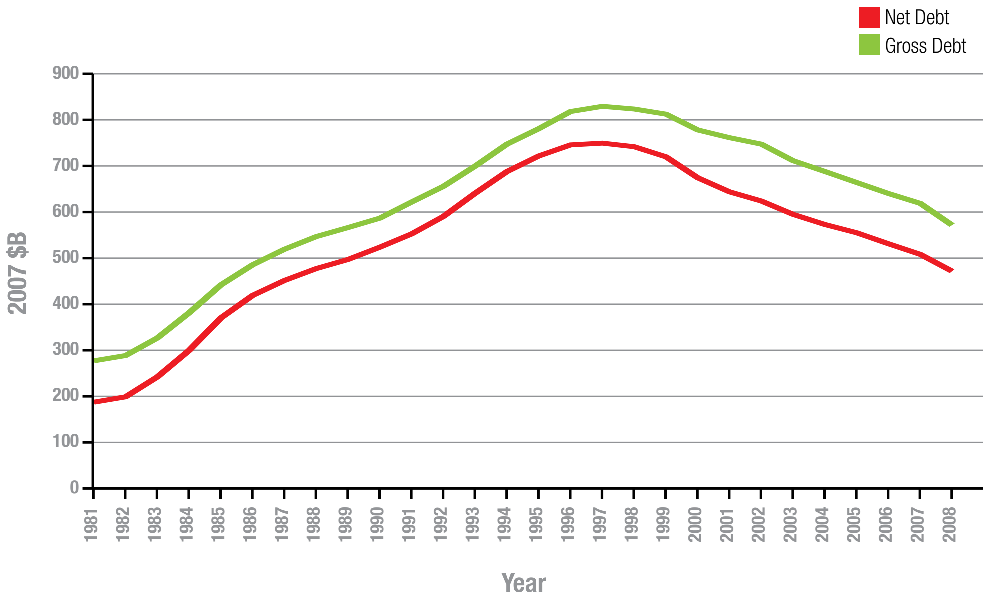

Figure 1. Federal debt (net and gross) in constant 2007 B dollars[11]

Over the last two decades, the federal debt has played a major role in limiting funds that can be allocated to legislated transfers to persons, provinces and discretionary programs. For example, in 1991, interest payments on the federal debt accounted for approximately 30 cents of every dollar spent by the federal government. Figure 2[12] shows a steady decline in interest charges since the 1990s, but both discretionary and statutory spending have continued to account for increasing shares of federal spending.

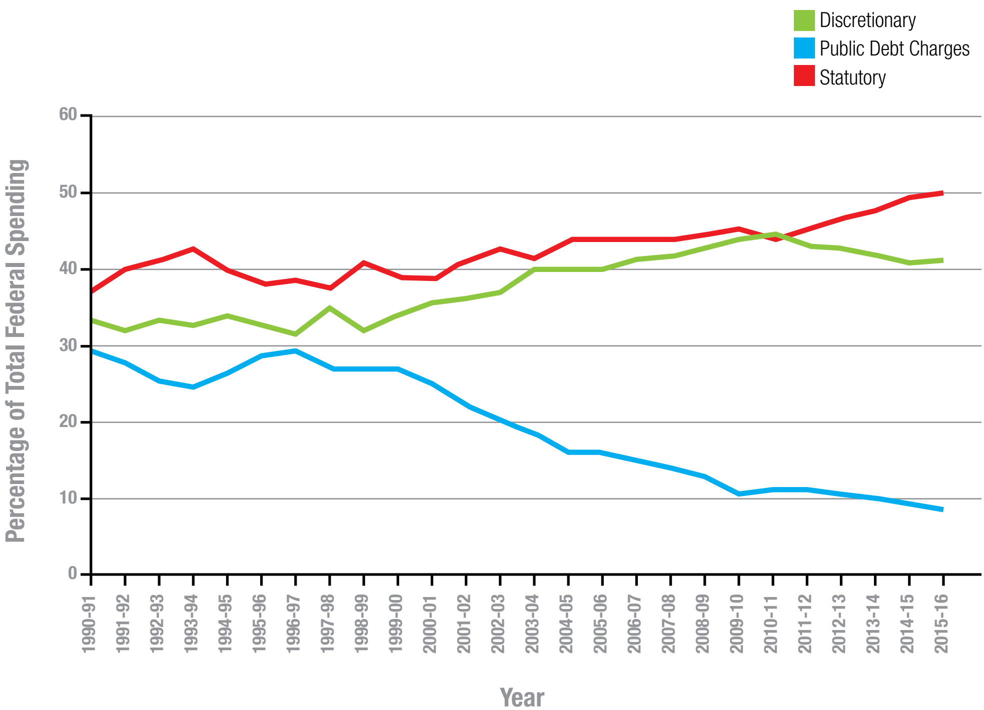

Figure 2. Categories of federal spending[13]

Figure 3[14] illustrates DND funding levels. The figure baselines DND and OGDs' operating expenses to fiscal year (FY) 1990–91 dollars. Setting the figure to 100, it traces the relative growth and contraction of both categories over the years. DND and the OGDs experienced contraction in response to the increasing federal debt and the resulting budget-reduction strategy. By 1999–00, the OGDs had recovered to their 1991 levels, and by 2010–11 peaked at 32 per cent (%) above the 1990–91 level.

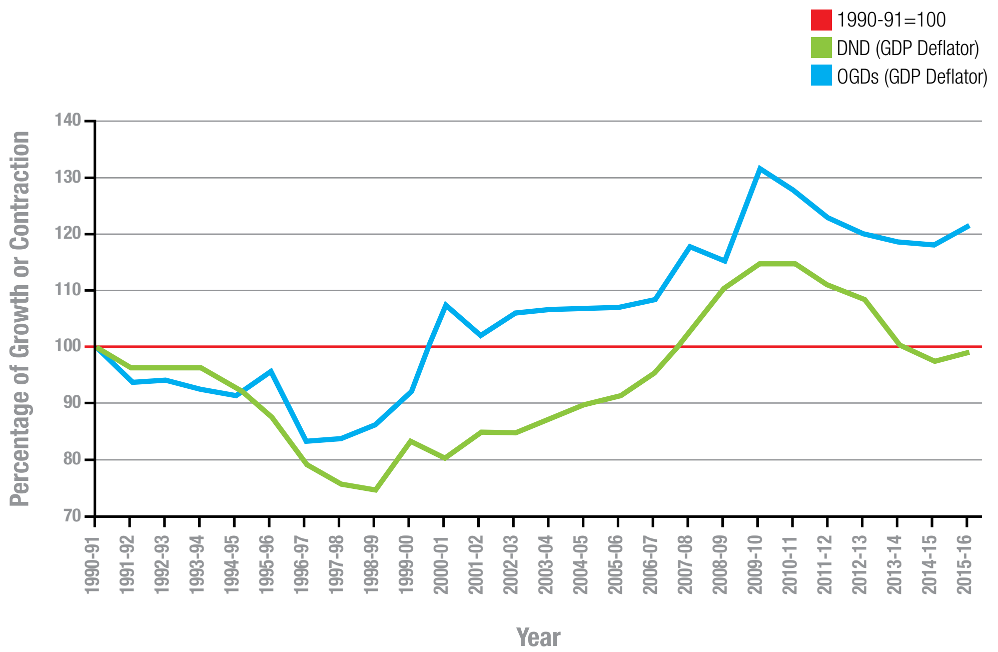

Figure 3. Relative growth/contraction of federal departments' expenditure levels, with FY 1990–91=100

In contrast, DND bottomed out at 25% below its 1990–91 level in FY 1998–99 and only recovered to its 1990–91 level in FY 2007–08. After peaking at 15% above its 1990–91 level in FY 2009–10, it is now back below its 1990–91 level. This is partly because that DND accounts for about a quarter to one-third of discretionary spending (see Figure 4[15]); in times of austerity, the government is more likely to prioritize other competing demands.

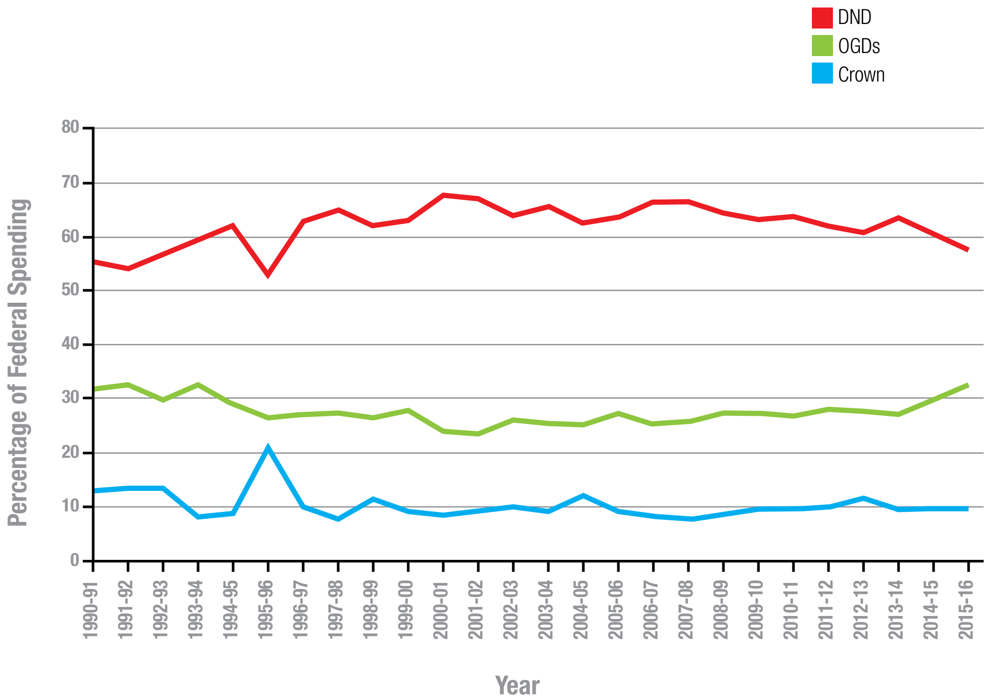

Figure 4. Per cent of federal spending, less transfer payments[16]

Funding (demand side)

There are other reasons as well for DND's relative neglect as compared to OGDs. As discussed briefly above, politics is regional in Canada, and defence, by its nature, is national. Consequently, advocacy is rather diffused for defence except in regions where its presence is significant. Most importantly, the relative preference for non-defence activity is a choice, one that has remained constant regardless of political party.

This choice, or the demand for military spending in Canada, is governed not only by competing demands and the implied trade-offs but also by a number of political and economic variables. Economists have been studying the collective-action problem associated with military alliances such as the North Atlantic Treaty Organization (NATO) and the consequences on the determinants for national defence spending. For example, Murdoch and Sandler[17] have developed a theoretical framework that treats nations as social-welfare maximizers to assess the strategic interactions of NATO member states. Studying the period from 1950 to the 1970s, the authors find that Canada and a number of smaller European nations enjoy a free ride on the efforts of larger member states.

Appealing to a far longer time span, from the inception of NATO until the 2000s, Solomon[18] finds subtle differences in the Canadian reaction to allies' defence spending. According to the study, Canada complements European defence spending (no free riding), but its reaction to US defence spending is inconclusive. In addition, the study finds that Canadian political-party affiliation does not influence defence spending; however, the relative increase in defence prices negatively influences military budgets.[19]

A more recent study by Sandler and Shimizu[20] sees the burden-sharing calculus shifting towards the exploitation of the richer member states (more free riding) due to NATO's recent doctrine of crisis response. According to the study, NATO's new doctrine requires nations to project forces beyond the alliance's area, requiring strategic lift and other force-projection capabilities.

The demand by nations for military expenditures is also affected by their relative prosperity or income levels. As Hartley[21] points out, nations that desire to maintain labels such as "great power" are willing to spend one per cent or more of their national wealth on military forces. Douch and Solomon[22] confirm the phenomenon in relation to middle powers. Middle-power nations also spend a proportional amount within their peer group to maintain their status.[23]

Producing defence (supply side)

The preceding subsection outlined the funding decisions of the federal government, which can be interpreted as the demand side of the resource-allocation strategy. Within the Westminster governance architecture, the elected government communicates its vision and priorities through a speech from the throne. The federal budget provides the funding profile for the stated priorities, and implicated government departments receive directions through White Papers.

Fetterly[24] points out that defence White Papers have remained remarkably constant (in substance) since the 1960s. In particular, common features include the defence of Canadian sovereignty, the protection of North America alongside the US, and projecting Canadian values internationally. As stated earlier, the vast Canadian geography makes geostrategic neutrality impractical.

Canada always has to contextualize its security environment within its bilateral and multilateral arrangements.[25] The stable defence-policy posture, however, belies the fact that changes to multilateral security arrangements have the potential to drag Canada into expeditionary operations that are well beyond the capabilities required for domestic or North American security. Thus, there is an implicit requirement to have a credible force that can mobilize and interoperate in an international security environment.

To operationalize these broad government mandates and tacit multilateral requirements, the military develops capability plans and strategies. This aspect is the supply side of resource management and the main theme of this book.

The supply side describes the production of military effects and the fulfilment of government mandates through the utilization of human and capital resources. In FY 2015–16, DND accounted for 57% of all federal equipment purchases and close to 30% of realty acquisitions. DND operates its own university

(Royal Military College of Canada), training institutions, health care system and police service, and owns over $26B in real property.[26] In terms of population and resources, DND is a small province.

While proper stewardship of these relatively vast resources is critical, Canadian taxpayers need to be aware of the value derived from them. DND provides multiple services that are visible to Canadian taxpayers, such as aid to civil power. Examples include the seasonal floods in Manitoba, the ice storm in Eastern Ontario and Western Quebec, national search and rescue coverage, maintaining military reserves in local communities, as well as security support for national and international events on Canadian soil.

Some services are partially visible, such as the North American Aerospace Defence Command (NORAD), the defence of North American airspace, and the Canadian Rangers' presence in northern communities. However, a large portion of DND activity is effectively invisible to the Canadian public. Force generation as well as the training and readiness of the forces consume large resources and are not visible to Canadians. International presence and commitments are not often effectively communicated, or Canadians do not understand the need to engage internationally.[27]

Given the paucity of visible benefits and relatively high costs, DND often faces considerable scrutiny, and without the benefit of a department-wide resource-management framework, regular attacks on its credibility. Since the late 1990s, DND has been developing and operationalizing strategic-management initiatives to align and communicate the production of military effects that respond to White Paper mandates. Rempel[28] and Blakeney et al.[29] provide a comprehensive survey of the strategic-management tools, such as CBP. These tools, concepts and operational-research techniques are enabling DND to link military effects to government outcomes and to better reflect the true resource costs of force structures and capabilities.

The Royal Canadian Air Force

Background

The RCAF, the youngest of the environments, came into existence shortly after the First World War (WWI), in 1924. However, Canadians participated in the air campaign in WWI as part of the British Empire.[30]

By the Second World War, the RCAF was the fourth largest of the Allied air forces and had a strong European presence during the early days of the Cold War.[31] The establishment of the Canada–US NORAD agreement in 1956 coupled with increased support to the United Nations (UN) facilitated a rapid increase in the number of RCAF personnel. However, as shown in Figure 5,[32] the RCAF's manning has declined persistently since the 1960s.

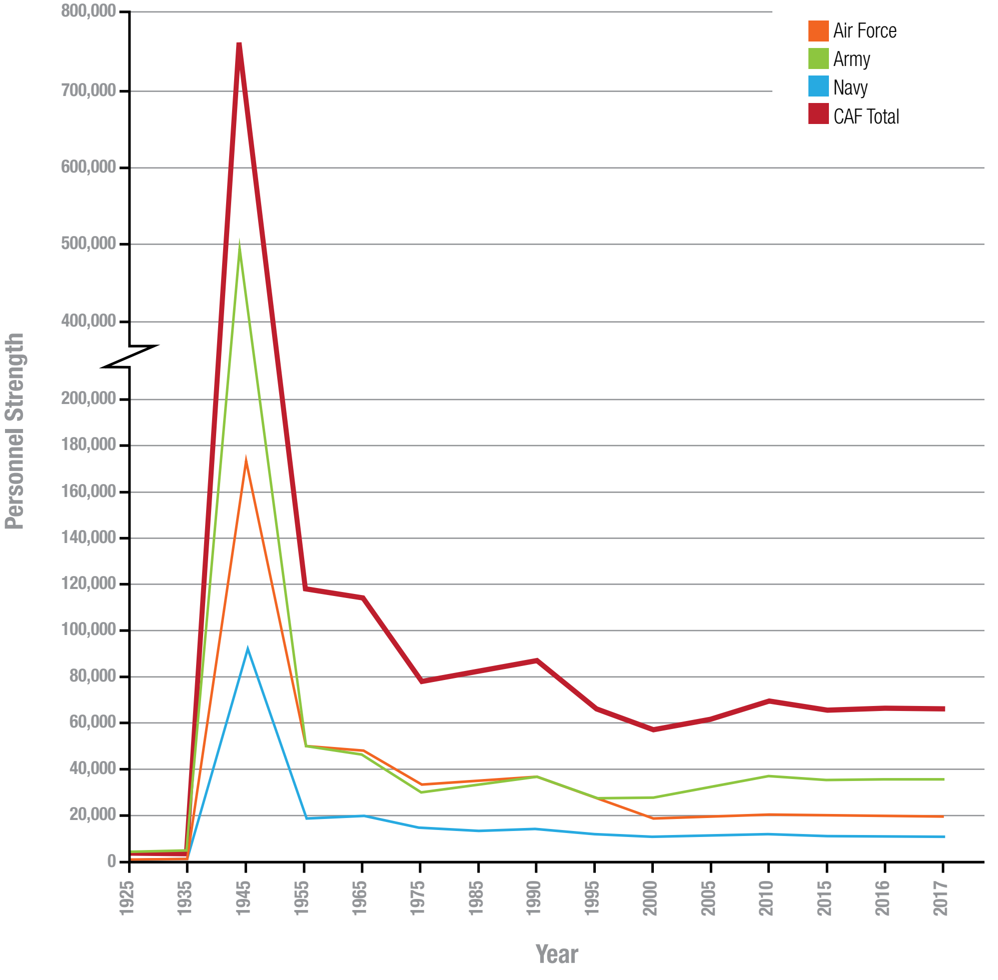

Figure 5. CAF personnel strength, various years[33]

Despite the decline, the RCAF remained the largest service/environment[34] from 1955 until 1990. By the end of the 1950s, the Cold War had reached its frostiest period, and the Canadian air force presence in Germany and France had increased to 12 squadrons of Canadian fighters.[35] Similarly, Canada's commitment to NORAD implied the formation of interceptor squadrons and the building of the Distant Early Warning (DEW) Line. A system of radar stations that could detect and characterize potential threats, the DEW Line provided an additional role for the RCAF. The 63-base DEW Line reached operational status in 1957.

The RCAF introduced and operated systems with nuclear weapons in the 1960s—albeit controlled by the US—in European- and North American–based fighter squadrons and the Bomarc missile sites. The latter resulted in a political crisis in Canada, where the Conservative government was defeated by the Liberal opposition.

The 1964 White Paper introduced substantial changes to CAF, including the integration of the services and a series of downward revisions in defence budgets. In addition, the 1964 White Paper placed a special emphasis on peacekeeping and justified the push to unite the services to support quick deployment and to fulfil peacekeeping obligations.[36] Politically, Canada could not extricate itself from NATO commitments, as the flexible-response doctrine necessitated the deployment of conventional forces in the European theatre. In addition, the federal government found that the commitment to peacekeeping was a cost-effective way of interpreting international and national expectations of the CAF's role. Meanwhile, the Canadian aerospace industry faced its own challenges stemming from technological changes, accelerating unit costs and budget reductions.[37] More importantly for the RCAF, licensed domestic production of aerospace equipment gave way to more reliance on US-built aircraft.

The RCAF also supported UN peace missions by providing combat (fighter pilots) and transport during the Korean War and significant aviation support for peacekeeping missions in the Middle East and Asia. Table 1 shows the types and amount of equipment used by the Canadian contingents, prior to the 1970s. During this time, the Americas (the Cuban missile crisis and humanitarian relief) and the Middle East region (traditional peacekeeping) dominated Canadian participation; air lift and to some extent sea lift accounted for almost all asset requirements. Between 1970 and the end of the Cold War (1991), the regions of activity remained the same, while the contingents' equipment needs shifted marginally towards logistics support.

Region	Type of Asset	Quantity
Americas	fighter squadron	31
Americas	cargo aircraft	21
Americas	destroyer	19
Middle East	cargo aircraft	17
Americas	frigate	16
Atlantic Ocean	destroyer	15
Americas	interceptor squadron	10
Americas	air transport squadron	6
Americas	composite unit	6
Middle East	aircraft carrier	5
Americas	brigade group	4

Region	Type of Asset	Quantity
Africa	cargo aircraft	4
Asia	destroyer	4
Middle East	transport squadron	4

Table 1. Frequently used assets for UN missions prior to 1970s[38]

Since 1990, Canadian troops have been deployed to practically all continents (see Table 2). The post–Cold War period also ushered in alternate peace missions led by organizations such as NATO and coalitions of the willing. The type of capital mix has included all three environments (sea, land and air). A number of factors have made recent peace missions expensive for both the UN and troop-contributing countries. First, the frequency of Canadian participation in these non-UN led missions has doubled in the last decade alone. Second, the missions are concurrent and span five continents. Third, the missions are complex and dangerous. The complexity and frequency of non-UN peacekeeping missions will certainly lead to a faster depreciation rate of CAF's (and in particular, the RCAF's) capital equipment.

Region	Type of Asset	Quantity
Americas	construction engineers and equipment	150
Europe	cargo aircraft	99
Europe	fighter aircraft	24
Americas	helicopter	22
Americas	AOR (oiler replenishment ship)	6
Americas	composite unit	6
Middle East	frigate	6
Africa	helicopter	6
Americas	infantry battalion	6
Africa	combat engineer troop	5
Americas	destroyer	5
Europe	frigate	5
Africa	infantry platoon	5
Europe	AOR	4
Europe	armoured regiment	4
Africa	cargo aircraft	4
Middle East	combat engineer regiment	4

Region	Type of Asset	Quantity
Middle East	helicopter	4
Africa	infantry company	4
Europe	infantry company	4
Europe	logistics battalion	4

Table 2. Frequently used assets for UN missions post 1990[39]

RCAF resource-allocation strategy

From a defence resource-management perspective, the relevant question we should ask is why did the personnel strength of the RCAF decline in comparison to the other environments? Typically, from an economics perspective, the use of inputs for any given production depends on the relative prices of these inputs. If defence outputs or outcomes are produced using a combination of armed forces personnel, civilians and equipment, one would assume that the relative price of RCAF personnel has risen.

Alternatively, our preceding discussions regarding demand have shown that governments have to make hard choices given multiple and competing demands. As Hartley[40] points out, often governments have three options when making decisions about defence resources. First, governments may recast the role of the armed forces (how much defence to produce) given the security environment and ability to fund the forces (for example, new White Papers or defence-review exercises). Second, they may engage in "review by stealth," which is a passive reduction through less training, etc.[41] Third, governments may search for productivity enhancements through process improvements, technology adoption or rationalization (strategic review or CAF transformation).

Note that each environment can make the case for an increased share of the defence fund allocated if the effects produced by the environment match the government's intent. For example, until the end of the Cold War, the RCAF enjoyed visible and measurable outputs compared to the other environments. From this perspective, it can be argued that it claimed a large portion of the funds. NATO's flexible-response doctrine implied a more equitable burden sharing[42] and necessitated the deployment of air assets in the European theatre.

Similarly, the joint continental-air-defence responsibility with the US provided valuable exposure to the largest military force, which also happened to be the largest trading partner. The Canadian government's decisions on its NORAD commitment are often made to follow the military's lead as opposed to setting its own agenda.[43] Finally, Canada's peacekeeping commitments prior to the 1990s relied on traditional peacekeeping roles, which suited the RCAF and its assets, as shown in Tables 1 and 2.

Post–Cold War, however, none of the above advantages were as important, perhaps with the exception of the NORAD commitment. The new NATO doctrine of crisis response implied projection of power and ground war, which increased the role of the Army relative to the RCAF. Until the purchase of the CC177 Globemaster and the associated strategic-lift capability in 2007, the RCAF could be considered substitutable to civilian or other military-lift capabilities. Peacekeeping also morphed into peace enforcement, nation building and complex humanitarian interventions. All these operations required a more coordinated response from all the environments and introduced new players such as NGOs, civilian police and international aid organizations.[44]

While the above discussion is consistent with the trend outlined in Figure 5, there are a number of confounding variables that may have affected the relative decline in RCAF personnel. Empirically or statistically speaking, one has to control for confounding factors before discussing implied association (not causation) between RCAF personnel changes and other factors, such as prices and temporal effects.

Ideally, to conduct a robust statistical analysis of the RCAF resources strategy, data on each of the military's environments is required. In addition, information on the relative valuation or monetized value of defence outputs is required. The measurement of defence outputs, particularly at the strategic level, remains elusive.[45] The current convention is to actually equate inputs with outputs. Stated differently, the cost of producing military forces is assumed to equal the output.[46] In the absence of such data, the following are used as potential explanatory variables:

- To account for the relative price effect of factors, long-term Canadian interest rates are used to proxy the price of capital, while the real-wage rate for aggregate non-RCAF labour is used as a proxy for the price of labour. Note that the relative price of labour is derived by subtracting the average standard cost of the RCAF (derived using the *Cost Factors Manual*) from personnel costs.
- For policy signals affecting RCAF resource strategy, the 1964 White Paper,[47] the NATO doctrinal shift from mutual assured destruction to flexible response and the budget cuts of the mid-1990s to combat government deficits are used.
- Finally, a proxy for the government's competing-demand narrative in the form of non-defence expenditures is used to account for demand-side signals.

As indicated in the introductory section of the chapter, Appendix A details the labour-demand model and statistical results. In general, the labour-demand model shows that the relative labour wages and capital affect the demand for RCAF personnel, as predicted by economic theory. In addition, the policy shocks of the post–Cold War and the 1990s budget reductions have a strong negative and statistically significant impact on RCAF personnel allocation. The steeper decline in RCAF personnel occurred during this period due to the combined effect of funding shortfalls, re-orientation of the RCAF from the European theatre, and the strong demand for pilots in other national air forces and the civilian market.

While the statistical model (described in detail in Appendix A) discussed above provides a quantifiable approach for examining the RCAF's personnel-allocation strategy, other cost drivers affect the RCAF as well. One of its main intermediate outputs is force generation: both human and equipment capital. This aspect is examined briefly in the next subsection.

Force-generation cost structure

In attempting to estimate the cost of a military capability, Solomon et al.[48] developed a strategic-level costing model. One of the model's key insights is the attribution of overhead costs and intermediate outputs, such as training, to key military capabilities. A closer look at the model's cost attribution to common and environment-specific training shows that RCAF training costs differ considerably from the other environments. First, RCAF training tends to use more contracted services than the other environments.[49] For example, as shown in Figure 6, maritime training has the least overhead, with 75% of its departmental impact showing up as direct costs.[50] For the Royal Canadian Navy (RCN), force generation and force employment tend to occur simultaneously and require minimal onshore support for training. Similarly, the common and land components have 70% of their training costs directly attributable to operations. In contrast, direct air training accounts for less than half (45%) of total direct costs of the RCAF.

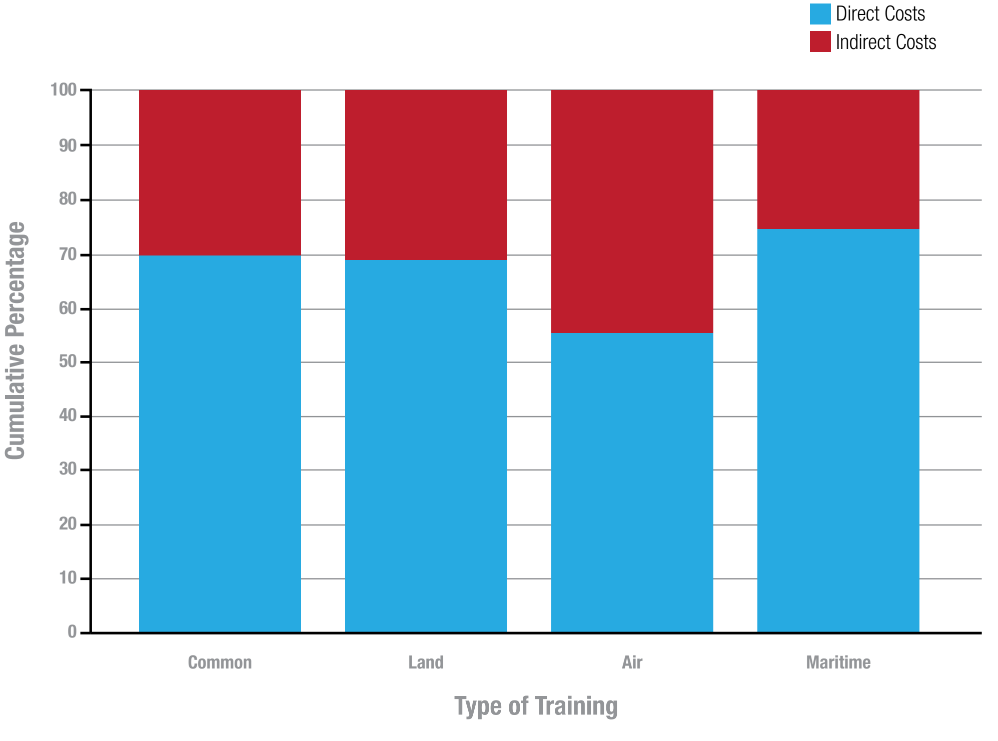

Figure 6. Ratio of direct and indirect training costs by environment[51]

Second, the use of contracted services implies, all things being equal, cheaper and efficient training. Third, the RCAF and resource managers in DND have to assume monitoring and oversight costs.[52] As discussed in Chapter 13, RCAF Pilot Training and ASD: Assessing and Improving a Dysfunctional Paradigm for the Future, the efficiency and savings failed to materialize due to suboptimal contract-and-performance-measure design.

Why do we use alternate service delivery (ASD) or the provision of services by the private sector through contracting? The main assumption here is that competition in the private sector fosters cost-effective operation and profit levels. Economic theory, however, is explicit in emphasizing the need for legitimate competition to induce efficiency gains in outsourcing. In addition, the active monitoring and proper accounting of oversight costs must be undertaken and unambiguously included in the overall cost of outsourcing. Contracts related to maintenance in aviation tend to be restricted to the original equipment manufacturer; while this restricts competition, the design of the contract is crucial for eliciting appropriate incentives to reduce price and increase productivity.

In addition to training, force generation on the capital side requires maintenance and airworthiness certification. Air assets, as a result, require more indirect support, or in military parlance, a lower tooth-to-tail ratio. According to Solomon et al.,[53] air assets such as maritime helicopters and tactical fighters have an even lower tooth-to-tail ratio (higher indirect support), with four and five personnel, respectively, employed indirectly for every individual employed directly. In essence, for every aircrew member operating the asset, there are four or five personnel on the ground providing maintenance and related activities to make the asset airworthy and combat ready.

In comparison, naval capabilities such as destroyers and frigates, require two or three personnel on shore, who provide maintenance support for every crew member who sails. Higher or proportionate tooth-to-tail ratios are observed for fleet and brigade headquarters (0.86) and mechanized infantry (0.9). According to the definition in Solomon et al.,[54] the indirect personnel requirement, or tail, stems from infrastructure and equipment support for the capabilities considered.

What Keeps the RCAF Leadership Awake at Night?

As discussed in Chapter 1, the majority of the chapters in this book deal with the recruitment, training and sustainment of people and equipment. While this is to be expected from the perspective of resource management, running an air force also requires an understanding of strategic-level issues. In fact, most business- and public-management texts often highlight the need to devote a considerable amount of senior-management time on visioning and mapping strategic direction.

Is this the case in the RCAF? While we are focusing on the RCAF in this book, the question of optimal allocation of public service, senior-management time for in-year resource allocation, crisis management and long-term planning is crucial.

For purposes of illustration and to contextualize the RCAF, we set out to examine the extant literature on resource management related to the RCAF. While the RCAF has the option to conduct studies internally or by contracting external sources, we examined studies conducted by Defence Research and Development Canada (DRDC) on behalf of the RCAF. This is a pragmatic choice, partially driven by data availability; it signals the RCAF's research priorities. In addition, we have information on DRDC's relationships with its clients and how research studies are tasked and executed.

This information is valuable for discerning and extracting studies that are commissioned or tasked by RCAF management as opposed to those generated by DRDC personnel and endorsed by RCAF management after the fact. The following filters were also applied to DRDC studies on the RCAF:

1. **RCAF filtered**. Depending on the level of experience of the defence scientist, the research report may reflect a methodology (approach) bias that may ultimately rescope or reformulate the research question outside of RCAF requirements.
2. **Technical duplicates**. Some studies are technical notes that describe the methodology or approach. They are produced to document scientific activity in support of a DND request. These studies are part of the final product or are supplementary works and were omitted to avoid duplicate results.
3. **External publications**. Proceedings or workshop presentations before international and national conferences or for academic journals were omitted from the sample, as these are often technical reproductions of client products. Their purpose is often professional development of defence scientists or an external validation of a relatively new methodology or approach.
4. **Client funded**. To ascertain that the studies sampled are RCAF generated and filtered, we chose a time period coinciding with client-funded research at DRDC.

Specifically, during the 2000–10 period, DRDC signed service level agreements with various DND groups (at the assistant-deputy-minister level) and environmental chiefs of staff to embed defence scientists with clients, in return by paying for the salaries and associated overhead costs. This arrangement provided a powerful signal to DND clients that the research and analytical products produced by DRDC are client focused and responsive to emerging requirements.

In order to avoid selecting studies that may have been influenced by the defence scientist's methodology bias, we further refined the sample to include studies conducted by experienced team leaders and defence scientists only. The DRDC Centre for Operational Research and Analysis (CORA) publication database was the source consulted.[55] The database is comprehensive and includes over 8,000 articles; it excludes studies that are classified beyond secret.

Using the filters discussed above (articles authored by experienced scientists, RCAF subject matter and time period from 2000–10), 35 articles were analysed. The articles are listed in Appendix C. The analysis results are shown in Figure 7. Over the 10-year period, operational research and analysis (OR&A) studies on force generation (recruitment, training and retention of RCAF personnel) accounted for 46% (16 articles) of the total RCAF publications. Another 38% (13 articles) of the studies dealt with force development or RCAF capabilities, while roughly 14% (5 articles) of the studies focused on strategic and long-term issues and 3% (1 article) focused on force employment.

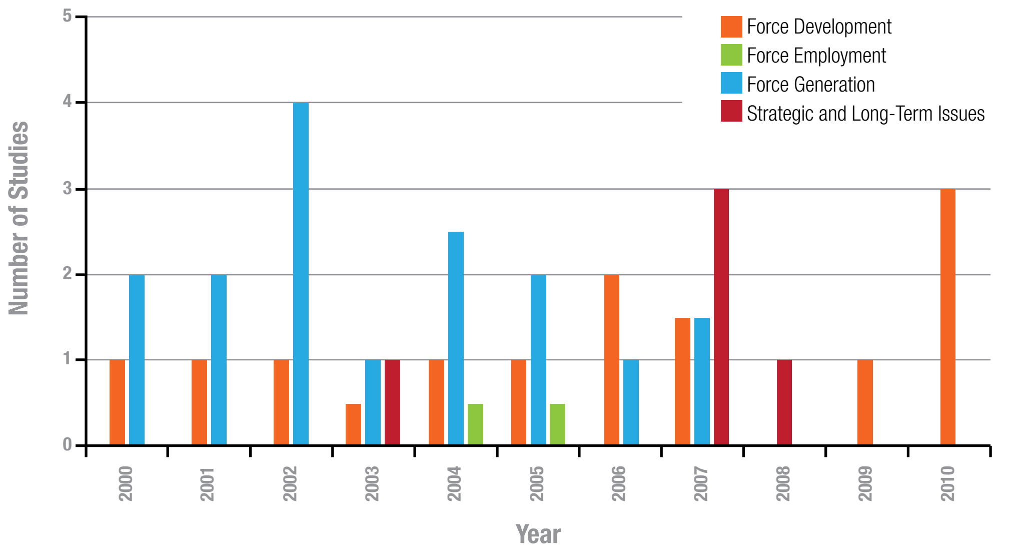

Figure 7. DRDC studies on RCAF by type, 2000–2010

In addition, force development and force generation tended to be a recurring theme for OR&A studies during the decade, while strategic and long-term as well as force-employment studies were carried out intermittently. The strategic and long-term studies identified in this analysis dealt with important issues, such as "The Future of Air Power for Small Air Forces."[56] However, the majority of these studies were conducted in 2007, when there was both the desire and expertise needed to conduct strategic studies on long-standing issues.[57] It is likely that the studies conducted in 2007 were originated by both the RCAF and DRDC.

Operational leaders in the RCAF focus on force generation. This is evident in the dominance of DRDC research in this area over the past two decades. Conversely, limited research has been undertaken in resource management in the RCAF. Perhaps this is because RCAF leaders believe that they will always have sufficient resources to undertake the assigned tasks.

However, as outlined in preceding sections of this chapter, the required resources are not always available, as necessary political and economic trade-offs occur at the central-government level. While implementing sound resource-management strategies can minimize the effects of reduced funding for activities, the agility to deal with policy shocks is equally important. The budget reductions in the 1990s and the geostrategic realities of the post–Cold War environment continue to affect RCAF resources. The challenges inherent in defence transformation can be indirectly observed in strategy documents produced by the various environments (e.g., the vision documents that were released in the early 2000s by the CA and the RCN).

To position their respective forces for future missions, the RCN published its vision in 2001, while the CA published a document about transformation in 2002. In 2003, the RCAF released a document entitled *The Aerospace Capability Framework: A Guide to the Transformation and Development of Canada's Air Force*, detailing how the vision will be implemented.[58] In addition, the RCAF document outlined capability requirements that support and extend existing equipment as opposed to new capabilities or transformation. The CA, on the other hand, while not precluding traditional open manoeuvre concepts, is shifting its focus to complex terrain, including urban locales. Interoperability and providing force multipliers is the RCN's focus and includes a wish list ranging from sealift to underwater warfare. Some analysts like Builder[59] point to the focus on technology and equipment that comes naturally to military personnel, especially to air force personnel, for "the airplane was the instrument that gave birth to independent air forces."[60]

That the RCAF is having difficulty transforming in keeping with the new geostrategic realities is not specific to Canada. For instance, Barzelay and Campbell[61] discuss the challenges the United States Air Force is facing in transforming itself to the new global realities. Public choice theory provides an alternative explanation. According to the theory, the main motive of people acting in the political marketplace (whether they are voters, politicians, lobbyists or bureaucrats) is self-interest. For bureaucrats, this self-interest is often depicted as budget maximization, since there are no profit motives to guide behaviour, as in the private sector.[62] The RCAF and other environments often link ASD and occupational reorganization to reinforce the linkages to platforms and private industry.[63]

Conclusions and Future Research Direction

This chapter provides a strategic-level assessment of the RCAF and discusses stylized facts about force generation, long-term planning and resource-allocation strategies. Appendix A includes a simple model of personnel-resource allocation for the RCAF. The model uses concepts and theories from economics to statistically estimate the interrelationships between RCAF personnel strength and factor prices (wages and price of capital). The model shows that the RCAF personnel-allocation strategy responds to factor-price signals as well as to policy shocks related to the 1990s budget reduction and post–Cold War geostrategic realities.

While the response to factor prices points to rational decisions within a constrained fiscal environment, the long-term capital plan and personnel profiles are in the midst of a downward trend. A number of factors explain this phenomenon. First, as discussed in this chapter, the capital intensity of the RCAF and the complexity of its capital requirement constrain its ability to advance its acquisition programs. In addition, the aerospace industry, the primary sourcing agent, is the prime focus of governments for economic and innovation agendas. Often, the government's vision for the industry and the RCAF's equipment requirements are divergent.

Second, air assets command higher indirect costs (fatter tail, in military parlance). This cost structure further exacerbates the resource-allocation strategy. While some of the maintenance costs can be contracted out to realize potential savings, the suppliers are few in number, thus constraining competition. As mentioned earlier, competition is a key requirement that facilitates cost reductions.

Third, as shown in the resource-allocation model, the RCAF has yet to adjust and adopt an alternative force posture to the new geostrategic reality. While this is not unique to the RCAF, its monopoly position as the sole provider of air assets makes strategic planning difficult. For example, there are no incentives for the RCAF to innovate on maritime air assets, as the effects (outputs) generated by these assets are more relevant for the RCN. Similarly, rotary-wing assets for the CA provide tactical and operational effects to the Army.

These are important issues that require in-depth analysis and, most importantly, data. While the quantification of military outputs remains a bridge too far, there are economic and management tools that can be applied to examine some of the challenges facing the RCAF. For example, a more in-depth assessment of the monopolistic nature of DND may provide clues on how to incentivize innovation.

Another worthy research avenue is the possibility of fostering increased competition. In a constrained budget environment, the CA may provide information about the RCAF tactical-lift project, while the RCN may divulge vital information about the costs of land vehicles. Competition among the environments may also provide government with bargaining power if the RCN decides to undertake a mission that the CA opposes. Force development can be undertaken in an agency with direct reporting to Parliament.

While competition may offer some solutions, it should be noted that politicians and governments may not be receptive to the idea. Selecting a winner in a competition usually leads to pressures from lobby groups, and a vote-sensitive politician may reverse decisions. The fact that DND faced difficulties in closing bases deemed unnecessary and costly is one good example. The main problem for politicians, unlike private sector managers, is that governments do not share in any efficiency savings that their policies might achieve. Perhaps the best time to engage a government to undertake revolutionary changes is during the twilight years, where legacy as opposed to the next election is the primary goal.

Appendix A: Labour Demand

The production of military effects is similar to any production in the wider economy, as it requires inputs in the form of labour and capital. Specifically:

$$Q = f(L, K) \quad (1)$$

Equation 1, known as the production function, relates total output produced (Q) to factor inputs such as labour (L) and capital (K). The manner in which these inputs are combined (f) represents production technologies. Alternatively, one can think of the above relationship (equation) as ends (Q) equaling ways (f) and means (L, K).

Specific to the RCAF example, air effects are not homogenous, and each air effect may require different production technologies and inputs. Thus, the demand for a particular input (labour), for example, depends on the relative price of the input as well as the production technology and military effect. Unfortunately, there are no monetized air effects to estimate a theoretically consistent demand for factor inputs or air-effects production. However, one can use the relative prices of factor inputs and other external determinants to derive a demand model. The external determinants (demand shifting or parameterization) include changes in threat or government demand for more air effects, technology and productivity gains in the RCAF.

As discussed in the main body of the chapter, the RCAF has faced a number of external shocks. For example, the 1964 White Paper amalgamated the services, while in the 1990s, DND faced a series of downward budget revisions in anticipation of the peace dividend. NATO also changed its doctrine to match the changing geostrategic environment. Specific examples include the flexible-response doctrine of the late 1960s and the crisis-response doctrine since 1999. The former resulted in the RCAF expanding its presence in Europe, while the 1999 shift exerted pressure on allies with force-projection capabilities. A demand for RCAF labour includes:

$$L_{RCAF} = f(p_L, p_K, I, E) \quad (2)$$

The demand for RCAF labour (L_{RCAF}) includes the prices of labour (wages – p_L) and capital (long-term interest rates – p_K) as well as revenue (I) and external factors (E). Revenue, to the extent it signals the demand for the military, is a legitimate factor that explains demand. However, this demand is distributed among the various environments (CA, RCN and RCAF) and supporting elements. Consequently, its impact on the RCAF may not be easily discernable. More crucially, however, defence outputs are often measured in terms of inputs.[64] Threat is an alternative measure of defence demand or output. While there are no direct threats to Canadian sovereignty, measures of global instability can serve as reasonable proxies. We adopt the strategy discussed in Douch and Solomon[65] and use nuclear arsenal and explosions as proxy measures of global instability.

Estimation of the RCAF resource-allocation strategy

We, thus, reformulate the above theoretical specification for statistical analysis and estimation as:

$$\ln RCAF_t = \beta_0 + \beta_1 \ln P_{lt} + \beta_2 P_{kt} + \beta_3 E_t + v_t \quad (3)$$

Where RCAF represents personnel strength, P_l is real wages of DND personnel (military and civilian) in 2015 prices, P_k is the relative price of capital, and dummy variables (E) represent policy shocks. Specifically, the 1964 White Paper (WP64), doctrinal change in NATO (DNATO) and the program review of the 1990s (DPR) represent likely policy changes that affect the RCAF resourcing strategy. The error term v_t indicates the stochastic nature of the statistical estimation. $\beta_0 - \beta_3$ are estimated parameters that signify the relationship between the dependent and independent variables. Alternatively, the statistical relationship is not deterministic. A second model with a threat variable is also estimated to compare and contrast the viable models that are consistent with economic theory. The threat variables considered include total nuclear arsenals (NTOT) and nuclear tests (EMT).

The statistical estimation method

Most economic and institutional data denominated in time are trended (non-stationary). For example, a country's income or gross domestic product (GDP) grows at a regular rate, with a continuously rising mean. When applying standard estimation techniques, the results are **spurious**.

For example, consider unrelated variables: the GDP of Canada and the price level in the Netherlands. Both drift upward or downward over a reasonably long sample period. If one then decides to perform a regression (a statistical test of a relationship between variables), a significant positive relationship is likely if they happen to drift in the same direction or a significant negative relationship is likely if they drift in the opposite direction. Granger and Newbold[66] provide a cogent discussion of this phenomenon and the associated mathematical derivation.

One can correct for this problem by taking the logarithm of the data, which provides a linear trend and possibly constant mean (integrated). In addition, the data are differenced (work with growth rates of the variable) to make the mean stationary. However, working with growth rates and other differenced versions of the original data may create other estimation problems. One problem stems from the effect of differencing on the error term of the regression. The error term has a mean of zero and a constant variance. In other words, we expect the errors to be random. Differencing the variables implies differencing the error term, which loses its property of randomness. In addition, working with growth rates potentially removes the existing structural relationship between the variables. This latter property, structural relationship, is the main reason we conduct statistical analysis.

So the ideal model ought to maintain stationarity in all variables, include dynamic properties to assess short-run relationship and maintain long-run properties implied by theory.[67] Theoretically, this is possible if two non-stationary variables happen to have a combination that eliminates the non-stationarity. It turns out that this only happens if there is a "true" relationship that links the variables together. Engle and Granger[68] and Johansen[69] provide a formal definition and discussion of this unique case, known as cointegration.

There are examples of economic time series data that exhibit non-stationarity but wander around in a somewhat predictable manner or do not drift too much from one another. For example, consider prices and wages or household income and expenditures.[70] Murray[71] cogently explains how the combination of some trended or non-stationary economic time series can become stationary.

In the article, Murray discusses a scenario where a drunk is looking for her unleashed dog she left outside the bar. By occasionally calling out the dog's name, both the dog and the owner adjust their meanderings (known as **error correction**). While the meanderings of the drunk may seem random and non-stationary, it is possible to say that if I found the drunk, her dog is likely close by, implying stationarity of the distance between them.[72]

The ability to specify an economic relationship using an error-correction mechanism and the intuition behind cointegration provide a powerful mechanism to test economic relationships. We employ this relatively new statistical approach to test the relationship between the RCAF resourcing strategy and factor prices and policy shocks. The statistical procedures used to test the existence of cointegration often imply that the variables under consideration are first-difference stationary (integrated of order 1), specifically, subtracting the time series from its one-period lagged series (Y_t-Y_{t-1}).

Unit root tests provide relevant information on the stationarity of the variables. If not, another approach, known as the autoregressive distributed lag (ARDL) approach to cointegration, applies a two-stage process for situations where unit root tests fail to provide definitive results. At the first stage, we examine the existence of the long-run relation between the RCAF personnel strength and relevant variables. The test consists of assessing whether the lagged levels of the variables (e.g., the price of capital) are statistically significant in the error-correction form of the underlying ARDL mode.[73]

The ARDL model has the additional advantage of being agnostic to whether the relationship we are examining is stationary (integrated of order 0 in econometric parlance), partially integrated or non-stationary (integrated of order 1). If the computed statistic falls outside the critical value band, one can make a conclusive decision without needing to know the order of integration of the variables. If the computed statistic falls within the critical value band, however, one requires extensive unit root tests on all variables.

As discussed, in the first step, the F-test ascertains the long-run relationship between the variables. The next step is to fit an appropriate ARDL model and make inferences about the model and variables. The F-test tests the null hypothesis of non-existence of the long-run relationship through a joint testing of the level variables in an error-correction version of an ARDL specification. See Table A1 for the results of long-run significance tests for the specifications outlined in Equation 3, which included the relative price of labour, capital and policy shift variables.

Specification	F-Test	Regressors
Equation 3 – Model 1	4.7***	f(RCAFp | $P_{(L)}$, $P_{(K)}$, WP64, DNATO, DPR, POST)
	1.71	f($P_{(L)}$ | $P_{(K)}$, RCAFp, WP64, DNATO, DPR, POST)
	2.05	f($P_{(K)}$ | $P_{(L)}$, RCAFp, WP64, DNATO, DPR, POST)
Equation 3 with threat variable (EMT) – Model 2	5.13***	f(RCAFp | $P_{(L)}$, $P_{(K)}$, EMT, DNATO, DPR, POST)
	2.69	f($P_{(L)}$ | $P_{(K)}$, RCAFp, EMT, DNATO, DPR, POST)
	3.03	f($P_{(K)}$ | $P_{(L)}$, RCAFp, EMT, DNATO, DPR, POST)
	1.44	f(EMT | $P_{(L)}$, $P_{(K)}$, RCAFp, DNATO, DPR, POST)

Notes:
1. Significance: ***1%.
2. RCAFp is the number of RCAF personnel. All other variables were defined previously.

Table A1. Long-run significance test (trans log form)

The test, known as the bounds test by Pesaran and Pesaran,[74] assesses the joint significance of the factor prices (in levels), which have a long-term relationship with RCAF personnel levels. A long-run relationship in econometric (economic statistics) jargon is a "true" relationship between estimated variables unaffected by estimation techniques or data generation artifacts. As shown in Table A1, the null hypothesis that there are no long-run relationships between the variables depicted in Equation 3 is rejected. Note that since only one specification for each model is significant, there is only one long-run relationship.[75] In model 2 (Equation 3 with threat variable), there are potentially two cointegrating relationships (at the 5% critical level) using the critical values provided in Pesaran and Pesaran.[76] However, Narayan[77] points out that the critical values for the bound tests are generated for large samples and, therefore, are not suitable for most applied work with smaller sample sizes. Since our study is based on a sample size of 63 observations, we use Narayan's small sample critical values. The results confirm that there is only one cointegrating factor (Table A1), and the factor prices in model 1 and factor prices and threat in model 2 are the long-run forcing (exogenous) variables.

In general, one anticipates a negative relationship between the real wages of non-RCAF personnel and the dependent variable (personnel strength of the RCAF). Note that as the cost of RCAF personnel rises, contracted services and civilians become more attractive. There is complementarity between labour demand for the RCAF and the price of capital. As a result, a positive relationship is anticipated between the two variables. The intuition here is that, as the price of capital increases, labour becomes attractive. The policy shock variables such as the 1964 White Paper (WP64), which authorized the integration of the services, and the major reductions in defence spending in Canada (DPR) are expected to negatively impact RCAF personnel levels. NATO's doctrinal change (DNATO) to flexible response, which maintained RCAF's presence in Europe, affects the RCAF personnel levels positively.

Table A2 shows the estimated long-run relationship between RCAF personnel resourcing as well as economic and policy factors. The factor-price variables are statistically significant, consistent with theoretical prediction. In addition, the post–Cold War (POST) and the major reductions in defence spending in Canada (DPR) policy variables are also significant, indicating the negative effect of these policy changes on RCAF personnel resourcing. If we interpret the results further, we see that a 10% change in the relative wage rate resulted in RCAF personnel reduction of about 5–7%, depending on the model, with or without the threat variable included. Similarly, the price of capital (proxied by the inflation-adjusted long-term interest rate) is also a statistically significant variable explaining RCAF personnel strength. The magnitude of the effect is rather muted; however, a one basis point increase in the interest rate increases personnel only by 2%, regardless of the model used. The substitution of labour for capital as a strategy tends to be limited, however, given government rules around procurement. In addition, the contractual relationship with military personnel allows a relatively quicker adjustment when faced with funding challenges.

Variables	Model 1		Model 2	
	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error
β_0	18.27***	0.63	15.49***	1.47
P_L	- 0.71***	0.059	- 0.46***	0.14
P_K	0.02 ***	0.005	0.02*	0.009
EMT	n/a	n/a	0.05	0.05
DNATO	- 0.008	0.038	- 0.12	0.09
WP64	- 0.07	0.051	n/a	n/a
DPR	- 0.22 ***	0.039	- 0.26***	0.08
POST	- 0.16**	0.056	- 0.33***	0.12

Notes:

1. Significance: ** 5% and ***1%.
2. The price of labour (P_L) is the total average cost of DND personnel (civilian, Regular and Reserve).
3. The long-term interest rate proxies the price of capital (P_K.)
4. Policy shocks are depicted by dummy variables, including DNATO, WP64, DPR and POST.

Table A2. Estimated long-run coefficients using the ARDL approach

The defence reductions of the 1990s (DPR) is associated with a 22% reduction in RCAF personnel (26% in the model that includes a threat variable). Meanwhile, the security environment of the POST is also associated with a negative impact on RCAF personnel. This period represents a 16–33% reduction in RCAF personnel. In model 2, the EMT is not significant.[78]

To understand the short-run effects of the RCAF resourcing strategy, economists often use a statistical model known as the error correction model (ECM) representation. The advantage of the ECM in this discussion is that it assesses the speed of adjustment to policy shocks. Specifically, if the RCAF faced a policy shock of, say, “equal misery” budget reduction, how quickly could it adjust? As depicted in Table A3, the ECM coefficient, estimated at –0.24, is statistically highly significant, reflecting the joint significance of the long-run coefficients. Additionally, the ECM coefficient is moderate, indicating a relatively quick adjustment to any shock in the short run. For model 2, the adjustment to shocks is slower (–0.12).

Variables	Model 1		Model 2	
	Short-Run Estimates	Standard Error	Short-Run Estimates	Standard Error
ΔRCAFp	0.72***	0.175	0.42***	0.075
$\Delta P+_L$	- 0.17***	0.024	- 0.05**	0.027
$\Delta P+_K$	0.005***	0.001	0.002**	0.001
$\Delta DNATO_+$	- 0.002	0.009	- 0.01	0.009
ΔEMT	n/a	n/a	- 0.005	0.005
$\Delta WP64^+$	- 0.018	0.012	n/a	n/a
ΔDPR^+	- 0.055***	0.094	- 0.03***	0.009
$\Delta POST^+$	- 0.04**	0.013	- 0.04***	0.01
ECM_{-1}	- 0.245***	- 0.027	- 0.12***	0.03

Notes.
1. Δ denotes the first difference of the variables.
2. From Equation 3, β_0 = The price of labour (P_L), the price of capital (P_K).
3. Policy shocks are depicted by dummy variables including DNATO, WP64, DPR and POST.
4. ECM is the error correction model.
5. Significance: ** 5% and ***1%.
6. + The coefficient of the first differences of the intercept in the error-correction form refers to the intercept in the ARDL representation. It is included in the error-correction form for completeness. The dummy variables should also be interpreted within the context of the ARDL approach.

Table A3. Error-correction representation (short-run estimates), sample period 1952–2015

The 1964 strategy to integrate the doctrinal shifts of the services (WP64) and DNATO did not have a significant effect on the RCAF's strategy. Despite the funding cuts to DND, the RCAF weathered the changes effectively due to its required presence in the European theatre and the expansion of Canada's NORAD commitment. However, the story changes markedly during the budget reviews of the 1990s (DPR) and POST. Both of these periods had a moderate and statistically significant negative impact on the RCAF resourcing strategy. This is evidence, albeit preliminary, that the RCAF's planning and requirements bureaucracy did not adapt fast enough to the changing national and international strategic focus.

If the adjustment to a policy shock is relatively quick and the relative prices of labour and capital are used to calibrate the new end state, are the choices optimal? This is difficult to interpret with available data and, especially, the lack of quantifiable outputs. However, RCAF resource allocation is rational given the constraints. If the RCAF and the environments do not have significant input on the funds allotted to DND, the choice is to be guided by factor-price effects (labour and capital costs). There is the possibility of a rational, albeit suboptimal, outcome when measures such as "equal misery" are imposed by central governments. For example, the decision of the 1990s to reduce force levels by means of financial incentives and attrition may have targeted the wrong segment (individuals who would have voluntarily left the forces) and those with higher marginal productivity.

For completeness, we have also included the results of the diagnostic tests for the ARDL estimates. As seen in Table A4, the model passes all the relevant diagnostic tests.

Statistics Test	Model 1		Model 2	
	LM Version [P-Value]	F Version [P-Value]	LM Version [P-Value]	F Version [P-Value]
A	$\chi^2(1) = .041393$ [.839]	$F(1,52) = .034740$ [.853]	$\chi^2(1) = .21650$ [.642]	$F(1,52) = .17872$ [.674]
B	$\chi^2(1) = .31380$ [.575]	$F(1,52) = .26452$ [.609]	$\chi^2(1) = .075630$ [.783]	$F(1,52) = .062288$ [.804]
C	$\chi^2(2) = .031572$ [.984]	n/a	$\chi^2(2) = .26552$ [.876]	n/a
D	$\chi^2(1) = .18597$ [.666]	$F(1,60) = .18051$ [.672]	$\chi^2(1) = .0052166$ [.942]	$F(1,60) = .0050487$ [.944]

Notes:

A **Serial Correlation** – Lagrange multiplier test of residual serial correlation
B **Functional Form** – Ramsey's RESET test using the square of the fitted values
C **Normality** – Based on a test of skewness and kurtosis of residuals
D **Heteroscedasticity** – Based on the regression of squared residuals on squared fitted values

Table A4. Diagnostic test ARDL model (2,0,0)[79]

Appendix B: Data Points for Figures 1–5

Year	Net Debt	Gross Debt
1981	187.1584	276.9306
1982	198.8024	288.4331
1983	242.0792	326.5868
1984	299.6940	381.2459
1985	370.1781	441.8254
1986	419.0615	485.5333
1987	451.4437	519.2121
1988	477.2469	546.7094
1989	497.0477	566.3085
1990	523.6941	586.7330
1991	552.5524	621.7580
1992	590.4711	655.7906
1993	640.8993	699.8054
1994	687.9611	747.4584
1995	721.7366	780.9659
1996	745.7706	818.2204
1997	749.5567	829.4573
1998	741.8125	823.6288
1999	719.8847	812.5175
2000	674.3493	778.1657
2001	643.8017	761.3932
2002	623.9090	747.4049
2003	594.9062	711.4554
2004	572.9190	687.9978
2005	554.9777	664.0689
2006	531.0940	640.1870
2007	508.1220	618.7650
2008	471.5500	571.5288

Table B1. Federal debt (net and gross) in constant 2007 B dollars, data is graphed in Figure 1[80]

Year	Statutory	Discretionary	Public debt charges	Total expenses
1990–91	37.3	33.4	29.3	100.0
1991–92	40.3	32.1	27.7	100.0
1992–93	41.3	33.4	25.3	100.0
1993–94	42.7	32.6	24.7	100.0
1994–95	39.8	33.8	26.4	100.0
1995–96	38.3	32.7	29.0	100.0
1996–97	38.5	31.7	29.8	100.0
1997–98	37.7	35.0	27.3	100.0
1998–99	40.9	31.9	27.1	100.0
1999–00	39.1	34.1	26.8	100.0
2000–01	39.0	35.8	25.2	100.0
2001–02	41.2	36.2	22.5	100.0
2002–03	42.8	37.0	20.3	100.0
2003–04	41.4	39.9	18.7	100.0
2004–05	43.8	40.1	16.0	100.0
2005–06	44.2	39.8	16.0	100.0
2006–07	43.7	41.2	15.1	100.0
2007–08	44.2	41.7	14.1	100.0
2008–09	44.5	42.8	12.8	100.0
2009–10	45.2	44.2	10.6	100.0
2010–11	44.1	44.6	11.3	100.0
2011–12	45.5	43.2	11.3	100.0
2012–13	46.8	42.7	10.5	100.0
2013–14	47.9	41.9	10.2	100.0
2014–15	49.8	40.7	9.5	100.0
2015–16	50.2	41.2	8.6	100.0

Table B2. Categories of federal spending, data is graphed in Figure 2[81]

FY	Growth Index	
	OGDs	DND
1990–91	100	100
1991–92	93.90365	96.22623
1992–93	94.01666	96.11390
1993–94	92.51709	96.02247
1994–95	91.61470	92.70212
1995–96	95.76475	87.56385
1996–97	83.36227	79.14985
1997–98	83.83635	75.59555
1998–99	86.26095	74.67277
1999–00	92.19426	82.98264
2000–01	107.58490	80.12313
2001–02	102.04950	84.87462
2002–03	106.06630	84.78119
2003–04	106.60030	87.10993
2004–05	106.85020	89.83858
2005–06	107.15810	91.64155
2006–07	108.38900	95.37092
2007–08	117.72230	103.18310
2008–09	115.28810	110.46920
2009–10	131.56140	114.96130
2010–11	127.51440	114.44790
2011–12	122.80340	110.89120
2012–13	120.06060	108.43850
2013–14	118.71880	100.26410
2014–15	118.18380	97.50700
2015–16	121.60670	99.16836

Table B3. Relative growth/contraction of federal departments' expenditure levels, with FY 1990–91=100, data is graphed in Figure 3

FY	Crown Corporations	DND	OGDs
1990–91	12.9	31.9	55.1
1991–92	13.4	32.5	54.0
1992–93	13.6	29.8	56.6
1993–94	8.1	32.5	59.4
1994–95	8.9	29.2	61.9
1995–96	20.7	26.5	52.9
1996–97	10.0	27.2	62.8
1997–98	7.8	27.3	64.9
1998–99	11.3	26.7	62.0
1999–00	9.2	27.9	62.9
2000–01	8.5	24.1	67.4
2001–02	9.4	23.6	67.0
2002–03	10.1	26.0	63.9
2003–04	8.9	25.6	65.4
2004–05	12.1	25.4	62.4
2005–06	9.2	27.2	63.7
2006–07	8.2	25.4	66.4
2007–08	7.7	25.8	66.4
2008–09	8.5	27.1	64.4
2009–10	9.6	27.2	63.2
2010–11	9.6	26.8	63.6
2011–12	10.1	28.0	61.9
2012–13	11.5	27.8	60.7
2013–14	9.4	27.2	63.4
2014–15	9.6	29.9	60.5
2015–16	9.6	32.7	57.7

Table B4. Per cent of federal spending, less transfer payments, data is graphed in Figure 4[82]

Year	Personnel Strength			
	CAF Total	Army	Navy	Air Force
1925	4,290	3,410	496	384
1935	5,163	3,509	860	794
1945	761,041	494,258	92,529	174,254
1955	118,077	49,409	19,207	49,461
1965	114,164	46,264	19,756	48,144
1975	78,033	29,710	14,820	33,503
1985	83,037	33,895	13,411	35,732
1990	86,787	36,014	14,115	36,659
1995	66,461	27,837	11,894	26,730
2000	57,484	27,720	10,745	19,019
2005	61,957	31,399	11,364	19,194
2010	69,075	36,745	12,091	20,239
2015	65,691	35,046	11,012	19,633
2016	66,045	35,491	10,911	19,643
2017	66,007	35,471	10,896	19,640

Table B5. CAF personnel strength, various years, data is graphed in Figure 5[83]

Appendix C: DRDC CORA Papers Analysed in Figure 7

Title	Authors
A Statistical Analysis of Fatigue Accumulation in CC-130 (Hercules) Centre Wings	S. Bourdon S. Guillouzic
Aerial Armed Reconnaissance and Fire Support: The Potential and Implications of the Attack Helicopter for the CF	T. Gongora
Air Force Strategy and Management: D Air SP Work Plan 2007–2009	P. D. Dickson
Air Mobility Operations Simulation Environment (Air MOOSE): Initial Design Specifications	D. W. Mason
An Air Force for Strategic Effect	P. D. Dickson K. E. Ennis
Analysis of Fleet Requirements for Fixed-Wing Search and Rescue Replacement Aircraft	S. Bourdon M. Rempel

Title	Authors
Analysis of Optimal CASARA Locations	S. Bourdon M. Rempel
Analysis of Risks Associated with Reliance on Non-Integral Strategic Airlift Solutions	D. W. Mason P. D. Dickson
Canadian Forces Combat Helicopter Force Structure Study: Force Balance Analysis	C. Scales D. Mason P. D. Dickson
CP-140 Force Structure Analysis	P. E. Desmier N. Roggenkamp
Creating a Strategy Focused Organization: Implementing the Air Force Strategy using the Balanced Scorecard	P. D. Dickson
Design Specifications: Simulation of Surface Surveillance System-of-Systems Success ('S6')	D. W. Mason
Fixed-Wing Search and Rescue Level of Service Evaluation Method and Tool	S. Bourdon
Force Structure Analysis – The Astra Model	P. E. Desmier
Force Structure Analysis – The EnRAM Model	P. E. Desmier D. C. Sexstone
Future Combat Air Operations System: Initial Assessment of Roles and Options	T. Gongora
Identifying Future Capability Requirements: The Case of the Aerospace Capability Exercise	T. Gongora
MATRICS: A Maritime Traffic Simulation	S. Bourdon Y. Gauthier J. Greiss
Modifications to the NFTC Resource Allocation Model (RAM)	C. J. Hunter C. M. J. McIlwraith J. N. Goodridge
NATO Flying Training in Canada: Assessment of Bombardier's Static Scheduling Tool	J.-D. Caron C. Hunter
Operational Research Support to the NFTC Program Using the Resource Allocation Model (RAM)	J.-D. Caron C. Hunter
Performance, Benefits, and Costs of Long Endurance UAVs for Domestic Maritime Roles	Y. Gauthier S. Bourdon
Pilot Production / Absorption / Retention Simulation User Interface	S. Latchman C. J. Hunter
Preliminary Based Ranking of Issues from the 2010 Aerospace Capabilities Initiatives	S. Bourdon

Title	Authors
Preliminary Results from the Pilot Production / Absorption / Retention Simulation (PARSim) MODEL	S. Latchman C. Hunter
Ranking of Issues from the 2009 Aerospace Capabilities Initiatives	S. Bourdon
Strategic Analysis with DRDC CORA and the Air Force: An Overview	P. D. Dickson T. Gongora
Strategic Visioning in Canada's Air Force: A History and the Lessons of Strategic Visioning and Planning, 1994–2004	P. D. Dickson
Support to Air Force Transformation SAR	S. Bourdon
The Airlift Planning Tools Suite (APTS)	S. Innes C. Hunter
The Canadian 'FIVE-W' Database ('Canadian Forces Including Vehicles and Equipment Worldwide') The Who-What-Where-When-Why of Canadian Forces Deployments Since 1990	D. W. Mason
The CP140 Risk Assessment Model	P. E. Desmier
The Future of Air Power for Small Air Forces: The Perspective from Canada	P. D. Dickson K. E. Ennis
The Impact of Offshore Oil Operations on East Coast SAR	N. Corbett C. Hunter
What Does a Balanced Tactical Helicopter Force Look Like? An International Comparison	T. Gongora S. Wesolkowski

Notes:
1. The period chosen reflects the period when client-funded positions became the norm and key DRDC CORA personnel assumed leadership positions with RCAF operational-research organizations.
2. Having strategic analysts in the RCAF is a relatively new phenomenon. The cited articles are assumed to be client funded.

Table C1. DRDC CORA papers analysed in Figure 7

Dr. Binyam Solomon is Senior Defence Scientist at Defence Research and Development Canada and an Adjunct Research Professor at Carleton University. He is currently on assignment as the special advisor to the Deputy Parliamentary Budget Officer. Previous appointments include co-editor of the journal, Defence and Peace Economics (2013–18), Chief Economist, Department of National Defence, and acting Chief Scientist at the Centre for Operational Research and Analysis. He has published extensively in economics, statistics and defence topics. His research interests include political economy, defence management, peacekeeping economics and time series methods. Dr. Solomon holds a PhD in Defence Economics from the University of York, United Kingdom.

Abbreviations

AOR	oiler replenishment ship
ARDL	autoregressive distributed lag
ASD	alternate service delivery
CA	Canadian Army
CAF	Canadian Armed Forces
CBP	capability-based planning
CORA	Centre for Operational Research and Analysis
DEW	Distant Early Warning
DNATO	NATO's doctrinal change
DND	Department of National Defence
DPR	1990s program review
DRDC	Defence Research and Development Canada
ECM	error correction model
EMT	threat variable
FY	fiscal year
GDP	gross domestic product
n/a	not applicable
NGO	non-governmental organizations
OGD	other government departments
OR&A	operational research and analysis
POST	post-Cold War
RCAF	Royal Canadian Air Force
RCN	Royal Canadian Navy
UN	United Nations
US	United States
WP64	1964 White Paper
WWI	First World War

Notes

1. Canada, DND, A-GA-007-000/AF-008, *Air Force Vectors*, abridged version (Ottawa: Director General Air Force Development, 2014), 4, accessed November 21, 2017, http://publications.gc.ca/collections/collection_2014/mdn-dnd/D2-300-1-2014-eng.pdf.

2. Keith Hartley, *The Political Economy of Aerospace Industries: A Key Driver of Growth and International Competitiveness?* (London: Edward Elgar, 2015).

3. Being capital intensive, the RCAF is the first recipient of government regulation or scrutiny around procurement.

4. Keith Hartley, "The Economics of Joint Forces," in *The Changing Face of Military Power*, ed. Andrew Dorman, Mike Smith, and Matthew Uttley (London: Palgrave, 2002).

5. D. W. Middlemiss and J. J. Sokolsky, *Canadian Defence: Decisions and Determinants* (Toronto, ON: Harcourt Brace Jovanovitch, 1989).

6. Michael Hart and Bill Dymond ,"Six Stewards of Canada's Economy: History by the Numbers Favours Mulroney and Chretien, while Trudeau Leaves a Legacy of Deficits and Debt," http://policyoptions.irpp.org/magazines/the-best-pms-in-the-past-50-years/six-stewards-of-canadas-economy-history-by-the-numbers-favours-mulroney-and-chretien-while-trudeau-leaves-a-legacy-of-deficits-and-debt/. Policy Options, June 1, 2003, accessed November 21, 2017

7. Hart and Dymond, "Six Stewards"

8. Hart and Dymond, "Six Stewards"

9. The data points are in Appendix B, Table B1.

10. The figure is based on National Economic Accounts standards as calculated by Statistics Canada. National Economic Accounts are more comparable internationally than official statistics from the Department of Finance due to accounting variations and standardization.

11. Canada, Department of Finance (Fiscal Reference Tables), various years.

12. The data points are in Appendix B, Table B2.

13. Canada, Department of Finance (Fiscal Reference Tables), various years.

14. The data points are in Appendix B, Table B3.

15. The data points are in Appendix B, Table B4.

16. Data from Fiscal Reference Tables 2016 and author's calculation.

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47. This imposed the force integration and emphasized peacekeeping as the Canadian Forces' main activity.

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50. The model classifies expenses for new capital equipment (including systems, pilots, operations and maintenance costs and civilians directly involved in the asset) as direct costs. Indirect costs include support from CAF bases, Assistant Deputy Minister (Materiel) as well as Defence Research and Development Canada (DRDC).

51. Solomon, Chouinard, and Kerzner, "Department of National Defence Strategic."

52. Basic flying as well as rotary-wing and multiple-engine training in Southport and Moose Jaw are currently conducted by the private sector with military instructors. This implies that the cost of equipment, operation and maintenance, training facilities as well as day-to-day management are treated as indirect costs.

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63. Aircraft maintainers were contracted out in response to the 1994 plan to reduce CAF. In some instances, such as the CC177, having the manufacturer provide maintenance is cheaper than having military technicians for a fleet of five aircraft.

64. Effectively, the dependent variable and the explanatory variables are the same.

65. Douch and Solomon, "Middle Powers and the Demand."

66. C. W. J. Granger and P. Newbold, "Spurious Regressions in Econometrics," *Journal of Econometrics* 2, no. 2 (July 1974).

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74. Pesaran and Pesaran, *Microfit 5.0*.

75. Pesaran and Pesaran, *Microfit 5.0*. In other words, there is only one cointegrating relationship, and the ARDL estimation can proceed in a single equation form. Had we found multiple relationships, we would proceed with a multi-equation estimation, such as vector autoregressive, or with a system of simultaneous equations.

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80. Canada, Department of Finance (Fiscal Reference Tables), various years.

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CH03

Defence Management for an Uncertain Future

Ross Fetterly

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Given the complexities of quickly evolving risks within a transformative environment, the pace of change is exceeding the ability of many organizations to develop the risk management and resilience leadership, expertise and processes to confidently adapt to the "new normal."

World Economic Forum[1]

Introduction

In the present international strategic environment, "modern natural science confers a decisive military advantage on those societies that can develop, produce, and deploy technology the most effectively, and the relative advantage conferred by technology increases as the rate of technology accelerates."[2] This persistent and compressing cycle both influences and shapes the institutional approach to defence management, while producing complexities that are distinct in nature and very challenging. In particular, in the current international strategic environment, where there is a near-term "high potential for dangerous global instability,"[3] the only certainty is change. Consequently, the allocation of defence resources will need to be a primary defence priority.

At the institutional level, defence management refers to "transforming allocated resources into military capabilities relevant to and in accord with government policy."[4] However, the current Canadian approach, process, and organizational structure are neither sufficiently adaptive nor efficient to nimbly optimize and align with strategic priorities. Whereas, within Canada and overseas, the Department of National Defence (DND) and Canadian Armed Forces (CAF) are known for delivering operational excellence while recognizing that our equipment or facilities may not be optimal, it is the quality of the Canadian defence team that facilitates this output. In this context, defence managers function in a complex, capital-intensive, and knowledge-dependent environment with a high consequence for error, which generally ranks defence as the most expensive national government function. The defining characteristics in defence include intense use of advanced technology, employment of large numbers of highly trained personnel possessing a range of very specialized and diverse skills, and the use of leading-edge weapon systems as well as effective coordination. Managing diverse military capabilities is an exercise that requires constant vigilance. Indeed, effectively managing this diverse range of discrete resources and functions is becoming the centre of gravity for defence organizations. In this environment, where defence-relevant strategic shocks occur that can change the conventional perspectives of defence departments, the shocks' "unanticipated onset forces the entire defence enterprise to reorient and restructure institutions, employ capabilities in unexpected ways, and confront challenges that are fundamentally different than those routinely considered in defence calculations."[5] Consequently, managing defence resources effectively in an uncertain environment will be central to sustained institutional success.

The Canadian defence posture since Confederation has been influenced by several strategic constants. These constants include geography, economic potential, and broad national interests, of which the "predisposing factor" is geography.[6] Canada's geographic location has traditionally separated the country from immediate military threats. With oceans to the east, west, and north of the country as well as a shared southern border with the United States, Canadians have viewed their nation as relatively secure, resulting in a remarkably stable strategic defence policy anchored by a small number of dominant ideas. Indeed, since shortly after the Second World War, an enduring consensus has existed "concerning Canada's defence needs and how we should satisfy them."[7] This can be characterized as the defence of Canada, the defence of North America in coordination with the United States, and support for international peace and security. As a consequence, Canadian defence policies have been and are likely to remain concerned with the development and administration of capabilities to meet those needs[8] within the context of the complex dynamics of the international security environment. The implication is that Canada will continue to provide sufficient funding for defence to meet the needs of the enduring strategic policy framework mentioned earlier, without placing particular pressure on the Canadian fiscal framework or displacing other primary national goals. Hence, based on this unique combination of enduring defence-policy stability and geographic separation from major external security threats, the Canadian defence establishment can focus, within this framework, on the central defence-management issue of allocating resources to needs. Viewed through the lens of remarkable consistency of broad strategic defence priorities in Canada, some force structures within the Royal Canadian Air Force (RCAF) may endure. In this regard, the departmental capability-based planning (CBP) process focuses on how military effects are provided and is largely agnostic about who provides them.

In defence establishments that tend to be conservative in nature, change can be difficult. However, the combination of an international strategic environment that has become less stable, the shifts in threats occurring on a non-linear basis, the growing unconventional nature of conflict, and the transition away from a unipolar world have made change not only inevitable, but necessary. In this environment, where change is a prominent feature faced by institutional leaders, this may necessitate consideration of contemporary defence priorities, which will impact multiple entrenched interests within National Defence Headquarters (NDHQ). Similarly, long-standing core military competencies may have to be revisited. Finally, major capital equipment programs could also be impacted.

In a contestable and uncertain international security environment with increasing global challenges, the RCAF's organization, structure, and capabilities will be paramount in enabling it to provide support to Canadians and the international community, as called upon by the Government of Canada. Indeed, with the current structure, the Canadian Forces Aerospace Warfare Centre (CFAWC) provides an internal RCAF institution for intellectual thought and capacity for concept development; a relatively small but focused strategic-level headquarters in Ottawa is integrated with the other environments, the Assistant Deputy Minister (Materiel), Chief of Program, and Chief of Force Development; and a robustly staffed operational-level headquarters in Winnipeg is located next to an operational-level Air Force training division. All of these elements contribute to a responsive and adaptive organization. In addition, the creation and establishment of 2 Wing in Bagotville as the RCAF expeditionary support organization adds a new operational capability. Nevertheless, the RCAF needs to continue to evolve and adapt to changing circumstances. With seven different distinct aviation communities in the RCAF, including fighters, land rotary wing, ship-based helicopters, search and rescue, tactical airlift, strategic airlift, and long-range patrol (not to mention that individual aircraft fleets need to be continually renewed and updated), effective strategic management of aviation capabilities is both essential and a primary organizational challenge. A key enabler is the effectiveness with which resources are allocated by the Air Staff in Ottawa and then managed at the operational level.

This chapter focuses on defence management, with the perspective that effective defence resource management will be a primary enabler for the defence establishment in both supporting and enabling change. Although the focus will be on management within defence, emphasis will be placed on the RCAF. This chapter will begin by discussing the defence-management conundrum, followed by factors currently driving change within defence management. Defence as a learning organization in a complex operating environment in 2017 will then be considered, and the chapter will conclude by emphasizing the use of defence analytics as an integrating mechanism to transform defence management to the same extent that the impact of digitization had on organizations in the 1990s. Indeed, in the coming years, defence business analytics is likely to be a central influence in shaping and unifying initiatives in defence-management reform.

The Defence-Management Conundrum

> There is a tendency in our planning to confuse the unfamiliar with the improbable. The contingency we have not considered seriously looks strange; what looks strange is thought improbable; what is improbable need not be considered seriously.[9]

The business model within the defence enterprise is unique. As a security organization of last resort for the national government, military establishments are developed, structured, resourced, and trained to fulfil that role. In this regard, Canada's Royal Commission on Government Organization in 1963 found that the military services needed to be able to operate seamlessly in times of peace or conflict.[10] A more recent perspective echoes the same view, whereby the normal concept of efficiency "does not work for [CAF], which, as the force of last resort, needs to be capable of operating well under conditions of chaos and complexity, when very little else is working."[11] Defence institutions need redundant systems, together with the capacity to rapidly surge capability. This stems from the environment and uncertainty under which defence operates, the shrinking decision cycle, the fact that defence is in constant transformation, and finally, the desire for detailed information—which is challenging for defence departments to provide—from national bureaucracies. According to this perspective, which has criticized management-based reforms in recent decades, the reforms' "underlying measure of effectiveness—efficiency—is essentially incompatible with military, and most other public service, organizations."[12] Indeed, the Royal Commission on Government Organization in the 1960s best expressed this perspective in the following manner:

> The test of each component of the Forces is its ability to perform its wartime task virtually without notice. The structure and procedures of the headquarters establishment must therefore be such as to enable it to discharge its responsibilities in the most economical and efficient manner consistent with its obligations to the combat formations under operational conditions.[13]

The federal government has progressed through a series of management reforms since 2000, with the objective of improving effectiveness and efficiency.[14] Nowadays, the defence department provides myriad reports to Treasury Board each fiscal year, has multiple governance reporting processes in procurement (e.g., third-party reviews), and responds to frequent internal and external audits. The expectation is that with all the documentation in the current digital era, substantial information is available in government departments. Consequently, central agencies expect this superior level of quality of information. However, in a defence department with a massive, multifunction, complex, and dispersed organization, this granularity of information is not always readily available.

In defence, short-term flexibility is minimal; whereas, by contrast, long-term flexibility is relatively unlimited. Therefore, the organizational ability in defence to bridge the gap between near-term and medium-term demands is key to maintaining a responsive defence organization that remains appropriate to an environment dominated by strategic shifts that can occur in a non-linear manner. There are two likely primary approaches to restructuring defence organizations. The first approach is referred to as "arm-the-man," where the force size considered reasonable in relation to the planned defence budget and capital expenditures becomes a residual expense. The second approach is referred to as "man-the-arm," where capital investment becomes the primary focus and personnel the residual cost. Globally, there is a tendency for both "governments and militaries to favour the arm-the-man approach."[15] The challenge for defence planners is, then, to manage a modest capital-equipment program and maintain equipment fleets over an extended period of time. Yet, that traditional approach to defence structure and management was upended on September 11, 2001, with the terrorist attack on the World Trade Center in New York City by al-Qaeda militants. This resulted in a paradigm shift of Western military forces towards expeditionary operations. This was in stark contrast to the situation during the long-standing Cold War, which largely ended with the fall of the Berlin Wall in November 1989. During that period, military forces maintained a largely steady and predictable operational tempo consisting of a regular training and exercise cycle as well as a steady equipment-replacement program. After September 11, 2001, the dominant dynamic of many military forces became large, high-intensity expeditionary operations that featured extended periods of combat operations and consumed equipment, personnel, and resources at a rapid rate.

Within military organizations, institutional learning in operations is rapid out of necessity. This was clearly evident over the decade that CAF was in Afghanistan, as the manner in which the military trained and then operated in the field shifted to reflect the operational environment. In contrast, change in defence-resource-management processes is much slower, and in this traditional, bureaucratic-type organization, change tends to be resisted. In the current environment, where the ability to adapt and change is necessarily shaping the defence-management context, the institutional ability to learn and adapt is becoming just as important, as has customarily been the case in operations.

Viewed from a historical perspective, defence organizations have been conservative in nature. In the current strategic environment, taking a continued incremental approach to change will leave military organizations vulnerable to adaptive innovators. Indeed, the ability and flexibility of defence-management processes are essential to provide needed sustainment capability in terms of operations and responsiveness over the long term. However, in recent years, the decision cycle in defence continues to be compressed, and this will reduce response time. In effect, although the decision-making processes in defence continue to evolve in response to the environment, the trend towards increasingly shorter time frames remains, placing a premium on readiness.[16] In contrast, major capital equipment projects in many Western countries now take longer to execute. Consequently, changing demands for equipment have the potential to negatively impact defence institutional responsiveness over the long term. The implication is that the defence establishment in Canada will need to make difficult reallocation choices in order to integrate emerging capabilities into CAF.

> The military can be viewed as a complex system that in peacetime transforms resources (inputs) into ready forces (outputs). Because this transformation involves a set of interactions among the inputs, many of which may be nonlinear, the output can at times appear random or unexpected. An additional complexity is that the system itself is dynamic. The rules by which it is governed are constantly changing as technology, threats, operational concepts, and the military itself change.[17]

Similarly, military historian Martin van Creveld observed that "all warfare consists of an endless series of difficulties, things that go wrong, is a commonplace, and is precisely what Clausewitz meant when talking about the 'friction' of war."[18] Whereas the Second World War ushered in a new era of mobility in warfare, both on land and in the air through technological advances in vehicles and aircraft, it also multiplied demands on the supply chain and the role of logistics resupply in theatre. In the current resource-constrained environment in defence, ensuring full expenditure of defence budgets to maintain readiness levels and to keep inventories of spare parts for aircraft, ships, and Army combat vehicles well stocked during fluctuating activity levels is a combat multiplier.

In a period of transition to new capabilities and an evolving institutional focus (cyber-security, unmanned aerial vehicles, and shifting operational requirements), effective defence-management processes are a necessary institutional enabler. Furthermore, in the current security environment, the skills required by military personnel are increasing. These include employing new technology, deploying multiple times in different complex operations, and training to develop new and required skill sets. In recent years, business planning, budget management, and governance processes have become the backbone of defence-resource management. Indeed, a core strength of defence establishments is that they are sophisticated, multilayered, and experienced planning machines, with training as a primary organizational function. At each of the strategic, operational, and tactical levels of defence, there are different degrees of knowledge and experience. As a result, decision makers at each level are faced with information asymmetry. At the strategic-headquarters level, knowledge of resources available and institutional priorities are readily available. Conversely, at the tactical level, knowledge of operations costs and funding mechanisms can be limited. What is important to understand in defence is that the "decision making process is a complex process with elements of rationality interspersed with competition for scarce resources and negotiations that result in solutions, that while not always based on logic, can be accepted by the major stakeholders."[19]

A defining characteristic within the defence sector in a country is the breadth and diversity of stakeholders. Within DND, the assistant deputy ministers of infrastructure, information technology, materiel, finance, and civilian personnel compete for resources. Within CAF, the Canadian Army (CA), Royal Canadian Navy (RCN), RCAF, Canadian Special Operations Forces Command, and Canadian Joint

Operations Command, each has different resource demands. Within the federal government, a number of departments are involved in defence, including Innovation, Science and Economic Development Canada and Public Services and Procurement Canada. Externally, in the private sector, the broad Canadian defence industrial base[20] supports air, land, and sea capabilities as well as materiel, infrastructure, and information technology. This diversity of interests adds to the complex nature of the defence sector and places a premium on the management of change in defence.

Managing Change in Defence Management

> The past few years have been a reminder that stability is not the natural state of the international environment, that peace is not self-perpetuating, and that whole regions can descend suddenly into anarchy.[21]

The long-standing unipolar world that emerged following the Cold War was not the end of history[22] but was a relatively short period of overwhelming American supremacy. Over the past decade and a half, the world has become a much more challenging and contested place. Globalization is changing the nature of relationships in a non-linear manner, both between and within nation states. In addition, there is an expanding number of non-state actors. This places a premium on responsiveness and effectiveness within defence establishments. This means that during periods of change, we cannot simply reset our plans and objectives; we need to evolve with the changing strategic environment. In practical terms, this means we have to continually adjust to the reality that "simultaneously maintaining ageing equipment, supporting new equipment, adapting to a transforming military force, and coping with shifting activities and activity levels compounds budgetary difficulties."[23] This adds significant complexity and difficulty to defence-resource-management processes and requires constant adaptation to remain responsive. In 2017, Western nations are struggling to recruit, train, and retain military personnel. Despite considerable effort, defence establishments have largely been unable to move the management of human resources from a non-integrated and disjointed paradigm, which is ineffective in matching bottom-up demand for military personnel, to one that is aligned with institutional defence priorities. This illustrates the necessity for an integrated defence-management approach that considers personnel, operations, and maintenance as well as capital equipment demands when making decisions.

In the current international strategic environment, the application of military force by governments is becoming less and less decisive, as nations begin to recognize that sometimes we can, at best, only manage difficult security problems under certain circumstances. The world has become more complex and less unipolar, and recent history has demonstrated that areas of unrest and conflict can be resistant to intervention and reform. While the United States may still largely maintain command of the commons,[24] threats emanating from failed or failing states—as well as from resurgent Russia and China—have become more of a challenge to the international community. Furthermore, military engagements overseas can now be multi-year and multifaceted, not linear. In effect, the traditional deployment cycle is now obsolete. In the past, reconstitution of RCAF personnel and equipment in a unit took place after the return from an expeditionary operation, followed by an extended period of traditional training and domestic operations. This has been overtaken by a global-security environment that generates constant demands for participation in complicated expeditionary operations that can have objectives that are difficult to achieve. Circumstances can bring multiple requests for engagement in ongoing overseas operations, or for national participation with diverse coalitions. To thrive in this environment, the RCAF needs to alter how it approaches resource management by being pragmatic and adaptive to shifting demands and opportunities. Indeed, the traditional business plan—which sets the priorities for the organization and allocates resources—is geared to making incremental changes over a period of years. However, in defence, where there are nations that aim to be adaptive innovators, the rate of technological change means that the RCAF and other mid-size military organizations must plan for a future that is likely to be very different from today. In effect, we need to be bolder in our resource management by positioning the RCAF at the leading edge of best practices and being more sensitive to changes in the strategic environment. In essence, resource management needs to prioritize adaptation to change. Indeed, this has been recognized institutionally within DND, where fiscal year (FY) 2017–18 business plans submitted to the Chief of Program are required to place an emphasis on re-prioritization of resources to meet changing circumstances. Requests for additional funds through the business-planning process now must take into account the entire RCAF resource-allocation plan, not merely identified funding shortfalls. This change in approach is part of a series of institutional governance reforms that facilitate systemic change in an unstable and shifting international security environment.

To achieve transformational change within resource management, behaviours in the RCAF need to change in order to accept more risk. This requires embedding risk management into current processes, in contrast to managing risk as a separate management function. While the department is working to bring integrated risk management into resource-management practices on an institutional basis, capacity issues limit adoption into the RCAF. Organizations that are structured to manage risks effectively have a greater likelihood of achieving objectives, and this places a premium on institutional resource-management strategies.

Military readiness represents a cornerstone of the RCAF and one of the four pillars of military capability. Combined with the other pillars of military capability, which include force structure, modernization, and sustainability,[25] they represent the primary RCAF cost drivers. Indeed, in the current resource-constrained environment, analysing the defence budget is, "in many respects, a debate over readiness. Nearly every part of the defence budget is related to readiness in one form or another, whether through pay and benefits for military personnel, funding for training and maintenance, or the development and procurement of weapon systems."[26] Viewed from this perspective, readiness involves training and preparing for operations, personnel, infrastructure, equipment, weapon systems, stocks, supplies, and appropriate maintenance. The current international security environment is intensifying the value of readiness and influencing the DND CBP process. The security-environment challenges stemming from peacemaking, hybrid wars, regional conflicts, and terrorism place a premium on outputs. This is producing an institutional shift from an emphasis on force structure to force generation as a predominant planning paradigm. This transference has conceptual, structural, and financial consequences, requiring enhanced financial management within defence departments. In particular, maximizing the use of allocated operations and maintenance resources in-year to support or enhance readiness, particularly in an interval of generational change, is a key enabler.

Adapting to Change

> Of the many diverse and fascinating challenges we face today, the most intense and important is how to understand and shape the new technology revolution.[27]

Adapting to change is a significant challenge for any large organization. This is particularly difficult in defence, where innate military conservatism "has consistently forced senior leaders and strategists into the sanctuary of convention."[28] Although, this has begun to change out of necessity in recent years in response to unconventional threats, hybrid conflicts, and the impact of massive refugee flows in Europe. The special circumstances of the international strategic environment in 2017 make this task particularly difficult. This change is driven by the pace (which is more exponential than linear), the breadth, and depth of change, which combine multiple evolving technologies as well as the transformational impact that it is having on organizations within diverse sectors of economies.[29] In general, the conditions for success in adapting to change begin with the "ability to interpret the external environment in all its aspects, subtle as well as obvious, and then to adapt one's own organizational formats, operational formats, and tactics to suit the requirements of the particular situation."[30] In the present environment faced by the RCAF, the historical institutional approach of increasing efficiency, while still valid, needs to shift to where the "ability to adapt to complexity and continual change has become an imperative."[31] This is particularly the case for expeditionary operations.

The dynamic nature of democratic and capitalist-based countries is shaped by the combined forces of technological advancement and innovation. Generally, the pace of change is uneven and disjointed, but the overall trend is accelerating. The result is a process that has been described as creative destruction. Specifically, economic change is propelled by innovation, resulting in a process "that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one."[32] This places a premium on resource management within defence. The Canadian Parliamentary Budget Officer estimates that the present force structure in defence "is unsustainable at current funding levels."[33] To be sure, there are challenges in defence in Canada that will not go away in the near to medium term, and this highlights the importance of effective resource management. First, the historical resource-constrained fiscal environment will continue. Second, the nature of defence equipment means that costs rise relentlessly,[34] placing continual pressure on capital-equipment-procurement budgets. Third, the consequences and costs of ageing equipment will continue to be borne by the military. Finally, CAF will be regularly called upon by the Government of Canada to undertake operations both domestically and internationally.

Canada as a nation benefited from an extended period of high oil prices over decades; therefore, to a certain extent, it was isolated from many global economic problems. However, with oil prices now greatly reduced and with a struggling global natural-resource industry and national overcapacity, Canada is much more susceptible to global events and variations in international economic performance. Just as the Canadian economy must now rapidly adapt to change, so must the defence department and military in order to remain relevant and effective. At the end of FY 2013–14, with the combined impact on the RCAF of the Strategic and Operating Review and the Deficit Reduction Action Plan, baseline funding was significantly reduced. However, with additional baseline funding received in FYs 2015–16 and 2016–17 for operational readiness and training as well as a stabilized budgetary environment in DND, the RCAF has leveraged this stability with a renewed campaign plan and better coordinated internal planning. Yet, recovery from several years of successive budget cuts will take time, and rising non-discretionary costs will likely continue to erode the pace of recovery.

The RCAF is exceptional in operations, both domestic and expeditionary, and has demonstrated that it can be both flexible and adaptive in operations (e.g., by demonstrating considerable learning in operations in Afghanistan through the adaptation of operational processes to align with the specific conflict environment). However, in managing defence resources, the RCAF is much less adaptive and, like many defence organizations, is pedantically bureaucratic. Why the difference? One explanation is that responsibilities in resource management are much more diverse. Consequently, effecting change is significantly more difficult. Alternatively, it could be that resource management is more complex than operations, or that we invest heavily in training for operations yet make less of an effort to provide the same level of training excellence or emphasis on resource management.

The nature of bureaucracies is that they flourish in an environment where consistent and standardized approaches can be applied when dealing with common problems. Traditionally, military organizations have been bureaucracies that "depend on standardization of tools, training, methods, and organization."[35] Deviation from this approach subverts both standardization and consistency, which remain hallmarks of conventional military behaviour and practice. Within this environment, inserting a practice that clashes with customary behaviour will be a challenge until it effectively replaces past practices. The combination of a focused organizational effort, direction, and resources is needed to substantially effect change. Indeed, "strategy is fundamentally about identifying or creating asymmetric advantages that can be exploited to help achieve one's ultimate objectives despite resource and other constraints,"[36] and maximizing the use of allocated resources supports this approach.

Internally, the RCAF needs to take the economic concept of resource scarcity seriously and, consequently, over plan to fully utilize the allocated budget and maximize capability and output. Allowing millions of dollars to go unspent annually undermines resource utilization and performance, which has a direct impact on institutional credibility. The challenge, therefore, is that while the objective of defence management is to build and sustain combat capabilities,[37] the link is not always linear, even though most of our planning depicts that it is linear. The conundrum for the CA, RCN, and RCAF in terms of defence management is how to provide the "incentives to face up to hard choices and get the most capability for the money they spend."[38] There are no easy solutions to this problem. In the current resource-constrained defence environment, the RCAF budget is the operationalization of defence policy in terms of air power, generating capability through integrating strategy, resources, and people. Although the RCAF invests heavily in training its personnel on an annual basis, it now needs to focus its institutional effort to become even more of a learning organization.

Defence as a Learning Organization

In the 2017 international strategic environment, organizational learning and innovation are two core enablers for operational success in the RCAF. Faced with the potential for rapid, non-linear shifts in security and threat profiles, we must ensure that military capabilities remain relevant and adapt to change. Therefore, a robust institutional capability to learn and adapt in keeping with the changing security environment, while maintaining a strong innovative focus to overcome operational challenges in conflict, is essential to success. In large organizations, the leadership cadre generally incorporates new information at a slower pace than individuals do. Hence, at an institutional level, learning is more difficult and complex; learning occurs at the lowest common denominator, which is the management team.[39] In the current international strategic environment, institutional learning is a primary contributor to the necessary agility to understand what is transpiring in the security environment and to be capable of acting on that knowledge appropriately. Indeed, this is fundamental to maintaining a long-term, sustainable competitive advantage.

Characteristics that are fundamental to military organizations in expeditionary operations[40] in the current decade are listed below. In essence, to be successful, military organizations and their personnel need to embrace the reality that, first and foremost, they must be a learning organization. This needs to permeate multiple areas, not only organizations whose role is to teach military personnel. For example, CFAWC is now the organization responsible for producing lessons learned following RCAF operations. Yet, this approach needs to extend to challenging how the organization operates and adapts through learning, so that:

- unforeseen challenges do not paralyse the organization;
- problem solving is a core organizational competency;
- organizational practices are challengeable;
- knowledge-collection methods set systematic learning in motion;
- leaders nurture a milieu conducive to learning; and
- organizational memory captures and retains but not rigidly.

The contemporary operating environment in expeditionary operations is fundamentally influenced by a myriad of difficult and complex challenges. As a result, it is almost certain that military contingents on these types of operations will face unforeseen challenges. This will require a strong institutional learning capacity, which includes both a strong problem-solving capacity and the ability to rapidly adapt standard operating procedures to a shifting operating environment. The framework under which this dynamic functions is, by its very nature, both institutional and systematic. Therefore, learning and adaptive skills need to be developed and practised at all levels within deploying contingents before they arrive in theatre. Knowledge-collection processes are the keys to capturing, documenting, and implementing changed practices and processes.

In the current international strategic environment, the use of new technologies by national military organizations does not assure victory in a conflict for that country. It is the "integration of innovation into effective methods and means that gives a strategic or tactical edge."[41] Consequently, defence establishments need to not only address disruptive technologies as a formal component of defence posture and management, but also be reflecting, thinking, and innovative organizations in which the values of ideas, concepts, and innovation are put into practice. In an environment where global defence postures are likely to be moderated by economic realities, this limitation on ambition will act as a mechanism to narrow capability gaps between national military forces. Viewed from the construct of minimal change in defence budgets in the short term, defence organizations "might find more value in productivity improvement and human capital-related initiatives"[42] than in focusing heavily on innovation initiatives.

Defence resources are allocated to three categories: personnel, capital as well as operations and maintenance. The most important is personnel, both military and civilian. Indeed, within defence, the most influential advance can be obtained from the quality of military personnel. In late 2016, Regular Force personnel numbers amounted to approximately 65,500, with an authorized strength of 68,000. This gap between actual and authorized force strength can restrict the capacity to change. The vacancies in environmental and central staffs at NDHQ limit staff capacity. If there is an enduring lesson in Canadian defence, it is of the central importance of the people within CAF. This is particularly relevant to the RCAF. At times of institutional change within defence, the focus tends to be overwhelmingly on equipment, at the expense of reforming the institution. Within the RCAF, reform began with the publication of the campaign plan in FY 2015–16. Reform in the RCAF now needs to shift to its people: how they are recruited, educated, trained, and prepared to operate in an increasingly complex and unstable international strategic environment will dramatically influence the air force of the future.

In the current international strategic environment, innovation is accelerating and defence organizations need to keep pace with technological change. In particular, defence management needs to embrace an orientation that is necessarily of a longer-term nature. The catalyst within defence is defence-management processes that are sufficiently flexible to meet the needs of an evolving environment. Within defence, where promotion is internal, leaders are generally a product of their experience. In a security environment that has changed dramatically, divergent thinkers are needed to help shape institutional change. With the increasing availability of data, a strategy to harness this information in order to improve resource management is key to boosting the effectiveness of resource utilization.

Defence Analytics

In a time of rapid but sporadic change, adapting to a shifting international security environment is essential to remaining current and relevant. To respond to this change, institutional awareness is indispensable and provides the necessary foundation for decision making. The integrating mechanism that supports change management is defence analytics, which is becoming increasingly important and used. Embracing defence analytics, out of necessity, will change decades of practices and procedures, consequently requiring considerable cultural change. It will require substantial growth in the analytical cadre in an organization where action and physical effort predominate. However, where the RCAF and the other services have an inherent advantage is in the existing planning and program culture. The more that this can be leveraged with existing business-planning and performance-measurement processes, the easier it will be to become a leading-edge organization that improves both resource utilization and decision making. Indeed, it is the key to future agility.

At present, the defining characteristic of change in defence management is the premium placed on information used for decision making. Increasing digitization has resulted in exponential levels of data generated by defence establishments. Notwithstanding the benefits of technological advances in recent years, with the rapid growth in data generated, we have "moved from data-poor but fairly predictable settings to data-rich, uncertain ones."[43] Therefore, the institutional ability to generate information in support of decision making has become a primary contributor to domestic and expeditionary operations.

One principal application of defence analytics is financial. This is particularly important in defence, where "given the relatively inflexible commitments of the defence forces, any significant curtailment of expenditure plans is likely to bear unevenly on the various elements of the defence budget."[44] Budgets constitute a tool within defence that is used to communicate information objectively, consistently, and accurately, in a formalized manner, at various levels within the organization. This linkage is important when managing an organization with the size and complexity of the RCAF, as well as being a practical mechanism to support execution of the *Royal Canadian Air Force Campaign Plan*. From that perspective, the conceptual framework behind budgets and business planning is to facilitate and drive planning, monitor expenditures, and measure performance. Therefore, both budgeting and planning are fundamentally linked, with budgets driving resource allocation and institutional discipline. However, to a considerable extent, budget management is separate and distinct from business planning in many different defence organizations. Yet, each contains information that is collectively necessary for decision making. The linkage of both processes, together with performance management, constitutes defence analytics.

The formal business-planning and budgeting process in defence is very formal and follows a structured and comprehensive annual cycle. However, historically, the management focus has been on controlling results. Conversely, the RCAF now needs to concentrate on "controlling the process."[45] In the defence environment, which functions with a certain level of uncertainty, integrated planning and budgeting are essential for program execution throughout the FY. While the RCAF needs to be more effective in terms of budget management, it must excel at knowledge management by aggregating and using information, understanding costs as well as maintaining a focused and timely internal procurement and yearly flying rate timeline. The RCAF organizational structure inherently supports decentralized decision making within the context of the campaign plan at the operational and wing levels, so as to support timely budget execution and resource usage. More timely and structured information on a real-time basis will support maximizing time during flying operations within the resource allocation to wing support organizations and optimize budget execution.

In order to effectively manage the RCAF enterprise, the air force needs to define itself over the next five to ten years by building a superlative analytics organization within the Air Staff. This would complement the analytics function within both the Assistant Deputy Minister (Finance) and Chief of Program organizations. In an ongoing resource-constrained environment, having an analytics organization with an objective to analyse a wide variety of data in order to establish an enhanced understanding of institutional cost drivers and patterns of expenditure and performance is essential. The desired effect is for the RCAF to be a data-driven organization that leverages information to target needed investment areas, leverage outputs, and manage over planning by sourcing and exploiting opportunities. Through the extensive use of data and the development of predictive models, daily business practices are improved and strategies can be employed to improve financial performance and overall efficiency. Business analytics also provides a linkage to improvements in institutional risk management, planning, and performance management.

In the current decade, the defining characteristic within defence is not speed, but the compression of time. In many organizations, decision cycles, as well as the time to react to change, have decreased. This is causing changes to long-established practices and procedures. While defence organizations have worked to get inside the decision cycle of their opponents for decades, the lessons from Iraq[46] and Afghanistan indicate that speeding up the decision cycle is no longer sufficient; military forces have to adapt their thought processes and procedures to remain effective. Faced with constant resource constraints, effective defence management becomes an institutional prerequisite. In particular, multiple bottom-up pressures, such as personnel costs, can have a crowding-out effect on operational funding. In the current security environment, out of necessity, defence is in a state of continuous transformation. This places a premium on strategic coherence within the defence establishment, an issue that has been a constant struggle for Western defence establishments in the 21st century.

We now live in a data-driven world, and the increasing availability of information is providing defence with the opportunity to transform defence management. Furthermore, the relentless onslaught of technological change, combined with widespread disruptive innovation in many sectors, is making traditional strategic-planning models obsolete. Within this context, continual enrichment of business intelligence, or defence-analytics architecture, is central to collecting, processing, and analysing data to make informed decisions. This is important in an environment where the pace of technological innovation remains high and its diverse effects can have a broad disruptive impact on the security environment. Defence has, out of necessity, a long-term focus; consequently, it has traditionally strived to employ predictive analytics in decision making. The ability to now collect and analyse vast amounts of data is a force multiplier in defence and will be a key support to decision making in the future. Indeed, in the coming decade, the "greatest challenge will be to develop new capabilities to manage and exploit big data."[47] The implication is that structural change within defence departments is needed; this is as important as investing in new technology. In this case, developing a robust defence analytics capacity to ensure that decision makers at the strategic, operational, and tactical levels have the information they need to make informed decisions needs to be elevated to the level of importance placed on training, capital equipment, conduct of operations, and governance.

The integration of finance, supply management, and spare-part usage in equipment fleets within a single central computer system is in progress. This is already providing unprecedented amounts of data to defence leaders. This information needs to be harnessed and analysed to optimize support to operations, allowing for both process optimization and responsiveness. Furthermore, forecasting and resource planning will increase in relevance and application. Data analytics, by its nature, is heavily dependent on automation, as the massive volumes of data generated would overwhelm a traditional labour-intensive organization. Data analytics that harvests the vast volumes of data within defence requires shifting to a data-intensive regime as well as an elevated level of expertise and leadership. This requires a defined architecture and processes that facilitate data collection, manipulation and analysis, as well as decision making.

The primary impact on defence as a result of the transition to a data-driven organization will be a strategic advantage, obtained from the shift of institutional resource management from a support function to a primary combat enabler. In the same manner that defence establishments continually adapt technology, strategy, and resources to an evolving security environment, there needs to be a paradigm shift in terms of how data is collected and analysed. In a bureaucratic organization like defence, change comes slowly. However, a shift needs to begin in the near term to take advantage of advances in analytics in the private sector. In particular, an analytics department needs to be established within NDHQ. Outputs should be used as an integral component in institutional decision making. This requires an integrated team of finance, engineering, supply, defence-science, and environmental-operational personnel. This facilitates informed decision making on how the data are collected, managed, analysed, and presented. Various methods, including statistical analysis, simulation, and econometrics, provide a broad-based approach to analysis. Central to establishing an analytics department is a cadre of civilian personnel trained and experienced in business analytics. Defence is already a heavily analytical organization. Analysis occurs in many areas, such as recruitment and retention of military personnel, optimal loading of CC177 Globemaster aircraft, and training requirements for officer classifications and military trades. This culture of analysis and research now needs to be leveraged in the form of defence-analytics support to both strategic and operational decision making.

Conclusion

The RCAF will likely face ongoing change as it continually adapts to disruptive shifts in the global security environment. Consequently, competencies will need to be enhanced or developed to deal with increasing ambiguity and uncertainty in the fluid nature of the international security environment. These competencies will need to build on current education and training, as well as the expertise RCAF personnel gain in their careers. Effective management of defence resources will be a primary enabler in supporting the transition to a future-security environment. In defence, the unit cost of capital equipment has been increasing rapidly[48] since World War II and shows no signs of abating. Indeed, while the quality and effectiveness of advanced weapon systems continues to improve, the cost of capital equipment is putting pressure on national defence budgets. Consequently, defence departments need to invest in defence analytics to take advantage of the massive volume of internal data being generated, and also to better manage costs. Defence departments need to position themselves at the leading edge of disruptive change—derived from the current revolution in business intelligence and analytics that make use of massive amounts of data—to significantly enhance decision making.

National defence establishments are exceptionally agile as a result of their broad combination of operations and support competencies and organizations. Nevertheless, this powerful depth, breadth, and complexity within the array of defence capabilities paradoxically brings certain vulnerabilities in the current security environment. Effective resource management and the strong culture of a learning organization will support a foundation that contributes to institutional success. Furthermore, information generated through defence analytics will improve defence planning and execution, while supporting strategies to reduce institutional vulnerability.

Contemporary Western military establishments are facing a number of fundamental and complex challenges from a range of dissimilar sources. In order to confront pressures on resources, it is essential that strategies be in place to maximize the use of those resources to enhance institutional adaptability. Addressing the need to improve resource utilization in the RCAF will come from shifting organizational behaviour, not from changes in policy. The international security environment entered a period of uncertainty some time ago. As a consequence, we will constantly be surprised by demands on requirements and resources, which will present the RCAF with significant challenges. In a high-turbulence threat environment, where speed to deploy is critical for the RCAF, effective management of air force resources is key to enabling and sustaining operations.

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Abbreviations

CA	Canadian Army
CAF	Canadian Armed Forces
CBP	capability-based planning
CFAWC	Canadian Forces Aerospace Warfare Centre
DND	Department of National Defence
FY	fiscal year
NDHQ	National Defence Headquarters
RCAF	Royal Canadian Air Force
RCN	Royal Canadian Navy

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Capability-Based Planning and the Royal Canadian Air Force

John A. Steele

CH04 Table of Contents

Introduction

Of the set of enterprise resource management (ERM) challenges facing the Royal Canadian Air Force (RCAF), arguably the most complex and surely the one most fraught with uncertainty is ensuring that the RCAF is able to do what Canada will require of it in the future. Part of the challenge is that the RCAF is only one of the Canadian military services[1] that, in combination and jointly, provide the military capability by which the Canadian Armed Forces (CAF) undertakes to meet its commitment to be strategically relevant, operationally responsive and tactically decisive.[2] Beyond this, the CAF operates successfully only with comprehensive support from the Department of National Defence (DND) institution, which faces its own operational and capability challenges, while complying with federal administrative policy and implementing the Government of Canada's (GC's) horizontal initiatives, i.e., those cutting across many federal departments. In developing what it likes to call air power, the RCAF must also make best use of evolving technology, anticipate adaptive military threats, accommodate changes in operational environments around the world, act in accordance with changing political realities, and deliver within imposed resource constraints.

The purpose of this chapter is to provide a convenient reference to publications[3] that reflect Canadian capability-based planning and RCAF force development (FD), along with interactions between them, and some implications. The intent is to develop a better understanding of the opportunities and challenges associated with developing a fully integrated force development system as part of sound ERM.

The chapter begins with a brief summary of the defence organization, followed by an introduction to FD, and then discusses the concept of capability-based planning (CBP) as an approach to whole-of-force development, along with the basic rationale for CBP. The chapter then outlines Canada's experience using CBP and the current state of CBP, including some of the lessons observed and ERM activity developed in response. Further on, a short summary is provided of work done within the RCAF to develop complementary processes for identifying, planning and ultimately delivering the air force that Canada will need in the coming decades. Subsequently, the state of linkages between CBP and the RCAF is explored, and a brief assessment is provided. At the end of the chapter, the current situation is reviewed from the perspective of more fully integrating the CBP process with RCAF FD processes and those of Canada's other military services.

To clarify the terminology for readers outside DND, Figure 1 shows how the senior levels of the Department are organized. The highest level of professional leadership is provided by the Deputy Minister (DM) and the Chief of the Defence Staff (CDS), who is Canada's only equivalent to an American four-star general, and is said to lead at Level Zero or L0. Green blocks indicate military-led organizations reporting to the CDS; blue blocks indicate civilian organizations reporting to the DM; and the white blocks in between indicate organizations reporting to both, with each leading a Level One (L1) organization. The senior L1 is the Vice Chief of the Defence Staff (VCDS), who is considered DND's resource manager.

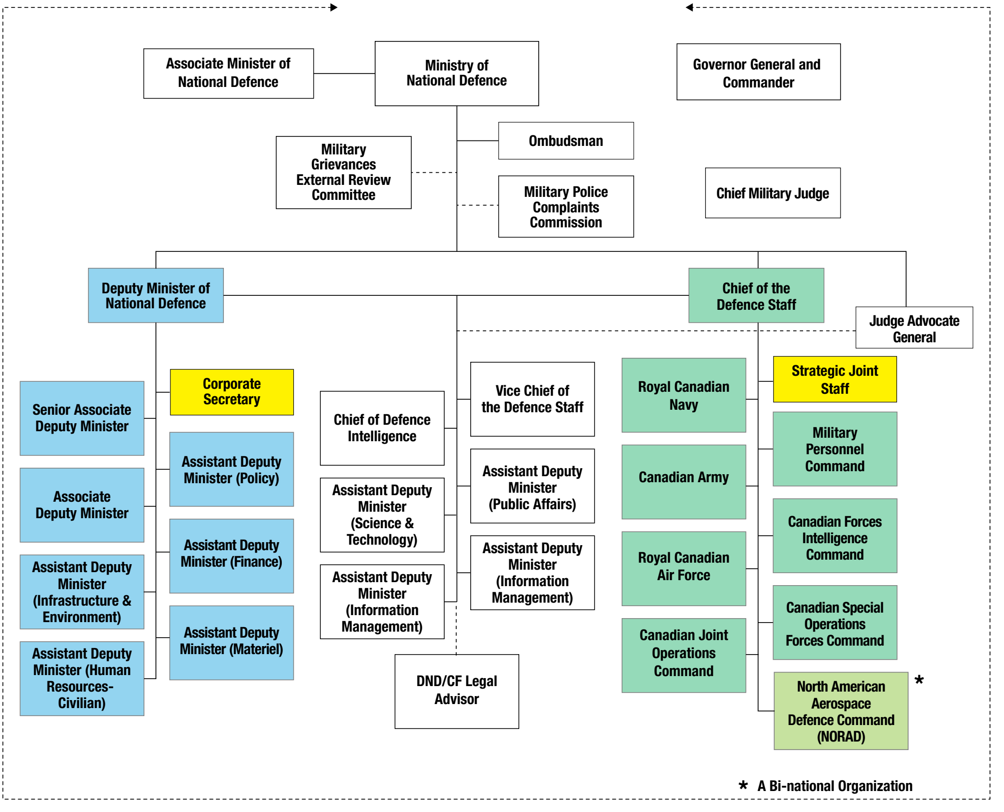

Figure 1. Senior DND organization chart[4]

Force Development

Force Development is the current term used for the process whereby services and the CAF draw up and execute plans to develop their military capability set. According to the Defence Terminology Bank, FD "is a system of integrated and interdependent processes used to identify, conceptualize and implement necessary changes to existing capabilities or to develop new capabilities."[5]

The term is not broadly used in this sense outside of the CAF, except within the United States (US) Army. It came into usage around the time when futures methodologies began to inform how the CAF should develop. In the Canadian context, the term Force Development supplements older related terms, such as Force Generation (production of military force elements) and Force Employment (military operations delivering command, sense and act effects), and more recently Force Support (military operations delivering shield and sustain effects, more or less) and Force Management (institutional support, in a broad sense), to make up what is known in Canada as the 5F model, provided by the Canadian Forces (CF) Transformation Team and reported in Lieutenant-General (LGen) Andrew Leslie's *Report* *on Transformation 2011*.[6] Although it had been developed further by 2013, the 5F model was still not well suited to supporting holistic analysis of the defence team. Its design consistently failed to track either the creation of value for defence, or specific process interdependencies. While its headings appeal to a military-centric mindset, it shed no light on the comprehensive dependence of military capacity and operations on defence institutions. The 5F model has since been further developed and used by the Royal Canadian Navy (RCN) to manage its activities, although the author has no information on the nature of this extended development and use.

For the most part, capability management and changes within the CAF are embodied in projects initiated and advanced by the service that naturally owns the capability, i.e., that owns the force elements logically delivering the corresponding capability effects. Since such advances routinely require capital investments for new or improved military equipment, and because capital procurement processes are assigned to stages and are quite elaborate, the centrally imposed process requirements are incorporated into the project approval gates set out in the Project Approval Directive (PAD).[7] This Project Approval Process (PAP), in its most generic form, goes through five phases with approval gates at each phase transition point, as shown below in Figure 2. First, access to capital spending authority normally occurs when a project enters the Definition phase, during which capital funding approval is required at different levels, depending on the total cost of procurement. Service commanders can allocate funds for projects with a value of up to $1M; the Deputy Minister can approve funding up to $5M; larger procurements require the approval of the Minister of National Defence or of the Treasury Board.

The approximate number of projects put through the PAP within a given service at any given time tends to be 100 or more, although this will also include investments to improve non-operational processes such as flight-training simulators and more institutional processes.

FD includes both the activities conducted within the military services as they determine and develop the force they want to become, and the central decisionmaking processes by Chief of Force Development (CFD) staff under the VCDS that prioritize capital investments and other resourcing decisions that support and enable the delivery of these future forces.

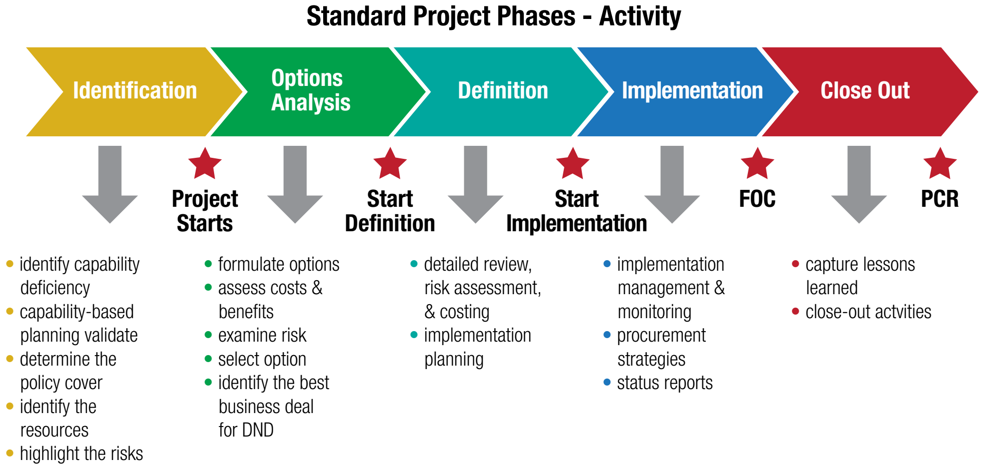

Figure 2. DND project approval process[8]

Capability-Based Planning

To quote from the CBP Handbook, a capability is

> the ability to achieve a desired end result. "Capability" is a description of the military operational output or outcome that a unit, force or organization is able (and usually constituted or organized) to deliver. Within the context of CBP "capability" is further defined as the ability to contribute to the achievement of a desired effect in a given environment within a specified time and the sustainment of that effect for a designated period.[9]

Thus, capabilities are intrinsically hierarchical constructs that can be broken down into contributing component capabilities that achieve intermediate outcomes. When defined in this way, each of the temporally sequenced and geographically separated assigned tasks that culminate in the achievement of large-scale military objectives and ultimate campaign objectives can be mapped to the employment of capabilities able to carry out the component tasks. Often, different force elements are able to carry out the same tasks in various ways and with different costs, risks, degrees of responsiveness, and logistical support burdens.[10] By focusing on operational tasks defined in terms of the resulting effects delivered in theatre, it becomes possible to achieve a very useful modular understanding of military forces that brings clarity to the trade-space in strategic resource allocation.

To illustrate how capabilities can be usefully defined, Table 1 shows the top level of the capability taxonomy used to support the analysis underpinning the Strategic Capability Roadmap (SCR) in the first whole-of-force round of CBP conducted under the CFD.[11] Notice that each capability name directly implies or even states the nature of the effects created. Aerospace Effects Production (AEP) refers to the production of operational effects that influence what happens in the aerospace environment. Also, there are no platforms or specific force packages mentioned. Capabilities are delivered by force elements, which can be thought of as personnel, equipment, and sometimes real property that, working together, make one or more capabilities available to a theatre of operations. The distinction between force elements and capabilities is an important one in Canadian CBP, although their definitions may vary between nations and even between communities within the CAF, and this can easily lead to confusion. Major platforms serve as a natural basis for defining many force elements, and each element will make available capabilities as numerous as the separate tasks it is able to complete. This is not to imply that there are no dependencies on capabilities delivered by other force elements in the course of delivery of a force element's own capabilities. While a fighter aircraft provides many different capabilities in the CBP sense, only some of which are unique to that platform, other force elements set some of the conditions for the fighter aircraft's success.

Domain	Capability
Command	Command Support
	Communications
	Joint Effects Targeting
Sense	Intelligence
	Surveillance and Reconnaissance
Act	Aerospace Effects Production
	Land Effects Production
	Maritime Effects Production
	Special Operations Effects Production
	Non-Kinetic Effects Production
Shield	Force Protection
Sustain	Sustainment
	Support Services
	Movements
	Theatre Activation and Deactivation
Generate	Force Generation

Table 1. Top level of the capability taxonomy used in the SCR[12]

Each capability listed in Table 1 was further broken down into a hierarchy of functions, then activities, and finally, examples of activities. The specific breakdown of AEP is shown in Table 2. In aggregation, the breakdowns of each item in Table 1 came later to be called the Joint Capability Framework (JCF) for the cycle. Note that the way the items under Functions and Activities are defined adheres closely to the principle that capabilities should be defined according to the tasks they are able to accomplish or the end state they achieve. Again, no identifiable force elements are named in the table, but only things that may need to be done. Furthermore, Examples of Activities include some that are not owned and provided by force elements belonging to the RCAF, such as Ground-Based Air Defence and Covert Operations. Conversely, there are RCAF capabilities that do not fall under AEP, such as Strategic Lift (Movements) and Close Air Support (Land Effects Production). CBP is most powerful when applied across an enterprise.

Capability	Functions	Activities	Examples of Activities
Aerospace Effects Production	Deny aerospace to the opposing force (OPFOR)	Defend friendly aerospace	Conduct air intercept
			Conduct defensive counter-air
		Defeat OPFOR aerospace assets	Conduct ground-based air defence
			Conduct anti-air warfare
			Conduct fighter sweep
	Provide freedom of manoeuvre in the aerospace	Combine forces for operations (ops)	Provide aerospace control
			Conduct combined air operations
		Destroy or suppress OPFOR aerospace assets on the ground or at sea	Conduct suppression of enemy air defence
			Conduct covert operations
			Conduct suppression of surface-to-air and surface-to-air missile threats
			Conduct offensive counter- air
		Protect own aerospace assets	Conduct air escort
			Conduct combat air patrol
			Monitor aerospace

Table 2. SCR decomposition of aerospace effects production[13]

It is worth noting that the power of the capability concept is now a well-accepted part of private-sector strategic analysis and plays a central role in the business architecture discipline.[14] It should not be surprising that the need to generate the right kinds of value efficiently and consistently as part of an enterprise strategy for success in a specific market context parallels, in most ways, the need to develop a military force for successful long-term national defence and security. Since capability concepts are as relevant in the private sector as they are in the defence sector, this report will single out the defence use of these concepts by referring to military CBP.

To further broaden the capability concept, while the CAF conducts operations around the world and maintains a sufficient number of prepared but undeployed forces to ensure near-term responsiveness, the DND institution is continually delivering its own operational outputs to achieve specific outcomes. The civilian (or predominantly civilian) portions of DND carry out a myriad of separate tasks that produce desired effects within specific organizational contexts within specified time frames, and are able to sustain those effects for designated periods, and sometimes permanently. These tasks include more generic forms of training, the management of real property, materiel, information systems, communications, finances and procurement, as well as the coordination required for any organization that is part of a large complex enterprise. These parts of the defence team must adapt to corresponding changes in their own environments. Thus, the concept of an institutional capability is every bit as relevant to DND as military capability concepts are to the CAF. However, the CBP concept does not yet play a visible role in civilian workforce development.

A succinct and highly influential definition of CBP[15] is provided in Paul Davis' distillation of a decade of contributing work from the RAND Corporation: "Capabilities-based planning (CBP) is planning under uncertainty, to provide capabilities suitable for a wide range of modern-day challenges and circumstances while working within an economic framework that necessitates choice. It contrasts with developing forces based on a specific threat or scenario."[16]

The emphasis of Western military planning in recent decades has shifted between designing in order to respond to a small number of apparent threats (as was the case during the Cold War) and designing for a broader range of less certain threats requiring a wide variety of types of military response. Influencing this shift is the apparent predictability of future military roles. During the latter stages of the Cold War, when global power hostility dominated strategic thought, the West perceived a clear existential threat and trained and equipped its forces to address the principal military challenge,[17] which was fully circumscribed in detailed computer simulations. Military planning was dominated by a single threat spanning a single scenario with well-developed variations. With the collapse of the Soviet Union, a vast corpus of strategic planning analysis lost most of its near-term relevance, and the realization emerged that the new top problem to solve was military planning under uncertainty. This brought into sharp focus the importance of managing force versatility and refining the breaking down of various military problems into their component parts, so that a modular approach to military tasks could fully enable the development of national forces that are robust in the face of uncertainty.[18]

Military CBP in Canada

Early exploration

Land forces have long embraced capability concepts in their force planning to deal with what is arguably the most complex of the three operational environments.[19] As early as 1995, the RCAF used CBP at Fighter Group HQ in North Bay, Ontario, in response to budget reductions, and, in order to develop the 1994 Defence White Paper,[20] used a Strategies-to-Tasks procedure[21] in a task-based analysis to rationalize the CF18 fleet size.[22] Between 1996 and 1998, Phase II of the Canadian Maritime Forces 2015 Study included modelling of the ability of various fleet options to meet the requirements of stochastically generated sets of taskings requiring distinct capabilities.[23] In 1997, the Directorate of Defence Analysis organized a workshop with participants from across DND to develop a set of force planning scenarios spanning the range of tasks that might be given to the CAF, anchored in the 1994 Defence White Paper as amplified by the 1997 Defence Planning Guidance.[24] The event generated

31 tasks[25] aggregated into 12 scenarios.[26] Shortly thereafter, an approach was proposed that consisted in linking a central CBP process based on initial risk assessments to drive capital planning.[27] By 2001, the CBP idea was well enough known and regarded for DND planning guidance to formally adopt it, along with a new Canadian Joint Task List (CJTL) developed to align with allied task lists. The CJTL would provide a menu of operational tasks to anchor capability definitions in order to bring clarity to the CBP dialogue.[28]

As other western nations began developing and implementing their own whole-of-force CBP, the impetus grew for international collaborations to compare experiences and develop best practice guidelines. Separate and contemporary studies were assigned within the NATO Research and Technology Organization (NATO RTO)[29] and under The Technical Cooperation Program (TTCP).[30]

Full CBP cycles

In 2005, the new CDS General Rick Hillier, on reviewing the recommendations of CDS Action Team 3 (CAT 3),[31] made it a requirement that CBP be institutionalized as part of a centrally driven, top-down approach to FD within DND.[32] This led to the development of a set of scenarios that would bracket the variety of anticipated future threats,[33] and to the development, validation and use of procedures and analysis in order to use force planning scenarios to identify capability deficiencies. By October 2007, four scenarios had already been analyzed for capability shortfalls when the task was assigned to go from there to a set of prioritized investments based on completed scenario analyses. The task of completing the scenario analysis, developing a way to complete the task and the needed supporting tools, and then execution was successfully accomplished in ten months by a fully integrated team of military officers and defence scientists.[34] The result was a departmentally endorsed list of capital projects called the SCR that informed the 2009 DND Investment Plan (IP).

From 2010 through 2012, a second full round of the CBP process was implemented by the Director Capability Integration (DCI), reporting to the CFD's Director General Capability and Structure Integration (DGCSI), with support provided by the Strategic Planning Operational Research Team (SPORT) of Defence Research & Development Canada's Centre for Operational Research and Analysis (DRDC CORA), as requested. The second round was carried out in three phases fairly similar to those shown in Figure 3, taken from the CBP Handbook,[35] but with some differences. DCI staff revised the menu of capabilities, called the JCF, starting from a set of capability domains (Command, Sense, Act, Shield and Sustain) that each break down into specific capabilities at progressively lower tiers. During this round, 114 capabilities were evaluated.

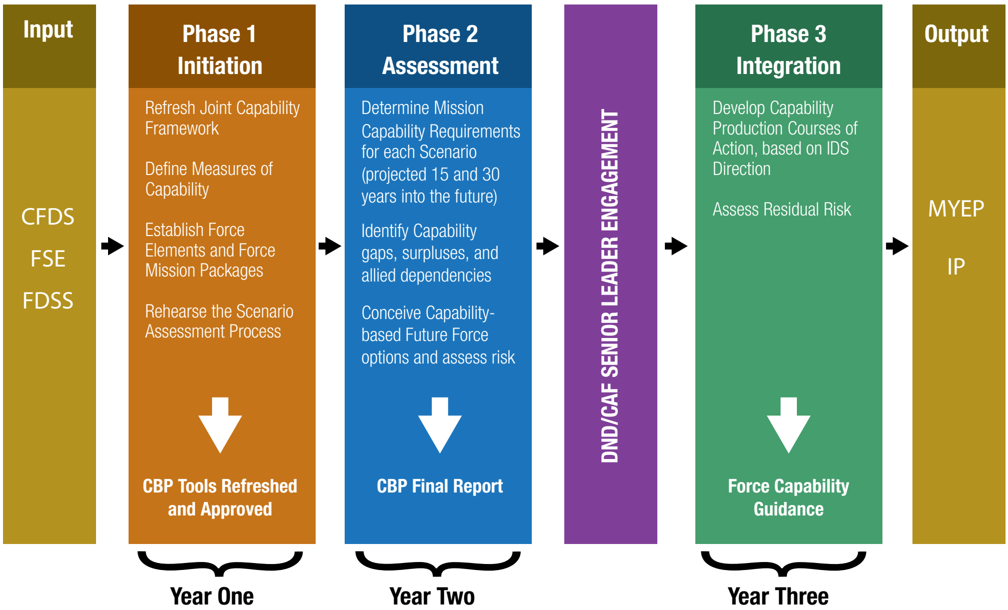

Figure 3. Current CBP process[36]

An FD Scenario Set (FDSS) of eight scenarios was developed to align with the six mandated missions of the *Canada First* Defence Strategy (*CFDS*):[37]

- conduct daily domestic and continental operations, including in the Arctic and through NORAD;
- support a major international event in Canada, such as the 2010 Olympics;
- respond to a major terrorist attack;
- support civilian authorities during a crisis in Canada such as a natural disaster;
- lead and/or conduct a major international operation for an extended period; and
- deploy forces in response to crises elsewhere in the world for shorter periods.

The scenarios were drawn from a Future Security Environment (FSE) document.[38] During Phase 1, military staff under the DCI developed operational objectives and force packages (consisting of force elements) to meet the requirements of the scenario crisis, and those of any allied forces assumed to make up the notional coalition. Operational planning procedures were tailored to the CBP activity that consisted in identifying necessarily distinct lines of operation, and the implied sequence of decisive points on each planned line of operation.

The steps in Phase 2 were carried out by Joint Capability Planning Teams (JCPTs) consisting of officers and non-commissioned members (NCMs) reporting to the DCI, plus subject matter experts in each service and from across the Department. The teams discussed scenario dynamics before assessing at each decisive point the appropriate measure of capability (MoC) values for the employed capabilities. In Phase 2, each capability provided by the force packages was assessed and rated for its importance to mission success (Mission Critical, Mission Essential, Mission Routine or Not Allocated) and for the adequacy of the force elements to provide the needed effects (No Capability, Ad Hoc, Matched or Affluent). Throughout this activity, free text comments were collected in order to compile qualifications with respect to judgments and important underlying considerations. However, the analysis did not specifically take into account investment costs or divestment savings, and referred only to the requirements indicated in the generated capability analysis. The CBP Final Report was produced, feedback was received from senior leaders, and Force Capability Guidance (FCG) was issued. The final report included specific capability recommendations, each with a description of related capabilities that needed specific investment, sustainment or divestment, and the context warranting the action, although the specific content of both documents is classified.

One of the realizations that emerged in 2012 from more than one source[39] was the need for more military personnel in operational units. However, the fiscal constraints of the time made it unlikely that the GC would authorize CAF growth beyond its approximately 68,000 regular force positions.[40] Consequently, the positions required would have to be created by removing less critical military positions in each service and within the DND institution that were freed up through some combination of reassignment of work to civilians, alternative service delivery, business process innovations, and assumed risk. The establishment changes required to make this adjustment were to be set out in the Multi-Year Establishment Plan (MYEP), a five-year schedule for reallocating positions between organizations that was to be reviewed every three years. The development of an analysis able to identify a suitable supply of institutional military positions to be reallocated began in earnest in September 2012, and two reports were submitted in the spring of 2013.[41] The recommendations in the analysis as to how to source the needed positions categorized the supply by organizational activity, but did not address interdependencies between organizations. The author's report documenting the initial MYEP position sourcing analysis[42] outlines alternatives for a more holistic and compelling analytical approach. With the complexity of the problem recognized, an interim approach based on fairly sharing the burden of giving up regular force positions was adopted, and a more robust analysis strategy was developed.[43] In summer 2016, DND formally endorsed the development of a more integrated strategy for defence team human resource management[44] in order to ensure holistic analysis and treatment of the risks involved in reallocating military positions from more institutional to more operational roles.[45]

The most recent three-year CBP cycle began in the fall of 2013, and once again followed the pattern in Figure 3. A rewritten FSE document[46] focused less on the broad circumstances that may arise in the future and more on those of specific military consequence, and is thus a document better suited to supporting FDSS development of ten scenarios spanning the six *CFDS* missions. Six MoCs were defined, including Scale, Survivability, Reach, Persistence, Responsiveness and Interoperability. The Scale MoC was intended to assess the basic effectiveness of the capability, which is difficult to do with a single scale for all capabilities. Therefore, four subcategories of capability effectiveness were developed (lethality, command and control, sustain, and generic) in order to better accommodate the diversity of capabilities to be assessed. Each MoC consisted of seven levels, although only Reach, Persistence and Responsiveness had anchored scales (e.g., Instant, Seconds, up to Months). The other MoCs had unanchored, descriptive scales (Very High to Very Low).

Phases 1 and 2 have produced their respective outputs,[47] but a plan for operational force structure capacity analysis using stochastic modelling was postponed because of the change in government and the announcement of a Defence Policy Review (DPR).

A graphic shown in Figure 4, produced by Paul Massel,[48] provides an overview of the changing methodology used for military CBP as practised within DND. It shows separate instances of its application with numbers defined, not according to full cycles completed, but according to separate adjustments and refinements of the methods used to carry out CBP, including the development and use of new tools to support them. Thus, the first full cycle involved the development and implementation of spirals 4 and 5, while the second cycle was the result of spirals 6 and 7. Spiral 8 represents the third full cycle, ending with a final report expected by the end of 2016, and in accordance with CBP process requirements, a Force Capability Plan (FCP) sometime later. However, the standard process may play out differently in light of the government's DPR, the completion date of which is unknown at this writing.

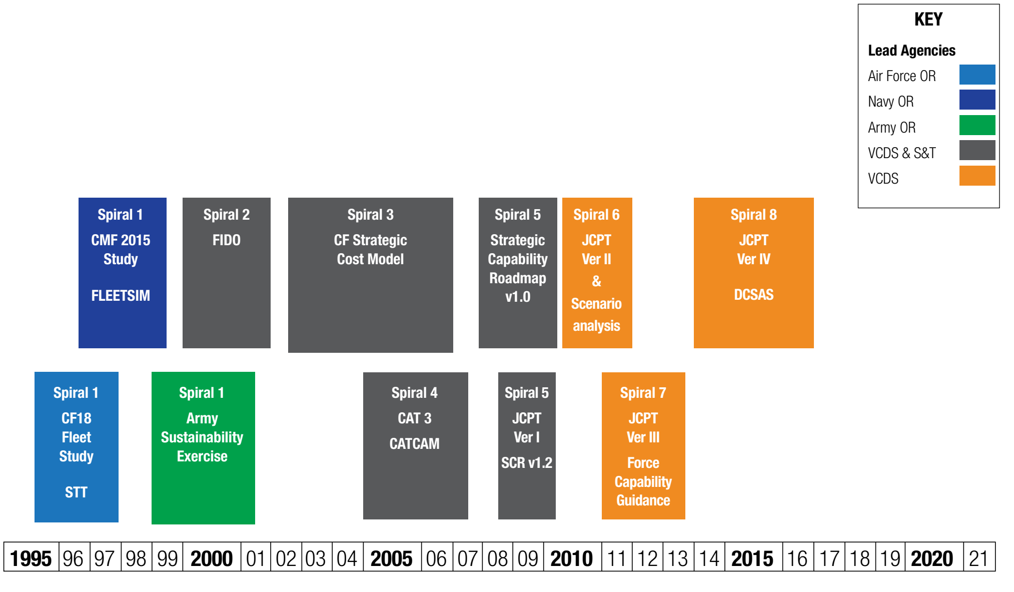

Figure 4. 20 years of CBP development in DND[49]

A Mature Generic CBP Model

A follow-up report to the 2003 TTCP technical report, written by Dr. Ben Taylor,[50] provides a useful CBP overview of particular successes and practical challenges to the institutionalization of CBP. In the report, he provides a generic CBP process diagram showing the logical flow of information and inputs that lead to an affordable, balanced set of investments that in turn result in the delivery of materiel and enable forces of optimal capability to deal with expected operational demands, which is Figure 5. The red-coloured top item illustrates input from above the defence organization. Gold-coloured items are essential inputs to the CBP process that produce the gray items in sequence, culminating in the blue coherent national force development plan informed by both resource constraints and risk.

Unique Features of Canadian Military CBP

It is instructive to compare Figures 3 and 5 and to focus in on some of the distinctive features of the Canadian CBP process. Elements common to both, beginning in Phase I, are the initial government guidance—i.e., up until the end of the most recent federal election in the fall of 2015, this was the *Canada First* Defence Strategy (*CFDS*)—and documents describing the future security environment (FSE). CFD guidance shapes the selection and definition of scenarios to reflect current defence priorities. The Canadian interpretation of Capability Partitions includes the following:

- refresh of the hierarchical taxonomy of capabilities in the JCF;
- definition of MoC scales and values to be used during this round; and
- development of a force element list and selection from it to define force mission packages per scenario.

Phase II begins with the gathering together and process orientation of Joint Capability Planning Team members from across the Defence team. Work begins with scenario analysis and operational planning to identify the operational tasks or lines of operation (LoOs) and the decisive points in each. This constitutes the determination of Capability Goals in Figure 5.

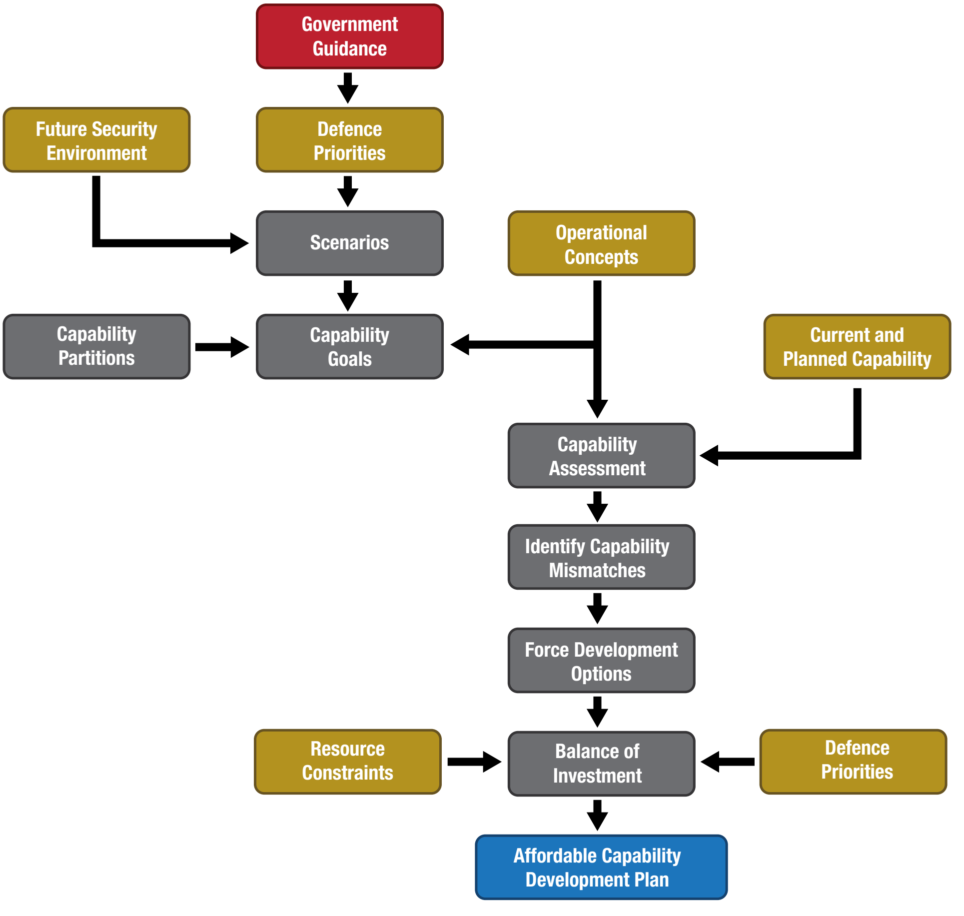

Figure 5. A generic CBP process[51]

The adequacy of the capabilities provided by the assigned force packages is then assessed through group analysis and professional military judgment. A necessary step during this stage is to obtain detailed, specific knowledge of the performance trajectories expected of each capability in what is called the Force of Tomorrow over time, given that capability-enhancing investments have specific dates for the delivery of initial operational capability (IOC) and full operational capability (FOC). Once these steps are completed for each scenario, the Capability Assessment phase is complete.

Then, the team can go to the Identify Capability Mismatches phase, during which it reviews the performance of capabilities across all scenarios in order to identify systematic weaknesses and associated risks. These analyses, combined with the text comments collected from JCPT participants, are used to identify specific FD initiatives suitable for managing the risks identified in the foregoing.

These are the Force Development Options built into the next block. All of these are outlined in the CBP final report, and spelled out in greater detail in the FCG, according to the direction developed through senior leadership engagement.

At this point, the Canadian CBP process diverges from the generic one in that Phase III never addresses Resource Constraints in specific terms. Instead, in Phase III, guidance is developed by capability area and sometimes by specific capability, with each designated as either "Invest," "Sustain" or "Divest." A list is drawn up of "Related Projects" that are sometimes actual projects, but more often platforms addressed by multiple projects. No specific account is taken of total estimated project costs, let alone planned spending amounts by year. The only definition provided as to the meaning of Invest, Divest and Sustain is relative increase in, reduction of or maintenance of capability levels, and these changes might be in quantity, effectiveness, or readiness levels. However, the CBP process as designed stops short of developing an Affordable Capability Development Plan (ACDP) that acknowledges and accommodates resource constraints and addresses specific capital projects. This omission of financial aspects from military CBP in Canada is also a significant divergence from its description in P. K. Davis' *Analytic Architecture for Capabilities-Based Planning, Mission-System Analysis, and Transformation*, [52] which specifically includes choice within an economic framework.

It should be stated that there is at least one good reason for military CBP, as illustrated in Figure 3, *not* to advance all the way to an ACDP. The Balance of Investment used to inform the plan includes all capital investment needs. Excluded from the Figure 3 analysis are other Defence capital investment needs, such as the following: capital equipment used exclusively for military training, such as simulators; recapitalization and improvement of real property used or not used during military operations, such as ranges, training facilities, military hospitals, military accommodations and dining facilities; and, large-scale institutional investments in personnel and resource management systems, to name a few. A good balance of capital investment requires holistic analysis of all competing capital investment needs. Since the scope of military CBP in Canada is much narrower than this, there must be input from other investment analysis processes carried out in parallel with CBP that can be taken into consideration at the same time as CBP results when determining the appropriate balance of investment. Otherwise, balance must be defined *a priori* in terms of capital budget segmentation for planning purposes, and this requires a final validation step where the operational capability risks implicitly assumed by not funding the highest-priority, unfunded, military capability capital projects are compared with the risks assumed by not funding the highest-priority, unfunded, capital projects in other categories.

It is worth noting that during the first full cycle of CBP, completed in 2008 and consisting in the delivery of the SCR, specific candidate investments were processed and placed in rank order.[53] The most immediate impact of the SCR was the foundation it provided for the 2009 IP submitted to and accepted by the Treasury Board of Canada. However, because the SCR did not explicitly deal with institutional capital investment needs, it is not known how institutional capital investment needs were addressed in the 2012 IP.

Another approach that highlights uniquely Canadian aspects of military CBP is to compare it with Davis' distilled definition of Capabilities-Based Planning, provided in P. K. Davis' *Analytic Architecture for Capabilities-Based Planning, Mission-System Analysis, and Transformation*[54] and quoted previously, which incorporates four key elements: definition and consideration of capabilities; planning under uncertainty; addressing a wide range of challenges and circumstances; and resource constraints necessitating choice. The fourth was just addressed, but the first three merit a brief comment in turn.

The determination to plan in terms of modular capabilities is clearly seen in the requirement to define and update the JCF, which provides the taxonomy of military capabilities, from which the planning process selects those relevant to each scenario. However, the JCF for the second cycle defined a menu of 114 capabilities for use in scenarios, and the third cycle defined 76 capabilities for evaluation. Indeed, the terms for defining the CAFs capability future were changed considerably for the third cycle. While the changes in the JCF for the third cycle may bring real improvement, such changes undermine the transfer of insight between cycles. In principle, JCFs need not change between cycles, because the operational tasks to be carried out by military forces actually change very little over time. What does change is technology and the ways it can be employed to better carry out those tasks. Therefore, capability frameworks of enduring utility are best defined in terms of operational end states achieved. On these, various military services will have less trouble coming to agreement. When that agreement extends to the CFD, i.e., the Strategic Joint Staff who manage force posture and readiness and the service FD communities, the pathway opens up to achieving a commonly understood language for describing future CAF capability attributes across all three horizons.[55] A strong starting point for developing an enduring JCF is the NATO capability framework. If departures from it can be clearly mapped back to it, the investment promises to bring consistency and save considerable work in preparing annual capability reports for NATO.

Paul succinctly surveys the elements of planning under uncertainty in *Lessons from RAND's Work on Planning Under Uncertainty for National Security*,[56] and sets out seven separate strategies for mitigating capability risk and summarizing work done to implement each one. Fundamentals include the need for exploratory analysis of the uncertainty space in order to identify the dimensions most relevant to the success of any plan and the parameters warranting more detailed exploration. Doing so results in much richer future insight than a single-point estimate and enables planning for the purposes of importing flexibility to address mission variations, adapting to various operational settings, and resilience against operational shocks.

Taking uncertainty into account is arguably the most difficult part of the Davis CBP definition to implement. The current DND approach to CBP goes no further than to articulate and explore a main variant of each of the scenarios in the FDSS. While reference is made several times in the CBP Handbook to the need for stakeholders to discuss "critical uncertainties that will drive the scenario vector,"[57] the exact meaning of this phrase is never given. The JCPT judgments all assume one set of scenario circumstances. Thus, uncertainty tends to get lost, resulting in ten single-point estimates of capability sufficiency. Comments from participants often note important dimensions that will affect judgments, but there is no systematic exploration of the possibility space and, therefore, no explicit handling of uncertainty in JCPT judgments.

Efforts to address the wide range of challenges and circumstances that the Canadian military will face go no further than to develop a range of scenarios intended to span the most relevant parts of the operational spectrum, and then assess tailored force packages in relation to each scenario mission.

Less rigorous exploration of possible convergences of future trends could be used to generate a wide variety of brief thought pieces to build a richer sense of the range of challenges and circumstances to be faced, while also helping to explore the uncertainties of the more fully developed FD scenarios.

Missing economic framework

The exclusion of financial constraints from the CBP analysis process may have limited its ability to provide a solid foundation for the 2013 capability investment plan. Upon analysis, the Treasury Board of Canada Secretariat (TBS) would not submit it to Treasury Board without some revisions and departmental commitments to capital investment governance improvements, including a commitment to revisit the question of which of the competing candidate investments would mature in order to proceed through to definition and be allocated capital funding. It was because of this DND commitment to the TBS that the Capital Investment Program Plan Review (CIPPR)25 initiative was set up in 2014, with a mandate from the VCDS and the chief financial officer (CFO) of DND "to undertake a rationalization of all investments at the Identification (ID) and Option Analysis (OA) stages before fall 2104. The aim is to produce a DND/CAF consolidated balanced folio consisting of critical, viable and affordable capabilities representing best value for money as well as institutionalizing a process that will be transparent, repeatable, rigorous and coherent against which all present future investments will be assessed."[58]

In the resulting activity, a model was developed to quantify the value of what each capital project promised to deliver, and a portfolio optimization approach was implemented in order to determine the combination of investments that promised to deliver the best total modelled value for money within the constraints of capital funding remaining to be allocated. Project value was modelled in terms of criteria originating:

- above Defence (including alignment with legislation, government policy and government priorities);
- at the senior levels of Defence (including CBP gaps and Defence Renewal priorities); and
- within project-sponsoring organizations (based upon relative priority that L1 seniors assign among their own projects).

The software developed within SPORT to support CIPPR is called Visual Investment Plan Optimization and Revision (VIPOR),[59] and it continues to generate growing interest outside Defence for several reasons:

- VIPOR uses appealing and illuminating visualizations to characterize candidate projects and constructed portfolios;
- VIPOR is interactive and allows users to manually drag and drop investments into or out of a portfolio and re-optimize around the added constraints, thus enabling real-time discovery of the opportunity cost of any project;

- VIPOR incorporates project dependencies so that a dependent project forced in drags with it others on which it depends, while supporting projects removed will take those they support with them; and
- VIPOR includes a model of project delivery capacity using fiscal proxies for project delivery burden and capacity.

The resulting analysis has since informed the official identification of those capital investments expected to be assigned funding budgets once they mature. This has also clarified which candidate investments are not expected to progress to expenditure authority under current funding levels, thus informing a more efficient assignment of sponsor and central effort to the advancement of major capital projects.

In light of the current approach taken by Canada to CBP, the creation of the CIPPR process was a necessary step for DND to take, since the CBP process stops just short of translating CBP insights into specific investment advice, and because careful consideration must also be given to institutional investments. The CIPPR process—because it considers the full range of departmental investment options and has developed a model of project deliverable value that goes beyond military operational capability—provides the broader analysis that is necessary if the ACDP at the bottom of Figure 5 is to span all major DND capital investments.

While the purpose of central CBP, as stated in the CBP handbook, is to inform Invest-Divest-Sustain (IDS) decision making, the process has fallen short of that mark because of its disconnection from "an economic framework necessitating choice." By taking no account of specific candidate investments and their costs, the process leaves unaddressed issues relevant to investment correction. In addition, the assumptions on which the analysis was based are better suited to identifying gaps in capability planning than in capability investment. This limits its suitability for the purposes of CIPPR, although this outcome is understandable since CIPPR and the decision processes it would inform were both defined after the most recent CBP cycle was set in motion.

A cynic might speculate that military CBP's avoidance of economic constraints was calculated to maintain pressure on the government to provide more funding to make it all affordable, thus excusing military leaders from restraining their own capability appetites, and leaving that task for the more civilian, institutional part of DND. However, a number of events and initiatives within DND over the past few years have shone more and more light on just how closely the interests of the military and civilian parts of the Defence team are linked. A case in point was the MYEP analysis mentioned on page 88. As the dynamics of this interdependency become better understood and appreciated, differences of thought in what is appropriate work for a civilian and for a member of the Forces—many of them more culturally than practically defined—are being bridged. The need for a holistic understanding of the entire organization is receiving increasing attention. As the fiscal constraints continue, there is a growing readiness to explore the actual limits on both CAF and DND capability in more holistic terms. However, the subject of FD in Canada's air force will be introduced first, before we return to enterprise-level capability planning in the last section.

Force Development in the RCAF

General Hillier, who established the central mandate for CBP while he was CDS, is well remembered for coining the term "decade of darkness" to describe the series of cuts to Canadian defence spending in the 1990s that left the CAF much in need of capability investment. That period was only the most recent episode in a longer series of events that still leave a mark on RCAF FD. These events are therefore briefly recounted here before I describe the current state of RCAF FD and its linkages to CBP.

Background

Unification of the RCN, the Canadian Army (CA) and the RCAF in 1968 arguably dealt the greatest blow to the RCAF. Only the Air Force saw all of its professional military education institutions dissolved or repurposed to joint-level functions, as well as several of its fleets placed under the control of other services to provide operational support, while having no environmental command of its own as a counterpart to Mobile and Maritime Command; that is, until 1975, when Air Command (AIRCOM) was established in Winnipeg. From 1968 onward, strategic doctrine and force development effectively ceased, making air force development a matter of system replacement until the Commander of AIRCOM convened an Air Doctrine Symposium in 1984, leading to the setting up of an Air Force Doctrine Board.[60] The Board then oversaw the development of *Project 2010 – A Flight Plan for the Future*, a 25-year FD look-ahead, and a decade later, the more ambitious *Project 2020 – A Flight Plan for Change*.[61] *Project 2020* results were published in three phases over two years, and set out global trends and factors affecting defence planning (Phase I), a vision of required air force missions, tasks and attributes (Phase II), and a plan to achieve them (Phase III).[62] Unfortunately, full release of and action on the plan were pre-empted by the release of the 1994 Defence White Paper and a decade of subsequent federal budgets imposing successively smaller end states for DND that by 2005 had shrunk the RCAF to half the strength that it had at the end of the Cold War, leaving it fragile and greatly in need of a strategic vision to mobilize its own transformation.[63] When DND issued *Shaping the Future of Canadian Defence: a Strategy for 2020* in 1999, the Navy and Army promptly developed their own service versions,[64] while the Director General of Air Force Development (DG Air FD) drafted and redrafted a series of Air Force papers[65] that seemed to respond, but were widely criticized within the Air Force. Its only extant strategic doctrine, *Out of the Sun*, dating from 1996, was rescinded in 2004 without replacement. The crippling and marginalizing reorganization that occurred at the time of unification, followed by only gradual reconstitution in the 1970s and 1980s, and later by 15 years of incremental downsizing, resulted in an Air Force almost completely divested of strategic visioning and force development capability.[66] Although the responsibility for FD belonged to DG Air FD, the organization was further hampered by a series of restructurings (as were much of the air staff) that began coincidentally with the 1999 release of *Strategy 2020*.[67]

Recognizing the serious need for RCAF investment in future air warfare concept development and experimentation (CD&E) leading to strategic development, the Air Force leadership decided in 2003 to set up the Canadian Forces Air Warfare Centre (CFAWC) at Canadian Forces Base (CFB) Trenton to address this void. However, because there was little recent experience and sparse knowledge of the dynamics of strategic FD, attempts to re-establish the capability in a new organization proved chaotic, thus thwarting development and acceptance of the structure, processes and governance necessary for

FD to achieve its objectives. Differing understandings of CFAWC's mandate and conflicting visions for its operating paradigm resulted in an extended struggle to find a footing for CFAWC in proactively exploring future needs and opportunities in air capability development.[68] The RCAF drafted and circulated an "Air Force Strategy" in 2007 that was endorsed by the Chief of the Air Staff (commander of the Air Force) and the CDS for internal use, but not for publication. Neither "Strategic Vectors" nor the "Aerospace Capability Framework" was formally rescinded. A 2009 draft "Air Force Strategy" informed by the *Canada First* Defence Strategy[69] was submitted to the senior DND management committee, but excluded from formal reference by the DND's senior strategic guidance products. As late as 2011, the RCAF still lacked both a functional FD framework and processes for developing, promulgating and monitoring implementation of an RCAF strategy.[70]

In the Foreword to the 2016 *Future Concepts Directive*, Lieutenant-General (LGen) Michael Hood, Commander of the RCAF, provides a succinct and, in light of the above, stoic summary of the current RCAF FD situation:

> Our capstone strategic publication *Air Force Vectors* (AFV) establishes: who and what we are as an Air Force, the air power we output, and our mission and vision. It would seem this should suffice to enable us to proceed with building that Air Force, and indeed historically that is the broad approach we have undertaken. We have used the core Air Force roles to define and build individual fleet capabilities. We have modified existing fleets based on bottom-up ideas related to that fleet. We have replaced expired fleets with modern versions of the same type of aircraft.
>
> This was effective in a paradigm where the technical nature of air power change predominantly remained focused within those same stovepipes of capability; more manoeuvrable and faster fighters, bigger transports, better radars, etc. Consequently, although the RCAF postulated a Conceive-Design-Build-Manage (CDBM) model of force development, the Conceive stage required (and received) little formal attention as an approach of "update and replace" was usually adequate. This is no longer the case, as AFV has identified that the RCAF can only optimally contribute to national strategic effects via a capability-based approach that includes Canadian Armed Forces partners, Government, industry, and other nations[71]

RCAF Strategic Guidance Framework

In the past five years, much progress has been made. The publication of *Air Force Vectors* (*AFV*)[72] ushered in the establishment of a functional strategic guidance framework, setting forth a clear statement of the RCAF identity, the RCAF's place in the CAF, and its mission and core processes. It articulates a vision for the RCAF as an agile, integrated air force with reach and power (AIRPower) essential for CAF operations, defines six core processes that are key to fulfilling the RCAF mandate,[73] and describes a structure for its implementation through a suite of strategic documents that would follow—a Campaign Plan, Annual Planning Directives, and a Future Concepts Directive.

Also published in 2013 and updated in 2015 was the *RCAF Campaign Plan* (CP)[74] providing details of the six LoOs that basically carry out the same core responsibilities listed in *AFV*. The CP includes sub-LoOs with work component milestones, decision points, and key success criteria for the next five years, thus managing the tension between the Sustain and Change agendas. In particular, it fully describes the "Develop and Innovate Air Power" core process outlined in *AFV* so as to include the following, as shown in Figure 6.

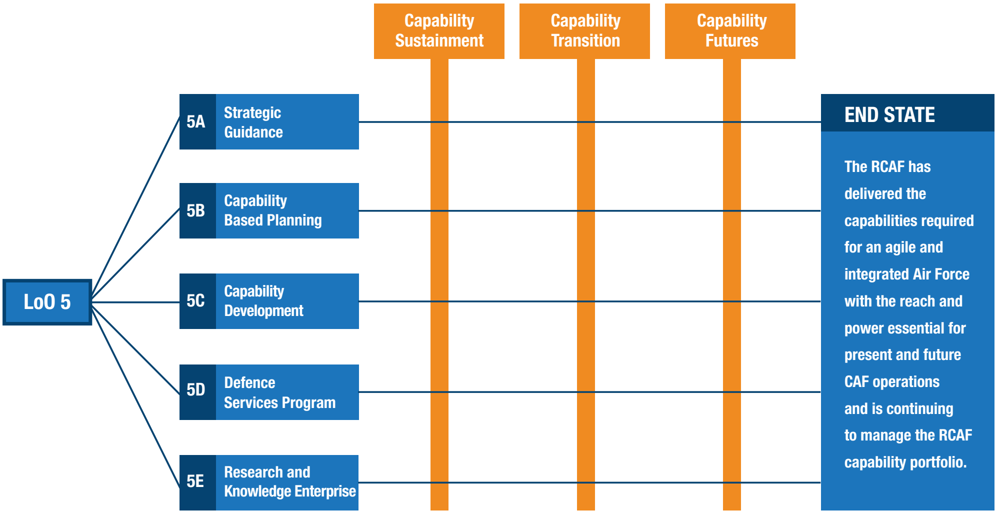

Figure 6. Sub-LoOs of the RCAF force development system[75]

- 5A – Strategic Guidance,
- 5B – Capability Based Planning (support for the CFD-owned process),
- 5C – Capability Development (RCAF development of its future),
- 5D – Defence Services Program (shepherding projects that will deliver the future RCAF through PAP), and
- 5E – Research and Knowledge Enterprise: support for RCAF FD from CFAWC, DRDC, Assistant Deputy Minister (Materiel) [ADM(Mat)] and knowledge generation occurring outside of DND.

Also published in 2013, revised in 2014 and 2016, is the Royal Canadian Air Force *Future Concepts Directive* (FCD)[76] which describes the FD processes used by the RCAF in terms of how they fit into the broader CAF FD context, which is shown in Figure 7. In particular, it focuses on CD&E processes (in the Conceive box) and input to CAF FD from the grey bar at the bottom.

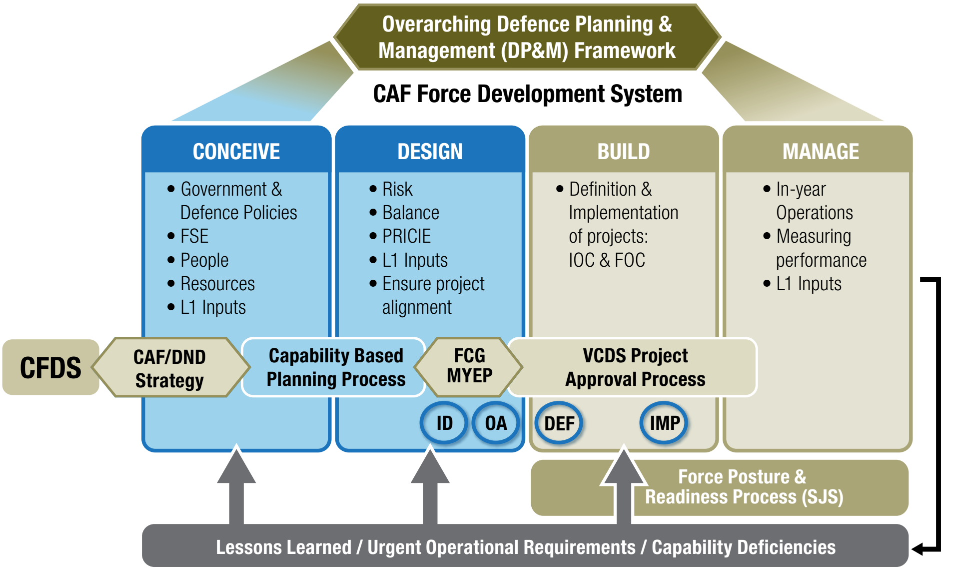

Figure 7. CAF Force Development System[77]

The FCD also introduces a taxonomy of concept types with type examples, as shown in Figure 8, and includes integrating concepts that may help the RCAF achieve new consistency of action with other allied players in the operating environment.

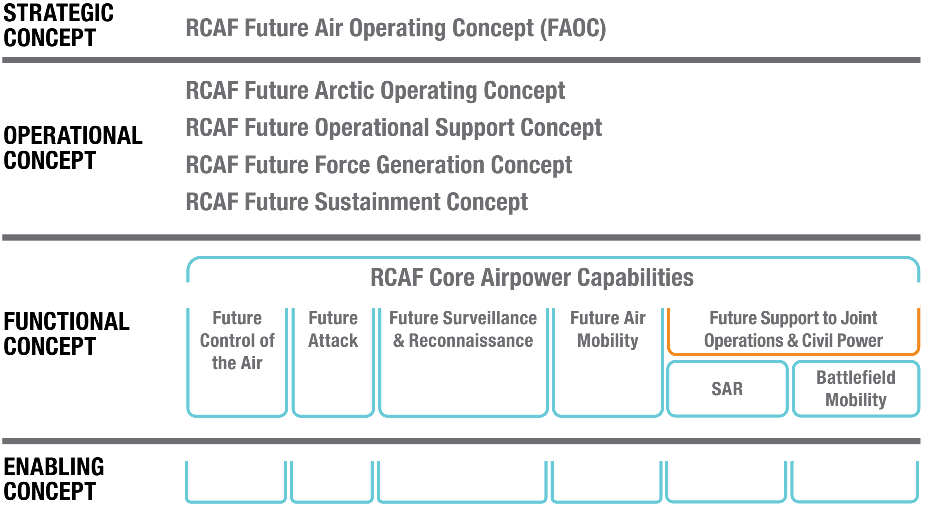

Figure 8. RCAF FCD taxonomy of concept types[78]

An example of a strategic concept is the Future Air Operating Concept (FAOC). CFAWC is drafting an FAOC describing how the RCAF will fight in the 2030 time frame, just beyond Horizon 2. The drafting of a FAOC began as early as 2011,[79] although it has been difficult to find the appropriate way to develop a FAOC. A DRDC CORA operational research team supporting and co-located with CFAWC has circulated for comment preliminary drafts of a scientific report setting out a FAOC concept that has gained traction and clarified the desired approach.[80]

RCAF FD Process Advances Under Development

CFAWC is developing a three-force construct that segments the RCAF's future into stages, each associated with force development processes appropriate to its associated degree of uncertainty. The stages are basically defined as follows:

- Force of Today includes the RCAF in being (capabilities of the moment) and plans to improve capabilities of the moment [through] any decision that has currently been made or has been planned with respect to any of the capability components[81] (PRICIE).[82] For example, if the RCAF decides today to complete a life cycle upgrade on a platform in 20 years' time, it is making a force-of-today decision even though the actual activity takes place in the future.
- Force of Tomorrow [is informed by] work to determine if current decisions are valid. Example: Ongoing analysis of the decision to conduct the life cycle upgrade. Over time, things may occur where the upgrade is conducted sooner or later, or the equipment is replaced because of a change in requirement or capability component.
- Future Force [is informed by] analysis of the FSE and the future operating environment (FOE) in order to establish capability requirements for the Force. Example: Based on new required operating concepts, technology advancements and personnel requirements, the Force requires new capabilities or modified current capabilities.

The criteria distinguishing the Force of Today from the Force of Tomorrow are important to understand and merit some discussion. The example offered under Force of Today, i.e., a decision to "complete a life cycle upgrade on a platform in 20 years' time" must be understood as a decision to commit funding to a life cycle upgrade, not just to a plan to carry out a life cycle upgrade. This is important because the RCAF or any service can only carry out minor capital projects under its own expenditure authority limits, currently defined as capital investments with procurement costs lower than $5M. This means that larger capital projects, even if they have the strongest possible support from the Commander of the RCAF, will only be delivered if they win in the cyclical competition[83] for limited amounts of uncommitted capital funding, mature to enter the Definition phase, and obtain GC agreement with senior Defence endorsement of the project's request for expenditure authority to carry out its plans. A change in the decision to upgrade the air frame may be initiated by the RCAF upon a review of RCAF priorities, but it might also originate with the GC if the expenditure fulfils a vision not shared by the government in power (e.g., the Chrétien Liberals' cancellation of the EH101 Sea King replacement), or is otherwise seen to hamper the achievement of major political objectives. So, it is not the RCAF's or even the CAF's Force of Today; it is the GC's Force of Today.

In order for FD decisions by the CAF, and ultimately by the GC, to develop the CAF required to meet future operational challenges, these decisions need robust support. The detailed operational constraints, the conceptual foundation, the tactical logic, and the capability dependencies taken into consideration in service FD capability investment plans need to be made meaningfully available to CFD as the central capability authority, to the CAF capability manager, to those persons building and assessing national capability plans (CFD), and to those persons who must authorize sound investment decisions. These facts highlight the importance of an integrated FD system. Successful execution of the CBP process depends on a clear understanding of how and why specific capability investments will prepare the CAF for the future.

An influence map outlining how the knowledge and plans of other defence stakeholders should have a bearing on RCAF development over all three time horizons has been developed with DRDC CORA support at CFAWC and is shown in Figure 9.[84]

The framework reflects a great deal of holistic thinking about the wide variety of references that need to be used in RCAF capability planning. The line leading to the right from the VCDS block in the top-left corner acknowledges the role of CBP and CBP products on CAF FD and the impact that government decisions taken during the Defence Policy Review can be expected to have on the vision for the RCAF.

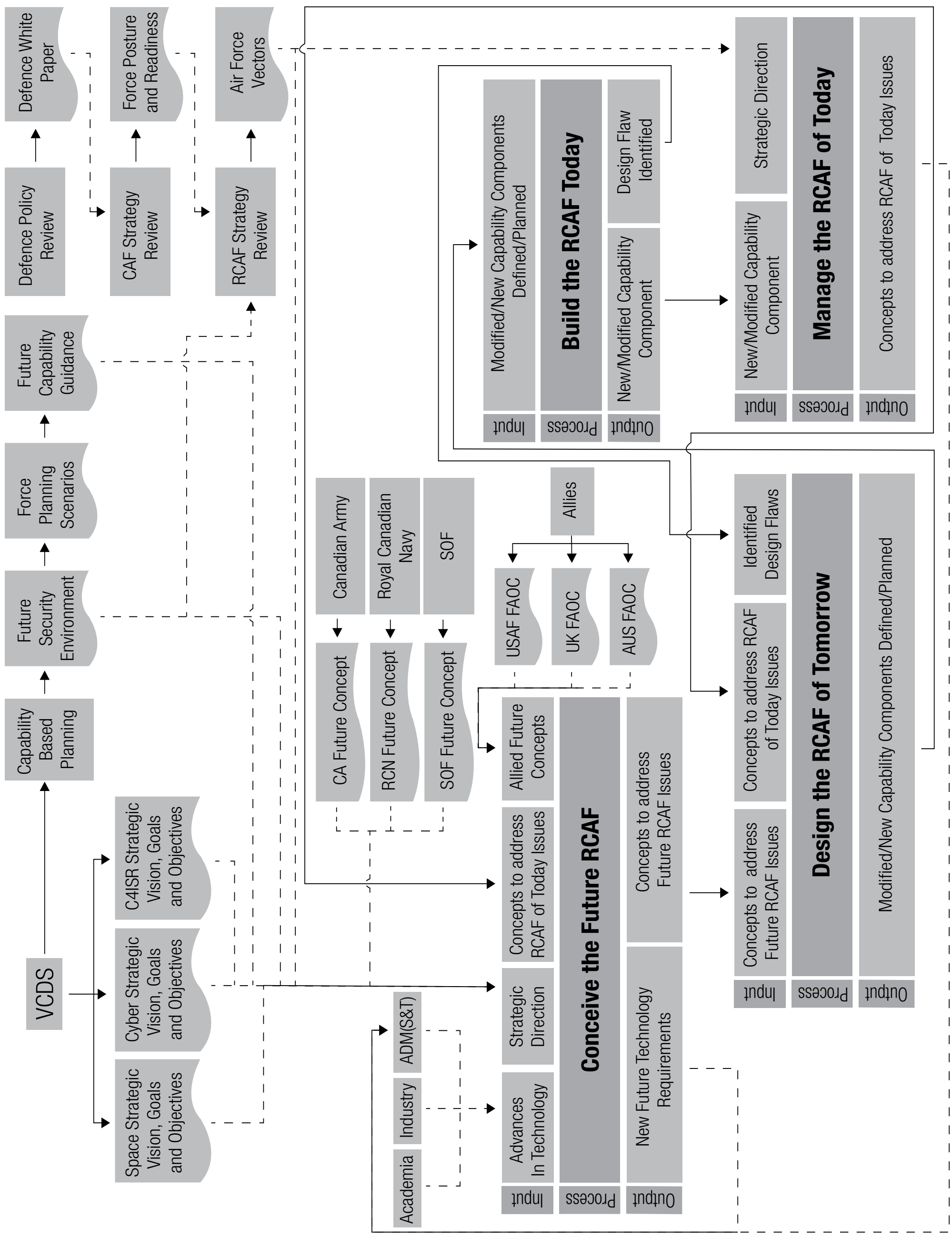

Figure 9. A process construct under development at CFAWC using the RCAFs of Today, of Tomorrow and of the Future

The figure also shows, in a downward direction from the VCDS box, the important roles that other central FD products play in establishing the visions for joint capability infrastructure that each service should plan to accommodate and exploit in future operations (about which more will be said in the next section). Near the middle, just below the CBP process blocks, the RCAF's role in future joint Canadian operations is acknowledged in the explicit reference to the future concepts of the other Canadian military services. The blocks below this acknowledge that the bulk of RCAF operations abroad will be with one or more of our closest allies. In addition, capability advances are seen to routinely require technological advances that are achieved commercially, and academia and Canadian defence scientists can play critical roles in furthering, developing and incorporating these advances into future military systems.

The framework also clearly shows the separate process levels needed to support robust decisions that will deliver the air power needed for Canadian defence in the future. The top layer in each of the Conceive, Design, Build and Manage blocks depicts the specific categories of input needed, while the bottom layer describes required outputs that need to supply FD work being done by other players within and outside the RCAF. Lessons learned from building and managing the RCAF of Today must be used to inform both the RCAF of Tomorrow and the Future RCAF.

It will be important to develop the internal structure of the conceptual option space of the Future RCAF very carefully. In the conceptual option space, the idea of long-term, task-based capabilities becomes very important so as to escape the "system replacement" mindset to which FD thinking defaults without fulsome concept development. The creativity needed to enter and vigorously explore the option space that accompanies the FOE will produce competing, overlapping and mutually inconsistent concepts that will muddle the boundaries implied by existing air concepts. They will require analysis and testing to fully define, distill and de-conflict them. In addition, numerous concepts must be developed in order for CD&E to qualify and enable downward selection to only the strongest, mutually compatible candidates. In fact, the absence of such overlap and inconsistency should be seen as a clue that operational imagination has hardly entered the conceptual option space at all.

The RCAF narrative during the last 12 years can be understood as a struggle to implement the processes in the box labelled Conceive the Future RCAF. Without that box, Air Force development is stranded in the "update and replace" paradigm that begins with Designing the RCAF of Tomorrow, without the benefit of Concepts to Address Future RCAF Issues. Taken as a whole, the *FCD* and the development work shown in Figure 9 constitute concerted RCAF efforts to describe and chart a course to attain the end state of achieving consistent, conceptually anchored and strategically informed FD. Figure 9 clearly shows the RCAF's reliance on and integration with key external stakeholders in RCAF capability development to achieve that goal, of which CFD is arguably the most influential.

Clearly, identifying and implementing the terms on which FD processes can become integrated across the CAF will only be possible with everyone on all sides helping to tackle the challenge. Success will bring benefits to all services, but the challenges are significant, not least of which is that the Commander of the RCAF and other service commanders each outrank CFD. The next section looks in further detail at the option space for enhanced linkages between CAF and RCAF FD processes, with a view to finding alternatives that will improve both sets of activities.

Linkages Between RCAF FD and CBP

Ideally, CAF and service FD processes would be simultaneously effective, mutually complementary and synchronized. With three large services with very distinct cultures and approaches to FD, the most important role in achieving integrated FD across the CAF is that of the CFD. Process integration can be expected to have a very direct impact on the success of the CFD and that of his supervisor, the VCDS, in developing the CAF to a point where it continuously fulfils its role in defending Canadian interests and values. The most significant first step may be the development of a shared understanding of how the CAF should logically be developed in terms similar to those in Figure 9. This shared understanding would be the basis of an integrated FD concept. Once defined, it would serve as a framework on which a coordinated and synchronized FD process could be built, with clear linkage points between it and FD processes in each service, and clear expectations of what each can expect from the other. The CFD needs access to the knowledge and logic that underlies the plans of each service, and the services (the RCAF perhaps more than the RCN and the CA) need a framework within which each can conduct analysis that generates a consistent and compelling body of evidence anchored in the Canadian military context to support the strategic capability initiatives that enable the entire CAF to effectively tackle the challenges of the future. Although such integration is attainable only with the support of each of the services, it is inevitable that the most important role in achieving these two outcomes should be that of the nation's central force developer. Therefore, it is worth taking a closer look at how the current CBP process and RCAF FD fit and do not fit together.

Central and RCAF force development approaches

As discussed above, the particular way in which CBP has evolved within the CAF fits nicely within the generic CBP process in Figure 5. The starting points of reference are specifically the FSE and Defence Policy as interpreted by the CFD. However, this contrasts with the terms on which RCAF FD is conceived in *AFV*, which states, "The RCAF is changing its emphasis on the role of futures analysis in its FD process. Acknowledging the practical limits of selecting capabilities based purely on predictive futurology, we will use ongoing analysis of enduring and emerging requirements to inform capability gap assessments and consequent concept development and experimentation."[85]

To address a perceived imbalance in the futures-based approach mandated in 2005, *AFV* in 2012 specifically includes two points of reference not mentioned in CBP: requirements that are long standing, continuing even today, and requirements emerging from recent and current experience. This creates a tension between two contrasting and arguably competing paradigms: one a linear extension from experience into the future, a paradigm rooted in decades of RCAF experience, and the other a more remote survey of the most relevant future challenges and a process that plays out their implications for the adequacy of the force being acquired. The best strategy is for both these approaches to coexist, occupying the places set for them in Figure 9, so that the FD dialogue includes the lessons learned with each approach, thus informing a set of investments including both best bets and suitable hedges. In this case, the unwillingness of the RCAF to lose sight of past and more recent considerations where predictions had a better basis acts as a useful counterbalance to the newer methodology developed specifically for the much less certain, longer-term future where "all bets are off."

Specific Process Linkages

The most authoritative extant reference describing the current state of CBP in DND is the CBP Handbook.[86] However, much has been learned in the two years since it was last edited. Although it is now clearly out of date in some respects, it does give a detailed representation of the thinking that went into the CBP cycle, for which a report on Phase II is soon to be submitted at this writing. The Handbook makes not only many references to "senior leadership" in the context of consultation and reporting, but also more general reference to L1 organizations and specific reference to service FD communities. Figure 10 shows a semantic diagram developed by using keyword searches of the Handbook's content to find references to the wider FD community, and building a conceptual map showing the references that were found. The figure is interpreted by sequencing text in blocks and on arrows into block-shaft-block sentences in the direction of the arrow. The numbers in round brackets refer to the paragraph numbers of the Handbook that state the relationship, and the relevant CBP phases are in square brackets. In the diagram, the service FD staffs are represented by the turquoise block near the middle. The magenta blocks represent each of the various products in the CBP process.

The figure implies that the services will have an impact on every part of the CBP process. However, the process for making this happen is not defined. Service input is obtained *ad hoc*, without any opportunity for the services to plan how they will answer questions asked by the central authority ahead of time and produce pre-defined FD products based on the logic informing their own initiation and refinement of capability projects.

As for the passing of CBP information to L1 FD staff to help them carry out their work, the Director Capability and Structures Analytical Support (DCSAS) will provide knowledge management support through the use of integrated analytical products, as required. However, services will only require such information if they know it is available.

Missing pieces

Recent RCAF experience has shown that it is difficult to re-establish conceptually supported strategic FD after doing without it for four of the past five decades. The creative and analytical work required to explore the capability option space fifteen or more years into the future is not easily planned and executed.

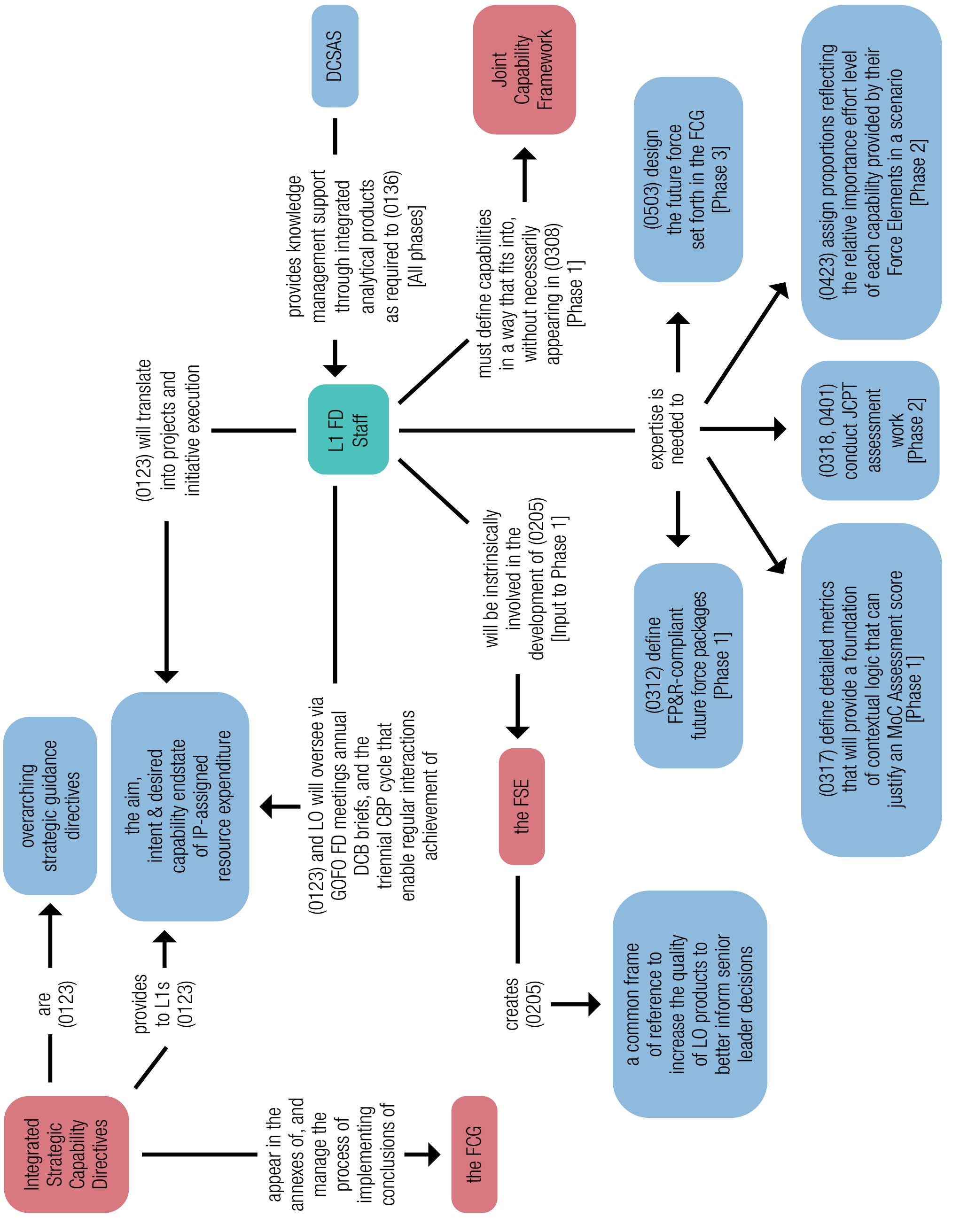

Figure 10. References to L1s / Services in the CBP Handbook[87]

The CBP process helps service force developers by providing periodically updated FSE documents, which is shown by a line in Figure 9. However, this help is almost incidental, creating a setting for future concept development, but little more. A further build-out of the FSE into a document describing the FOE would provide a more relevant reference for both service and central FD work. While the framework in Figure 9 explicitly acknowledges that the concept of the Future RCAF must be informed by the FSE and FCG, the RCAF FD community, in their efforts to obtain value from CBP products to advance their own work, have found little that helps them with concept development.[88] In part, this is because products intended to inform IDS decisions to make capability adjustments fifteen years in the future are actually relevant to the design of the RCAF of Tomorrow, not the design of a Future RCAF. The CBP process is better understood as a filter than as a generator of capability options, and basically depends on services developing their own future concepts. The joint capability planning teams then assess the operational significance of capability development options that are mature enough and useful enough for investments to be made to exploit them.

Future force design must be based initially on coming up with new ideas and using a variety of creative processes in a disciplined way to take advantage of the RCAF's extensive and detailed operational air power expertise and the array of defence challenges that may emerge in the future. Carefully recording the details of the resulting concepts will make it possible to identify alternative air power concepts. Additional concept characterization will be enabled by other processes that systematically explore how well those concepts might meet future operational requirements and how well they fit with current operational paradigms. As concepts mature, it becomes possible to devise experiments to illustrate concept utility in more quantitative terms. Future RCAF options can be constructed from the best of these concepts and existing operational concepts with which they are compatible and complementary. These options, once validated, provide the building blocks for a validated Future Air Operating Concept.

If future concept development is to become an ongoing discipline within the RCAF, concept development must not be treated episodically. Concept work is challenging, and people involved in it must work with abstractions and things that can only be imagined. It is a skill set every bit as perishable as any pilot skill. An enduring concept development and experimentation capability requires sustained and ongoing concept generation, elaboration, development and experimentation processes.

Consequently, there is considerable unexplored potential for the CFD to shape its processes in order to provide whole-of-force context and foster FD process consistency that improves the foundations for both service and CAF FD. The current arrangement leaves the CFD at the mercy of services selecting who will represent them in JCPTs, and service force developers guessing at major elements of strategic FD.

What is offered here are a few thoughts for the CFD that will bring greater consistency to FD processes across the CAF, add value to service FD processes, and generate a more comprehensive body of shared knowledge and understood context that will enhance the pools of expertise on which CBP must draw.

Vectors for enhanced central FD leadership

CFD has an opportunity to create a more complete compendium of information to promote and support service FD processes by expanding documents about the FSE beyond a description of possible or probable futures and including implications for military operations, as well as a document addressing the FOE. It should address interactions between the social, political and technological dynamics of probable futures, and include indications of the potential impact on operations in order to give analysts an idea of potential impacts on capability effectiveness. Support for the development could come from DND staff experts in scientific and technical intelligence, strategic analysis, future concept development, and defence science research in order to develop and outline specific challenges to specific capabilities in each service. The degree to which these challenges threaten to defeat or degrade expected capabilities would be explored by asking questions for which service FD staffs must provide answers that address mitigating concepts and investments, planned delivery of improved capability systems, and how materiel (including computing equipment), personnel and real property elements of capability can enable effectiveness to be achieved. By making it a requirement that services specifically address these issues, they act together to propel those responsible for service FD design into the same future option spaces to address the same operational challenges. This will help to place the CAF FD dialogue within a shared context.

In addition to the above, there is a wider international FD context. The US, the United Kingdom (UK) and NATO as a whole will each face similar challenges in the FOE across the full spectrum of warfare. The position of the CFD is uniquely suited to compiling and interpreting the international context and Canadian service responses to CFD futures-based challenges in a single volume including a summary and analysis of its content. By flagging the impediments to consistent CAF development as an integrated national force, as well as unaddressed or under-addressed operational task requirements, the CFD would provide a valuable body of information for every part of the Canadian FD community. The generated results will be used to compile a much more extensive corpus of information for JCPTs to use in their capability decisions, thus helping to set the bar for the sound judgments required of CBP, and mitigating many of the expertise limitations imposed by the services' varying levels of commitment to the central CBP process. The results would also provide a much more useful overview as the services develop and explore options for their own future capabilities.

Force planning takes up a large part of Defence ERM and includes several dimensions that are driven by or based on CBP. The next section summarizes the main ERM dynamics that interact with CBP and must be taken into consideration as the RCAF plans its own future.

The Current Situation

Drivers of CBP development from inside DND

There are several circumstances that are expected to propel changes in the way the CAF conducts military CBP. Some stem from the CAF's experience with CBP, while others have arisen outside the Department. Those from inside DND include the following:

Force capability monitoring: Defence leaders want to understand how well military capabilities are expected to address defence challenges over time. However, as illustrated for the RCAF, the approach taken in Horizon 1 may differ markedly from that taken in Horizon 3, by bringing unnecessarily different concept definitions and terminology to the dialogue. An example is the meaning of words such as "capability," as well as the way in which the same capabilities are defined by different defence communities, and even by communities not associated with a specific service. Standardization of the vocabulary used throughout capability stakeholder communities is needed if FD analysis is to foster a shared understanding of how CBP is shaping, and needs to shape, future capabilities over all time horizons. The analytical approach used for the SCR specifically included production of integrated timelines of capability development over a period of up to 20 years.[89] The terms on which NATO manages and reports capability requirements provide a highly relevant starting point toward a stable, shared hierarchical taxonomy of military capabilities for use throughout DND and the CAF.

CIPPR process: The task involved in the CIPPR process is to identify the best possible combination of major capital investments, using the year-over-year cost of project delivery method and a model of the value that each combination promises to deliver. The value model for military capability investments relies on CBP analysis of the capability gaps that will need to be closed or pre-empted by investment deliverables. A necessary condition for useful analysis is for the gap analysis to include an examination of the sufficiency of what DND has already committed to buying and nothing more, excluding from the assessment every investment still competing for capital funding. This approach recognizes that new investment and divestment decisions are based on decisions already made. CBP products fulfil their purpose to inform IDS decisions only to the extent that they differentiate the utility of candidate capability investment deliverables in order to show the relative importance of the capability gaps to be closed or pre-empted and the extent of the closure or pre-emption delivered by each investment. The only way to build an investment case is to highlight the difference between having and not having its deliverables. Therefore, the assessed force must exclude all unfunded deliverables if CBP is to show what it means not to have them.

Integrated human resources strategy: As mentioned in the description of how the second CBP cycle drove the need for a MYEP on page 88, the CAF has broadened the terms of its search to find ways to shift military positions away from more institutional activities and into more operational activities by expanding the analysis to include reserves and civilian employees. The MYEP has been re-scoped to specify adjustments in all three components of the Defence team. It is the author's belief that any analysis identifying and adequately characterizing for mitigation the risks that attend a shift of military positions out of institutional functions must recognize the value to the defence enterprise that is delivered by personnel in those positions. Then, alternative approaches to delivering that same value with reduced military participation can be designed and tested. This will require something such as CBP applied to the DND institution that treats institutional operations in a way analogous to military operations in military CBP. Capability concepts will come to inform the way both the Chief of Force Development and the Chief of Program divisions develop the evolving Defence team to ensure that it can affordably and effectively meet Canada's future defence needs. The current Assistant Deputy Minister for Civilian Human Resources has begun work to define civilian capabilities[90] and has been engaging the Director General for Military Personnel Research and Analysis, a research centre under the ADM for Science & Technology but integrated into the Chief of Military Personnel organization, for the task of modelling the dynamics of civilian HR life cycle processes.

DND use of a departmental results framework for strategic management: A team working under the Chief of Program is leading DND in the development of a program structure called a Departmental Results Framework (DRF). The DND DRF will meet the requirements of the TBS Policy on Results[91] for purposes of government reporting. However, it is also to provide a coherent basis for defence ERM. The main source of that coherence will be its evolution from the Program Alignment Architecture (PAA) announced in 2014, which was designed for the very purpose of enabling coherent defence ERM.[92] The PAA is a hierarchical taxonomy of defence activity spanning the entire breadth of what has to happen for DND to fulfill its mandate. Its overall design is briefly described in Appendix A, and the PAA itself, included in Appendix B to this chapter. At its core, successful ERM depends on a sound understanding of mandate-relevant value and the processes by which it is created and preserved through resource investments. In order to inform construction of an enterprise-level model of value creation and management, enable delivery of the Integrated HR Strategy, and implement DRF-based ERM, DND is about to conduct a systematic survey of defence enterprise activity in terms of how and where DND activity adds value to DND's fulfilment of its mandate for Canadian defence and security. The survey will be carefully controlled to manage the level of detail needed for it to be useful to inform strategic decisions. This will enable construction of a networked model of the way defence activity creates and combines value in the strategic portfolios targeted by each activity[93] and the way in which those strategic portfolios combine to deliver the readiness and operational outputs on which Canada's national defence depends.

Drivers of CBP development from outside DND

As of this writing, several transitions in Canadian defence are underway:

New defence policy: Following the election of Justin Trudeau as Canada's Prime Minister with a Liberal majority in the House of Commons, the government issued a new mandate to the newly appointed Minister of National Defence (MND), and released the mandate letter to the public online.[94] Since then, the new government has initiated a DPR with public consultations. This will likely result in a new policy foundation for the CFD's future CBP process.

Capital funding levels: The greatest impact of the CIPPR process, and especially of the VIPOR software developed to support it, has been to provide, perhaps for the first time ever, a clear understanding of the opportunity cost of each of the major capital investments competing for unallocated capital funding. This detailed understanding is making it possible for the DPR to address perceived gaps between what the government has expected Defence to do in the coming decades and the capital funding provided for the task. Any shift in capital funding levels will create increased impetus for the CBP products to provide analysis suitably grounded for future investment trade-off analysis in the CIPPR in order to make full use of the insights required from military CBP.

Conclusions

Military CBP in Canada is at a turning point. After three full cycles, its role of informing capability investment decision making is only now coming into clear focus. This clarity presents an opportunity to align the production of CBP outputs with the specific decisions they must inform, investment-related and otherwise, and to foster greater coherence in FD activity across the services. The RCAF, in particular, stands to benefit from greater central FD leadership, having recently produced the RCAF Strategic Guidance Framework and currently redesigning FD processes that can discover and develop concepts that can be used to implement the most advanced air power capability options. The RCAF staff involved in this work clearly acknowledge that they depend on other stakeholders to fill in the rest of the picture, and that the work is an excellent starting point toward achieving an integration that can be very useful for CAF development in the service of Canada's defence interests.

The CFD has an opportunity, with VCDS support, to help each of the services enter more fully into the conceptual option space, where evolving challenges can be understood militarily, and technological breakthroughs can be used to take advantage of new capability opportunities in the FOE. The growing need to manage risk in the defence institution arising from the squeeze between continuing fiscal restraint and increased operational personnel requirements is creating a demand for new types of analysis that are able to model and inform institutional risk management. With a Defence Policy Review nearing completion and a new US government, many changes to the strategic defence planning environment are in play. At the same time, departmental leadership in developing the analyses required to meet these needs is rising to the challenge. If a place can be found in the force development dialogue for the various FD perspectives of the CAF and of the RCAF, in particular, and if experience with capability-based techniques of enterprise-level FD can be leveraged to address the challenges of workforce development, then DND is poised to advance toward a much fuller realization of the benefits of what P. K. Davis defines as "*planning, under uncertainty, to provide capabilities suitable for a wide range of modern-day challenges and circumstances while working within an economic framework that necessitates choice.*"[95] [emphasis added]

Appendix A: Understanding the Program Alignment Architecture

Many readers will know that DND announced a new PAA in 2014. However, many Defence Team members bristle at the mention of the PAA because of their experience with previous versions. In general, the idea behind the PAA and the real power of the 2014 one is not widely appreciated. In reality, the new PAA is based on a surprisingly simple idea illustrated below.

Since 2003, the TBS has required federal departments to have a PAA that will bring consistency to strategic reviews conducted to inform resource reallocation decisions, and which will serve as a structure for reporting to Parliament and to Canadians what it does with tax money to fulfil its mandate from the GC. There are two key reasons for having a PAA:

- to determine the links between resources invested and results obtained; and
- to draft a simple narrative of what DND does to fulfil its mandate to Canadians.

Previous PAAs did not perform either of these activities very well because DND staff were preoccupied with the organizational structure of DND. While structure is critically important to help us do our jobs, it misses the point. The new PAA is strictly about turning money into actual defence. If you want to identify where something belongs, the most relevant question to ask is this: How does this activity add value to the defence of Canada?

The new PAA includes a map where you can locate the answer to that question. It was designed specifically to enable tracking of the transformation of money spent into valuable defence outcomes. The following explains the PAA structure and provides additional information:

1. Job 1 is combat operations; so it is also Program 1. The essence of combat is force elements going out the door to stand against what threatens Canada's future, domestically and continentally (1.1) or internationally (1.2). Everything we do in both settings relies on functions that operate anchored in Canada (1.3), including overarching C2 (1.3.1), Intelligence ops (1.3.2) and Op Support (1.3.3). (All three of these sub-programs have ongoing elements and commitments that are domestic [1.1.2-1.1.4], international [NATO 1.2.3] or both [1.3.4 Mil diplomacy / Global engagement].)
2. We also do non-combat things that Canada cares about, and these are Program 2. They include providing assistance when disasters hit (2.1) and providing support for the safety and security of Canadians at home (2.2). We also stay connected to the culture with heritage, ceremony and youth programs (2.3).
3. Combat operations are only possible if you have ready force elements, and Program 3 is where we produce them, whatever their role:

    a. producing force elements that know how to operate is 3.3;

    b. making sure they can work with other ready force elements is 3.2;

c. keeping them ready once they get ready is 3.1; and

d. organizing and coordinating 3.1–3.3 happens in 3.4.

4. It is assumed with all of the above that you already have the necessary ingredients to create force elements. Program 4 is where we set up and maintain the necessary resource pools or "Capability Elements" and make them available, including:

a. military personnel (4.1);

b. military equipment (4.2);

c. real property with military purpose (4.3); and

d. military information systems (4.4).

The availability of each pool depends on our ability to manage its life cycle, including:

i. figuring out what we have and what we need for this cycle; and then

ii. acquiring what we need and do not have;

iii. preparing what we do have;

iv. upgrading as needed;

v. maintaining all of it;

vi. disposing of it at the end of its useful life; and

vii. learning how life cycle management needs to change.

Each of these tasks is done in some form for each pool of Capability Elements.

5. The purpose of all of the above is to deliver our current set of military capabilities; however, the world keeps changing and what we can do must change along with it or become ineffective. All of the work involved in identifying and implementing the required capability changes takes place in Program 5.

a. Capabilities are managed individually by military services, either traditional (CA, RCN, RCAF or statement of operational requirements [SOR]) or by newer mini-services, such as space, cyber and chemical, biological, radiological and nuclear (CBRN), which are temporarily maintained by CFD. Advancement of specific capabilities takes place in 5.1:

i. the design of capability improvements and all the project management necessary to deliver them takes place in 5.1.1;

ii. figuring out how we will use them once we get them is done in 5.1.2; and

iii. everything involved in investing in defence-relevant science to enable management and changes in defence takes place in 5.1.3.

b. Defence success comes only with consistent defence planning for the use of capabilities and to implement changes across the whole set of capabilities. This takes place in 5.2, and includes the following:

i. studying the FSE and testing various future force concepts in relation to the FSE to determine which of the competing capability investments is most needed (5.2.1); and

ii. managing utilization of what we currently have for the long term (5.2.2).

Note: All of the above rely on the service of military *and* civilian personnel. Civilian personnel are integral to Programs 1 to 5, although many play a part in Program 6, the one generic to federal departments. Internal Services are defined by the TBS. Where an activity seems to overlap with the above, consider it to be part of Program 6 only if it is not specifically included in programs 1 to 5.

6. Doing all of the above is impossible without the departmental institution, and much of what they do takes place in Program 6 – Internal Services. Because these services are common to every federal department, they follow a standard pattern set by the TBS as follows:

a. Management and Oversight (6.1) focuses on executive-level action. This includes generals and flag officers. Direction below that level only stays in 6.1 if it cannot be identified closely with either programs 1 to 5 or sub-programs 6.2 to 6.10;

b. Communications (6.2) is mostly done by the ADM (Public Affairs);

c. Legal Services (6.3) is where the CAF Legal Advisor plays a role (activities of military lawyers under the Judge Advocate General [JAG] are part of 4.1.9);

d. Human Resources Management (6.4) is where the Assistant Deputy Minister, Civilian Human Resources (ADM[HR Civ]) plays a role. It is the non-military counterpart of 4.1, i.e., ensuring that there is an available pool of civilians for use in specific functions. Most civilians are not in 6.4, which contains only HR professionals, HR managers and HR administrative support staff;

e. Financial management (6.5) includes activities above and beyond any specific element of programs 1 to 5;

f. Information management (6.6) is an Assistant Deputy Minister, Information Management (ADM[IM]) responsibility, and consists in making sure that DND has provided and protected access to the information we need and disposes of what we do not need;

g. Information technology (6.7) consists in safeguarding non-defence-specific networks, applications and user support, and is conducted under the oversight of Shared Services Canada;

h. Real Property (6.8) concerns institutional property that does not have a direct role in programs 1 to 5, and therefore concerns the specifically institutional footprint (because DND leases most (or all) of its space in Ottawa, there is relatively little activity in 6.8.);

i. Non-military equipment life cycle processes (other than acquisition) come under 6.9; and

j. Acquisition comes under 6.10, and includes centralized support for contracting and procurement.

The accumulation of value from spending Canadian tax money can be tracked as we move upward through the PAA:

- Program 6 establishes the requirements of all federal departments, regardless of their specific domain;
- Program 5 works out how and what we need to do over time to carry out what the defence mandate requires of us;
- Program 4 makes available pools of each type of military resource needed to prepare force elements for use in defence;
- Program 3 takes those military ingredients and shapes them into force elements that it prepares and keeps prepared throughout the readiness cycle. At this point, Defence has provided deterrence and enabled the CDS to put options on the Prime Minister's desk; and
- Programs 1 and 2 enable the Defence team to actually go out and do what only Defence can do for Canada.

With this structure, you can find a place for everything we do with Canadian tax dollars, and say why we do it. This makes for meaningful reporting.

A good illustration of this is the "Snowman Diagram" in Figure A1, showing the Defence team's most important strategic inventories (ovals) and the way they build on each other:

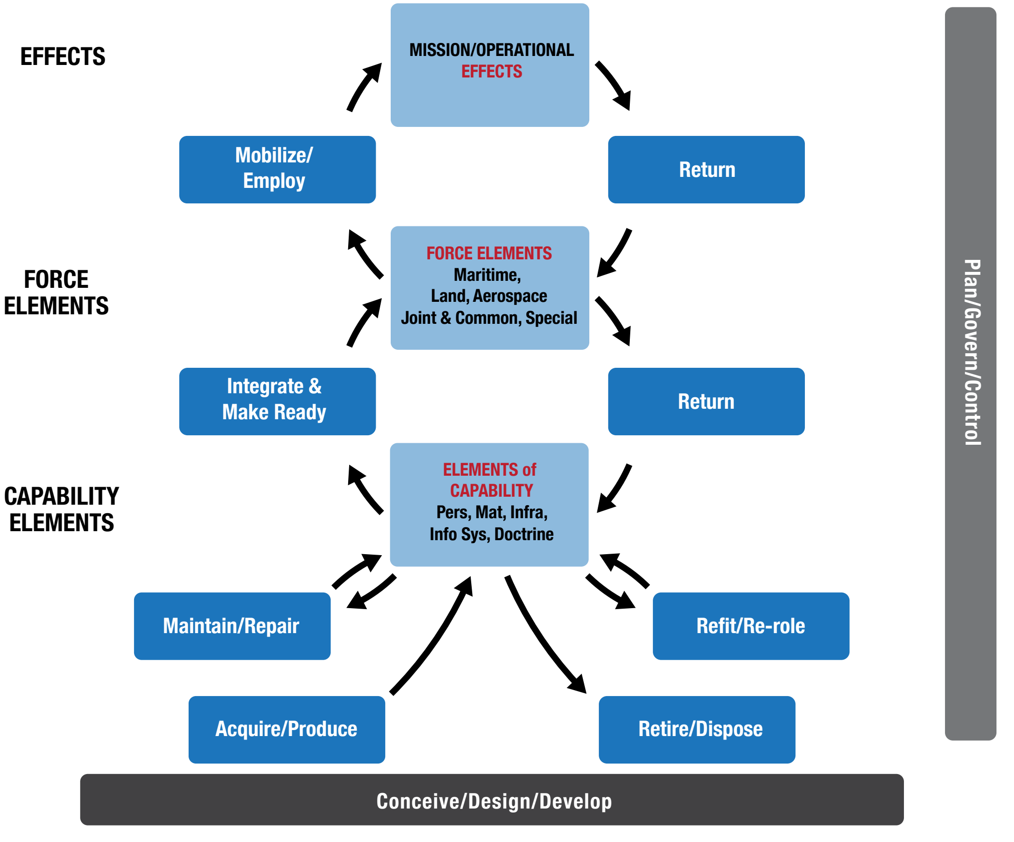

Figure A1. A conceptual model of defence processes shown in the 2014 PAA[96]

- “Mobilize / Employ” and “Return” are Programs 1 and 2;
- “Integrate and Make Ready” and “Return” are Program 3;
- The other four blue boxes are Program 4, although they appear differently for each type of capability element;
- The “Conceive/Design/Develop” bar at the bottom is essentially Program 5; and
- The “Plan/Govern/Control” side bar can be found throughout the other programs, but at the executive level, it tends to be 6.1 – Management and Oversight, along with some supporting institution-wide analysis.

These are broad generalizations to help understand the big picture, and there are lots of exceptions, because the work of Defence is more complex than this.[97]

Appendix B: Program Alignment Architecture

National Defence Program Alignment Architecture (PAA)

Strategic Outcomes	Programs	Subprograms	Sub-subprograms
Defence operations and services improve stability and security, and promote Canadian interests and values.	1.0 Defence Combat and Support Operations	1.1 Domestic and Continental Defence Operations	1.1.1 Operations to defend Canada against armed threats
			1.1.2 Ongoing defence, security and sovereignty of Canada operations
			1.1.3 Ongoing defence operations through NORAD
			1.1.4 Ongoing continental defence operations in cooperation with the US
		1.2 International Combat Operations	1.2.1 International operations over extended periods
			1.2.2 International crisis and surge response operations
			1.2.3 Ongoing defence operations through standing NATO commitments
		1.3 Ongoing Centralized Operations and Operational Enablement	1.3.1 Overarching command and control of domestic and international operations
			1.3.2 Ongoing defence intelligence operations
			1.3.3 Operational support services
			1.3.4 Military diplomacy and global engagement
	2.0 Defence Services and Contributions To Government	2.1 Disaster Relief and Humanitarian Operations	2.1.1 Domestic and continental assistance and response operations
			2.1.2 International humanitarian assistance and disaster response operations
			2.1.3 Non-combatant evacuation operations
		2.2 Defence Services for Canadian Safety and Security	2.2.1 Counterterrorism, terrorism event response and consequence management operations
			2.2.2 Assistance for major Canadian event operations
			2.2.3 National Search and Rescue Program
			2.2.4 Search and rescue operations
			2.2.5 Defence services for other government departments and agencies
			2.2.6 Canadian Safety and Security Program
		2.3 Military Heritage and Outreach	2.3.1 Military history, heritage and awareness
Defence remains continually prepared to deliver national defence and defence services in alignment with Canadian interests and values.	3.0 Defence Ready Force Element Production	3.1 Force Elements Readiness Sustainment	3.1.1 Maritime roles – readiness sustainment
			3.1.2 Land roles – readiness sustainment
			3.1.3 Aerospace roles – readiness sustainment
			3.1.4 Special operations roles – readiness sustainment
			3.1.5 Joint and common roles – readiness sustainment

National Defence Program Alignment Architecture (PAA)

Strategic Outcomes	Programs	Subprograms	Sub-subprograms
		3.2 Force Elements Integration Training	3.2.1 Maritime environment – integration training
			3.2.2 Land environment – integration training
			3.2.3 Aerospace environment – integration training
			3.2.4 Special operations environment – integration training
			3.2.5 Joint– integration training
			3.2.6 International and domestic – interoperability training
		3.3 Force Elements Production	3.3.1 Maritime environment – force element production
			3.3.2 Land environment – force element production
			3.3.3 Aerospace environment – force element production
			3.3.4 Special operations – force element production
			3.3.5 Joint and common – force element production
		3.4 Operational Readiness Production, Coordination, and Command and Control	3.4.1 Maritime environment – force element production, coordination, and command and control
			3.4.2 Land environment – force element production, coordination, and command and control
			3.4.3 Aerospace environment – force element production, coordination, and command and control
			3.4.4 Special operations environment – force element production, coordination, and command and control
			3.4.5 Joint and common – force element production, coordination, and command and control
	4.0 Defence Capability Element Production	4.1 Military Personnel and Organization Life Cycle	4.1.1 Military personnel – regular force portfolio management
			4.1.2 Military personnel – reserve force portfolio management
			4.1.3 Military personnel – recruitment
			4.1.4 Military personnel – transition and release
			4.1.5 Military personnel – professional development training
			4.1.6 Military personnel – occupation training
			4.1.7 Military personnel – morale and well-being
			4.1.8 Military personnel – health care
			4.1.9 Organization – security, protection, justice and safety
			4.1.10 Military personnel and organization – strategic coordination, development and control

National Defence Program Alignment Architecture (PAA)			
Strategic Outcomes	**Programs**	**Subprograms**	**Sub-subprograms**
	4.0 Defence Capability Element Production	4.2 Materiel Life Cycle	4.2.1 Materiel – portfolio management
			4.2.2 Materiel – acquisition
			4.2.3 Materiel – equipment upgrade and insertion
			4.2.4 Materiel – divestment and disposal
			4.2.5 Materiel – engineering, testing, production and maintenance
			4.2.6 Materiel – inventory management and distribution
			4.2.7 Materiel – strategic coordination, development and control
		4.3 Real Property Life Cycle	4.3.1 Real Property – portfolio management
			4.3.2 Real Property – acquisition
			4.3.3 Real Property – divestment and disposal
			4.3.4 Real Property – operations, maintenance and repair
			4.3.5 Real Property – environment and remediation
			4.3.6 Real Property – strategic coordination, development and control
		4.4 Information Systems Life Cycle	4.4.1 Information systems – portfolio management
			4.4.2 Information systems – acquisition, development and deployment
			4.4.3 Information systems – system management and user support
			4.4.4 Information systems – strategic coordination, development and control
	5.0 Defence Capability Development and Research	5.1 Capability Design, Development and Integration	5.1.1 Capability design and management
			5.1.2 Concept, doctrine development and warfare experimentation
			5.1.3 Science and systems development and integration
		5.2 Strategic Direction and Planning Support	5.2.1 Strategic capability planning support
			5.2.2 Strategic force posture planning support

National Defence Program Alignment Architecture (PAA)			
Strategic Outcomes	**Programs**	**Subprograms**	**Sub-subprograms**
	6.0 Internal Services	6.1 Management and Oversight	
		6.2 Communications	
		6.3 Legal Services	
		6.4 Human Resources Management	
		6.5 Financial Management	
		6.6 Information Management	
		6.7 Information Technology	
		6.8 Real Property	
		6.9 Materiel	
		6.10 Acquisition	

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Abbreviations

ACDP	Affordable Capability Development Plan
ADM	Assistant Deputy Minister
ADM(HR Civ)	Assistant Deputy Minister (Civilian Human Resources)
ADM(IM)	Assistant Deputy Minister (Information Management)
ADM(Mat)	Assistant Deputy Minister (Materiel)
ADM(S&T)	Assistant Deputy Minister (Science & Technology)
AEP	aerospace effects production
AFV	Air Force Vectors
AIRCOM	Air Command
CA	Canadian Army
CAF	Canadian Armed Forces
CAT	CDS Action Team
CAT3	CDS Action Team 3
CATCAM	CDS Action Team Capability Assessment Methodology
CBP	capability-based planning
CD&E	concept development and experimentation
CDS	Chief of the Defence Staff
CF	Canadian Forces
CFAWC	Canadian Forces Air Warfare Centre
CFB	Canadian Forces Base
CFD	Chief of Force Development
CFDS	*Canada First* Defence Strategy
CIPPR	Capital Investment Program Plan Review
CJTL	Canadian Joint Task List
CMF	conceptual military framework
CORA	Centre for Operational Research and Analysis
CP	campaign plan
DCB	Defence Capability Board
DCI	Director of Capability Integration
DCSAS	Director Capability and Structure Analysis Support
DG Air FD	Director General Air Force Development
DG CSI	Director General, Capability and Structures Integration

DM	Deputy Minister
DND	Department of National Defence
DPR	Defence Policy Review
DRDC	Defence Research & Development Canada
DRF	Departmental Results Framework
DTB	Defence Terminology Bank
ERM	enterprise resource management
FAOC	Future Air Operating Concept
FCD	Future Concepts Directive
FCG	Force Capability Guidance
FCP	Force Capability Plan
FD	force development
FDSS	force development scenario set
FOC	final operating capability
FIDO	Fundamental Investigation of Defence Options
FLEETSIM	Fleet simulator, Strategic capability roadmap
FOE	future operating environment
FP&R	force posture and readiness
FSE	future security environment
GC	Government of Canada
GOFO	general officer/flag officer
HR	Human Resources
ID	identification
IDS	Invest-Divest-Sustain
IOC	initial operating capability
IP	Investment Plan
JCF	Joint Capability Framework
JCPT	Joint Capability Planning Team
L0	level 0
L1	level 1
LoO	line of operation
MND	Minister of National Defence
MoC	measure of capability

MYEP	Multi-Year Establishment Plan
NATO RTO	NATO Research and Technology Organization
NCM	non-commissioned member
Op	operation
OPFOR	opposing force
Ops	operations
PAA	Program Alignment Architecture
PAD	Project Approval Directive
PAP	project approval process
PCR	project completion report
RCAF	Royal Canadian Air Force
RCN	Royal Canadian Navy
S&T	science and technology
SCR	Strategic Capability Roadmap
SOF	special operations forces
SOR	statement of operational requirements
SPORT	Strategic Planning Operational Research Team
STT	Strategic Task Team
TBS	Treasury Board of Canada Secretariat
TTCP	The Technical Cooperation Program
ver	version
VCDS	Vice Chief of the Defence Staff
VIPOR	Visual Investment Plan Optimisation and Revision

Notes

1. In order to make the term "environment" available for its more generic meaning, this chapter uses the American term "service" to refer to the CA, the RCN and the RCAF.

2. Canada, DND, VCDS*: About Us,* January 20, 2016, accessed July 18, 2018, http://www.forces.gc.ca/en/about-org-structure/vice-chief-defence-staff.page.

3. Most technical publications are available through the searchable DRDC Defence Research Reports website at http://pubs.drdc-rddc.gc.ca/pubdocs/pcow1_e.html.

4. Canada, DND, VCDS*: About Us*.

5. Canada, DND, *DTB,* record 32172, http://terminology.mil.ca/index-eng.asp#.

6. Canada, DND, *Report on Transformation 2011*, July 2011, accessed July 18, 2018, http://www.forces.gc.ca/en/about-reports-pubs/transformation-report-2011.page.

7. Canada, DND, VCDS, Director Defence Program Coordination 6, *Project Approval Directive 2015*, April 8, 2015, accessed July 27, 2016, http://vcds.mil.ca/sites/intranet-eng.aspx?page=18032.

8. Canada, DND, Project Approval Directive 2015.

9. Canada, DND, CFD, *Capability Based Planning Handbook,* 2014.

10. The classic example is delivering indirect fires into an area, which can be delivered by land-based artillery, offshore naval gunfire, aerial bombing and other means.

11. Gary Christopher, et al., *Strategic Capability Roadmap Version 1.0 – Analytical Framework,* Technical Report TR 2009-013 (Ottawa: Defence R&D Canada – Operational Research Division, 2009), accessed July 18, 2018, http://pubs.drdc-rddc.gc.ca/BASIS/pcandid/www/engpub/DDW?W%3DSYSNUM=532766&r=0.

12. Christopher et al., *Strategic Capability Roadmap*.

13. Christopher et al., *Strategic Capability Roadmap*.

14. Business Architecture Guild, "A Guide to the Business Architecture Body of Knowledge (R) (Bizbok Guide)," *Bizbok Guide (R),* September 28, 2015, accessed June 11, 2016, http://www.businessarchitectureguild.org/?page=BIZ.

15. The usual American usage is Capabilities-Based Planning.

16. Paul K. Davis, *Analytic Architecture for Capabilities-Based Planning, Mission-System Analysis, and Transformation* (Santa Monica, CA: RAND, 2002).

17. An accompanying assumption was that if they prepared for the most difficult operations required to address the main threat, training to meet other operational requirements would be accomplished fairly easily.

18. It should be noted that capability-based planning had already emerged naturally as a part of US military planning in the course of designing detailed responses to specific Soviet courses of action. The assignment of differing tasks to the same force element motivated capability definition. See also Paul K. Davis, *Analysis to Inform Defense Planning Despite Austerity* (Santa Monica, CA: RAND, 2014), 107–16; accessed July 18, 2018, http://www.rand.org/pubs/research_reports/RR482.html.

19. Andrew Godefroy, "Chasing the Silver Bullet: The Evolution of Capability Development in the Canadian Army," *Canadian Military Journal* 8, no. 1 (Spring 2007); accessed July 18, 2018, http://www.journal.forces.gc.ca/vo8/no1/godefroy-eng.asp.

20. Canada, DND, *White Paper on Defence 1994*, accessed July 18, 2018, http://publications.gc.ca/site/eng/429769/publication.html.

21. David E. Thaler, *Strategies to Tasks: A Framework for Linking Means and Ends*, (Santa Monica, CA: RAND, 1993), accessed July 18, 2018, http://www.rand.org/content/dam/rand/pubs/monograph_reports/2006/MR300.pdf.

22. M. Dixson and R. B. Darlington, "Strategies-to-Task Decision Brief," briefing note, Fighter Group / Canadian NORAD Region Headquarters, (North Bay, ON), August 10, 1995.

23. P. L. Massel et al., *The Canadian Maritime Forces 2015 Study – Phase II: Analysis of Maritime Force Structure Alternatives Using the FleetSim Model*. ORD Report R9903 (Ottawa: DND, Operational Research Division, 1999).

24. Canada, DND, *Canadian Defence Planning Document 1997*, Red de Seguridad y Defensa de América Latina, accessed July 18, 2018, http://www.resdal.org/Archivo/d00000b6.htm.

25. The term "task" was given a very high-level meaning that today would be broken down into many smaller tasks.

26. A. Bradfield, G. L. Christopher and Lieutenant-Colonel (LCol) D. MacLean, *The Development of a Scenario Set for Departmental Force Planning*, DOR(J&L) Research Note 9822 (Ottawa: Directorate of Operational Research [Joint & Land], Operational Research Division, 1998), accessed August 12, 2016, http://www.dtic.mil/dtic/tr/fulltext/u2/a640559.pdf.

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Aircraft Acquisition Cost Estimation Case Study: The F-35A Joint Strike Fighter Unit Recurring Flyaway Cost

Bohdan L. Kaluzny

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Abstract

The goal of the Canadian Department of National Defence (DND) Future Fighter Capability Project (FFCP) is to replace the CF18 fleet upon its retirement. One of the options under consideration was the Lockheed Martin F-35A Lightning II aircraft, also known as the Joint Strike Fighter (JSF) conventional take-off and landing (CTOL) variant. As a signatory to the JSF Production, Sustainment and Follow-On Development Memorandum of Understanding, the United States (US) JSF Project Office (JPO) routinely provided DND with the latest projection of the unit recurring flyaway (URF) cost of the F-35A JSF. However, DND lacked the ability to generate an independent estimate or perform sensitivity analysis. Recognizing the deficiency, Defence Research & Development Canada (DRDC) developed an F-35A URF cost estimation model. The cost estimation methodology is a *quantity effect* model employed by the RAND Corporation that combines cost improvement and production rate effects. The model was used to:

- reverse engineer JPO cost projections to determine best-fit learning and production rate slopes;
- provide a secondary, independent URF cost projection of future F-35A production lots based on the latest actual cost data (for completed or partially completed F-35As);
- determine the sensitivity of cost to changes in quantity effects (learning); and
- determine cost sensitivity to changes in production quantities.

The model provided DND with the means to further scrutinize JPO cost estimates and facilitated sensitivity analysis, such as determining the potential financial impact on Canada should international partners cancel or downsize their F-35A orders.

Introduction

Background

The goal of the DND FFCP is to replace the CF18 fleet upon its retirement so as to maintain a manned fighter capability for the defence of Canada and North America, and for Canadian Armed Forces (CAF) collective expeditionary operations. One of the options under consideration was the Lockheed Martin F-35A Lightning II aircraft, also known as the Joint Strike Fighter (JSF) conventional take-off and landing (CTOL) variant. The F-35 JSF is a single-engine, stealthy, supersonic, multi-role fighter. It is manufactured in three versions: a CTOL variant (F-35A) as seen in Figure 1, an aircraft-carrier version (F-35C), and a short take-off/vertical landing (STOVL) version (F-35B). There were plans to build more than 3,000 F-35 JSFs for the US and international partners, potentially including Canada. Pratt & Whitney is manufacturing the F135 propulsion systems, while the Lockheed Martin Corporation is manufacturing the air vehicle and is responsible for final assembly (air vehicle system and engine) of each F-35. In 2001, the 10-year System Development and Demonstration (SDD) phase of the F-35 program began, and 22 test aircraft were built.[1] Low-rate initial production[2] (LRIP) started in 2007.

Figure 1. Lockheed Martin F-35A CTOL[3]

As a signatory to the JSF Production, Sustainment and Follow-On Development Memorandum of Understanding,[4] signed in 2006, the JPO routinely provided Canada with the latest projection of the URF cost of the F-35A JSF (the price that Canada should expect to pay). Figure 2 shows the evolution of JPO cost projections between 2011 and 2015. The figure shows the URF cost curves and production rates of the F-35A CTOL projected by the JPO. The URF cost of an aircraft is the cost of purchasing the aircraft (including related management, hardware, airframe, vehicle systems, mission systems, propulsion, and engineering change order costs) as it rolls off the production line (spare parts, support equipment, etc., are not included). The cost amounts in this and all subsequent Tables and Figures are masked to protect the sensitivity of the data.

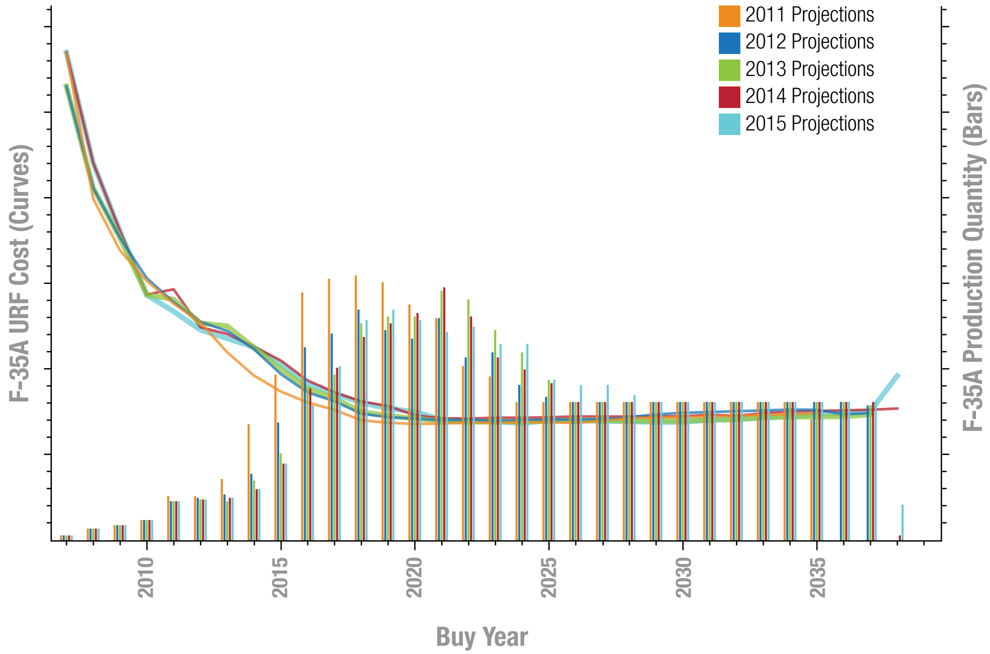

Figure 2. JPO F-35A CTOL cost projections and production profiles (2011–15)

Affordability has been heralded as the cornerstone of the F-35 program. It is claimed that this would be achieved through a very high level of common parts and systems across the three versions of the aircraft. Streamlined assembly methods were intended to cut production time significantly. The theory is that a large quantity ordered over time would lead to accumulated experience in producing the same system year after year, reducing the unit cost. This is referred to as the cost improvement effect. A second factor, called the production rate effect, results from changing the quantity of aircraft produced in a given year (or time period), with high production rates likely to reduce the unit cost through greater operating efficiency and the spreading of fixed costs over more units. Until 2011, Canada relied solely on the US JPO for projected costs. Subsequently, DRDC provided DND with the ability to model independently the estimated average URF cost that Canada would have to pay for F-35A CTOL aircraft. The cost estimation methodology presented herein is a *quantity effect* model used by the RAND Corporation that combines cost improvement and production rate effects.[5] The model was used to:

- reverse engineer JPO cost projections to determine best-fit learning and production rate slopes; and
- provide a secondary, independent URF cost projection of future F-35A production lots based on the latest estimate-at-completion (EAC) actual cost data (for completed or partially completed F-35A LRIP lots).

As part of the Government of Canada's comprehensive response to Chapter 2 of the 2012 Spring Report of the Office of the Auditor General of Canada (2012), DND, through the National Fighter Procurement Secretariat (NFPS), provides annual updates to Parliament on JSF F-35A costing forecasts. The model developed by DRDC has been used by DND to provide updated cost estimate analyses in support of these annual updates submitted to the government.

Objective

The goal is to explain the F-35A CTOL URF cost estimation model developed by DRDC and show how it was used to generate secondary, independent estimates, reverse engineer JPO cost projections, and perform sensitivity analysis. The models provided the FFCP project office with the means to further scrutinize JPO cost projections and defend DND's estimates. The models presented facilitated sensitivity analysis, such as determining the financial impact on Canada should international partners cancel or downsize their F-35 orders. For rigour and defensibility, both the methodologies and data were detailed explicitly in original reports;[6] however, the data and specific results are masked in this chapter because they remain sensitive information.[7] These omissions should not hinder the intent of this chapter, which is to introduce readers to the models and types of analyses that Canadian DND decision makers used to scrutinize JPO cost projections and provide Parliament with reliable updates. A similar version of this work was outlined in a presentation given at the 2011 Society of Cost Estimation and Analysis / International Society of Parametric Cost Analysis Conference (Albuquerque, NM) and subsequently published in that conference's proceedings.

URF costs are only one component of aircraft acquisition costs, and the latter are only a subset of the total life cycle costs of a program. DRDC helped DND and the NFPS to define and model the life cycle costs. Details and additional references are available in the NFPS annual updates to Parliament. Readers interested in the political history of the Canadian CF18 replacement program should consult the September 2016 Conference of Defence Associations (CDA) Institute Vimy Paper by Shimooka.[8]

Outline

Section 2 explains the available data and major modelling assumptions, while Section 3 presents the quantity effects model suitable for projecting F-35A costs (the Appendix provides detailed information on the mathematical theory of learning curves used to develop the quantity effects model). Section 4 outlines how the model was applied to the F-35A data and planned production profile in order to reverse engineer quantity effects parameters and produce an independent estimate of Canada's average F-35A URF cost. Section 5 shows how the model was useful in risk and uncertainty analysis.

Data and Assumptions

As of 2016, the Lockheed Martin Corporation has completed, partially completed, or started 10 production lots. The JPO provided DND with completion rates and EAC average URF costs for LRIP lots broken down into the air vehicle component (includes airframe, mission systems and vehicle systems) and the engine component. EAC costs are developed by the JPO and are based on actual production costs collected to date. EAC costs most closely approximate the actual production costs incurred for each lot. They are not settlement costs; all cost overruns are included. In addition, all EAC costs presented include any contractor incentive fees.

The JPO also provided DND with the latest JSF production planning profile. These data include the number of F-35A units that international participants plan to buy in each year (from 2007 to 2038). The delivery year is assumed to be two years after the buy year indicated. For each buy year, the data indicate the total number of units to be purchased (lot size) and the JPO's predicted average URF cost[9] in millions of then year (TY) US dollars (USD). This is an incremental average lot cost, defined as the total cost of a lot divided by the number of units produced in the lot.[10] The data can be used to calculate a product-sum of the quantities and the JPO's predicted costs, as well as to compute the average URF by dividing by the total quantity to be procured.

Simplifying assumptions had to be made based on the limited data available to DRDC, as follows:

- Only URF F-35A CTOL costs were considered and predicted. These costs do not include potential modifications that might be incorporated in a "partially common" subset of the aircraft (e.g., a drag chute).
- Only F-35A CTOL data (production numbers and costs) were considered. The JPO production profiles indicated that a number of F-35C carrier variants and F-35B STOVL aircraft would be produced. These two variants represent nearly 30% of the total projected F-35 production. It is claimed that all variants share a high degree of commonality. Including F-35B and F-35C quantities may have a favourable effect on lowering the URF costs of F-35A aircraft; however, it can also be argued that potential production line changes in order to switch between variants may have a detrimental effect.
- Because of 100% propulsion system commonality with the F-35A, F-35C production numbers were considered when projecting the costs of the engine.
- A major assumption of the quantity effects model used to generate a baseline cost estimate is that accumulated experience in producing the same system year after year can reduce the unit cost. Planned or unanticipated design or engineering changes can negate some of the achieved learning. Ideally, the system's development and testing phase should be complete. The JPO confirmed that any development and testing costs incurred are not included in EAC costs; however, any retrofit costs (e.g., component remove-and-replace costs) are included.
- Another major assumption of the quantity effects model is that trends in costs arising during the completion of LRIP lots will continue through future lots. This assumes the continuation (extrapolation) of the typical cost improvement (learning) curve observed for the first three lots.
- Because of the limited dataset and to ensure the validity of the mathematical models, it was necessary in some cases to rely on historical US military aircraft production and learning rate percentages.

Methodology

A key component of the JSF project is affordability, intended to be partly achieved through the large quantity of aircraft produced. The theory is that a large quantity ordered over time will lead to accumulated experience in producing the same system year after year, reducing the unit cost. This is referred to as the *cost improvement effect*.[11] A second factor, called the *production rate effect*, results from changing the quantity of aircraft produced in a given year (or time period), with high production rates likely reducing the unit cost through greater operating efficiency and the spreading of fixed costs over more units.

The Appendix expands on the theory of cost improvement and production rate effect models. However, without loss of continuity, readers may choose to go to the mathematical model used for URF cost estimation.

Quantity effects model

The *quantity effects model*, as defined by the RAND Corporation,[12] is a combination of cost improvement and production rate curves:

$$LAC_i = T_1 \times [\bar{Q}_i(b)]^b \times r_i^c. \tag{1}$$

where

- LAC_i is the average incremental cost of the aircraft, or equivalently the cost of the aircraft at the midpoint of lot *i*;
- T_1 is often associated with the cost of the first aircraft produced. However, this parameter is typically estimated, not inputted, and represents the cost intercept at a rate of production equal to 1 and for the first unit of production;
- $\bar{Q}_i(b)$ is defined as the midpoint of lot *i*, but it is not simply the middle point of the number of aircraft produced, but rather the likely fractional point where half of the lot's total cost is expended;
- b is the cost improvement slope, and 2^b is the cost improvement slope percentage;
- r_i is the production rate, proxied by the number of aircraft produced in lot *i*; and
- c is the production rate slope, and 2^c is the production rate percentage.

In 2008, the RAND Corporation used the quantity effects model in a study carried out for the US Air Force and the US Navy that looked into the reasons for the rising cost of fixed-wing aircraft.[13] The RAND Corporation researchers examined the cost improvement (CI) effect and the production rate (PR) effect for 24 military aircraft programs for which there were at least five annual buys and for which the midpoint and lot size correlations were less than the absolute value of 0.6 (they avoided systems with higher correlations potentially leading to statistically misleading results). The restricted dataset is said to include a diverse array of Air Force and Navy programs over the past 50 years, including attack, cargo, electronic, patrol, and training aircraft. Table 1 summarizes the RAND Corporation's findings (the statistics were not available [n/a] in some table entries).

	Military Aircraft	Fighter Jets
Mean CI slope %	0.97	0.93
Standard deviation of CI slope %	0.13	n/a
Mean PR slope %	0.89	0.78
Standard deviation PR slope %	0.23	n/a
Number of aircraft	24	6

Table 1. Historical cost improvement and production rate slope percentages

The RAND Corporation also analyzed the historical production rate effect for the F100 engine variants (100/200 and 229) of F-15 and F-16 fighter jets, and reported an average PR slope of 97%.[14]

In addition, the RAND Corporation used the same quantity effects model in 2007 in a study it did for the US Office of the Secretary of Defense that assessed the cost saving obtained from multi-year contracts for the F-22A Raptor.[15] One of the research objectives was to use Equation (1) to estimate the cost improvement and production rate slopes for the F-22A. However, the actual F-22A production history showed that the production rate and unit midpoint values were so highly correlated that determining the production rate and cost improvement slopes simultaneously through multivariate analysis was deemed invalid. To overcome this problem, the RAND Corporation researchers used the average historical production rate slope percentages of 89% and 97%, respectively, for the air vehicle and propulsion system.[16]

Non-linear multivariate regression model

To determine the quantity effects of the F-35A production, a non-linear multivariate regression model based on Equation (1) is applied. The regression model has the following form:

$$\mathrm{Ln}(LAC_i) = \mathrm{Ln}(T_1) + b \times \mathrm{Ln}(\bar{Q}_i(b)) + c \times \mathrm{Ln}(r_i) + \varepsilon_i \tag{2}$$

where

$$\bar{Q}_i(b) = \left(\frac{\left[(Q_i + 0.5)^{1+b} - (Q_{i-1} + 0.5)^{1+b} \right]}{(1+b) \times (Q_i - Q_{i-1})} \right)^{\frac{1}{b}} \tag{3}$$

and T_1, b, and c are parameters to be estimated and ε_i is the error term. The derivation of the lot midpoint, $\bar{Q}_i(b)$, is provided in Appendix A.

Combining Equations (2) and (3) reduces the regression to:

$$\mathrm{Ln}(LAC_i) = \mathrm{Ln}(T_1) - \mathrm{Ln}(1+b) - \mathrm{Ln}(Q_i - Q_{i-1}) \\ + \mathrm{Ln}\left((Q_i + 0.5)^{1+b} - (Q_{i-1} + 0.5)^{1+b}\right) + c \times \mathrm{Ln}(r_i) + \varepsilon_i. \tag{4}$$

Equation (2) results from taking the natural logarithm of Equation (1) and adding an error term. As a result of the log-transformation of the lot average cost model, the uncertainty in the prediction outputted by the model can be presented by a log-normal distribution. The log-normal distribution is a probability distribution of a random variable whose logarithm is normally distributed. The logarithmic transformation is commonly used for positive data, and the log-normal distribution domain of zero to infinity is more suitable for modelling costs than a normal distribution, which includes the negative domain. The majority of total cost estimates for weapon-system acquisition programs modelled by the US Deputy Assistant Secretary of the Navy (Cost & Economics) are log-normally distributed and often skewed right.[17]

Model Application

Using the quantity effects model developed in Section 3, regression analysis was done to obtain the following results:

- Section titled "Quantity effects of JPO F-35A cost projections" shows how the quantity effects model can be fitted to the entire JPO planning profile and cost projections to determine the (statistically) most likely cost improvement and production rate effects as per the JPO predictions.
- Section titled "An independent estimate of average URF cost" details how the quantity effects models can be fitted to the estimated-at-completion costs for completed or partially completed LRIP lots. The fitted models can be used to project future F-35A lot costs, and in particular to estimate the average URF price that a participating country can expect to pay.

Quantity effects of JPO F-35A cost projections

To determine the quantity effects of the F-35A production, the non-linear multivariate regression model of Equation (4) can be applied to the complete set of JPO data. For example, using data available in 2011, the quantity effects curve was fitted to the JPO projected costs for all planned lots from 2007 to 2035. For each lot $i = 1 \ldots 29$, LAC_i was set to the JPO projected average aircraft cost, Q_i was set as the JPO projected aircraft production sequence number of the first aircraft of lot i, and r_i was set to the lot size.

Figure 3 is a graph showing both the JPO projections (solid line) and the fitted quantity effects curve (dashed line). In this case, the correlation of lot midpoint and production rate is 0.31, less than the RAND limit of 0.6, indicating that fitting both the production rate and cost improvement slopes should yield statistically reliable results. The best fit parameters are $T_1 = 319.8$, a cost improvement slope percentage of 94%, and a production rate slope percentage of 89%. The cost improvement slope percentage indicates that 6% savings/efficiencies are realized every time the cumulative number of aircraft produced doubles. The production rate slope percentage indicates that 11% savings/efficiencies are realized every time the total aircraft produced in a lot doubles. Table 2 shows the parameter confidence intervals, standard errors, and statistical tests ($R^2 = 0.9999$). Applied to Canada's potential buying profile at the time, the average URF cost predicted by the quantity effects model was within 1% of the JPO estimate.

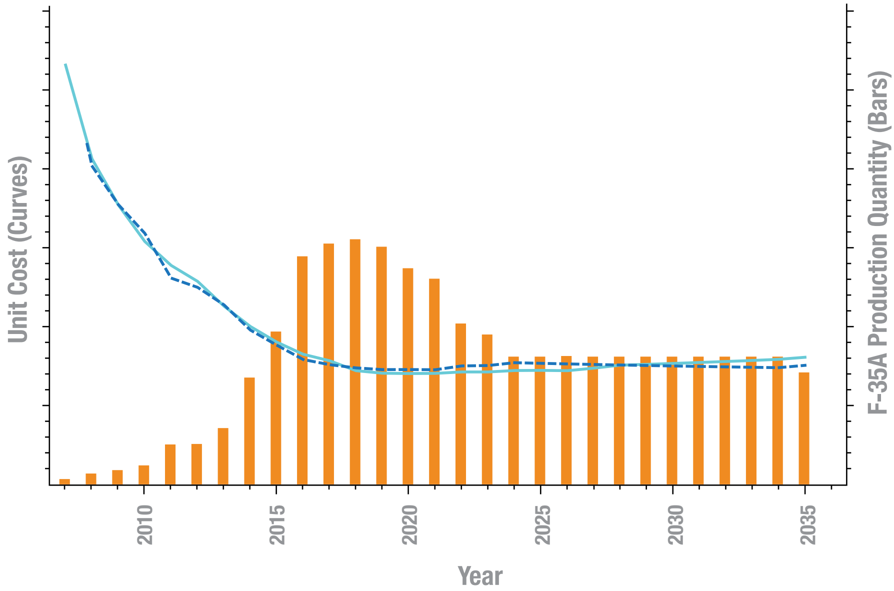

Figure 3. Quantity effects curve (dashed line) fitted to the F-35A CTOL costs projected by the JPO (solid line)

Parameter	Estimate	Standard Error	95% Confidence Interval	*t*-Statistic	*P*-Value
T_1	319.8	10.7	(297.8, 341.8)	29.8	≈ 0
CI Slope %	0.94	0.01	(0.93, 0.95)	162.9	≈ 0
PR Slope %	0.89	0.01	(0.86, 0.91)	85.1	≈ 0

Table 2. Parameter estimates of the quantity effects curve fitted to the F-35A CTOL costs projected by the JPO

Statistically, the best-fit CI and PR slope percentages over the 29 years of production indicate that the URF costs (predicted by the JPO at the time) are driven by both the production rate and cost improvement due to learning.[18] It was interesting to note that the best-fit production rate slope coincided with the historical production rate slope observed by the RAND Corporation, while the best-fit learning slope was slightly more favourable than what was historically observed (see Table 1).

While the JPO has documented observed learning rates for initial production lots that support the 94% learning slope, the argument can be made that the best-fit learning slope may be too optimistic to sustain for all 29 years of production. Hartley claims that gradually "economies of learning"[19] are reaped at a decreasing rate to such an extent that it is conceivable that at some point learning will cease, and average direct labour input per aircraft will tend to become constant. Reaching a learning saturation point is plausible because the JSF production run is over 30 years.[20]

To provide further insight into the JPO's anticipated learning and production rate slopes, the quantity effects regression models could be fitted to subsets of the JPO planning profile and cost projections, e.g., the first 10 lots and the first 19 lots. The goal would be to reverse-engineer the anticipated learning/production rate slopes for early years (rather than for the entire 29-year production plan). Sample results are summarized in Table 3 and show that where the JPO projects that learning will be more of a factor in early production lots, the best-fit learning slope percentages are 90% and 91%, respectively. It should be noted that there is a high correlation (exceeding the RAND Corporation's proposed limit of 0.6) between lot midpoints and production rates when only the first 18 or fewer lots are considered. This indicates that there is a possibility that the regression results where only the first 10 lots are considered are not statistically reliable (however, the results generated for 19 and 29 lots are indeed reliable).

	Lots 1-10	Lots 1-19
CI Slope %	0.90	0.91
PR Slope %	0.93	0.92
Correlation	0.99	0.57

Table 3. Parameter estimates of the quantity effects curve fitted to subsets of the F-35A CTOL costs projected by the JPO

An independent estimate of average URF cost

The production profile and EAC costs (normalized to a common base year) for the first completed or partially completed lots represent the data for which the quantity effects regression model can be applied in order to project cost estimates for future production lots, including the lots from which countries such as Canada may potentially plan to procure F-35A jets. Ideally, the quantity effects regression model would be used to estimate the production rate and cost improvement slopes simultaneously. However, for the limited actual F-35A production history (less than 10 LRIPs), the production rate and lot midpoint values are highly correlated, suggesting that such an approach is invalid as it may lead to statistically misleading results. The RAND Corporation came up against the same hurdle when applying the quantity effects model to initial F-22A production data.[21] To increase the model's degrees of freedom, the RAND Corporation researchers established the production rate parameter, *c*, to reflect the mean production rate slope percentage of 89% that the RAND Corporation researchers had observed for US military aircraft over time (see Table 1). Similarly, a production rate slope percentage of 97% was established for propulsion system cost estimation. Quantity effects models were then used to fit the best cost improvement slopes. By using the RAND Corporation approach, the quantity effects model can be applied several times to the F-35A data to establish one of the parameters each time, as follows:

- the propulsion system production rate slope percentage is established to reflect the mean historical production rate slope percentage of 97%;
- the air vehicle production rate slope percentage is established at 89%, as RAND Corporation researchers had observed relative to US military aircraft programs throughout history;
- the air vehicle production rate slope percentage is established at 78%, as RAND Corporation researchers had observed for US fighter jet programs throughout history;
- the air vehicle cost improvement slope percentage is established at 97%, as RAND Corporation researchers had observed for US military aircraft programs throughout history; and
- the air vehicle cost improvement slope percentage is established at 93%, as RAND Corporation researchers had observed for US fighter jet programs throughout history.

The LRIP completion rates were used as data weights to indicate the relative amount of influence over the parameter estimates in the quantity effects regression model. To provide some sample results, the following figures and statistics were generated using data available in 2011.

F135 engine cost estimation

Figure 4 is a graph showing the propulsion system quantity effects curve derived from the weighted regression models setting the production rate slope at 97%. Table 4 shows the parameter estimates—listing the best-fit estimate, the standard error and the 95% confidence interval—and statistical tests. The results indicate a 93% learning slope. It is interesting to note that although the F-135 is a derivative of the F119 engine (built for the F-22), the early LRIP data indicate a cost improvement effect. In order to project future F-135 costs, the production quantities of both the F-35A and F-35C variants were considered because the propulsion system is the same.

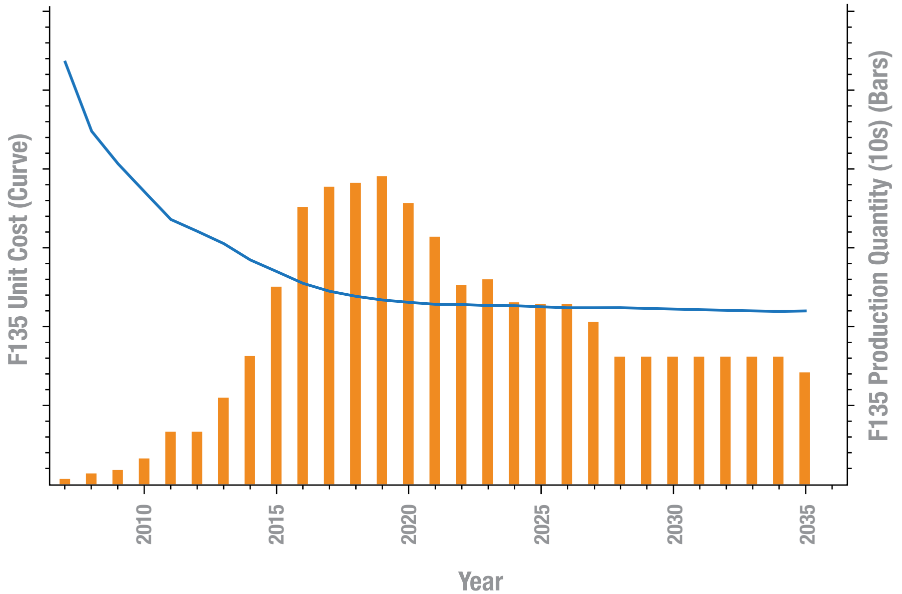

Figure 4. Quantity effects curve fitted to the F135 propulsion system EAC costs

Parameter	Estimate	Standard Error	95% Confidence Interval	*t*-Statistic	*P*-Value
T_1	28.4	1.02	(15.5, 41.3)	27.9	0.023
CI Slope%	0.93	0.02	(0.74, 1.13)	60.8	0.010

Table 4. Parameter estimates of the quantity effects curve fitted to the F135 Engine EAC costs projected by the JPO

F-35A air vehicle cost estimation

Figure 5 is a graph showing the four air vehicle quantity effects curves derived from the weighted regression models setting individual parameters. Table 5 shows the parameter estimates for the four quantity effects models used. Where applicable, each table entry lists the best-fit estimate, the standard error, and the 95% confidence interval. The results indicate fitted learning slopes of 95% (PR set to 89%) and 103% (PR set to 78%) and production rate slopes of 86% (CI set to 97%) and 91% (CI set to 93%). Of the four curves generated, the curve generated based on historical production rate slopes of US fighter jets (78%) differs the most. Consistent with RAND Corporation studies, the quantity effects model with an air vehicle production rate parameter set to reflect the mean historical production rate slope percentage of 89% was selected as the primary estimation model.[22]

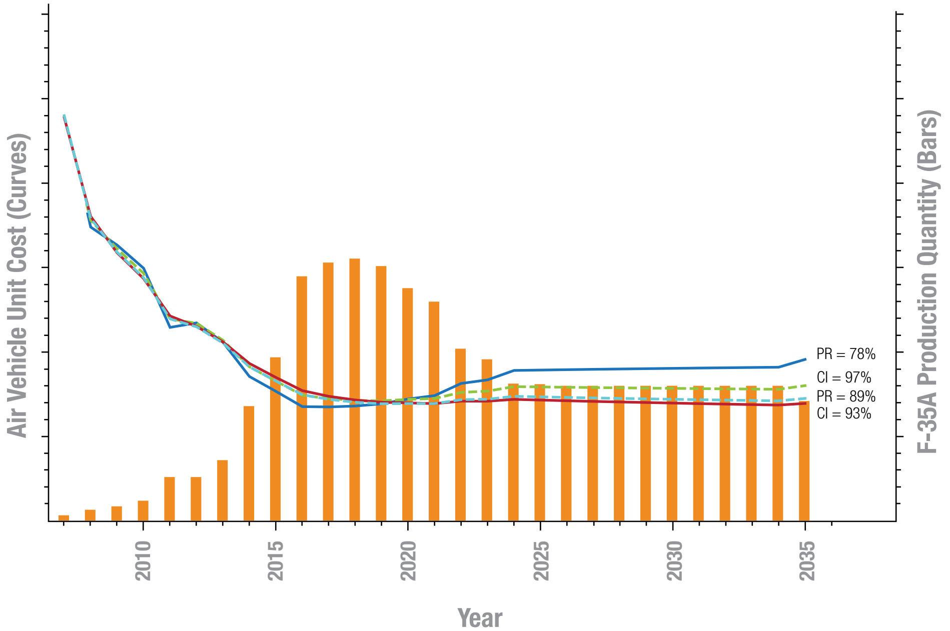

Figure 5. Quantity effects curves fitted to F-35A air vehicle EAC costs (LRIP 13)

Parameter	PR = 89%	PR = 78%	CI = 97%	CI = 93%
T_1	276.5, 7.4, (182.8, 370.1)	306.3, 20.9, (40.0, 572.5)	282.1, 15.2, (88.3, 475.8)	269.8, 7.2, (178.7, 360.8)
PR slope %	0.89	0.78	0.86, 0.02, (0.60, 1.12)	0.91, 0.01, (0.78, 1.05)
CI Slope %	0.95, 0.01, (0.81, 1.08)	1.03, 0.03, (0.65, 1.42)	0,97	0.93

Table 5. Parameter estimates (including standard error and 95% confidence intervals) of the quantity effects curves fitted to F-35A CTOL EAC costs

F-35A (air vehicle and engine) cost estimation

Figure 6 is a graph showing the four derived air vehicle quantity effects curves combined with the F135 engine quantity effects model. For comparison, the JPO cost projection curve is also shown in the graph (gray dotted line).

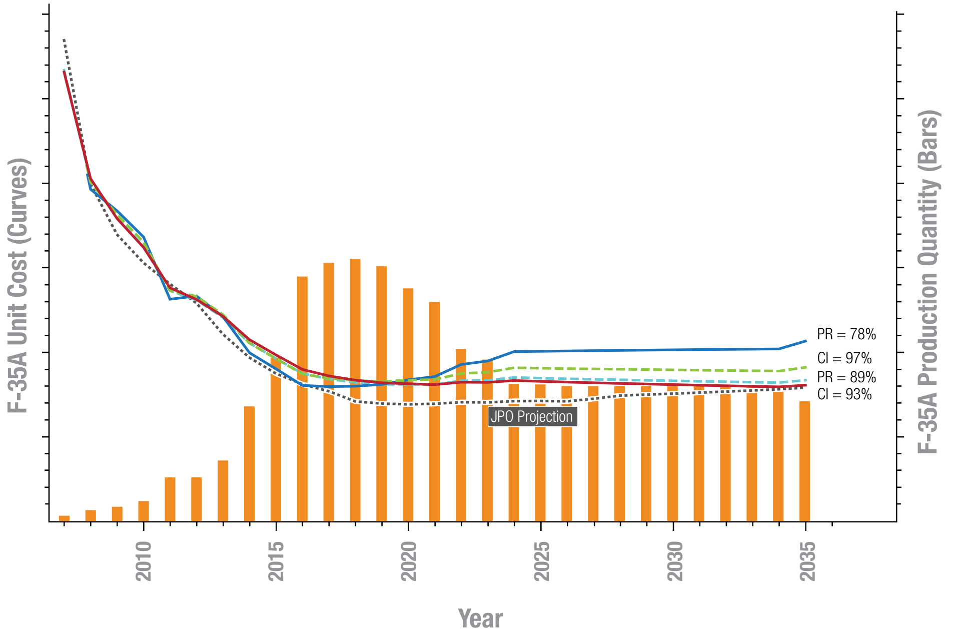

Figure 6. Quantity effects curves fitted to F-35A URF EAC costs

For Figure 7, a model with an air vehicle production rate parameter set to 89% was used to show the projected F-35A costs based on the best-fit quantity effects model (dashed line) in comparison with the JPO projections (dotted line). (Note that the curves in Figure 7 are present in Figure 6.)

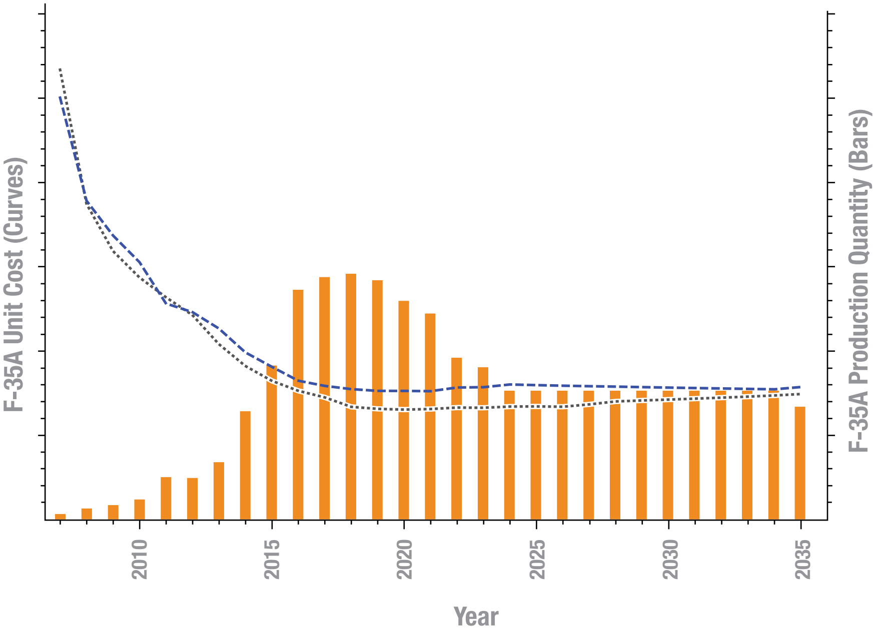

Figure 7. Quantity effects model (dashed curve) and JPO cost projections (dotted curve)

Risk and Uncertainty Analysis

It was necessary for DND to attempt to identify and quantify JSF acquisition program risks and uncertainties, e.g., foreign exchange, withdrawal of international participation, higher-than-expected inflation, increased overhead and labour rates, potential setbacks in software development, intellectual property issues, and requirements above and beyond planned engineering changes. DND's Assistant Deputy Minister Finance (ADM [Fin]) staff oversaw the task of identifying and quantifying a subset of these risks and uncertainties. The ADM(Fin) developed the Future Fighter Capability Cost Risk Register and updated analyses every year for submission to Parliament. The quantity effects model presented herein was used to analyze uncertainty in learning effects and uncertainty in quantities produced. Examples of such analyses are provided in Sections 5.2 and 5.3, respectively. However, Section 5.1 begins with a discussion of uncertainty in the quantity effects model itself.

Model uncertainty

There is statistical uncertainty in the parameter estimates (cost improvement and production rate slopes) of the quantity effects cost models for the air vehicle and engine. The statistical uncertainty is driven by the input data. The statistical prediction error of the cost estimates is represented by continuous probability distributions. For regression models, prediction bands provide a measure of confidence concerning where the true function lives. A higher level of confidence requires wider bands. For example, Figure 8 illustrates the 50% and 80% single prediction bands of the F-35 air vehicle quantity effects regression model (single prediction bands incorporate both the variation in parameter estimates and the overall variation in response values). Figure 8a shows the bands between 2007 and 2011, and how the input data (EAC LRIP 13 costs) are fitted. Figure 8b shows the bands for the entire production plan. The prediction error increases the further the model extrapolates.

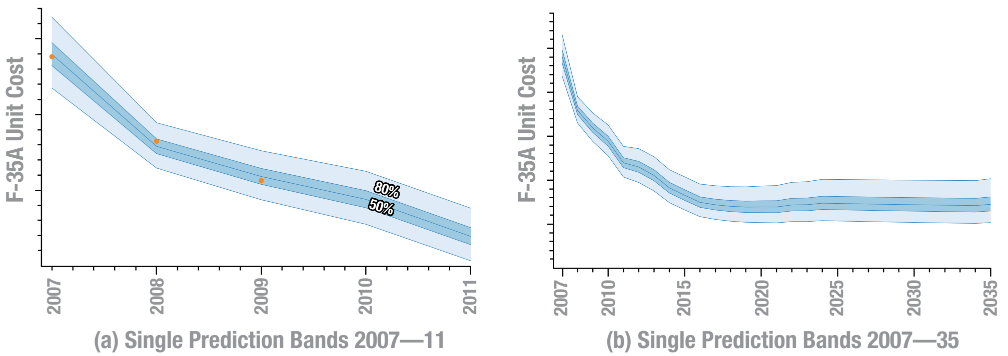

Figure 8. Single prediction bands of the F-35A air vehicle quantity effects regression model: (a) 2007–11 (b) 2007–35

Cost improvement and production rate slope percentages uncertainties

The prediction uncertainty associated with the best-fit quantity effects model provides marginal value when one attempts to quantify the true risks and uncertainties of the JSF program. Cost improvement and production rate slope percentages are indeed uncertainties of the JSF program, and sensitivity analysis of these parameters (CI and PR) is a way to observe changes in the prediction, i.e., quantity effects model outputs, when these parameters change. For example, Table 6 lists a projected average URF cost percentage change (compared with a PR of 90% and a CI of 94%) as a function of various air vehicle cost improvement and production rate slope percentages. It is interesting to focus on the 92%–96% CI range and 88%–92% PR range. This range includes the best-fit quantity effects model CI and PR percentages as well as the reverse engineered JPO CI and PR percentage projections. A very rough calculation shows that, in this range, a ±1% point deviation in the air vehicle PR slope percentage results in a roughly ±5% change to the URF cost, while a ±1% point deviation in the air vehicle CI slope percentage results in roughly ±7% change to the URF cost.

	Production Rate Slope											
CI Slope	80%	82%	84%	86%	88%	90%	92%	94%	96%	98%	100%	102%
80%	-71%	-69%	-67%	-65%	-62%	-60%	-56%	-53%	-49%	-45%	-41%	-36%
82%	-68%	-66%	-64%	-61%	-58%	-54%	-51%	-47%	-42%	-37%	-32%	-26%
84%	-65%	-62%	-59%	-56%	-52%	-48%	-44%	-39%	-34%	-28%	-22%	-15%
86%	-61%	-58%	-54%	-50%	-46%	-41%	-36%	-30%	-24%	-17%	-10%	-2%
88%	-57%	-53%	-49%	-44%	-39%	-33%	-27%	-20%	-12%	-4%	4%	14%
90%	-52%	-47%	-42%	-36%	-30%	-23%	-16%	-8%	1%	10%	21%	32%
92%	-45%	-40%	-34%	-28%	-20%	-13%	-4%	6%	16%	27%	39%	52%
94%	-39%	-32%	-25%	-18%	-9%	0%	10%	21%	33%	46%	61%	76%
96%	-31%	-23%	-15%	-6%	4%	14%	26%	39%	53%	68%	85%	103%
98%	-22%	-13%	-4%	7%	18%	31%	45%	59%	76%	94%	113%	134%
100%	-11%	-2%	9%	22%	35%	49%	65%	83%	102%	123%	145%	170%
102%	0%	12%	24%	38%	54%	71%	89%	109%	131%	155%	181%	210%

Table 6. Example sensitivity of an average URF cost subject to changes in air vehicle cost improvement and production rate slopes

Risk of withdrawal of international participants

A key component of the JSF program is affordability, largely driven by efficiencies resulting from high production rates. One of the highly publicized risks of the program is the potential withdrawal of international participants. To give Canadian decision makers an appreciation of this risk, the best-fit quantity effects models determined in the section titled "An independent estimate of average URF cost" were applied to hypothetical production profiles with reduced F-35A CTOL orders. Consider the following example scenarios (in order of increasing risk):

- Scenario A: A major European partner withdraws (reduction by ~100 aircraft);
- Scenario B: Two major partners withdraw (reduction by ~200 aircraft);
- Scenario C: All countries except for the US and Canada withdraw (reduction by ~450 aircraft);
- Scenario D: The US downsizes to 75% of its original order, and Canada is the only remaining international participant; and
- Scenario E: The US downsizes to 50% of its original order, and Canada is the only remaining international participant.

To generate each scenario, the JPO production planning profile was adjusted. Downsizing was assumed to be uniform (across all years) and unaffected order quantities were unchanged. F-35C orders (used for propulsion system cost projection) were unchanged. Table 7 shows the F-35A cost estimates (percentage change) for the five scenarios. The results are given for each lot (buy year). Combined air vehicle and engine cost totals are shown.

		Estimated Cost (as a % of the Baseline Estimate)				
Lot	Year	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
4	2010	0%	0%	2%	8%	19%
5	2011	0%	0%	0%	7%	17%
6	2012	0%	1%	5%	12%	22%
7	2013	3%	3%	7%	14%	26%
8	2014	2%	3%	10%	18%	29%
9	2015	3%	4%	12%	19%	30%
10	2016	2%	4%	13%	20%	30%
11	2017	2%	4%	13%	20%	30%
12	2018	2%	4%	12%	19%	28%
13	2019	2%	4%	11%	18%	27%
14	2020	2%	4%	10%	17%	26%
15	2021	2%	4%	11%	18%	28%
16	2022	1%	2%	7%	15%	25%
17	2023	1%	2%	6%	13%	24%
18	2024	1%	1%	3%	10%	21%
19	2025	0%	1%	3%	10%	20%
20	2026	0%	1%	3%	10%	20%
21	2027	0%	1%	3%	10%	20%
22	2028	0%	1%	3%	10%	20%
23	2029	0%	1%	2%	9%	20%
24	2030	0%	1%	2%	9%	20%

Lot	Year	Estimated Cost (as a % of the Baseline Estimate)				
		Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
25	2031	0%	1%	2%	9%	20%
26	2032	0%	1%	2%	9%	20%
27	2033	0%	1%	2%	9%	19%
28	2034	0%	1%	2%	9%	20%
29	2035	0%	1%	2%	9%	19%

Table 7. F-35A URF cost estimates upon withdrawal/downsizing of international participation (as a % change)

Assuming that the participating country (e.g., Canada) intended to procure aircraft between 2015 and 2021, based on the F-35A cost estimates shown in Table 7, the country would expect to pay 2% more should a major European partner withdraw, 4% more should two major partners withdraw, 12% more should all countries except for the US and Canada withdraw, 18% more should the US downsize to 75% and all other countries withdraw, and 28% more should the US downsize to 50% and all other countries withdraw.

The model shown was used in October 2015 to estimate the negative financial impact on JSF partners should Canada choose to withdraw from the program.[23]

Conclusion

Until 2011, Canada relied solely on the US JPO for projected costs. Subsequently, DRDC developed a model in order to independently estimate the average URF cost that Canada would likely pay for F-35A CTOL aircraft if the latter were the option chosen for replacement. The cost estimation methodology presented herein is a *quantity effect* model used by the RAND Corporation that combines cost improvement and production rate effects. The model was used to:

- reverse engineer JPO cost projections in order to determine best-fit learning and production rate slopes;
- provide a secondary, independent URF cost projection of future F-35A production lots based on the most recent actual cost data (for completed or partially completed F-35As);
- determine the sensitivity of cost to changes in quantity effects (learning); and
- determine cost sensitivity to changes in production quantities.

The model provided DND with the means to further scrutinize JPO cost estimates, facilitated sensitivity analysis, and ultimately helped DND to better defend its cost estimates. As part of the Government of

Canada's comprehensive response to Chapter 2 of the 2012 Spring Report of the Auditor General of Canada, DND, through the NFPS, has provided annual updates to Parliament on JSF F-35A costing forecasts. DND has used the model developed by DRDC to provide updated cost estimate analyses in support of these annual updates.

Appendix A

Theory

In Section A.1, the mathematical basis for the cost improvement effect, historically referred to as the learning curve effect, is outlined.[24] Section A.2 discusses the production-by-lots model, and Section A.3 expands on it in order to model the production rate effect. These subsections provide additional information to round out the chapter, but do not represent original research and should not be attributed to the author.

History of learning curves

In 1936, at Wright-Patterson Air Force Base in the United States, Wright[25] was the first to study the aircraft production quantity effect. He noted that the more times a task was performed, the less time was required on each subsequent iteration. Wright observed that every time that total aircraft production doubled, the required labour time decreased by 10% to 15%. The Wright learning curve is usually formulated as follows:

$$CAC(Q) = A_1 \times Q^b. \tag{5}$$

$CAC(Q)$ is the cumulative average cost associated with producing the first Q units; A_1 is the cost associated with the first unit produced; and b is the learning slope. Computing 2^b yields the learning slope percentage.

Wright's learning curve for aircraft production has been generalized to apply to other industries and to resources other than labour time (see Henderson[26] experience effect). Variant learning curve models have also been developed. The Management and Accounting Web[27] maintains an up-to-date bibliography on learning and experience curves. The Crawford model[28] is the most commonly applied learning curve. It expresses the cost of unit Q, the marginal cost, as

$$MC(Q) = T_1 \times Q^b. \tag{6}$$

In Equation (6), T_1 and b are parameters to be estimated.

Goldberg and Touw[29] and Lee[30] show that the Wright and Crawford learning curve models are related. Multiplying Wright's cumulative average cost, $CAC(Q)$, by the quantity Q yields the total cost, $TC(Q)$, of producing the first Q units,

$$TC(Q) = Q \times CAC(Q) = A_1 \times Q^{1+b}, \tag{7}$$

and the marginal cost is the derivative of the total cost relative to cumulative quantity:

$$MC(Q) = \frac{d\,TC(Q)}{dQ} = A_1 \times (1+b) \times Q^b. \tag{8}$$

Given Wright's parameter A_1, setting $T_1 = A_1 \times (1+b)$ yields Crawford's learning curve model.

Lot-midpoint learning curves

The Lockheed Martin Corporation produces F-35 aircraft in lots. The basic defining features of a lot are the number of units that the lot comprises and the (incremental) total cost of the lot. The average cost per aircraft in a given lot can be computed by simple division for the fixed number of aircraft. However, an average aircraft cost per lot does not necessarily mean that all units are equally costly, or that increasing (or decreasing) the lot size maintains the average cost per aircraft. In the case of production by lots, the lot-midpoint learning curve model formulated by Goldberg and Touw[31] is suitable:

$$LAC_i = T_1 \times [\bar{Q}_i(b)]^b. \tag{9}$$

In Equation (9), LAC_i represents the average cost of an aircraft from lot i, T_1 the cost of the first aircraft produced (of the entire production), $\bar{Q}_i(b)$ the midwpoint of the ith lot, and b the learning slope. The lot midpoint, $\bar{Q}_i(b)$, is a function of b. To determine a lot midpoint, the learning slope must be known, because the lot midpoint is defined as the (generally non-integer) quantity whose marginal cost is equal to the lot average cost.

Using the theory of continuous learning curves, $\bar{Q}_i(b)$ can be computed in usable form. The incremental total lot cost of lot i is approximated by the integral under the marginal cost curve ($MC(Q)$). Define Q_i as the cumulative quantity of units produced up to and including lot i. Then the ith lot begins at unit $Q_{i-1}+1$ and ends with unit Q_i. $TC(Q_i)-TC(Q_{i-1})$ is the incremental total lot cost of lot i:

$$TC_i - TC_{i-1} \approx \int_{z=Q_i+0.5}^{z=Q_{i-1}+0.5} T_1\, z^b\, dz = \frac{T_1}{1+b} \times \left[(Q_i+0.5)^{1+b} - (Q_{i-1}+0.5)^{1+b}\right]. \tag{10}$$

Dividing the right-hand side of Equation (10) by the size of lot i yields the average incremental lot cost, LAC_i:

This Figure—

$$LAC_i \approx \frac{\frac{T_1}{1+b} \times \left[(Q_i+0.5)^{1+b} - (Q_{i-1}+0.5)^{1+b}\right]}{Q_i - Q_{i-1}}. \tag{11}$$

(The symbol ≈ means approximately equal to.) Setting the marginal cost $T_1 \times [\bar{Q}_i(b)]^b$ to LAC_i and solving for the lot midpoint yields:

$$\bar{Q}_i(b) \approx \left(\frac{\left[(Q_i+0.5)^{1+b} - (Q_{i-1}+0.5)^{1+b}\right]}{(1+b) \times (Q_i - Q_{i-1})} \right)^{\frac{1}{b}}. \tag{12}$$

Production Rate Effect

To determine a production rate effect, measure the effect of producing different quantities in a given year (or time period). The unit cost is affected through operating efficiency and the spreading of fixed costs over the number of units. The cost improvement curve (learning curve) is augmented as follows to model the production rate effect:

$$LAC_i = T_1 \times [\bar{Q}_i(b)]^b \times r_i^c. \tag{13}$$

In Equation (13), r_i is the production rate of lot i. Goldberg and Touw[32] show that to properly handle the production rate effect, r_t would ideally be the number of units produced in annual buy t, and LAC_t would be the cost of the unit at the midpoint, $\bar{Q}_t(b)$, of annual buy t. In reality, several F-35 lots are in progress concurrently. However, the data provided by the JPO and in US Selection Acquisition Reports do not provide details of which lots are produced at which plants (including subcontractors) and at which stages of assembly. Lot size is often used as a proxy for production rate: Goldberg and Touw[33] state that the lot size provides a "serviceable approximation" of the true production rate.

A second issue relative to modelling of the production effect occurs when the production rate is highly correlated with the cumulative quantity. Several authors, e.g., Large et al.,[34] have shown that results (estimation of parameters b, c, and T_1) are unreliable when this is the case.

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Abbreviations

ADM(Fin)	Assistant Deputy Minister (Finance)
CAF	Canadian Armed Forces
CDA	Conference of Defence Associations
CI	cost improvement
CTOL	conventional take-off and landing
DND	Department of National Defence
DRDC	Defence Research & Development Canada
EAC	estimate-at-completion
FFCP	Future Fighter Capability Project
JPO	Joint Strike Fighter Project Office
JSF	Joint Strike Fighter
LRIP	low-rate initial production
NFPS	National Fighter Procurement Secretariat
PR	production rate
STOVL	short take-off/vertical landing
URF	unit recurring flyaway
USD	US dollars

Notes

1. The F-35 Lightning II Program, accessed July 25, 2018, www.jsf.mil/f35/f35_background.htm.

2. Low-rate initial production is used in US military procurement programs to indicate the phase of initial, small-quantity production of a weapon system.

3. Photo credit: Lockheed Martin Corporation.

4. JSF Program Office: JSF Production, Sustainment and FollowOn Development Memorandum of Understanding, accessed on July 25, 2018, www.jsf.mil/downloads/documents/JSF_PSFD_MOU_-_Update_4_2010.pdf.

5. M. Arena et al., "Why Has the Cost of Fixed-Wing Aircraft Risen? A Macroscopic Examination of the Trends in US Military Aircraft Costs over the Past Several Decades," Report MG696NAVY/AF (Santa Monica, CA: RAND, 2008); O. Younossi et al., "F-22A Multi-Year Procurement Program: An Assessment of Cost Savings," Report MG664OSD (Santa Monica, CA: RAND, 2007).

6. B. Kaluzny, "The Unit Recurring Flyaway Cost of a Canadian Joint Strike Fighter," Technical Report DRDC CORA TR 2011-200 (Ottawa: Defence Research and Development Canada Centre for Operational Research and Analysis, 2011); B. Kaluzny, "Canadian F35A Unit Recurring Flyaway Cost Estimation: 2014 Update for NGFC Cost Risk Assessment," Technical Report DRDC-RDDC2014L173 (Ottawa: Defence Research and Development Canada Centre for Operational Research and Analysis, 2014).

7. All cost figures presented herein are masked to protect the sensitivity of the original data. The cost axis of all graphs shown is also hidden. Results are presented as a percentage or percentage change.

8. R. Shimooka, "The Fourth Dimension: The F35 Program, Defence Procurement, and the Conservative Government, 2006–2015," Technical Report 33, CDA Institute Vimy Paper, September 2016.

9. URF cost includes costs of airframe, vehicle and mission systems, propulsion, and engineering change orders (concurrency).

10. Cost data were converted to 2012 USD, the Base Year (BY) used by the JPO, using the Naval Center for Cost Analysis Joint Inflation Calculator and adhering to US Office of the Secretary of Defense guidelines.

11. The terms "cost improvement" and "learning" are used interchangeably.

12. Arena et al., "Why Has the Cost of Fixed-Wing Aircraft Risen?;" Younossi et al., "F-22A Multi-Year Procurement Program."

13. Arena et al., "Why Has the Cost of Fixed-Wing Aircraft Risen?"

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18. The quantity effects model including both cost improvement and production rate parameters was found to better fit the data than a learning curve model (without production rate extension).

19. K. Hartley, "Factors Affecting the Cost of Airplanes," *The Journal of Industrial Economics* 13, no. 2 (1965), 122–28.

20. Annex E, "Follow-on Development Process" of the JSF Production, Sustainment and Follow-On Development Memorandum of Understanding indicates that JSF production will follow an evolutionary acquisition approach that is designed to deliver new capabilities (software and mission systems) in a time-phased implementation (approximately every two years). According to the literature (see Stocker, 2010 and references therein), evolutionary acquisition tends to affect the life-cycle cost of a platform, but not so much the acquisition cost.

21. Younossi et al., "F-22A Multi-Year Procurement Program."

22. The *t*Statistic for T_1 and CI slope percentage is 37.5 and 86.7, respectively. The *p*Value for T_1 and CI slope percentage is 0.017 and 0.007, respectively.

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CH06

Forecasting the Operating and Maintenance Costs of Aircraft

Paul E. Desmier

CH06 Table of Contents

As far as the laws of mathematics refer to reality, they are not certain; as far as they are certain, they do not refer to reality.

– A. Einstein, 1921

Introduction

In Canada, a great deal of analysis and media attention has always focused on the acquisition costs of aircraft, but very little information or analysis has been made available relative to the costs of operating and maintaining fleets over their life cycle. In their whimsically titled but serious article, Taylor and Murphy[1] point out that budgetary pressures on the United States (US) Department of Defense (DoD) are forcing the military and civilian leaders in the DoD to focus their attention on the full-life cycle costs of new weapon-system procurements (and not just development and production)—from initial operating capability through to end-of-life and disposal. Operations and maintenance (O&M) costs tend to be the largest portion of life-cycle costs and can typically range from 60% to 80% of the total costs of a major weapon system.[2]

The Department of National Defence (DND) and the Canadian Armed Forces (CAF) own, operate and maintain equipment costing more than $30B. In fiscal year (FY) 2015–2016, DND spent in excess of $2.5B to maintain and repair its equipment, with costs rising as equipment ages and plans for replacement continually getting deferred because of budgetary pressures.

In 2005, DND commenced formal procedures for an all-encompassing contracting approach for the maintenance and repair of all new fleets of ships, aircraft and land vehicles. The resulting in-service support contracting framework (ISSCF) has been implemented as policy since July 2008, and became a departmental directive in August 2010. Under the ISSCF, the prime contractor selected at the time of acquisition is also awarded the in-service support contract, thus establishing a clear point of accountability with the prime contractor for equipment reliability. Rather than multiple contracts per fleet, there is now only one support contract that is fixed-price, platform-level, performance-based, incentivized and long-term (>20 years). While not without risks (see Auditor General, 2011),[3] the goal of the ISSCF is to achieve maximum value for money, while sustaining full operational capabilities.

There have been a number of studies, mainly in the US, focusing on aircraft usage in order to better predict current and future operating and maintenance costs. The US Air Force (USAF) uses both bottom-up and top-down approaches to forecast operating and support (O&S) costs,[4] and estimates based on both approaches are used to draw up final budgets. With the bottom-up and top-down approaches, usage parameters are applied, i.e., mainly flying hours aggregated from the wing level (bottom-up) or from historical data (top-down), as a validation for the final estimates.

Literature Review and Prior Work

Hildebrandt and Sze (1990)

Hildebrandt and Sze[5] build log-linear regression models for total O&S costs as a function of flying hours per aircraft, flyaway cost, number of aircraft, initial operating capability (IOC) year, and average age of each mission design (MD) fleet.[6] When regressed under all explanatory variables, the fighter-attack, cargo aircraft and IOC variables were not statistically significant, but they became significant when flyaway costs were removed from the model (although only 51% of the variance in total O&S costs could be accounted for by the remaining explanatory variables). In general, they found that total O&S costs were more responsive to increases in flying hours than to increases in flyaway cost. In addition, O&S costs increased less than proportionally with flying hours, i.e., a 1% increase in flying hours equates to a 0.62% increase in total O&S costs.

Wallace, Houser and Lee (2000)

With the USAF cost-per-flying-hour (CPFH) model, otherwise known as the proportional model, projected flying hours for individual fleets at Mission Design Series level are multiplied by CPFH factors[7] to arrive at future budgets. Wallace et al.[8] found problems with the CPFH model in contingency operations, when flying-hour behaviour changes significantly. In Operation (Op) DESERT STORM (First Gulf War), for example, proportional models overestimated the amounts of materiel by more than 200%. They found that, while flying hours increased, the number of landings per sortie dramatically decreased, and the amount of time that the aircraft spent on the ground was small, leading to fewer events that could cause ground-induced failures. They postulated that a materiel consumption model must include variables other than simply flying hours. To account for wartime surges, they created a physics-based model that took the ground environment, flying hours, and take-off/landing cycles into consideration. When analyzed for the C-5B Galaxy transport aircraft during Op DESERT STORM or for the C-17 transport, KC-135 transport/tanker and F-16C fighter during Op ALLIED FORCE (Kosovo), the physics-based model consistently predicted removal causing failures during wartime surges more accurately than the proportional model.

The Canadian CF18 fleet also experienced similar surges in flying hours during Ops DESERT STORM and ALLIED FORCE, as well as during post-modernization. At the same time, the fleet experienced a steady decrease in the yearly flying rate (YFR) as the size of the fleet was reduced from 125 aircraft in FY 1991–92 to the current 77 aircraft. From FY 1991–92 onwards, the YFR decreased at the rate of 8,900 $\ln(y)$ hours, where y is the year index, i.e., $y = 1$ up to 18. Therefore, any increases in maintenance costs due to wartime surges would be dampened by the steady decrease in annual hours.

Unger's technical report[9] sought to improve on the top-down CPFH approach. Unger's main concern with the CPFH metric was that multiplying an average cost factor by projected flying hours might result in incorrect estimating of budgets because of fixed costs. Instead, by using a log-log transformation on costs and flying hours to stabilize variance, Unger built a multiple regression model at the MD level. Unlike the CPFH model, which implies a doubling of maintenance costs with a doubling of flying hours, Unger chose to treat flying hours as an explanatory variable in order to ascertain whether fixed and variable costs were present.

When the model was run with 34 MDs, a statistically significant model was found with a flying hours coefficient, β_2, of 0.56, consistent with non-trivial fixed costs, i.e., zero flying hours does not lead to zero costs and diminishing marginal costs. Because of the log-log specification, the relationship is non-linear. Instead of showing a doubling of maintenance costs with a doubling of flying hours, Unger's model showed that doubling flying hours leads to a 56% increase in maintenance costs.

When Unger's log-log model was run on annual CF18 data from the 1991–92 and 2008–09 fiscal years, it did not produce statistically significant results for any coefficients, and the explanatory variables, average age and flying hours accounted for only 8% of the variance in O&M[10] costs. In this case, a doubling of flying hours resulted in a 25% increase in O&M costs.

If we remove the log transformation in Unger's model and apply it to the same CF18 data, we find all coefficients to be statistically significant, but still only 22% of the variance in O&M costs can be accounted for by the average age and flying hours. Nevertheless, the cost implications of coefficients show that a one-year increase in average age leads to a $4.47M increase in O&M costs, and one flying hour leads to a $2.82K increase in O&M costs. Thus, a fleet yearly flying rate of about 13,000 hours would result in an O&M bill of approximately $36.7M, or about 7 to 10 times less than expected using current program management O&M estimates.

Desmier (2011)

A first analysis for the CF18 fleet investigated the trend in the ratio of historical annual O&M per flying hours to amortized capital costs.[11] Since only historical O&M data from FY 1991–92 were available, the dataset was backcast from FY 2008–09 in order to estimate the first 10 years of CF18 O&M growth, i.e., 1982–83 to 1991–92 fiscal years. The resulting model displayed autoregressive[12] behaviour and accounted for 87% of the variability in the data. It was noted that the Lag2 coefficient was not statistically significant at the 5% level and thus could not be distinguished from chance variation. However, since our interest was mainly in the expected value trend in O&M cost growth for the CF18 fleet, which we assumed could be translated directly to F-35A O&M growth, the Lag2 ratio model was considered suitable because it provided a much better fit at the right tail (see Figure 1) than a Lag1 model.

	Coefficient	Standard Error	p-value	t-value
Constant	1.83	9.41	0.8481	0.19
Lag1	0.937	0.223	0.0008	4.20
Lag2	- 0.0153	0.227	0.9471	- 0.07

Table 1. CF18 O&M to capital ratio model regression statistics

While the autoregressive (2) [AR(2)] model displayed reasonable results, there were issues that could not immediately be overcome. Aside from the large uncertainty from FY 1982–83 to FY 1991–92 (shown in Figure 1), the AR model had limitations when the backcast structure was reversed to forecast the CF18 model, because the lagged variables defined in the backcast were no longer predictive in the forecast. A second issue was the formulation of a Lag2 model with annual data, because it was assumed that usage in year *t* affected costs in year *t*+2. Armstrong, in his analysis of depot-level repair of the F-15 fleet,[13] showed there was no discernible lag structure for the response or explanatory variables. Unger initially believed that O&S costs would be lagged by one or two years,[14] but further discussions with maintainers and the lack of any statistical significance of the lagged variable indicated that aircraft usage would most likely affect costs within the same years. For the CF18 fleet, the scheduling of periodic inspections every two years (400 flying hours) means that normally we would expect to see a lag effect in maintenance spending; however, this assumption must be adjusted with changing operational tempo. For example, recent operations in Libya saw some aircraft flying up to 100 hours per month, making it necessary for the number of periodic inspections to be increased to meet the demand.[15]

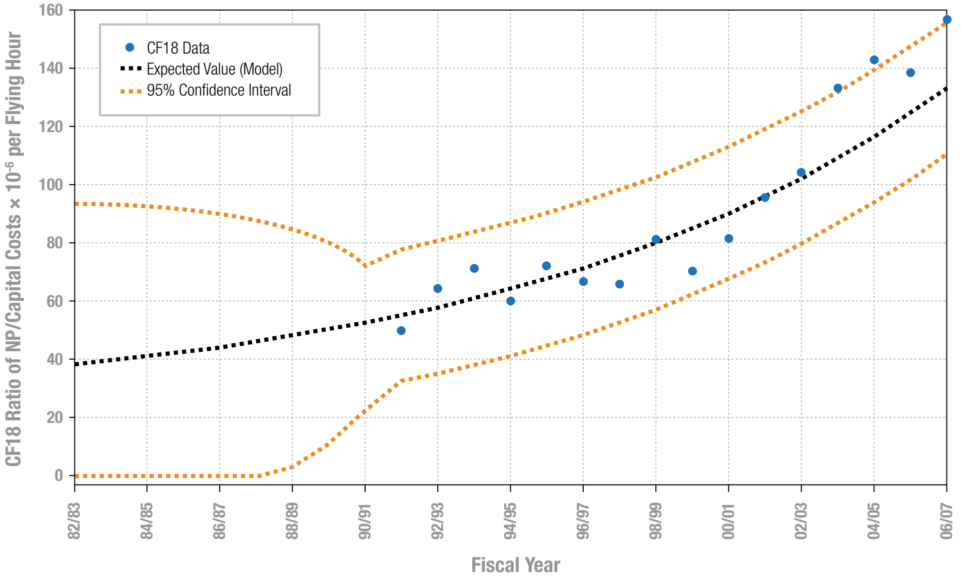

Figure 1. Original CF18 ratio model

Method: The Ratio Model

For any new acquisition or significant upgrade, a method is required to draw up a forecast[16] for future O&M costs. However, given that some acquisitions are based on new technologies, there is no past history to tell us how their O&M cost curves will look as a function of usage and age.

In the case of fighters, and specifically the F-35 Joint Strike Fighter (JSF), the US bases its estimates on a bottom-up modelling effort using the Operating and Support Cost Analysis Model (OSCAM), which uses a system dynamics engine with a comprehensive user interface to capture the evolving time dynamics of a system, while allowing for a structured costing environment based on the cost breakdown structure of the weapon system.[17] The OSCAM, which was jointly developed through a strategic partnership between the US Naval Center for Cost Analysis (NCCA) and the United Kingdom (UK) Ministry of Defence, with support from QinetiQ Ltd., uses historical databases to support life-cycle cost estimates that include what-if analyses, trade-off studies and analysis of alternatives. An OSCAM JSF model—originally designed for estimating O&S costs for ships and shipboard systems, with variants for land vehicles and aircraft—was developed in 2008 to perform cost analyses for the three aircraft variants, and includes data specific to the partner countries.

At the DND, rather than attempt to build a model with countless variables and associated uncertainties, it was felt that it would be more desirable to have a high-level, top-down, ratio-based method where the past spending history of the fleet being replaced—which for fighters would be the CF18 fleet—would become a template for forecasting future spending for the F-35 fleet. The CF18 O&M cost growth and variance, when coupled with amortized capital costs, would provide the trend and confidence levels for predicting future F-35 O&M costs.

The establishment of a ratio-based method for determining O&M costs has already been explored within DND. In 2006, Groves produced a seminal paper[18] describing five key economic trends that were driving cost growth in the O&M program at a faster rate than budgets could support. His Observation 4 highlighted the fact that "O&M costs for new or replacement acquisitions are frequently underestimated" either deliberately in order to influence a positive outcome in project approval decisions, or unintentionally because of a lack of rigour. In his analysis, Groves felt that a historical ratio of annual amortized capital to annual O&M spending would provide a better means to estimate the future O&M costs of new acquisitions.

In 2009, Sokri,[19] building on a RAND analysis,[20] developed an O&M to capital ratio model where life-cycle O&M costs were estimated based on an estimated optimal replacement age for the fleet. While useful to some degree for existing systems, there was no extension of the analysis to include replacement systems.

Ratio equation

In general, for any new acquisition, the analysis uses historical capital and O&M costs of existing systems to model the ratio of O&M to capital amortized over time as a template for forecasting O&M costs of similar-class fleets. The results of the analysis, which is considered a high-level, top-down analysis, are based on the assumption that the new fleet adheres to the same mission profiles as the old fleet, i.e., the new fleet cannot take on entirely different missions, nor can the frequency of these missions be altered significantly from those of the old fleet.

$$\text{O\&M}_{m\,(\text{New})} = \left[\frac{(\text{O\&M/Flying Hours})_{i\,(\text{Old})}}{\text{Capital}_{i\,(\text{Old})}}\right] \times \text{Capital}_{m\,(\text{New})} \times \text{Flying Hours}_{m\,(\text{New})}\,, \qquad (1)$$

where

- Year i starts at the first year of O&M spending for the old fleet and continues to the last FY of spending;
- Year m starts at the first delivery of the new fleet and continues to the estimated airframe life expectancy (usually 30 years); and
- Capital is discounted at a rate of 4.0%, which is the rate of return that could be earned on an investment in the financial markets with similar risk, and is amortized over the life of the fleet.

The modelling method uses the spending and usage history of the old fleet as a template for determining the spending trend for the new fleet. Multiplication by the capital and flying hours inflates the spending trend so as to account for the technological advances inherent in a generationally advanced aircraft.

Analysis

Controlling for aircraft age

There is a significant body of literature on how age affects the maintenance costs of military equipment. In a study for the US Army, Peltz et al.[21] assessed the impact of age, location and usage on individual M1 (Abrams) tank failures. Their study showed that M1 tank age had a positive log-linear effect corresponding to a 5±2% increase in tank failures (and by extrapolation, an increase in maintenance costs) per year of age.

In a major body of work on aging military aircraft, Pyles[22] showed that, in general, as aircraft aged, maintenance workloads and materiel consumption exhibited late-life growth that was dependent on aircraft flyaway costs—more expensive (and more complex) aircraft experienced higher growth rates. Hildebrandt and Sze[23] used the "bathtub" curve hypothesis[24] to analyze average aircraft age and demonstrated a positive effect, but they did not find any evidence of an early decrease in costs.

Not limiting analysis to military aircraft, Dixon[25] analyzed the effects of age on commercial aviation and found that young aircraft (0 to 6 years old) had considerable age effects, including a 17.6% annual rate of increase in maintenance cost per flying hour. Mid-range aircraft (6 to 12 years old) demonstrated a 3.5% increase, and older aircraft (more than 12 years old) showed only a 0.7% increase. Dixon discounted the 17.6% rate of increase for young aircraft because of the expiry of aircraft warranties and the transfer of maintenance cost responsibility from the manufacturer to the owner. However, the 0.7% rate of growth was consistent with commercial aircraft over 12 years old, but because the data were limited (airlines do not keep aircraft for much longer than 20 years), it was postulated, pessimistically, that very old aircraft may incur higher maintenance costs.

Although age is a linear function, the average age of the fleet is not, because it depends on the fleet delivery schedule at inception, and the disposal schedule at end of life. Figure 2 shows the average age and how the fleet size has changed over time, and indicates monthly increments. The rate of increase in fleet size from 1982–83 to 1988–89 is due to the staggered delivery schedule. From 1989–90 to 2009–10, there was a near-continuous increase in the fleet's average age, and only minor disruptions due to attrition and disposal. The decrease in average age in 2009–10 is attributable to the disposal of 10 aircraft. Average age per fiscal year will be used in the regression analysis for the CF18 ratio calculation (Equation 1).

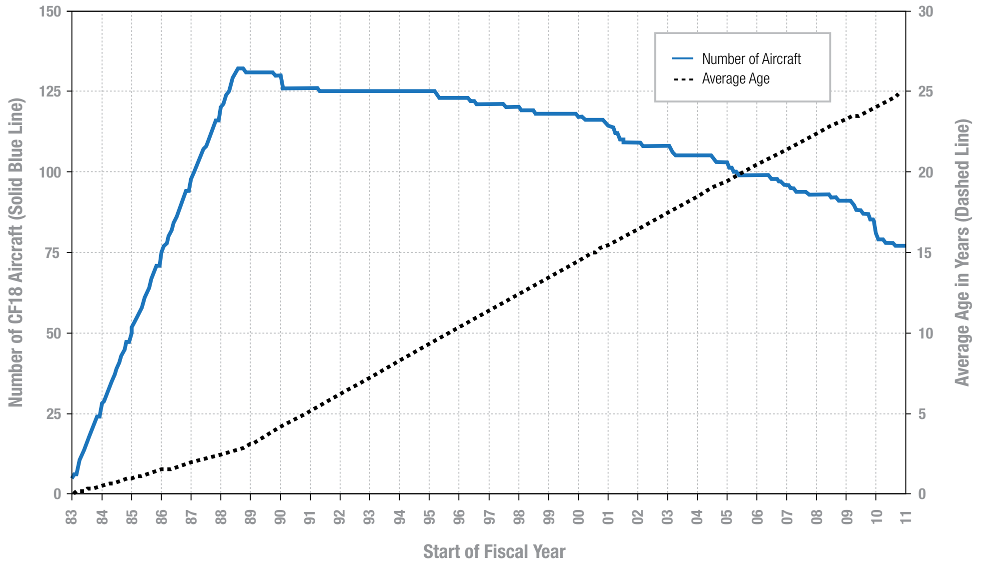

Figure 2. Number of CF18 aircraft and fleet average age from 1983–84 to 2010–11

Fighter aircraft: CF18 → F-35A

> The following analysis was originally completed in 2012 and has not been updated, hence the dates and costs will have changed significantly since then. Given that in FY 2016–2017, Canada must still hold a competition for a fighter aircraft, this analysis should be looked at in terms of its method for determining future O&M costs, and not in terms of the actual data displayed and used.

Canada is examining options for renewing its fighter capability in order to replace an aging fleet of CF18 aircraft. One of the options under consideration is the Lockheed Martin F-35A Lightning II aircraft, also known as the Joint Strike Fighter. The JSF is considered one of the most expensive weapons programs currently funded by the US DoD, and may replace a wide range of aging fighter and strike aircraft in the inventories of the US and eight international partners, including Canada, with three variants: the F-35A (conventional take-off/landing [CTOL]), the F-35B (short take-off/vertical landing [STOVL]), and the F-35C [carrier variant or CV]). Canada is considering the CTOL variant.

From a Canadian perspective, the CF18 has reached the end of its service life, given that its original estimated life expectancy (ELE) was to 2003. The fleet has already undergone aggressive fatigue life management and structural repair programs necessary to extend the ELE to beyond 2020. However, as age continues to overtake the fleet, spare parts are becoming increasingly difficult to obtain, resulting in reduced readiness and the need to cannibalize retired aircraft. Also, emerging threats from more capable aircraft and surface-to-air missiles expose the fleet to significant risk. Given the above, the Canadian government has identified the requirement to replace the CF18 with a next-generation fighter.

In an open procurement competition, it may be assumed that a number of fighter types will be given consideration, including the F-35A. The first step in solving Equation 1 is to build the CF18 model.

CF18 capital costs

In order to populate the ratio equation (Equation 1), we need to collect capital, O&M and usage (flying hours) data for the CF18 fleet. Table 2 lists the CF18 annual capital expenditures,[26] as well as the discounted capital expenditures (columns 2 and 3 respectively), which were discounted to FY 1981–82.[27] The first six years of spending accounted solely for the purchase price of the fleet.

Figure 3. F-35A Lightning II (Photo: Master Sgt. Donald R. Allen, USAF)

Twenty-nine upgrades that modified and/or extended the life of the CF18 fleet were taken into consideration and the amortization includes the extended life. Since the CF18 model requires capital amortized for the life of the fleet, capital spending from 2011–12 to 2019–20 (blue text) was forecast from the previous 16 years of data, i.e., 1995–96 to 2010–11. The best fit model was a Lag1 AR model that accounted for 99% of the variability in the data. Table 3 lists the model regression statistics. When amortized to FY 2019–20 (38 years), the annual amortized capital cost for the CF18 fleet amounts to $114.96M.

CF18 O&M costs and the ratio model

Columns 4 to 6 of Table 2 list the annual O&M spending (Column 4), the fleet flying hours (FHrs, Column 5) and the ratio values given as O&M per flying hours per amortized capital (Column 6), respectively. Unfortunately, O&M expenditures were not available prior to 1991–92.[28] Consequently, in order to build the ratio model as specified by Equation 1, a backcast approach was used, where the existing data set was forecast in reverse to establish the initial tail.

The dataset, consisting of the observed ratio values (black entries in Column 6), was backcast from 2008–09 as a time series regression model of the form,

$$\left(\frac{\text{O\&M/FHrs}}{\text{Capital}}\right)_{\text{t}} = \beta_0 + \beta_1\, Age_t + \sum_{i=2}^{n} \beta_i\, x_{t,i} + \epsilon_t,\ t = 08/09 \ldots 91/92\,, \qquad (2)$$

where Age_t is the average age of the fleet at time t (Table 2, Column 7), $x_{t,i}$ are the n intervention variables (pulses and level shifts), and ϵ_t is the white noise error term.

FY	Capital ($M)	Capital Discounted ($M)	O&M ($M)	Flying Hours	CF18 Ratio ($\times 10^{-6}$ per Hr)	Average Age (Years)	CF18 Ratio Model ($\times 10^{-6}$ per Hr)
1981–1982	565.60	565.60					
1982–1983	565.60	543.85			36.59	0.19	28.542
1983–1984	777.70	719.03			38.01	0.64	30.707
1984–1985	777.70	691.38			39.54	1.07	32.821
1985–1986	742.35	634.57			41.00	1.54	35.121
1986–1987	777.70	639.22			42.58	2.03	37.487
1987–1988					44.20	2.53	39.930
1988–1989					46.50	3.15	42.947
1989–1990					49.67	4.13	47.735
1990–1991					53.05	5.17	52.803
1991–1992			225.00	38,966	50.23	6.18	57.686
1992–1993			225.00	30,216	64.78	7.18	62.559
1993–1994			222.58	27,058	71.56	8.18	67.432
1994–1995			182.27	26,241	60.42	9.18	72.304
1995–1996	0.66	0.38	197.36	23,704	72.43	10.15	77.033

FY	Capital ($M)	Capital Discounted ($M)	O&M ($M)	Flying Hours	CF18 Ratio (×10⁻⁶ per Hr)	Average Age (Years)	CF18 Ratio Model (×10⁻⁶ per Hr)
1996-1997	50.59	28.09	178.17	23,142	66.97	11.16	81.964
1997–1998	2.69	1.44	176.79	23,235	66.19	12.15	86.790
1998–1999	19.90	10.22	202.94	21,629	81.62	13.12	91.516
1999–2000	22.90	11.31	169.77	20,892	70.69	14.12	96.389
2000–2001	16.59	7.88	170.98	18,188	81.77	15.08	101.069
2001–2002	10.23	4.67	183.39	16,593	96.14	15.98	105.467
2002–2003	22.59	9.91	193.30	16,051	104.76	16.98	110.354
2003–2004	281.46	118.77	218.14	14,186	133.77	17.98	115.221
2004–2005	221.26	89.77	211.49	12,812	143.60	18.95	119.915
2005–2006	229.70	89.61	216.33	13,530	139.09	19.87	124.408
2006–2007	37.59	14.10	223.00	12,324	157.41	20.77	128.808
2007–2008	34.54	12.46	212.00	12,899	142.97	21.70	133.322
2008–2009	20.01	6.94	193.00	13,682	122.71	22.64	137.904
2009–2010	17.24	5.75				23.47	141.978
2010–2011	344.83	110.57				24.26	145.820
2011–2012	21.25	6.55				25.26	150.693
2012–2013	22.69	6.73				26.26	155.566
2013–2014	22.05	6.29				27.26	160.439
2014–2015	22.33	6.12				28.26	165.311
2015–2016	22.21	5.85				29.26	170.184
2016–2017	22.26	5.64				30.26	175.057
2017–2018	22.24	5.42				31.26	179.930
2018–2019	22.25	5.21				32.26	184.803
2019–2020	22.24	5.01				33.26	189.676
Total	**5,738.99**	**4,368.32**					

Table 2. CF18 data and model results (values highlighted in blue are forecast; costs in Can$ millions)

	Coefficient	Standard Error	p-value	t-value
Constant	3.22×10^{7}	5.21×10^{6}	0.0001	6.17
Lag-1	- 0.446	0.202	0.0514	- 2.21
Pulse $_{t=03/04}$	2.60×10^{8}	1.01×10^{7}	0.0000	25.83
Pulse $_{t=04/05}$	1.96×10^{8}	1.04×10^{7}	0.0000	18.83
Pulse $_{t=05/06}$	2.14×10^{8}	1.01×10^{7}	0.0000	21.25
Pulse $_{t=10/11}$	3.20×10^{8}	1.01×10^{7}	0.0000	31.71

Table 3. CF18 capital regression statistics

The best fit regression model accounted for 98% of the variability in the data, and with a Durbin Watson statistic of 2.3185, there was no significant autocorrelation in the residuals[29] for Lag 1.[30] Table 4 lists the model regression statistics.

Model Component	Coefficient	Standard Error	p-value	t-value
Constant	48.992 (β_0)	12.0	0.0018	4.09
Age	3.256 (β_1)	0.483	0.0000	6.75
Level Shift $_{t=92/93}$	26.9605	5.70	0.0006	4.73
Level Shift $_{t=97/98}$	- 40.0177	5.15	0.0000	- 7.77
Pulse $_{t=93/94}$	13.8147	5.54	0.0299	2.49
Pulse $_{t=97/98}$	13.5187	5.97	0.0446	2.27
Pulse $_{t=00/01}$	- 11.2209	5.41	0.0624	- 2.07

Table 4. CF18 ratio model backcast regression statistics

Forecast (ratio) model

Backcasting of the limited ratio data was done solely in order to estimate the ratio values for the years from 1982–83 to 1990–91 inclusive. With the backcast estimates and the observed ratio data from 1991–92 to 2008–09 (Table 2, Column 6), a forecasting regression model was built in the form of

$$\left(\frac{\text{O\&M/FHrs}}{\text{Capital}}\right)_{\text{t}} = \beta_0 + \beta_1\, Age_t + \epsilon_t,\ t = 82/83 \ldots 08/09\,, \tag{3}$$

where the time *t* now represents all 27 years from 1982–83 to 2008–09.

The regression model accounted for 88% of the variability in the data. Table 5 lists the model regression statistics; Table 2 (Column 8) lists the forecast CF18 ratio model values; and Figure 4 describes the CF18 ratio model and the expected value trend. However, there is evidence of positive autocorrelation in the residuals for Lag 1 (Durbin Watson statistic: 0.642). With autocorrelation present, the estimated regression coefficients are still unbiased, but there will be a bias in the standard errors of the estimates, which for positive autocorrelation will be smaller than the true standard errors, and the confidence intervals will be underestimated. Respecification of the model through either a polynomial regression or an AR(1) correction on the residuals was unsuccessful. In the case of the former, the addition of a quadratic series amplified the right-tail estimate beyond all reasonable expectations for O&M spending; whereas, in the case of the latter, an AR(1) correction in the residuals did correct for the autocorrelation, but left a trend model with significant noise, such that a one-to-one transformation from the CF18 to the F-35A would have been unrealistic.

Model Component	Coefficient	Standard Error	p-value	t-value
Constant	27.594 (β_0)	4.48	0.0000	6.16
Age	4.8729 (β_1)	0.354	0.0000	13.77

Table 5. CF18 ratio model forecast regression statistics

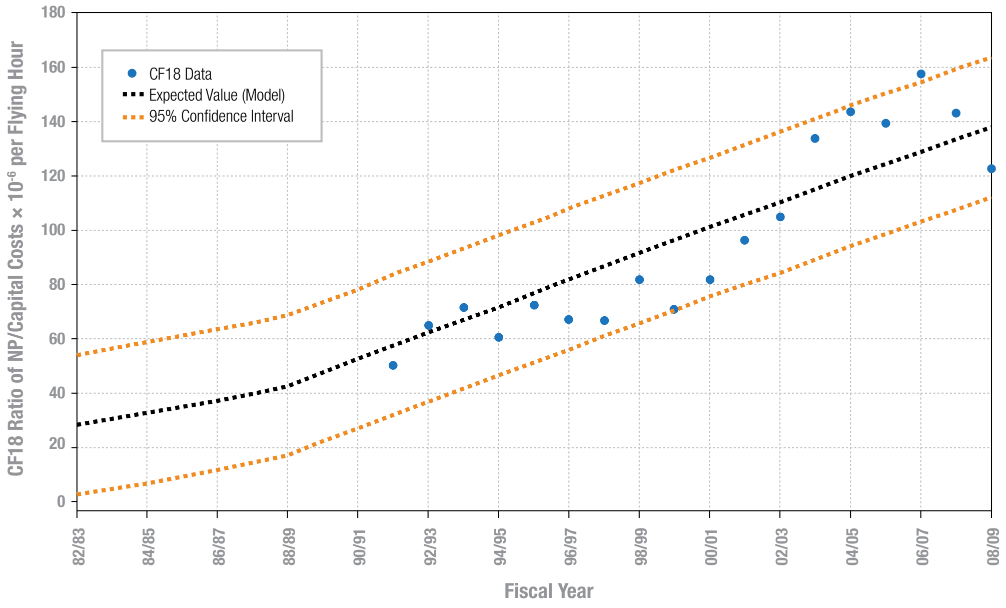

Figure 4. CF18 ratio model

Testing for residual normality

Normality tests[31] are used to determine whether or not a dataset is well defined by a normal distribution. If the residuals from a regression model are not distributed normally, the residuals should not be used in any statistical tests derived from the normal distribution because the response variable (ratio) or the explanatory variable (average age) may have the wrong functional form, or important variables may be missing.

Table 6 lists the observations (including the 1982–83 to 1990–91 estimates), the fitted values and the residuals from the ratio model. Unfortunately, testing for normality with such a small data sample (27 points) is always problematic because they almost always pass a normality test. A failure to reject the null hypothesis that the sample was taken from a normal distribution may reflect normality in the population, or it may reflect a lack of strong evidence against the null hypothesis because of the small sample size. There are a number of theoretical goodness-of-fit tests that are specialized for small samples, and two of the best-known distance tests are the AndersonDarling and the Lilliefors.[32] However, Doornik and Hansen have devised an omnibus test for univariate[33] normality that is based solely on the third and fourth moments, skewness and kurtosis respectively.[34] The test controls well for very small samples[35] and is easy to implement.

As per the notation of Doornik and Hansen,[36] sample moments (m_i) are defined for sample size n as

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i\,, \quad m_k = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^k\,, \quad \sqrt{b_1} = \frac{m_3}{m_2^{3/2}} \quad \text{and} \quad b_2 = \frac{m_4}{m_2^2}\,, \tag{4}$$

where b_1 and b_2 are the sample skewness and kurtosis respectively, and are not independently distributed, although they are uncorrelated. Letting z_1 and z_2 denote the transformed skewness and kurtosis as per Doornik and Hansen,[37] where the transformation creates statistics closer to standard normal, and the test statistic E_p is defined by

$$E_p = z_1^2 + z_2^2 \,\widetilde{app}\, \chi^2(2)\,, \tag{5}$$

where *app* denotes "approximately distributed as" and $\chi^2(2)$ specifies the χ^2 distribution with two degrees of freedom (DOF). Results of the test for the residuals of the regression model are displayed in Table 7. With a p-value of 0.9474, the results indicate a failure to reject the null hypothesis that the sample comes from a normal distribution at a significance level of 5%. The quantile-quantile plot (Figure 5) of the log-transformed O&M data against the normal distribution shows little deviation from the 45degree line, indicating that the data are reasonably well defined by the normal distribution.

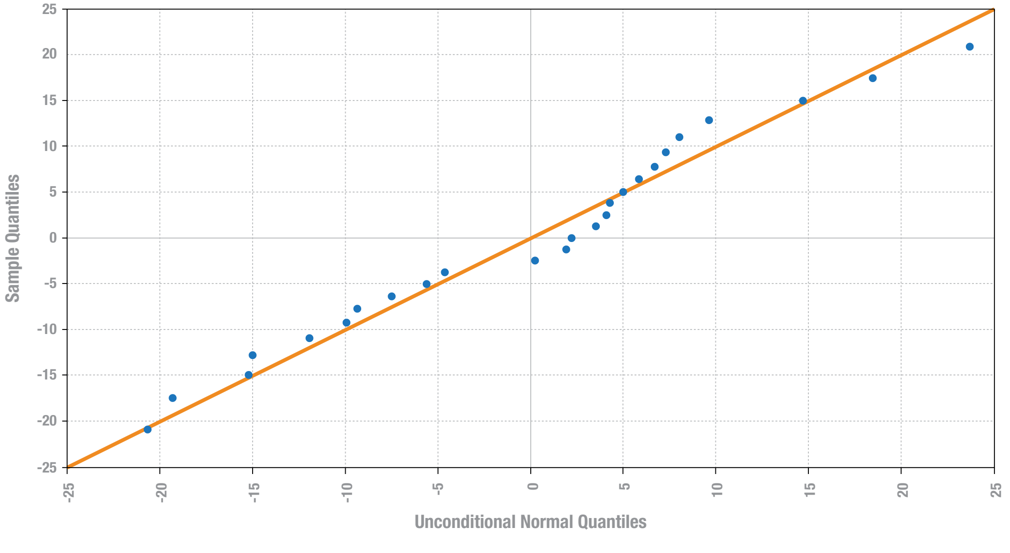

Figure 5. Quantile-quantile plot of the CF18 ratio model residuals

Discussion of the Model

The CF18 ratio model was built as a simple regression model with average age of the fleet as an explanatory variable, and the ratio of O&M costs per flying hour and amortized capital costs as the response variable. As discussed, 88% of the variability in the ratio can be explained by the increasing average age of the fleet, all model coefficients are statistically significant, and the residuals satisfy the normality tests, but exhibit positive autocorrelation, which causes the confidence intervals to be underestimated.

Fiscal Year	Initial Data	Forecast (Fit)	Residual	% Error
1982–1983	36.590	28.541	8.05	22.00
1983–1984	38.010	30.707	7.30	19.21
1984–1985	39.540	32.821	6.72	16.99
1985–1986	41.000	35.121	5.88	14.34
1986–1987	42.580	37.487	5.09	11.96
1987–1988	44.200	39.930	4.27	9.66
1988–1989	46.500	42.948	3.55	7.64
1989–1990	49.670	47.735	1.93	3.90
1990–1991	53.050	52.803	0.25	0.47
1991–1992	50.230	57.686	-7.46	-14.84
1992–1993	64.776	62.559	2.22	3.42
1993–1994	71.557	67.432	4.12	5.76
1994–1995	60.425	72.305	-11.90	-19.66
1995–1996	72.426	77.033	-4.61	-6.36
1996–1997	66.974	81.965	-15.00	-22.38
1997–1998	66.189	86.790	-20.60	-31.12
1998–1999	81.621	91.516	-9.90	-12.12
1999–2000	70.688	96.389	-25.70	-36.36
2000–2001	81.775	101.070	-19.30	-23.59
2001–2002	96.144	105.470	-9.32	-9.70
2002–2003	104.760	110.350	-5.59	-5.34
2003–2004	133.760	115.220	18.50	13.86
2004–2005	143.600	119.920	23.70	16.49
2005–2006	139.090	124.410	14.70	10.55
2006–2007	157.410	128.810	28.60	18.17
2007–2008	142.970	133.320	9.65	6.75
2008–2009	122.710	137.900	-15.20	-12.38

Table 6. CF18 ratio model fitted values and residuals

Moment Statistics		p-value given H_0	
skewness	0.0809	0.8389	H_0 = no skewness
kurtosis	2.5740	0.7962	H_0 = no kurtosis
z_1	0.2034	0.5806	H_0 = no negative skewness
z_2	0.2583	0.6019	H_0 = no negative kurtosis
E_p	0.1080	0.4194	H_0 = no positive skewness
DOF	2	0.3981	H_0 = no positive kurtosis
		0.9474	H_0 = data are normally distributed

Table 7. Normality testing of CF18 ratio model residuals

Clearly, flying hours and average age have strong causal relationships with increasing costs, and this study makes use of both, but only average age was regressed on the ratio. Treating flying hours as a regressor did not meet with similar success. Unger's log-log model was applied to the CF18 fleet with only 8% of the variability in the log of O&M costs explained by average age and the log of flying hours. In addition, neither coefficients of flying hours nor average age in Unger's model were significant.

In a 2011 study, Maybury proved that flying hours do not cause O&M spending for the CF18 or the CC130 fleets.[38] Using Granger causality tests with two-dimensional vector AR models, Maybury showed that the forecast of O&M spending could not be improved using flying hours as an explanatory variable. Furthermore, in a 2010 study, Maybury applied the methods of random matrix theory to search for relationships between O&M spending and the performance of the CC130 fleet.[39] Using 13 high-level performance indicators that were expected to highly correlate with O&M spending, he found no meaningful relationships between spending and the indicators.

Therefore, the CF18 ratio model is defined by Equation 3 and the parameters in Table 5. An earlier AR(2) model, discussed previously, did provide a reasonable upward trend in O&M spending, but could not be confirmed as the best choice for the CF18 fleet. When comparing the two (see Figure 6), we see that, while the AR(2) model starts off with a higher ratio estimate, the difference decreases to zero within seven years, and the model eventually provides estimates that are less than the regression estimates for the majority of the CF18's life cycle.

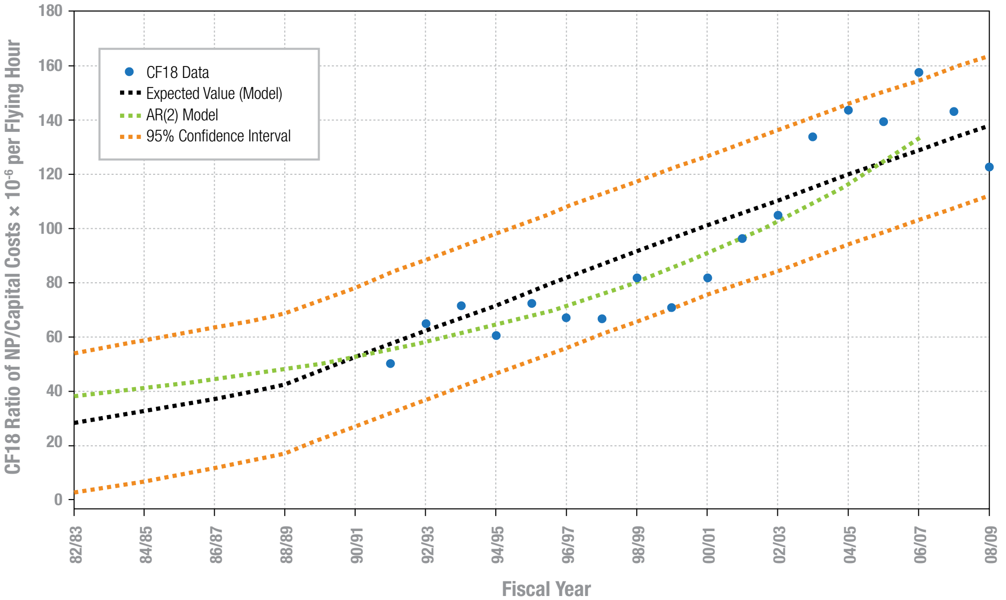

Figure 6. The CF18 ratio model (black) and an earlier AR(2) version (green)

The issue of sample size has already been addressed in developing the backcast model. Since only annual data were available, we are limited to the age of the CF18 fleet (27 years, including 9 years of backcast data) in developing the forecast. Although there is no minimum standard for the number of data points required for a model, for an annual model, Wang and Jain[40] suggest a sample size of 20+k data points, where $k = k^0 + 1$, and k^0 is the number of explanatory variables, and the number 1 represents the constant term in the model. At the 95% confidence level and 20 degrees of freedom, the critical t value is approximately 2.

A final point that needs to be addressed is the forecast model confidence intervals. They are based on regressing CF18 ratio data on average age. Ordinarily, there would be no issue if the data were based solely on observations; however, the CF18 discounted capital costs are, in part, forecast, which introduces a variation in the total discounted capital. In addition, the CF18 ratios used to build the forecast model include backcast expected values, which also introduce a variation in the first 9 years of data. A bootstrap simulation, or some other methodology, would have been required to factor the additional variation into the final model. However, there are an infinite number of models that could be constructed using this approach, and not all would be statistically relevant. Being able to factor out the relevant from the irrelevant presents a significant methodological problem that could not be resolved in this study. Thus, the confidence intervals presented with the final model are rough estimates, and most likely underestimate the true variation in the data and the model.

Results

This section translates on a yearly one-to-one basis the CF18 ratio model to the F-35A fleet as an expected value trend. To establish the initial trend in F-35A O&M spending, the year in which CF18 O&M spending began (1982–83) was translated to the year in which F-35A O&M spending will begin (2016–17). In the case of the latter, the start of F-35A O&M expenditures is directly tied to the forecast flying hours (assuming that no authorized payments are made in advance) and, by proxy, to the fleet size. Assuming no attrition, Table 8 lists the F-35A fleet size based on the delivery schedule and the forecast fleet flying hours that were used as a baseline for analysis.[41]

For example, for 2016–17, we apply Equation 1 with the data from i.e.,

$$\begin{aligned} \text{O\&M}^{\text{F-35A}}_{16/17} &= \left[\frac{\text{O\&M/FHrs}_{82/83}}{\text{Capital}_{82/83}}\right]^{\text{CF-18}} \times \text{Capital}^{\text{F-35A}}_{16/17} \times \text{Flying Hours}^{\text{F-35A}}_{16/17} \\ &= 28.542 \times 10^{-6} \times 228.29 \times 10^{6} \times 350 \\ &= \$2.30 \times 10^{6}\ , \end{aligned} \tag{6}$$

and for the year 2017–2018,

$$\begin{aligned} \text{O\&M}^{\text{F-35A}}_{17/18} &= \left[\frac{\text{O\&M/FHrs}_{83/84}}{\text{Capital}_{83/84}}\right]^{\text{CF-18}} \times \text{Capital}^{\text{F-35A}}_{17/18} \times \text{Flying Hours}^{\text{F-35A}}_{17/18} \\ &= 30.707 \times 10^{-6} \times 228.29 \times 10^{6} \times 1225 \\ &= \$8.60 \times 10^{6}\ , \end{aligned} \tag{7}$$

where 228.29×10^6 is the annual amortized capital costs for the F-35A over a 30-year amortization period, and 350 and 1,225 hours are the flying hours for the first and second years of fleet usage (Table 8) (recall units for the ratio term are hours^{-1}).

FY	Fleet Size	Flying Hours (Baseline)	Flying Hours (12,000 hrs from 21/22)
16/17	3	350	350
17/18	7	1225	1225
18/19	13	3075	3075
19/20	26	5358	5358
20/21	42	8578	8578
21/22	55	12345	12000
22/23	65	15443	12000
23/24	65	15795	12000
24/25	65	15795	12000

Table 8. F-35A forecast fleet size and annual flying hours

Scenario 1: Baseline analysis

The first scenario constitutes the baseline analysis where the basic configuration for projected fleet flying hours is used to forecast F-35A O&M. Figure 7 shows the baseline O&M forecast for the F-35A fleet and the 95% confidence interval. The first 7 years constitute the build-up of the fleet with corresponding increases in flying hours. When compared to the 20-year sustainment costs estimated by DND ($5.7B), the baseline analysis showed that traditional[42] O&M expenditures for the F-35A totalled approximately $4.0±1.5B. For 30 years of operations (2016–17 to 2045–46), total O&M expenditures were estimated to be $8.7±2.4B.

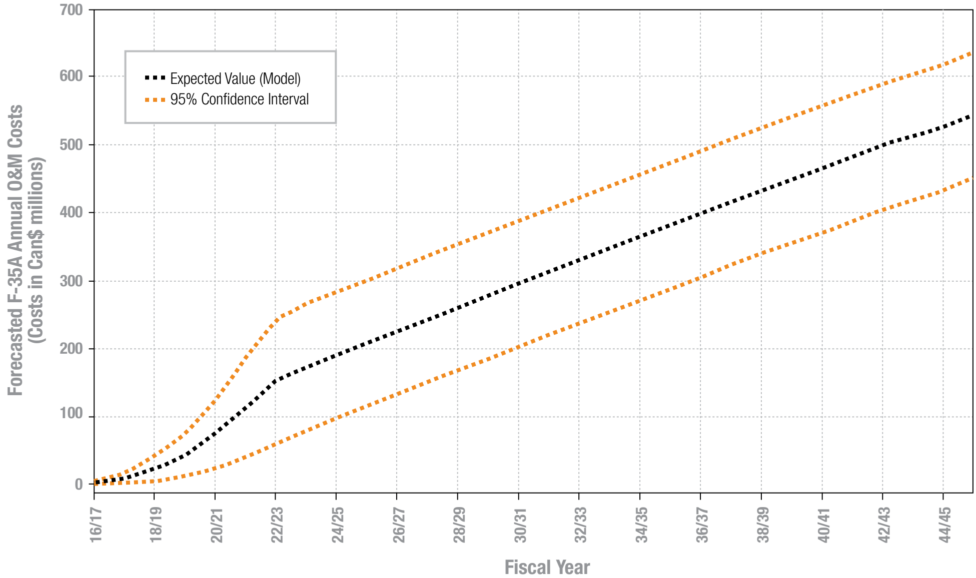

Figure 7. Forecast F-35A baseline annual O&M costs

Scenario 2: Annual flying hours reduced to 12,000 from FY 2021–22

In the second scenario, adjustments are made to the baseline analysis by reducing the annual fleet flying hours to 12,000 hours, starting in 2021–22. Figure 8 shows the impact of the reduction. The total O&M costs for 30 years of operations are estimated to be $6.7±1.9B, an expected saving of $2.0B from the baseline. For 20 years of operation, the estimated O&M is $3.1±1.2B. The difference between the baseline O&M forecast and the 12,000-hour result is shown in Figure 9. The expected O&M cost saving can be seen in the highlighted area.

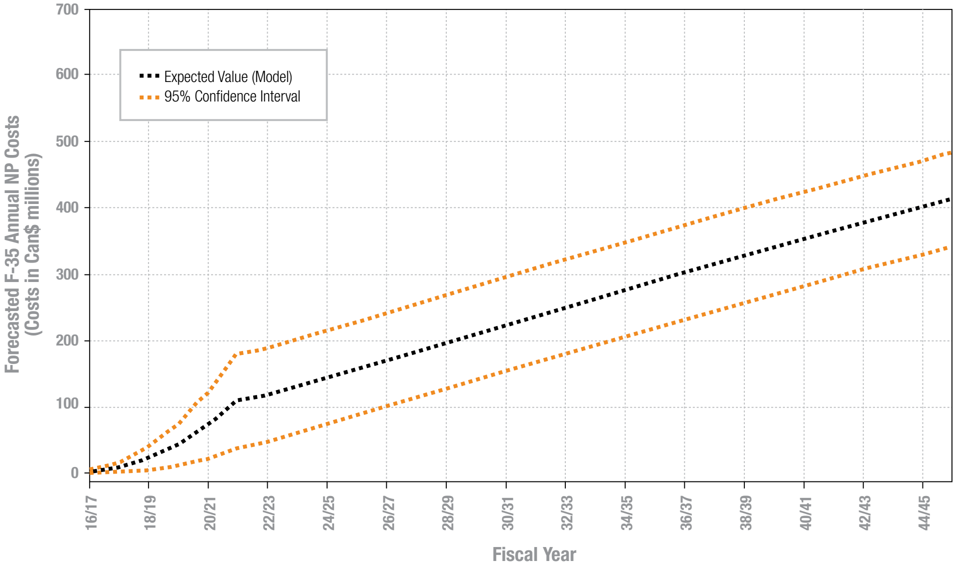

Figure 8. Forecast F-35A O&M costs for 12,000 annual flying hours, starting from FY 2021–22

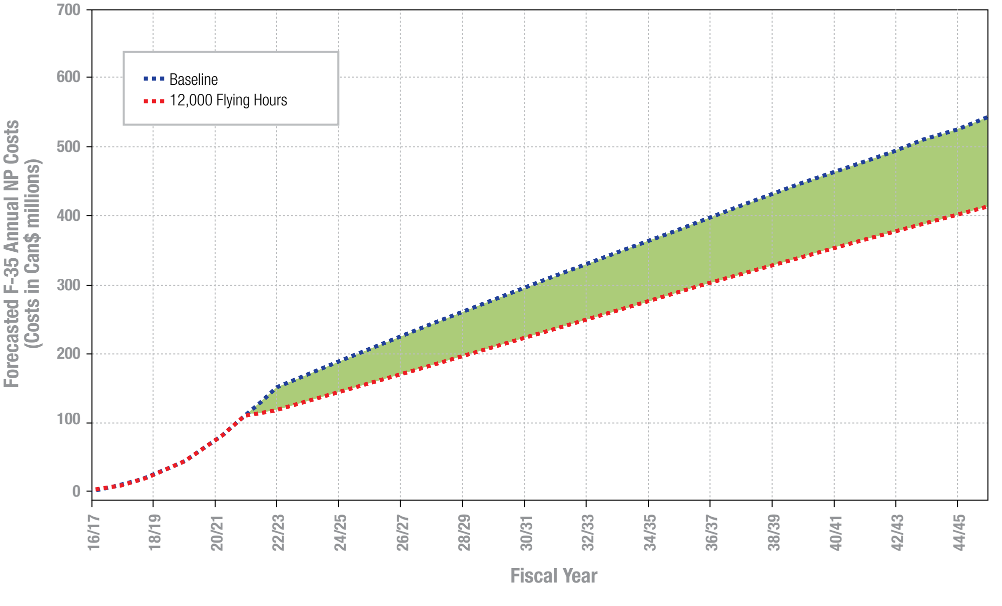

Figure 9. O&M cost comparison between baseline and 12,000 annual flying hours

Scenario 3: Adjustments to unit recurring flyaway (URF) costs

Since the signing in 2006 of the Production, Sustainment, and Follow-On Development of the Joint Strike Fighter Memorandum of Understanding,[43] the US JSF Program Office (JPO) has consistently provided updates relative to the unit recurring flyaway (URF) costs for the 65 F-35A (CTOL variant) aircraft that Canada may choose to acquire. In 2011, a model was developed with the Defence Research & Development Canada (DRDC) Centre for Operational Research and Analysis (CORA) in order to provide the DND Program Management Office with an independent estimate of the average URF costs that Canada will likely pay based on where within the JSF production line Canada will draw its aircraft.[44] Based on a RAND Corporation methodology, the CORA model was used to provide a secondary, independent estimate for URF cost projections based on June 2011 cost estimates and production profile plan.

According to the January 2012 production planning profile,[45] Canada will take delivery of 3, 4, 6, 13, 16, 13 and 10 aircraft during the years from 2016–17 to 2022–23 respectively. Based on the CORA model, the per-aircraft (air vehicle and engine) cost at delivery in US dollars is indicated in Column 2 of Table 9. Column 5 lists the total URF at delivery when converted to Canadian dollars, using 1.050 as the rate of exchange.[46]

Delivery Date	Cost per Aircraft (US$M)	Delivery Schedule	URF (US$M)	URF (C$M)
2016–2017	102.92	3	308.76	324.19
2017–2018	95.10	4	380.41	399.43
2018–2019	93.07	6	558.42	586.35
2019–2020	92.29	13	1199.81	1259.80
2020–2021	92.61	16	1481.71	1555.79
2021–2022	94.18	13	1224.29	1285.51
2022–2023	95.54	10	955.43	1003.20

Table 9. F-35A URF cost estimates (CORA model) adjusted to Canadian FY

Replacing the JPO URF estimates (sensitive data not shown) with the model estimates (Table 9, Column 5) results in an increase of \$0.8B in total capital costs, which amortizes to \$240.6M annually over a 30-year period. When the baseline flying hours are used, Figure 10 shows the impact of the increase in the O&M forecast for the F-35A fleet and the 95% confidence interval. The total O&M costs for 20 and 30 years of operations are estimated to be \$4.2±1.6B and \$9.2±2.5B respectively, for an expected increase of \$0.2B and \$0.5B respectively, from the baseline estimate. The difference in O&M costs is highlighted in Figure 11.

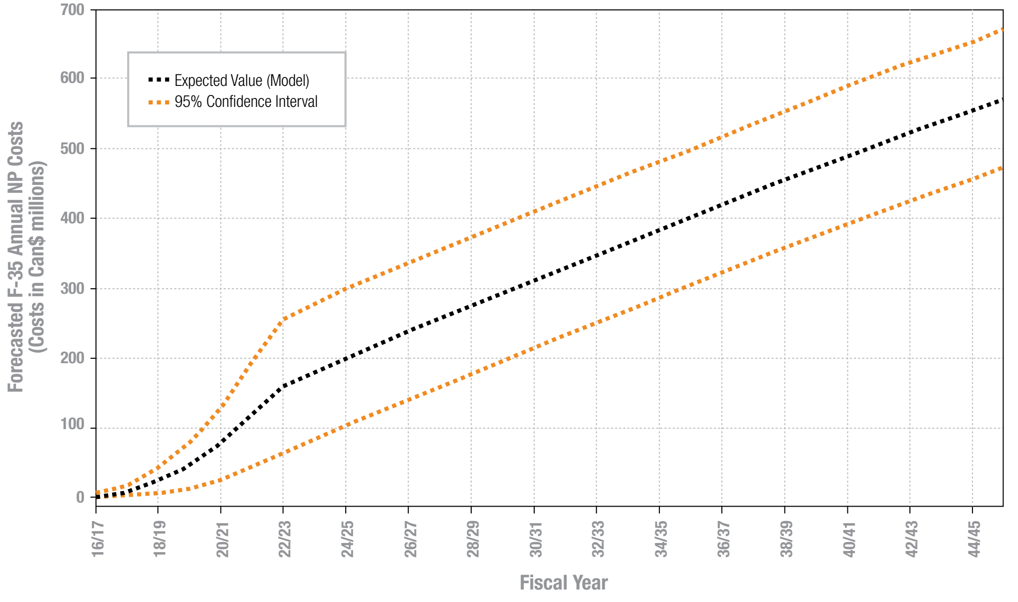

Figure 10. Forecast F-35A annual O&M costs based on the CORA model URF

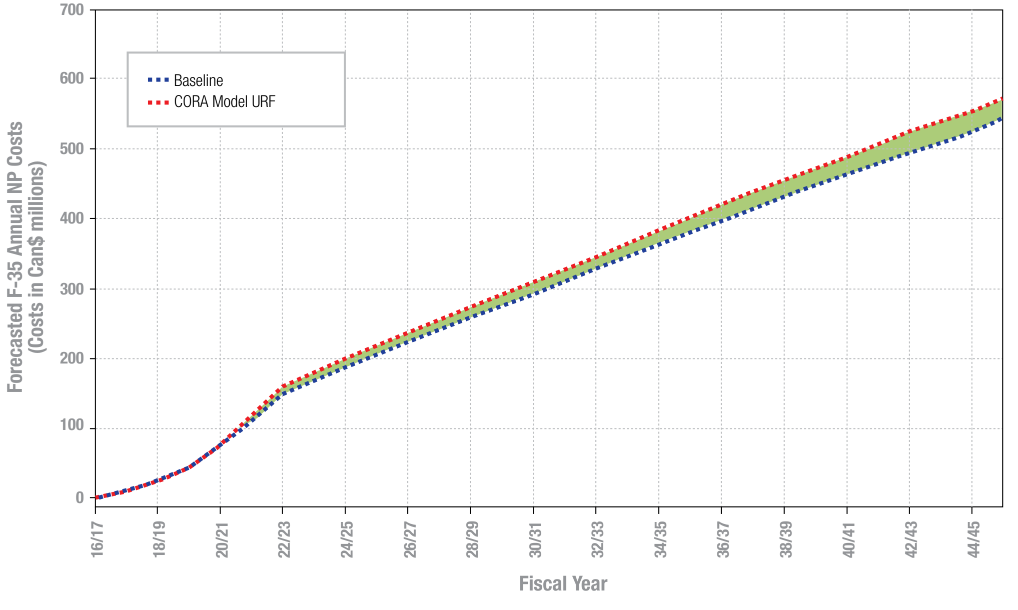

Figure 11. Comparison between baseline and CORA model URF O&M expected value costs

Scenario 4: Adjustments to unit recurring flyaway costs with annual flying hours reduced to 12,000 from FY 2021–22

In the final scenario, adjustments are made to the CORA model URF cost scenario by reducing the annual fleet flying hours to 12,000 hours starting in 2021–22. Figure 12 shows the impact of the reduction. The total O&M costs for 20 and 30 years of operations are estimated to be \$3.3±1.2B and \$7.1±2.0B respectively. Figure 13 highlights the difference in O&M costs.

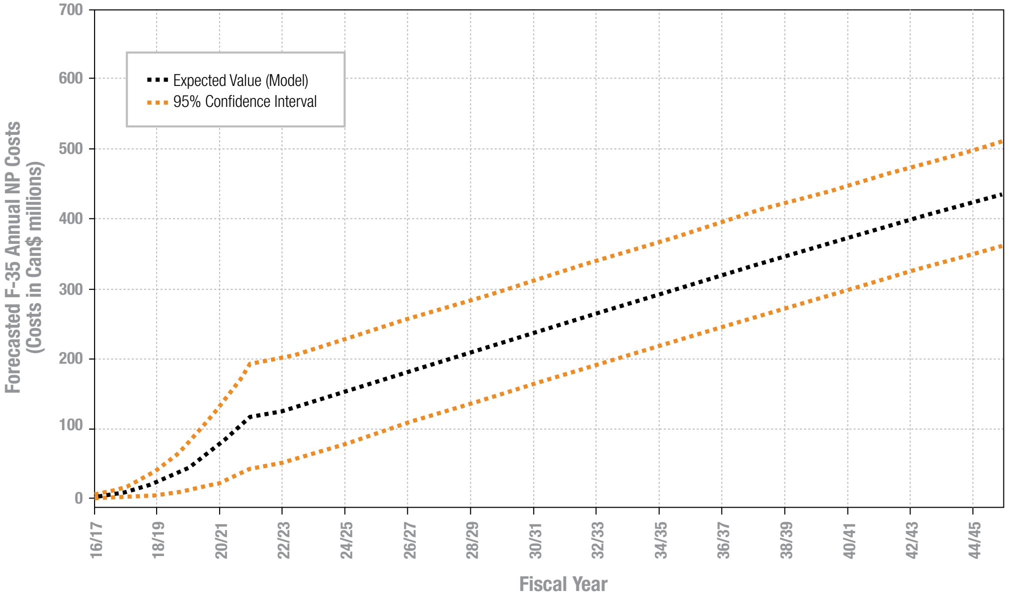

Figure 12. Forecast F3-5A annual O&M costs based on the CORA Model URF and 12,000 annual flying hours, starting from FY 2021–22

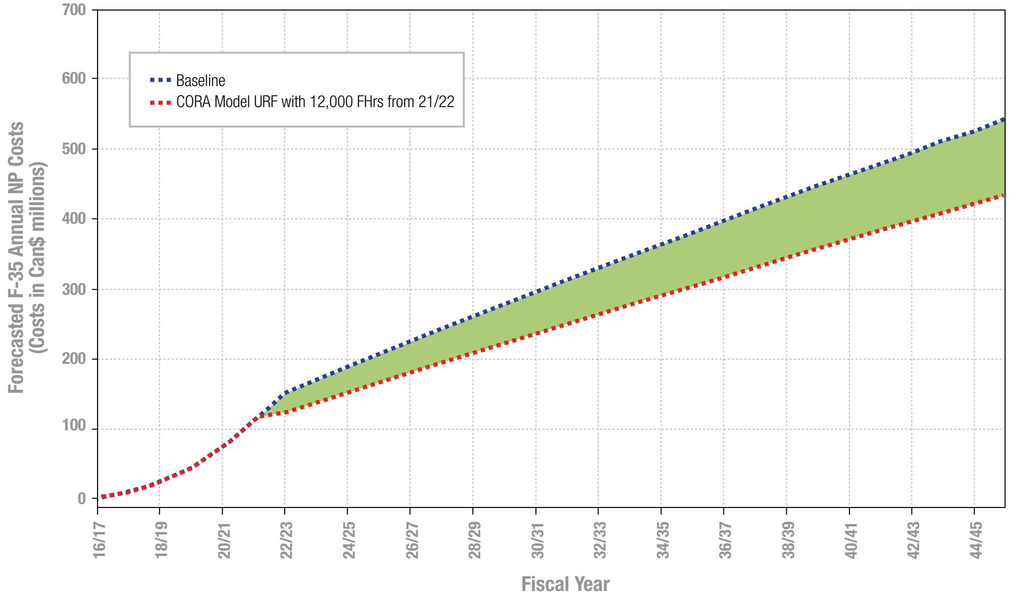

Figure 13. Comparison between baseline and the CORA model URF with 12,000 annual flying hours, starting from FY 2021–22

Conclusions

The objective of this study was to provide the DND Project Management Office with a forecasting model that could be used to estimate annual O&M costs for the 65 F-35A aircraft that Canada may choose to acquire. This report documents an extensive literature search, and includes previous analyses in support of the project, complete datasets (that are unclassified) and analysis thereof, and a forecasting methodology and its application.

In a series of scenarios, annual O&M estimates are provided from first delivery to the end of the estimated life of the fleet (currently 30 years). The model incorporates a sensitivity analysis for changes in baseline flying hours or initial costings, and provides a comparison analysis to determine the impact on baseline adjustments. Each result is specified as an expected value with a 95% confidence interval so that the reader can gauge the upper and lower limits of the O&M forecasts.

The forecasting methodology uses historical O&M and amortized capital costs of the CF18 fleet in a ratio-based approach as a template for forecasting the O&M demand of the F-35A fleet. The results of this analysis, considered to be a high-level, top-down analysis, are based on the assumption that the F-35A fleet fulfills the same mission profiles as the CF18 fleet, i.e., the F-35A fleet cannot take on entirely different missions nor can the frequency of these missions be changed significantly from those of the CF18 fleet.

For the CF18 fleet, aircraft usage in terms of annual flying hours is built into the ratio model as a proxy for fleet size. Also built into the ratio model is average age to account for cost-growth rates as the aircraft age and how those rates might change in the future. A simple regression model was developed, where it was assumed that age causes increases in O&M per flying hours (capital cost is an amortized constant).

As was recently proven for the CF18 fleet,[47] flying hours do not Granger-cause O&M.[48] Consequently, regressing O&M against average age and flying hours did not produce statistically significant results. Other explanatory variables were also not considered. As in the case of the CC130 fleet,[49] no meaningful relationships could be found between spending and 13 high-level performance indicators.

Lastly, the methods shown in this study can be applied to any system, provided there is an analog system from which to draw data to build a forecast. The method has already been applied successfully to the CC130 (Hercules transport aircraft) replacement, the CC130J,[50] and more recently to army vehicles such as the Tactical Armoured Patrol Vehicle (TAPV)[51] and the upgrade to the Light Armoured Vehicle (LAV) III.[52]

In June 2017, Dr. Desmier completed 35 years conducting analysis in support of the Department of National Defence and the Canadian Armed Forces. In that period, he held positions as Deputy Chief of Staff Operational Research and Chief Scientific Advisor to the Commander of Air Command, Director of Operational Research for the Air Staff, and Director of Operational Research for the Materiel Group. He has conducted analyses in many diverse areas, most notably: torpedo dynamics and lethality studies, nuclear EMP (electromagnetic pulse), dynamics of guided missile systems, space-based radar coverage and satellite surveillance, force structure analysis, foreign exchange risk, and cost and schedule risk. Dr. Desmier holds a PhD in Mathematical Physics from McGill University, Montreal, Quebec.

Abbreviations

AR	autoregressive
CAF	Canadian Armed Forces
CORA	Centre for Operational Research and Analysis
CPFH	cost per flying hour
CTOL	conventional takeoff/landing
CV	carrier variant
DND	Department of National Defence
DoD	United States Department of Defense
DOF	degree of freedom
DRDC	Defence Research & Development Canada
ELE	estimated life expectancy
FHrs	flying hours
FY	fiscal year
ISSCF	In-Service Support Contracting Framework
JPO	United States Joint Strike Fighter Program Office
JSF	joint strike fighter
LCol	Lieutenant-Colonel
Maj	Major
MD	mission design
NP	national procurement
O&M	operations and maintenance
O&S	operating and support
Op	Operation
OSCAM	Operating and Support Cost Analysis Model
STOVL	short takeoff/vertical landing
URF	unit recurring flyaway
USAF	United States Air Force
YFR	yearly flying rate

Notes

1. Mike Taylor and Joseph "Colt" Murphy, "OK, We Bought This Thing, But Can We Afford to Operate and Sustain It?" *Defense AT&L: Product Support Issue* (March–April 2012), 17–21, accessed July 23, 2018, http://dau.dodlive.mil/files/2012/03/Taylor_Murphy.pdf.

2. Taylor and Murphy, "OK, We Bought This Thing."

3. Canada, Office of the Auditor General of Canada, *2011 Fall Report of the Auditor General*, Chapter 5 – Maintaining and Repairing Military Equipment – National Defence.

4. US O&S costs in general include operating, maintenance, repair, overhaul and support costs for DoD weapons and equipment, and pay and other benefits for military and civilian personnel. Costs are calculated based on the six major categories of the Cost Assessment and Program Evaluation (CAPE): (1.0) Unit-Level Manpower, (2.0) Unit Operations, (3.0) Maintenance, (4.0) Sustaining Support, (5.0) Continuing System Improvement, and (6.0) Indirect Support (CAPE), "Operating and Support Cost-Estimating Guide," Office of the Secretary of Defense, Cost and Program Evaluation (March 2014, Section 6).

5. Gregory G. Hildebrandt and Man-bing Sze, "An Estimation of USAF Aircraft Operating and Support Cost Relations" (Santa Monica, CA: The RAND Corporation, N-3062-ACQ, 1990).

6. Each aircraft type comprises multiple MDs. For example, fighters contain MDs F-15 and F-16. However, each MD may contain multiple Mission Design Series (MDS), e.g., for the F-15 MD, there are five MDSs: F-15A, F-15B, F-15C, F-15D and F-15E. Because of data reporting structures, the total cost could only be accounted for at the MD level.

7. CPFH factors are derived from historical consumables, spare parts and fuel costs, and formulated through a multi-stage process involving many stages of input and review.

8. John M. Wallace, Scott A. Houser and David A. Lee, "A Physics-Based Alternative to Cost-Per-Flying-Hour Models of Aircraft Consumption Costs" (Fort Belvoir, VA: Defense Technical Information Center, ADA387273, August 2000).

9. Eric J. Unger, "An Examination of the Relationship Between Usage and Operating-and-Support Costs of U.S. Air Force Aircraft" (Santa Monica, CA: The RAND Corporation, TR594AF, 2009).

10. In Canada, O&M costs refer to standard aircraft expenditures, which can be classified under the following headings: spares, consumables, R&O (repair and overhaul), software support, engineering services, rate negotiations (company costing rates plus profit), embodiment fees (cost of parts, plus a negotiated fee for "embodying" the parts into the repair), logistics,

publications, subcontractors, technical/field service representatives, and travel (Lieutenant-Colonel [LCol] F. R. S. Bradley, email message to author, 2011). They do not include other operating costs, such as salaries, fuel and oil.

11. P. E. Desmier, "Forecasting National Procurement Costs for the Next Generation Fighter" (Canada, DND, DRDC-CORA, LR-2011-191, 2011 [Protected A]).

12. A time series is a sequence of measurements of a variable usually made at evenly spaced time intervals. An AR model is when a value from the series is regressed (lagged) on previous values from the same series. Thus, an AR(1) model is lagged one-time step and an AR(2) model is lagged at least two-time steps.

13. Patrick D. Armstrong, "Developing an Aggregate Marginal Cost per Flying Hour Model for the U.S. Air Force's F-15 Fighter Aircraft," PhD thesis (Ohio: Wright-Patterson Air Force Base, Air Force Institute of Technology, 2006).

14. Unger, "An Examination."

15. Captain D. M. Munroe, email message to author, January 6, 2012.

16. Forecast vs. Simulation: A forecast is a likely picture of the future, such as a likely behaviour of future fighter O&M spending trends. A simulation is a likely picture of the future fighter O&M spending trend if the future fighter force behaves in a predetermined way. Simulation can be used for testing forecasting techniques and for measuring their performances over complex scenarios.

17. M. Mertz et al., "Using the Operating and Support Cost Analysis Model (OSCAM) to Support Total Ownership Cost Estimates" (Alexandria, VA: American Society of Naval Engineers, August 30, 2011).

18. Major (Maj) R. A. Groves, "Defence Economic Trends Contributing to Rising Costs in the O&M Program," Internal Memorandum, November 29, 2006.

19. A. Sokri, "Forecasting the Life Cycle Costs of Military Equipment with Application to the CP140A Arcturus" (Canada, DND, DRDC CORA, TN 2009-029, July 2009).

20. Victoria A. Greenfield and David M. Persselin, , "How Old is Too Old? An Economic Approach to Replacing Military Aircraft," *Defence and Peace Economics* 5, no. 14 (2003): 357–68.

21. Eric Peltz et al., "The Effects of Equipment Age on Mission-Critical Failure Rates: A Study of M1 Tanks" (Santa Monica, CA: The RAND Corporation, MR-1789-A, 2004).

22. Raymond A. Pyles, "Aging Aircraft: USAF Workload and Material Consumption Life Cycle Patterns" (Santa Monica, CA: The RAND Corporation, MR-1641-AF, 2003).

23. Hildebrandt and Sze, "An Estimation."

24. The bathtub curve is used in reliability engineering to illustrate the rate of early decline in failures when an aircraft is first introduced, then a stable constant rate during its mid-life period, and lastly the rate of increase in failures during the wear-out period as the aircraft exceeds its design lifetime.

25. Matthew Dixon, "The Maintenance Costs of Aging Aircraft: Insights from Commercial Aviation" (Santa Monica, CA: The RAND Corporation, MG-486-AF, 2006).

26. P. Bergeron, email message to author, August 4, 2011.

27. Using 4.0% as a discount factor yielded $4.368B in total discounted capital costs. If we had used the percentage change in Gross Domestic Product (GDP) (see Statistics Canada, "Table 30: Implicit Price Indexes, Gross Domestic Product," accessed July 23, 2018, http://www.statcan.gc.ca/pub/13-019-x/2011003/t/tab0030-eng.htm as the discount factor, the total discounted capital costs would have been $4.835B, a difference of less than 10%.

28. In addition, the values for 2009–10 and 2010–11 were not considered "stable" enough to be used in a forecasting application. See LCol. F. R. S. Bradley, email message to author, September 9, 2011.

29. Autocorrelated error simply means that there is a *systematic* relationship between the error terms that has not been accounted for. This is most noticeable in time series data, because time introduces a systematic impact on each successive term. The goal is to recognize its existence and account for it in the model.

30. It is noted that the analysis is using 18 data points to backcast 9 years of past expenditures. Given that there were only annual data available, structural changes, if any, within the years would not be captured by the aggregate.

31. Violations of normality cause problems when determining whether model coefficients are significantly different from zero and when calculating confidence intervals. Extreme observations can exert excessive influence on parameter estimates and cause confidence intervals to be too wide or too narrow.

32. Nancy R. Mann, Ray E. Schafer and Nozer D. Singpurwalla, *Methods for Statistical Analysis of Reliability and Life Data*," Wiley Series in Probability and Mathematical Statistics (New York: Wiley, 1974); and R. R. Zylstra, "Normality Tests for Small Sample Sizes," *Quality Engineering* 7, no. 1 (1994): 45–58.

33. Univariate models, sometimes called *naive* or *projection models*, are based on fitting a model only with present and past observations without taking into account any other economic factors. Conversely, multivariate models are dependent on one or more additional data series, called predictor or explanatory variables. Models of this type are sometimes called *causal models*.

34. Jurgen A. Doornik and Henrik Hansen, "An Omnibus Test for Univariate and Multivariate Normality," *Oxford Bulletin of Economics and Statistics* 70, issue supplement s1 (2008), 927–39.

35. The formulae break down for ≤ 7 observations.

36. Doornik and Hansen, "An Omnibus Test."

37. Doornik and Hansen, "An Omnibus Test."

38. D. W. Maybury, "O&M Spending Correlations with Flying Hours for the CC130 and CF188 Fleets" (Canada, DND, DRDC CORA, LR 2011-209, 2011).

39. D. W. Maybury, "A Random Matrix Theory Approach to National Procurement Spending – Applications to the CC130 Hercules Fleet Performance" (Canada, DND, DRDC CORA, LR 2010-168, 2010).

40. George C. S. Wang and Chaman L. Jain, *Regression Analysis Modelling and Forecasting* (Great Neck, NY: Graceway Publishing Company, 2003).

41. Fleet size and flying hours are constant from 2023–24. Also, as for costs, the delivery schedule and fleet flying hours have been adjusted for the fact that the US fiscal year starts on October 01 and ends on September 30.

42. Traditional refers to standard aircraft O&M expenditures, which can be classified under the following headings: spares, consumables, repair and overhaul (R&O), software support, engineering services, rate negotiations (company costing rates plus profit), embodiment fees (cost of parts, plus a negotiated fee for "embodying" the parts into the repair), logistics, publications, subcontractors, technical/field service representatives, and travel (Bradley, 2011).

43. JSF Program Office, "The Production, Sustainment, and Follow-On Development of the Joint Strike Fighter," 2010, accessed July 23, 2018, .http://www.jsf.mil/downloads/documents/JSF_PSFD_MOU__Update_4_2010.pdf.

44. Bohdan N. 0. Kaluzny, "The Unit Recurring Flyaway Cost of a Canadian Joint Strike Fighter" (Canada, DND, DRDC CORA, TM 2011-200, 2011).

45. A. Turpin, email message to author, January 19, 2012.

46. Turpin, email message to author.

47. Maybury, "O&M Spending."

48. The number of flying hours is said to "Granger-cause" O&M if it can be shown that the values of flying hours provide statistically significant information about future values of O&M. In this case, the forecast of O&M spending could not be improved using flying hours as an explanatory variable.

49. Maybury, "A Random Matrix."

50. P. E. Desmier, "A Comparison Between Legacy National Procurement and In-Service Support Contracting Framework for the CC130J Super Hercules Aircraft" (Canada, DND, DRDC CORA, TM-2013-151 [Protected A], 2013).

51. P. E. Desmier and Maj J. L. D. Rioux, "Forecasting National Procurement Costs for the Tactical Armoured Patrol Vehicle" (Canada, DND, DRDC-RDDC-2015-R102 [Protected A] 2015).

52. Desmier and Rioux, "Forecasting National."

CH07

The Canadian Aerospace Industry: An Important Segment of the Defence Industrial Base

J. Craig Stone

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Introduction

The Canadian aerospace industry is an important part of the Canadian economy and continues to be a significant subset of the Canadian defence industrial base. According to data from the most recent survey and analysis by Innovation, Science and Economic Development Canada (ISED), the industry contributed more than $28B to Canada's gross domestic product (GDP) and more than 200,000 well-paid jobs.[1] Since there are a number of additional procurement projects related to the Royal Canadian Air Force (RCAF) remaining on the horizon, many might argue that the future looks promising; however, Canada's aerospace industry and particularly those firms associated with the defence sector have historically been subject to cyclical patterns of defence investment.

This chapter will provide an assessment of Canada's aerospace industry in 2016, with particular emphasis on the structure of the industry and its economic impact and outlook for the future. The chapter will begin first with some basic data on the overall Canadian defence industrial base in order to situate the aerospace industry within the broader context.[2] Further on, the chapter will provide a brief review of some of the latest research dealing with the aerospace industry in Canada, followed by the most recent results of the 2014 Industry Canada and Aerospace Industries Association Survey conducted by Statistics Canada. Lastly, the chapter will outline some of the challenges facing the industry in the future and how that may impact the RCAF.

The Defence Industry in Context

The Deloitte *2016 Global Aerospace and Defence Outlook* states that after several years of declining growth, there is an expectation of increased growth in 2016.[3] While the reduction in growth was attributed to a decline in spending in the past few years within the United States (US) defence sector under sequestration, the expected growth for 2016 will result from an expected increase in US defence spending. The outlook for the commercial aerospace sector remains positive, particularly since passenger volume in developing nations is expected to continue growing. Growth in this sector is good news for Canada, since most of its aerospace activity is in the commercial rather than the defence sector. Within the broader defence sector, rising tensions around the world will persuade a number of nations to increase their defence budgets.[4] According to the *Defense Outlook 2017* by McKinsey & Company, defence executives expect the Middle East and Asia-Pacific regions to post the most growth in defence spending.[5]

The most recent information on Canada's aerospace and defence industry comes from survey data gathered by ISED in conjunction with the Aerospace Industries Association of Canada (AIAC) and the Canadian Association of Defence and Security Industries (CADSI) in 2014. The results of this survey were included in two reports that were released: one on the aerospace industry and one on the defence industry.[6] The results from the surveys confirm that both the aerospace and defence industries in Canada are "high-wage, export-intensive, technology-rich, and pan-Canadian."[7] Positive comments like this are what can and should be expected from associations representing Canada's aerospace and defence industries. The results of past surveys for the defence industry, although not carried out consistently and often using different assumptions and parameters, indicate that the statement about the quality and types of jobs is valid in a general sense.

However, an important issue is whether or not the results of the 2014 survey are reflective of the industries over time or just a momentary increase in impact based on some recent aircraft purchases by the RCAF and the Canadian Armed Forces (CAF) engagement in Afghanistan.[8] Table 1 provides some data from studies done in the late 1980s, and during the 1990s and 2000s, as well as data from the most recent 2014 study.[9] The data in Table 1 show wide disparities in impact and numbers of jobs over time. This is partly a data-collection issue and partly an issue of the cyclical nature of defence spending. For example, the Aerospace and Defence-Related Industries Statistical Survey Report 1995 reports on actual data from 1984 up to 1994, and then provides estimated data up to 1999; but, this data is gathered and presented as total sales, gross output, net sales, and value added, rather than presented in relation to GDP. In contrast, the more recent studies by CADSI and ISED on the impact of the defence industry and the aerospace industry contain data relative to industry sales as a contribution to GDP. In addition, these more recent studies provide data on how that contribution is divided between direct, indirect and induced effects—information that was not always provided in previous studies.

Year	Study	Contribution to GDP or Revenues	# of Jobs
1987	John Treddenick, Centre for Studies and Defence Resource Management, Kingston	$8.3B	88,830
1990	Aerospace and Research Branch, Industry Canada	$9.1B	65,679
1996	Canadian Defence Industries Association (CDIA)	$5.5B	50,227
2000	CDIA	$6.9B	57,851
2013	KPMG	$9.0B	109,000
2014	CADSI / ISED	$6.7B	63,000

Table 1. Impact of the defence industry over time[10]

An additional complication in trying to determine the long-term trends in the success or continued growth and expansion of Canada's defence industry is that in 2016, it is more complicated than in 1990 to determine who belongs to the defence industry. The KPMG study actually contains data for the defence and security industry rather than just for the defence industry. The Canadian Defence Industries Association (CDIA) changed its name to the Canadian Association of Defence and Security Industries in 2001 to better reflect the reality of the growing overlap of defence- and security-industry activity.[11]

More problematic is the inconsistent attention to gathering data consistently over time in order to make evidence-based assessments of the overall state of Canada's defence industrial base. While the recent data indicate that the economic impact is substantial in specific areas, having access to long-term consistent data would help the government make informed decisions on issues such as where future growth should be encouraged but needs investment, where research and development by government can help industry, and where sustainment challenges for key national security capabilities are at risk, to name just three of many areas.[12] What is clear when reviewing data gathered in the 1980s and 1990s is that there are years when industry sales and revenues fell, industry employment fell, and industry contributions to GDP decreased. What is not clear is whether there is a direct correlation with the level of defence spending, the level of capital investment from defence spending, and increases or decreases in defence industry activity. If there is a correlation, it is not clear which sectors of the industry are impacted the most.

Despite the challenges related to long-term data, the most recent studies on the defence industry provide ample evidence that the sector is significant. When expected spending on CAF investments in new fighter aircraft and ships is added to the mix, the prospects for future growth are very positive. Tables 2 to 4 highlight the key information from the most recent 2014 survey on the state of Canada's defence industry.

	Jobs	GDP
Direct Defence Industry Impacts	27,975	3,067,184,125
Indirect Impacts in the Broader Economy	19,927	2,020,969,360
Induced Impacts in the Broader Economy	14,831	1,581,087,608
Total Impacts Across the Economy	62,733	6,669,241,093

Table 2. Estimated economic impact of the defence industry[13]

		2011 Estimates	2014 Estimates
(a)	Defence Industry Total Goods and Services (G&S) Sales ($B)	9.42	9.93
(b)	Defence Industry G&S Exports ($B)	4.64	5.95
(c)	Total GDP Impact in the Canadian Economy that Resulted from (a)	5.99	6.67
(d)	Defence Industry Research and Development (R&D) ($M)	251	N/A
(e)	Defence Industry Direct Jobs (000s)	26.54	27.98
(f)	Total Jobs Impact in the Canadian Economy that Resulted from (a)	63.55	62.73

Table 3. Summary of defence industry basic industrial metrics and their impact on the broader economy[14]

Within the direct industry impact data highlighted in Table 2, it is important to note that, although most of the firms involved in the industry (more than 90%) have fewer than 250 employees, most of the sales and exports (over 80% of sales and 90% of exports) are generated by larger firms with more than 250 employees.[15] Moreover, of the $10B in sales of G&S highlighted in Table 3, almost 60% or $6B was exported outside of Canada. The 2014 survey noted that this was an increase in exports of more than 20% from the last survey in 2011, and it continued to be generated primarily by firms with more than 250 employees.[16] This is consistent with and supports the point made by Solomon that the Canadian defence industrial base, although export dependent, is efficient enough to compete internationally in the defence market.[17] It also highlights the challenge faced by most Canadian firms, i.e., that Canadian defence spending alone is not significant enough to keep them in business, and they need export sales and revenue to stay in business.

Table 4 highlights the regional distribution of defence industry employment across Canada. Canada's two largest provinces—Ontario and Quebec—also have the largest percentage of defence industry employment, i.e., 68% of the total employment across the country.[18] That employment focuses on a broad range of G&S, with each of the regions in Canada having expertise in particular sectors of the industry. Table 4 shows the top 5 defence industry activities in each region. Maintenance, repair and overhaul (MRO) activities are carried out across the country, and are a key factor in the sustainment and support of military capability. More importantly for the aerospace focus of this chapter is that 47% of the total industry sales and 48% of exports are in the air and space domain.[19]

	Estimated Regional Distribution Of Defence Industry Jobs (2014)%	Top Five Defence Industry Activities in 2014
Atlantic Canada	17	1. Military aircraft MRO 2. Naval ship MRO 3. Naval ship-borne systems (i.e., mission systems) and components 4. Combat vehicles and related MRO, and "Other Defence" 5. Aircraft fabrication, structures and components
Quebec	24	1. Combat vehicles and related MRO, and "Other Defence" 2. Firearms, ammunition, missiles, rockets and other munitions and weapons 3. Military aircraft MRO services 4. Airborne communications, navigation and other information systems, software and electronics 5. Aircraft fabrication, structures and components
Ontario	44	1. Combat vehicles and related MRO, and "Other Defence" 2. Airborne communications, navigation and other information systems, software and electronics 3. Aircraft manufacturing, structures and components 4. Airborne sensor/information collection, and fire control, warning and countermeasures systems 5. Land/man portable sensor/information collection, and fire control, warning and countermeasures systems
Western and Northern Canada	15	1. Military aircraft MRO services 2. Naval ship fabrication, structures and components 3. Aircraft fabrication, structures and components 4. Combat vehicles and related MRO, and "Other Defence" 5. Naval ship-borne systems (i.e., mission systems) and components
Total	100	

Table 4. Industry employment by region[20]

Aerospace Industry in Canada

Recent studies of Canada's aerospace industry have found that Canada is "among the leading aerospace nations in the world," and that its industry is the 5th largest in the world, and 2nd largest relative to its size.[21] A Conference Board of Canada report prepared for the Emerson Aerospace Review by Alan Arcand notes that aerospace is a key sector of the economy, and "the sector's share of global aerospace activity is greater than the country's share of global gross domestic product."[22] When measured against GDP, Canada's economy is the 14th largest, which means Canada is punching above its weight in the aerospace sector.[23] Arcand also says that the aerospace industry in Canada "is dominated by a small group of large companies, and the largest— Bombardier Inc.—is one of 9 companies that control over 95 % of global civilian aerospace revenue."[24]

In its description of Canada's aerospace sector, the Emerson Review notes that the sector employed about 40,000 people in 1938 and produced 40 planes per year; whereas, today, Canada's "700 aerospace companies generate $22B in annual revenue" and employ 66,000 people.[25] When looking at where economic activity within the sector occurs, it is important to know that, although aerospace companies are scattered across Canada, Montréal has the largest concentration of them. The Conference Board assessment by Arcand states that Montréal is "considered to be one of the three world-class aerospace centres in the world, along with Toulouse (France) and Seattle (US)."[26] The report goes on to say that "Montréal is also one of the few places in the world where an entire aircraft can be assembled using parts sourced from within a 30-mile radius."[27]

The working group report on supply chain development that was completed for the Emerson Aerospace Review devoted considerable time to discussing the structure of Canada's aerospace industry and where Canadian firms fit within the broader global industry supply chain. Figure 1 shows how the market is structured. Examples of original equipment manufacturers (OEMs) in Canada are Bombardier, Bell Helicopter and CAE, with Tier 1 companies such as Pratt & Whitney and Thales providing OEMs with engines (in the case of Pratt & Whitney) and complete systems.

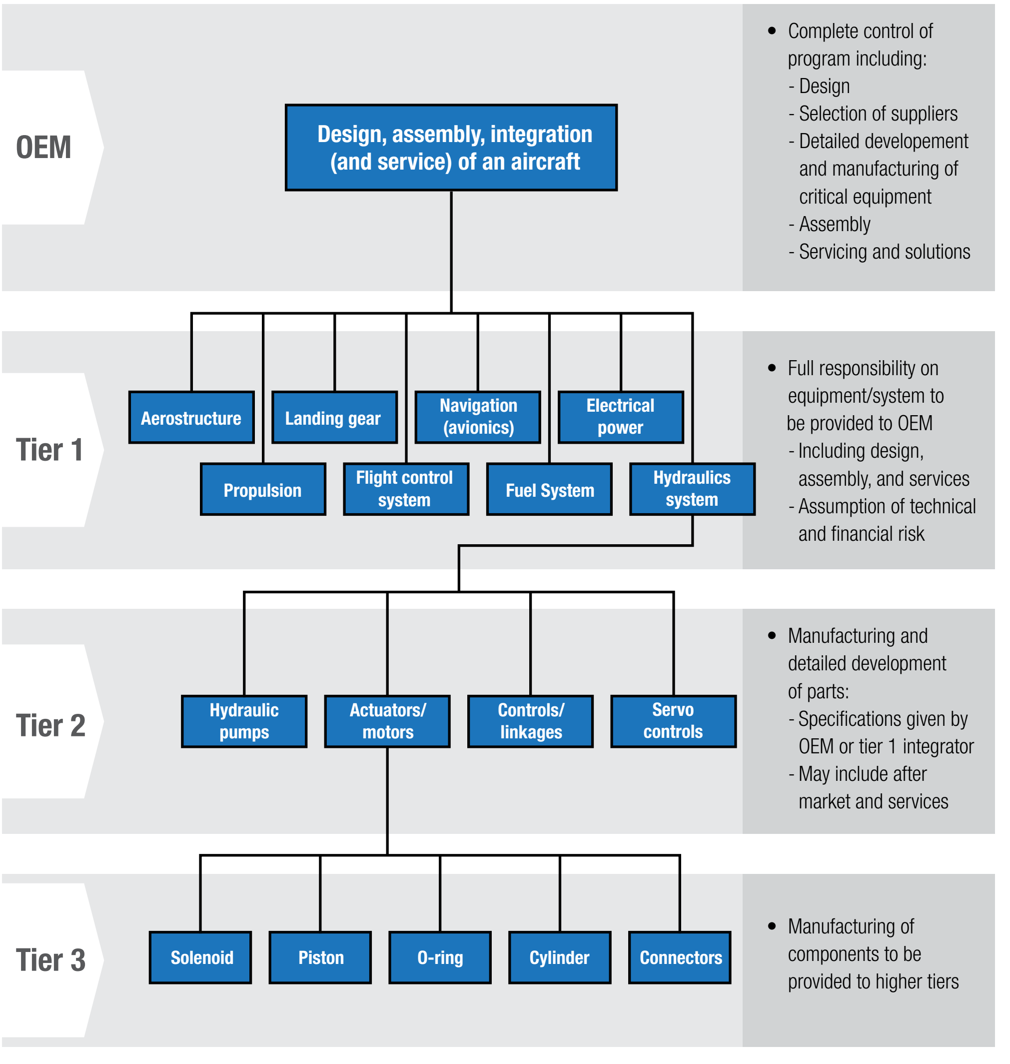

Figure 1. Tier structure of the Canadian aerospace industry for production of an aircraft[28]

Despite the success implied above, it is important to remember that Canada's aerospace industry is not the same as that of most other nations. In most global competitor nations, the defence sector of the aerospace industry plays a much larger role. In Canada's case, aerospace operates primarily within the civilian sector, and our defence activity is significantly less. For example, Arcand noted that "military-related activity accounted for less than 17 % of total revenues in 2009 and is largely export based."[29]

The data in Table 5 demonstrate the significance of Canada's aerospace sector to the Canadian economy. Employment and economic impact are presented as aerospace manufacturing or aerospace MRO. When compared with the defence industry data provided in Table 2, which includes firms with defence aerospace business, the aerospace industry is significantly larger, almost three times larger in terms of economic impact and employment. It is clear from the data that most of Canada's aerospace industry is focused on the commercial rather than the defence sector. However, it is the government's early involvement in the defence sector that has helped companies achieve success in the commercial sector. The Jenkin's report on key industrial capabilities highlights the success of CAE when making the point that

> the role of the government as customer in building an innovative defence industry is key, and the proof is that virtually every successful company in Canada's defence sector today—several of which also have large commercial businesses—got its start with a Government of Canada contract. The first contract is vital, not only in refining the cost and performance characteristics of any new or improved product, but also to validate it beyond the domestic market. In fact, the Panel did not find any example of a successful Canadian defence supplier of scale, the creation of which was "self-generated" under regular market forces.[30]

	Impact on Canadian GDP ($millions)				Impact on Canadian Employment (persons)			
	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
Aerospace Manufacturing	9,461	5,492	4,435	19,388	57,663	43,146	34,118	134,927
Aerospace MRO	3,800	3,188	2,081	9,069	31,298	28,758	16,832	76,888
Aerospace Total	13,261	8,680	6,516	28,457	88,961	71,903	50,950	211,814

Table 5. Economic and employment impacts of Canadian aerospace, 2015[31]

The issue of scale is important for a country such as Canada. As indicated earlier, Canada is having a greater impact in the sector than the size of its overall economy might imply, and close to 80% of aerospace manufacturing is exported.[32] Table 6 shows the regional distribution of Canada's exports, as well as how exports have increased in the past 5 years. Not surprisingly, the data in Table 6 show that most of Canada's aerospace manufacturing exports go to the US (60% in 2015) and increased by 77% during the 2010–15 time frame.

	Share of Total Exports (2015)	Growth of Exports (2010–15)	Growth of Exports (2014–15)
United States	60%	77%	15%
Europe	21%	14%	20%
Asia Pacific	12%	105%	23%
South and Central America	3%	9%	- 5%
Middle East	2%	- 8%	- 43%
Africa	2%	11%	- 1%

Table 6. Share and growth of aerospace exports by region, 2010–15[33]

The data in Table 6 also show the inconsistency of exports around the world, with negative growth in some regions and positive growth in others. This inconsistency also applies to broader issues related to economic impact and employment. Data in the *State of Canada's Aerospace Industry, 2016* study also indicate that although revenues increased from $27.7B to $29.8B between 2014 and 2015, employment dropped from 90,381 to 88,961, R&D spending decreased from $1.93B to $1.91B, and the impact on GDP was a decline from $13B to $13.3B.[34] More specifically, the reductions are primarily in the aircraft manufacturing sector rather than the aircraft MRO sector. If we recall that Canada is a bigger player in the commercial aerospace market than in the defence market, inconsistencies in the commercial marketplace could have a greater-than-otherwise-expected impact on Canadian small- or medium-size enterprises (SMEs).

One final aspect of the aerospace sector that is useful to look at prior to focusing more specifically on the defence aspects of aerospace is the regional distribution of industry employment. Much like the broader defence industry data highlighted in Table 4, the aerospace industry is also nationwide in its representation across the country. As in the defence industry, the largest percentages are in Quebec and Ontario, but Western and Atlantic Canada are also represented, and the type of activity varies, depending on the region. Table 7 provides data on the distribution of aerospace manufacturing and aerospace MRO in 2014.

Region	Aircraft Manufacturing (%)	Aerospace MRO (%)
Atlantic Canada	4	14
Quebec	55	18
Ontario	24	27
Western Canada	16	44

Table 7. Share of aerospace industry employment by region[35]

The aerospace defence industry accounted for 17% of all aerospace sales in 2014. By comparison, 80% of aerospace sales were in the commercial sector and 3% of sales involved commercial space systems. Notwithstanding the relatively small percentage of overall aerospace sales, aerospace defence industry sales accounted for almost half of all defence industry sales in 2014.[36] The data in Table 8 show that the same applies to export activity: the defence aerospace industry accounts for nearly half of exports in the defence industry.

	Aerospace	Marine	Land and Cross-Domain / Other
Sales	47	13	40
Exports	48	10	42

Table 8. Shares of total defence-industry sales and exports by domain[37]

Within the defence aerospace industry, more than 75% or $3.5B out of $4.64B in sales came from MRO and avionics, sensors, airborne electronics and simulation systems rather than actual aircraft platforms. Tables 9 and 10 provide data on aerospace defence sales by type of G&S. While Table 9 provides data on aerospace defence sales and the percentage of those sales in relation to the overall aerospace industry, Table 10 provides data on aerospace defence sales and the percentage of sales within the aerospace defence industry. Two significant issues emerge in the data.

First, MRO activities are a significant portion of aerospace defence sales both in value and as a percentage of sales. This is one of the main reasons why defence industry officials and their associations advocate for ensuring that Canadian firms are given due consideration in selecting and awarding procurement contracts. It helps Canadian industry firms to develop (as necessary) and maintain the technical skills and capability to provide through-life support services for military equipment, thus enabling them, in theory, to be competitive in the global marketplace.[38] As mentioned earlier, because the amount of defence spending in Canada is limited, the only way to remain economically viable is to be successful in the global marketplace.

	Aerospace Defence Sales by Value ($B)	Defence Share of Overall Aerospace Sales (%)
MRO services	2.0	46
Avionics, sensors, airborne electronics and simulation systems	1.5	57
Aircraft platforms structures, propulsion and parts	1.01	5
Space systems	.09	11
Unmanned aerial systems/vehicles (UAS/V) and components	.04	68

Table 9. Canadian aerospace defence distribution of aerospace activities, 2014[39]

	Aerospace Defence Sales by Value ($M)	Share of Overall Aerospace Defence Sales (%)
MRO services	2,001	43
Aircraft fabrication, structures and components	1,012	22
Airborne communications, navigation, other information systems, software, electronics	765	17
Airborne sensor/information collection, and fire control, warning and countermeasures systems	578	12
Simulation systems for aircraft	153	3
Military space systems	90	2
UAS/V and components	40	1
Total Aerospace Defence Sales	4,639	100

Table 10. Canadian aerospace defence sales by type of G&S, 2014[40]

Second, aircraft manufacturing is only 22% of defence sales, which is much lower than in the commercial aerospace sector. Nevertheless, it is important to remember that our strength in aircraft manufacturing in the commercial sector has also given industry firms an opportunity to apply those skills to the provision of MRO services in both the defence and commercial sectors. As shown in Table 11, the aerospace MRO component of the aerospace industry posted consistent growth in GDP (except in 2013), employment, revenues and R&D from 2010 to 2015. Skills acquired in this sector allow Canadian firms to compete in the provision of support for Canadian defence requirements. Again, the implication is that Canadian aerospace firms need export opportunities to remain successful. Government policies must support and promote opportunities for future growth and economic benefits to accrue to Canada and Canadian aerospace firms.

		2010	2011	2012	2013	2014	2015
GDP ($M)	Aerospace Manufacturing	8,493	8,610	8,974	9,485	9,976	9,461
	Aerospace MRO	3,048	3,266	3,348	3,322	3,520	3,800
	Aerospace Total	11,541	11,876	12,322	12,807	13,496	13,261
Employment (persons)	Aerospace Manufacturing	52,801	54,067	56,648	58,079	60,139	57,663
	Aerospace MRO	24,837	27,050	28,542	28,695	30,242	31,298
	Aerospace Total	7,7638	81,117	85,190	86,774	90,381	88,961

		2010	2011	2012	2013	2014	2015
Revenues ($M)	**Aerospace Manufacturing**	13,953	16,147	15,860	17,926	20,310	22,179
	Aerospace MRO	6,078	6,620	6,985	7,022	7,401	7,659
	Aerospace Total	20,031	22,767	22,845	24,948	27,711	29,838
R&D ($M)	**Aerospace Total**	1,552	1,662	1,837	1,988	1,936	1,914

Table 11. Canadian aerospace industry economic activities, 2010–15[41]

Future Challenges

Canada's aerospace industry is at an important juncture. Despite its success in the past and its current strength, there are several areas of concern in the future. The Emerson Aerospace Review highlighted a number of challenges, which, when combined with some other assessments, could be associated with four broad interrelated issues: globalization, consolidation, competition, and government support.[42]

Globalization

In his report to the aerospace review, Jorge Niosi noted that although Canada ranks fifth in the global civil aerospace industry, based on sound policies implemented by government in the past half century, the rise of new competitors will create future challenges. He states:

> Canadian producers lack critical mass, yet they need to enter emerging country markets (host of future competitors) with advanced new products. An examination of Canada's aerospace innovation policies compared with other OECD [Organization for Economic Co-operation and Development] countries finds that some areas of research (composite materials) and some policies, namely cluster policies could be improved by adding support to cooperation among existing companies, universities and government laboratories in Canada's aerospace clusters, and by providing support to graduate studies and research within and among the same clusters.[43]

This assessment is consistent with the views of others when one looks at the challenges associated with globalization and the future of aerospace activities in Canada. For example, the Jenkins report on innovation submitted to the government noted that a common refrain from SMEs was that "innovation support is too narrowly focussed on R&D—more support is needed for other activities along the continuum from ideas to commercially useful innovation."[44] PricewaterhouseCoopers (PWC) stated in its sectoral analysis that "the outlook for aerospace-related economic output (i.e., value-added terms in 2005 prices) in this country is weak compared to other leading countries."[45] Aerostrategy Managing Consultants, in discussing Globalization 2.0, stated that many Tier 1 suppliers in taking on responsibility for sourcing parts and components for their own systems, are setting up manufacturing facilities in lowcost locations such as Mexico.[46]

Despite the expected increased global demand, the countries where the demand is expected—BRIC countries (Brazil, China, India and Russia), for example—will want to promote their own aerospace industries and will insist that firms establish production facilities on site. This will provide growth opportunities for successful Canadian companies but will not necessarily create jobs in Canada.

Another aspect of the globalization issue for Canada is that the limited number of OEMs in Canada are also moving some of their global manufacturing operations to lower-cost locations. The same AeroStrategy report discussed above noted that Bombardier had set up a facility in Mexico for a number of reasons, one of which was "access to a low-cost, dependable, and skilled labor force."[47] This issue of globalization is also interlinked with consolidation and competition challenges. Competition in the global market propels some of the initiatives to move facilities to lower-cost labor-force markets.

Consolidation

One of the issues identified by the Emerson Aerospace Review was the challenge that Canadian industry will face as OEMs consolidate their supply chains. Emerson notes as follows:

> To reduce the risk and cost of managing their supply bases, airframe manufacturers are moving from a business model with many direct supplier relationships to one where they partner with fewer tier 1 integrators. In turn, the tier 1 integrators are adopting the same model and reducing their supply bases by choosing fewer tier 2 suppliers. This is leading to the concentration of aerospace work with fewer tier 1 and 2 firms.[48]

When viewed in the context of establishing production facilities abroad to ensure future orders, this type of consolidation could have a significant impact on Canada's SMEs at the Tier 2 and Tier 3 levels of the supply chain. For example, Bombardier used 130 suppliers to produce its CRJ 700, 900, 1000 series aircraft in 2001, but is using 30 to produce its C Series aircraft.[49]

For the RCAF, the longer-term impact of globalization and consolidation, if the trends continue, is likely to be a more limited number of firms in Canada able to conduct MRO activities. The potential outcome would be bigger budgets required for higher maintenance costs (lack of competition), repair activities having to be sent abroad, and allowances having to be made for longer periods of time without equipment. All of these issues will have an impact on the RCAF's capabilities and readiness levels to meet government requirements.

Competition

In the global context, both of the first two issues set the stage for increased competition. Increased demand expected in other parts of the world will lead to national players competing for their own country's business. Based on past practice, this will be particularly difficult in the aerospace defence sector because nations use national security exemptions to protect their own industries. But even in the commercial aerospace sector, there will be challenges from new players. Arcand notes that China, Russia and Japan are all targeting the regional and single-aisle jet market.[50] This could put additional pressure on Bombardier and its supply chain in Canada, particularly, for example, if COMAC, the Chinese manufacturer is successful in obtaining one-third of the market share in its domestic market.[51]

In economic terms, the BRIC countries have room to grow. AeroStrategy notes that "the relatively low penetration of the aerospace industry in the economies of these countries highlights the growth potential."[52] In all of these BRIC countries, penetration is well below 1% of GDP; whereas, there is much higher penetration in countries such as Canada (1.6%) and the US (1.4%). If China's penetration were on a par with Germany's at 0.9%, it would be worth close to $40B.[53] Table 12 provides details on aerospace penetration for a number of nations.

Country	Aerospace Industry ($B)	GDP ($B)	Aerospace Penetration (% of GDP)
France	50.39	2,864.35	1.8
Canada	23.60	1,501.79	1.6
US	204.00	14,264.60	1.4
United Kingdom	32.67	2,678.47	1.2
Germany	32.13	3,662.36	0.9
Russia	10.00	1,671.45	0.6
Brazil	7.55	1,575.15	0.5
Japan	14.10	4,908.35	0.3
India	4.00	1,226.18	0.3
China	12.00	4,415.99	0.3

Table 12. Aerospace penetration by nation (% of GDP)[54]

Perhaps one positive aspect of this market-penetration issue is that the US market is larger by dollar value than all of the other nations listed in Table 12 ($204B, compared to $186.44B for the rest) and 60% of Canada's exports go to the US. Nevertheless, now that the US has a new administration with a more nationalistic focus, Canadian firms will have to continue their efforts to remain competitive, and this must include government support.

Government Support

The Emerson Aerospace Review highlighted the challenges and opportunities facing Canada's aerospace industry, and as part of the recommendations to government, one key area falls under the government-support requirement, i.e., creating conditions that encourage innovation. Government support to promote innovation was also the focus of the *Review of Federal Support to Research and Development*, which included specific recommendations as to how the government could help small- or medium-size firms get innovative solutions to market.

The Emerson Aerospace Review states that "creating conditions in which innovation is encouraged and accelerated requires coordinated efforts on the part of industry, research institutions, and governments" and notes further on that the "research intensity of the Canadian aerospace manufacturing industry currently lies in the middle of the pack among major aerospace powers."[55] The R&D review by Jenkins also noted that the federal government had to do more than just focus on R&D when it comes to innovation. The review team heard that the government should:

- be more focused on helping innovative firms to grow and, particularly, on serving the needs of SMEs;
- be more outcome-oriented as well as more visible and easy to access;
- focus on improving whole-of-government coordination combined with greater cooperation with provincial programs; and
- provide more support for other activities along the continuum from ideas to commercially useful innovation, rather than the existing narrowly focussed support on R&D innovation.[56]

In addition, there is scope for the Canadian government to emphasize that the aerospace industry is of strategic national importance. The Emerson Review notes that Canada does less than other nations to recognize this sector as being strategically important, and this is demonstrated by the lack of government-funded R&D when compared with other major aerospace powers.[57] Table 13 highlights how far behind other nations Canada is in supporting R&D in the aerospace industry. Lastly, Niosi has argued that while government support for exports is comparable to that of other nations, there is scope for "increasing direct support to R&D in space budgets, industry-university collaborative R&D in aerospace, and cluster innovation."[58]

Country	Share of R&D Funding (%)
Canada	16
France	27
Germany	39
United Kingdom	21
United States	62

Table 13. Share of R&D performed in the aerospace manufacturing sector that is funded by government expenditures (as of 2009)[59]

It is clear from the various reports that there is room for the government to do more in this area of promoting innovation, and recent budget and policy announcements by the government have demonstrated a willingness to do more. In a related context, the industry's input during the 2016 Defence Policy Review consultations was consistent with the industry's desire for government to develop a defence industrial strategy. This would be in line with Emerson's recommendation that the aerospace sector be identified as a national strategic sector in the economy. A national defence industrial strategy would indicate to the industry and to other nations the sectors that the government believes are strategic and require sustained or additional support.

Conclusion

The articulation of a defence industrial strategy matters to the RCAF as well. Government support in particular areas of the defence aerospace sector will impact the RCAF's ability to develop and sustain air capabilities not only in terms of the capabilities that will actually exist in Canada but also from a broader budgeting and resource-management perspective. Knowledge of the nation's existing capabilities is an important part of the force generation decisionmaking process. For example, when developing a new capability, the RCAF may wish to locate the capability near the defence aerospace industry in order to use experienced operators with technical expertise and, thus, make maintenance and servicing more cost-effective and shorten the time required for repairs and cyclical maintenance.

A separate but related issue for the RCAF is whether or not a Canadian firm or a foreign firm has the expertise and intellectual property (IP) for a capability. Government support during the actual acquisition process to get Canadian companies involved in the acquisition has longer-term benefits for the RCAF when it comes to making upgrades over the life of a capability. To give the CF18 as an example, Canada has upgraded this platform a number of times since it was initially acquired in the early 1980s, and the upgrades have been done by Canadian companies. This is not to say that the upgrades could not have been done by a foreign company (in this case, a company in the US), but rather, it should be noted that there is increased flexibility for the RCAF to do this in Canada. They are not competing with US priorities, or with exchange rate variations for the budget, or with IP ownership. The issue is not to argue that one way is better than another, but rather to make the point that RCAF planners need to know where the capabilities are within Canada or abroad in order to plan and budget accordingly. Not having a defence industrial strategy setting out the government's priorities further complicates the already difficult and complex process of developing capabilities for the future and sustaining capabilities in the present.[60]

To conclude this chapter, it would be useful to return to the global context of the aerospace industry and what that implies for Canada. Most industry executives have a positive outlook for the future, but they also expect to see continuing mergers and acquisition activity, and half of them expect to see more consolidation.[61] Canadian aerospace firms will not be immune to these global activities, and the Canadian government must remain engaged and informed if it wants to ensure continued success and growth in this key segment of the Canadian economy.

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Abbreviations

AIAC	Aerospace Industries Association of Canada
BRIC	Brazil, China, India and Russia
CADSI	Canadian Association of Defence and Security Industries
CDIA	Canadian Defence Industries Association
CSDRM	Centre for Studies in Defence Resources Management
G&S	goods and services
GDP	gross domestic product
IP	intellectual property
ISED	Innovation, Science and Economic Development
MRO	maintenance, repair and overhaul
NDHQ	National Defence Headquarters
OEM	original equipment manufacturer
PWGSC	Public Works and Government Services Canada
R&D	research and development
RCAF	Royal Canadian Air Force
SME	small or medium-size enterprise
UAS/V	unmanned aerial systems/vehicles

Notes

1. Canada, Innovation, Science and Economic Development (ISED) and Aerospace Industries Association of Canada (AIAC), *State of Canada's Aerospace Industry 2016 Report,* 2016, 4, accessed July 25, 2015, http://aiac.ca/wp-content/uploads/2016/06/State-of-Canadas-Aerospace-Industry-2016-Report.pdf .

2. Note that a detailed discussion about the defence industrial base in Canada is provided by Solomon in Binyam Solomon, "The Defence Industrial Base in Canada," chapter 6 in *The Public Management of Defence in Canada*, ed. Craig Stone (Toronto: Breakout Education, 2009), 111–39.

3. "2016 Global Aerospace and Defense Sector Outlook: Poised for a Rebound" Deloitte, January 2016, 3, accessed July 25, 2018, ttps://www2.deloitte.com/gu/en/pages/manufacturing/articles/2016-global-aerospace-defense-outlook.htmlm. The outlook indicates that growth, although rising, was increasing at a reduced rate, i.e., 5.8% in 2012, 3.2% in 2013, 1.9% in 2014, and a nominal decline of minus 0.22% in 2015. Growth for 2016 is expected to be 3.0%.

4. The defence sector in this context is actually what other reports refer to as the defence industry. For Canada, there is an aerospace industry that includes both commercial or civilian activities and a defence sector of that aerospace industry. Various reports and studies refer to the Canadian or global defence industry, which includes aerospace, while other reports and studies deal with the larger aerospace industry, which includes both commercial and defence activities. It is important to understand which specific part of the industry is being discussed.

5. John Dowdy and Elizabeth Oakes, *Defense outlook 2017: A global survey of defense industry executives* (New York: McKinsey & Company, April 2015), 2, accessed July 25, 2018, http://www.mckinsey.com/industries/advanced-electronics/our-insights/defense-outlook-2017-a-global-survey-of-defense-industry-executives. Here the outlook takes in the entire defence industry, including the aerospace sector. In the survey conducted by McKinsey, 100% of respondents expected an increase in defence spending in the Asia-Pacific region (either 1% to 5%, 6% to 10% or 10% to 20%) and 88% expected an increase in defence spending in the Middle East. In contrast, only 13% expected an increase in North America. This is based on 2014 survey data that are both consistent and at odds with what is indicated in the Deloitte study. The survey data are consistent in indicating that growth was falling in 2014, and at odds because Deloitte expected increased growth from 2016 onwards. The two-year difference in years matters in this case because the market expectations have changed in two years.

6. See Canada, ISED, *State of Canada's Aerospace Industry: 2016 Report*; and Canada, ISED and Canadian Association of Defence and Security Industries (CADSI), *State of Canada's Defence Industry, 2014*, accessed July 25, 2018, http://www.defenceandsecurity.ca/UserFiles/File/Presentations/StateOfDefenceIndustry/State%20of%20Canada's%20Defence%20

Industry%202014.pdf. Note that the aerospace industry report includes both commercial and defence activities, while the defence industry report includes an aerospace sector, but not the entire aerospace industry.

7. Canada, ISED, *The State of Canada's Defence Industry, 2014*. See also Canada, CADSI, *At a Crossroads: Canadian Defence Policy and the Canadian Defence Industrial Base*, Canadian CADSI submission to the Minister of National Defence's Advisory Panel on the Defence Review, April 2016, accessed July 25, 2018, https://www.defenceandsecurity.ca/UserFiles/File/Events2016/DefenceReview/CADSI_Defence_Review_2016_Submission.pdf.

8. A key issue in examining the impact of the aerospace industry is understanding the relationship between actual government spending on defence that affects industry in terms of jobs and business versus how much economic activity occurs as a result of broader export and commercial activities not related to government defence spending.

9. Treddenick's study is one of a number of studies completed by the Centre for Studies in Defence Resource Management in the 1980s and early 1990s. The Centre looked at issues related to defence spending, to various parts of the defence sector, and to the economic impact of defence spending. Data in Table 1 came from John Treddenick, *The Economic Significance of the Canadian Defence Industrial Base CSDRM Report Number 15* (Kingston: The Royal Military College of Canada Centre for Studies in Defence Resources Management, summer 1987), 41. Although it was the 1987 study that was used in Table 1, the first economic impact study was completed in 1982 and was an annual publication until the Centre was closed in 1995 as part of the defence budget reductions associated with the Defence Program Review and the *1994 Defence White Paper*. See John Tredennick, *The Economic Impact of Canadian Defence Expenditures* (NDHQ Study Directive S2/80) (Kingston: The Royal Military College of Canada Centre for Studies in Defence Resources Management, summer 1983). Other data used in Table 1 came from Bernie Grover, *Statistical Overview of Canadian Defence Industry for the Year 2000* (Ottawa: Canadian Defence Industry Association (CDIA), February 2002); KPMG, *The Economic Impact of the Defence and Security Industry in Canada* (Ottawa: KPMG, May 2012), accessed July 25, 2018, www.defenceandsecurity.ca/UserFiles/File/IE/KPMG.pdf; and Canada, ISED, *The State of Canada's Defence Industry, 2014*; and, Canada, Industry Canada, *Aerospace and Defence-Related Industries Statistical Survey Report 1995*, April 1996.

10. Source: Various reports and survey data from Industry Canada, the Centre for Studies in Defence Resources Management (CSDRM), CDIA, CADSI and KPMG. See Endnote 9.

11. The CADSI website at www.defenceandsecurity.ca, accessed July 25, 2018, states that "the concept of CADSI first came into being in 1991 with the founding of the Canadian Defence Preparedness Association. The association became known as the Canadian Defence Industry Association in 1998. It grew to include security and changed to the Canadian Association of Defence and Security Industries in 2001."

12. The government has a stated intention to focus on innovation, and data must be available to help inform decisions about where limited resources should be focused. The issue for long-term data is that some industries or sectors may be doing fine at a particular point in time, but the long-term trend may show sectors at risk.

13. Canada, ISED, *State of Canada's Defence Industry, 2014*.

14. Total GDP impact (Column [d]) and total jobs (Column [g]) includes direct, indirect and induced effects in accordance with the Canadian System of National Accounts and the input-output-related concepts associated with economic multipliers. They are not the same as the multipliers used by ISED in the industrial and regional benefits or industrial and technical benefits policies and their concepts of direct and indirect benefits; Canada, ISED, *State of Canada's Defence Industry, 2014*, 31.

15. Canada, ISED, *State of Canada's Defence Industry, 2014*, 6.

16. Canada, ISED, *State of Canada's Defence Industry, 2014*, 10.

17. Solomon, *The Defence Industrial Base in Canada*, 135.

18. Canada, ISED, *State of Canada's Defence Industry, 2014*, 32. The ISED survey actually includes a detailed breakdown of the primary industrial activities in each region of the country.

19. Canada, ISED, *State of Canada's Defence Industry, 2014*, 17.

20. Canada, ISED, *State of Canada's Defence Industry, 2014*, 27.

21. Canada, Public Works and Government Services Canada (PWGSC), *Beyond the Horizon: Canada's Interests and Future in Aerospace, Volume 1,* Aerospace Review mandated by the Government of Canada, November 2012, 1. The review was conducted by David Emerson, a former Minister of Industry, on behalf of the government. He provided two substantial reports: Volume 1 on the Aerospace sector and Volume 2 on Space. Other reviews include the ISED and AIAC survey report released in 2016 and a similar report from 2011 (see Canada, *State of Canada's Aerospace Industry 2016 Report*; and, AIAC, *The State of the Canadian Aerospace Industry: Performance 2011* (Ottawa: AIAC, July 2012) as well as broader global assessments where Canada is included as part of the discussion. See Alan Arcand, *Canada's Aerospace Industry: The Impact of Key Global Trends* (Ottawa: The Conference Board of Canada, 2012). This report by Arcand was one of a number of reports prepared for the Emerson Aerospace Review.

22. Arcand, *Canada's Aerospace Industry*, i.

23. Arcand, *Canada's Aerospace Industry*.

24. Arcand, *Canada's Aerospace Industry*, 1.

25. Canada, PWGSC, *Beyond the Horizon*, 13.

26. Arcand, *Canada's Aerospace Industry*, 1.

27. Arcand, *Canada's Aerospace Industry*, 1.

28. Canada, PWGSC, *Beyond the Horizon*, 13.

29. Arcand, *Canada's Aerospace Industry*, 1.

30. Canada, PWGSC, *Canada First: Leveraging Defence Procurement Through Key Industrial Capabilities*, Report of the Special Advisor to the Minister Public Works and Government Services Canada, February 2013, 5.

31. Canada, ISED, *State of Canada's Aerospace Industry 2016 Report*.

32. Canada, ISED, *State of Canada's Defence Industry, 2014*, 8.

33. Canada, ISED, *State of Canada's Aerospace Industry 2016 Report*, 19.

34. Canada, ISED, *State of Canada's Aerospace Industry 2016 Report*, 18.

35. Canada, ISED, *State of Canada's Aerospace Industry 2016 Report*, 10.

36. Canada, ISED, *State of Canada's Aerospace Industry 2016 Report*, 11.

37. Canada, ISED, *State of Canada's Aerospace Industry 2016 Report*, 21.

38. With access to new procurement contracts provided, Canadian industry gains access to new value-added technologies. This allows Canadian firms to adopt and apply that knowledge in the broader export market. Without access to initial Canadian procurement, they would not be able to do this.

39. Canada, ISED, *State of Canada's Aerospace Industry 2016 Report*, 12.

40. Canada, ISED, *State of Canada's Aerospace Industry 2016 Report*, 22.

41. Canada, ISED, *State of Canada's Aerospace Industry 2016 Report*, 18.

42. Other studies in addition to Canada, *Beyond the* Horizon, include the Deloitte, KPMG and McKinsey defence outlooks, National Defense Industry Association reports, US Aerospace Industry Association reports, and assessments by Allied nations.

43. Jorge Niosi, "R&D Support for the Aerospace Industry–A Study of Eight Countries and One Region," *The Aerospace Review* (Ottawa, University of Quebec in Montreal [UQAM], July 13, 2012), 3.

44. Canada, PWGSC, *Innovation Canada: A Call to Action*, Review of Federal Support to Research and Development–Expert Panel Report, Tom Jenkins, Chair, February 2011, E2.

45. PricewaterhouseCoopers (PWC), *Sectoral Structure Analysis Aerospace Review* (Ottawa, PWC, July 2012), 6.

46. AeroStrategy, *Aerospace Globalization 2.0: Implications for Canada's Aerospace Industry, A Discussion Paper* (Ann Arbor, MI: AeroStrategy Managing Consulting, November 2009), 9.

47. AeroStrategy, *Aerospace Globalization 2.0.*

48. Canada, PWGSC, *Beyond the Horizon*, 26.

49. Canada, PWGSC, *Beyond the Horizon*, 26. The review provides examples of four different manufacturers (Embraer, Roll-Royce, Airbus and Bombardier) all showing the same trend: a significant reduction in the number of suppliers in their supply chains.

50. Regional and single-aisle jets are related but not identical. Regional jets are generally smaller aircraft that service larger hubs. They can have turbo prop or jet engines. Single-aisle planes include not only regional jets but also planes with larger carrying capacities, and they are not limited to servicing hubs. An increase in the number of global competitors will impact Bombardier, which is in both of these markets.

51. Arcand, *Canada's Aerospace Industry*, 11.

52. AeroStrategy, *Aerospace Globalization 2.0*, 15.

53. AeroStrategy, *Aerospace Globalization 2.0*, 15.

54. AeroStrategy, *Aerospace Globalization 2.0*, 16.

55. Canada, PWGSC, *Beyond the Horizon*, 29.

56. Canada, PWGSC, *Innovation Canada: A Call to Action*, E2.

57. Canada, PWGSC, *Beyond the Horizon*, 32.

58. Niosi, "R&D Support," 200.

59. Canada, PWGSC, *Beyond the Horizon*, 32.

60. The RCAF will make decisions about long-term requirements with or without a defence industrial strategy, and those decisions will be based on the best information available at the time. Having a defence industrial strategy will provide better information for that decision making.

61. Dowdy and Oakes, *Defense Outlook 2017*, 5.

Additional Readings

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CH08

Military Procurement and Civil Aerospace: Diverging Paths?

Richard Shimooka

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Introduction

Since the publication of the *Canada First* Defence Strategy (*CFDS*) in 2008, the relationship between military procurement and industrial development has faced increased scrutiny. The debate has been coloured by subsequent events, including the Emerson and Jenkins studies, controversies surrounding the F-35 aircraft, and the National Shipbuilding Procurement Strategy (NSPS).

While the *CFDS* is the most recent attempt to develop integration between government and industry, there have been numerous attempts over the past 70 years. Arguably, the most prominent has been the Canadian Forces' relationship with the aerospace industry. Of the three major environmental commands, the Royal Canadian Air Force (RCAF) has the largest acquisition budget and employs some of the military's key platforms, such as the tactical fighter force, strategic and tactical airlift fleets, and search and rescue aircraft. The Canadian aviation industry is one of the most vibrant sectors of the economy, and is the fifth largest in the world by revenue. Given their relative strengths, it would be fairly easy to assume that there is a strong link between these two groups.

As we will see, however, except for the decade after the Second World War (WWII), the military and industry relationship has been on divergent paths. If anything, the current policy, industry structure, and nature of military capabilities ensure that a separation will continue to persist.

This paper will begin by examining the various models of procurement and defence industrial base development between 1945 and 1990. Subsequent sections will include the following: (1) an outline of the Industrial and Regional Benefits Policy (IRBP), which is the foundation for the current military-industrial relationship;[1] (2) a review of the three major facets of this policy: direct offsets, indirect offsets, and in-service support (ISS); (3) a review of the current status of Canada's military-aerospace industry relationship and what the future holds in store for this relationship; (4) a review of recent efforts to significantly reform Canada's relationship with its defence industrial base; and (5) a review of the unique features of the Joint Strike Fighter Program (JSFP).

A Primer on Models of Defence Procurement

After 1945 and into the 1990s, defence production in Western states tended to follow one of four approaches. Initially, most countries attempted to develop and produce arms indigenously in order to become as self-sufficient as possible. During WWII, Canada became an important industrial hub for the production of allied aircraft, such as the Avro Lancaster, the De Havilland Mosquito, the Consolidated PBY and the Hawker Hurricane. In 1944, the Government of Canada (GC) decided to try to organize its growing industrial strength to achieve a coherent goal.

Countries have sought to achieve numerous objectives by using this approach. It could help ensure that their militaries tailor purchases to their unique requirements, while serving as a pretext for subsidizing domestic economic development. From 1945 to 1960, Canada sought to achieve most of these objectives by launching a major initiative to develop an indigenous military aircraft industry. The main focus of this initiative was the CF100 Canuck and CF105 Arrow programs, in which Avro Canada produced both aircraft.[2]

Nevertheless, many states did not have the technological capability to develop systems to meet all of their military requirements, often because of the continuous development of advanced adversary capabilities. In other cases, the development costs were prohibitive. Therefore, a common alternative was to undertake licensed production of a foreign system, usually an American or British design. This allowed states to retain their industrial capacity and keep abreast of major technological advances without a major investment in research and development (R&D). The Canadian government attempted to implement this approach between 1950 and 1975, with Canadair producing licensed-built copies of the North American F-86, the Lockheed T-33, the Bristol Britannia, the Lockheed F-104 and the Northrop F-5.

By the 1960s, the increasing cost and complexity of major weapon systems soon made it uneconomical for many states to continue seeking to achieve the entire range of arms production indigenously. Consequently, North Atlantic Treaty Organization (NATO) allied nations other than the United States (US) came up with a novel alternative—multinational programs—to deal with the growing cost and complexity of modern weapons. In these cases, a group of states collaborated to jointly conceive, design, develop, manufacture and support a system. While multinational programs held out the promise of reducing the costs and risks of a development program, the reality was much less positive. Participating states attempted to protect their domestic industries by guaranteeing that they received a significant portion of the available work. These workshare arrangements were often fixed and distributed based on political considerations and procurement commitments, not efficiency. Thus, cost overruns, delays and sub-optimal performance outcomes were common.

Canada has less experience with this multinational approach, given that the sole procurement of this type was the Canadian-French Eryx anti-tank launcher, which was a successful program. Canada was one of the initial partners in one of the largest multinational programs, the Panavia Tornado multi-role fighter, but decided to withdraw from the program in 1968 after a relatively short period of participation.

Despite these efforts, most states found the cost of domestically manufactured systems to be unaffordable by the 1970s. Canada purchased its last CF5 fighter in 1975, ending its 40-year history of indigenous fixed-wing fighter production. The following year, the government was forced to nationalize the country's largest aerospace producer, Canadair, in order to avert the company's imminent bankruptcy. With no further military contracts forthcoming, the firm refocused its efforts on civilian projects, and was later purchased by Bombardier. Excluding some notable exceptions, such as the Canadair/Bombardier CC144 business jet and the Bell CH146 Griffon utility helicopter, henceforth, the bulk of Canada's aviation capabilities would be purchased from abroad.

Canadair's belated experience reflected much broader shifts within the Canadian aviation industry, which had gained momentum after the 1959 cancellation of the Avro Arrow. Revenues from domestic military contracts declined rapidly after the project's termination, as GC abandoned its indigenous military development strategy. Consequently, domestic firms started looking abroad for new contracts. This was not quite a novel approach, given that Canadian firms were highly integrated with American and British industry from the outset of WWII. Canadair, for example, was the Canadian subdivision of major US defence contractors: first Convair Corporation, then General Dynamics. This high level of integration facilitated Canadian domestic aerospace industry reorientation towards the export market in the aftermath of the Arrow's cancellation.

The shift towards greater integration was facilitated by a separate event in 1956, when Canada and the US signed the Defence Production Sharing Agreement (DPSA): a wide-ranging accord over industrial base integration.[3] Its most significant effect was to give Canadian second- and third-tier manufacturers unfettered access to the US defence industry market so that they could compete for subcontracts with major programs on the same level as American firms.[4] In return, American primes were given the opportunity to export to Canada without any trade restrictions. The DPSA resulted in dramatic changes to Canada's defence industrial base. Rather than being tied to unsustainable Canadian prime manufacturers, the DPSA allowed second- and third-tier manufacturers to sell their components to much stronger American competitors. The results were immediate and dramatic: by 1964, over 50% of Canada's aircraft production was exported to foreign markets, with exports of some specific systems reaching 98%.[5] Canadair, for example, started producing parts for the F-111, the C-5 and the F-14—major aircraft never purchased by GC.

Despite the growing export orientation, the lack of domestic funding for defence-related activities was not without consequences, the most significant being the departure of Canadian firms from the military aviation sector. Prior to 1960, defence production had dominated the industry landscape. The most successful civilian program during that period was the Canadair North Star, a licensed production of DC4 aircraft that amounted to 71 aircraft delivered, half of them to military customers. Avro's effort, the ground-breaking Jetliner, was cancelled after one prototype was built. Canadian prime contractors as a whole produced over 2,100 military fighters (CF100s and Sabres) between 1945 and 1960.

The decline of Canada's military aerospace R&D activities after 1959 and the new market opportunities created by the DPSA pushed domestic firms towards the civilian market. There was good reason for this. Despite some periods of slower growth, the volume of passenger and cargo travel grew relatively steadily from 1960s onwards. By 1990, approximately 16% of the Canadian aviation industry's revenues came from military sources, down from 30% in 2009.[6] Through consolidation, Canada's three prime contractors eventually merged into one firm under Bombardier. However, a much more significant trend was the growth of Canadian "sub-tier" subcontractors. These firms, which provide niche capabilities, have become the core revenue driver for Canada in aviation. This is most evident in Quebec. Although the province is home to the country's only prime contractor, Bombardier, the firm only accounts for 5% of all revenues. In fact, Tiers I and II (major subcomponent manufacturers such as HerouxDevtek) and Tier III (major subcomponent manufacturers such as Asco and Howmet Georgetown Casting) accounted for 25% and 55% of the industry's profits, respectively.[7] Their success was due to four major factors:

- well-educated and efficient manufacturing base workforce;
- lower labour costs due to public healthcare and lower wages;
- weak Canadian dollar increasing foreign purchasing power;
- multiple free trade agreements that facilitate intra-border trade.

The three main trends in the Canadian aviation industry—civilian focus, export orientation and subcomponent specialization—all but eliminated any direct avenue for domestic development through direct military-related procurement. Nevertheless, the government sought to obtain some benefit from foreign manufacturers that would help with the development of Canadian industries.

Canada adopted an approach known as offsets to obtain a reciprocal benefit. Rather than the direct benefit of producing something in Canada, offsets created a fluid transaction process to enable money spent on defence procurement to have some developmental benefit for Canadian industries. Throughout the 1970s, this was an ad hoc process. Competitions between foreign manufacturers were evaluated on the amount and quality of domestic investment. In one case, officials informed a preferred vendor that it had to partner with a Canadian firm if it wanted to obtain a contract.[8] This state of affairs continued until 1986, when the Mulroney Government unveiled the IRBP that remains in force today (but has evolved into Industrial Technical Benefits [ITB] with value proposition [VP]).

Industrial and Regional Benefits (IRB) Overview

IRBs are an obligation placed on any item or service purchased by GC from a foreign firm. IRBs are mandatory for certain projects with a value greater than $100M, and discretionary for projects with a value between $2M and $100M.[9] Under the Government Contracting Regulations, firms are required to invest back into Canada an amount equal to the original contract, which must be fulfilled within a fixed period, usually within one year of the contract's expiry. The original intent was to ensure that Canadian industries obtained some benefit from foreign-sourced goods. While most foreign items procured by GC are covered, few receive as much scrutiny as those intended for the Department of National Defence (DND), probably because the Canadian Armed Forces (CAF) use the most foreign-sourced items within government and because the costs are often very high and attract attention. Furthermore, major multilateral trade agreements, such the North American Free Trade Agreement (NAFTA), prohibit offsets, and can only be bypassed with a National Security Exemption.

Offsets have a checkered history, as will be apparent further on in this study. Many countries have abandoned similar practices after finding that they sometimes result in sub-optimal outcomes. In the 1980s, Australia used mandatory offsets, only to switch to a more flexible approach where foreign firms directed their funding to specific strategic industries.[10] In Canada, IRBs can be divided into one of two categories, direct offsets and indirect offsets.

Direct offsets

Direct offsets occur when the foreign investments are directly related to the program concerned. An example would be Fleet Canada Inc.'s contract from Boeing to produce a front pylon and cockpit nose enclosure for the CH47 Chinook, which Boeing is producing for the CAF. The government also considers any work carried out on the same platform for other countries as a direct offset. In the Chinook case, any additional production by Fleet Canada for foreign customers is considered a direct offset. Although the government generally prefers direct offsets, many programs have great difficulty using direct offsets to meet all of their IRB requirements.

There are several factors underlying this problem. For most off-the-shelf purchases, the opportunities for direct offsets are limited. Major weapon programs have highly integrated manufacturing processes with tightly defined supply chains. Aerospace projects, in particular, require subcomponents to be built to extremely demanding specifications. Integrating a new Canadian supplier into an established supply chain will often require an onerous qualification process by the prime manufacturer and, in most cases, by the prime manufacturer's home government as well. Although Canadian firms are extremely advanced and very competitive internationally, such a qualification process may add unacceptable delays or cost increases to a project.

Although a Canadian company might be technically competent to fulfill a subcontract, it is often unable to do so in a price-competitive manner. Usually, the previous producer has had years of experience manufacturing a subcomponent, during which time learning curves have been devised to reduce costs. Thus, a Canadian firm will have great difficulty competing against an established producer.

A good example of this problem can be seen in the future Japanese production of F-35 fighters. Because Japan is a non-partner purchaser of the F-35, and because there are specific legal injunctions against foreign sales of military equipment, Japanese industry participation is limited solely to aircraft purchased for the Japanese Air Self-Defence Force (JASDF). Japanese firms will produce radar, engine and possibly aerostructure components, which together usually amount to about 10% of the unit cost for a US-produced F-35. However, Japanese industrial participation will increase the total cost of Japanese-produced F-35s to 150% of the cost of the US-manufactured version.[11]

Lastly, programs may simply not have sufficient IRB opportunities. If GC selects a mature, off-the-shelf capability, it often has limited industrial benefit potential. The enabling technologies may be outdated and may not provide a meaningful benefit for Canadian industry. Moreover, if a program is coming to an end, the potential value of the IRBs may be curtailed.

Indirect offsets

In lieu of direct offsets, foreign firms will often meet their IRB requirements through a second approach, known as "indirect offsets." These investments are not directly related to the project, but are recognized as a legitimate means to fulfill a foreign firm's obligation. In many cases, indirect offsets are the primary means by which the IRB requirements of particularly large foreign contracts are met. The C-17 program had almost no direct opportunities for Canadian participation because the C-17 aircraft line was mature and nearing the end of production. One common method used by Boeing Aerospace is to offer subcontracting work to Canadian firms for Boeing's civilian aircraft production. A typical example is Boeing's signing of a $13M contract with Avior Industries in Quebec to produce vertical fin fairings for the 787 Dreamliner.[12] This contract was one of several that the aerospace giant awarded in order to meet its IRB obligations for the C-17, CH-47, and Scan Eagle unmanned aerial vehicle programs. These can be considered high-value contracts, which are only obtainable because Canada has world-class aerospace firms.

Unfortunately, foreign firms frequently struggle to meet their IRB obligations even with such high-value indirect offsets. In February 2014, then Minister of Industry Diane Finley stated that more than one-quarter of the $23B in outstanding reciprocal commitments since 2011 had yet to be fulfilled.[13] While these contracts are usually fulfilled, the economic literature suggests that their long-term economic benefit is limited.[14] There are several factors that limit the ability of firms to undertake high-quality indirect offsets. Probably the main issue has to do with the persistence of the investment, which is largely due to restrictive government regulations, which stipulate that IRBs must be delivered a maximum of five years after the final delivery. Consequently, firms usually focus on short-term investments to meet their IRB requirements and neglect the long-term development of Canadian industries. These activities can have negative consequences for Canadian companies by creating market distortions that are detrimental in the long term. Often, firms will have to ramp up production and even expand manufacturing capacity to meet the temporary demand of such a contract. Once the contract is completed and demand returns to normal, the excess capacity cannot be supported and the benefit is lost.

Another shortcoming of IRBs is that it is generally difficult to ensure that they actually provide assistance for the development of new technologies and products. Because of the short-term focus of foreign firms, many investments go towards existing products and services, rather than to creating new ones. One notable exception is the somewhat common practice of providing funding for university research centres. However, it is difficult to achieve sustained long-term economic development with indirect offsets.

Given their prevalence and nature, indirect offsets actually highlight the limited ability of Canada's aerospace industrial base to meet RCAF requirements. With few industrial opportunities available for direct participation, relatively little direction, and the imperative to obtain 100% contract value, most foreign reinvestment goes to supporting the most active and competitive Canadian aerospace firms.

In-service sales and support and IRBs

Although there have been significant challenges in using acquisition-related IRBs to promote the domestic defence industrial base, one category of IRBs has met with some success. In-service support is a general term for contracts that are required to keep a capability operating in service. It has become an increasingly important part of the IRB program, partly because of broader changes to how the CAF carry out their maintenance and logistical activities. Prior to the 1990s, DND was almost entirely responsible for keeping systems in service. Because military personnel carried out the bulk of the actual maintenance on aircraft, the contracting out of services to outside parties was much more limited, and mostly related to very specific tasks. In the late 1980s, this began to change. Using the term "alternative service delivery" and having to adjust to budgetary pressures, DND looked to the private sector to provide a cheaper alternative to carrying out these activities in-house. In addition, the complexity of systems, particularly aircraft, made it increasingly difficult to maintain the required in-house expertise.

Since then, the CAF have broadened the scope of services that they contract out, and private firms have become increasingly responsible for keeping capabilities in-service. In some cases, the CAF will only carry out a limited series of tasks that are immediately required to keep a capability in-service at home or at a deployed location, known as first-line maintenance. This includes basic maintenance and relatively simple repairs. Everything else, including substantial repairs (second-line maintenance) and major engineering refits and refurbishment (third-line maintenance) are the responsibility of a contracted firm. In addition to maintenance, training and logistical functions are other activities that are often contracted out to private firms. Spares pool management, in particular, is one activity that is frequently contracted out.

In 2012, GC implemented this approach further by reorganizing all maintenance functions into a single-point-of-accountability (SPA) model.[15] This emulated changes made by the US Government in the 1990s, which were collectively referred to as performance-based logistics (PBL). As the name suggests, PBL was a movement towards using performance specifications rather than military specifications in contract language.[16] The emphasis was to "buy measurable outcomes, i.e., those measures of effectiveness used, to define the outcomes."[17] PBL allowed firms to determine an efficient way to provide support functions that resulted in significant reductions in the operating costs for capabilities to which they were applied. Industry has facilitated this shift by introducing designs and systems that are optimized for this approach. A major step is the growing use of line-replaceable units and other modular components that can be easily replaced by front-line maintenance staff. Another step is the broadening application of health management systems such as the C130J's Data Transfer and Diagnostic System.[18] This system monitors the aircraft's systems and passes information to maintenance crews and support contractors. The information is used to identify who is responsible for specific repairs and facilitate spares-pool management.

To accrue the maximum benefits from a PBL relationship, they must last for several years so that the firm can identify and implement cost-saving measures. In the mid-2000s, Canadian acquisition contracts started to include provisions for ISS that extended the effective life of a capability.[19] Unlike acquisition contracts, ISS programs offer better opportunities for the participation of Canadian firms. First, the domestic industrial base includes a number of companies that can partner with a foreign firm to provide relevant services. Specific services that can be counted towards meeting the original manufacturer's IRB requirements are subcontracted to specialized Canadian firms.

Two unique aspects of the Canadian aviation industry facilitate this process. First, the Canadian aviation industry has a well-developed maintenance, overhaul and repair (MRO) sector. Unlike those involved in manufacturing and production, civil MRO firms face fewer challenges in converting to military contracts. The CC130J program is a good example of this trend. Canadian firms that provide services include:

- **Cascade Aerospace**, which provides third-line maintenance, including technical support, engineering support services, aircraft structural integrity, corrosion prevention and control, incorporation of aircraft modifications, and other services;
- **IMP Aerospace**, which provides warehousing services, including all spares and support and test equipment item management, receipt of supplies, order fulfillment, defective goods processing, and packaging/shipping activities;
- **CAE**, which provides maintenance simulators and training devices, courseware and services; and
- **Standard Aero**, which will provide support and service for the CC130J's Rolls Royce AE2100 engines.[20]

The main contractor on this list, Cascade Aerospace, focused mainly on civil aviation before winning its first military contract to support the early model CC130s in 2005.[21] Another firm on this list, IMP, represents a different trend. Because of the military's overall shift towards alternative service delivery in the 1980s and 1990s, Canada also has a robust defence-oriented MRO sector. Firms such as IMP, Bombardier, and Standard Aero are long-term service providers for DND.

Despite the presence of strong industry partners, Canadian firms rarely provide all the necessary services to meet the requirements of an ISS package. This may be attributable to security or proprietary restrictions, the technological limitations of domestic firms and/or cost factors. The ISS contract with Boeing Aerospace for the CC177 Globemaster III illustrates all of these issues. Support for Canada's aircraft is provided under the Globemaster III Integrated Sustainment Program, which is the same program that the United States Air Force (USAF) uses to provide support for its C-17s. Much of the heavy maintenance for the aircraft is actually provided at Walter Robbins Air Force Base in Georgia. While this provided a much greater cost savings than any domestic provider would provide, it also meant that there were few opportunities for direct IRBs for Canadian companies.

While the CC177 program is probably an extreme example of foreign IRBs related to ISS contracts, most foreign firms still require some degree of indirect offsets to meet Canadian regulations. However, unlike acquisition contracts, there is much greater potential benefit for Canadian industries through ISS-related IRBs. A 5-to-20-year contract period offers foreign firms an opportunity to make significant, sustainable investments in Canadian firms. For example, the Canadian firm HerouxDevtek won a 7-year, $70M contract that was tendered to meet CC130J ISS IRB requirements.[22]

Since 2012, the government has modified the SPA approach. As highlighted in the Emerson Report (discussed below), the approach often made it difficult for Canadian providers to effectively compete against foreign firms, particularly if the latter were established suppliers of the services or produced the platform (which, by extension, meant that they often owned the intellectual property). A different model was introduced with the Fixed-Wing Search and Rescue (FWSAR) Project, where the prime contractor was forced to partner with a Canadian provider in its bid and guarantee that a substantial portion of FWSAR activities was carried out by the Canadian partner.[23]

Despite these limitations, ISS is somewhat of an anomaly in the aerospace military-industry relationship in Canada. The strength of the sector and longer investment periods have ensured a better return on foreign procurement for Canada and helped develop the local industry. It is a model that the government would like to build on.

Jenkins and Emerson Reports, and the Defence Procurement Strategy

In late 2012, GC commissioned a report to be prepared by a panel headed by Tom Jenkins, a leading executive in the technology industry. The panel's main objective was to ensure that the government invested effectively in its current and forthcoming defence acquisitions, estimated to total approximately $49B between 2008 and 2027. Its secondary objective was to break through some of the interdepartmental deadlock that has characterized recent defence procurement programs. Officials from Industry

Canada, Public Works and Government Services Canada, and DND frequently sparred over when domestic industrial considerations should override the military's preference for the best-performing foreign system.

The Jenkins Report set out a comprehensive basis on which to adjudicate the interdepartmental debate, and concluded that preference should be given to several key sub-sectors of defence capabilities where Canada had a comparative advantage, including the following: Arctic and maritime security; protecting the soldier; command and support; cyber security; training systems; and ISS.

In competitions involving these sub-sectors (later called key industrial capabilities or KICs), Canadian firms would be given priority over foreign companies in order to promote the domestic industrial base. This also illustrated the second broad objective of the policy: improving industrial outcomes. Probably the most important policy in this case is the so-called "value proposition," whereby foreign competitors' bids would also be evaluated for their benefit to Canadian industry as a rated requirement, not just in prioritized areas.

Unfortunately, some of the recommendations in the Jenkins Report may be problematic, given the current market structure and existing GC regulations. Most foreign firms struggle to meet their IRB obligations without affecting the cost and/or the delivery schedule of the capability. Their current involvement is determined by the regulations and the opportunities available in the Canadian market. As profit-seeking businesses, foreign firms will already try to identify the best economic opportunities possible. The heavy emphasis of IRBs on aviation-related industries is primarily due to that sector's competitiveness in the global environment. The reason why foreign firms do not invest more is that the current regulations limit what constitute profitable activities.

However, the inclusion of industrial benefits evaluation criteria for projects poses a risk for the CAF. The CAF could be saddled with more costly and less capable equipment (or lower-quality service in the case of ISS) to address domestic industrial imperatives. If significant enough weighting is given to the evaluation criteria, then foreign firms will increase the value of IRBs and the project costs in order to win a contract. This is likely to happen, because the Jenkins panel suggested that Public Works and Government Services change its perspective from lowest short-term cost to long-term economic benefit when assessing programs. However, the evaluation criteria are currently implemented in this manner.

The Jenkins Report is not the only report commissioned by the government. In 2009, the government commissioned former MP David Emerson to investigate the current state of the Canadian aviation industry and the government's involvement in it. Most of the report focused on enhancing the sector's competitiveness through direct investments and altered regulation. However, the panel made two recommendations concerning offsets. The first was for better administration of the IRB program, including early identification of potential investments.[24] The second recommendation suggested that foreign manufacturers with both acquisition and ISS contracts (obtained based on the SPA model) be required to partner with domestic firms to provide maintenance services. The recommendation cautioned that these relationships "should ensure significant and ongoing transfer of technical data and intellectual property, which will permit the Canadian company to develop engineering and design expertise that protects Canadian security interests and facilitates the company's participation in the global market."[25] While the goals of the recommendation are laudable, there are problems in implementing this, as we will discuss in the next section on the ISS program for F-35s.

The Jenkins and Emerson reports have both been followed by a series of concrete reforms to the IRB policy, of which the following are the more significant:

- identify 60% of IRB contracts up front;
- require firms with major IRB obligations to provide strategic plans for investments;
- create an investment framework for R&D and commercialization; and
- increase the valuation relative to introducing Canadian firms into global value chains (GVCs).[26]

Several of these recommendations were previously made in the Emerson and Jenkins' reports, and were widely accepted by the major stakeholders in the procurement process. The key reform was included in the 2014 Defence Procurement Strategy (DPS). In particular, Option No. 4, introducing Canadian firms into GVCs, attracted considerable attention, and actually involves two separate reforms. The first introduced a requirement that foreign contractors guarantee that a certain portion of IRBs (renamed Industrial Technical Benefits or ITBs) be direct offsets. However, if an offsetting contract brought a Canadian firm into a recognized GVC, it could be counted towards this new requirement. These contracts would also be much less stringent about the timing requirements specifying that ITBs must be delivered during the contract period. Rather, the contract's value would be assessed according to the potential of the contract, which would now be included as a rated requirement of the overall procurement process. Within the government, this is known as the VP, and it could have a significant impact on the outcome of a close competition.

The implications of this shift will be significant. Depending on the established proportion of direct versus indirect requirements and the influence that domestic industrial considerations have on the evaluation, this change could have a significant impact on the selection of a winner in a competition. If Canadian contracts demand a high proportion of direct offsets and include that in the evaluation criteria, the GVC policy would disproportionately favour the biggest defence contractors that oversee a diverse product line. A provisional list would include Boeing, Lockheed Martin, BAE Systems, EADS, and Northrop Grumman. For a firm such as Boeing, which already is a major subcontractor in Canada, the GVC policy will have a minimal effect on its day-to-day operations, and will give it a leg-up over some of its competitors. Smaller defence contractors without large industrial bases will find it difficult to meet these requirements and remain cost competitive, because they would have fewer opportunities to incorporate Canadian companies into their industrial production chains.

As noted above, the VP could also result in the Canadian Forces receiving less effective capabilities. However, as one government participant said, there is one scenario where this may not be the case: "In a lowest cost per point of technical merit evaluation, the only way to make up points on the technical/cost side of the equation is to lower your price or increase your technical score."[27] However, this participant noted that this approach does not work for every program.

On a broader level, the DPS has the potential to dramatically alter Canada's relationship with industry. The prior IRB policy made compliance a mandatory requirement: thus all major foreign competitors were required to provide offsets, but they were given considerable latitude as to how they would invest that funding. As noted above, the funding would tend to flow to Canada's most productive economic performers. While there were shortcomings in this system, such as poor long-term economic performance, the investments were largely market based and reinforced the strengths of Canadian industry. In its present form, the DPS gives DND and Industry Canada the ability to influence where foreign producers make their reciprocal investments, but its effect is generally benign. Since 2014, the government has prioritized existing areas of market strength related to the capability to be procured. A good example is the medium range radar program, where the government decided to direct competing foreign firms' ITB investments towards the defence electronics sector.[28]

The potential pitfall of the new ITB approach is that the government may attempt to funnel offset investments into nascent or immature sectors. Activity in these areas is inherently riskier, and firms may be developed in these areas that are not financially viable without continued government investment. This would represent a return to the domestic economic development model, albeit on a far smaller scale than what existed in the 1950s.

Offsets and the Joint Strike Fighter/F-35 Program

In the past 30 years, the JSFP has been the one key exception to the above discussion. From its inception, this program was designed to facilitate international cooperation in a previously unseen manner. It was clearly understood that the industrial benefits related to participation in the JSFP would not be the typical offsets specified in Canada's IRB policy. Unlike previous multinational programs, the JSFP was intended to have a value-oriented industrial approach. During the initial stages, key allies were approached to join the Program. They were expected to make an initial financial contribution, ranging from US$2.5B for the United Kingdom (the only Tier 1 partner) to US$110M for Denmark (the smallest Tier 3 contribution). This status determined the Program partners' ability to influence specifications for the fighter and its support system. However, all of the partners were given an opportunity to have their domestic companies bid for Program subcontracts—a very lucrative opportunity given the F-35's potential production run of over 3,000 units. The subcontracts would be awarded based on a best-value format, and offsets would not be offered except in exceptional circumstances. This meant that the Program's work share was determined on the basis of value and cost effectiveness, rather than on the fixed-arrangement basis characterizing previous multinational efforts.

GC believed that domestic aviation firms were well placed to win a disproportionate number of contracts in the JSFP, given their generally excellent performance in subcontracting work in the civil aviation industry and their good reputation with the prime contractors. The government provided these firms with additional assistance by holding information sessions and offering loan guarantees to facilitate the acquisition of required high-tech equipment and knowledge. These contracts would extend for the entire expected production life of the Program, about 25 years, and longer for support activities. Moreover, in the interest of program cost-effectiveness, the contracts generally involved the production of and/or provision of support for most F-35s produced. Therefore, the payback is reasonably expected to be much more beneficial. Based on current estimates, Canadian firms will receive approximately $9.71B in direct acquisition-related contracts.[29] Canada's nominal IRB return on the F-35s would only be about $6.8B to $7.5B.[30]

Nonetheless, the JSFP's industrial approach faces some drawbacks that affect all aspects of the Program. As noted above, interested states had to join the Program during the early development phases to become industrial partners. This is unlike most procurement programs, where Canada can decide to join at any other time and receive reciprocal IRB contracts. Thus, industrial partnerships like the F-35 require Canada and other states to share similar requirements at roughly the same time. Differences in timing may have serious consequences. For example, the JSFP prime contractors require a timely commitment to procure aircraft under the Program in order to establish the contracts required for production and support of the fleet. This also speaks to the uniqueness of the F-35 project, which may not be replicated in the future. Given the difficulties involved with organizing the international partnership, it is not surprising that such an ambitious industrial production scheme has not been attempted in any other project. It remains to be seen whether others will adopt such an approach.

Other drawbacks are evident in the acquisition and ISS phases of the Program and are related to several different factors. All aspects of the F-35 engineering, manufacturing and design process are tightly controlled by the prime contractor. In previous eras, subcontracting firms would be given significant leeway to design and manufacture a component. This would require substantial engineering capabilities, the benefits of which could be applied to other ventures. Contemporary aerospace and military projects feature less discretion for subcontractors in the production contracts, thus curtailing their need for an engineering capability. This is partly due to the increasing complexity of military systems and the related security measures implemented to protect the technology. Because projects nowadays are built with much tighter tolerances, prime contractors have little room to accommodate subcomponents that do not conform to their original specifications. Subcontractors within this approach are more responsible for manufacturing a completed subcomponent than actually designing it. To some extent, this disadvantage is balanced by the enhanced ability of such Canadian subcontractors to compete for other advanced technology aviation work as a result of the skills and equipment acquired through involvement in the JSFP.

The centralized control issue is more apparent in the ISS field, where Canadian subcontractors' ability to manage repairs is becoming increasingly limited. The RCAF's CC130 Hercules fleet best illustrates this difference. Currently, Canada operates two separate fleets of Hercules: a legacy fleet of 18 E and H model aircraft (purchased between 1960 and 1995) and a new fleet of 17 Jmodel aircraft (delivered between 2010 and 2012). Cascade Aerospace provides the third-line maintenance and engineering for both fleets, although its actual responsibilities vary significantly. The firm is the prime contractor for these services for the legacy fleet, which requires significant engineering services. Any major refit, overhaul or repairs are engineered and implemented by Cascade, and this is a major revenue stream for the firm.

The situation is significantly different for the CC130Js. While the majority of the touch labor is accomplished in Cascade's facilities in Abbotsford, BC, much of the advanced engineering work is carried out outside Canada. Cascade retains some of the latter functions, but Lockheed Martin retains stringent oversight over Cascade's work. This is a characteristic of the SPA model that the CAF currently uses, as well as of the PBL approach. Lockheed Martin carries out much of the engineering in their facilities in the US, with Cascade employees only responsible for implementing the approved maintenance procedures and practices.

A similar approach for the F-35 will be implemented as for the CC130J. L3 Military Air Systems (MAS) is currently responsible for CF18 third-line maintenance and has entered into a "sustainment alliance" with Lockheed Martin to carry out a similar role for F-35s in RCAF service.[31] As with the CC130E/H, L3 MAS and its predecessor Bombardier introduced RCAF-specified modifications to the CF18 aircraft over their lifetime. While the aircraft still required significant original equipment manufacturer support, the arrangement required significant organic engineering support from the Canadian firms. It is certain that the F-35 will further increase the proportion of required original equipment maintenance support at the expense of indigenous industry engineering capability.

Conclusion

Over the past 70 years, the relationship between DND and the Canadian aviation industry has gone through significant changes. Because of various internal and external factors, the government has failed to achieve its initial objective of creating a sustainable aerospace defence industry. In large part, Canada now lacks the development and manufacturing capability to meet its military aerospace requirements domestically. Instead, defence procurement has contributed to the growth of a vibrant Canadian civil aerospace industry that ranks among the world leaders in its sector. Many of the recent reforms will make it possible to continue along this path, by converting military investments into domestic contracts for civil aerospace firms.

At the same time, the Canadian aerospace industry should be viewed as a cautionary tale for attempts to develop an indigenous production base. In fact, the private-sector economy has largely defined the contours of Canada's defence industry. Unless a sector can devise a sustainable economic model, it will be hard pressed to survive without consistent government funding. Furthermore, the increasing cost of military systems means that having a viable export market is all but a prerequisite for industry success.

The 2014 DPS partly acknowledges this reality. It is intended to improve the performance of Canada's industrial and technical benefits strategy by identifying indigenous sectors for investment and channeling offsets towards them. Under the current assessment criteria, the government now provides greater safeguards to ensure that the funding is directed to areas that are already economically viable and related to the original procurement.

However, this is not the case with the government's signature defence industrial development project. In 2008, the government announced a significant initiative to promote the development of an indigenous defence industrial base. The largest component is NSPS, which would involve the construction of a several new classes of ocean-going vessels for the Royal Canadian Navy and the Canadian Coast Guard. The Canadian shipbuilding industry contracted significantly after the final HALIFAX class frigate was delivered in 1995, and is no longer able to produce large vessels of the type required by the Royal Canadian Navy. Consequently, the federal government must make an initial investment to enable domestic firms to acquire the necessary infrastructure and personnel to undertake construction projects. The federal government will then also pay a premium on its initial vessels, while these firms relearn how to carry out these types of construction projects. This will likely come at a higher cost than what can be obtained in foreign shipyards.

Both the DPS and the NSPS illustrate the potential risks to CAF capabilities and national security. Both allow for the selection of a capability to be determined in part by the industrial/economic outcome, not solely by the efficacy and cost. This is problematic because the purpose of military procurement is to acquire the required capabilities to enable the CAF to safely and effectively fulfil the wishes of GC and of Canadians. In blunt terms, that means being able to survive an engagement with an adversary and, if required, defeat an enemy. In that context, while the support of domestic industry is important, this need should not be allowed to put the defence of Canada and/or members of the CAF at risk. To be fair, in procurements initiated since the announcement of the DPS, ITB performance has been given limited importance in the assessment criteria. However, the risk remains.

While the original objective of an indigenous capability has not been achieved in many ways, the next best scenario has been achieved. With appropriate management and continued close cooperation with its allies, Canada can acquire the types of complex and advanced military capabilities needed for the future, while supporting the long-term viability of Canadian industry. However, it cannot do this to any great extent by directly tying the two areas together. Recognizing their diverging paths and crafting a policy that builds on this reality could be a win-win situation for Canada.

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Abbreviations

CAF	Canadian Armed Forces
CFDS	*Canada First* Defence Strategy
DND	Department of National Defence
DPS	Defence Procurement Strategy
DPSA	Defence Production Sharing Agreement
FWSAR	Fixed-Wing Search and Rescue
GC	Government of Canada
GVC	global value chain
ISED	Innovation, Science and Economic Development Canada
IRB	industrial and regional benefits
ITB	industrial technical benefits
JSFP	Joint Strike Fighter Program
MAS	Military Air System
MRO	maintenance, overhaul and repair
NSPS	National Shipbuilding Procurement Strategy
PBL	performance-based logistics
PWGSC	Public Works and Government Services Canada
R&D	research and development
RCAF	Royal Canadian Air Force
SPA	single point of accountability
USAF	United States Air Force
VP	value proposition

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Managing the Personnel Resources of a Military Occupation: Attrition Forecasting and Production Planning

Lynne Serré

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Introduction

The *Canada First* Defence Strategy allocates just over half of total defence spending to the Canadian Armed Forces (CAF) and to Department of National Defence (DND) personnel: the DND's most important resource.[1] Canada's military personnel are a highly skilled, trained and diverse workforce, and Regular Force (Reg F) personnel are employed in just over 100 different military occupations, many of which are also found in the Reserve Force (Res F). One of the primary tools used to manage the health of occupations within the CAF is the Annual Military Occupation Review (AMOR). An occupation is said to be healthy if it has sufficient qualified personnel to meet its operational requirements. Knowledge of attrition plays a crucial role in effectively managing an occupation's health, and attrition forecasts are needed in order to plan the annual recruitment and training of CAF members, as well as for budgeting purposes.

Background

The AMOR is a military personnel management tool that provides occupation authorities, occupation advisors, branch advisors, training authorities and other DND/CAF representatives with a forum to discuss and address internal and external issues that may impact the health of an occupation.[2] Examples of internal issues affecting the health of occupations include retention strategies, career advancement opportunities, limitations on recruitment and training capacity, compensation and benefits, advanced training opportunities, and deployment opportunities. Examples of external issues include changes to industry accreditation standards and pay rates and employment opportunities in comparable civilian occupations.

The health of an occupation can be measured by comparing the size of its trained effective strength (TES) to its preferred manning level (PML). The TES is the number of personnel who have reached the operationally functional point (OFP) for their occupation. The OFP is reached when personnel have completed all training and qualifications required for first employment in their occupation.[3] The PML is the number of authorized positions for each occupation and rank, and is used to establish the target size for the TES. Thus, an occupation is healthy if its TES is close to its PML.[4]

The amount of time and training needed for new recruits to reach the OFP depends on their occupation as well as the entry plan through which they enrolled. For example, a new recruit who enrolled through a university training plan must first complete his/her university degree before starting occupational training, and thus can take up to four or more years to reach the OFP, compared to a recruit who enrolled with a degree.

When a recruit reaches the OFP, an employable member is said to have been produced. Thus, for an occupation to stay healthy, its annual production must match annual attrition as closely as possible. Since it can take several years for a new recruit to reach the OFP, attrition forecasting plays a crucial role in maintaining an occupation's health because recruitment needs must be established well in advance. Attrition forecasting in support of the AMOR is conducted each year by the Director General Military Personnel Research and Analysis (DGMPRA), a research centre within Defence Research and Development Canada (DRDC).

One of the key deliverables of the AMOR is the recommended intake needed to meet the production requirements that will either maintain or restore the health of an occupation. The recommendations from each AMOR are used as the starting point for the development of the CAF's strategic intake plan (SIP), which defines the recruitment plan for the following year. The SIP aligns the AMOR recommendations with the CAF's strategic interests, while taking financial constraints into account.[5]

Outline

The purpose of this chapter is to describe the process by which the attrition behaviour of a CAF occupation is analyzed and used to forecast future attrition volumes in order to inform the annual intake and production planning that occurs in the AMOR. The chapter is organized as follows: the second section provides an overview of the planning models used in the AMOR by the Royal Canadian Air Force (RCAF). The planning models have two main components. The first component, discussed in the third section, focuses on the modelling of intake and production. The second component, outlined in the fourth section, focuses on attrition forecasting. The fifth section explains how the planning model is used in the AMOR and how AMOR stakeholders should assess the model output, and possibly discuss retention and recruitment strategies. The sixth section discusses how in some cases, the current metric of comparing an occupation's TES to its PML may not reflect the occupation's true health. At the end of the chapter, the seventh section provides a summary of the chapter's main points.

Overview of the Planning Models

Planning models are used during the AMOR to determine the annual intake needed to meet the production requirements that will maintain or restore the health of an occupation. Forecasted attrition volumes play a key role in these models because attrition is often the driving force behind production and intake requirements. Future production and intake requirements can also be driven by growth or a reduction in an occupation's PML, as well as by an existing personnel shortage or surplus.

The planning models used by the RCAF were designed and developed by the DGMPRA, and tailored to each officer and non-commissioned member occupation to accommodate differences in their training systems. Each planning model has the same overall structure, which can be divided into two components. The first component, described in more detail in the third section, focuses on determining the intake needed so that the annual production targets either maintain or restore the occupation to a healthy level. The second component forecasts TES attrition and the TES population using the methodology outlined in the fourth section. The two components of the model are interdependent. Attrition volumes influence production requirements because production targets must be set in order to fill vacancies arising from attrition. At the same time, production influences attrition volumes because annual production influences the size of the TES.

Figure 1 illustrates the two components of the planning model for an occupation with two entry plans. The intake column represents the number of members recruited, while the production column represents the number of recruited members who reach the OFP. In this example, the intake column shows five new members recruited in Year 1, three in Year 2, and three in Year 3. Members recruited under Entry Plan 1 reach the OFP in the same year they were recruited, while members recruited under Entry Plan 2 reach the OFP in the year after they were recruited. Both entry plans are subject to attrition, which may be the result of training failures. Once a member reaches the OFP, he or she can occupy a vacant position in the occupation's TES. For example, of the two members recruited under Entry Plan 2 in Year 1, only one reaches the OFP and joins the TES in Year 2; the other member is lost to attrition.

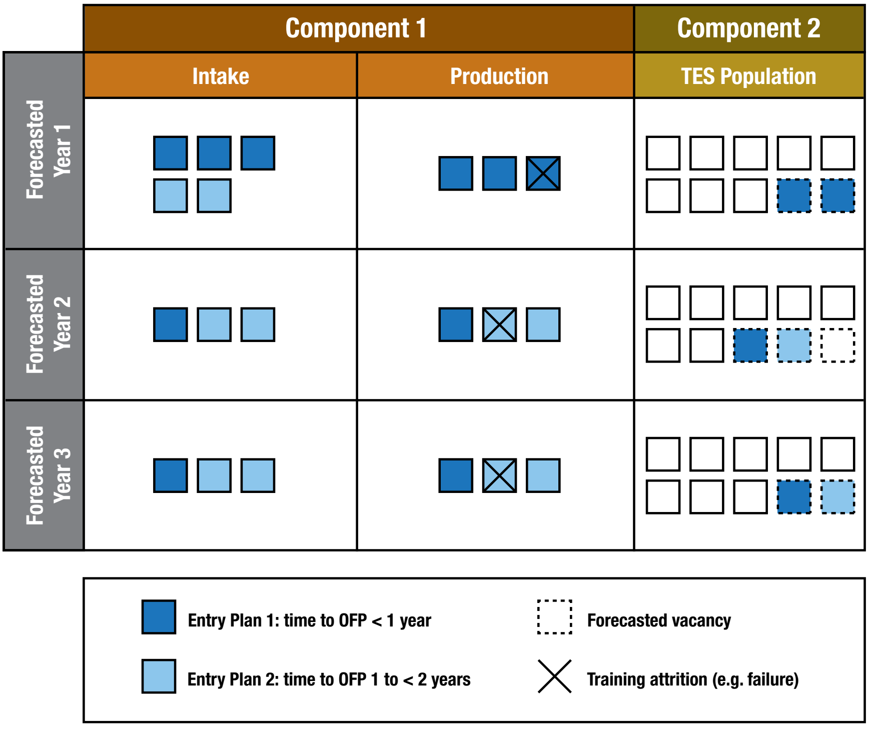

Figure 1. Overview of the components of an occupation planning model

Modelling of Occupation Intake and Production

To determine the annual intake needed to achieve a desired level of annual production, there are several factors that must be considered, including the intake distribution by entry plan, training success rates, training school capacity, and any training backlogs. Each of these factors is described in greater detail below.

Intake distribution by entry plan

Because the recommended intake levels from each AMOR are used as a starting point to develop the SIP for the CAF, the recommendations must be broken down by entry plan and by intake source, either internal or external. Internal recruitment refers to members recruited from within the Reg F, while external recruitment refers to members recruited from outside the Reg F. The planning models must take into account the intake source and entry plan because of the varying times it takes to reach the OFP, because this will influence the annual number of members produced.

For external recruitment, entry plans can be grouped into two categories: Direct Entry and Paid Education. An applicant who enrolls through a Direct Entry plan would have already met the education requirements of the occupation, while an applicant who enrolls through a Paid Education plan would still have to complete his/her college or university studies. For a given occupation, the time to reach the OFP for those enrolling through Paid Education plans will be longer than those enrolling through Direct Entry plans because college or university studies must be completed in addition to occupation training. Although Paid Education plans require more time to reach the OFP, applicants who enroll through these plans will also have a longer period of mandatory service.

Component transfers from the Res F are also a form of external recruitment and provide a valuable source of trained military personnel. Reservists who are already trained in an occupation that also exists in the Reg F may transfer directly to the TES and therefore have the shortest time to OFP. Since Reservists may not have completed all of their training or may choose to change occupations, they may transfer through any of the external entry plans, including Paid Education plans.[6]

Internal recruitment is a valuable source of experienced military personnel. There are a variety of entry plans for internal recruitment purposes, including paid education options as well as mechanisms to enable non-commissioned members to go into officer occupations. Some occupations, for example, a supervisory trade with no junior ranking positions, are only open to internal recruitment, while other occupations depend on a mix of internal and external applicants. Although internal recruitment is a valuable source of experienced personnel, when members move from one occupation to another, they create a vacancy in the occupation from which they left. Therefore, depending on the health of an occupation, the total number of members permitted to move to another occupation may be very limited.

The intake distribution by entry plan will vary from one occupation to another, depending on the occupation's ability to attract internal and external applicants through each entry plan, as well as the need for skilled versus unskilled applicants. Additionally, the distribution by entry plan may vary from year to year, depending on production targets and the respective times to OFP of each entry plan. For example, an occupation that is below PML may increase the proportion of intake targeted through a Direct Entry plan rather than a Paid Education plan because of the shorter time to OFP. Conversely, an occupation that is above PML may increase the proportion of intake targeted through a Paid Education plan in order to keep production lower in the shorter term.

Training success rates

Training from the time of enrolment to OFP can be divided into three phases: (1) university or college studies, (2) basic military training, and (3) occupational training. The first phase applies only to those who enrolled through a Paid Education entry plan. The second phase, basic military training, applies to all military members, and, for those who enrolled through a Paid Education entry plan, is typically completed concurrently with Phase 1. The third phase consists of one or more courses specific to the occupation.

Each phase of training is subject to training failures, which may result in the member releasing or being reassigned to another occupation for which he/she is better suited. Additionally, because training can take months or even years, members may fail to reach the OFP for reasons other than training failures. For example, a member may choose to voluntarily release during basic training or may suffer an injury during occupational training that results in a medical release. The training success rates used in the planning models should reflect the proportion of the intake expected to reach the OFP regardless of the reason.

School capacity and training backlogs

Annual intake and production must be planned in accordance with the capacity of the training school. This is one reason why an occupation's return to PML may be planned over several years. Alternatively, it may be possible to increase a school's training capacity on a short-term basis to help the occupation recover more quickly.

Minimum course capacity should also be considered so that a sufficient number of personnel are available for the course to be given. To optimize the use of training resources, intake should be planned in terms of multiples of the course capacity, so that courses are given at maximum capacity. Depending on the occupation, it is possible that both Reg F and Res F members may take the same course. Therefore, the number of Reservists who may start training should also be taken into account, because this reduces the course capacity for Reg F recruits. However, Reservists have lower training priority than Reg F members.

The number of personnel awaiting training is another factor to consider when planning future intake and production. Depending on the number of personnel awaiting training and their expected wait time, it may be desirable to reduce intake in the near term in order to clear the training backlog.

Modelling of Occupation Attrition

When the CAF's Reg F population as a whole is considered, attrition is defined as releases from the Reg F, which includes members leaving for voluntary or medical reasons and members who have completed their service. For the AMOR, attrition forecasting is done at the occupation level. Therefore, the definition of attrition must be expanded to include transfers to another occupation, because members who transfer out of an occupation create vacant positions that will need to be filled. This expanded definition of attrition is especially important when modelling occupations that feed into other occupations because releases alone may severely under-represent the annual number of vacancies created by departures.

An attrition rate is defined as the proportion of members in a given population that release or transfer out within a specified period of time. The method used to calculate and report attrition rates must be selected in such a way as to be compatible with the type, format and meaning of the available personnel data. The DGMPRA's historical personnel database consists of year-end snapshots of the Reg F population extracted from DND's Human Resources Management System. For reporting and forecasting purposes, the DGMPRA calculates annual attrition rates using a method that accounts for the fact that recruits and transfers arrive throughout the year. Details can be found in the appendices.

Within the context of the AMOR, attrition reporting and forecasting is done for an occupation's TES. Future releases and transfers out from an occupation's TES are forecasted in order to determine the number of vacancies that will need to be filled, which will then be used to determine the annual production and intake requirements. Figure 2 shows typical annual TES attrition rates and year-to-year fluctuations for a Reg F occupation over a 10-year period.

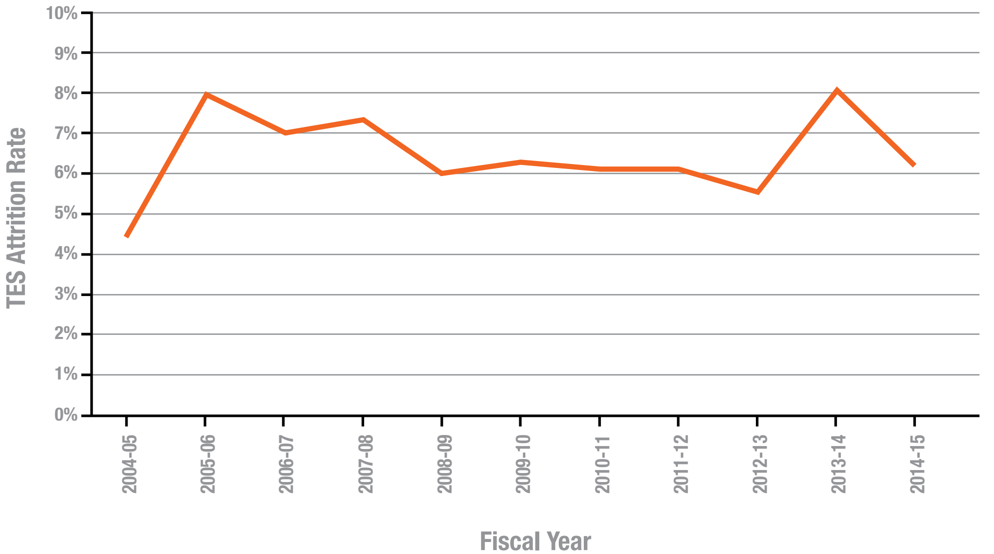

Figure 2. Typical annual TES attrition rates for a Reg F occupation

Attrition rates by years of service

Attrition patterns are often examined on the basis of years of service (YOS) because of the relationship between terms of service (TOSs) and YOS. As defined in *ADM (HRMIL) Instruction 05/05–The New CF Regular Force Terms of Service*,[7] a term of service (TOS) is an agreement between a member and the CAF to provide military service until lawfully released. Over the course of their careers, CAF members are offered a sequence of TOSs, which may bring them all the way to compulsory retirement age. TOSs are usually based on a fixed term measured in YOSs. Although it is possible for members to release before completing the service specified in their TOS, choosing to do so may alter the pension and/or relocation benefits to which they would have been entitled if they had completed their service. These benefits have been shown to influence a member's decision to release early or to complete his/her TOS.

Figure 3 shows a 5-year weighted average TES attrition rate broken down by YOSs for officers and non-commissioned members in the RCAF based on release and population records from April 1, 2010 to April 1, 2015. TOSs have changed over time, which can lead to shifts in the YOS-based attrition behaviour of the CAF population. These shifts often occur over several years or even decades. For example, the Intermediate Engagement 20 (IE20) brings a CAF member to 20 YOSs, at which point he or she is eligible to release with an immediate annuity. Consequently, there is a peak in attrition at

20 YOSs, as can be seen in Figure 3. However, in 2005, TOSs were revised and the IE20 was replaced by the Intermediate Engagement 25 (IE25). Although the TOS changes were made over a decade ago, members serving under IE20 at the time were given the choice to remain on IE20, rather than converting to IE25, and most chose to remain on IE20. In addition, because most members serving under IE25 have yet to reach 20 YOSs, the impact of these changes has not yet been observed, and the peak in attrition at 20 YOSs remains highly visible over 10 years later. However, it is expected that the 20 YOS attrition spike will disappear within the next 10 to 15 years, and a new 25-YOS spike will emerge.

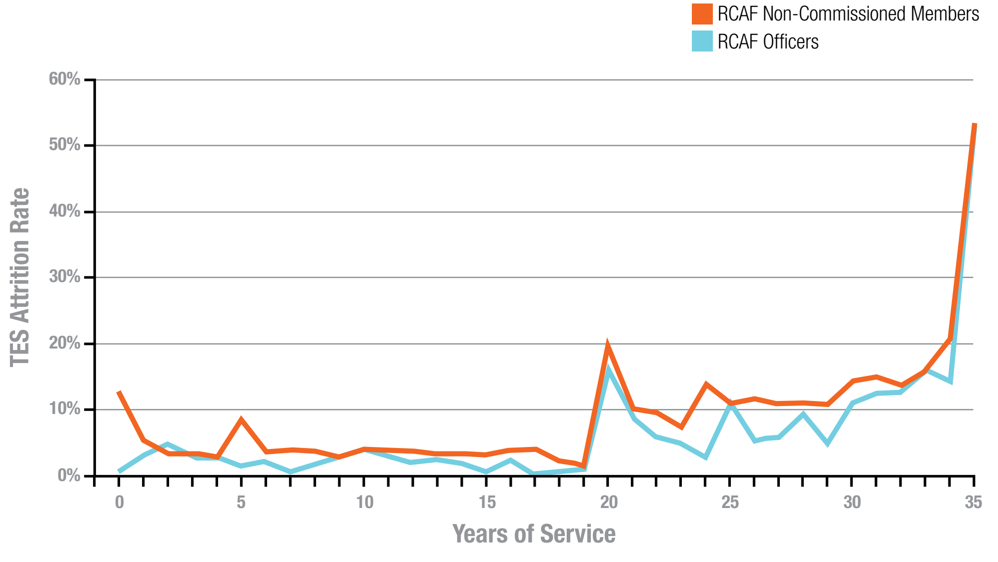

Figure 3. Five-year weighted average TES attrition rates

Forecasting of attrition

The attrition forecasting methodology applied within the context of the AMOR uses a YOS-based attrition rate model and requires three key items of input data:

- the occupation's current population breakdown by YOS (called the population's YOS profile);
- historical attrition rates by YOS; and
- expected future annual production.

The current YOS profile of the occupation is aged one year at a time. Then, for each YOS, the corresponding YOS-based attrition rate is applied to the population and the estimated production is added. This process is repeated for each forecasted year; mathematical details can be found in Appendix B.

A sample population YOS profile and attrition rates by YOS are shown in Figure 4. It can be seen from the figure that even if the YOS-based attrition rates were to remain constant, it is possible for the overall future attrition volume and rate to vary from year to year because of changes in the population demographics. For example, consider the TES population between 18 and 20 YOS shown in Figure 4. The TES population is much larger at 18 YOS than at 19 YOS, and much larger at 19 YOS than at 20 YOS. Therefore, assuming that attrition behaviour remains constant, the attrition volume would be expected to increase over the next 2 years because the population passing through the high attrition point at 20 YOS is larger than in the previous years. Thus, the attrition forecasting methodology takes into account both the historical YOS-based attrition behaviour of an occupation and its population YOS profile.

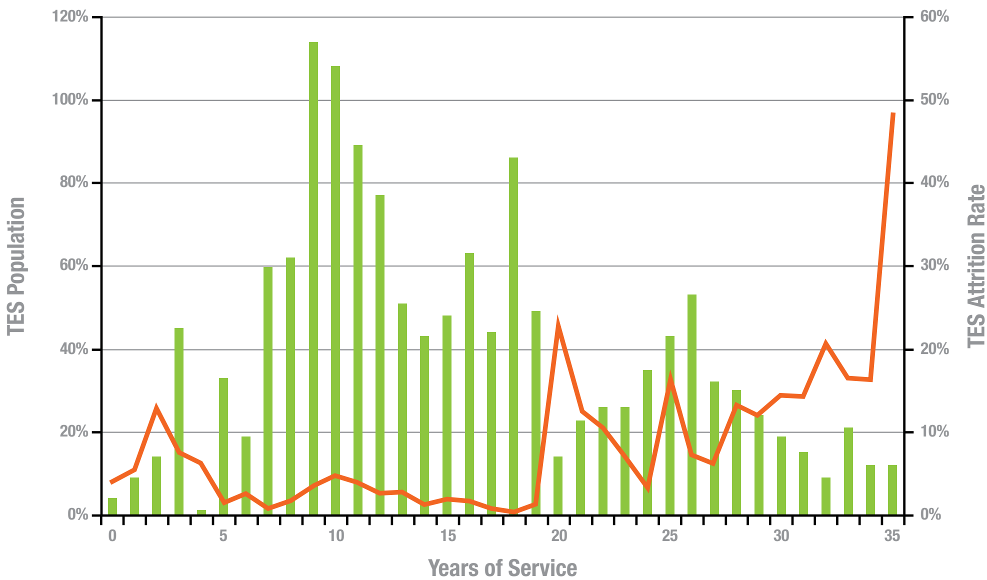

Figure 4. Sample YOS profile and attrition rates

The historical YOS-based attrition rates will vary depending on the number of years of history used in the attrition rate calculation. This will impact the resulting attrition forecast as shown in Figure 5, which presents the same historical attrition rates as in Figure 2, but shows three different forecasts based on attrition models using three different historical periods. The choice of historical period used to represent an occupation's attrition behaviour is influenced by several factors, including the size of the population, the variability in past attrition rates, and shifts in past attrition behaviour. Research into the choice of historical period carried out by the DGMPRA[8] resulted in a three-step selection process. The first step is to analyze the historical data from a statistical point of view for any changes, shifts or trends in the attrition rates, while considering the available sample size. The second step is more subjective and consists in assessing whether the historical period identified in the first step should be modified given other available information, such as changes in policies or changes to an occupation's structure that may influence attrition. Discussions with subject matter experts (SMEs), such as the occupation managers, can provide invaluable context for the historical data by highlighting past changes in policies, occupation structure, morale or the economy that may have influenced attrition behaviour. SMEs can also provide insight into any upcoming occupation or policy changes. The third step is to conduct sensitivity analyses to assess the impact that various historical periods will have on the forecasted attrition volumes. The sensitivity analyses can provide best- and worst-case attrition scenarios based on historical attrition behaviour.

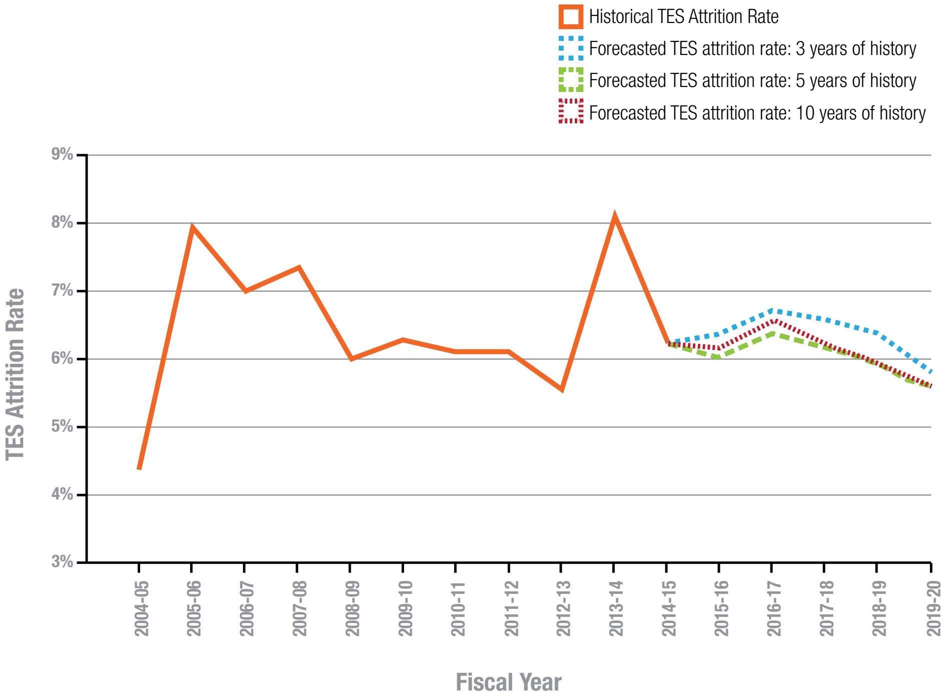

Figure 5. Sample attrition forecasts based on varying amounts of historical data

Other research by the DGMPRA[9] demonstrated that the number of years to be forecasted and population size must also be taken into consideration when selecting the historical data period. As a general rule, short-term forecasts (less than five years) should be based on shorter historical periods, while long-term forecasts should be based on longer periods. Attrition behaviour in the next one to three years is more likely to be consistent with recent historical behaviour than attrition behaviour five to ten years from now, as policies and economic conditions change over time. However, more history should be used for smaller occupations in order to increase the amount of data available to build the attrition model.

When new occupations are created or existing ones undergo changes, historical attrition behaviour may not be available. If, for example, in the case of an occupation for which only experienced personnel from within the CAF (i.e., personnel with over 5 YOSs) are currently recruited, a decision is made to open up the recruitment plan for that occupation to direct entry recruits, the occupation will now have members with 0 to 5 YOSs for whom there is no historical attrition behaviour. In such a case, it may be necessary to base attrition behaviour on one or more occupations with similar characteristics in order to forecast future personnel demand.

Forecasting of challenges and limitations

In the context of the AMOR, all types of attrition, whether for voluntary, medical or other reasons, in addition to transfers out of the occupation, must be forecasted because each departure creates a vacancy in the occupation's TES. At the CAF level, from 2011 to 2015, voluntary attrition was the most common type of attrition for trained Reg F personnel, followed by medical attrition and service completion. However, the ordering and proportion of release types varies by occupation. For example, in some occupations managed by the RCAF, service completion was the most common type of attrition.

Internal factors, such as policy changes to pay and benefits, and external factors, such as economic conditions, can impact one or more types of attrition; and sometimes in opposite ways. For example, an increase in the compulsory retirement age may impact service completion and voluntary attrition behaviour, and perhaps medical attrition rates as well because of its potential for contributing to an aging workforce. Regardless of the type of attrition affected, these internal and external factors can lead to changes in the overall attrition behaviour of the occupation, often in ways that are difficult to predict quantifiably. Since the attrition forecasting methodology is based on past attrition behaviour, if future attrition behaviour differs significantly from past behaviour, this will affect the accuracy of the forecasts. The accuracy of the forecasts will also be affected by deviations in the expected production in future years, which is often dependent on whether the occupation was able to meet its recruitment targets.

An inherent challenge with occupation-level forecasting in the CAF is the size of the populations being studied: from 2011 to 2015, 80% of occupations within the RCAF averaged less than 50 releases from the TES per year and 95% of occupations averaged less than 100 releases from the TES per year. The small release volumes pose a challenge in terms of detecting and quantifying trends between occupation-level attrition and external economic factors, such as unemployment rates, as well as the lag time between changes in the economy and changes in attrition behaviour. Because of the unique nature of the work in some military occupations, the impact of economic factors likely varies by occupation and may be minimal or even negligible in some cases.

Operating the Planning Models and Evaluating the Output

The planning models are spreadsheet-based models designed to allow interactive and instantaneous what-if scenario analysis to be conducted during the AMOR meeting while all stakeholders are present. Each year, in advance of the AMOR meetings, the DGMPRA populates the planning model for each occupation with the needed historical data and current TES population and conducts the attrition forecasting. Model inputs, such as intake distribution by entry plan and training success rates, are validated by the occupation managers and updated as needed.

The planning models provide three key outputs:

- an attrition forecast over the next five to ten years;
- the projected gap between the TES and PML over the next five to ten years; and
- the annual intake by entry plan needed to meet the production requirements over the next five to ten years.

The third output is one of the key deliverables of the AMOR and provides a starting point for drawing up the CAF's SIP.

Generally, the planning models are set up to provide a five-to-ten-year outlook on the occupation's health. When an occupation is below PML, the occupation manager aims to set the annual production levels in the planning model in such a way that the occupation's TES returns to PML, often gradually over a number of years, as shown in Figure 6. Once production levels are established, the model calculates the annual intake needed by considering factors discussed in the third section, such as the intake distribution by entry plan, the training time and the training success rate. When considering the intake plan proposed by the model, it is important to assess whether the intake targets are achievable by taking into account the occupation's success at meeting past intake targets. For example, if an occupation has a proposed intake of 50, but only succeeded in meeting half of last year's target intake of 40, then a target intake of 50 may not be attainable.

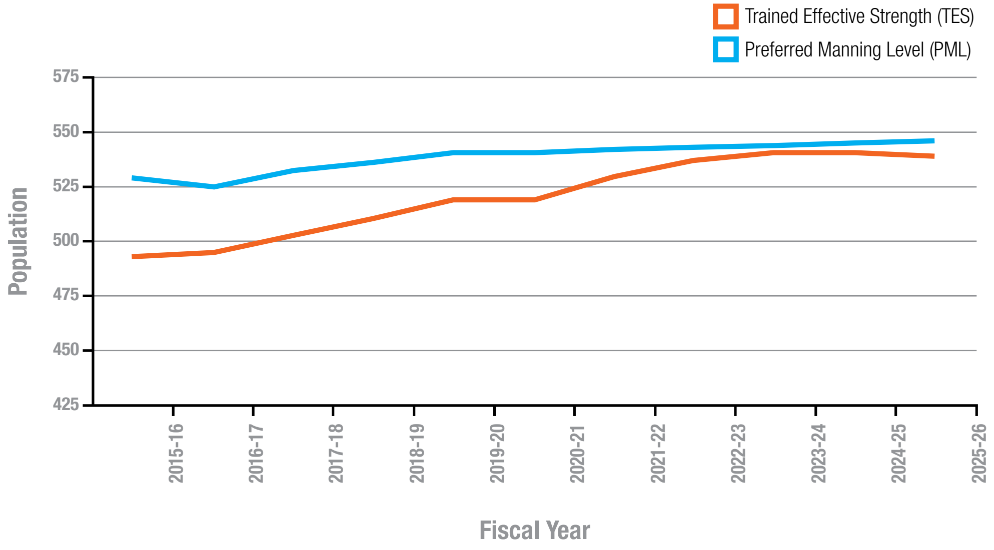

Figure 6. Sample chart from the planning model user interface showing the projected TES and PML gap

The process of determining the production targets is often iterative. If the proposed intake is not expected to be achievable, the model user, typically the occupation manager, can adjust the production targets to reduce the annual intake. AMOR stakeholders are then able to immediately see the impact of lower intake targets on the occupation's long-term health, which can be used to support or initiate discussions about strategies that may be required to boost annual intake, such as advertising campaigns or the use of specialized recruiters.

If stakeholders at the AMOR meeting have reason to expect that future attrition will be higher or lower than that forecast by the model, the planning model is set up so that the model user can increase or decrease the attrition forecast by a fixed percentage in order to see the potential impact on the occupation's long-term health for the current set of production targets. If attrition is expected to be higher than in the recent past, the AMOR can be used as a platform to discuss new or ongoing retention initiatives while all stakeholders are present, which could include retention bonuses, advanced training opportunities, or changes to the TOS sequence. Alternatively, stakeholders may consider increasing their production targets to accommodate an anticipated increase in attrition.

It is important that the recommended intake be reviewed by the training authorities to ensure that the school has the capacity to meet the training demand. A surge in recruitment is only possible if the schools can accommodate the increased number of recruits, which may require approval and funding for additional training instructors and infrastructure, or for training options outside the CAF, such as courses offered by external contractors. While a surge in recruitment may be supported by the model and recommended by the stakeholders, the development of the SIP will align the recommendations from each AMOR with the CAF's strategic interests, while taking financial constraints into account. In particular, the overall intake target for the CAF must align with its annual capacity to process and enroll applicants. Therefore, in some occupations, a reduction in the recommended intake may be necessary so that the overall intake goal does not exceed capacity.

Discussion

An occupation is healthy if it has sufficient qualified personnel to meet its operational requirements, which is measured by comparing an occupation's TES to its PML. However, if the PML has remained unchanged for years while the operational demands on the occupation have increased, the PML may have become outdated and is in need of review. In these cases, it is possible for an occupation to be unhealthy even though its TES is equal to its PML.

In order to review the PML of an occupation and its personnel requirements, the occupation's operational and workload requirements must be reviewed. If the number of positions is found to be insufficient, instead of increasing the PML, it may be possible to reduce pressure on the occupation by finding efficiencies in administrative tasks or reassigning selected administrative and training tasks to civilian or Reservist positions. Alternatively, it may be possible to redistribute an occupation's workforce either geographically, for example, to military bases with a higher operational tempo, or to convert positions exercising an institutional role to an operational role. If an increase in establishment size is the only option, it may be difficult to increase the occupation's PML without impacting the health of another occupation because the total number of paid positions across all occupations within the CAF is subject to financial constraints.

Another aspect of occupation health is whether there are sufficient qualified personnel in the lower ranks to be promoted into the higher ranks when vacancies arise through attrition. If attrition is unusually high in one rank, there may not be a sufficient number of qualified personnel to be promoted when vacancies arise in the next rank. Previous periods of low recruitment or force reduction programs can also create experience gaps, resulting in a small pool of qualified personnel who are eligible for promotion to the next rank. Although not captured in the planning models, this aspect of health may be discussed during the AMOR.

Conclusion

The AMOR is a military personnel management tool designed to manage the health of occupations within the CAF. One of the key deliverables of AMOR meetings is the recommended intake level by entry plan for each occupation, which provides the starting point for drawing up the CAF's SIP. Attrition forecasting plays a key role in determining the annual intake and production needed to restore and maintain an occupation's health. Production requirements must be planned in order to fill future vacancies arising through attrition as well as to manage any desired growth or reduction in an occupation's PML.

This chapter describes the process used by the DGMPRA, in support of the AMOR, to measure historical attrition behaviour, forecast future attrition volumes, and plan production and intake requirements for occupations managed by the RCAF. This process does not always lead to healthy occupations across the RCAF, because there are many complex factors that may place an occupation in an unhealthy situation. However, it allows personnel planning decisions to be made with objective information about the state of the occupation and knowledge of the likely outcome of possible courses of action. In general, this produces more effective personnel planning decisions that will help keep occupations within the CAF as healthy as possible in a context of continuing economic, budgetary, and policy challenges and changes.

Appendix A: Reporting Historical Attrition Rates

Overall attrition rate

Prior to the methodology review, the DGMPRA and its predecessors, following the notation used in Okazawa's study,[10] calculated the annual attrition rate for a given year n, denoted by $\alpha(n)$, as follows:

$$\alpha(n) = \frac{a[n]}{p[n] + a[n]}$$

where $a[n]$ represents total attrition between years $n - 1$ and n, and $p[n]$ represents the population at the end of year n. In this case, $p[n]$ includes all recruits as though they enrolled at the beginning of year n. However, since recruits are enrolled gradually throughout the year, the population in the denominator is overestimated and the resulting attrition rate is underestimated.

The new methodology assumes that recruits enroll randomly throughout the year and therefore are present for only half of the year on average. The derivation under this assumption (see complete details in Okazawa's study[11]) yielded the following formula for calculating the annual attrition rate for a given year n:

$$\alpha(n) = \frac{a[n]}{p[n-1] + \frac{1}{2} r[n]}$$

where $r[n]$ represents total recruitment between years $n - 1$ and n.

Often, attrition rates are calculated over a period of years rather than for a single year, especially when populations are small and attrition is highly variable from year to year. To calculate the attrition rate over a period of N years, the following formula is adapted to a weighted average attrition rate, denoted by WAAR(α):

$$\text{WAAR}(\alpha) = \frac{\sum_{n=1}^{N} a[n]}{\sum_{n=1}^{N} (p[n-1] + \frac{1}{2} r[n])}$$

YOS-based attrition rates

Okazawa's study[12] also derived new formulas for reporting attrition rates by YOS. When breaking down an occupation by YOS, recruits usually enter at the zero YOS point. However, transfers from other occupations may enter the occupation at YOS points greater than zero. Following the notation in Okazawa's study,[13] let $p_m[n]$ represent the population with m YOS at the snapshot time n, let $T_m[n]$ represent the number of transfers in between year $n - 1$ and n who would have had m YOS at the snapshot time n, and let $a'_m[n]$ represent total attrition between year $n - 1$ and n with m YOS on the date of their release or transfer out. The weighted average YOS-based attrition rate is

$$\text{WAAR}(\alpha_0) = \frac{\sum_{n=1}^{N} a'_0[n]}{\sum_{n=1}^{N} (\frac{1}{2}\, p_0[n-1] + \frac{1}{2}\, r[n] + \frac{1}{6}\, T_1[n])}$$

for $m = 0$, where $r[n] = T_0[n]$ represents recruits, and

$$\text{WAAR}(\alpha_m) = \frac{\sum_{n=1}^{N} a'_m[n]}{\sum_{n=1}^{N} (\frac{1}{2}\, p_{m-1}[n-1] + \frac{1}{2}\, p_m[n-1] + \frac{1}{3} T_m[n] + \frac{1}{6}\, T_{m+1}[n])}$$

for $m > 0$.

Appendix B: Formulas for Forecasting TES Attrition

The DGMPRA's forecasting methodology breaks down the occupation's TES population into YOS segments and projects each of these segments forward through time. Since new members are hired throughout a year, any given member will spend the first part of a year with m YOS and the remaining part of the year with $m + 1$ YOS. Because the DGMPRA's personnel database consists of year-end snapshots, YOS will be measured as of the snapshot time n.

Following the notation used in Okazawa's study,[14] let $a_m[n]$ represent total TES attrition between year $n - 1$ and n of members who would have had m YOS at the snapshot time n, let $p_m[n]$ represent the TES population having m YOS at the snapshot time n, and let $T_m[n]$ represent the expected production between year $n - 1$ and n having m YOS at the snapshot time n. Then, the future TES population for year n with m YOS can be calculated as follows:

$$p_m[n] = (1 - \text{WAAR}(\alpha_{m-1,m}))p_{m-1}[n-1] + (1 - \tfrac{1}{2}\,\text{WAAR}(\alpha_{m-1,m}))T_m[n]$$

where, for $m > 0$,

$$\text{WAAR}(\alpha_{m-1,m}) = \frac{\sum_{n=1}^{N} a_m[n]}{\sum_{n=1}^{N} (p_{m-1}[n-1] + \frac{1}{2}\, T_m[n])}$$

and, for $m = 0$,

$$\text{WAAR}(\alpha_0) = \frac{\sum_{n=1}^{N} a_0[n]}{\sum_{n=1}^{N} (\frac{1}{2}\, T_0[n])}$$

Future annual TES release volumes can then be forecasted by applying the weighted-average attrition rate WAAR(α_m) defined in Appendix B to the forecasted TES population as follows:

$$a_m[n] = \text{WAAR}(\alpha_m) \times (\tfrac{1}{2}\, p_{m-1}[n-1] + \tfrac{1}{2}\, p_m[n-1] + \tfrac{1}{3} T_m[n] + \tfrac{1}{6}\, T_{m+1}[n])$$

for $m > 0$, and

$$a_0[n] = \text{WAAR}(\alpha_0) \times (\tfrac{1}{2}\, p_m[n-1] + \tfrac{1}{2}\, T_0[n] + \tfrac{1}{6}\, T_1[n])$$

for $m = 0$.

Total TES attrition for year n can then be calculated by summing the predicted release volume at each YOS point m:

$$a[n] = \sum_{m=0}^{\max YOS} a_m[n]$$

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Abbreviations

AMOR	Annual Military Occupation Review
CAF	Canadian Armed Forces
DGMPRA	Director General Military Personnel Research and Analysis
DND	Department of National Defence
DRDC	Defence Research and Development Canada
OFP	operationally functional point
PML	preferred manning level
RCAF	Royal Canadian Air Force
Reg F	Regular Force
Res F	Reserve Force
SIP	strategic intake plan
SME	subject matter expert
TES	trained effective strength
TOS	term of service
YOS	years of service

Notes

1. Canada, DND, *Canada First* Defence Strategy, 2008.

2. Canada, DND, *CAF Military Personnel Instructions 01/08 – Annual Military Occupation Review (AMOR)*, revised on 25 September 2013, 2008.

3. Canada, DND, *The Canadian Armed Forces Military Employment Structure*, Volume 1 of 4, 2015.

4. The standard threshold used within DND is that an occupation is healthy if its TES is no more than 5% below its PML. An occupation's health is considered critical once its TES is more than 10% below its PML.

5. Canada, DND, *CAF Military Personnel Instructions 01/08.*

6. Canada, DND, *CAF Military Personnel Instructions 01/08.*

7. Canada, DND, *ADM (HRMIL) Instruction 05/05 – The New CF Regular Force Terms of Service*, revised on 17 January 2008, 2005.

8. M. Fang, *Systematic Review on Attrition*, presented to the TTCP Workforce Modelling and Analysis Working Group, Ottawa, May 6, 2008 (Ottawa: DRDC, 2008).

9. S. Okazawa, *Determining the Optimal Volume of Historical Data to Use in Attrition Models*, DRDC CORA Technical Memorandum 2008-02 (Ottawa: DRDC, 2008).

10. S. Okazawa, *Measuring Attrition Rates and Forecasting Attrition Volume*, DRDC CORA Technical Memorandum 2007-02 (Ottawa: DRDC, 2007).

11. Okazawa, *Measuring Attrition Rates and Forecasting Attrition Volume*.

12. Okazawa, *Measuring Attrition Rates and Forecasting Attrition Volume*.

13. Okazawa, *Measuring Attrition Rates and Forecasting Attrition Volume.*

14. Okazawa, *Measuring Attrition Rates and Forecasting Attrition Volume*.

Additional Reading

Canada, Department of National Defence. *Report on Plans and Priorities*. 2016.

Aircrew Simulated Flight Training for Aircrew: Evaluating the Benefits

Stuart Grant

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Introduction

People are a foundational element of the Royal Canadian Air Force (RCAF), so having well-educated and highly skilled people is essential to achieving the RCAF's strategic objectives.[1] Consequently, the RCAF spends considerable time and funds to develop and maintain trained aircrew. Because other key contributors to air power also require time and funding, judicious management is needed when determining how many resources to allocate to training and how the allocated resources are to be used. Therefore, as far back as the early years of powered flight, flight simulation has been used as an aircrew training tool.[2] Beginning in the 1960s and 1970s,[3] reviews of the scientific literature on flight simulation training using flight simulators and aircrew training devices found a growing body of evidence that simulation training is effective. The ongoing acquisition and operation of flight simulators by armed forces, airlines and flight training schools attests to the value of flight simulation for aircrew training.

Although flight simulators[4] can be effective training devices, acquiring and training with simulators requires time, money and personnel. To decide when, where, why and how to use flight simulation for training, it is necessary to understand the benefits versus the costs of flight simulation. This chapter provides an overview of decisions to invest in aircrew training, with an emphasis on the training methods that use flight simulation. Although the valuation of the inputs into flight simulation is fairly mature, the valuation of the training benefits is not, so the latter is discussed in depth. Further on, consideration is given to the methods used to understand and weigh the costs and benefits. Three examples of these methods as applied to RCAF flight simulation training are then provided to illustrate the methods and to discuss their strengths and weaknesses. The chapter concludes with a discussion of some of the challenges involved in using these methods in training and of how future work may mitigate these challenges.

Investing in Aircrew Training

Decisions concerning investments in aircrew training can involve the commitment of substantial resources. For example, the Operational Training System Provider procurement of simulation training equipment for the RCAF's CC130J and CH147 aircrew cost $348M and $235M respectively.[5] The wording of the *Financial Administration Act*[6] and Cicero's (43 BC) assertion[7] that an abundance of money is the sinews of war make it imperative that these decisions be justifiable.

Although the components of the process used by governments to make investment decisions have been described in various ways, that of the United Kingdom provides the following straightforward and adaptable description of what the process involves:[8]

- identify objectives;
- identify options for achieving the objectives;
- identify the criteria to be used to compare the options;
- analyze the options;

- make choices; and
- provide feedback.

In the case of investing in aircrew training and flight simulation, it is a given that one of the objectives is to obtain qualified aircrew, and that the options will include flight simulation as at least one part of a blended learning approach. Other objectives, such as the effect on national industry and the economy, are relevant to particularly substantial government investments. As part of Canada's Defence Procurement Strategy, the Industrial and Technological Benefits Policy (ITBP)[9] includes the following objectives in all defence procurements with a value of more than $100M:

- provide support for the growth and sustainability of the defence sector in Canada;
- promote the growth of prime contractors and suppliers in Canada;
- increase innovation through research and technological development in Canada; and
- increase the export potential of Canadian companies.

Criteria are needed to compare investment options, including the costs of the investment and the benefits obtained. Lastly, a decision-making method is required so that a selection can be made based on these comparisons.

Valuation of Input Costs

The criteria describing the resources invested are the costs of the investment. Cost analysis can be demanding, but well-established methods are available. A cost structure describes the expected costs, and there are numerous examples available for particular circumstances and stakeholders. These include a comprehensive cost element structure for modelling and simulation,[10] military training in general,[11] and aircrew training in particular.[12]

To obtain data for the identified costs, DND's (Department of National Defence) cost factor manuals are useful and authoritative sources of data on the cost of personnel[13] as well as equipment and facilities.[14] The manuals helpfully include some fully worked exercises for estimating the cost of operating major ships, vehicles and aircraft. The Director Aerospace Equipment Program Management (Tactical Aviation & Simulation) has specific experience with the project costs of aircrew flight simulation training in the RCAF. In the case of contractor-supplied training, the contract documents should provide the necessary costing data for analyzing current programs, which may also be helpful in looking at future contracted training. Lastly, the Department also provides a standardized method for managing the costing risks in projects.[15] For illustration purposes, relatively recent worked examples of costing are available.[16] There may be some difficulty in dealing with inputs other than money, personnel, facilities and equipment if they are not market-traded goods. In this case, shadow pricing, as discussed further on in the valuation of benefits, can be used.

Valuation of Benefits

The desired results of the investment, as described in the criteria, are the benefits. Many benefits can be ascribed to training aircrew using flight simulation over and above the benefits of aircrew training in general. The methods used by DND to understand and evaluate these benefits are much less developed than the methods used for costing. As far back as 1994, the first Chief Review Services (CRS) recognized the effectiveness of flight simulation, but had difficulty quantifying the benefits.[17] Reasons included shortcomings in the Department accounting systems' ability to capture costs, a lack of training effectiveness data, and methods for analyzing the problem. This difficulty is not unique to DND. The United States (US) Department of Defense (DoD) also struggles with determining "how much is a pound of training worth?"[18] Results that provide straightforward financial benefits are easier to analyze than results that are basically non-monetary.

Assessing training effectiveness

A basic step in evaluating the benefits of training and flight simulation is to determine the type of training provided by a particular option. Although training generally works, and the viability of using flight simulation technology to provide effective training is well established, the effectiveness of particular solutions may vary, and evidence of their effectiveness for the intended use should be obtained.

Some kinds of training effectiveness data are better than others, and Kirkpatrick's four-level model of training evaluation is useful in this regard.[19] The first level of evaluation, i.e., learning reaction, is proven to have limited value. Asking trainers and trainees whether they like the system or want to use it has little predictive value as to whether they will gain from its use. Nevertheless, it is worth noting whether or not they show a strong dislike of the system, because this may indicate that the system is indeed ineffective, or at the very least, the system will not have an opportunity to provide training value if the users resist using it. The second level is determining whether the trainees learn in the training context. This should be taken as a necessary, but not sufficient, condition for showing training effectiveness. If the trainees cannot demonstrate that they have learned something in the training situation, it is very unlikely that they will demonstrate the benefits of learning once they are back on the job. The third level of effectiveness evaluation is to determine whether the training transfers to the job, and the conduct of operations is necessary for the training system. Evidence of this demonstrates that the training system is serving its intended purpose. The fourth level of training effectiveness is to determine whether the impact of the training on the enterprise can validate the initial objective of training the aircrew.

When there is evidence of training transfer, it should be looked at critically because these assessments are often subject to a number of errors.[20] A particularly common error, and one especially relevant to the comparison of training options with the baseline scenario, is to misinterpret a statistical result as meaning that there is no significant difference between outcomes. A finding that there is no statistically significant difference between the outcomes of competing training methods only means that it is not possible to tell the difference using the data provided. This result might arise because the competing methods are equally effective or ineffective, but there is more likely to be an insufficient quantity or quality of data to be able to detect a difference. A better approach is to determine the training effect of each option, including a confidence interval. This will provide an estimate of the effectiveness of the training option as well as the reliability of the estimate. Poor or insufficient data will be revealed if there is a wide range of estimated value of the training effect.

One way to obtain better estimates of training effectiveness is to collect more data. However, collecting more data gives rise to least two problems. First, there must be an opportunity to collect the relevant data, which will not be possible if the system concerned does not yet exist, or if the training of interest is too dangerous to test. The second problem is cost. Increasing the number of observations may become unaffordable. Given these problems, it may be better to concede that the behaviour of interest cannot be measured reliably and to look for an alternative approach. Boldovici[21] provides a detailed explanation of the challenges of statistical analysis and experimental design to determine training effectiveness.

In evaluations of training systems, ratios are sometimes used to express the effectiveness of training. Training efficiency ratios, incremental training efficiency ratios and percentage transfer are calculations that attempt to relate the amount of training benefit obtained from one system (typically a simulator) to the training benefit obtained or required from another (such as live flight). These ratios, while accurate in and of themselves, can lead to at least two misunderstandings. First, when used in isolation, they hide critical data. Boldovici[22] provides the following example of a training effectiveness ratio (TER)

$$TER = \frac{L_c - L_s}{S_s}$$

where L_c is the number of live training trials that a control group needs to achieve the standard, L_s is the number of live training trials that a simulator-trained group needs to achieve the standard, and S_s is the number of simulator trials provided for the simulator-trained group. Consider the case where the control group needs 10 live trials to achieve the standard and the simulator group needs 5 live trials to achieve the standard after receiving 5 simulator trials. The TER equals 1.0 and is interpreted as showing that the simulator trials are as effective as the live trials. However, any system that uses a combined total of 10 trials to achieve the standard produces the same ratio. A system requiring 9 simulated trials and 1 live trial is the same as a system requiring 1 simulated trial and 9 live trials.

A second concern about the use of ratios is that they strip away the context of the data and invite users to extrapolate outside the conditions that produced the ratio. A simulator that produces training results as good as those of the live system with one population of trainees or at one stage of training may not be as effective with other populations or at different stages of learning. Boldovici[23] advises that reporting the raw training results is the most informative way to communicate training effectiveness. If ratios are to be used, they should be accompanied by careful explanations of how they should and should not be interpreted.

Assumption of live training as a gold standard

Live training is sometimes uncritically assumed to be the "gold standard" of training, even though it might be better viewed as simply the baseline scenario method. As a result, the proponents of flight simulation are often challenged to demonstrate its effectiveness, even when the live comparator is not,[24] and this can compromise the ability to evaluate options. Reliable, diagnostic data on the baseline scenario training method should be obtained as well, so that informative comparisons can be made. However, this may require additional work on the part of the analyst because ongoing training programs frequently record only outcome data, such as whether or not an individual met the standard. Unit records for small arms training in the Canadian Army (CA) typically include information on whether the soldier passed his/her annual personal weapons test. Additional information may be kept as to whether a re-test was required, because this is important for tracking ammunition expenditure. Better data, such as information on the difficulty involved in particular types of shooting (e.g., deliberate fire or snap shooting), could be valuable in determining which particular type of training might yield the greatest benefit for qualification rates.

Another aspect of treating live training or the baseline scenario as the gold standard is that the training benefit it delivers becomes the objective for the new system. Before accepting that level of proficiency as the objective, it is worth considering whether a different level of proficiency should be sought. The proficiency attained through the baseline system might be operationally justified, but it might simply be the best that can be achieved with the baseline system. Such approaches can undervalue the opportunities that newer training technologies can offer. One way in which this arises is where cost minimization is set as the predominant factor in evaluation.[25] As a result, the training option is evaluated at the extreme end of the cost-capability trade off attainable by that system.

Monetary benefits

A benefit, seemingly the overriding benefit, of flight simulation is cost avoidance. The fungibility of money puts aircrew training in direct and indirect competition with other government priorities (e.g., flying for operations and health care). Training methods that avoid costs relative to other methods have a compelling appeal at every level of this competition. For this reason, the perennial shocks to government finances—from the oil embargo imposed by the Organization of Petroleum Exporting Countries in the 1970s to the financial crisis of 2008—have been used to sell flight simulation. The results produced by cost avoidance methods are attractive to analysts because they are measured in the same units as costs, permitting the calculation of gains, losses and ratios.

The most obvious, and perhaps most important, cost avoided by flight simulation is the reduced number of training sorties, where the costs to be avoided are substantial. The cost of aviation petroleum and lubricants, operations and maintenance, and the national procurement costs of flying a CF18 or a CT142 for an additional hour are $8,700 and $1,400 respectively.[26] The cost of aircrew, maintenance personnel and support personnel, and other costs for each flight hour are also available.

Data for analyzing cost avoidance can often be readily collected from simulation devices.[27] Cooley et al.[28] compared the same training tasks performed in flight simulation and in a live environment and were able to make a strong case for real cost avoidance. However, if the constraint of identical training events is not imposed, it is possible to produce data showing very high cost avoidance. For example, Worley et al.[29] report on a program of hardware in the loop testing of missiles that conducted 8,400 simulated AIM120 launches per year. Taken at face value, this produced a cost avoidance of over

US$2.4B. This is inconceivable for a live test program: the report offered 12 as a more realistic option for live testing. Similarly, an experimental simulation-based basic gunner course for the CA's L1A1 Leopard tank fired over 9,400 simulated rounds—many more than are used in the standard live-fire course.[30] Again, counting the live-fire cost of the simulated rounds fired would provide a total savings that was unrealistic. The real benefits were the time saved by the experimental course and the live rounds saved relative to the original course. The intention in issuing this caution is not to discount the value of conducting many more training events in simulation than would be affordable in live training. Indeed, that is one of the attractive aspects of flight simulation. The caution is that in order to avoid unrealistic estimates of cost avoidance, an upper limit on cost avoidance should be established based on plausible alternative solutions. The benefit provided by additional events in simulation should be determined otherwise, such as greater proficiency, wider experience or reduced forgetting.

Using a simple cost structure consisting of personnel and operating costs, Orlansky et al.[31] found that the cost of conducting close air support in flight simulation amounted to one-tenth of the cost of conducting the training live. However, personnel and operating costs are not the only costs. Many other costs can and should be determined for the entire flight training option being considered, including all training devices (e.g., aircraft, simulators and classrooms) and entire system life-cycle costs (e.g., research and development, initial acquisition and disposal, and direct and indirect operating costs).[32] Jolley and Caro[33] provided a dated but particularly thorough analysis that found, in addition to the more obvious costs, that flight simulation avoided $10 in janitorial services and nearly $1,000 in driver's wages per month. These non-flight costs can be expected to become increasingly important in the costing of aircrew training as pure live-flight training baseline training options become less common, and blended learning options using combinations of live, simulated and computer-based training become the norm.

Non-monetary benefits

The RCAF's mission is not to make a profit, but to provide the Canadian Forces with relevant, responsive and effective airpower to meet the defence challenges of today and into the future.[34] The mission is non-monetary, so it follows that non-monetary contributions to that mission should not be overlooked. This next section looks at some of the non-monetary benefits resulting from the use of flight simulation in aircrew training.

Operational effectiveness

Perhaps the pre-eminent non-monetary benefit of flight simulation for aircrew training is operational effectiveness. The RCAF exists to deliver air power, and training is essential to achieving that goal. This is difficult to incorporate into formal decision making, but I nevertheless offer it first because it speaks directly to why aircrew are being trained and deals with the gravest of outcome measurements. Definitive data in the form of causal effect data relative to the impact of training on combat performance are very rare and dependent on natural experiments. Weis,[35] who analyzed air-to-air combat in the First and Second World Wars, found that a pilot in his/her first air combat mission had a very high chance of being shot down, but a pilot who had shot down 5 aircraft had only a 5% chance of being shot down in an air-to-air engagement, and less than 1% after 30 victories. This finding can be taken as evidence of a strong effect of experience on performance, but it does not involve training or simulation.

The US experience in the Viet Nam War is an even more compelling case for the operational benefits of flight simulation training. In the first four years of the air war, United States Air Force (USAF) and United States Navy (USN) pilots both achieved a kill ratio of about 2.5:1 over their North Vietnamese adversaries. During a lull in the air war, the USN introduced its TOP GUN fighter weapons school for its pilots, which used live simulations to train pilots for air-to-air combat. Following the hiatus, the USN achieved a kill ratio of over 12:1; whereas, the USAF kill ratio was virtually unchanged.[36]

Simulation data may be useful for assessing the benefits of flight simulation training for combat performance. However, informative and objective data are the result of knowledgeable and deliberate planning, and were not always obtained in early studies.[37] Later, carefully planned studies of collective training using flight simulation provided quantitative data showing improvements to many fighter combat components, including communications, situational awareness and sensor employment.[38] Deitchman[39] used flight simulation to assess the benefit of training on the outcome of a war between NATO and Warsaw Pact forces. Probability of acquiring a target, probability of killing a target, and sortie rates were varied in order to represent different levels of aircrew training. Probability of kill, engagement rate and tank vulnerability were used to represent different levels of tank unit training. The effect or benefit was the change in the amount of territory retained by NATO during the war. This approach offers a quantitative and in-depth measurement of operational performance improvement arising from a training effect, although the linkage between the training benefit and the war outcome involves a causal chain that would require extensive effort to justify.

Availability

Availability is the opportunity cost of using aircraft for training. Aircraft used for training are not available for operations. This includes training aircraft, because the number of training aircraft will be determined by the number of sorties that must be flown. The benefit of increased availability of aircraft for conducting operations could be readily measured in aircraft days per year, for example.

Health and safety

The use of flight simulation instead of live flight offers the benefit of greater safety through fewer opportunities for flight mishaps leading to injuries and damage to aircraft and property. Flight simulation training can also improve safety by changing the types of live flight that are undertaken. Training in particularly risky flight manoeuvres and emergency procedures can be provided and practised in a simulated environment only, without endangering the aircraft and the pilot. This is a real benefit because more aircraft can be damaged in training for emergencies than in actual emergencies.[40] A good example is the training helicopter autorotation. In a survey of civil helicopter accidents, it was found that 7% of accidents involved autorotation failures. However, autorotation is not an emergency; it is a procedure performed to deal with an emergency.[41]

A negative health benefit introduced by flight simulation training is simulator sickness.[42] Simulator sickness describes the collection of oculomotor disturbances, nausea and disorientation sometimes experienced following the use of immersive simulations. Its incidence varies with individuals, simulators and circumstances. Proper construction and use of simulators reduce the likelihood of simulator sickness, but it can still occur. For this reason, some organizations limit the duration of flight simulator training and prohibit flying for set periods of time following flight simulation sessions.

Various approaches can be taken to measure improved safety quantitatively. The number of sorties required, the number of emergency procedures supported in flight simulation, or the number of expected accidents avoided[43] might be used. Given the low and highly variable number of air accidents in the RCAF (ranging between 4 and 13% for all fleets and all causes between 2004 and 2014),[44] it is likely to be difficult to produce reliable estimates of changes attributable to a particular training investment. Likewise, any training or flight restrictions needed to prevent or mitigate the effects of simulator sickness could also be determined as a quantitative measurement that will produce a wide range in values because of the variability of simulator sickness.

Environment

Conducting aircrew training with flight simulation rather than using live flights can provide environmental benefits.[45] If fewer flights are conducted, less chemical pollution is generated. The effects of noise from aircraft on human populations and active sonobuoys on marine mammals, for example, are also reduced. Reduced intrusion of electronic emissions by radars, radios and jamming systems upon other users of the electromagnetic spectrum might also be considered a type of environmental benefit. Avoiding the use of flares, chaff and weapons may also be seen as a benefit for the environment.[46] Quantitative measurements could be produced through an absolute reduction in these emissions, such as a reduction in chemical pollutants and exposure levels, or compensation paid to affected populations.

Security

A final example of a benefit arising from flight simulation training is security. Training using live flight is more observable than training conducted in properly protected simulators. Simulation training denies the opportunity afforded by live flight training to observe flight manoeuvres and weapons performance. Were this opportunity to be denied during live exercises, aircrew might be instructed to alter or omit operational tactics, thereby compromising the training value. This is more commonly true for things that can be monitored from a distance, such as the use of active sensors and jamming systems. Even things that are simple to observe, such as training sortie rates and the numbers and types of aircraft available, may have intelligence value to an adversary. The security benefit provided by training in simulation can be appreciated by considering a USAF study on training surprise.[47] By training in simulation, a trainee can potentially develop much higher levels of capability than might otherwise be observed, and conduct extensive mission rehearsal without revealing any intentions. Of course, it is sometimes desirable to publically demonstrate capabilities and intentions. This can always be done using the operational capability being questioned. Simulation provides the benefit of making such demonstrations optional. Security benefits might be measured by counting the number of training sorties or training tasks that can be carried out without compromising those tasks. If training costs are increased to preserve confidentiality, such as flying to remote training areas, those costs could be measured.

Industrial and Technical Benefits

The ITBP[48] identifies four specific benefits to be considered in applicable defence procurements: defence work done in Canada; work undertaken by suppliers in Canada; research and development carried out in Canada; and contributions to Canadian exports. It also makes allowance for high-quality investments in Canadian industry to be considered. These criteria can be expected to be emphasized in training simulation investments because the ITBP objective is to implement the Jenkins report,[49] which identified training systems as a key industrial capability to be strengthened in the course of defence procurement.

Analysis of the Options and Making the Investment Decision

When investment in training capability is contemplated, it is done in anticipation of obtaining one or more benefits, which may include monetary and non-monetary benefits. Some decisions can be relatively simple, such as deciding whether a particular training investment is worthwhile. Selecting from among a set of training solutions proposed by sophisticated suppliers is more demanding. This entails not only a decision as to whether the investment is worthwhile, but also a decision as to the relative merit in the set of solutions. If the scope of the training investment is not limited to a small set of possible training solutions, a design decision is put forward with the objective of selecting a design that is in some way the best possible design.

All approaches to making these decisions weigh the benefits in relation to the costs. Financial cost is included in all of them, but they can be divided into two classes, depending on how they deal with non-monetary benefits. The monetary approaches use money as the common basis for comparison; whereas, the multi-criteria approaches preserve the innate measurements of the non-monetary benefits.

Monetary Decision Methods

These methods maintain a purely financial approach to making the decision. The most basic method is a straight cost comparison where the costs of options that meet the objectives are compared and the lowest cost is selected. A similar method is an examination of cost savings, where the savings generated by each option relative to a baseline scenario drive the decision. Within DND, the Directorate of Strategic Finance and Costing[50] produces a *Costing Handbook* that describes several methods used in government and industry to make such determinations and provides advice on their use in the Department. Of these, cost-benefit analysis, activity-based costing, return on investment, and pay-back period may be applicable to evaluating investments in flight simulation training.

In some cases, purely financial criteria may be a sufficient basis for selecting from among training options, assuming that the training outcomes are comparable (discussed further on). Cooley and

Gordon[51] argue that when cost avoidance is known to be the largest benefit and reliable data on the incurred and avoided costs are available, it may not be necessary to consider other benefits. Evaluating the cost avoidance offered by competing options is simple: simply choose the biggest number.

Shadow pricing

The monetary decision methods are appealing, but it is difficult for the analyst to explicitly omit non-monetary benefits because, by definition, benefits are things that the investing institution values. They understand them as important and would like to incorporate them in the analysis. However, legislators and departmental executives will not be persuaded by “arm-waving arguments” and they require objective data.[52] It is clear from the non-monetary benefits described earlier that there is, unfortunately, no simple way for them to jointly and objectively influence the investment decision.

One way to incorporate non-monetary benefits into the monetary decision-making methods is through the practice of shadow pricing, whereby market prices are assigned to intangibles that have no market in which to establish a price. In this way, the analysis can be done using a single measure of merit, i.e., the dollar.

To establish shadow pricing for human life, as is required for the monetary analysis of safety benefits, the probability of death can be combined with a monetary value of the life to produce a monetary benefit or savings. The value of the life can be obtained from different perspectives. The human capital approach is based on pricing the economic and non-economic opportunities afforded by days of health.[53] The Moor and Andrews analysis[54] of multi-ship training for the USAF incorporated the benefit of safety into the analysis by assuming that two aircraft would be destroyed and four pilots killed during two years of training operations. They used USAF budget data for the cost of these aircraft and US General Accounting Office data for the USAF’s cost of training a pilot to obtain the safety benefit as cost avoidance measured in dollars. This enabled the calculation of the dollar value of the simulation training benefits that, when combined with the cost data, produced a transparent basis for evaluating that training investment. That method used to monetize safety benefits might be extended to other non-monetary benefits, but has at least two shortcomings. First, it depends on estimating the rates of occurrence of relatively rare but high-impact events, such as aircraft accidents, that can introduce considerable variability into the ensuing cost estimates. Second, if used as the sole influence of safety on the decision-making process, the method values lives only in financial terms, which is contrary to RCAF values. The Treasury Board of Canada uses a method called the Value of a Statistical Life, which it expects other government departments to use.[55] According to this method, people are asked how much they would be willing to pay for a reduction in the probability of death, or conversely, how much money they would have to be paid to accept an increase in the probability of death. These values are then used to calculate the value of a statistical life to the person affected.[56] Treasury Board put the value of a statistical life at $5.2M in 1996 dollars[57] based on a study by Chestnut et al.[58]

Shadow prices for other benefits can also be obtained through methods of stated and revealed preferences. According to these methods, monetary values are assigned to non-monetary assets by observing the decisions that individuals make regarding these assets. The amount that individuals are willing to pay to obtain such an asset or to avoid a situation provides a monetary value for that asset to that individual. The price people are willing to pay to visit a remote wilderness reveals how they value it, in the same way that the discount in real estate prices associated with proximity to airports reveals the monetary value associated with airplane noise. De Bruyn et al.[59] provide an extensive treatment of shadow prices for environmental benefits and costs.

Sokri[60] proposed a unique application of the willingness-to-pay method to place a value on military training by conducting a survey of military members to determine how much they would be willing to pay for their training. The assumption is that military training is a non-market public good and is amenable to the willingness-to-pay method that has been used to place valuations on public goods, such as wilderness areas and noise abatement. The drawback of this proposal is that the respondents are not the payers or necessarily representative of those who pay for military training. Although they may be the recipients of the training, they are not the sole or even primary beneficiaries of the training, because the training is ultimately being provided to benefit the nation and not the trainee. The method is not entirely transparent because the answers provided by the trainees could be influenced by the benefits that accrue to the trainee as an individual in terms of its entertainment value or effect on future career prospects. These influences might produce an artificially high value for training in marksmanship and multi-engine flight and an artificially low value for training in nuclear-biological-chemical defence and sea survival.

A shadow price might also be determined by taking the market price of an alternative method of achieving an objective. As a case in point, the benefit obtained from training can be compared to the benefit obtained from upgrading the weapon system.[61] These reported studies compared the cost of weapon system upgrades to tanks and attack aircraft with the cost of training required to deliver equivalent system performance across the expected life span of the hardware upgrade. The cost comparison could then be used to drive the investment decision or to otherwise put a value on the training. This approach may be most preferable when a decision can be based on a small number of benefits that can be evaluated for each alternative.

Multiple-Criteria Decision Making

Instead of using monetary value as the basis for decision making, multiple-criteria decision-making (MCDM) methods support decision making that preserves measurements of the individual benefits. These methods are more complicated, but they allow the important criterion of cost and the powerful monetary analytical techniques to be retained and combined with data and analytical techniques best suited to the non-monetary benefits. One branch of this family of methods, which consists in selecting from established alternatives, is called multiple-attribute decision-making (MADM) methods. The other branch of the family, which consists in selecting from a large number of potential solutions, is known as multiple-objective decision-making (MODM) methods.[62] Both can be used in conditions of certainty and uncertainty.[63]

To use MCDM, a measurement scale must be established for each criterion. Monetary criteria, of course, are readily measured using currency, and a ratio scale is provided that supports all types of mathematical operations. Non-monetary criteria require at least an ordinal scale, where different scores indicate that one score is better than another (e.g., letter grades assigned upon course completion), and ideally will support a ratio scale (e.g., time to complete a task). Worley et al.[64] offer a helpful heuristic for developing scales to measure the benefits of modeling and simulation: do it faster, do it better, do it cheaper and do it all. In the case of "do it faster," the basis for the benefit is saved time, which leads to quantitative measurements such as course length or time required until being mission ready. "Doing it better" implies a better training result, such as greater proficiency, which can be expressed quantitatively in terms of speed and accuracy. "Doing it cheaper" has already been discussed. "Doing it all" implies the control opportunities of flight simulation. In some cases, more types of data can be collected and used in flight simulation than in real events. Aircrew can train in many more types of weather, emergency conditions and geography in a simulated environment than in live flight. Table 1 provides examples of measurements of the non-monetary benefits described in this chapter.

Benefit	Measurement Scale
Operational effectiveness	Difference between planned and actual time on target
Availability	Number of days per year when an aircraft is not used for training
Safety	Number of emergency procedures that can be performed in simulation
Environment	Pounds of fuel consumed per training course
Security	Number of training tasks compromised in order to preserve confidentiality of data
Defence work done in Canada	Number of defence items provided by Canadian defence firms
Work done by suppliers in Canada	Percentage of contract value earned by Canadian firms
Research and development done in Canada	Number of full-time scientific researchers employed full-time in Canada
Contributions to Canadian exports	Maturity of export strategy

Table 1. Example of measurement scales for non-monetary benefits

An MADM analysis was designed to assess USAF simulator training and was applied to T38 training.[65] The core of the analysis was a cost structure that could be used to determine the life-cycle costs of aircrew training devices. Eight additional high-level worth issues, presented in Table 2, were identified, which summarized 66 low-level issues.

Benefit
Management / Administration
Resource Management
Operations / Tactics
Training
Political
Personnel
Training Effectiveness
Aircrew Training Device Technology

Table 2. High-level worth of ownership factors[66]

Their approach was to then convene a meeting of a board of representative stakeholders for the purpose of rating each of the issues or criteria on a scale of low to high benefit. The ratings were averaged across raters and used for decision making. They cautioned against using weights to combine the criteria, arguing, first, that the ordinal ratings did not have the ratio properties needed for multiplication and, second, that weighting gave decision makers an opportunity to import their biases into the analysis.

More recently, the US DoD Modeling and Simulation Steering Committee commissioned a study to develop a set of measurements for assessing the benefits of investments in modelling and simulation and methods for evaluating the measurements.[67] To carry out this task, the people conducting the study looked at five different perspectives on the decision-making problem facing the stakeholders. The program perspective was concerned with the costs, schedules, affordability and effectiveness of the solution being acquired. The community perspective focused on managing the modelling and simulation (M&S) capability as one of several capabilities within the same practice area, such as training, testing or analysis. The enterprise perspective had to do with the role and effect of the M&S capability across the DoD as a whole. The federal perspective was similar, but concerned with the influences that span departments. The societal perspective encompassed points of views obtained from academia, industry and civil society. The study concluded that the program, community and enterprise perspectives were critical to decision making, while the federal and societal perspectives were important, but secondary.[68]

Based on the above, cost element structures were developed for the community and enterprise perspectives that could generate investment cost data that were not captured at the program level. Objectives or benefits were also developed for each perspective. The report puts forward detailed sets of objectives for each perspective, and notes that they are not identical. To enable assessment of the benefits, measurement scales are required for each.

The study recommends, based on the extensive data and the analysis, that decisions should be based on a type of return-on-investment measurement. The measurement can be calculated from the program, community or enterprise perspective, but the DoD perspective should ultimately dominate. To bring together the costing measurements and the various criteria, the report recommends the use of an MADM method. The return on investment and the non-monetary benefits are calculated for the program, the relevant community and the enterprise perspectives. Contrary to the recommendation of Allbee and Semple,[69] the method involves the use of weights to combine the evaluations from all the perspectives into a single utility score. The opportunity for decision makers to adjust weights is seen as beneficial in that it provides a way to explicitly introduce higher-level priorities into the decision making.[70]

This method is notable for its thorough treatment of stakeholders, perspectives, objectives and benefits. This creates flexibility, which makes the method adaptable for users outside the DoD. For example, the RCAF could put more emphasis on the federal perspective, and use it to incorporate ITBP objectives. The method makes recognition of the broader implications of a single M&S project for the wider enterprise a standard procedure rather than the exception. This approach could be invaluable in facilitating the interoperability and supportability of future RCAF flight simulation acquisitions, for which the RCAF has been criticized in the past for taking a parochial view and serving a single operational community. However, the thoroughness of the method involves a daunting amount of work. Conducting the analysis may be manageable with the resources provided for acquisition projects, but the analysts may have difficulty obtaining effective engagement from all the relevant stakeholders across the defence enterprise and from the federal stakeholders. These stakeholders may not be able to obtain the time, expertise or authority to exercise their role in implementing the method in a timely manner.

Training-Specific Factors Relevant to Evaluating Benefits

Individuals making investment decisions concerning aircrew training can use the evaluation methods and decision-making support techniques used for other government investments. Nevertheless, there are considerations specific to flight simulation and training that can influence how the analyses are conducted. This section provides some observations regarding the measurement and assessment of training that may help analysts working in this area.

Examples

Three examples from the RCAF flight simulation acquisition program illustrate the multi-dimensional nature of training benefits and some of the techniques used to assess them.

Aadvanced distributed combat training system

The Advanced Distributed Combat Training System (ADCTS) was a project set up to acquire distributed simulation capability for training CF18 pilots.[71] This project is an example of the importance of non-monetary benefits in aircrew flight simulation training. The people involved in the project noted the importance of economic constraints on flight training as an aspect of the acquisition. However, even in the case of training for pilots of the aircraft with the highest per-hour, full-cost, non-monetary benefits were also identified as critical aspects of the project. Extending the life of the airframes through reduced flight hours, improved team training, and reductions in the effects of live flying on the natural and cultural habitat were also identified.

The ADCTS project is also an example of taking the legacy training system as the gold standard of training. The evaluation was based on careful calculations of the number of hours of flight simulation that would be required of the training devices. For each task in the current training syllabus, such as instrument flight, basic fighter manoeuvres and electronic warfare, the number of simulator hours was specified. This approach provided the supplier with important information for estimating its cost. It also appeared to provide useful information for calculating cost savings for the RCAF, based on the assumption that the simulator hours could be subtracted from the live flight hours. However, this approach left the live flight hours as the means to make up any shortcoming in the simulator's effectiveness. Conversely, if the simulator is more effective than live flight, the hours asked of the simulator may be more than required or may be inefficiently allocated by task type.

CC130 training device prioritization

An exercise conducted to identify and prioritize training device requirements for the RCAF's CC130 community provides an example of an MADM method used to set up a training simulation project.[72] The Canadian Forces Aerospace Warfare Centre (CFAWC) was planning a project to augment the simulation training capability of the CC130 community and required options to be identified and prioritized. The nominal group technique (NGT)[73] was used in conjunction with the analytic hierarchy process (AHP).[74] The NGT involves a group of participants independently generating ideas or options and then pooling them for subsequent evaluation by rating and ranking. In this case, the NGT was used with representatives of the CC130 community to identify training deficiencies in the CC130 simulation capabilities, as well as potential training devices to address those deficiencies, and to develop criteria for evaluating the devices. The AHP is a measurement system that uses choices between alternatives to produce ratio scores for all the alternatives. It was used to provide a priority score for the training devices being considered based on the group's ratings of the merits of the devices against the criteria. The candidate training devices, training deficiencies and evaluation criteria are shown in Tables 3, 4 and 5 respectively.

Level D flight simulator with full field of regard for flight deck
Mission capable flight training device – full capability, full field of view
Mission capable flight training device – advanced level, multi-role, full field of view
Mission capable flight training device – entry level, multi-role
Crew compartment trainer integration with flight deck
High fidelity air operations modelling
Visual threat recognition and avoidance trainer and search and rescue spotter
Full mission simulator upgrade
Rear vision device visual simulation
Desktop Hercules inspection point
Status quo

Table 3. Candidate training devices

Extreme weather
Austere airfield
Ground objects for low-level flight
Mountain operations and terrain
Night operations
Air and ground threats
Electronic homing effects
Effects of clutter on homing and search
Multiple resources
Air to air refueling

Table 4. Simulation training gaps

Crew proficiency benefit
Cost – initial
Cost – operations and maintenance
Time to acquire
Mission training coverage
Benefit to crew currency
Impact of training plan
Change in yearly flying rate
Support to human performance in military aviation

Table 5. Evaluation criteria

In a sensitivity analysis, the results were found to be stable, and the participants felt that they were a good representation of their deliberations. This exercise demonstrated that an MADM method could be quickly implemented and used with the RCAF operational community with limited preparation in order to reach agreement on the non-monetary benefits of simulation for their training gaps. CFAWC used the results of the exercise to select the highest priority project achievable with their resources. However, this application also demonstrates that an MADM process can go smoothly even though the data may not be uniformly valuable. The assessments were based on the considerable depth and breadth of knowledge of the CC130 operational community, which might be expected to provide a substantial amount of insight into training gaps and benefits. But this background was not necessarily suited to making decisions about the effectiveness of future simulators, and their assessments were also greatly influenced by their community's concerns. Yearly flying rate and crew currency were important criteria, but initial and ongoing costs proved to be of little import to the final outcomes.

Small arms trainers

A specialized MCDM tool[75] was used to determine the location and number of small arms trainers (SATs) for RCAF training. The Training Device Estimation Model (TraDE) is an MODM that can be used to both propose and evaluate fleets of training devices.[76] The TraDE uses descriptions of many types of training devices, including their relevant criteria, such as costs, student throughput and effectiveness for each training objective in an entire syllabus. The TraDE takes the descriptions, along with the locations and sizes of training cohorts, and randomly generates a large number of potential training solutions consisting of the quantities, types and locations of training devices that can provide the required training. Each of these solutions is then evaluated in relation to multiple objectives, such as acquisition cost, travel costs, travel time and training time. The best-performing solutions are selected, and a generic algorithm is used to generate additional potential solutions for evaluation. The evaluation process does not combine the criteria using weightings or other methods, but instead selects performance relative to each criterion for independent inspection. The TraDE eventually settles on a set of potential solutions that are Pareto-optimal in the sense that a solution cannot be found that brings about an improvement with respect to one criterion without causing a negative impact with respect to another criterion.[77] This last set of solutions can then be reviewed in more detail or submitted to decision makers to consider trade-offs between the criteria.

This application of the TraDE is a forward-looking example of how MCDM can leverage computing power to optimize the monetary and non-monetary benefits arising from simulation training. However, it relies on having extensive ratio data on the effectiveness of the candidate-training devices. Its behaviour when using interval or ordinal data for training effectiveness is not known. Any use of the TraDE in training investment decisions should be done in tandem with other methods until the TraDE is more fully developed.

Conclusion

Investing in simulation to train aircrew can be an effective way to carefully manage the resources provided for the RCAF. Indeed, the combined pressures of tight budgets and the high cost of live flight make the cost savings achieved with simulation training very important, if not essential, to sustaining modern air forces. However, cost savings are not why a nation maintains an air force. The benefits obtained from the incurred costs are vitally important, which is why prudence is called for. The monetary and non-monetary benefits of simulation training must be assessed against the cost of the investment. Major training investment decisions are made by people far removed from training and RCAF operations, so a transparent and stable logic chain linking the benefits of the training system to the decision is required.

The costs of simulation training for aircrew can be reduced to a one-dimensional monetary calculation, if necessary, but this is not the case for the benefits. Consequently, MCDM methods are available to effectively assess monetary and non-monetary benefits. The US DoD effort[78] is an example of a well-constructed and comprehensive method. Two particular benefits of this method are flexibility and scope. Because of its flexibility, the method can be adapted from its DoD target environment to DND, where the influence of other government departments can be very influential in large procurements.

The scope of the DoD effort also provides a model of how to coordinate the use of simulation training across DND. This could be a substantial benefit in that it helps to achieve the goals of simulation re-use and interoperability in the Canadian Armed Forces (CAF)[79] and the RCAF.[80]

Alternatives to the MCDM method that involve the use of shadow pricing to represent non-monetary benefits make all these benefits interchangeable and may therefore result in the loss of important information. If non-monetary benefits are excluded entirely, it is advisable that the decision makers be specifically informed of the benefits that are not being considered in the decision-making process, so that the decision-making process can be understood and traced.

Perhaps the greatest obstacle to evaluating the benefits of simulation training for aircrew is the availability of solid evidence of the effectiveness of the simulation options under consideration. Poor-quality training effectiveness data and analysis can be guarded against by having training experts review the data. The absence of data is more difficult to deal with. New training options, and even some training systems that have been in use for years, do not have large amounts of good-quality data concerning their efficacy. The first step should be to gather these data for evaluation purposes, but doing so may prove prohibitive because of the time and cost involved. Several attempts have been made to develop analytical tools to predict the efficacy of training systems.[81] Unfortunately, these models have not been sufficiently validated.[82] Research that consists in validating analytical models for the purposes of predicting training effectiveness could be a way to compensate for an absence of training effectiveness data and thus improve the quality of training system investment decisions.

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Abbreviations

ADCTS	Advanced Distributed Combat Training System
AHP	analytic hierarchy process
CA	Canadian Army
CFAWC	Canadian Forces Aerospace Warfare Centre
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DoD	Department of Defense
ITBP	Industrial and Technical Benefits Policy
MADM	multiple attribute decision making
MCDM	multiple criteria decision making
MODM	multiple objective decision making
M&S	modelling and simulation
NGT	nominal group technique
RCAF	Royal Canadian Air Force
SAT	small arms trainer
TER	training effectiveness ratio
TraDE	Training Device Estimation Model
USAF	United States Air Force
USN	United States Navy

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CH11

RCAF Resource Management: Effectiveness and Efficiency in Strategic Air Transport and Search and Rescue Capabilities

Ross Fetterly and Christopher Penney

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Introduction

In a period of budgetary austerity, it is essential that effective and efficient management of defence resources be predominant throughout defence organizations, as "financial and economic constraints are redefining the ability of the North Atlantic Treaty Organization (NATO) to provide security in the coming decade."[1] Faced with budgetary deficits, the national governments of Canada and its defence allies have been significantly reducing their defence budgets. Although funding has now stabilized for the most part, the extent to which the defence establishment can reform and adapt to the dramatic changes in both the fiscal and security environments will determine the level of effective military capability that can be delivered in the future. A significant contributor to output maximization will be the ability of military organizations to develop and sustain a long-term focus.

Although defence establishments operate in an environment subject to frequent, sudden and erratic changes, the unanticipated nature of emerging conflicts "forces the entire defense enterprise to reorient and restructure institutions, employ capabilities in unexpected ways, and confront challenges that are fundamentally different from those routinely considered in defense calculations."[2] Despite a rapidly evolving international security environment, governments have been cutting defence budgets in response to multi-year deficits. The key difference between military transformation in 2017 and the Military Technical Revolution (MTR) of the 1980s and the Revolution in Military Affairs (RMA) of the 1990s,[3] as well as military transformation at the turn of the century, is that the transformations in those earlier periods focused on advances in military technologies and the combination of those technologies, doctrines, and military organizations in "reshaping the way in which wars are fought;"[4] whereas, today, the transformation under budgetary restraint is centred on how we can manage defence resources more effectively and productively.

Primary objective of this chapter

The primary objective of this chapter is to examine the distinctive features of resource management within an air force organization. Given that the Royal Canadian Air Force (RCAF) must balance readiness, adaptability, and the overriding need for military effectiveness against budgetary constraints, an emphasis on efficiency in operation and resource allocation is needed. The conundrum in the defence environment is that military effectiveness and efficiency can be impacted differently, depending on the circumstances. Furthermore, the relative importance of these two variables can shift as circumstances change. The approach taken in this chapter is distinct in that it provides an internal military perspective on decision making and resource allocation within the RCAF.

The public sector, and national defence in particular, is not subject to the competitive pressures of markets, which makes it challenging to ensure efficient outcomes in defence resource management. Problems include defining and measuring efficiency and effectiveness, and examining the determinants of efficiency and effectiveness in public spending.[5] Viewed from this perspective, an enhanced institutional recognition that military decisions are in many respects economic decisions is required. Consequently, it is critically important to carry out appropriate analysis and to choose suitable alternatives for comparison in order to determine the most efficient use of military resources.[6] Consequently, improving processes and procedures within defence in order to determine the most efficient ways to allocate resources will need to be a fundamental aspect of defence resource management in the current security environment. This places an emphasis on the relationships between inputs, outputs and outcomes: a primary focus of defence resource management. This chapter contributes to the literature in this area.

This chapter is structured as follows. The first section describes the distinctive features of military organizations, and further on, resource allocation in the RCAF, from Air Force (AF) capability to direct AF budget allocations. The second section describes how the RCAF allocates flying hours in a fiscal year between force generation (FG) and force employment (FE). The third section looks at fixed and variable costs, and illustrates the limited in-year AF flexibility to respond to significant price increases and other monetary factors influencing military operating costs. The fourth section discusses how defence organizations react to changes in defence cost drivers. The fifth section looks at a case study comparing flying hours and the cost of aviation fuel for both the CC130H Hercules aircraft and the CC177 Globemaster III aircraft. The sixth section outlines the two approaches being taken by the RCAF to maximize utilization of inputs. Lastly, the chapter ends with the conclusion.

Distinctive Features of Military Organizations

Military forces provide governments with many capabilities, including providing support for civil authorities following a natural disaster; assisting overseas nations struggling in the aftermath of earthquakes or tsunamis by providing potable water, building schools, roads, and bridges, and deploying field hospitals; and joining multinational coalitions and engaging in combat operations. Although some specialized civilian agencies and enterprises may be more efficient in carrying out some of these activities, they do not have the broad range of capabilities of military forces. Moreover, military organizations can deploy in large numbers relatively quickly and operate self-sufficiently in a foreign territory.

The environment in which defence resources are managed is very distinct from that of the private sector. Within the private sector, operating costs are a key determinant in decisions to repair or replace equipment, and continual innovation results in lower-cost options or alternative methods for delivering products and services. This process is guided by price signals within the market, which results in a generally efficient reallocation of resources. In defence, military organizations are hampered by rigidities resulting from the availability of personnel and platforms, as well as the time-sensitive nature of operations. Furthermore, the price mechanism is usually unavailable to help allocate resources efficiently. In the case of search and rescue (SAR) and military air transport, these capabilities are specialized functions provided in Canada by the AF. Indeed, this illustrates the conflicting demands of military efficiency versus economic efficiency, which are common to all countries and can lead to a lack of alternative near-term substitutes for existing military capabilities provided through existing defence equipment and weapon systems.

Defence organizations are also potentially subject to the inherent economic inefficiency of government. In the public sector, resource allocations are unable to achieve the efficient outcomes of the free market because of the absence of prices and the profit motive. According to the predictions in public choice theory models, bureaucrats seek instead to spend budgets and attempt to appropriate ever greater resources, potentially contributing to inefficiency in the process.[7] The current international strategic threat profile is distinct from the potential Warsaw Pact and NATO conflict and nuclear confrontation that existed during the Cold War, and is now characterized by internal conflicts within nations, terrorism by sub-state groups, rogue states, and conflicts over resources and land. In 2017, there are clear consequences for Western military forces due to a situation where "protracted violent actualization of conflict"[8] has become the norm. Canada is actively participating in the multinational coalition against the Islamic State of Iraq and the Levant in the Republic of Iraq through Operation IMPACT, as well as in Central and Eastern Europe in support of NATO reassurance measures through Operation REASSURANCE.[9] The impact on defence forces resulting from a broad threat spectrum is a demand for increased use of defence resources to respond to various threats. In a period of budgetary restraint, this creates significant challenges for governments and defence planners.

Whereas the differentiator in military operations could previously be measured in terms of scale and potency, today it is more about agility and the ability to create an appropriate military effect. The RCAF, like other military organizations, can be considered a multi-faceted system that converts resource inputs into operationally ready forces. Because this transformation "involves a set of interactions among the inputs, many of which may be non-linear, the output can at times appear random or unexpected."[10] Complexity is amplified by the dynamic nature of the system, the relentless advances in technology, the continually shifting international strategic environment, the need to adapt operational concepts to that environment, and more abstract factors such as leadership, which when combined end up transforming the military over time.

The RCAF and Managing AF Resources

The long-term challenge for the RCAF budget is that, although flexibility in the current fiscal year may be minimal, short-term decisions concerning activities or programs can have a major impact on future fiscal years. Consequently, there is a need for a broad multi-year resource management strategy whereby the government does not explicitly incorporate temporal asymmetry between the Department of National Defence (DND), which manages the largest discretionary budget and capital outlays, and other departments that focus on transfer payments and recurring operations. Within the DND, medium-term planning is done within a structured and comprehensive business planning process.

In the RCAF, the objective function (mandates and priorities derived from defence policies) generally remains the same, with missions subject to change as per government direction, and where constraints increase, the relative prices of labour and capital more broadly are focused on demand, such as SAR, or strategic airlift missions arising from operational requirements. Constraints are addressed through a combination of creative solutions and internal reallocation within both the RCAF and the DND.

Business planning and resource allocation in the RCAF are determined through the total air resource management (TARM) process. Informed by budget realities, the TARM is the process "used to collect user requirements, balance them against capacity, prioritize the list, allocate suitable resources, and produce a means to enable effective long-term planning and employment of aerospace capabilities in the RCAF, while providing visibility to supported commanders."[11] The primary cost driver in the

RCAF, as well as the basis for AF training and operational plans in a fiscal year, is the yearly flying rate (YFR). The distinct challenge for the RCAF is that, while the fiscal environment has changed dramatically, both the core missions and the long-term focus of the AF have remained essentially constant. Because of increased base and equipment operating costs, funding priorities remain centred on operations and on supporting operations. However, this can change, depending on government policy or shifts in resource allocation priorities.

Elements of Air Force Capability	Funding
Assistant Deputy Minister (Materiel) [ADM (Mat)] National Procurement	$1,107M
REG F Military Pay	$1,286M
RCAF Funding Allocation	$961M
Assistant Deputy Minister (Infrastructure and Environment [ADM (IE)]	$196M
Total Air Force Capability Funding	**$3,550M**

Table 1. RCAF capability funding in fiscal year (FY) 2016–17

The resources allocated to fund RCAF capability in FY 2016–17 are listed in Table 1[12] and consist of the DND allocation of $3.55B. This funding represents a mix of AF fixed and multi-year expenditure levers. AF capability can be defined as "the power to achieve a desired operational effect."[13] The first element of RCAF capability consists of $1.107B for procurement of aircraft spare parts and fleet maintenance contracts, and is allocated to the Assistant Deputy Minister (Materiel) [ADM(Mat)]. The second element of RCAF capability is allocated to the Chief of Military Personnel (CMP) to fund $1.286B in pay and benefits for Regular Force (Reg F) personnel. The third RCAF capability allocation is $961M allocated directly to the AF to manage AF bases (Wings), fund training and conduct operations. The final RCAF capability allocation is $196M allocated to the Assistant Deputy Minister (Infrastructure and Environment) [ADM(IE)].

The elements of the FY 2016–17 RCAF budget allocation of $961M are listed in Table 2.[14] This allocation consists of the following: $45M for minor capital equipment; $79M in pay and allowances for military reservists; $79M in pay for civilians; $84M for contracted flying training and support (CFTS) consisting of primary and basic flying training and multi-engine and helicopter pilot training programs conducted at the Southport Aerospace Centre (SAC) in Manitoba; the $46M contract to manage 5 Wing Goose Bay; the $158M contract to manage the 15 Wing Moose Jaw NATO Flying Training in Canada (NFTC) contract; and $470M allocated to operations and maintenance expenditures. This in-year funding allocation has limited short-term flexibility. The flying training is provided under multi-year contracts, as is the contract to manage the base at 5 Wing Goose Bay. The number of civilians and military Reservists employed on the bases is determined by operating and support requirements. Reductions in staffing levels on bases began in 2010–11 with the operating budget freeze and continued with the recent federal government deficit reduction and action plan (DRAP) to reduce the federal budget deficit.[15]

Expenditure Categories	Funding
Minor Capital	$45M
Military Reserve Force Pay and Allowances	$79M
Civilian Pay	$79M
Contracted Flying Training Support	$84M
5 Wing Goose Bay Contract	$46M
NATO Flying Training in Canada Contract	$158M
Air Force Operations & Maintenance	$470M
Total Air Force Funding Allocation	**$961M**

Table 2. RCAF funding allocation in FY 2016–17

The in-year flexibility available to the RCAF of $470M in FY 2016–17 is shown in Table 3.[16] This represents approximately 13% of the funds allocated to AF capability by the DND. This allocation consists of $57M for administrative, operational and training travel, $19M for machinery, $59M for supplies, $13M for repairs, $11M for rentals, $88M for services, and $5M for communications. The key component of direct RCAF expenditure is aviation fuel. This funding consists of $132M for FG and $86M for FE. FG is the foundation of RCAF activity, and consists in producing crews, including pilots, air combat systems officers, flight engineers, loadmasters and other occupations, as well as the integration and sustainment of capabilities. FE is the employment of RCAF aircraft on operations. In previous fiscal years, AF budget reductions resulting from the strategic review (SR) and DRAP focused on preserving the aviation fuel budget and reducing expenditure in categories such as civilian and reserve pay, travel, maintenance and contracting. As a result, future flexibility in these categories is now limited. The current funding levels will constrain RCAF capability and capacity over the medium to long term. In the case of a sustained resource-constrained environment, the AF will be challenged to maintain current operational levels.

Expenditure Categories	Funding
Administration, Operational and Training Travel	$57M
Machinery	$19M
Supplies	$59M
Repairs	$13M
Rentals	$11M
Services	$88M
Communications	$5M
Aviation Fuel (FG)	$132M
Aviation Fuel (FE)	$86M
Canadian Air Force In-Year Flexibility	**$470M**

Table 3. RCAF in-year flexibility in FY 2016–17

RCAF Yearly Flying Rate

The YFR is tracked closely for each fleet and consists of two primary elements: FG and FE. FG and FE are linked by missions that combine FG and FE objectives. This relationship is illustrated in Figure 1. As the RCAF progresses from FG to FE, readiness levels increase.

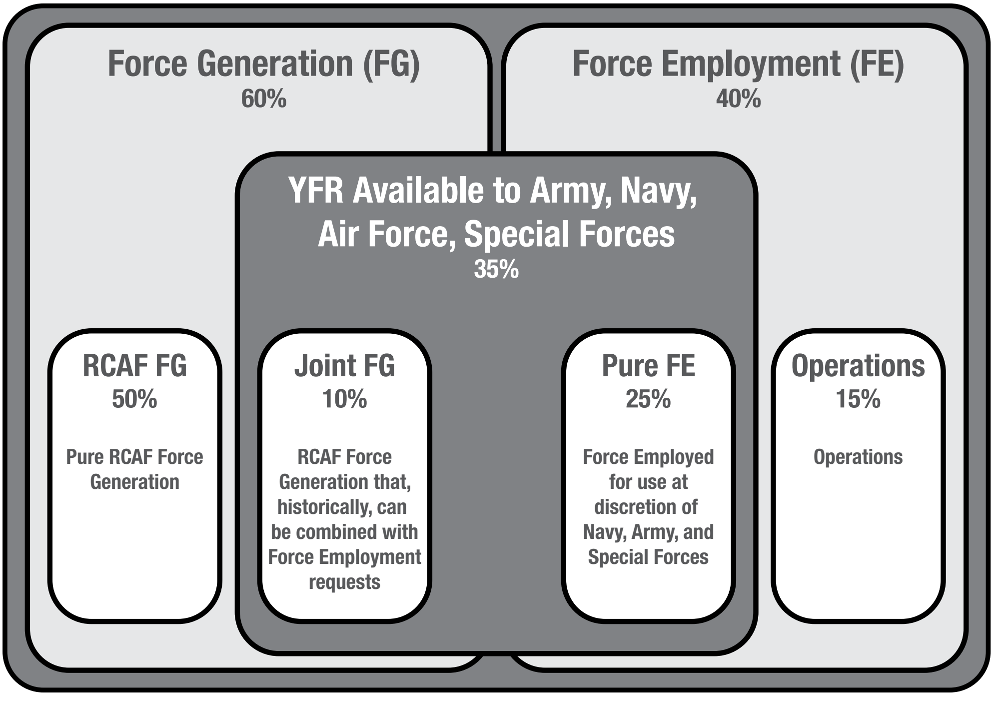

Figure 1 . Simplified YFR allotment (approximate distribution)

The annual YFR Plan for the 16 fleets is developed through the TARM process, and generally follows the apportionment in Figure 1. Although this is a planning guideline, the actual apportionment can vary on an annual basis, depending on training requirements or operational demands. Of primary importance is FG flying hours. FG hours support the future force. These flying hours are used to train and develop pilots and aircrew to attain and then maintain qualifications, as well as enhance their qualifications to be eligible for positions, such as Aircraft Captain, and usually account for about half of the hours flown. FE may also result in a need for further FG as deployed pilots return to Canada and need to re-certify qualifications that were not employed during extended overseas deployments.

Maintaining the level of pilot qualifications is one of the primary functions of FG hours. Institutional levels of qualified aircrew only increase or decrease at a relatively slow pace; consequently, it can take years for the institutional capacity of the AF crews to decline; yet to recover capacity is a medium-term activity. In recent fiscal years, reduced flying hours has correlated with diminishing experience levels, and the perishable nature of advanced aircrew skills is a growing challenge. A primary focus in FY 2016–17 is on the training and development of junior aircrew and technicians.

FE supports the current force. FE as developed through the TARM process accounts for about 25% of the YFR. This is a departmental and Canadian Armed Forces (CAF) process overseen by the Strategic Joint Staff (SJS), who develop an FE plan for the next fiscal year in which priorities are set out and available hours are apportioned to the Royal Canadian Navy (RCN), Canadian Army (CA), RCAF and Special Forces.

To maximize output, approximately 10% of the yearly flying hours are *joint* FG, which serves both the RCAF and training objectives of the RCN, CA and special forces. During certain missions, the AF has the flexibility to use FG hours where training will occur, in order to also carry out an FE task. Lastly, operations generally account for 15% of yearly flying hours. FG mission-specific hours may also be used to prepare crews for deployments. FE hours for operations, depending on the circumstances, can exceed the planned YFR; this may result when some fleets, such as the CF18 Fighter fleet or the CC177 Strategic Airlift fleet, fly a considerable number of unforecast hours on an expeditionary operation directed by the government during a fiscal year.

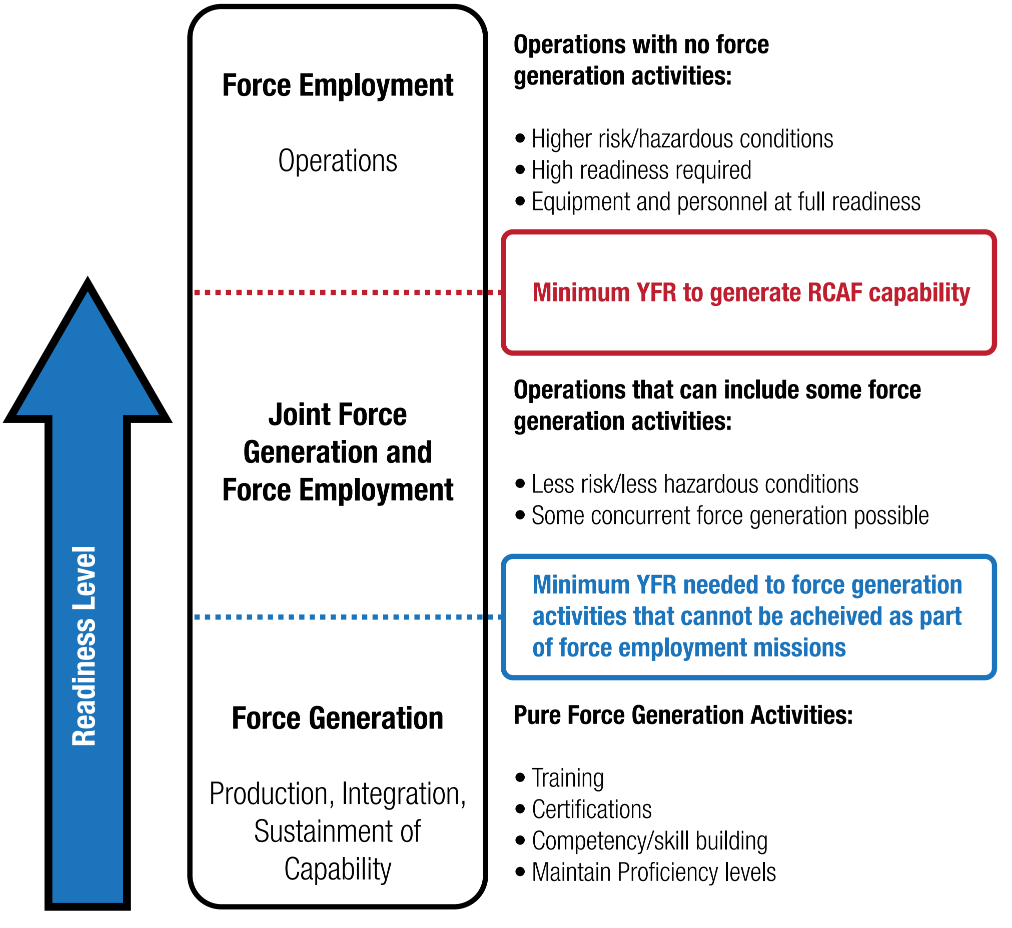

Figure 2. Notional RCAF program activity

The notional RCAF program activity shown in Figure 2 reinforces the building block nature of AF program activity, and highlights the inherent flexibility in AF training and operations, while linking capability closely with readiness. Air force organizations tend to prefer FG over FE, subject to operational requirements, because FG is a prerequisite to FE. The objective of this approach is to ensure maintenance of existing capabilities. On an annual basis, production of new pilots and integration of aircrews into operational squadrons, as well as sustainment of capability, continues to be the basis on which capability can be subsequently delivered. This perspective provides community of practice, while reinforcing the training and development of young aircrew and technicians. This aspect is particularly important in an organization that must promote internally to replace personnel who leave the AF to pursue careers in the civilian aviation industry.

Readiness is a continuous focus for an organization that provides AF capabilities to government. Indeed, with the RCAF supporting a number of overseas missions simultaneously in 2017, the concept of AF capability readiness is a very contemporary issue. The challenge is that governments must either allocate resources towards maximizing immediate capability or allocate resources with a long-term focus and higher capability.[17] This implicitly requires inter-temporal substitution: defence planners must choose a rate of FG in order to produce a desired level of FE in the future. Maintenance of a sustained level of readiness consumes significant military resources. Sustained readiness over an extended period of time, while perhaps efficient from a military perspective, is expensive. Because defence expenditures are fungible and paid for out of a largely fixed annual budget, money expended on readiness can result in reduced allocations for infrastructure maintenance or capital equipment procurement. At some point, maintaining elevated readiness levels may negatively impact future military capability.

Fixed and Variable Components of RCAF Resource Management

Figure 3 provides a succinct graphic illustration of factors affecting annual flying hour availability and draws attention to the fixed components that drive long-term flying hour costs. Because government policy drives force structure decisions, long-term infrastructure fixed costs resulting from government policy are based on the number of air bases operating across Canada. The infrastructure costs of maintaining and repairing buildings, the civilian personnel working on the bases, and ongoing facility operating costs restrict the AF's near-term flexibility. Similarly, the second component of AF capability is the number of aircraft fleets in service, the quantity of aircraft in each fleet and the age of each fleet. This further constrains flexibility and the ability of DND and AF leadership to evolve as the international security environment evolves. This generates requirements for crews to fly those aircraft and for maintenance personnel to repair and service aircraft. Medium-term fixed costs incurred to support the AF are also generated by the ADM(Mat) organization, which handles contracted services, major maintenance cycles and mid-life upgrades.

To operate an air force in Canada, a country that is thousands of kilometres wide and has a geographically dispersed population, a base structure and associated infrastructure are required to support RCAF training and operations. This is illustrated in the largely fixed elements of Tables 1 and 2. Even in the short-term variable costs, including in-year parts and repairs, contracted services and fuel, decisions made in-year can have follow-on effects in future fiscal years. For example, if training courses are cancelled in a given year owing to a funding shortfall, this can impact aircrew availability two to three years in the future.

Future-year planning is supported by notional funding allocations for the upcoming five fiscal years, provided by the Vice Chief of the Defence Staff (VCDS). Business planners use the notional allocation for the upcoming fiscal year as the starting point for planning, and then identify potential funding shortfalls. The RCAF Business Plan for the upcoming fiscal year provides a detailed description of the financial situation. Funding shortfalls, by category of activity, are explicitly accounted for, and the impact of a failure to obtain additional funding is also outlined. In essence, the RCAF Business Plan provides a refresh of the upcoming and subsequent three fiscal years. This allows for adjustments due to changing circumstances or demands through reallocation of resources, and adjustments to training or the YFR. Although the RCAF is in a cost-constrained environment, only a limited amount of funding will be provided by the departmental Investment Resource Management Committee (IRMC). FG flying hours for a fiscal year are developed based on planned, forecast pilot production, the experience levels of crews, and the need to sustain or grow capabilities across the AF fleets. While constrained in the near term by the number and types of aircraft, fleet operating levels can be adjusted annually within the TARM process to reflect changes in operational requirements and demands on certain fleets.

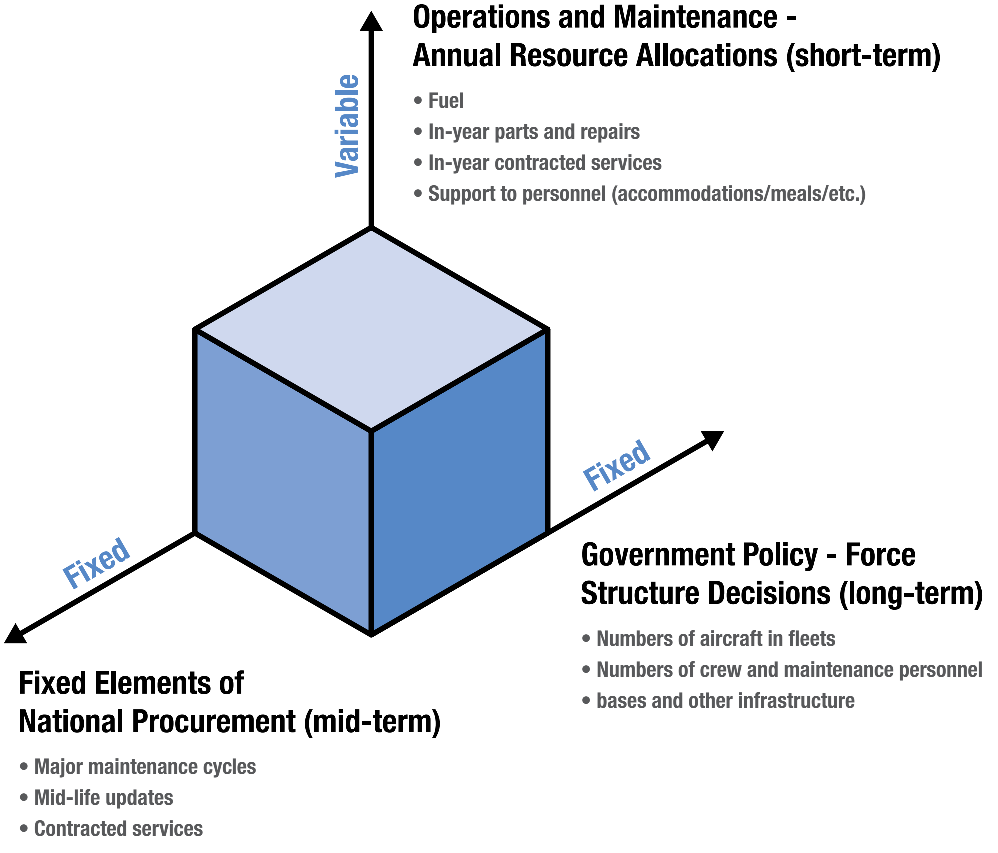

Figure 3. Factors affecting annual YFR availability

Monetary Factors Influencing Military Operating Costs

The substantial fixed AF costs are further impacted by a number of exogenous factors that shift depending on the Canadian economy and act as a constraint on RCAF operating costs. This includes the cost of aviation fuel, the foreign exchange rate, and defence-specific inflation. Changes in AF costs resulting from adverse shifts in-year of any of these factors are addressed out of necessity through the departmental in-year budget management process. In the absence of available in-year funding to address monetary factor pressures, the options are to manage cash flows or reduce AF budgets in response to decreased purchasing power.

The primary direct-cost driver in the RCAF is aviation fuel. Between fiscal years 2011–12 and 2013–14, aviation fuel accounted for between 28% and 30% of the RCAF budget.[18] Moreover, similar to any organization engaged in international trade, the DND uses foreign currencies to purchase capital equipment and pay for operating costs in operations outside Canada. The AF's FE activities are both domestic and international. Consequently, foreign exchange rates have a significant impact on the costs of AF operations overseas. The DND employs a "risk-neutral" approach to foreign exchange rates "most likely due to political and institutional constraints towards the generally perceived speculative nature of the foreign currency markets. As a consequence, and as a result of Canada's small industrial base, the DND finds itself exposed to substantial foreign exchange risk in the acquisition and maintenance of equipment and supplies."[19] The DND spends a considerable amount in foreign currencies. Table 4 shows the percentage spent from fiscal year 2002–03 to fiscal year 2014–15.[20]

	USD	EUR	GBP	Other	Total
2002–03	7.0%	1.2%	0.7%	0.0%	8.9%
2003–04	5.7%	1.1%	0.7%	0.2%	7.7%
2004–05	5.3%	1.7%	0.7%	0.2%	8.0%
2005–06	5.6%	1.1%	0.5%	0.5%	7.6%
2006–07	6.2%	1.4%	0.4%	0.6%	8.6%
2007–08	10.7%	2.0%	0.3%	0.8%	13.7%
2008–09	9.4%	1.9%	0.2%	0.8%	12.3%
2009–10	9.5%	1.6%	0.2%	0.9%	12.2%
2010–11	9.5%	2.1%	0.3%	0.8%	12.8%
2011–12	11.5%	2.8%	0.5%	0.4%	15.2%
2012–13	4.9%	1.4%	0.2%	0.1%	6.6%
2013–14	3.7%	0.8%	0.1%	0.1%	4.7%
2014–15	8.2%	0.9%	0.1%	0.2%	9.4%

Table 4. Percentage of foreign expenditure in the defence services program

The linkage between aviation fuel and foreign exchange rates is generally a lack of purchasing power parity relative to aviation fuel overseas, although some relief is currently provided by price decreases in aviation fuel. Defence-specific inflation impacts on military aircraft spare parts purchased from the original aircraft manufacturer or a licensed producer.

In contrast to general consumer goods, defence departments cannot, "under most circumstances, reap the benefits of an open, competitive market; there is no 'store brand' of the parts needed [to repair military equipment fleets]"[21] because substitution of parts from different suppliers cannot be made when the equipment manufacturer raises prices. The defence industry aircraft manufacturer usually operates as a monopoly in the sale of parts because of intellectual property and equipment warranties, and therefore has a significant influence on the price of spare parts. This characteristic of defence markets is in contrast to much of the pattern in the private sector. In the case of inflation indexes, where the purpose "is to relate changes in the quantity of resources bought or sold to the amount of money spent on them,"[22] defence market characteristics generally drive costs higher than in the private sector.

Reacting to Long-Term Change in Defence Cost Drivers

In many organizations, the predominant focus tends to be on the near term. In contrast, a fundamental construct of defence organizations is that they must simultaneously be able to operate effectively in the current security environment, while preparing the foundation for military forces up to 30 years in the future. Consequently, desired transformation in a military context can come up against significant structural barriers. In particular, in an organization intended to cultivate and ensure continuity, transformation entails fostering deliberate shifts to new ways of thinking and operating in a changing security environment. In view of "the intrinsic complexity and unknowns of warfare, militaries to a greater extent than other government organizations are structured to promote standardization and predictability in order to hedge against uncertainty and the deleterious consequences of uncharted and uncoordinated action."[23] Furthermore, as the external environment changes, so do equipment requirements. Capital equipment procurement in defence is complicated by the fact that "the economic and operational environments assumed during the design and acquisition decision processes may not be the same as when the system is acquired or fielded."[24] Consequently, military organizations usually change only with considerable caution and deliberate analysis over a period of many fiscal years. Because of the high cost of major capital equipment in defence—once in service and with subsequent mid-life upgrades and other regular technology injects—that equipment can remain in service for decades, while maintenance costs increase with age.[25]

A nation's defence establishment is unique within that nation's public-sector organizations. In the discipline of public administration, national military forces are distinct in that their output is security and they "have to prove their existence every day in a market where their supply needs to meet a demand."[26] With a current international strategic environment that can be described as complex, unpredictable, and subject to seemingly random shifts in threats, defence leaders must continually shape and position defence establishments to prepare "for what might happen."[27] This necessarily occurs in an environment of considerable uncertainty, yet institutional failure can have significant adverse consequences for the nation. To be able to adapt to an environment distinguished by the dynamism of continually shifting pressures, defence by its very nature is a long-cycle activity. Institutionally, defence can adjust to system shocks, but this takes an extended period of time, which could be measured in years. Understanding the dynamics of cost drivers and how they change over time, and developing strategies to address cost growth through long-term strategies are essential to constrain cost pressures.

Efficiency and Effectiveness in Defence

Military organizations are costly in nature, employing large numbers of personnel, high levels of technology and a wide range of defence platforms. In recent years, the concept of efficiency has come into focus, both from the perspective of effectiveness in operations and from the perspective of costs. Historically, however, efficiency savings have been modest. This is due to structural barriers within defence, and includes the role of the military, the lack of incentives, and Parliamentary reluctance to make certain changes. In fact, the nature of military operations "propels commanders and managers to translate efficiencies into better performance rather than savings."[28] Better performance drives increased effectiveness of military outputs. In effect, this is a de facto efficiency, yet one that does not produce savings.

In the case of the RCAF, the primary cost drivers are focused on delivery of output. This includes utilizing aircraft, consuming fuel and completing various missions. In effect, the CA, RCN, RCAF and special forces are mechanisms to deliver capability. As such, in the near term, they have limited ability to increase efficiency and have an overwhelming emphasis on effectiveness, measured by their force posture and readiness. In the long term, current RCAF resources could be shifted, in part, to other training means, such as increased use of simulators. This will be discussed in more detail later in the chapter. While near-term constraints do not negate valid reasons for seeking efficiencies within a resource-constrained environment, they highlight the need for incentives in defence to change current practices, procedures or behaviours in order to achieve efficiencies. This has more resonance at the departmental level, such as in logistics support.[29] Furthermore, increased efficiency in defence can be obtained from international cooperation among allies to reduce costs in programs and capabilities,[30] as well as from emphasizing the role of business intelligence, having sufficiently skilled staff in key roles, and changing cultures and behaviours in defence to adapt to contemporary circumstances.[31] A key incentive would be to allow defence to keep some or all of the funds from efficiencies obtained to re-invest in vital priorities, such as increased investment in equipment.

Case Study: The Relationship Between Flying Hours and the Price of Aviation Fuel

In the previous sections in this chapter, it was stated that about half of the total RCAF funding allocation for a given fiscal year is allotted to operations and maintenance, and of this, approximately half is again discretionary in nature and subject to the in-year decision making of AF defence planners. The 2016–17 fiscal year budget allotted $218M to cover fuel costs for the purposes of FG and FE. Defence planners are tasked with maintaining operations and sustaining adequate personnel numbers given these budget constraints. However, fuel costs are volatile, and even relatively small variations in the price of fuel can result in millions of dollars of either excess spending or savings.

In this case study, we test the hypothesis that defence planners alter FG and/or FE activities to deal with unexpected, exogenous cost changes and to comply with budgetary requirements. To that end, we develop an empirical model and test whether there is any relationship between fuel prices and flying rates across several different mission types.

Data overview

This analysis draws primarily upon two sources of data. First, we obtain flying rates for the CC130H Hercules SAR and CC177 Globemaster III strategic airlift platforms. Second, aircraft-specific fuel prices are derived from off-base fuel expenditures in year-end operations budgets. Each data series covers the 2010–11 to 2013–14 fiscal years.

The flying rates for each platform are divided among several mission types. The CC130H SAR aircraft has four mission types:

- **Mission type 1 –** *FG*: training for already qualified pilots, air combat systems officers, loadmasters and flight engineers for their SAR qualification;
- **Mission type 2 –** *FG*: SAR, squadron-specific training for aircrew as well as for SAR technicians posted to the squadron;
- **Mission type 3 –** *FE*: SAR employment of CC130H Hercules aircraft; and
- **Mission type 4** – *FE*: air transport operations flown by 424 Squadron CC130H Hercules aircraft that are not SAR operations.

The CC177's operations are divided into three missions:

- **Mission type 1** – *FG*: training for already qualified pilots, following their initial training on the aircraft in the United States (US);
- **Mission type 2** – *FE*: transport missions; and
- **Mission type 3** – *FE*: transport missions generally related to expeditionary operations.

The delineation between FG and FE missions is not perfect. As mentioned in section 4 under the heading "RCAF yearly flying rate," some joint FG/FE activities are undertaken. These types of missions fall solely into the FE category within this case study; in other words, FG missions would strictly include FG, while FE may contain some amount of FG.

Figure 4 displays total flying hours for the CC130H and CC177 aircraft for each month in the four fiscal years covered in this case study. The CC130H hours follow a declining trend over this period, with strong seasonal components evident: SAR missions occur relatively frequently during the summer months, and this high-demand period is preceded by increased FG. Furthermore, there are usually fewer flying hours in December and January than in other months, partly because of the tendency for FG missions not to occur at the very end and very beginning of the calendar year because of the holiday season.

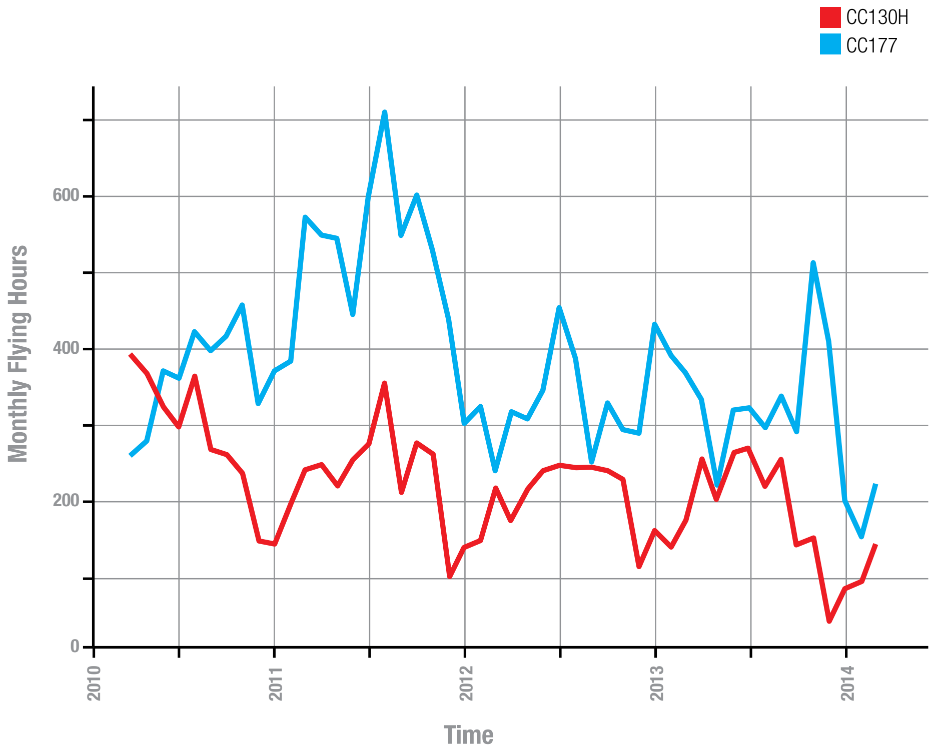

Figure 4. Monthly flying hours, CC130H and CC177, 2010 to 2014

Flying rates for the CC177 platform remain relatively steady over the course of the four years, with spikes in activity occurring irregularly. Only the 2011–12 fiscal year stands out significantly, with increased flying rates attributable to the AF's participation in the CAF mission in Libya under Operation MOBILE. Seasonal aspects are less evident, but indeed still present, in the CC177 flying rates, with a holiday season decrease mirroring that of the CC130H.

Monthly fuel prices for the two aircraft fleets are displayed in Figure 5. We also include a series of the spot price of US Gulf Coast kerosene to show the relationship between the two fuel price series and the exogenous price of fuel. The aircraft-specific prices are calculated based on the monthly average of actual invoice costs per litre of fuel for each fleet. While the two series are indeed highly correlated, there may be significant differences because of geographical considerations: for example, fuel purchased in remote locations is usually more expensive.

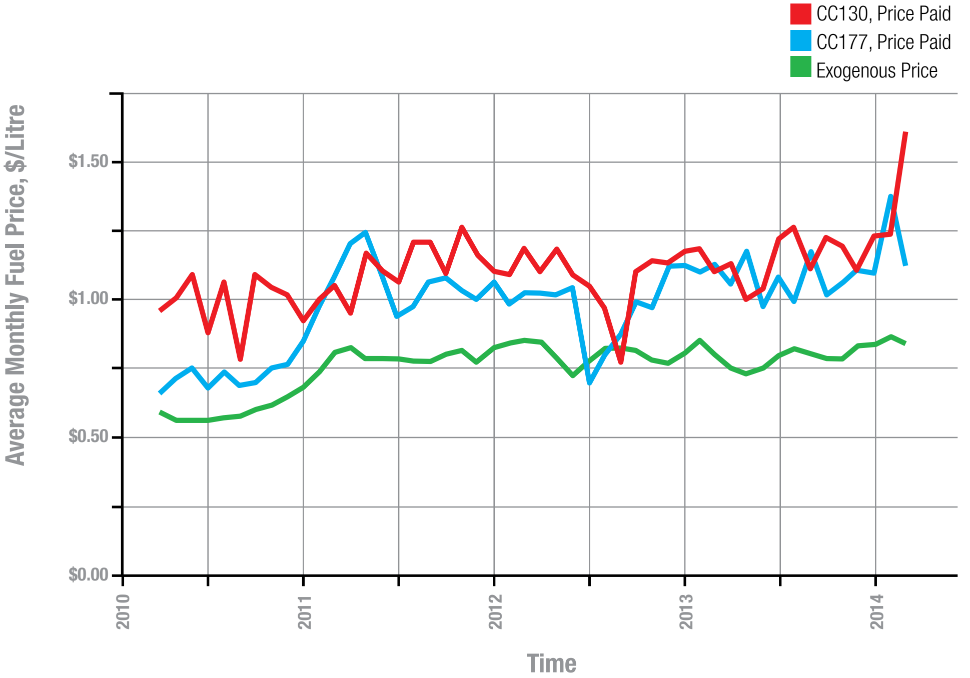

Figure 5. Monthly average fuel prices, CC130H and CC177, 2010 to 2014

Figure 6 presents a direct comparison of flying rates and fuel prices, with each point matching a total number of flying hours (y axis) with an average fuel price (x axis) for a given month. While this graph does not demonstrate any obvious relationship between the two series, it ignores the time dimension and does not examine individual mission types that may demonstrate clearer responses to changes in fuel price.

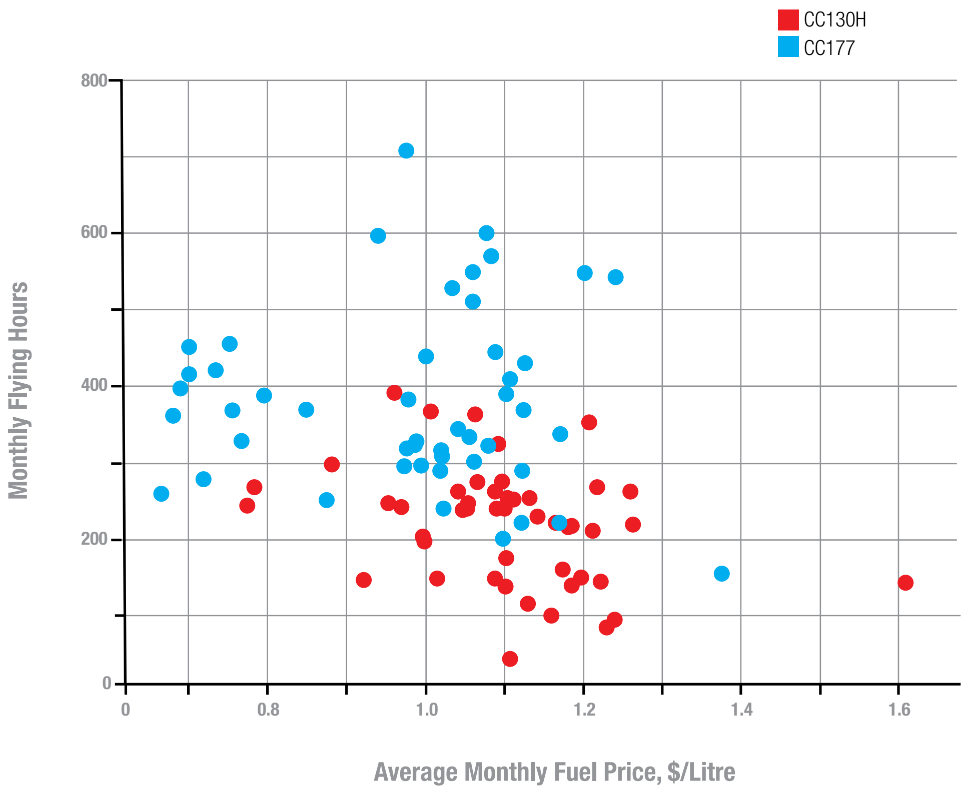

Figure 6. Monthly flying hours and off-base fuel prices, CC130H and CC177

Model

Testing the hypothesis of whether fuel prices affect flying rates requires the specification of an econometric model. We then use the available data to obtain model estimates and determine whether the hypothesized relationships have statistical significance. Since we are working with time series data, and have several series for which we are unsure of the structure, the appropriate model type is a vector autoregression (VAR). This framework can be used to find linear interdependencies among the variables of interest and examine how one variable can affect another over time.

For the purposes of model estimation, we increase the level of detail by adopting weekly frequencies for each data series. Furthermore, the two aircraft fleets—CC130H and CC177—are modelled separately to allow for the potential of their exhibiting differing behaviours. Each of the models has three data series in total: one containing the fuel prices and one each for the *FG* and *FE* flight hours.

A general VAR model is comprised of a set of variables and equations where each variable is explained by lagged values of itself and those of the other remaining variables in the system. This can be represented algebraically as:

$$x_t = B_0 + B_1 x_{t-1} + \cdots + B_k x_{t-k} + u_t$$

where '*x*' represents a vector of variables, 'B' a vector of coefficients, 't' a time indicator, and 'k' the total number of lags included in the model.

In this analysis, we use fuel prices and FG and FE flight hours as the included variables. In the VAR framework, this means that we seek to explain each variable as a function of previous values of itself (i.e., relating this week's FG flight hours and those of last week and the week before) and previous values of the other variables (i.e., relating this week's flight hours to last week's fuel prices).

Seasonality and "first-differencing"

Given the earlier discussion on the potential effects of seasonality, i.e., FG missions generally not occurring during the December holidays and FE missions reaching a peak during the summer months, we first identify and remove these effects from the data series using a seasonality decomposition procedure.[32] Standard VAR assumptions must also hold. In particular, all included series must be stationary. To that end, each series is represented as a first-difference: the change in values from one period to the next.

Results

To assess the results of this model, we focus on two methods: Granger causality tests and impulse response functions.[33] The Granger causality test concerns predictive ability only. It allows us to determine whether any of the series included in the model provide statistically significant predictive information on any of the other series, i.e., whether past values of a given variable are useful for explaining current and future observations of another variable.[34] This is a reasonable starting point when examining the relationship between fuel prices and flight hours; if such a relationship does exist, absent the presence of confounding factors, a Granger causality test should dismiss the alternative.

The short-run relationships between the variables in a VAR analysis can easily be interpreted in the form of impulse response functions (IRFs). These functions trace the reaction of current and future values of each of the variables to a one-time exogenous shock in another variable, assuming all else is held constant. For example, using IRFs we can observe how an exogenous shock in the price of fuel affects flying hours for a given aircraft and mission type (FG or FE) over time, or how a sudden (temporary) increase in the flying hours for a given mission type might affect those of another mission type.

CC130H

The test for Granger causality among all the variables indicates that no statistically significant predictive relationship exists in this system of equations. The test for the hypothesized fuel price to flying hours relationship is narrowly rejectable, with a p-value of 0.1406, while the other relationships do not have any statistically observable effects. However, there is some evidence of instantaneous causality between the various series: FG and FE hours are strongly linked in this regard. This is to be expected: in a given week, there are only so many flying hours to be distributed among alternative uses.

The impulse response functions, given in Figure 7, show the response in FG and FE flying hours following a one-time, one standard deviation shock in fuel prices. The instantaneous effect of a change in fuel price is clear, showing a decrease in FG and an increase in FE hours. However, the effects are not particularly significant: each shift is less than 2.5 hours in size, and both are close to being statistically rejectable.

Figure 7. Impulse response functions, CC130H

The short-run effect of a shock in fuel prices is even less pronounced: both the FE and FG series exhibit slight oscillations around zero, and the 95% confidence interval only rarely, and very marginally, excludes zero.

The intuitive reasoning behind such reactions is unclear. While these suggest that defence planners may slightly decrease training flight hours in response to a significant increase in costs, we cannot eliminate other possibilities, namely, that a third factor is driving both effects. For example, Canada's participation in the multilateral military intervention in Libya in 2011 (Operation MOBILE) could have caused both effects: resources might be diverted away from training (FG) in favour of strategic airlift capabilities (FE), while the uncertainty created by the conflict could increase the global market price of oil. We also cannot completely eliminate the possibility that these effects are the results of mere statistical noise, because the level of confidence of the VAR estimates surrounding these effects is close to being rejectable.

CC177

The results of the analysis for the CC177 platform reveal some minor differences with the CC130H. The Granger causality test for the fuel prices to flying hours relationship is more significant, with a p-value of 0.08857, with a stronger indication of instantaneous causality, yielding a p-value of 0.03789. A similar trade-off between FG and FE hours is also apparent: instantaneous causality for both the FG and FE series is close to the 0.01 level of significance.

The impulse response functions for the CC177 platform are provided in Figure 8. The instantaneous causality between FG and FE is again visible in the period following the shock, though the effect dissipates quickly. Beyond this initial shock, there is no statistically significant persistent effect.

Figure 8. Impulse response functions, CC177

Discussion

In the private sector, when managers are faced with decreasing budgets or increasing costs of inputs, they may respond by decreasing output or seeking cheaper inputs into the production process. In the case of national defence, such options are not always available. Defence planners usually cannot vary "output" because requirements pertaining to FE and FG tend to be very rigid. In addition, decisions regarding personnel and platforms are long term in nature and not generally subject to in-year flexibility.

This case study provides empirical support for the hypothesis that RCAF defence planners have very limited opportunity for substitution in the face of increasing in-year costs. Postponing FG or substituting towards operations that combine both FE and FG might be possible in theory. The VAR model provides a small amount of empirical evidence in that regard, showing that an unexpected increase in fuel costs might be associated with a decrease in FG flying hours in each platform; however, the effect is both small and plausibly rejectable from a statistical perspective. It appears very likely that RCAF defence budgets are indeed at the mercy of exogenous increases in costs: defence planners implicitly assume that the output is a given, and the budget must therefore conform to it, rather than vice versa.

The Solution Space: Changing Both Medium- and Long-Term Practices

The RCAF has minimal in-year flexibility to respond to substantive changes in large cost drivers, such as aviation fuel. The strategy to sustain CAF output, while faced with increasing costs, will likely consist of a combination of short-term, medium-term and long-term strategies. This section focuses on two major approaches being taken by the CAF to maximize utilization of inputs, one with a short-term focus and a second designed to have a long-term impact. The objective is to demonstrate the type of leadership-driven institutional change needed to manage resources in a manner that maintains the long-term sustainability of AF operations.

The combination of government financial regulations and laborious procurement procedures, in combination with a broad range of diverse activities, make it a challenge for the CAF to spend the full budget allocation in a given fiscal year. Various factors can contribute to the slippage of funds in a given fiscal year; for example, adverse weather conditions can result in the cancellation of FG missions or in the late receipt of planned shipments of equipment and supplies, which then miss the year-end cut-off. Despite the recurrence of such factors in virtually every fiscal year, budget managers in defence generally do not design budgetary resource allocation and expenditure patterns to fully account for budgetary and activity slippage.[35] Systematic overplanning is a leadership-driven institutional strategy to ensure full expenditure of annual budgetary resources. Indeed, in a demanding fiscal environment, "resource constraints require a more integrated approach in defense."[36] Overplanning begins with an analysis of the structural unexpended rate (SUR) by an individual major cost driver. For example, salaries for civilian public servants and military reservists employed by the AF are funded from the RCAF budget. Each has a historical unexpended rate of expenditure, and effective resource management consists in overplanning to that rate, with scheduled off-ramps later in the fiscal year if they are required to avoid over-expending government appropriations. When this approach is also applied to the planned flying rate in a fiscal year, procurement of goods and services, as well as maintenance and repair of buildings, will increase in-year output and more effectively spend the budget. While this approach focuses on a short-term, repeated annual strategy to maximize resource utilization, a long-term strategy to maintain AF capabilities into the future has a greater institutional impact.

The current use of the synthetic environment in the RCAF lags behind the aviation industry in the use of simulators for training. In order to increase the cost effectiveness of FG in the CAF, the *RCAF Air Simulation Strategy 2025*[37] was released to formalize a strategy of capacity building of air simulation from 31% to 47% of FG over the next decade. The effect gained by this strategy is to incrementally shift expensive aircraft FG flying hours to a synthetic training environment. This has several effects. First, this acts as a force multiplier: as new capabilities are fully implemented in the CAF, the additional YFR can be increased to the planned capacity, providing an overall increase in FE hours, while simultaneously decreasing live aircraft FG and replacing that training with simulators. Second, cost variations are reduced by increased use of the synthetic environment. Up-front costs are required to purchase simulators, build facilities to operate them, hire operators, and fund ongoing operations and maintenance costs, including regular software upgrades. Once in place, managing the cost of this particular activity provides significant cost reliability and decreases the risk of cost overruns in operating budgets, as compared to operating aircraft fleets to provide this capability. Planning for simulator use can occur well in advance and in coordination with specific fleet communities. This has the additional benefit of decreasing FG flying hours on certain aircraft fleets, reducing costs and potentially extending the forecast life of that fleet.

Simulators are an effective tool to both save costs and tailor training scenarios to the needs of specific crews. The primary impact of increased simulator use is to decrease aircraft operating hours; this results in cost savings in aviation fuel and in maintenance and overhaul costs. Furthermore, simulation training costs are relatively constant, and regular updates in simulator technology and mission profiles can be accounted for in training budgets. Increasing the level of integration of simulator culture into the RCAF would increase the means by which aircrews can both achieve and maintain readiness across the aircraft fleets in order to deliver capabilities across the spectrum of operations.

Conclusion

The RCAF is in a period of transition that includes managing a range of diverse yet interrelated factors. Following a series of annual budget cuts beginning with the 2008–09 international financial crises, the CAF received modest budget increases in both the 2015–16 and 2016–17 fiscal years. This reflects the importance of the role of air forces in the current international security environment, and the frequency with which they are now called upon by Western governments. While demands for FE flying hours are increasing as a result of deployed operations, the RCAF is in the midst of a generational change, with half of the AF personnel having only nine or fewer years of service.[38] This creates a significant challenge to seamlessly integrate new pilots into squadrons and ensure that they receive the experience and training to take on increasing responsibility. Nevertheless, without sustained flying hours in future fiscal years, there may be increasing risks of diminishing experience levels and loss of advanced aircrew skills. Lastly, the RCAF is implementing new capabilities through the recently purchased CC130J Hercules aircraft fleet, the new CH147F Chinook helicopter fleet, and the introduction of the shipborne CH148 Cyclone helicopter into service, while planning to increase the use of flight simulation to support FG.

The cost of aviation fuel ranged between 27% and 30% of in-year RCAF budget operations and maintenance flexibility between the 2011–12 and 2013–14 fiscal years and is a major cost driver in the AF TARM system. Yet, as illustrated in this chapter, the relationship between flying hours and the price of aviation fuel is weak. This reflects the importance of FG and, in particular, the overriding need to ensure that there are qualified pilots to keep the AF well positioned to meet its demands.

In the coming years, the RCAF will likely continue to be faced with significant financial constraints. To prepare for future challenges, and to improve the medium-term cost structure of the AF, the capacity to shift pilot training towards flight simulation is a key institutional priority. In an organization that has to balance short-term demands, adapt to a continually changing international strategic environment, remain relevant when faced with rapidly advancing technology, and maintain a focus on long-term sustainability, it is important to ensure an institutional focus within the RCAF leadership. The CAF strategy, as articulated in the RCAF *Air Simulation Strategy 2025*, is illustrative of how a defence organization can institutionally shift costs over time, and create efficiencies through a focus on maximizing long-term output.

Appendix

VAR Regression Results

The complete model results for the CC130H and CC177 VAR models are given below.

CC130H

Fuel price	Estimate	Std. Error	t-value	Pr(>|t|)	
Δ fuel price$_{t-1}$	-0.63092	0.07324	-8.615	~ 0.00000000	***
Δ FG hours$_{t-1}$	0.07575	0.07643	0.991	0.32291600	
Δ FE hours$_{t-1}$	0.10007	0.08989	1.113	0.26705100	
Δ fuel price$_{t-2}$	-0.49875	0.08575	-5.816	0.00000003	***
Δ FG hours$_{t-2}$	0.15773	0.0817	1.931	0.05505900	.
Δ FE hours$_{t-2}$	0.13976	0.10381	1.346	0.17985800	
Δ fuel price$_{t-3}$	-0.32107	0.08977	-3.577	0.00044400	***
Δ FG hours$_{t-3}$	0.06486	0.08826	0.735	0.46332100	
Δ FE hours$_{t-3}$	0.05236	0.11655	0.449	0.65378000	
Δ fuel price$_{t-4}$	-0.39828	0.09464	-4.209	0.00003996	***
Δ FG hours$_{t-4}$	0.08398	0.08577	0.979	0.32881300	
Δ FE hours$_{t-4}$	0.17365	0.11681	1.487	0.13882200	
Δ fuel price$_{t-5}$	-0.26001	0.09297	-2.797	0.00570500	**
Δ FG hours$_{t-5}$	0.05079	0.07909	0.642	0.52156800	
Δ FE hours$_{t-5}$	0.1638	0.10508	1.559	0.12074800	
Δ fuel price$_{t-6}$	-0.08047	0.07859	-1.024	0.30716500	
Δ FG hours$_{t-6}$	-0.04925	0.07054	-0.698	0.48591100	
Δ FE hours$_{t-6}$	0.07787	0.08838	0.881	0.37945100	
constant	0.98294	1.12003	0.878	0.38129500	

FG hours	Estimate	Std. Error	t-value	Pr(>|t|)	
Δ fuel price$_{t-1}$	-0.048048	0.072636	-0.662	0.50911000	
Δ FG hours$_{t-1}$	-0.461958	0.075799	-6.095	0.00000001	***
Δ FE hours$_{t-1}$	-0.06694	0.089154	-0.751	0.45370000	

FG hours	Estimate	Std. Error	t-value	Pr(>|t|)	
Δ fuel price$_{t-2}$	0.010589	0.085046	0.125	0.90105100	
Δ FG hours$_{t-2}$	-0.483522	0.081032	-5.967	0.00000001	***
Δ FE hours$_{t-2}$	-0.186142	0.10296	-1.808	0.07223600	.
Δ fuel price$_{t-3}$	0.022571	0.089029	0.254	0.80014200	
Δ FG hours$_{t-3}$	-0.310295	0.087529	-3.545	0.00049700	***
Δ FE hours$_{t-3}$	-0.006559	0.115593	-0.057	0.95481100	
Δ fuel price$_{t-4}$	-0.067517	0.093858	-0.719	0.47283000	
Δ FG hours$_{t-4}$	-0.259476	0.085065	-3.05	0.00262000	**
Δ FE hours$_{t-4}$	-0.093204	0.11585	-0.805	0.42212300	
Δ fuel price$_{t-5}$	-0.232136	0.092205	-2.518	0.01266000	*
Δ FG hours$_{t-5}$	-0.133506	0.078438	-1.702	0.09041600	.
Δ FE hours$_{t-5}$	-0.017319	0.104219	-0.166	0.86819800	
Δ fuel price$_{t-6}$	-0.133253	0.077942	-1.71	0.08900100	.
Δ FG hours$_{t-6}$	-0.144163	0.069957	-2.061	0.04072100	*
Δ FE hours$_{t-6}$	-0.014911	0.087656	-0.17	0.86511400	
constant	-0.617087	1.110815	-0.556	0.57920200	

FE hours	Estimate	Std. Error	t-value	Pr(>|t|)	
Δ fuel price$_{t-1}$	0.130168	0.061438	2.119	0.03540000	*
Δ FG hours$_{t-1}$	0.005663	0.064114	0.088	0.92970000	
Δ FE hours$_{t-1}$	-0.721883	0.07541	-9.573	~ 0.00000000	***
Δ fuel price$_{t-2}$	0.113569	0.071935	1.579	0.11610000	
Δ FG hours$_{t-2}$	-0.027666	0.068539	-0.404	0.68690000	
Δ FE hours$_{t-2}$	-0.723522	0.087087	-8.308	~ 0.00000000	***
Δ fuel price$_{t-3}$	0.037235	0.075304	0.494	0.62160000	
Δ FG hours$_{t-3}$	-0.012017	0.074035	-0.162	0.87120000	
Δ FE hours$_{t-3}$	-0.760452	0.097773	-7.778	~ 0.00000000	***
Δ fuel price$_{t-4}$	0.141398	0.079389	1.781	0.07650000	.
Δ FG hours$_{t-4}$	-0.011945	0.071951	-0.166	0.86830000	
Δ FE hours$_{t-4}$	-0.522603	0.09799	-5.333	0.00000028	***

FE hours	Estimate	Std. Error	t-value	Pr(>|t|)	
Δ fuel price$_{t-5}$	0.139007	0.077991	1.782	0.07630000	.
Δ FG hours$_{t-5}$	0.026577	0.066346	0.401	0.68920000	
Δ FE hours$_{t-5}$	-0.460077	0.088152	-5.219	0.00000048	***
Δ fuel price$_{t-6}$	0.12783	0.065926	1.939	0.05400000	.
Δ FG hours$_{t-6}$	0.074376	0.059172	1.257	0.21040000	
Δ FE hours$_{t-6}$	-0.163704	0.074143	-2.208	0.02850000	*
constant	-0.31162	0.939568	-0.332	0.74050000	

Significance codes: 0 < * < 0.001 < ** < 0.01 < * < 0.05 < . < 0.10**

CC177

Fuel price	Estimate	Std. Error	t-value	Pr(>|t|)	
Δ fuel price$_{t-1}$	-0.626702	0.074201	-8.446	~ 0.00000000	***
Δ FG hours$_{t-1}$	0.101262	0.091516	1.106	0.27000700	
Δ FE hours$_{t-1}$	0.237144	0.104162	2.277	0.02399600	*
Δ fuel price$_{t-2}$	-0.44027	0.08724	-5.047	0.00000110	***
Δ FG hours$_{t-2}$	0.130208	0.097222	1.339	0.18218400	
Δ FE hours$_{t-2}$	0.23088	0.135217	1.707	0.08947700	.
Δ fuel price$_{t-3}$	-0.3502	0.093947	-3.728	0.00025900	***
Δ FG hours$_{t-3}$	0.066379	0.103299	0.643	0.52132000	
Δ FE hours$_{t-3}$	0.174198	0.160575	1.085	0.27946100	
Δ fuel price$_{t-4}$	-0.483896	0.09317	-5.194	0.00000056	***
Δ FG hours$_{t-4}$	0.011414	0.102882	0.111	0.91179000	
Δ FE hours$_{t-4}$	0.248586	0.1757	1.415	0.15886500	
Δ fuel price$_{t-5}$	-0.374248	0.095198	-3.931	0.00012100	***
Δ FG hours$_{t-5}$	0.084905	0.104769	0.81	0.41879100	
Δ FE hours$_{t-5}$	0.289863	0.175042	1.656	0.09949100	.
Δ fuel price$_{t-6}$	-0.178555	0.09585	-1.863	0.06412900	.
Δ FG hours$_{t-6}$	-0.097304	0.104445	-0.932	0.35278900	
Δ FE hours$_{t-6}$	-0.006978	0.159444	-0.044	0.96514200	
Δ fuel price$_{t-7}$	-0.158399	0.090388	-1.752	0.08142100	.

Fuel price	Estimate	Std. Error	t-value	Pr(>|t|)	
Δ fuel price$_{t-1}$	-0.626702	0.074201	-8.446	~ 0.00000000	***
Δ FG hours$_{t-7}$	0.145476	0.09341	1.557	0.12115500	
Δ FE hours$_{t-7}$	0.041116	0.131415	0.313	0.75474700	
Δ fuel price$_{t-8}$	-0.220926	0.077094	-2.866	0.00466300	**
Δ FG hours$_{t-8}$	0.046816	0.085855	0.545	0.58623500	
Δ FE hours$_{t-8}$	-0.121205	0.104075	-1.165	0.24574400	
constant	0.768224	1.121638	0.685	0.49429000	
FG hours	**Estimate**	**Std. Error**	**t-value**	**Pr(>|t|)**	
Δ fuel price$_{t-1}$	-0.06133	0.05981	-1.025	0.30653100	
Δ FG hours$_{t-1}$	-0.53465	0.07377	-7.248	~ 0.00000000	***
Δ FE hours$_{t-1}$	-0.01734	0.08396	-0.207	0.83659600	
Δ fuel price$_{t-2}$	-0.0687	0.07032	-0.977	0.32989400	
Δ FG hours$_{t-2}$	-0.66596	0.07837	-8.498	~ 0.00000000	***
Δ FE hours$_{t-2}$	0.05572	0.10899	0.511	0.60984300	
Δ fuel price$_{t-3}$	0.05562	0.07573	0.734	0.46362500	
Δ FG hours$_{t-3}$	-0.31757	0.08327	-3.814	0.00018800	***
Δ FE hours$_{t-3}$	0.11636	0.12943	0.899	0.36986500	
Δ fuel price$_{t-4}$	-0.06278	0.0751	-0.836	0.40429900	
Δ FG hours$_{t-4}$	-0.36014	0.08293	-4.343	0.00002357	***
Δ FE hours$_{t-4}$	0.12209	0.14162	0.862	0.38979900	
Δ fuel price$_{t-5}$	-0.06993	0.07673	-0.911	0.36338600	
Δ FG hours$_{t-5}$	-0.2682	0.08445	-3.176	0.00176100	**
Δ FE hours$_{t-5}$	0.16246	0.14109	1.151	0.25109200	
Δ fuel price$_{t-6}$	-0.01887	0.07726	-0.244	0.80732500	
Δ FG hours$_{t-6}$	-0.31144	0.08419	-3.699	0.00028800	***
Δ FE hours$_{t-6}$	0.05932	0.12852	0.462	0.64495900	
Δ fuel price$_{t-7}$	0.12842	0.07286	1.763	0.07967500	.
Δ FG hours$_{t-7}$	-0.19212	0.07529	-2.552	0.01156400	*
Δ FE hours$_{t-7}$	0.09508	0.10593	0.898	0.37063700	
Δ fuel price$_{t-8}$	0.03414	0.06214	0.549	0.58340400	

Fuel price	Estimate	Std. Error	t-value	Pr(>|t|)	
Δ fuel price$_{t-1}$	-0.626702	0.074201	-8.446	~ 0.00000000	***
Δ FG hours$_{t-8}$	-0.20392	0.0692	-2.947	0.00364300	**
Δ FE hours$_{t-8}$	0.04791	0.08389	0.571	0.56868700	
constant	-0.15703	0.9041	-0.174	0.86230800	

FE hours	Estimate	Std. Error	t-value	Pr(>|t|)	
Δ fuel price$_{t-1}$	-0.004374	0.054208	-0.081	0.93577700	
Δ FG hours$_{t-1}$	0.0166	0.066858	0.248	0.80420400	
Δ FE hours$_{t-1}$	-0.796724	0.076097	-10.47	~ 0.00000000	***
Δ fuel price$_{t-2}$	0.071493	0.063734	1.122	0.26348800	
Δ FG hours$_{t-2}$	0.028955	0.071026	0.408	0.68401100	
Δ FE hours$_{t-2}$	-0.84988	0.098784	-8.603	~ 0.00000000	***
Δ fuel price$_{t-3}$	0.071119	0.068634	1.036	0.30151000	
Δ FG hours$_{t-3}$	-0.094032	0.075467	-1.246	0.21439900	
Δ FE hours$_{t-3}$	-0.864311	0.11731	-7.368	~ 0.00000000	***
Δ fuel price$_{t-4}$	0.055847	0.068067	0.82	0.41304600	
Δ FG hours$_{t-4}$	-0.148707	0.075162	-1.978	0.04941500	*
Δ FE hours$_{t-4}$	-0.765092	0.12836	-5.961	0.00000001	***
Δ fuel price$_{t-5}$	-0.106883	0.069548	-1.537	0.12611000	
Δ FG hours$_{t-5}$	-0.162031	0.07654	-2.117	0.03565400	*
Δ FE hours$_{t-5}$	-0.481316	0.127879	-3.764	0.00022700	***
Δ fuel price$_{t-6}$	-0.03629	0.070024	-0.518	0.60492600	
Δ FG hours$_{t-6}$	-0.083409	0.076303	-1.093	0.27581800	
Δ FE hours$_{t-6}$	-0.27177	0.116484	-2.333	0.02076000	*
Δ fuel price$_{t-7}$	-0.023618	0.066034	-0.358	0.72102100	
Δ FG hours$_{t-7}$	-0.080849	0.068242	-1.185	0.23770000	
Δ FE hours$_{t-7}$	-0.217165	0.096007	-2.262	0.02490800	*
Δ fuel price$_{t-8}$	0.041857	0.056322	0.743	0.45835600	
Δ FG hours$_{t-8}$	0.14999	0.062722	2.391	0.01783000	*
Δ FE hours$_{t-8}$	-0.049553	0.076033	-0.652	0.51541800	

FE hours	Estimate	Std. Error	t-value	Pr(>|t|)
constant	-0.205407	0.819425	-0.251	0.80235700

Significance codes: 0 < * < 0.001 < ** < 0.01 < * < 0.05 < . < 0.10**

Granger Causality Tests

The results of the Granger causality tests for each model are provided below.

CC130H Granger Causality Tests:

Granger causality H0: fuel price does not Granger-cause FG hours, FE hours
F-Test = 1.4464, df1 = 12, df2 = 558, p-value = 0.1406

H0: No instantaneous causality between: fuel price and FG hours, FE hours
Chi-squared = 5.1127, df = 2, p-value = 0.07759

Granger causality H0: FG hours does not Granger-cause fuel price, FE hours
F-Test = 0.7241, df1 = 12, df2 = 558, p-value = 0.7284

H0: No instantaneous causality between: FG hours and fuel price, FE hours
Chi-squared = 14.2155, df = 2, p-value = 0.0008187

Granger causality H0: FE hours does not Granger-cause fuel price, FG hours
F-Test = 0.9217, df1 = 12, df2 = 558, p-value = 0.5247

H0: No instantaneous causality between: FE hours and fuel price, FG hours
Chi-squared = 17.6047, df = 2, p-value = 0.0001504

CC177 Granger Causality Tests:

Granger causality H0: *fuel price* does not Granger-cause *FG hours, FE hours*
F-Test = 1.5168, df1 = 16, df2 = 534, p-value = 0.08857

H0: No instantaneous causality between: *fuel price* and *FG hours, FE hours*
Chi-squared = 6.546, df = 2, p-value = 0.03789

Granger causality H0: *FG hours* does not Granger-cause *fuel price, FE hours*
F-Test = 1.9992, df1 = 16, df2 = 534, p-value = 0.01171

H0: No instantaneous causality between: *FG hours* and *fuel price, FE hours*
Chi-squared = 8.2596, df = 2, p-value = 0.01609

Granger causality H0: *FE hours* does not Granger-cause *fuel price, FG hours*
F-Test = 1.2878, df1 = 16, df2 = 534, p-value = 0.1993

H0: No instantaneous causality between: *FE hours* and *fuel price, FG hours*
Chi-squared = 9.1351, df = 2, p-value = 0.01038

Structural Break Diagnostics

The following graphs represent the empirical fluctuation processes generated by cumulative sums (CUSUM) of standardized ordinary least squares residuals. These series are used to test for structural breaks in the model relationships. Under the null hypothesis, the fluctuation processes at least weakly converge to a process that exhibits Standard Brownian Motion; the alternative hypothesis is that this not the case, and there exists at least a single structural change point in the series.

The results of the test for the CC130H and CC177 are provided below.

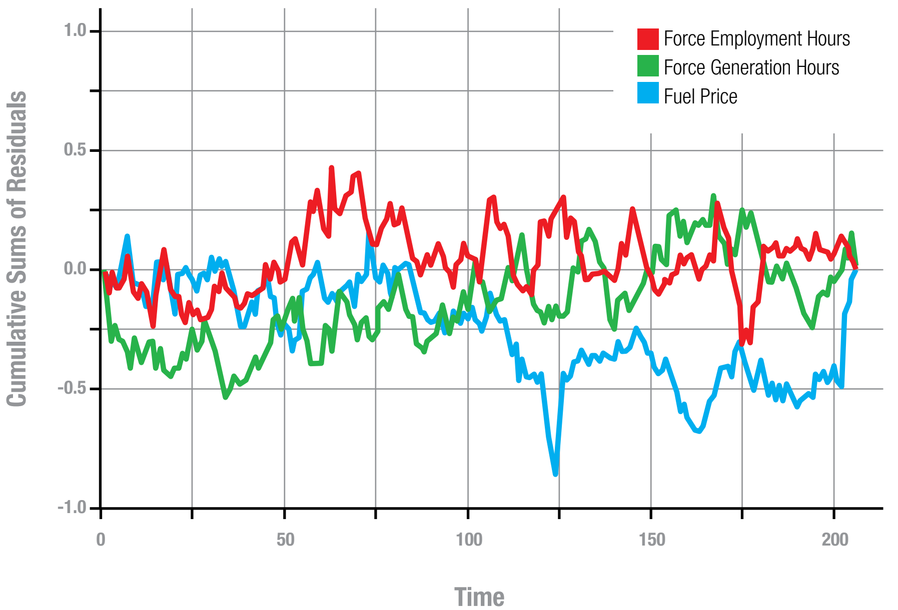

Figure A.1. Empirical Fluctuation Processes for the CC130H VAR Model

The structural change test for the CC130H VAR model fails to reject the null hypothesis, returning a p-value of 0.5438.

Figure A.2. Empirical Fluctuation Processes for the CC177 VAR Model

Meanwhile, the structural change test for the CC177 VAR model also fails to reject the null hypothesis, returning a p-value of 0.2569. Thus, there is not enough statistical evidence to conclude in favour of the existence of a structural break in either of the two models.

White Noise Tests

Listed below are the results of the tests for White Noise residuals of each of the series in the CC130H and CC177 VAR models. In all cases, we fail to reject the null hypothesis of the independence of the errors.

CC130 White Noise Errors Test:

Fuel price

X-squared = 1.4564, df = 5.323, p-value = 0.9358

FG hours

X-squared = 0.857, df = 5.323, p-value = 0.9807

FE hours

X-squared = 2.8424, df = 5.323, p-value = 0.7618

CC177 White Noise Errors Test:

Fuel price

X-squared = 0.6685, df = 5.313, p-value = 0.9892

FG hours

X-squared = 4.5805, df = 5.313, p-value = 0.511

FE hours

X-squared = 2.3382, df = 5.313, p-value = 0.8315

Ross Fetterly retired in 2017 from the Canadian Forces after a 34-year career as the Royal Canadian Air Force's Director of Air Comptrollership and Business Management. He previously served as the Military Personnel Command Comptroller, and in other senior positions with the Department of National Defence Assistant Deputy Minister (Finance). He is currently a Fellow with the Canadian Global Affairs Institute. Retired Colonel (Col) Fetterly completed a tour in February 2009 as the Chief CJ8 at the NATO base headquarters at Kandahar airfield, Afghanistan, where he was responsible for finance, contracting and procurement. Col Fetterly was employed as the deputy commanding officer of the Canadian contingent in the United Nations Disengagement Observer Force in the Golan Heights in 2000–01. He has served as an Air Force Squadron Logistics Officer and as a Finance

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Abbreviations

ADM(IE)	Assistant Deputy Minister (Infrastructure and Environment)
ADM(Mat)	Assistant Deputy Minister (Materiel)
AF	Air Force
CA	Canadian Army
CAF	Canadian Armed Forces
DND	Department of National Defence
DRAP	deficit reduction and action plan
FE	force employment
FG	force generation
FY	fiscal year
IRF	impulse response function
NATO	North Atlantic Treaty Organization
RCAF	Royal Canadian Air Force
RCN	Royal Canadian Navy
Reg F	Regular Force
TARM	total air resource management
VAR	vector autoregression
YFR	yearly flying rate

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NATO Flying Training in Canada Resource Allocation Model

Charles J. Hunter, René Séguin and Jean-Denis Caron

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Note: The authors would like to gratefully acknowledge the contribution of Captain Daniel Ladouceur for his modelling effort of the proposed future aircrew contracted training.

Abstract

NATO Flying Training in Canada (NFTC) is a three-phase program offering undergraduate and postgraduate pilot training at 15 Wing Moose Jaw, and 4 Wing Cold Lake, respectively. Since it was set up in 2000, the NFTC program has struggled to achieve its primary objective, which is to graduate pilots on time in order to sustain the various operational aviation communities within the Royal Canadian Air Force (RCAF) and other participating nations. The purpose of this paper is to describe the NFTC Resource Allocation Model (RAM), which is a highly regarded flight simulation planning tool for the NFTC program developed by the Operational Research and Analysis Directorate (ORAD) at 1 Canadian Air Division Headquarters. The NFTC RAM is endorsed by Air Force Training (AF Trg) and used on a regular basis to increase the accuracy of the estimates of graduation dates and assess the impact of allocating more or fewer resources to pilot training.

Introduction

Canadian ab initio students selected for pilot training are streamed through a multi-phase program, shown in Figure 1. The NFTC contracted portion is a three-phase program offering basic, advanced and fighter lead-in pilot training at 15 Wing Moose Jaw and 4 Wing Cold Lake, respectively.[1] Phase IIA, Basic Flying Training, is common to all prospective RCAF pilots and is conducted at 15 Wing. Graduates are then streamed into jet, multi-engine or rotary wing pilot training programs (which are provided under a separate contract along with the Phase I introductory flying training at Southport, Portage la Prairie). Advanced jet pilot training (Phase III) continues under the NFTC banner at 15 Wing. Phase IV, postgraduate Fighter Lead-In Training, is conducted under NFTC at 4 Wing. Harvard CT156 aircraft are used in NFTC Phases IIA and IIB, while Hawk CT155 aircraft are used in Phases III and IV. Since it was set up in 2000, the NFTC program has struggled to achieve its primary objective, which is to graduate pilots on time in order to sustain the various operational aviation communities within the RCAF and other participating nations. The purpose of this paper is to describe the NFTC RAM, which is a highly regarded flight simulation planning tool for the NFTC program developed by ORAD.[2] It is endorsed by RCAF AF Trg at 2 Canadian Air Division Headquarters, and has been used on a regular basis over the past 13 years.

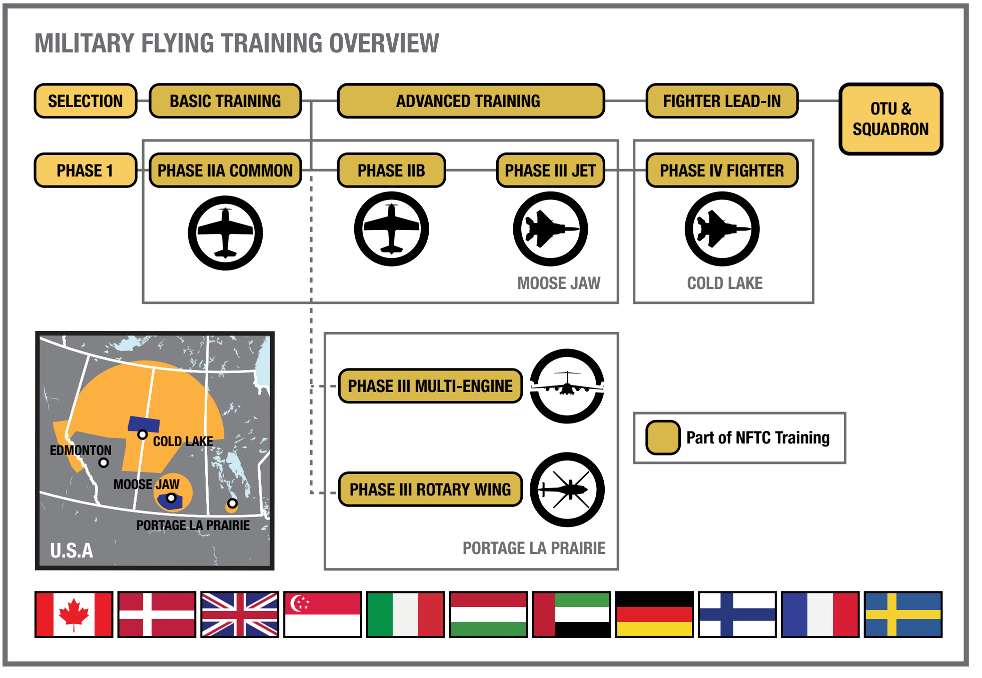

Figure 1. Canadian Ab-Initio Pilot Training Program: NATO Flying Training in Canada (NFTC)

Historical support for pilot training provided by the ORAD

Since late 2002, the ORAD has been providing the RCAF with analytical advice regarding student capacity and resource allocation issues related to the NFTC program.[3] NFTC RAM development originally focused on Phase IV of the program after the crash of one of the CT155 Hawk aircraft reduced the number of available training aircraft.[4] The program was expanded to include Phases II and III in 2004.[5] Another reason why the model was necessary was that the RCAF training schools were failing to graduate their cohorts of students by the expected graduation dates. The NFTC RAM was created to increase the accuracy of the estimated graduation dates and to assess the impact of allocating more or fewer resources to pilot training. The simulation tool has undergone several developmental iterations to improve its level of sophistication and realism, most recently in 2013.[6] Subject matter experts (SMEs) reaffirmed the assumptions in the model, updated the operations losses input data, and confirmed that the model is a reasonable representation of the operational planning conducted under the NFTC program.[7]

Simultaneously, the ORAD carried out major upgrades in order to include the pilot training phases that were not part of the original model (i.e., Phase I introductory pilot training and Phase III advanced multi-engine and rotary wing pilot training, which are conducted under a separate contract at Portage la Prairie, Manitoba). The ORAD also added many new features. For the first time, the model enhancements were completed with the assistance of an external contractor.[8] Today, the NFTC RAM is one of several resource allocation models that address various aircrew training issues.[9] The generic version is called the Undergraduate Pilot Training Resource Allocation Model (UGPT RAM) and can be applied to any phase of pilot training listed in Figure 1. The main intention of this paper is to describe the NFTC RAM model and how it has been used to identify and solve resource allocation issues related to student pilot training in the various phases of the NFTC program.

Model Description

The NFTC RAM was designed and built to address NFTC program planning issues. It is a stochastic simulation programed in C++ with a Visual Basic front-end interface. The model simulates the operation of a pilot training school conducting one of the NFTC pilot training phases. The school conducts many types of courses throughout the year. An instance of a course is called a serial, and usually more than one serial of each course is being taught at the school simultaneously, each being at a different stage of completion. Each course consists of a series of specific lessons (standard classroom lessons, simulator sessions or flight missions), with each lesson requiring a specific set of resources. The complete list of all the activities that a student must complete and the associated resources required is called a course flow. Inputs and outputs are mainly accomplished through Microsoft Excel spreadsheets.

The model does not attempt to optimize the scheduling per se, but rather follows typical syllabus course flows to allocate resources to the various concurrent serials. Because resources are limited, scheduling conflicts arise and not all activities of every concomitant serial can be carried out each day. Decisions have to be made as to which activities will be scheduled and which ones will be delayed. The decisions are based on a priority hierarchy. In this respect, the tool is more a resource planning tool than a scheduling tool, and is therefore used to determine how long each type of course flow should typically last and the most significant factors that influence course flow length and graduation dates. To ensure robust results, the tool is seeded with a few years' worth of serials for each course flow and run several times.[10]

The model's primary objective is to determine student load limits based on a specified set of resources (or, conversely, the resources required to enable a specific number of students to graduate) during each phase of the NFTC program. Because of the stochastic nature of the problem, there is inherent variability in the graduation dates of the serials from run to run within the NFTC RAM. Therefore, in order to decide whether or not a scenario is successful, measures of effectiveness (MOEs) were defined in consultation with 2 Canadian Air Division Air Force Training (2 Cdn Air Div AF Trg) for the graduation dates of course serials.[11] An NFTC RAM scenario is deemed successful if MOE 1 requirements are met and the requirements for either MOE 2 or MOE 3 are also met. The rules are as follows:

- MOE 1: 75% of the students in serials of interest[12] graduate on time (or early) in at least 75% of the NFTC RAM runs;
- MOE 2: 90% of the students in serials of interest graduate no more than five working days late in 75% or more of the NFTC RAM runs; and
- MOE 3: 75% of the students in serials of interest graduate no more than five working days late in 95% of the NFTC RAM runs.

The next two sections describe the tool's main features and assumptions that are included to make the model as realistic as possible in order to reflect the conduct of operations at the RCAF pilot training schools. This enables AF Trg to be confident that the model is representative of the NFTC program when evaluating scenario combinations of student loadings and resources.

Simulation tool's main features

Since the original NFTC RAM was designed, many features have been added to it to increase the model's fidelity and provide AF Trg with as much realistic insight as possible into what actually occurs at the training schools. The following list summarizes the main features in the current version of the model.[13]

- *Multiple courses run concurrently:* Instead of using student equivalencies, the model can accommodate all courses competing for resources and schedule them concurrently (i.e., Regular Student, Flying Instructor, Transition, Conversion, and Proficiency).
- *Training plan mission element ordering*: Missions can be sequential and prerequisite-driven, or arranged in blocks based on the resource type.
- *Extended phase for some students*: This is useful when additional mission activities only apply to a subset of those students starting a course and have to be taken immediately after the first part is finished. An example is Royal Singapore Air Force (RSAF) students who do not participate in all NFTC phases; so, for some courses, they have additional missions appended to the end of the regular course.
- *Mission alternate selection flexibility*: Even though this feature has only been implemented in the latest version, the ORAD has long promoted it as having the greatest potential to impact course duration, after weather. The ability to select an alternative activity in the syllabus when the primary event cannot be assigned (usually because of weather, but also because of a lack of resources) is extremely valuable.
- *Priority course flows*: An ordering for course flow types can be assigned based on their having a higher priority.
- *Seasonal daylight flying limitations*: Student flying is primarily conducted during daylight hours. Because winter days are much shorter than summer days in Canada, this feature allows flying activity to be reduced during the winter months.
- *Variable student serial sizes*: The model permits varying class sizes per serial; whereas, the NFTC contract assumed fixed student course sizes.
- *Real weather or flying training day calendar*: This may be selected, depending on whether or not the school has conducted a detailed flying mission weather requirement analysis. When selected, the legacy calendar simply randomly assigns a fixed number of non-flying days to a month, depending on the season.
- *Mission failures with variable number of remedial activities*: Some failures are not related to student performance, but others are, and they require specific remedial training events that must be carried out before the student can re-attempt the failed mission.

- *Multi-student/aircraft mission*: Some lessons require a number of students to work as a team and they must be paired (formation flying). A matching algorithm is used to determine whether other students of the same type are in the queue waiting to be paired for the same mission. Other activities require additional support aircraft (air combat manoeuvres). The model assigns these additional aircraft as necessary.
- *Three types of simulator devices allowed with assignment hierarchy*: These range from very simple types, such as cockpit procedures and part-task trainers, to 4- or 8-channel flight training device (FTD) non-motion simulators. The assignment algorithm searches to try and assign the lowest fidelity FTD type possible to each simulator mission, while keeping the more sophisticated devices available for missions that can only be carried out with those devices.
- *Full-day ground school (GS) and half-day GS*: The value of this feature is not to be underestimated because of the unwritten premise "to get the students to the flight line" as soon as possible. GS is scheduled at the start of courses and the later portion of the GS can be scheduled for only half a day, with the other half day consisting of simulator session or flying missions.
- *Two missions a day per student*: Students can be scheduled for two missions per day with rules related to the type of missions that are allowed together, when permitted, and rules concerning which student serials allow two missions per day. Users can switch on the catch-up rule for two missions a day, which will only activate if a student completes a section of the course late, and will terminate once the student catches up.
- *Refreshers invoked after long breaks or delays*: Refresher missions occur when students of a selected serial go several days without performing a mission. Under such conditions, students will spend a training period performing a simple flying mission or an FTD refresher mission before continuing their course flow.
- *Students closest to graduating receive priority*: Students in serials who are approaching their graduation date can be given priority in order to increase the likelihood of their graduating on time. This is done primarily to tweak the scenario when the results are close to following the MOE rules.
- *Student availability/sickness*: This involves a daily probability to account for students unable to attend class.
- *Temporary resource surges or losses*: This is a legacy feature from earlier versions that is used to determine the impact of a temporary loss of a resource for a specific period of time (e.g., a special inspection resulting in the grounding of all aircraft for one week). Surges can be used in combination with one or more of the planned, dynamic and/or deployed features.
- *Planned weekend missions*: This deliberate planned feature allows a user to set a predetermined frequency (once, twice, or every week of the month) for a Saturday mission activity over a specified period of time.
- *Dynamic weekend activity*: As the term suggests, this option is invoked depending on a combination of how far behind a student is and how many students within a serial are late. The rates are user defined and the model will dynamically activate one day on a weekend or activity on both days, depending on the severity of the lateness problem, and keep it activated until the students

get back on track with their serial. Both "planned" and "dynamic" can be applied to simulator and/or flying activities.

- *Deployed training*: The model can perform a portion of the flying missions in the syllabus from a deployed site. The user specifies which serials, the missions, and how many aircraft are to go along with the students.
- *Instructor proficiency:* The model allows for instructor pilot (IP) proficiency training to be scheduled in one of two ways, one of which is to schedule IP proficiency training only if surplus aircraft sorties are available after all student missions are carried out. Alternatively, IP proficiency training may be scheduled as a course, in which IP proficiency flying will compete with students for resources.
- *Complex weather conditions*: A combination of weather conditions may be included in the complex requirements for flying missions (i.e., instrument flight rules [IFR] conditions, but cloud break at 2,000 feet and clearhood flight available between certain altitudes).
- *Crosswinds calculation*: If the airfield has a single runway and the weather conditions call for a crosswind limit, the model can calculate the crosswind limit based on the runway orientation.

Model assumptions

For the NFTC RAM, there are general assumptions that are applied across all scenarios and phases, and others that are phase- or scenario-specific. Listed below are the main general assumptions with explanatory sub-descriptions provided, where appropriate.

1. The normal workday is split into AM and PM periods. Other periods can be used to schedule activities outside the normal workday (e.g., early morning or evenings). These other slots are used first because it is assumed that the resource will be consumed outside the program.

2. Operations losses are included and attributed throughout the model, but the cause factors are not summarized.

3. There is more than one type of individual mission failure possible:
   - straight repeat if caused by a non-student-related factor (weather deterioration, equipment malfunction); and
   - remedial training activity list, depending on the failure type and student performance.
4. Competing students are allocated resources according to the priority hierarchy:
   - students prevented from carrying out a mission during the previous period (scheduled, but unable to be carried out);
   - students who fail a mission;
   - students from a priority course flow;
   - students close to graduation; and
   - students who have not had a mission for the longest time.

5. Aircraft:

- aircraft availability is an issue outside the model. The number of sorties is assumed to be launchable missions, split between the AM and PM period, which the NFTC contractor must provide on a daily basis. Items such as scheduled or short-term maintenance are henceforth the contractor's responsibility.
- the model does not explicitly consider waves of aircraft launches. For each phase of pilot training, the NFTC contract specifies a number of aircraft sorties launched, recovered, turned around, and repeated a set number of times per day. Typically, this involves having a much more detailed knowledge of aircraft mission planning than is taken into consideration in the NFTC RAM. An example would be 17 CT155 aircraft sorties launched 5 times a day for a total of 85 sorties supported.

6. Student attrition handled in blocks (what proportion and in which portion of the course flow they "attrit" [the percentage who fail]):

- the number who "attrit;" and
- apportionment based on how far students have gotten to in the course before they leave.

7. The availability of IPs to support student missions is predetermined outside the model. An IP availability workbook is used to determine the trained effective strength of each instructor category and produce a daily number of missions that can be supported. The model then reads in the total sorties from the IP availability spreadsheet calculation:

- each instructor category has separate sortie generation ratios;
- administrative duties are to be considered when setting the sortie ratios;
- account for annual leave, professional development, and posting season impact for military IPs; and
- the number of IPs on sick leave is calculated daily within the tool.

8. A weather condition is specified for each flying mission in a course flow. Historical weather data are used to calculate the probability of flying conditions not being met. Data are collected over a 25-year period, with monthly averages for each factor computed.[14] The following meteorological factors are assessed at each airfield: ceiling, visibility, temperature, wind chill, wind velocity and wind direction.

9. The following additional weather-related factors are considered in the production of the weather probability matrix:

- James Brake Index (friction of runway/taxiway);
- migratory birds; and
- aircraft weather limitations (icing procedure in winter).

Running the NFTC RAM

Each NFTC RAM scenario is based on a set of input Excel spreadsheets specific to the NFTC training phase concerned. The input requirements consist of the following:

- a course flow listing the syllabus that a student follows for each type of course conducted;
- student attrition rates;
- course serial information (start/end dates, number of students per serial, extended students, priority rules, etc.);
- IP flying proficiency requirements;
- preference settings (for course flow priority, dynamic weekend, planned weekend periods, and mission type count); and
- a weather probability matrix generated for all the weather conditions that apply to this phase.

As additional resources, the inputs include:

- aircraft sorties for each AM/PM period and Summer/Winter season variation;
- number of flying-training daytime slots for each device (AM/PM);
- total instructor availability sorties (calculated outside the model);
- deployed training periods and resources drawn; and
- surge/loss periods with associated resource adjustments.

Usually, the bulk of the input for a scenario is defined once and kept constant. The analyst subsequently goes through an iterative process of conducting runs and analyzing the results, and then tends to focus on making changes to resources, start/end dates (course duration) or serial class sizes. This continues for a fixed annual student load until success is achieved by meeting the requirements of MOE 1 and one of MOE 2 or MOE 3.

The model collects a wealth of statistics on many items of interest and outputs them into various Excel workbooks. Macros are applied to the data to produce meaningful summary graphs and tables. The main ones (results as to the number of students in serials graduating on time, course duration, and resource utilization statistics) are described below as part of the example scenario. An assortment of other output statistics is generated and includes the following:

- number of times that students performed two missions per day;
- schedules for all courses/students enrolled in the phase over the years of interest;
- course belt displaying course duration and overlap of concurrent courses;

- resource demand and cancellation of missions exceeding capacity; and
- mission counts by type which can be used for airfield saturation calculations.

NFTC RAM Scenario—an Example

The best way to illustrate the usefulness of the NFTC RAM is to provide a sample scenario. The scenario described in this section is for a newly proposed combined Phase II / Phase III Harvard aircraft course. Throughout the first 12 years of the NFTC program, the Phase II course was considered a common core course and conducted solely on CT155 Harvard aircraft. After graduation a portion of the students were selected for advanced jet training (see Figure 1) and continued with an extended syllabus using CT155 aircraft, and then transitioned to the Phase III jet aircraft course using CT156 Hawk aircraft. The intent of this scenario is to identify the resources required to successfully start 124 regular students in the new Phase II / Phase III Harvard aircraft blended course consisting of 153 training mission elements, beginning in 2012.

Scenario inputs

For this sample scenario, the percentage of serials for MOE rules can also be represented as the fraction of serials out of the total number of serials of interest. For 2012 and 2013, there is a total of 16 regular student serials.

The closest serial count that meets/exceeds each of the MOE rule percentage criteria is as follows:

MOE	Rule
1	Students in 12 of 16 serials must graduate on time in 75% of the runs.
2	Students in 15 of 16 serials must graduate no more than 5 working days late in 75% of the runs.
3	Students in 12 of 16 serials must graduate no more than 5 working days late in 95% of the runs.

The following is the list of scenario input parameters:

Student load	124 Phase II and 32 Phase III
Number of serials	8 serials in each of 2012 and 2013, but also seeded with concurrent 2011 and 2014 serials
Aircraft sorties	85 (mid-Feb. to mid-Nov.), 72 (Winter)
FTD	27 slots (3 devices with 9 time slots each day)
IPs	70 IPs 5 Commanding Officer category, 16 Supervisors, 49 Line IPs
IP proficiency requirements	1,200 sorties (Monday to Friday)
GS	35 days full-day GS followed by 30 days half-day GS

Results

The scenario was run 500 times. The results graph displayed in Figure 2 indicates that 14 of 16 serials were on time or early 88% of the time. This means that this scenario meets MOE 1 requirements. A separate calculation was performed on the serial results data (not shown in the figure) to estimate how late the other serials were. The result was that 15 of 16 serials were no more than 5 working days late 96% of the time, which means in this example that the requirements for both MOE 2 and MOE 3 were met and, therefore, that this is a successful NFTC RAM scenario.

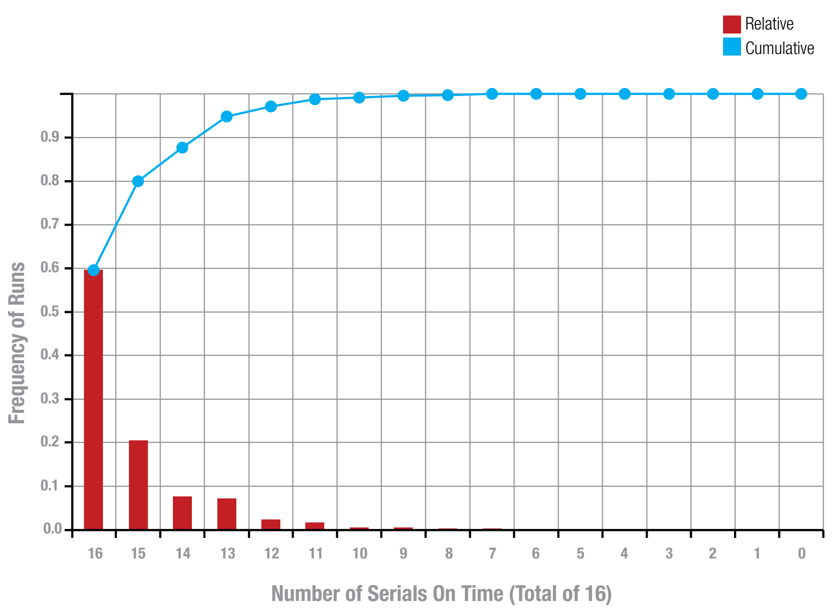

Figure 2. NFTC Phase II course serials results with 124 students

Figure 3 shows a comparison between the planned course durations (blue line) based on the input provided by AF Trg and the NFTC RAM computed course durations (magenta line). The comparison is consistent with the results figure in that for all serials, the model average duration (magenta dots) are below the planned values (blue dots), which suggests that the courses, on average, should be early or on time. The bars above and below the expected model durations indicate the inherent variability in the results. Note that for a few serials, the bar crosses over the planned value (i.e., Serial 1304), indicating that students in this course serial are expected to graduate slightly late on some occasions.

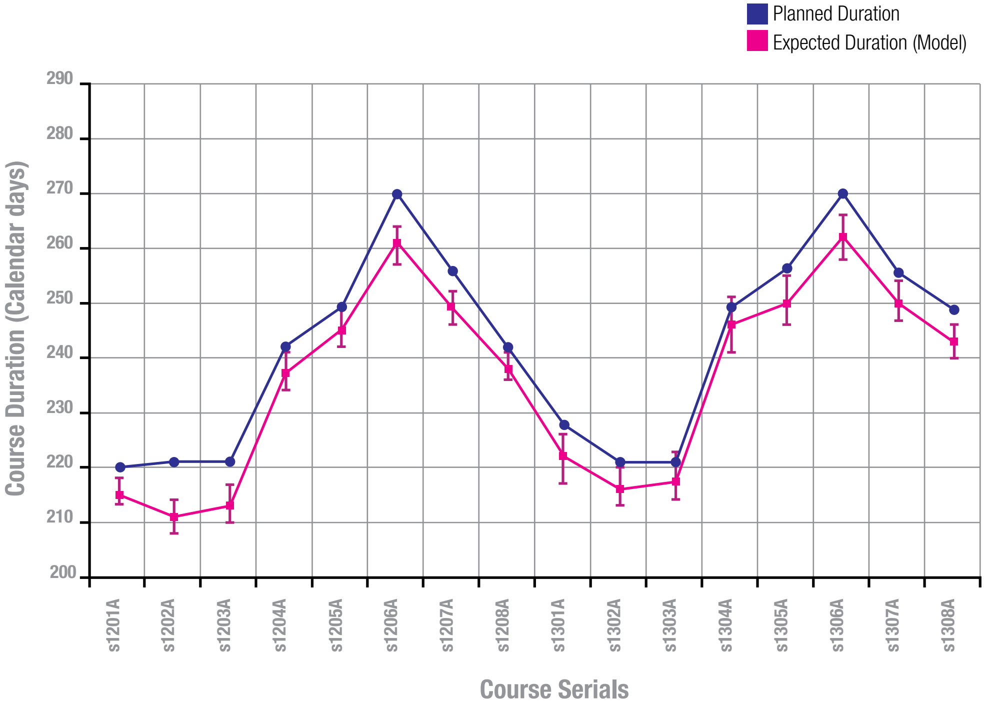

Figure 3. NFTC Phase II course duration with 1st and 3rd quartiles

Figure 4 shows the frequency with which working days are taken up with FTD slots for the execution of a single NFTC RAM run. It should be remembered that the maximum available is 27 for this scenario. The large frequency bar at 27 means that all 27 slots were being used during 84 working days out of 245. Because of the stochastic nature of the NFTC RAM, multiple runs are necessary. Over the 500 runs conducted, this maximum value of 27 varied from a low of 65 days to a high of 84 (shown in Figure 4). The FTDs are in high demand as can be seen by the shape of this chart: the bars to the left are very low to non-existent.

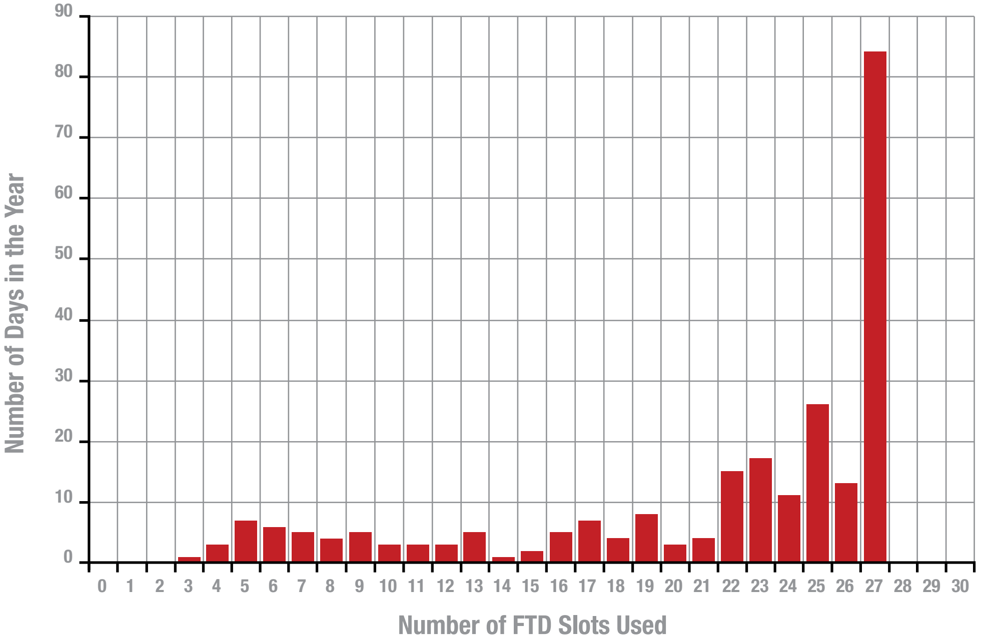

Figure 4. FTD time slot utilization

However, this is not an over-stressing scenario for the FTD resource because other FTD statistics indicate relatively low cancellation rates because of demand exceeding supply. The NFTC RAM provides additional output statistics and graphical representations that allow for a more indepth look at resource utilization. Traditionally, based on ORAD analysts' experience, FTD utilization capacity issues do not tend to start occurring until the maximum slot value is reached in half of the working days available (in this case, it would be more than 122 days).

Figure 5 shows another resource output graph generated from a single run of the NFTC RAM model. It indicates that this scenario is not aircraft intensive because the maximum number of sorties, i.e., 85 during the normal period (February–November), rarely occurs, nor does the maximum number of 72 during the winter period. One can see that the graph drops to zero fairly frequently. The main reason is that poor weather prevents flying approximately 30–35 days per year. Furthermore, on some days, conditions are such that only some flying missions can be flown. This weather analysis helps to explain why the graph is so noisy. It should be noted that the same resource output statistics and graphs can be produced for both FTD and flying missions.

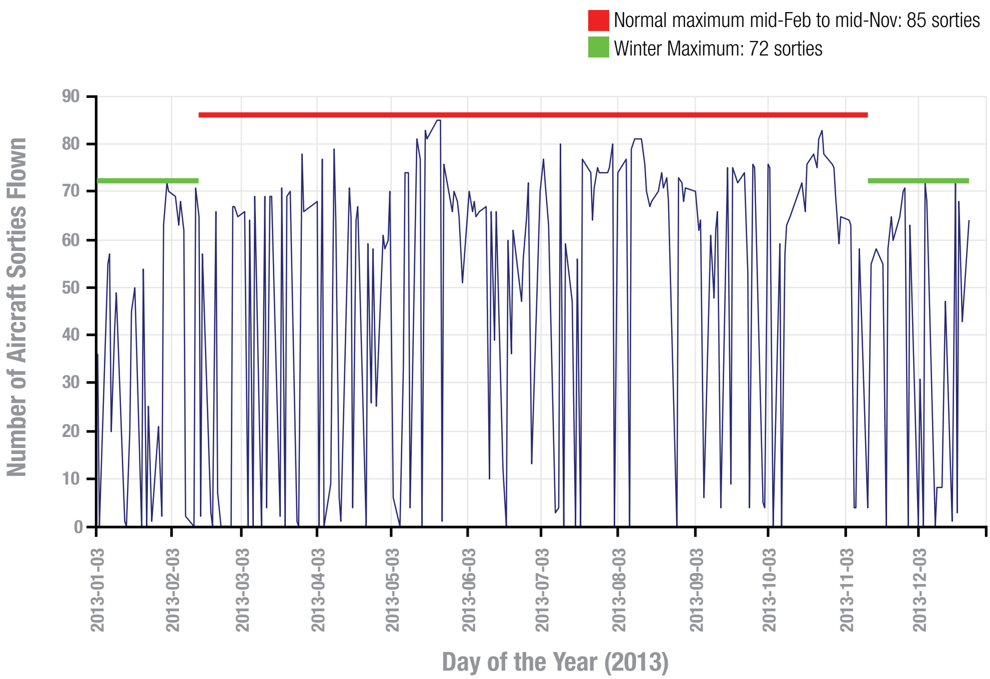

Figure 5. Daily flying mission rates

The example given is just one type of question (or task) related to ab initio pilot training that the RCAF has submitted to the ORAD over the past 14 years. Typically, these questions (or tasks) have fallen into one of two categories: (1) for a fixed number of resources (aircraft sorties that can be generated, flying simulator slots, and instructor pilots), determine the student throughput capacity for a given phase of the pilot-training program; and conversely, (2) define the student workload in order to calculate the amount of resources required to graduate students in the course serials on time. The example given above falls into the latter category.

The following are other types of questions asked or tasks assigned by the client:

1. What is the impact of more course serials with fewer students per serial? It was determined that the overall result was a "smoothing out" of resource utilization (reduction of the height and depth of peaks and valleys) for all simulator and aircraft sorties. However, too many course serials also opened up the possibility of potential conflict for instructors (not enough slack time between mission events) and classroom availability.[15]

2. For a given phase of the training program, how to determine the best serials in which to place international students and predict the course duration when the syllabus is different for each group? This required significant interaction with contractors and 2 Cdn Air Div AF Tng in order to take

into account numerous considerations that were external to the model (i.e., alignment with the international students' flying program, and students to be interspersed with Canadian students or provided with a dedicated course serial).[16]

3. How to estimate the impact of changing climate patterns? There has always been a common belief that weather on the Prairies has deteriorated for the purposes of flying training over the past few decades. It has already been mentioned that the ORAD completed an in-depth investigation of the NFTC syllabus and actual weather conditions, and determined the impact that actual weather conditions had on the prediction of course durations and the reliability of estimated graduation dates.[17] However, to answer this particular question, the ORAD completed a separate analysis in which it broke up the weather input into five-year segments and assessed whether the ability to fly missions was increasing or decreasing (weather getting worse) over the years in Moose Jaw.[18]

4. Course syllabus re-design can determine course duration and best start/end dates. Originally, the course syllabus was organized in a sequential, prerequisite-driven manner. This meant that students could never get ahead of the syllabus, and also that there was no flexibility in the mission scheduling. In the example given above, part of the blending of the Phase II / Phase III course also involved the arranging of the individual missions into blocks, primarily based on resource, FTDs and flying. This rule change improved the predictability of resource utilization, but did not result in any improvement in terms of course durations (in most cases, the length of courses was not shortened).[19]

5. Assess the impact of instructor pilot proficiency requirements on the resources allocated to the program. For many years, proficiency was an afterthought, but as greater priority was given to maintaining IP flying proficiency, these missions began to compete for the limited resources allocated.[20]

6. Miscellaneous questions or tasks[21] involving less formal publications or oral presentations on analytical results:

   - estimate the recovery period after unforeseen losses (e.g., aircraft maintenance losses, prolonged severe weather conditions);
   - determine the impact of implementing planned weekend flying before the winter period: this definitely had the desired effect of building up mission Xs (completed missions) in advance, and when planned, allowed for greater predictability of how much overtime was needed and when;
   - allow for mission selection flexibility: this involved drawing up a set of mission alternatives that can be performed when the primary mission cannot be assigned (usually because of weather or unavailable resources). After weather, this is probably the next largest change impact introduced into the NFTC RAM. The formalization of this practice made the predication of course duration so much more reliable because it allowed courses to stay on track, although on a daily basis, the students may not be able to carry out their primary mission assigned in the schedule. Note that the ORAD ascertained that some of the positive aspects of this feature were muted when combined with the course syllabus arranged in blocks starting in 2013, because the alternative mission list was reduced, particularly alternatives between flying and simulated missions; and
   - determine the impact of deployed site operations (flying portion only, normally done to avoid bad weather at the primary location).

Summary

This paper has demonstrated how the development and application of the NFTC RAM came into being. It has involved a very close working relationship between the RCAF training community and the ORAD team over a long period of time. The model is endorsed by the RCAF and used to support critical resource allocation decisions related to pilot training conducted under the NFTC program. The ORAD has also been tasked to help attract countries to participate in the NFTC program by identifying where student loading opportunities exist (excess capacity) and/or by verifying the resource implications of adding students to an already full training phase. The arrival of the Kingdom of Saudi Arabia students, starting in 2012, is an example of the international impact that the NFTC RAM has had.

It is impossible in a brief paper to cover all the features and assumptions contained in the NFTC RAM. The sample scenario is just an abridged subset of the model's capability and the potential impact it can have. RCAF aviation training relies heavily on the ORAD's analysis and advice made possible by the NFTC RAM.

Future work: ORAD modelling of next generation aircrew training

In 2016, the RCAF Future Aircrew Contracted Training (FACT) project team asked the ORAD to provide insight into the next generation of Canadian military aircrew training.[22] The client for this project is the RCAF's Directorate of Aerospace Simulation and Training (DAST). The goal is to assess options for the basing and resource allocation of the next generation of military aircrew training. The official task description as requested by DAST is as follows: "Produce an infrastructure space analysis comparing future requirements with existing infrastructure for each of the location options given the data for each course."[23] There are three possible locations to be considered where future military aircrew training may take place: Moose Jaw, Saskatchewan; Southport (near Portage La Prairie), Manitoba; Winnipeg, Manitoba.

DAST has specified the desired format of the gathered information:

- "a graphical representation of peak periods on the airfields, flying training areas and low-level navigation routes for each of the location options;"[24] and
- "a report detailing the problematic air traffic management areas and additional airfield/airspace infrastructure required for each of the location options."[25]

Given that the future syllabi for and estimated required throughput of future aircrew training will be supplied by the FACT team, the ORAD's task is to determine the resources required in order to provide this training. The ORAD's primary tool for providing this type of analysis is the software package called the Undergraduate Pilot Training Resource Allocation Model (UGPT RAM).[26] The UGPT RAM is a mature model adapted from the original NFTC RAM that has been verified, validated, peer reviewed, published, and implemented in the current pilot-training scheme. Although it was originally built to model pilot training, it can also be easily adapted to incorporate aircrew training for air combat systems operators and airborne electronic sensor operators. By using the UGPT

RAM, one can estimate parameters such as the number of instructors required, the number of daily flying sorties required, and the number of simulators required. However, physical considerations are outside the scope of the UGPT RAM.

Figure 6 illustrates the conceptual flowchart of the process that the ORAD plans to implement in order to complete an options analysis for each of the hypothetical training locations (and combinations thereof). The existing UGPT RAM model is used first in order to investigate the resources required to produce the desired number of students, given the new syllabus. Once an acceptable outcome has been produced by using the UGPT RAM to determine future aircrew training resource allocation requirements, course durations, and start/end dates, etc., the next step will be to determine the infrastructure required to support this resource utilization. Such considerations include runway congestion, airspace congestion, impact on local or regional air traffic, and adequacy of facilities. The plan is to construct a mixed-methods simulation model called the Future Aircrew Training Infrastructure Requirements (FACTIR) simulation model in order to answer these questions.[27]

Any combination of courses may be located at any combination of the training locations. The purpose of the FACTIR simulation model is to investigate the adequacy of and/or impact on infrastructure of any of these options. The FACTIR model will use the details of the course schedule script output from a UGPT RAM run and simulate the execution of the script over several years, based on the infrastructure constraints of the location configuration being studied, as well as gather various statistics for analysis.

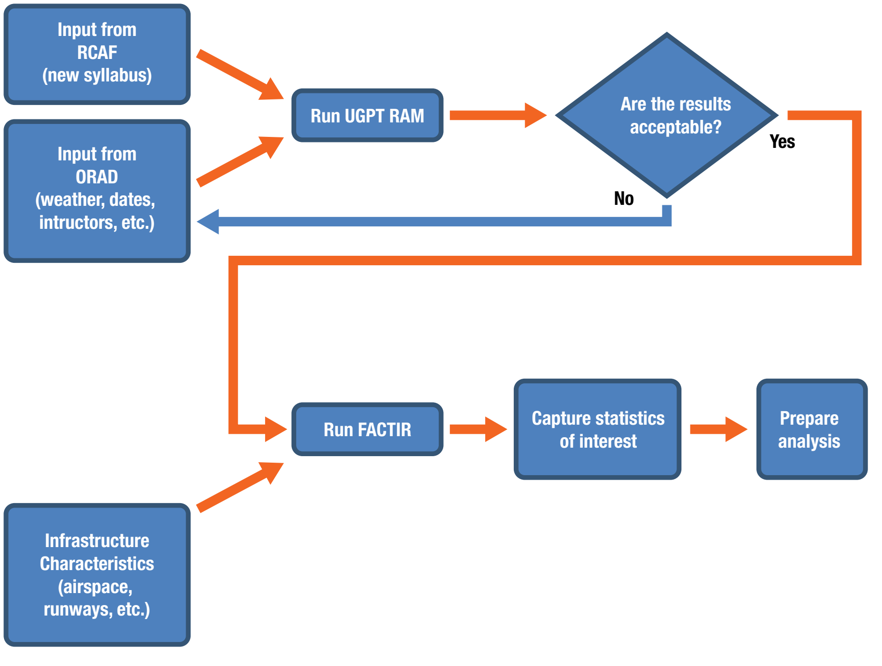

Figure 6. UGPT RAM and FACTIR simulation interaction

The ORAD is currently in the software development phase with a preliminary version of a FACTIR model that can address these issues for a single fleet, and will soon be able to examine various options for future aircrew contracted training and provide the RCAF with detailed analyses based on simulations. Being able to illustrate the uncertainty in critical variables, such as weather, resource availability and failure rates, prior to entering into a long-term contract, should result in a better stating of requirements and the inclusion of clauses that include flexibility in the assigning of resources as necessary based on agreed funding rules and sound analysis.

The value of this latest effort is quite important because the ORAD has been involved with the NFTC program since 2002, but did not play an important role in stating the original requirement associated with this 20-year contract. For the next generation of pilot training, and perhaps for the training of all aircrew, the goal is to write a Statement of Requirements that is backed by sound operational research analysis and modelling.

Charles J. Hunter joined the Operational Research and Analysis Establishment in July 1983, with an MSc degree in Statistics. His postings include the Directorate of Mathematics and Statistics and various Air Force headquarters: Air Transport Group, Air Command, Fighter Group / Canadian NORAD Region, and 1 Canadian Air Division / Canadian NORAD Region, where he was Director for Operational Research and Analysis for more than 20 years. He has worked on numerous topics such as air-launched cruise missiles, search and rescue, CF18 strategic air-to-air refuelling, battle management and other C4I initiatives, pilot force generation, and redesign of the Air Operations Centre. He retired from DRDC CORA in July 2018, having worked directly with the RCAF for 32 years.

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Jean-Denis Caron holds a BSc degree in mathematics and a MA in applied mathematics and computer science from the Université du Québec à Trois-Rivières in Canada. Since 2002, he has been a Defence Scientist with Defence Research and Development Canada – Centre for Operational Research and Analysis (DRDC CORA). He is currently the team leader of the Maritime Operational Research Team in Ottawa, providing decision support, quantitative analysis, and modelling and simulation to the Royal Canadian Navy.

Abbreviations

AF Trg	Air Force Training
Cdn Air Div	Canadian Air Division
CANR	Canadian NORAD Region
CFFTS	Canadian Forces Flying Training School
CORA	Centre for Operational Research and Analysis
DAST	Directorate of Aerospace Simulation and Training
D Air CFG	Director Air Contracted Force Generator
D Sim and Trg	Directorate Simulation and Training
DRDC	Defence Research and Development Canada
FACT	Future Aircrew Contracted Training
FACTIR	Future Aircrew Training Infrastructure Requirements
FLIT	fighter lead-in training
FTD	flying training device
HQ	headquarters
IFR	instrument flight rules
IP	instructor pilot
MOE	measure of effectiveness
NATO	North Atlantic Treaty Organization
NFTC	NATO Flying Training in Canada
ORAD	Operational Research and Analysis Directorate
RAM	Resource Allocation Model
RCAF	Royal Canadian Air Force
RSAF	Royal Singapore Air Force
UGPT	Undergraduate Pilot Training

Notes

1. CAE Canada, "NATO Flying Training Canada (NFTC)" (Ottawa: CAE Canada) accessed August 20, 2018, https://www.cae.com/defence-security/air/training-centres/nato-flying-training-in-canada-nftc.

2. Operational Research and Analysis Directorate (ORAD) is a team of Defence Research and Development Canada (DRDC) Centre for Operational Research and Analysis CORA defence scientists co-located with the RCAF at 1 Canadian Air Division Headquarters (1 Cdn Air Div HQ).

3. L. Low, R. W. Funk and S. A. Latchman, "Automation of Flying Training Day (FTD) Calendars," Air Command (AIRCOM) Headquarters (HQ) Operational Research Division (ORD), Research Note 9602, December 1996; J. D. Caron and C. Hunter, "NATO Flying Training in Canada: Assessment of Bombardier's Static Scheduling Tool," 1 Cdn Air Div/ Canadian NORAD Region (CANR) HQ CORA Research Note 0209, December 2002; J. D. Caron and C. Hunter, "Operational Research Support to NFTC," 1 Cdn Air Div/CANR HQ CORA Project Report 0402, December 2004.

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5. Jean-Denis Caron, "Expansion of the NFTC Resource Allocation Model to Phases II and III," 1 Cdn Air Div/CANR HQ Research Note 0402, April 2004.

6. C. J. Hunter, C. McIlwraith and N. Goodridge, "Modifications to the NFTC Resource Allocation Model (RAM)," DRDC CORA Technical Memorandum TM2007-44, October 2007; René Séguin and Charles Hunter, "Undergraduate Pilot Training Resource Allocation Model (UGPT RAM)—A Comprehensive Description," DRDC CORA TM 2013-221, December 2013.

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CH13

RCAF Pilot Training and Alternate Service Delivery: Assessing and Improving a Dysfunctional Paradigm for the Future

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Editor's Note: This is a modified version of the Masters in Defence Studies research paper submitted to the Royal Military College of Canada on January 4, 2015.

Introduction

Air power is a key component in the complex matrix of tools available to the federal government to achieve Canada's strategic objectives both militarily and diplomatically. It follows that force generation (FG) is essential to the sustainment of aerospace capability. To generate and sustain air power, the Royal Canadian Air Force (RCAF)[1] requires a robust, organic and cost-effective pilot training system. However, military pilot training is an expensive and complex activity. In 2012, the RCAF spent approximately $346.65M on training for all occupations, including $304.92M allocated directly to the training of pilots to wing standard.[2] Given the high cost of and extended timeline for training pilots,[3] it is vital to the national interest and to the RCAF that this training remain effective and affordable.

However, despite the importance of FG, the RCAF has had a sustained and systematic shortage of trained military pilots since the Force Reduction Program (FRP) of the early 1990s. The FRP's objective was to reduce military personnel costs associated with "establishment reductions and base closures."[4] The resulting savings were then to be balanced between reducing overall expenditures and increasing critical capital acquisition funding.[5] This program targeted specific military occupational classifications (MOCs) and many experienced military pilots took the option of early paid retirement.

Moreover, the need to reduce numbers of military personnel led the Department of National Defence (DND) to embrace the Canadian government-wide alternate service delivery (ASD) initiative.[6] With the philosophy of reducing costs and maintaining core combat capabilities, non-core activities such as support services were specifically targeted under a DND-derived ASD strategy.

Because of these fiscal pressures and labour realities, the RCAF and the Government of Canada have adopted an outsourcing approach for pilot training. This approach has resulted in two complex, multi-billion dollar ASD contracts that are essential to the production of newly winged RCAF pilots. The current contracts, NATO (North Atlantic Treaty Organization) Flying Training in Canada (NFTC) and contracted flying training and support (CFTS), differ in their basic approach to providing the RCAF with pilot training and related services. Because these contracts were awarded sequentially with several years between each one, there was an attempt to apply lessons learned from one contract to the other. However, the success of the ASD approach in the pilot training environment has been mixed. While pilots were and are being trained, they have not been trained in sufficient numbers to meet RCAF requirements.[7] According to the Chief Review Services (CRS) audit of initial MOC training in 2012, "The evaluation found that there has been a shortfall of between 200 and 250 [pilots] for the past ten years and there are no indications this problem is being resolved."[8]

With the largest of the contracts, NFTC, ending in 2021, the RCAF has commenced the lengthy process of assessing its future pilot training requirements. The outcome of the analysis will have a profound impact on the next multi-billion-dollar pilot training contract. Given that from now until

2021 is a relatively short timeline for getting such a large project finalized in the unwieldy government procurement system, negotiations have recently been concluded to extend the operating period of the NFTC contract until 2023.[9] In either case, it is critically important to focus on those factors that will determine the success or failure of future pilot training.[10]

While there are other pilot training programs in operation around the world to which the RCAF might look for lessons learned, there is no example that the RCAF can simply duplicate to meet its needs. The biggest of these, the Euro-NATO Joint Jet Pilot Training (ENJJPT) program in the United States (US), is a much bigger program than NFTC, and it operates with a government subsidy, which is not allowed in Canada. Another example is the United Kingdom (UK) Military Flying Training System. While this program operates as a public-private partnership, it is still several years away from being fully operational,[11] and therefore too new for valid comparison. In addition, the Royal Australian Air Force (RAAF) and the Republic of Singapore Air Force (RSAF) operate a public-private partnership to provide training in a joint arrangement.[12] The RCAF sent representatives to look at this program, and while there appear to be some elements of the program worthy of further investigation, it is also not a comprehensive solution. In addition, there are several other examples of bilateral pilot training arrangements around the world.[13] Although some aspects of these programs will be mentioned, a detailed analysis is beyond the scope of this paper.[14]

Given this context, this paper contends that there are several factors that the RCAF must consider in order to take advantage of the positive aspects of outsourcing, while avoiding the pitfalls it has already experienced with ASD. These lessons learned must be applied during the development of the next generation of RCAF pilot training contracting to ensure that successes are replicated, while failures are mitigated or avoided altogether. These factors include implementation of ASD principles and philosophy, the capital asset acquisition paradigm, resource requirements, performance measurement, the RCAF-contractor relationship and marketing.[15] They will be referred to as the critical factors that will serve as a guide in the examination of the NFTC and CFTS contracts. Appreciating this broad spectrum of variables is vitally important because air power operators tend to focus on capital asset requirement determination and selection—specifically which aircraft and simulators to employ—and fail to fully appreciate the implications of a contract structure that is not designed to ensure effective delivery of services. In fact, the success of the future pilot training program is almost entirely dependent upon effectively addressing these variables. As well, the structure of the contracting paradigm—for example, resource ownership and control—is fundamental to the future success of pilot training in the RCAF.

To make this argument, the paper is divided into eight sections. The following will deal with the geostrategic background of and the neo-liberal rationale for contracting and the way in which Canada has embraced ASD. The second will look at the RCAF experience and identify problem areas and relevant variables. The third will discuss the contractor perspective on pilot training support contracts. The fourth will outline lessons learned that should be applied to the next contract. Lastly, the fifth will set out recommendations and conclusions with respect to structuring the future pilot training system.

Background of ASD and the RCAF

During the Cold War, the Canadian military, like its NATO allies, maintained an operational structure based on the bi-polar superpower paradigm of large-scale armoured and mechanized maneuver formations for the Central European Theatre. This paradigm required military formations to be both self-contained and self-sustained.[16] Military logistics and support were integrated with combat formation units and, although there were civilians employed by the military, they were not employed in critical positions or positions directly contributing to combat operations.[17]

The abrupt end of the Cold War and the deteriorating economic situation in the early 1990s forced defence establishments to seek a solution for rising personnel costs and shrinking capital acquisition allocations. Because of these pressures, militaries around the world turned to the nascent and cutting-edge private firm concept of outsourcing.[18]

In Canada, the White Paper on Defence in 1994 set the tone for a shift to the outsourcing of capabilities considered to be non-core activities. The Canadian ASD paradigm originated in this capstone document. The introduction of ASD within DND rapidly gained momentum and the pace of outsourcing activity continued to accelerate at a faster rate than the analysis of the effects of outsourcing could be analyzed. Therefore, despite the warnings of the Auditor General, ASD became ingrained in Canadian military operations and support.[19] By examining the origins of the ASD philosophy, a better understanding of the outsourcing paradigm can be obtained. The current applications in the form of large outsourced RCAF pilot training contracts originated in the private-sector management theorems that were embraced by both the Crown[20] and DND. It is against this backdrop that future programs must be considered.

Origins of ASD

In the aftermath of the collapse of the former Soviet Union in 1991,[21] Canada and its allies questioned the rationale for large defence budgets. The apparently imminent threat of Soviet expansionism was popularly viewed to have disappeared.[22] The altered political world order was believed to have resulted in a more stable and predictable defence environment. Many governments used the apparent demise of an overt threat as grounds for channelling funds previously directed to the military towards non-military items that required increased funding or provided much greater political capital with the voting populace.[23] Such savings became popularly known as the "peace dividend."[24] However, debaters at the time were unable to agree on the size and scope of the windfall. Studies indicating that because of the Soviet demise, NATO members could afford a strategic military funding reduction of 1%[25] were in direct contrast to statements from politicians that military expenditures could be reduced by up to 25%, if not more.[26]

While this geostrategic earthquake was rumbling through NATO's defence establishments, the world found itself embroiled in a pervasive recession that added impetus to defence funding reductions. There were many reasons for this fiscal tumult, not the least of which was the sharp increase in fuel prices following the 1991 Coalition invasion of Kuwait and Iraq during the First Gulf War.[27] In addition, high public and private debt loads limited governments' fiscal flexibility to spend their way out of the recession by incurring further debt.[28] Therefore, governments looked for reductions in activities that were viewed as soft from a political perspective.[29] The result was ever-increasing pressure to reduce expenditures on items, such as defence, that were often the biggest discretionary budget item.[30] Thus, the stage was set on both the strategic and political fronts for a paradigm shift in the delivery of military effect.

To achieve the desired savings, governments around the world sought to emulate the efficiency gains made by private companies during the previous decade.[31] Outsourcing became pervasive around the globe in both the public and private domains as governments and private companies sought to maintain or increase levels of service while reducing costs.[32] There was a concerted attempt to reduce overhead or activities that were not a component of the core competency of the agency or business. In the public-sector world of fiscal crisis and ever decreasing budgets, private-sector management theory, as embodied by ASD, was viewed as the solution to public-sector inefficiency and mismanagement.[33]

These fiscal and political factors resulted in the 1994 White Paper on Defence. This document outlined government plans to decrease financial and personnel resources allocated to national defence. These resources would be applied instead to the deficit to help reduce the national debt. As stated in this capstone document, "At the present time, our prosperity—and with it our quality of life—is threatened by the steady growth of public-sector debt."[34] In addition, the government made the source of additional government funding cuts very clear: "Although National Defence and the Canadian Forces have already made a large contribution to efforts to reduce the deficit, the Government believes that additional cuts are both necessary and possible."[35] The White Paper went on to state that "the Department and the Forces will also reshape the defence program and operate more efficiently to deliver the elements of the policy outlined in the White Paper."[36] It is noteworthy that despite such overt statements regarding the reduction in resources there was no real concomitant change in the government's view of the military's strategic roles because the traditional roles were maintained.[37] Thus, there was a continuation of the traditional capability-commitment gap that has often existed in the Canadian military context.[38] Defence policy during this time was "based more upon domestic determinants (the economy)"[39] than Canada's place in the geostrategic situation. The 1994 Defence White Paper called for major cuts in defence spending and the government directed DND to operate with fewer resources and people and less infrastructure.[40] With this imperative unmistakably at the forefront of government thinking, there was a foundational shift in the delivery of military effect that profoundly shaped the future of national defence and the Canadian Armed Forces (CAF).

The outsourcing of support services was fundamental to the government's strategy of reducing resource allocation to the military. In fact, when the ASD program was launched in 1995, the government publicly set "a goal of saving $200M a year by 1999 and $350M a year by 2001."[41] This benchmark embodies the reality that defence funding decisions were to be made primarily with the aim of minimizing expenditure versus being driven by capability requirements. Such goal setting is indicative of the inherent danger of ASD, which is that cost cutting becomes the measure of success instead of streamlining service or delivering better service for the same or even slightly greater cost.[42]

In fairness, the military ASD revolution was not purely a Crown-driven event, but rather the government was opportunistic in reacting to positive reports from several allies, including Australia, the UK and the US.[43] Available reports indicated that Canada's allies were realizing savings on the order of 20% to 30%.[44] Therefore, it was against this political backdrop that defence planners recognized that a new course had to be charted within the altered funding paradigm in order to maintain operational capability.[45]

To achieve its cost reduction objectives, the government focused on two main areas. Firstly, the government viewed services requiring military personnel inputs as inherently wasteful and sought efficiencies to minimize personnel requirements. As clearly outlined in the 1994 White Paper, "Most areas of defence will be cut. The relative weight of the naval, land and air establishments will be altered to allow for the transfer of more resources to where they are most needed—mainly to operational land forces. Everything is being made leaner."[46] Secondly, ASD solutions were to be found wherever possible to reduce costs. This policy specifically targeted logistical support functions that were deemed to be non-core activities as related to the delivery of combat power. Both the procurement of equipment and the delivery of support functions were prime candidates for cost reductions. Thus, the 1994 White Paper paved the way for the emergence of ASD as a key component of government and defence policy.

Reducing the number of uniformed military personnel

Military personnel are very expensive and their value is often difficult to determine using productivity matrices used in the private sector, which makes them a prime target for cuts. In fact, military manning realities are such that personnel overhead is much higher than that of private corporations. Professional development, deployments and annual leave require additional personnel to cover absences from garrison duties. By contracting out what were "non-core" military functions to civilian companies, personnel costs could be greatly reduced.[47] Additionally, DND retained much of the same infrastructure with the associated personnel required as caretakers as it had for most of the preceding decades during the Cold War. Thus, ASD was as an enabler to reduce a costly infrastructure footprint that would result in concomitant reductions in personnel and funding requirements.[48] As stated by the Office of the Auditor General (OAG) in 1999, DND policy was that "in-house support activities were to be transferred to Canadian industry if business case analyses demonstrated a potential for increased cost effectiveness, or shared with private industry under various partnership arrangements."[49] Indeed, the 1994 White Paper candidly stated, "Personnel cuts will continue."[50] There was also a specific mention of "more emphasis on renewable, short-term periods of service for members of the Canadian Forces."[51] This initiative to reduce the number of uniformed service personnel and departmental civilians was in addition to the FRP that had begun in 1992 and continued through 1996.[52] The resultant boon of personnel cost savings in salaries and pensions would be used to compensate for reduced budgets and in this way governments could reap the dual benefit of sound fiscal management while maintaining capabilities and capital projects.[53] In the Canadian context, although the military personnel footprint would be reduced, the transfer of such spending to direct civilian job creation would also result in regional economic development outcomes that could produce advantageous political capital, while reducing the amount of precious government resources allocated to the military.

ASD for support functions

The second component of the Crown's ASD strategy was the contracting out of support functions deemed to be non-core activities. There was an enormous opportunity to reduce costs given that the OAG estimated that in 1995, non-core support services "consumed approximately one-third of the Department's budget of $10.3B."[54] Several non-core support services were targeted for review by DND, such as equipment maintenance, supply services and information technology.[55]

Another component of this approach was the review of the national procurement strategy, especially as it related to capital acquisition and logistics. The government directed DND to adopt better business practices and to increase its emphasis on the rather new industry concept of just-in-time delivery of common usage items to reduce inventory costs.[56] It decreed that DND increase the procurement of off-the-shelf commercial technology that met essential, but not necessarily complete, military specifications. As stated in the 1994 White Paper, "Full military specifications or uniquely Canadian modifications will be adopted only where these are shown to be absolutely essential."[57] This was a key strategy for reducing costs and personnel requirements within DND. The resulting savings were applied to a combination of debt reduction and the generation of political capital through targeted private industry benefits.

The implementation of the ASD strategy and philosophy within DND set the stage for civilian involvement in military pilot training. DND determined that training was a non-core activity as related to core combat capability. Thus, assets previously required for FG could be re-directed to force projection at lower overall cost. Similarly, because of the revised procurement policy, training assets were also non-core and were ripe for lease-based arrangements. This had the side benefit of reducing the number of large headline-attracting capital acquisition programs that were politically sensitive following the EH101 debacle.

This modus operandi was already in its nascent stages as the FRP got under way in 1992, and the changes resulting from the evolving strategic situation began to play out. At that time, there were already some partnerships in place when outsourcing began to gain momentum following the 1994 White Paper. As well, in the aftermath of the government's acceptance of the ASD concept, several large service support contracts were awarded to private industry. Despite mixed results and misapplication of outsourcing theorems, the indiscriminate movement towards contracting out services and partnering with private industry continued unabated.

The RCAF was the first military service to embark on large-scale partnerships with private industry. Bombardier International (BI)[58] signed the CFTS contract arrangement in 1992. In this contract, BI took over the delivery of Phase I Primary Flying Training and provided ground instruction and aircraft maintenance for Basic Helicopter and Multi-Engine training at former Canadian Forces Base (CFB) Portage La Prairie in Southport, Manitoba. Capital assets were either contractor-furnished equipment (CFE) through purchase, or government-furnished equipment (GFE) through lend arrangement to the contractor. This partnership was good for both the military and private sectors. Because the intent in 1989 had been to close the base, the contract signing and subsequent reinvigoration of the aerodrome facilities was heralded by the local community for its job preservation and income generation. BI considered this contract as a foothold in the growing military training environment.[59] For its part, the RCAF obtained a benefit from a personnel perspective. Valuable maintenance personnel were redirected to other fleets and, although all flying instruction except Phase I was provided by military pilots, there was a reduction in the requirement to send pilots from operational units to the training environment. These outcomes were in complete harmony with the government's ASD ideals.

As the outsourcing movement gained momentum, the government embraced ever larger support contracts despite warning signs that the desired savings or operational effects were not being achieved.[60] An example of this larger-scale outsourcing was the contracting out of all base support functions at 5 Wing Goose Bay in April 1998 to SERCo of the UK. The objective, as stated in a Vice-Chief of the Defence Staff (VCDS) review of the program, was to "reduce overhead costs . . . (and) . . . obtain cost reductions, achieve flexibility, and achieve added value."[61] Under this contract, the number of CAF personnel at the base was reduced from about 270 to 90. This was a significant savings given the costs associated with military personnel living in an isolated location such as Goose Bay. The commitment to the outsourcing paradigm on a large scale was unambiguous.[62]

Conclusion

The Canadian government turned to outsourcing as a reaction to the changing strategic landscape of the early 1990s. The combination of an economic recession and the end of the Cold War provided an opportunity and to some extent forced the government to seek budgetary reductions. The White Paper of 1994 clearly outlined the intent to reduce resources allocated to the military through outsourcing wherever possible. The government entered into these contractual arrangements based on private-sector theories and embraced them wholeheartedly on an ever-increasing scale as the implementation of the White Paper progressed.

RCAF Pilot Training and ASD

In the mid-1990s, the RCAF fully embraced the outsourcing of its expensive and obsolescent pilot training system. In keeping with the hypothesis that a private industry solution was less expensive than a military-owned system, the RCAF outsourced its undergraduate pilot and basic fighter pilot training in two multi-billion-dollar programs,[63] which were based on public-private partnerships with contractors and other allied nations.[64] The first of these contracts was NFTC, awarded in 1998, with training commencing in 2000. The second was CFTS, which commenced transition operations in 2005 and became operational in 2007. The contracts included the delivery of flying training by a civilian corporation as the prime contractor, with capital assets provided through a mix of GFE and newly purchased CFE. Each program uses a corporate account that is not part of the RCAF's operating budget baseline, but is managed by the RCAF on behalf of the VCDS.[65] Because the contracts were awarded sequentially, there was an attempt to apply lessons learned from NFTC to CFTS. Primarily, these lessons learned had to do with attempting to build increased flexibility into the CFTS program. Both are organized in a manner consistent with the government's ASD objectives: reduction in the number of uniformed military personnel and cost reduction.

It should be noted that with the extension of the operating period of the agreement, NFTC will end in 2023, and that if an option to extend the agreement is invoked, NFTC will end in 2024. Meanwhile, the CFTS will end in 2027. There is a strong desire to harmonize the training elements in one contiguous system after 2027. Because the programs are now mature, an examination of their strengths and weaknesses reveals many lessons that can and should be applied to the next pilot training solution.

NATO flying training in Canada

In 1996, DND obtained Program Management Board (PMB) and Treasury Board (TB) approval for a 20-year, $2.8B[66] sole-source contract with BI to provide the RCAF with support services for pilot training. This complex agreement was the largest service contract awarded by the government at that time.[67] To this day, there are few in government or DND who understand both the contract structure and the operational impacts on pilot production and cost.[68] By examining the history of NFTC and its strengths and weaknesses, we can better situate our consideration of any future pilot training contract.

In 1992, NATO identified a requirement for common fast-jet training and invited member nations to submit proposals. The initiative sought to reduce costs and increase interoperability. The US had offered to continue to host large-scale Allied operations at the ENJJPT centre at Sheppard Air Force Base. However, the US concurrently determined that the forecast NATO training requirement, post-2000, would exceed the ENJJPT capacity.[69] At the same time, DND was looking at options for the future of military pilot training; three options were considered. The first option was to recapitalize the fleet at a cost of approximately $700M, but early on, this was deemed unaffordable and difficult politically in an environment of declining defence budgets.[70] The second option was to extend some portion of the legacy training fleets, i.e., CT114 Tutor and some CF18 Hornet aircraft, to complete specialty jet training, but this would also have been very expensive in terms of operating costs. The third option was to retire the Tutor fleet and purchase offshore jet training.[71] Given the strong desire to maintain a domestic training capability and NATO's search for a second centralized training site, DND began to explore a fourth option involving a domestic multinational training centre.

In December 1994, BI submitted to the Crown an unsolicited proposal for a public-private partnership that contained a developed business case. Thus, the Crown submitted a proposal to NATO in 1995 to host a training centre. This led to the creation of an overall NATO flying training concept that included ENJJPT in the US and NFTC in Canada.[72] While the bulk of NATO training would be given in the US, DND attempted to position itself as an overflow alternative. DND developed a fully costed proposal in June 1996[73] and the NFTC Project Office was set up on November 18, 1997.[74] The contract between BI and the Crown, officially called the Canada Services Agreement (CSA) was awarded in 1998, and several countries agreed to participate in the program. NFTC began in 2000.[75]

Strengths of the NFTC program

When one looks at the NFTC program, there are several aspects of the program that were advantageous to DND, including the following: compliance with government ASD policies and objectives; reduction of uniformed personnel requirements; fleet modernization in a challenging capital project environment; built-in mechanisms to facilitate sales to other air forces; achievement of a level of economy of scale; and automatic triggers requiring increased resource allocation in the event of sales. Consideration should be given to analyzing these factors to ensure that the current program's strengths are carried forward to any future training model.

The NFTC program combined the objectives of the Crown, BI and DND. The CSA was a landmark endeavour that was extremely complex and included structural elements that are unique to this day in Crown contracting. As stated by the Standing Committee of Public Accounts in June 2003: "In developing the NATO Flying Training in Canada program, the Department of National Defence has found an innovative way of training its pilots. This program promises to showcase the talents of Canadian Air Force instructors and the skills and ingenuity of the private sector participants."[76] In keeping with Crown ASD principles, the benefits of the NFTC program were as follows: job creation; 15 Wing Moose Jaw kept open and viable; assistance provided for Canada's aerospace industry; and a noticeable contribution made to the NATO alliance.[77] Given DND's objective of retaining domestic military flying training, the NFTC concept was a near-perfect fit with the Crown's strategic objectives.

Under the partnership agreement, the number of military personnel required at the NFTC program's two sites for conducting military flying training decreased by several hundred. DND provided program management, existing infrastructure such aerodrome facilities, military flying instructors, and the military flying areas, amounting to more than 700,000 square kilometres (km^2).[78] As the prime contractor, BI was responsible for providing aircraft, simulators, classroom training systems, maintenance services, and ground school training.[79] BI signed a number of other agreements with various subcontractors to supply specialty services, such as weather reporting, snow and ice control, firefighting, food and janitorial services, as well as a simulator, called a flight training device (FTD) in the NFTC lexicon, and maintenance. In short, the RCAF conducted the flying training and civilians carried out the bulk of the support activities, thus achieving the Crown's objective of reducing the number of uniformed personnel.

The program's capital assets were funded in an innovative and unique manner.[80] To manage mutual risk, the government set up a not-for-profit company called Milit-Air, which was incorporated on March 12, 1998, under Part II of the *Canada Corporations Act* and had no capital or assets.[81] It was established for the sole purpose of acquiring aircraft, FTDs and other capital assets for NFTC program use.[82] Milit-Air raised money through a bond issue with a principal value of $720M that was used to purchase the aircraft and other capital assets, which were then leased to BI, which charged DND for their use.[83] Milit-Air was able to successfully raise funds at a favourable rate because of the federal government's guaranteed, unconditional lease payments for the aircraft.[84] It is noteworthy that the Department of Finance suggested in 1997 that the equipment be purchased by the government and provided as GFE. While DND responded with an analysis comparing public- and private-sector financing rates, the study was conducted at a point where, if the financing model was altered, the capital assets would not have been in place in time for the planned training start date at the end of 1999.

DND determined that a new pilot training program was unaffordable, based on funding issues and the relative size of the RCAF requirement. One method to reduce unit cost was to increase the size of the program. An example of this is ENJJPT which, at three to four times the size of NFTC, generated much greater economies of scale.[85] Therefore, the program was designed based on the assumption of foreign participation. In fact, the TB authority for the project included a large pre-approval amount that facilitated expansion without the need to obtain additional authority until the ceiling was to be exceeded. The hope was that countries could be enticed to train in Canada in much the same way as was the case with the World War II British Commonwealth Air Training Plan and the NATO Air Training Plan from 1950 to 1958, and subsequent smaller-scale initiatives.[86] During the programdevelopment phase, it was evident that with a relatively small amount of foreign participation, the RCAF could both modernize its training and do so at lower cost than other options.[87]

Although only small numbers of allied participants were needed, it was clear that such commitments were critical to the economics of the program launch. Some nations were faced with the same type of budgetary issues, and the fact that NFTC cost twice as much as ENJJPT hindered firm commitments. Nevertheless, there were many bilateral and multilateral discussions, and several nations indicated interest in the program.[88] Commitments from Denmark and the UK were sufficient to facilitate the program launch with the expectation that more nations would follow. These initial launch nations were indeed followed by Italy and Singapore in 2000.[89]

While the achievement of economies of scale was a cornerstone of NFTC from the outset, the program was designed with mechanisms to facilitate expansion.[90] This was not the only rationale for a flexible structure given that DND intended to be well positioned to capitalize on variations in Allied jet pilot demand and ENJJPT capacity. According to DND, "NFTC ensures that there will be flexibility in accommodating fluctuations and surges in NATO jet-pilot training requirements."[91] There were two types of customers envisioned for the program. The first was the short-term customer who required a limited number of slots over a relatively short time of a few years. In order to serve the short-term customer, the program would capitalize on excess capacity, or rather, existing capacity that was not fully sold to current customers. An example of this type of customer was Austria, which signed for six jet training slots over a three-year period (two per year) to fill a short-term training requirement as the country transitioned from a legacy fleet to a Eurofighter Typhoon fleet.[92] Even for such a relatively short-term agreement, Austria was required to either provide qualified flying instructors (QFIs) or reimburse the program financially.[93] The second type of customer was one that signed up for the program over the long term. An example of such a customer was Hungary, which signed on to the program in 2002 and whose training commenced in 2003. Hungary purchased several training slots per year over the remaining term of the contract. The numbers of students required by Hungary triggered a purchase of additional aircraft because the requirement exceeded existing excess capacity.[94] Additionally, Hungary was required to provide QFIs at a pre-determined ratio in relation to the numbers of students. Thus, there were built-in provisions to add QFIs and aircraft to the program when new nations signed up, to ensure that there were sufficient resources to meet the training demand.

There was also a provision to add FTD resources to the program in the form of the Additional Asset Reserve Fund as new customers joined the program. Under this financial provision within the contract, a certain portion of the program training fee was to be allocated to program improvements. One of the things envisioned was that once enough student training was sold, there would be sufficient money available to purchase additional FTD assets. This fee was applied to NFTC customers who signed up after the initial four launch customers.[95]

Weaknesses of the NFTC program

The NFTC contract also included several contractual weaknesses. The three main problem areas were the complex nature of tuition fees, high levels of government guaranteed revenue, and several invalid initial resourcing assumptions. These weaknesses were to have negative impacts that inhibited the success of the agreement from the perspective of DND and the prime contractor.

The structure of tuition fees was necessarily impacted by the requirement to pay the capital asset leasing fees. The tuition fees consisted of five different types of fees payable: transition fees, firm fees, firm fixed fees, variable fees and cost reimbursable. Transition fees were costs associated with the program start-up from May 1, 1996, until all training phases were loaded and running. Firm fees had to do with the maintenance of aircraft and the administration of program-related infrastructure. Firm fixed fees concerned the lease principle and interest payments to Milit-Air related to the bonds used to acquire the capital assets. They are payable twice a year for the 20-year term of the program. Variable fees have to do with aircraft spare parts, consumable spares and engine overhauls, and cost reimbursable refers to fuel, oil and oxygen.[96] This multitude of fees made the financial aspects of the contract difficult to understand for people outside the small group of dedicated financial officers who administered the program.

Even the complex series of fees that comprise the tuition fees provides only a simplified view of NFTC[97] costing. In fact, each user paid different tuition fees, depending on when they joined the program, because of differing periods to cover capital amortization, and the number of students enrolled by the nation, which could trigger a requirement for increased capital assets to cover the increased training assets. Initially, the concept was one where a simplified costing could be provided based on a fully calculated "power by the hour" valuation that took all aspects of the student training requirements into consideration.[98] This concept was very difficult to calculate because the price of the flying hour depended on who was flying it, where, and using which aircraft. All of this complexity made marketing challenging in that the potential customer requested a price before making a commitment; however, an accurate price was difficult to generate until a commitment was made. This is noteworthy because the previously discussed government unconditional guarantee of the lease payments meant that these payments are owed whether or not Canada trains the number of pilots to which it is entitled. Specifically, even if no training were to be conducted, Canada would still be required to pay 79% of the overall program costs.[99] The risk is that the contractor could be unable or choose not to deliver the range and number of services required. In such a case, while seeking costly and lengthy legal recourse, Canada would still be responsible for the approximately $1.3B associated with the firm fixed fees.

Tuition fees and costing were not the only complex issues relative to NFTC. One of the biggest drawbacks that has inhibited the success of the program from both a DND and contractor perspective is that several of the base assumptions upon which the contract was drawn up were incorrect or optimistic. These invalid assumptions led to an overall under-resourcing of the program. The fundamental problem was that, in order to keep costs down, the program was resourced to the mean demand instead of to the peak demand.

Flawed assumptions in the NFTC contract

There are several examples of false assumptions leading to inadequate resourcing in the program. However, to begin this discussion, it is critically important to understand that, while a vast and varied amount of support is required to sustain and maintain a flying training operation, there are three very expensive key assets. The key assets, which will either facilitate or preclude the success of such an operation, are aircraft, FTDs and QFIs. To calculate the requirement for these key assets, there are various preliminary assumptions on which the resourcing decisions are made, such as the following: the flying training day calendar (FTDC); aircraft capabilities; training plan (TP) effects on FTD utilization and availability; QFI manning; proficiency hours; the sortie generation paradigm; and sole-source contracting.[100]

The FTDC is almost certainly the key assumption on which all other factors are based. The FTDC refers to the number of days per year when the weather is conducive to flying training, which are called flying training days. Days that are not suitable for training are called bad weather days. The calendar is drawn up based on 30 years of historical weather data for the training site. In the case of NFTC, the two training sites are 4 Wing Cold Lake and 15 Wing Moose Jaw. Given that both sites have been used for training over a period of decades, there was extensive weather data available. The other factor required in the flying training day calculation is the weather requirements for the phase of training or mission. In general, ab initio or pre-wings standard training phases require better weather than post-wings training phases, because as trainees progress through the various phases, their ability to adapt to different types of weather limits increases, and hence weather requirements generally decrease. Also, ab initio training phases concentrate on developing basic pilot skills, during which time better weather is desired so that training time can be focused on skill development with a reduced impact from adverse weather conditions.

In the case of NFTC ab initio training phases, those conducted at 15 Wing were scheduled based on a 175 FTDC, and the post-wings phase at 4 Wing was based on a 192 FTDC. This was the same FTDC applied to Tutor training in Moose Jaw and CF5 training in Cold Lake, the previously used legacy airframes. However, over time this assumption was proven to be substantially inaccurate. The inaccuracy was largely due to the different capabilities of the pre-and post-NFTC aircraft. For example, the RCAF operated the Tutor aircraft with a crosswind limit of 25 knots (kts) for trainee solo missions and with a crosswind limit of 35 kts when the mission was conducted with a QFI (called a "dual" mission). In the case of the Harvard aircraft, the initial crosswind limit for the airframe, both dual and solo, was 16 kts. Later in the program, these limits were expanded, after being proven safe, to 15 kts for trainee solo missions and 25 kts for dual mission. Moreover, the Tutor aircraft was authorized to penetrate a cloud layer at 5,000 feet containing light-to-moderate rime icing, while the Harvard aircraft is not authorized to operate in icing conditions. Clearly, given the different capabilities of the airframes, the FTDC must be different. In fact, ab initio phases using the Harvard aircraft now operate with a 168 FTDC. This difference is partly attributable to different capabilities and partly to more accurate weather modelling that reflects changes in trending weather patterns over the last 10 to 15 years. Therefore, from a mathematical perspective, using a 175 FTDC for ab initio Harvard aircraft phases would lead to the assumption that fewer aircraft are required than were necessary to complete the training.

Another key assumption has to do with FTD utilization rates. The method used to calculate the number of required FTDs was based on the total number of FTD missions required. Therefore, the number of FTDs included in the TP was multiplied by the number of student training slots sold and then divided by the number of working days. The number of working days was used rather than flying training days because it was assumed that FTDs would be completed on bad weather days. Thus, the assumption was a smooth, consistent FTD utilization rate, whereby the required work was distributed over a longer period, thus reducing the amount of resources in terms of staff and physical assets required to be able to meet the requirement.

However, such thinking ignores the realities of a training plan in which virtually each flight has a prerequisite FTD mission. As a result, and because of student course commencement dates—courses are given to groups of students so as to minimize ground school instructor requirements—the supply of available Harvard aircraft FTDs was often inadequate. Thus, the reality is that, given the TP mission flow, FTD utilization was a peak-valley paradigm. This was problematic from many perspectives in that it made FTD instructor manning, which was a contractor responsibility, extremely difficult because the contractor was loathe to provide instructors for peak period requirements because frequently not all the instructors were required during the valley period. But, when students could not complete an FTD because of lack of availability, they subsequently could not complete the associated flying mission, which meant that available aircraft were not flown. Even though a sufficient number of FTDs may have been available during the year, they were not always available at the right time, which had a direct impact in terms of reducing program efficiencies.

There were several issues that negatively impacted the success of the QFI manning assumptions. One was an incorrect assessment of QFI availability, which led to the use of a three-to-one student-to-QFI ratio. This assumed that QFIs would minimize the need for professional development courses, deployments, and duties not directly related to flying. Since operations began, there has been a steady increase in the number of QFIs required. This has been exacerbated by regulatory changes whereby RCAF members are now given up to 12 months of maternity allowance or 9 months of paternity allowance, thus reducing the available trained effective strength of QFIs.[101]

Early in the program, it was acknowledged that there was an insufficient number of QFIs to complete the training requirement. In 2001, 2 Canadian Forces Flying Training School (2 CFFTS) recommended an increase in the number of QFIs to 80, up from the allocated 60. By early 2002, the manning level had been increased to 71, and it has continued to slowly increase over the term of the program.[102] The Centre for Operational Research and Analysis, later renamed Operational Research and Development, was commissioned by 1 Canadian Air Division (1 Cdn Air Div) to develop a resource allocation model (RAM) for NFTC. This modelling went through several iterations to refine given changing QFI obligations and availability. Nevertheless, the QFI-to-student ratio is now set at two to one. Therefore, part of the issue in this case was a series of developments and changes in regulations that occurred early in the program and altered previously established assumptions.

Another factor that was to have a profound impact on resourcing decisions and on program success was the sortie generation paradigm, or more colloquially called the “wave pattern.” It was determined, based on the number of sold training slots and the use of a 175 FTDC, that the Harvard aircraft program required 81 sorties per day. In addition, the contract was designed around a 10.5-hour flying day as a baseline for the manning and resource allocation of the subcontractors. Any request to extend this time required both funding and negotiation between DND, the prime contractor and the subcontractors. This resulted in a five-wave program paradigm that helped to reduce the number of aircraft needed to provide the required sorties. For example, this number of sorties could be provided in four waves of 21 aircraft or five waves of 17 aircraft.

NFTC QFIs are assumed to conduct two airborne missions per day. QFIs generally fly first and third waves or second and fourth waves, leaving the fifth wave to be filled with student solo missions or other missions, such as proficiency missions, which require a QFI. The difficulty in fully manning the fifth wave resulted in a situation where the program was calculated for five waves, but was only able to use four plus. In addition, in the NFTC paradigm, two instructional missions normally require eight to nine hours; so any time required for secondary duties, personal administration, physical fitness, mandated online courses or professional development is in addition to the eight- to nine-hour work day. This makes two missions per day difficult for QFIs to sustain over the long term. Therefore, from the outset, the fifth wave was problematic from a manning perspective, and the program should have been more correctly designed to be either a four-wave program, requiring more aircraft, or a six-wave program, requiring more manning.

QFIs require dedicated flying time each year to guarantee a high level of proficiency. This ensures that trainees are exposed to a high flying standard to be emulated and that the QFI is compensated from a skills perspective for the high level of his/her flying time during which the trainee will be flying the aircraft. Given that NFTC was set up in order to be expanded, proficiency hours were associated with each trainee flying slot. Therefore, as more trainee slots were sold, more proficiency time would be available for the increase in QFIs required to instruct the new trainees. However, the number of proficiency hours associated with the slots was relatively low and was based on calculations from the pre-NFTC paradigm.

In 2000, 1 Cdn Air Div proficiency hour requirements were significantly increased for all units. Based on the number of sold slots that NFTC had available, the built-in proficiency hours accounted for approximately 40% of the revised requirement.[103] To compensate for this gap, trainee slots were converted to proficiency hours. This substantially reduced the number of slots available for student training. For example, Canada had purchased 131 Phase 2A slots, but on average used 16 slots to increase the number of available proficiency hours to meet the 1 Cdn Air Div minimum requirements. This was one of the main reasons why NFTC production goals were not met during the first 12 years of the program. These flawed assumptions led to a downward spiral in relations between the RCAF and the contractor. Because of capacity issues and flawed assumptions, RCAF student loads were not at the expected levels. This created a situation where the contractor was burdened with a revenue shortfall amounting to tens of millions of dollars because of unflown hours.

In May 2011, the contractor informed the RCAF that it was restricting services, including surge, to the contracted minimum as per the contractor's interpretation of the contract. As a result, the RCAF set up a tiger team to examine the impacts. The tiger team was also tasked to find a solution within the bounds of the resource availability newly interpreted by the contractor, as well as to increase production to offset pilot shortages arising from reduced capacity at NFTC. The outcome was a revolutionized pilot training paradigm, including end-to-end changes to pilot candidate recruitment, aircrew selection methodology and training philosophy at both CFTS and NFTC. Implemented in 2012, the revised system is now producing approximately 115 new wings graduates (NWGs) at minimal increased cost from a system that had previously averaged 85–90 NWGs per year. It should be noted that the cost, had the pilot training paradigm not been changed, to reach a production level of 115 NWGs per year (NFTC and CFTS combined) was estimated to be a minimum of $800M over the remaining term of the NFTC contract (2011–21).

Another problem area was the sole-source nature of the NFTC contract. DND submitted a sole-source rationale in the belief that the BI-led consortium included all the contractors that had bid as prime contractors on the 1991 CFTS contract. Thus, DND was satisfied that the consortium represented the only qualified bidder. In addition, the industry team was the entity that had expressed a committed interest in the program. There was also the belief that because of the lower competing cost of ENJJPT and the high level of cost scrutiny exercised by potential customer nations, a situation was created in which BI was strongly incentivized to keep costs low. DND also stated that the sole-source route was the only option able to meet the NATO imposed timeline.[104]

Though there was concern about the sole-source approach, the program continued, despite the findings of the Office of the Auditor General (OAG) that neither the sole-source rationale nor the Public Works and Government Services Canada (PWGSC) directly negotiated profit margin met government contract regulations.[105] In the case of a 20-year service agreement, the contract is a de facto sole-source contract, even if a competition is held to select the de jure service provider. Because of the very high levels of guaranteed revenue within the contract and the high termination penalties, the RCAF is tied to the service provider with the winning bid. Even if DND elected to exercise the right of termination within the CSA, the resulting costs could be as high as 79%, the guaranteed portion of the remaining contract value.

NFTC: Conclusion

NFTC is an innovative program that incorporated a public-private partnership in which DND avoided the pitfalls of a high-profile capital project during a time of restraint. This was in keeping with the intended direction set out in the 1994 White Paper and allowed the RCAF to significantly update and modernize its pilot training system. In addition, expansion of the program through sales to allied air forces was a key tenet. Such sales were needed to achieve sufficient economies of scale to make the program viable. The TB approval included authority to conclude sales of training services to the benefit of DND and the Canadian economy. The CSA itself contained built-in mechanisms to ensure sufficient resources in the event of expansion. All of this contributed to a high-quality training system.[106]

The main flaws in the contract were the capital asset paradigm and critical faulty assumptions related to the three key resources. These problems hampered production. In fact, based on the CRS audit in 2012, production between 2001 and 2010 never exceeded more than 74% of the target output.[107] The paradigm used to purchase the capital assets obligated Canada to pay for training regardless of delivery. There were also faulty resourcing assumptions in critical areas, such as the following: FTDC, aircraft capabilities, TP effects on FTD utilization and availability, QFI manning, proficiency hours, and the sortie generation paradigm.

Contract Flying Training Support

In 2005, DND obtained approval[108] for a 20-year (plus a 2-year transition period) $1.77B contract with Allied Wings (AW), a division of Kelowna Flightcraft, to provide the Crown with support services for pilot training.[109] The total contract value, including escalation during the term of the contract and transition funding, was nearly $2.3B.[110] While there are many similarities with NFTC, there was an attempt to integrate the lessons learned during the first years of that contract.[111] Therefore, by examining the history of CFTS and its strengths and weaknesses, we can more effectively assess any future pilot training contract.

CFTS background

In 1989, the Crown announced a series of military base and installation closures to reduce the deficit and slow debt growth.[112] This was followed by the announcement of the intent to close CFB Portage La Prairie later that same year and to cease military flying training operations.[113] DND began an initiative to rejuvenate its primary and helicopter flying training, which had seen little change for many years. There was also discussion about setting up a multi-engine flying training phase.

In 1992, following a competitive bidding process, BI began delivering training for a five-year term that also included two optional one-year extensions, both of which were exercised. Under the terms and conditions of the contract, BI provided primary flight training, including flying instruction, new aircraft and a ground school. BI also provided maintenance for new CFE multi-engine aircraft, and loaned aircraft for the helicopter pilot training to DND. In addition, BI provided the full scope of airfield operations activities under agreements with several subcontractors and the newly formed Southport Aerospace Centre Incorporated. This brand new, locally owned, not-for-profit economic development agency was established in the same way as the not-for-profit management corporations that had assumed responsibility for other former DND bases.[114] Several contract extensions were concluded following the preliminary term.

The RCAF viewed this initial experience as an innovative method for accessing new aircraft and modernizing training in a restricted financial environment. Using the template of the initial CFTS contract, all desired ASD services were contracted out to a prime contractor. The RCAF therefore decided to continue with the public-private partnership paradigm used in the follow-on CFTS contract and in NFTC.[115]

CFTS similarities to NFTC

There were many similarities between NFTC and CFTS. Primarily, the two contracts shared an outsourcing paradigm in which the Crown contracted out a broad range of support services to a single prime contractor, and both contracts facilitated a pervasive modernization of their respective components of the pilot training system.

Under both programs, a civilian corporation was employed as a prime contractor. In their prime contractor role, AW and BI were responsible for providing all contracted services. Some of these services were provided by AW and BI themselves and others by subcontractors. The concept of a prime contractor relieved the RCAF and the Crown from the task of managing multiple agreements with several companies. The RCAF paid a service fee for a civilian entity to manage sub-agreements with other civilian companies. This concept was consistent with the ASD philosophy of reducing personnel impacts by outsourcing administrative and management functions. However, the disadvantage was that another layer of profit was required. While the subcontractors included profit in their agreements with AW and BI, the prime contractors included profit again for management services.

As was the case with NFTC, one of the main advantages of the ASD option was the recapitalization of training assets and infrastructure. Under the terms of the CFTS contract, AW provided many new capital assets to modernize and update the training provided at Southport. Through CFE, AW committed to purchasing Grob G120A aircraft for primary flying training and Beechcraft King Air C90Bs for multi-engine flying training. Unlike with NFTC, the new assets were purchased directly by the prime contractor through a third-party, not-for-profit entity. However, to achieve better financial terms for AW, the Crown acted as an underwriter for the loans required to purchase the CFE capital assets. As for the GFE component, DND supplied both Bell 206 Jet Rangers for basic helicopter training and several militarized Bell 412CF Outlaw helicopters in order to introduce more advanced helicopter training. This was a departure from the long-standing methodology of helicopter training that involved teaching core skills on a basic training platform. The course length was increased significantly, and the addition of the second more advanced platform essentially created a basic and advanced helicopter training plan. The aim of this increase in training was to enhance common core skills and at the same time reduce the amount of training required at the more expensive Operational Training Unit level of training. AW was also responsible for purchasing new simulators for a higher level of synthetic training than in the past, as well as responsible for all tasks related to primary flying training. RCAF QFIs were to provide flying instruction for helicopter and multi-engine training, while AW and its subcontractors were responsible for ground school instructors, courseware, flight services, and the aircraft for multi-engine and rotary (helicopter) training. In keeping with the theme of modernization, AW built new aircraft hangars and an 80,000-square-foot (7,432 square-metre) training complex.[116] Thus, overall, the two contracts shared a similar paradigm with respect to overall structure and concept.

Strengths of the CFTS program

A review of the resulting training program will reveal many aspects of the CFTS program that are advantageous to DND, and several key program benefits that CFTS shares with NFTC. These benefits include compliance with government ASD policies and objectives, reduction of uniformed personnel requirements, and fleet modernization in a difficult capital project environment. In addition, CFTS has the following several strengths that are largely the result of lessons learned from the NFTC experience: greater flexibility to facilitate change in the work; variation in quantity (VIQ) provisions; and the implementation of a performance incentive fee (PIF).

CFTS has many of the strengths of the NFTC program. In much the same way as NFTC, CFTS adheres to the Crown's ASD principles. The program is seen as a boon to the local community and to the province of Manitoba in that it created dozens of new, high-paying, steady jobs.[117] Local politicians and business people believe it to be the culmination of a long-protracted campaign to keep the base open, contrary to DND planning. In fact, the awarding of the CFTS contract to AW was an improvement on the level of activity conducted at the Southport facility. At the same time, the program meets DND's dual objectives of retaining domestic military flying training and reducing the number of uniformed military personnel. In addition, there was a significant modernization of the capital assets used in the training program. Of special importance was the introduction of three advanced simulators, two of which, one for the Outlaw aircraft and one for the King Air aircraft, had full motion capability.[118] The efficacy of the overall program was greatly increased because these highly capable simulators decreased the program's reliance on favourable weather to conduct training. It also greatly expanded the envelope of tasks that could be rehearsed on the ground prior to going airborne.

Given that CFTS commenced several years after NFTC, there was an attempt to apply lessons learned to the newer contractual arrangement, including greater flexibility to facilitate change in the work, VIQ provisions, and the implementation of a PIF. The overall objective of these changes was to increase contractor incentive and flexibility, which were felt to be lacking in the NFTC context.

An example of this ability to facilitate and implement change is that the training concept of CFTS changed significantly in the early years. There was provision in the base CFTS contract for three slots per year for a Phase II Grob which was initially termed Phase I Extended. Because of Phase II training production shortfalls at NFTC,[119] the provisions of the base contract were expanded in a five-year amendment. The aim of this $50-million contract addition was to replicate the training at NFTC, and it was considered sufficient to be able to continue on to the helicopter or multi-engine training. However, it was not considered completely equivalent to enable graduates to go on to fast jet training at NFTC. The amendment included the creation of a Grob FTD because such training was considered integral to Phase II training. One of the more interesting elements in implementing the amendment was that the company agreed to work "at risk" for two years before negotiations ended and the amendment was signed. During this time, missions programed in the TP for the FTD were flown in the aircraft.[120] Thus, the programs became even more similar and symbiotic, one feeding the other and vice versa, as the overall training evolved from a programmatic perspective. There were several other examples, such as the increase in Phase I training from 113 to 140 students[121] resulting from a completely revised training plan produced by the RCAF.[122] As well, because of a significant shortage of available helicopter pilots, airborne instruction for the Basic Helicopter Course (BHC) was also added to the list of AW-delivered services from 2009 to 2013.[123] These examples indicate significant development in the CFTS program training plan.[124]

Furthermore, there was the inclusion of a mechanism to create course-loading flexibility that could be exercised by the technical authority (TA) without significant contract negotiation.[125] In the NFTC paradigm, there was a set number of training slots per phase within the contract. If in any given year, the RCAF wished to increase the number of slots, the available capacity had to be contractually verified and a price negotiated; this was often a very lengthy and challenging process. To counter this situation, the CFTS contract included a mechanism known as VIQ. At the heart of this concept was the ability of the RCAF to increase or decrease the annual volume of a contractual task by 10%. Therefore, using Phase I as an example, the RCAF could increase the annual loading from 113 to 124 at no additional cost. This flexibility could be exercised in any CFTS flying training phase or supporting contractual task. However, there was some protection for the contractor revenue stream in that, if the quantity was reduced in any given year by 10% or less, then the RCAF was not entitled to a refund. Therefore, as a result of VIQ, the RCAF could load anywhere from 102 to 124 Phase I slots with no change in cost. The only notification required for such a change was an annual production forecast letter sent to the contractor.[126] This mechanism increased the RCAF's ability to respond to short-term fluctuations in training requirements for any reason, without variations in funding obligations.

In another divergence from the NFTC paradigm, CFTS embraced the PIF concept, which had been used in other DND contracts, such as the 5 Wing Goose Bay support services contract with multi-national SERCo.[127] The basic concept was that a reduced amount of profit would be paid for delivering the statement of work (SOW) requirements and that a PIF would comprise most of the contractor's profit. Thus, the objective was that the contractor would be highly motivated to "provide excellent performance in identified areas of emphasis."[128] The incentive was significant for the contractor because the total value available over the life of the contract was $57.5M or an estimated $73.27M, including estimated escalation. The assumption was that the contractor would make only a small profit for delivering the SOW, but that the PIF would encourage innovation, excellence and flexibility.[129] This objective was largely achieved in that the contractor expressed a strong desire to obtain the highest possible PIF reward.[130] To give an example of the positive incentive the contractor obtained from the PIF, AW shared a portion of the reward with its employees in order to encourage a high level of participation. AW correctly surmised that this motivation increased the odds of a higher overall award. An example of this motivation was the tendency of the contractor to accept work or adjustments to the SOW on an "at-risk" basis as a demonstration of collaboration and flexibility. While there were challenges associated with the administration of the PIF, overall, the PIF was an effective tool in managing the CFTS contract and exercising a positive influence on the contractor.

Weaknesses of the CFTS program

The CFTS contract also includes several problem areas. The main issues are substantial PIF administration requirements and a lack of flexibility for marketing. From the perspective of DND, these weaknesses had a negative impact on the overall success of the agreement.

While it is accurate to describe the PIF as a positive aspect of the CFTS program, administration of the fee was labour-intensive and a source of friction between the RCAF and the contractor. There are two semi-annual meetings held by the Performance Incentive Fee Board (PIFB).[131] This group receives submissions from both the contractor and the Performance Evaluation Team (PET) Chair,[132] each of which outlines their perspectives on the portion of the available PIF that the PIFB should grant to the contractor. In addition, the PET is required to collect data every month from numerous tactical and operational subject matter experts (SMEs), who are called performance monitors (PMs). The PMs are tasked to observe and monitor a specific area of the SOW and report to the PET. At the end of the monthly meetings, the PET and the contractor do their best to validate all of the observations and clarify any contentious areas. At the end of the six-month performance evaluation plan (PEP), the

PET collates the monthly reports into a detailed draft report which includes all of the observations for the period and a recommended score for presentation to the PIFB. During the process, there are several opportunities for contractor input and perspective. The PIFB then determines what percentage of the PIF the contractor should receive for the period. There is also a follow-on process during which the contractor can request a further consideration of the PIFB.[133] These are all secondary duties for existing personnel with no additional person years allocated to specifically account for this large volume of administrative tasks.

Another area of prolonged disparity, within the context of the PIF, centred on the performance criteria (PC). According to the CFTS Contract, Annex F, the PC allow the RCAF to provide the contractor with desired areas of focus to improve overall delivery of service.[134] Early in the contract, the PIFB purposefully elected to maintain general areas of focus based on the assumption that it would limit contractor initiative and ingenuity if the PC were too specific. However, the contractor wanted PC that were as specific as possible so that activities could be properly focused. The aim was to produce the most positive observations and hence the largest possible PIF award for the contractor and its employees. It took several performance evaluation PEPs for reality to take hold in this regard and for the positive impact of the PIF to become effective.

Another problem area of the CFTS contract was the lack of flexibility for marketing. Initially, the program was heralded as the next logical step for the RCAF to solidify its position as an "international centre of excellence for foreign military aviator training."[135] In 2005, a top AW official stated that, while NFTC was the linchpin of Canada's international flying training, "the missing ingredient was really a marketable primary, multi-engine and helicopter training component."[136] This opinion was not only the perspective of industry because, as the National Defence Backgrounder of 2005 clearly stated, while the primary objective of CFTS was to provide training for the RCAF, the intention was "to continue marketing the CFTS pilot training program to its NATO, commonwealth and other military allies."[137] Therefore, from the outset of CFTS, there was a clear determination on the part of the contractor and the RCAF to actively market and expand the program.

However, unlike NFTC, there was no clear authority or mechanism inherent in the contract to facilitate expansion. The aim of marketing within the CFTS context, as stated in Article 22.0 Flexibility for Marketing, is "to reduce costs and to expand the CFTS program."[138] To achieve this goal, Canada was authorized to market any transient or excess spare capacity. However, the definition of these authorities was not included in the text of the contract. In addition, the TB authority for the program only referred to the sale of excess capacity, and there was no authority to expand capacity because of a sale. This meant that any sale leading to expansion required an application to TB for expanded marketing authority, which was an arduous process.[139] The contractor was authorized to market training to civilian users, but only with the TA's written permission to ensure that such a sale would not impugn the delivery of RCAF contracted training. In practice, this limited the contractor to sales of training such as those conducted in the Bell 412 FTD after the hours of RCAF training. While such sales did occur, they had a minor monetary impact on the overall program. Therefore, while the marketing of training was a stated CFTS goal of both the contractor and the RCAF, the approved mechanisms within the contract were highly restrictive.

CFTS: Conclusion

CFTS is the most recent component in the development of RCAF outsourcing of pilot training services. CFTS was consistent with the Crown's ASD objectives, such as reducing numbers of uniformed personnel while modernizing training fleets and increasing the use of simulation in training. In addition, CFTS encompassed several improvements resulting from the application of lessons learned from the larger and more complex NFTC. These improvements included greater flexibility to facilitate changes in the work, VIQ provisions and the implementation of a PIF. However, the CFTS contract also had problem areas such as difficulties resulting from differing levels of risk tolerance on the part of the contract stakeholders, onerous PIF administration requirements, and lack of flexibility for marketing and expansion. These issues should be considered in the study of a future outsourced pilot training model.

Conclusion

Faced with a challenging political and strategic situation as the 20th century ended, the RCAF outsourced its pilot training system in an initiative involving two large-scale, multi-billion-dollar ASD contracts for NFTC and CFTS. NFTC was in large part a unique and innovative approach to addressing a deteriorating training system within the confines of multiple political and financial constraints. The RCAF employed a public-private partnership on a large scale with a prime contractor providing capital assets and support services. The objective was to establish a close, direct relationship with the contractor that could be expanded through foreign sales benefitting all parties. However, fundamental flaws in the assumptions underlying the contract and the inherent pitfalls of the paradigm limited the productivity and success of NFTC.

The CFTS contract was based on a similar contracting archetype, but there was an attempt to apply lessons learned from NFTC. There was a concerted effort to increase flexibility by including contract clauses that facilitated a variance in training quantity at no incremental cost. In addition, PIFs were used to incentivize the contractor to be innovative, creative and responsive. Although the mechanics of PIFs were burdensome and at times contentious, they were largely successful in motivating the contractor to strive for an environment of continuous improvement.

Because the programs are now mature, a review of their strengths and weaknesses provides insight into the benefits and pitfalls of ASD as applied in the dynamic pilot training environment. Overall, the RCAF achieved its goal of rejuvenating its pilot training system, but there are also important lessons that must be applied in the future to ensure success.

Contractor Perspective

Upon reviewing CFTS and NFTC, it is evident that these large contracts have been both successful and in need of improvement from an RCAF perspective. The future stakes for the RCAF are high, given the large financial outlay required and the term of the potential agreement, but interesting as well is that this opinion is shared by the contractors. Consequently, for the sake of collaborative improvement, both prime contractors were consulted to solicit their input on areas that could be improved in their respective contracts.[140] The questions focused on the contractual construct and the degree to which their respective corporate objectives were, or were not, achieved.[141]

The contractors' observations were grouped based on the critical factors.[142] To ensure the best possible outcome for the RCAF in the next contract, it is essential that the contractor's perspective and feedback be considered. By achieving some understanding of the contractors' business objectives, the RCAF is more likely to achieve its future goals.

Capital asset acquisition paradigm

For both CFTS and NFTC, a CFE paradigm was used to acquire program capital assets. From the contractor's perspective, the main issue was the definition of requirement as set out in the statement of requirements (SOR) and then refined in the SOW. In the case of NFTC, the contractor was directed to purchase the Hawk aircraft. As for the turboprop aircraft, the best available solution did not meet the requirements for anti-icing or crosswind capability; however, the aircraft was nonetheless accepted by the RCAF. As discussed, the NFTC resourcing model was not adjusted for the revised capability, which meant that from the beginning, the contractor faced an uphill battle to provide the required sorties. In short, if a CFE solution is to be used, then the contractor should be free to match the platform to the requirement, and if this is not the case, then the initial resourcing assumptions must be adjusted, which may increase cost.

Another aspect of the CFE paradigm is the applicability and application of government contracting policy and regulations. For example, the Milit-Air CFE asset paradigm was approved by TB under the rules at the time, but new rules were implemented with the release of the PWGSC Management Manual.[143] PWGSC as the contract authority (CA) imposed new regulations on a 20-year, firm, fixed-price contract, and the contractor had no recourse. This illustrates the continuing problem that the CFE paradigm in this long-term contract created for the contractor, because as the regulatory landscape changed, the contractor was expected to respond at its own cost, which was difficult to account for in the contractor's business plan.

Resource requirements

The contractors had numerous comments about resource requirements. As previously discussed, there are three primary resources: QFIs, FTDs and aircraft. One of the loudest complaints was that the RCAF was unable to meet its contractual obligation to provide sufficient QFIs for NFTC and some portions of CFTS.[144] Indeed, this issue was one of the biggest problems early on in NFTC. Military personnel management is such that the process to request and approve a permanent change in unit establishment often takes two or more years, because all RCAF priorities must be considered. Therefore, from a contractor perspective, it seemed incongruous to be rebuked for providing insufficient sorties when, had there been more sorties available, there would not have been sufficient QFIs to crew them. As well, because QFI manning was so problematic in the early years of NFTC, there was a requirement for near-constant surge operations. Thus, there was an RCAF expectation that surge was needed, but it increased the contractor costs considerably with no reward or incentive to solve what was, at least partially, an RCAF problem.

Surge capability is a function of staffing and assets, both of which have long lead times to effect a resource increase. The concept of short-term surge capability requires appropriate lead time for the surge, because only current assets, including salaried personnel, are available. To build a true short-term surge capability, an equivalent overcapacity, which is not used when not required, must be available. While a built-in overcapacity makes sense from an operational perspective, it also requires extra funding. It is often difficult to justify and obtain approval from the Crown to fund a capacity that is only to be used a portion of the time. However, there are limits to what can be done during additional waves and weekends, because overtime staffing and funding create financial pressures for the contractor. Moreover, weather and aircraft original equipment manufacturer (OEM) issues are outside RCAF and contractor control, as indicated in the statistical deviations from the NFTC RAM, which requires the execution of short-term surge capability. Because the overcapacity is often not available, the required capability must be generated from "surging" the available assets. This approach is costly; it is only implemented with the support of volunteer civilian staff when outside of defined contractual limits; and it must only be used when necessary to avoid the "programmatic burnout of endemic surge."

It must also be understood that businesses operate according to a just-in-time management concept. Industrial firms strive for efficiency and maximum use of resources to control costs. When applying this concept, industrial firms do not seek resources when there is peak demand for them, unless it is specifically stated in a contract and they are remunerated for it. Industrial firms calculate the resources needed based on the degree to which demand can be managed so that less-than-peak-demand resources are required. This method controls costs and reflects the competitive nature of private industry. The result is that the production flexibility desired by the RCAF is often not available because the project is resourced in such a way that anything above average demand is in fact a surge. The contractors agreed that this was a big source of customer discontent, although the effect was a reduced price point.

Performance measurement

Another key source of trepidation for the contractors is performance measurement. Both contractors are involved in long-term, fixed-price contracts. From their perspective, both contracts had performance elements, but it was clear to the contractors that cost certainty was the primary driver.[145] However, in the NFTC context, as production problems became more pervasive, the RCAF-contractor relationship became challenged. The contract remained firm and fixed, but the CA took a performance-based approach and threatened penalties and holdbacks for poor performance, but with no concomitant benefits for excelling or exceeding.

Another issue was the performance measurement method. While the predominant performance criterion is the graduation of the planned number of students within intended time frames, it was extremely difficult to measure compliance with this criterion. There are numerous factors that can negatively impact pilot production, and many of them are not within the contractor's control. For example, the contractor provides resources for the respective program based on a weather model, but most years include variances from the mean of the model.[146] In this case, it is irrational to hold the contractor solely responsible for deviations. Accommodations must therefore be made in the overall performance measurement method, but this does not rectify a deficiency in student production from an RCAF perspective. Consequently, the case may often arise where the RCAF is not receiving the required student production, but because of accommodations made, the contractor is in full compliance with the SOW.

Relationship

Overall, one of the biggest challenges is the relationship between the contractor and the customer, and clearly, there is a divergence of interest among the main players involved in the contracts. The primary interest of business is profit and customer satisfaction, while the aim of the RCAF is production, and the CA's main concern is to minimize expenditure and eliminate risk. This disagreement of purpose leads to significant relationship issues where process and profit are concerned.

Relationship process

From the contractor's perspective, the Crown is a challenging customer because of its multi-headed nature[147] and the complex processes involved with the contracts. However, it must be remembered that, in fact, while the RCAF is the end user, the customer, in a legal sense, is the CA. Moreover, the contractor often finds it extremely difficult to achieve the objectives of all the stakeholders. Such a complex environment is not conducive to flexibility and innovation. In fact, even the most benign amendment is costly and time-consuming.[148] As a result, the contract language is often one-sided and draconian. An example of this would be the previously mentioned outsourcing of flying instruction for the CFTS BHC from 2009 to 2013. In 2012, because of a change in the interpretation of the TB authority for the program allowing civilian flying instruction, instruction for BHC had to be re-militarized. The contractor lost revenue and employees, and was dismayed at what seemed to be an arbitrary change in policy. Overall, the structure seems to have been created not only to avoid risk, but also to eliminate risk, unlike the commercial environment where risks are managed in order to achieve the required objective. This atmosphere does not foster a collaborative problem-solving or a bilateral-risk management approach.

Another problem area in the contracts was the near-constant state of change. This issue was demonstrated in customer contract management. The number of amendments to both contracts was several times higher than that foreseen in the SOW. This resulted in increased staffing levels within contract departments as well as additional work to produce costing proposals, all of which significantly increased the contractor's costs in those areas, beyond what was anticipated and beyond the funding provided within such a long-term, firm, fixed-price contract. In addition, because of personnel rotations for personnel management reasons, there were consistency problems (staff turnover) and qualification deficiencies (seniority trumping qualifications) with Crown counterparts, as compared to the business environment. The continual rotation of Crown decision makers made contracting with government more challenging and expensive, when compared with what was normally the case for commercial enterprises.

Relationship profit

To establish and maintain a productive relationship, it is important to understand the contractor's profit drivers. A company's profit requirement is a function of level of effort and risk. Long-term, firm, fixed-price contracts are low-risk for the Crown because of increased cost certainty. However, for the contractor, these same contracts are high-risk and become progressively higher-risk the longer the term of the contract. This risk profile stems from future cost uncertainties because project complexity and duration increase the number of unknowns in a project. Therefore, the contractor builds in cost buffers to account for the unknowns. The buffers may, in fact, turn out to be insufficient, in which case the contractor is put in a loss position. There is not necessarily a set expectation of profit, although as the risk increases, so do the profit requirements.

However, in the case of pilot training contracts, the revenue structure is based on the number of students enrolled in courses and the resulting flying hours flown. Any reduction in these areas has an adverse impact on revenue streams and profit. Once a contract becomes revenue negative, the contractor is placed in a very tenuous position that cannot help but negatively influence relationships, unless there are provisions for adjustments. There are no such provisions in long-term, firm, fixed-price contracts.

Marketing

Contractors are keenly interested in marketing. One of the main reasons why both contractors became interested in these programs was that aviation was a core enterprise within their respective business models. Expanding into military pilot training was a natural extension of their business. The participation of allied nations was a potential opportunity to further expand business relationships within the participating allied nation. This strategy was also consistent with the publicly declared aims of both programs. In the case of NFTC, the program was launched once the minimum foreign participation was secured, but the program's business case was based on the premise of increased foreign participation, which never materialized to the degree initially forecast. This has had a drastic impact on the financial metrics of the program. With respect to CFTS, although expansion was a stated objective of the program, the associated authority was never secured. Therefore, in the contractors' opinion, marketing was a secondary activity for the RCAF, and neither program was exploited to its full potential.

Conclusion

The future pilot training paradigm will no doubt include ASD in some form. So it is critically important that an understanding of the contractor perspective be taken into consideration and incorporated where possible. The current CFTS and NFTC contractors agreed to provide input regarding issues they would like to see improved in the future. Their observations were insightful and enlightening. Overall, there is a great deal of difficulty arising from the multi-headed customer aspect of the current pilot training contracts, which results in misaligned priorities and poor communication. Frustration arises from the number of stakeholders, the varying interests and the cumbersome contracting policies, which reduce overall effectiveness. This issue is exacerbated by the high turnover of RCAF and government personnel involved in contract administration on behalf of the Crown. Moreover, the contractors find that the zero-risk tolerance demonstrated by the CA is not only detrimental to the RCAF's pilot training goals, but also inhibits productivity and innovation on the contractor's part. The most interesting comments had to do with the need for a proactive and collaborative relationship between the RCAF and its service providers, which, in military parlance, acts as a force multiplier.

Lessons Learned

As key dates approach, the future of the RCAF and its pilot training system is undecided. In examining the background of ASD in Canada, and the outsourcing of the pilot training system and the contractor perspective, there are lessons to be taken into consideration for the future paradigm. These lessons are categorized for each of the critical factors. Before drawing conclusions about the future, it is imperative to consider first the key lessons learned in the past.

ASD philosophy and principles

Overall, the application of ASD principles and philosophy in the RCAF pilot training system has produced many positive results, but it has not proven to be a panacea as hoped. ASD savings amounted to a mere $60M per year rather than the intended $300M per year targeted by the year 2000. The fundamental premise of ASD is that private-sector companies leverage the full spectrum of the free market to achieve efficiencies unattainable by public agencies. This theory assumes that companies are more agile and innovative in finding solutions than bureaucratic government organizations. However, it was clear that ASD was far from meeting the savings targets set out in the 1994 White Paper.[149] The other main issue was the overall assessment and performance measurement of the progress of ASD, which was not only difficult, but also fatally flawed.[150] It is fundamentally important to note that the CRS audit of NFTC in 2012 determined that production between 2001 and 2010 never exceeded more than 74% of target output.[151] Therefore, despite meeting 1994 White Paper objectives of reducing the number of uniformed personnel and outsourcing non-core activities, production deficiencies have proven that ASD is not a universal remedy for the challenges of RCAF pilot training.

Capital asset acquisition paradigm

The most important future program factor is the capital asset acquisition paradigm. The acquisition methodology used in the current contracts is private financing based on guaranteed revenue streams. Crown fiscal austerity made it more expeditious and politically palatable to use operation and maintenance (O&M) funding instead of capital funds. In practical terms, the RCAF leased the capital assets, although this was not the method recommended by the Department of Finance as far back as 1997.[152] This approach, while it did facilitate the acquisition of a new training fleet, resulted in two main negative outcomes: increased cost and unintended consequences.

The most palpable impact of CFE capital assets was increased program cost. For example, the cost of a Grob aircraft was $1.4M;[153] however, under the CFTS contract, the RCAF will pay $3.4M for each aircraft. In the case of the King Air aircraft, which cost $3.3M,[154] the RCAF will pay $13.2M. These values are calculated based on known purchase cost, including profit, administration and a 10% private financing rate. Given that DND does not finance capital purchases, but instead pays large milestone cash payments, the costs of CFE through private financing are approximately three times higher than direct purchase costs.[155] Even if DND were to finance such a purchase, this would be done using Crown borrowing at the Consolidated Revenue Fund lending rate, which is updated and published regularly by the public debt section on the Department of Finance website.[156] While the net result of such a course of action would result in a reduced cost advantage, CFE financing would still be 200% more expensive.[157] Therefore, DND's direct purchase cost of the CFTS aircraft would have been $40.5M through a government-financed purchase of $62M versus the selected $126M CFE option. Thus, the overall cost of the CFTS program would have been approximately $85.5M lower had the aircraft been purchased through private financing, which amounts to a program cost saving of 5%.[158] In the case of NFTC, the cost of the program would have been approximately $564M lower had the aircraft been purchased and then provided as GFE.[159] Such savings would have significantly reduced the training cost per student.

There are other potential benefits of public financing. As discussed, the reduction in cost per student would have made the program more attractive to potential customers. Some of the customers who left early might have elected to remain in the program.[160] It might also have been easier to sign up additional customers, which at the same time, would have increased NFTC program expansion, contributed to the contractor's revenue stream, and provided further benefits to the RCAF in the form of greater economies of scale.

Another benefit of public purchase of the capital assets is that the problems associated with high guaranteed revenue would have been mitigated. The high levels of guaranteed revenue are linked to lease principle and interest payments for program CFE capital assets. The contractor's desire for guaranteed revenue is understandable given the high cost of the capital acquisition paradigm. However, such guarantees are unconditional and irrevocable, regardless of the contractor's performance.[161] This creates a risk that in times when the RCAF is unable to fully use the available training, the contractor may elect to restrict services. Specifically, when faced with a revenue shortfall, the most effective way to eliminate the deficit is to reduce costs as close as possible to the level of guaranteed revenue. This creates a downward spiral where the RCAF reduces training to the level of available service, which then forces the contractor to further reduce service delivery. This is exactly what led to the NFTC contractual cataclysm in 2011. During that period of friction with the contractor, the RCAF was still required to pay all guaranteed fees.

One of the main follies of the NFTC program was to include both the training plan and the contract in the Integrated Training Plan, which included all of the NFTC syllabi. Any change to the TP had to be carefully assessed, with aircraft fatigue and engine life taken into consideration, because changes could negatively impact the longevity of the asset. This led to the TP being included in the NFTC agreement. Consequently, any change made to the syllabus became an issue requiring analysis not only from an operational and maintenance perspective, but also from a legal and contractual perspective. As a result, it became difficult to understand why changes were made, and in many cases, they hindered the development of the TP and the ability to address concerns regarding production. Even those changes that the RCAF considered to be inherently beneficial were met with scepticism by civilian partners.[162]

Another challenge is that because of civilian ownership of the training fleets, these aircraft do not fit into the RCAF's weapon system manager (WSM) structure. This organization within DND[163] provides dedicated engineering management support for all RCAF aircraft, except for the CFE fleets. Had the GFE option been selected, the training fleets would have been assigned a dedicated WSM. The WSM would have facilitated upgrades and improvements that would have eased changes in support of the TPs, as well as modifications to facilitate compliance with changes to aviation life support equipment

(ALSE) during the life of the program.[164] In the case of the NFTC fleets, each potential upgrade had to be analyzed as to the applicability of the contract. If the proposed upgrade was deemed to be outside the scope of the relevant contract, then the RCAF was liable for the funding, but there was no clearly defined mechanism to facilitate such changes to civilian-owned fleets through government funding.[165] In addition, upgrades are affected by the ability of the contractor, as Technical Airworthiness Authority (TAA), to process changes. This problem arises in a number of ways, one of which is the requirement to have adequate engineering capability to process proposed changes as the TAA. There was a negative delta in this area for a number of years in NFTC, until the contractor began outsourcing work to other contractors, and in-sourcing to parent company engineering. Though the WSM organization is dedicated to the management of military fleets, CFE aircraft fall outside this organizational structure, which also creates additional procedural challenges for the implementation of upgrades or modifications to the training fleets.[166] Therefore, it is clear that the CFE paradigm increased the cost of both CFTS and NFTC, while also adding unintended consequences.

Resource requirements

The availability of sufficient resources is one of the most important factors in the success of the next evolution of the pilot training paradigm. It is critically important to properly assess resource requirements and to ensure that sufficient resources are available. The production inadequacies of NFTC were rooted in incorrect baseline assumptions related to the three main resource areas. As defined by the NFTC RAM these are QFIs, aircraft and FTDs. The assumed ratio of QFIs to students in NFTC was incorrect. Experience has demonstrated that during ab initio training, a ratio of one QFI to two students is required, given the same constraints and personnel time demands as NFTC. Because QFI numbers were increased during the first decade of the program, proficiency requirements were more than doubled, which further decreased the resources available for student training and production.

Lastly, the initial TP model, in which FTD missions were sequential prerequisites for flying missions, was far too inflexible to be able to respond to less than ideal or predicted weather conditions. The assumptions as to the ability to mitigate FTD availability by conducting training on bad weather days have been categorically disproved. An FTD mission is required when student training requires it, and not when the FTD is available. For example, if a student requires an FTD on a Monday in order to conduct the related flight on a Tuesday, the FTD must be available and not in use for other students. If the FTD is not available on the Monday, but is available on Tuesday, the student is automatically behind schedule. This is even more problematic during periods of adverse weather that may delay the flying mission, which leads to further regression in the student's training schedule. Any delay in FTD availability exposes the false assumptions regarding the efficacy of the five-wave program and its role in minimizing the number of aircraft procured. These factors create a situation of peak and valley resource demand. Simply put, NFTC was resourced at the mean of demand, based on the assumption that scheduling and management would flatten the utilization sine wave. This has been disproven by actual operations. Pilot training is inherently time-sensitive because of the requirement for usable weather, which cannot be controlled or perfectly predicted. The NFTC RAM and the new Undergraduate Pilot Training Resource Allocation Model (UPTRAM) use a weather model that has been significantly updated and which is much more scientific then the legacy FTDC. The RAM is quite accurate over a given time; however, there are statistical variations of in-year weather. While resource demands affected by weather will even out over time, courses are often not of sufficient duration to account for all such variations. Therefore, adequate resourcing, i.e., peak or near peak, is required to allow the program to operate on a regular basis without the need for constant or near-constant surge.

Performance measurement

Another important area of consideration in the contracted flying training environment is performance measurement. All contracts are based on a quantity of service delivered within a given amount of time. The normal methods by which the RCAF measures the success of its pilot training are not easily applied in the contracting environment. This was clearly indicated in a 2005 letter from Commander 1 Cdn Air Div [167] to the Assistant Chief of the Air Staff[168] concerning NFTC: "the current contract is unclear regarding program deliverables and how success of the program is to be judged."[169] In the legacy training environment, the success indicator was the graduation of a given number of NWGs per year that, ideally, met the RCAF requirement. Progress throughout the year was measured by quantifying the number of sorties completed in relation to the ideal number in order to graduate the required number of NWGs and maintain the proficiency of the QFIs. When these targets were not met, then the system entered surge operations in order to attain the level required to meet the objective. Simply put, the RCAF controlled all the levers, i.e., personnel and resources, to meet its objectives.

However, in the contracting environment, there are factors that are either not controlled by the RCAF or less easily influenced. In the outsourcing environment, the contractor provides the minimum resources required to deliver the contracted services. In one respect, this is advantageous because it reduces RCAF costs to a minimum. However, when a program falls behind the required production, the limitations of the contract hinder the reacquisition of targets. For example, the NFTC contracted flying training day is 10.5 hours from Monday to Friday. There are additional limits on the number of aircraft and FTD sorties available and the number of sorties available for use on weekends. As well, the contract places limits on the amount and method of surge operations available to the RCAF. Surge options are defined in section 6.4 Rectification – Schedule Slippage of the NFTC SOW. There are three options available, including additional aircraft per wave within the normal working day, extending the operating day to generate more sorties (fifth-wave Hawk or sixth-wave Harvard) and working weekends as required. These options must be discussed and agreed to by the contractor at the bi-weekly key performance indicators (KPI) meeting. This is done as a method to control contractor costs in the firm, fixed-price paradigm; so any deviation from these restrictions comes at increased cost.

In addition, the measurement of contractor service delivery performance can be frustratingly difficult. As previously mentioned, the RCAF traditionally measures success by the number of trainees that graduate on time. However, if the number of bad weather days is higher than that predicted in the program model, training delays cannot be counted against contractor performance. In addition, the measurement of the delivery of sorties is impacted by resource unserviceabilities and weather conditions that are deemed beyond the control of the contractor. An example of this issue is the continuing problem associated with the availability of the Rolls Royce Adour engine used in the Hawk aircraft.[170] Because the contractor operates according to its business plan and provides resources for the program based on the program model assumptions, there is limited accountability when these assumptions fail to hold true, the weather fails to cooperate, and so forth.

One of the results of the NFTC contractual problems in May 2011 was the setting up of the bi-weekly KPI meeting between the RCAF and the contractor. Given the problems with the contract, i.e., insufficient production from the RCAF's perspective and negative revenue from the contractor's perspective, it was mutually agreed that a new approach was required. As previously discussed, the RCAF re-engineered the pilot training paradigm to deliver the required training using reduced resources in order to consider updated resource assumptions. From the contractor's perspective, the new paradigm was initiated on an at-risk basis aimed at fulfilling the promise of increased training activity. The new NFTC syllabus, along with the revised CFTS syllabus, was initially accepted by both contractors and the CA on a trial basis that allowed for a better assessment of the financial impacts. Flying activity is critical to the revenue of the NFTC contractor. To support production and flying activity, a new method of measuring performance was required, so the KPI forum was set up in an attempt to redefine the performance management framework and empower local RCAF commanders and the contractor's supervisory staff to jointly maintain a reasonable operational tempo and increase student throughput.[171]

The objective of the KPI meetings is to review program progress and mutually agree on adjustments based on performance. To draw up the agreement, three key indicators were considered as measurement tools for the program: X count, staff proficiency and yearly flying rate (YFR).[172] The KPI group consists of operators, maintenance employees and contractual representatives from both the RCAF and the contractor. The group reviews program progress in relation to the three measured factors in order to determine whether surge operations are required. There is also a statistical review of sorties not completed and the reasons why. The main focus of the analysis is to determine whether the numbers of lost sorties comply with the model, whether the contractor has provided a sufficient number of sorties, and whether the RCAF has honoured its obligations to provide sufficient QFIs. Although surge operations are included in the contract, there is often scrutiny of the need for surge operations because there is a cost to the contractor and there is a preference for certain options over others because of cost implications. Moreover, because of various union collective agreements affecting the civilian labour force, sufficient notice of any surge operations must be given in order to honour such commitments. In addition, civilian workers work overtime on a voluntary basis and cannot be compelled to do so. Therefore, the contractor requires sufficient time to ascertain whether or not it can support the surge request for additional waves or weekend operations.

Overall, the holding of KPI meetings has had a positive impact on NFTC and supports the new training paradigm. Student throughput has increased and so has the YFR. However, there are limitations on the effectiveness of KPI meetings because there is still a strong contractual influence on the group's behaviour and not enough flexibility to capitalize on operational opportunities, such as an unforecast period of better than predicted weather. The current KPI structure is too contractually focused, and players in operations are not sufficiently empowered to have an impact on the program.[173]

As discussed earlier, the drafters of the CFTS contract attempted to boost the contractor's incentive to achieve a high rate of performance by including a PIF. The administration of PIFs is very labour-intensive for both the RCAF and the contractor. As well, the RCAF wanted to give the contractor an opportunity to be innovative. However, this methodology does not recognize the cost and risk to the contractor associated with innovation. There was an attempt to mitigate this issue by providing broad target areas for the contractor to work towards, but this was found to create an environment of conflict during the evaluation process, which reduced the positive impact of the incentive. This predicament was resolved by providing more specific goals and detailed performance criteria for the contractor within a given time frame.

Performance measurement was a problem for both CFTS and NFTC. The method for measuring program success was not clearly defined. As well, neither program—and more so NFTC—was appropriately modelled and resourced to be able to absorb annual variances in weather and fleet availability. Surge mechanisms appeared to be well defined, but the associated triggers were unclear in the contract wording, which limited operational flexibility. Lastly, while PIFs can be said to be largely successful, they placed a considerable administrative burden on both the RCAF and the contractor. Addressing these problematic areas of performance measurement will facilitate future success.

Relationship

Based on the experiences of the RCAF and the contractor, it is apparent that a functional relationship is of paramount importance to ensure the success of both parties in the ASD environment. It is also evident that the contractor's revenue drivers are often not always apparent to the end user. Moreover, the risk avoidance focus of government contacting policies and procedures ignores the transfer of risk that long-term, firm, fixed-price contracts impose on a contractor in an environment as fluid as pilot training. Thus, there are several lessons to be considered in contractor relationships that can benefit the RCAF and help the RCAF achieve its objectives in the next pilot training paradigm.

First and foremost is the reality of profit and revenue. Private-sector industrial firms enter into business arrangements to earn profits: profit is the result of revenue exceeding costs. While government policies acknowledge this need for profit, the protection of taxpayer dollars in the public-sector environment takes precedence, and so policies and regulations are tailored to providing profit in consideration of associated risk and minimizing financial outlays. While minimizing risk and outlay is intrinsically good from the public-sector perspective, it must be done in such a way as to meet the needs of private-sector firms and ensure mutually beneficial relationships.

It seems clear from the government's method of profit categorization that the government does not acknowledge the transfer of risk to contractors in long-term, firm, fixed-price contracts in such a dynamic environment. While the contractor attempts to build buffers into its pricing, thus increasing cost, there is a great risk that its estimates will not cover changing costs a decade or more later in the term of the contract. When the contractor is revenue negative, not only is profit absent, but also the business is costing the contractor money, as exemplified by the NFTC contract. This creates a situation where cost control becomes a primary focus of private-sector firms, and it is much less likely that the goals of the customer will be met. This is especially true in the case of pilot training, where revenues are inherently dependent on the use of contracted capacity. Because the RCAF controls student loads and YFR utilization, the importance of this to the contractor must be fully appreciated. It must also be recognized that the flexibility in training sought by the RCAF is only secured at a financial cost. Moreover, there is a price attached to the concept of prime contractor. This adds a layer of profit to both CFTS and NFTC that increases the cost of student training. This impacts program flexibility and the ability to market training, thus reducing potential economies of scale.

Secondly, government contracting policy and zero-risk tolerance are not well-suited for the pilot training paradigm. Contracting policies are cumbersome and the resulting lead time to effect change is incongruous with RCAF pilot training requirements. It is also apparent that the cognitive recognition of the impact of risk transfer to the contractors was not fully understood. Moreover, the environment is contractually very difficult, and costlier for the contractor. The multi-headed customer that is RCAF pilot training imposes formidable challenges on the contractor to satisfy all of the parties concerned, who often seem to have conflicting risk acceptance profiles. Instances where revenue and risk are not aligned result in poor relationships that imperil the objectives of all concerned.

Lastly, it is clear that neither the RCAF nor its contractors fully appreciated the degree of change inherent in the programs. Such activity was considered in the SOW, but the volume of amendments has grossly exceeded both business cases. Undoubtedly, a component of this activity in the case of NFTC results from the previously discussed programmatic problems, such as false initial resourcing assumptions. However, the TP has been completely redrafted on two occasions thus far, and there have been many smaller-scale modifications. The reality of pilot training, as demonstrated by experience, is continuous TP improvement and development. Sufficient consideration given to this fact in the future will ensure a proper business model and less resistance to change by all stakeholders.

It is critically important for the RCAF to have a mutually beneficial relationship with its contractor or contractors in the future. In addition, government contracting policies are not ideally suited to the pilot training environment. Lastly, the volume and pace of TP changes were far beyond what was forecast in either program. It is apparent that in the dynamic area of large-scale pilot training contracts that a high degree of change is a fundamental reality.

Marketing

Marketing was an important aspect in the setting up of both programs. However, it has proven difficult to attract and keep customers. Although NFTC was basically set up to facilitate marketing, CFTS was not, which limited the degree of success. Moreover, program costs did not compare well with other alternatives.

In the case of CFTS, there was intent to sell training, but there was no authority to expand the program as there was with NFTC.[174] The strategy seemed to be that once a customer was found, then the authority to expand would be secured. However, this approach did not consider the impacts of the cumbersome and arduous approval process. As well, the synergy of CFTS and NFTC was not appreciated within the RCAF.[175] It was assumed that other nations were only interested in purchasing fighter training. However, this was not always the case. The Royal Saudi Arabian Air Force (RSAAF) purchased Phase I training in addition to, and in fact as a prerequisite for, their NFTC training. There were also several other nations that expressed interest in CFTS helicopter or multi-engine training, but such sales were hindered by the lack of authority to expand capacity. For example, the Royal Saudi

Navy, the Royal Brunei Air Force, the Brazilian Navy and the German Navy have expressed interest in CFTS training slots. Unlike CFTS, NFTS contained built-in expansion gates that increased the three key resources as student numbers increased. The problem was that an aircraft model only has a limited production run period. For example, 21 Mk 115 Hawks were built and then production moved on to an altered version.[176] Therefore, after the first few years of a program, it was unlikely that similar aircraft would be available for purchase. In addition, mixed fleet operations (old and new models) would therefore have to be considered or additional aircraft purchased at program commencement as a hedge for future sales, which would increase overall cost.

Conclusion

A review of the background of ASD in Canada, its effects on the current contracts and the contractor perspective reveals many lessons learned. In fact, there are lessons learned for each of the critical factors. Proper consideration of these issues will lay the groundwork for future success.

The CFE capital asset acquisition methodology used for the two contracts made it possible to recapitalize the training fleets. However, it also resulted in two significant negative outcomes: higher costs and unintended consequences related to the lease-based paradigm. The much greater cost, when compared with a GFE solution, limited program flexibility in a tight fiscal environment and greatly hindered marketing efforts. Incorrect resourcing assumptions and high guaranteed contractor revenue streams created production issues that could not be overcome without drastic program changes. The cooperation achieved in NFTC to facilitate change highlights the value of a strong RCAF-contractor relationship. This relationship was continually under siege by archaic government contracting policies ill-suited to the dynamic pilot training environment. By giving these lessons proper consideration, a number of recommendations can be made for the future paradigm.

Conclusion

The RCAF stands at a crossroads in its pilot training program. Fiscal and political factors resulted in the 1994 White Paper on Defence. This document outlined government plans to decrease financial and personnel resources allocated to national defence. To achieve its cost reduction objectives, the government focused on minimizing military personnel requirements and reducing costs through outsourcing. The establishment of NFTC and CFTS solidified the development from the traditional military-manned system to an ASD paradigm. But, ASD has not proven to be the panacea that it was believed to be in the 1990s.[177] Moreover, the financial benefits realized have been a fraction of what was initially envisioned.[178] Nonetheless, this is not to say that gains have not been realized. In a time of extreme financial restriction, training fleets were recapitalized and a high-quality training system was set up. But aside from unachieved financial objectives, there are several other negatives that have arisen from the ASD paradigm that was used, for example, the unintended consequences and increased cost associated with CFE capital assets. The purpose of this paper is to examine the effects of ASD on RCAF pilot training and to determine a way forward that emphasizes ASD strengths, while eliminating its weaknesses.

To emphasize the positive aspects of outsourcing, while sidestepping the negative aspects, the RCAF must learn from its experience. There are several critical factors that must be considered and addressed if the future program is to be successful, because some form of outsourcing will be used. These factors include implementation of ASD principles and philosophy, the capital asset acquisition paradigm, resource requirements, performance measurement, the RCAF-contractor relationship, and marketing. In fact, the success of the future pilot training program depends on effectively addressing these critical factors.

Lessons learned from an examination of these critical factors must be applied during the development of the next generation of the RCAF pilot training paradigm. The ASD paradigm has reduced the number of military personnel required to conduct pilot training. This frees up highly trained personnel to carry out operational tasks. Costs savings obtained from outsourcing in this context are difficult to measure. While the Crown's savings targets for ASD were not met, a fully developed cost comparison with a traditional military solution has never been completed. This would be a worthwhile topic for future research.

The capital asset acquisition paradigm is one of the key factors to consider in the development of the future program. The current system uses a CFE model that was made necessary by the fiscal climate and expedient O&M funding. However, even a rather cursory analysis clearly demonstrates that this method is far more expensive than a GFE solution. This reality must be carefully considered in future planning because lower costs make the program more palatable to government and more marketable to potential customers. A GFE solution would also eliminate the complications arising from the high levels of guaranteed revenue required by CFE fleets. This was a major contributor to the problems that both the RCAF and the contractor had with NFTC. It must be remembered that a CFE solution was recommended by the Department of Finance back in 1997.[179] However, obtaining capital funding can be more difficult, and therefore a detailed business case comparing a CFE and a GFE capital asset paradigm should be a high-priority future research topic for the RCAF. If a CFE paradigm is selected, then careful consideration must be given to the inclusion of CFE fleets in the RCAF aircraft management structure to mitigate the unintended consequences of leased aircraft.

Whichever solution is selected for the future, resource allocation will determine the efficacy of program production. There are three key assets that must be modelled and resourced properly: aircraft, FTDs and QFIs. During NFTC, there were many incorrect assumptions in program resourcing that handicapped the program from the outset. Some of these assumptions were the following: FTDC, aircraft capabilities, TP effects on FTD utilization and availability, QFI manning, proficiency hours, the sortie generation paradigm (wave pattern), and sole-source contracting. Overall, CFTS and NFTC were resourced to the mean of demand. This left both programs unable to easily respond to surge requirements made necessary by unforecast weather or other production hindrances. Another future research area should be resourcing methodology to ensure proper modelling assumptions at near-peak resourcing. This should result in a business case in which the increased cost of near-peak resourcing is compared with the cost of program inefficiencies arising from production losses and surge operations.[180]

Performance measurement is a key component in need of improvement in the future. Accurate and fair measurement ensures value for dollar for the Crown and contributes to contractor performance and profitability. However, the vagaries of flying training make performance measurement a very difficult exercise. NFTC administrators implemented a KPI model to improve RCAF-contractor communication. However, as currently set up, the KPI meetings are much too contract focused. In the future, the KPI meetings should be operations focused. Stakeholders must be empowered to make decisions and act within the bounds of the contract. This will benefit both RCAF production and contractor revenues.

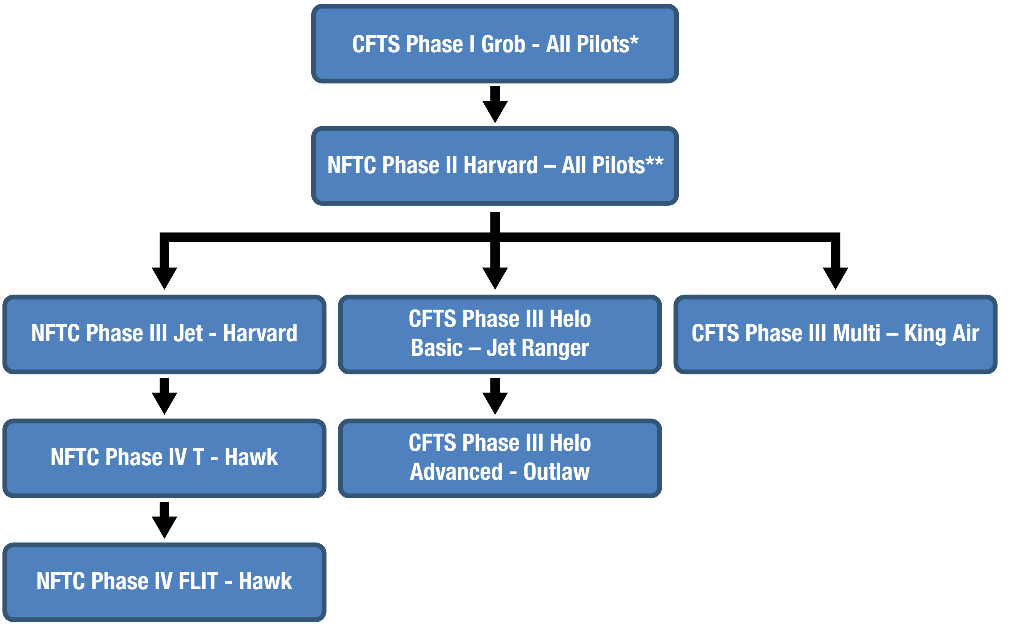
Another mechanism to achieve better performance is to increase contractor incentives. The CFTS contract implemented a PIF, which offers a financial inducement for contractor innovation and exceeding service parameters. It also gives the RCAF an opportunity to boost contractor efforts in desired focus areas. Therefore, a future research topic should be to quantify the impact of PIFs in Crown contracts, and consideration should be given to including PIFs in any future program.

In the future, there should also be a focus on the relationship between the RCAF and contractors. Many checks and balances are needed within the government contracting process to ensure that federal funds are spent in the public's interest. However, the net result is that the Crown, as represented by the CA, has very little tolerance for risk. Moreover, the CA and its procedures do not recognize the high level of risk that long-term, firm, fixed-price contracts impose on contractors. From the contractor's perspective, government procedures and limitations are often frustrating and hinder program growth and productivity. A sound relationship guaranteeing a reasonable profit is essential to the future program. Future research should focus on the correlation between revenue and contractor relationships in Crown contracts.

Marketing must be approached systematically in order to be successful. NFTC was set up with training capacity sales in mind and contained built-in expansion triggers and mechanisms. Moreover, the requisite authority for expansion should be obtained prior to program inception because of lengthy approval timelines. Program expansion will contribute to economies of scale and thus lower costs for all participants. Marketing outreach to potential partners should start now during the program definition stage.

The Future Aircrew Training (FAcT) program will facilitate the training of RCAF aircrew for the next two decades, starting in 2023. This massive undertaking gives the RCAF an opportunity to better structure its delivery of aircrew training and apply numerous lessons learned based on a review of the critical factors. To ensure the success of this endeavour, the Crown should act as its own prime contractor with specific services contracted directly to subcontractors. Moreover, the Crown should carefully analyze the benefits of a GFE capital asset solution. These two elements alone can generate potential savings in the hundreds of millions of dollars. In the long term, the future training paradigm should keep these two elements as core principles. Upon this basis must be built a properly resourced and modelled program with clearly understood performance measurement mechanisms that are properly authorized to be marketed and expanded. This program should also acknowledge the importance of a healthy productive relationship with contractors. In doing so, the RCAF will ensure the success of its future training program, leverage the benefits of ASD and avoid pitfalls.

Appendix A: RCAF Pilot Training Phases (CFTS and NFTC)



Appendix B: Contractor Survey Questions

1. What attracted your company to the military flying training industry?

2. From your perspective, what elements of the contract worked best for your company?

3. What elements of the contract did not work well from a contractor perspective?

4. What would you like to see changed in the next contract with respect to contract wording and structure?

5. What are your thoughts on how best to balance the RCAF's requirement for flexibility (surge, changing student loading, Training Plan changes, etc.) and a company's desire for predictable revenue streams and profit?

6. What role does profit play in a company's outlook toward such a contract? What are the company's profit expectations?

7. In such a large multi-year contract, is a company expected to increase its ROE (return on equity)/profit annually? Is it expected to grow revenue?

8. What has been your biggest hurdle in dealing with government contracting procedures?

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Abbreviations

1 Cdn Air Div	1 Canadian Air Division
2 CFFTS	2 Canadian Forces Flying Training School
ADM (Mat)	Assistant Deputy Minister (Materiel)
ALSE	aviation life support equipment
ASD	alternate service delivery
AW	Allied Wings
BHC	Basic Helicopter Course
BI	Bombardier Incorporated
BMAT	Bombardier Military Aviation Training
CA	contracting authority
CAF	Canadian Armed Forces
CFB	Canadian Forces Base
CFE	contractor-furnished equipment
CFTS	contracted flying training and support
CRS	Chief Review Services
CSA	Canada Services Agreement
DND	Department of National Defence
ENJJPT	Euro-NATO Joint Jet Pilot Training
FG	force generation
FLIT	fighter lead-in training
FRP	Force Reduction Program
FTD	flying training device

FTDC	flying training day calendar
GFE	government-furnished equipment
HBC	Hawker Beechcraft Corporation
KPI	key performance indicator
MOC	military occupational classification
NFTC	NATO Flying Training in Canada
NWG	new wings graduate
OAG	Office of the Auditor General
OEM	original equipment manufacturer
PACC	Standing Committee on Public Accounts
PC	performance criteria
PEP	performance evaluation plan
PET	Performance Evaluation Team
PIF	performance incentive fee
PIFB	Performance Incentive Fee Board
PM	performance monitor
PMB	Program Management Board
PWGSC	Public Works and Government Services Canada
QFI	qualified flying instructor
RAAF	Royal Australian Air Force
RAM	resource allocation model
RCAF	Royal Canadian Air Force
RSAAF	Royal Saudi Arabian Air Force
RSAF	Republic of Singapore Air Force
SME	subject matter expert
SOW	statement of work
sqn	squadron
TA	technical authority
TAA	Technical Airworthiness Authority
TAS	Traffic Avoidance System
TB	Treasury Board
TMA	Training Management Authority
TP	training plan

UPTRAM	Undergraduate Pilot Training Resource Allocation Model
VCDS	Vice Chief of the Defence Staff
VIQ	variation in quantity
WSM	weapon system manager
YFR	yearly flying rate

Notes

1. The term RCAF is used throughout this paper, although the air component of the Canadian Armed Forces was not reconstituted as the RCAF until 2011.

2. Canada, Department of National Defence (DND), Chief Review Services (CRS), *Evaluation of Aerospace Training and Readiness Part 1 – Air Force Initial Occupational Training*, November 2012, accessed August 24, 2018, http://www.crs-csex.forces.gc.ca/reports-rapports/2012/187p0940-eng.aspx.

3. The timeline from induction to achievement of RCAF wings standard averages about four years.

4. Canada, DND, CRS, Director General Audit, *Audit of Force Reduction Program*, January 1997, 2/17, accessed August 24, 2018, http://www.crs-csex.forces.gc.ca/reports-rapports/pdf/1997/705529-eng.pdf.

5. Lieutenant-Colonel (LCol) Clifford Beattie, "The Hypothetical Most Efficient Organization: The Fatal Flaw in the Alternative Delivery Process," Canadian Forces College paper, 2000, accessed on August 24, 2018, https://www.cfc.forces.gc.ca/259/181/51_beattie.pdf .

6. Beattie, "Hypothetical Most Efficient Organization."

7. The combined programs, NFTC and CFTS, produced approximately 85 to 90 new wings graduates (NWGs) per year from 2000 to 2012. This contrasts with the fact that the system was funded to produce 95 NWG until 2008, at which time there was a funding increase for CFTS to support an increase to 105 NWGs (Program Management Board, PMB 0708).

8. Canada, DND, *Evaluation of Aerospace Training and Readiness*, 13.

9. The original NFTC contract expired in 2021. However, in December 2016, a Modification of Operating Period agreement was signed that extends the contract to December 2023, with an option to further extend the agreement to December 2024.

10. Starting in 2015, the RCAF amended and rebranded the project. Future Pilot Training was renamed Future Aircrew Training (FAcT) and includes training for pilots, air combat systems operators (ACSOs) and airborne electronic sensor operators (AESOPs). The intent is to leverage synergies amongst the aircrew training requirements.

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14. The focus of this review is the RCAF experience with large-scale ASD as applied to pilot training capability.

15. This paper will refer to the following six factors as the critical factors: implementation of ASD principles and philosophy; the capital asset acquisition paradigm; resource requirements; performance measurement; the RCAF-contractor relationship; and marketing.

16. Major (Maj) Jennifer M. Stephens, "Delivering Value Through Logistics," *Army Logistician* 40, no.6 (November–December 2008), accessed August 24, 2018, http://www.almc.army.mil/alog/issues/NovDec08/delivervalue_spectrum.html.

17. Stephens, "Delivering Value Through Logistics."

18. Kindred Motes, The Rise of Privatised Military Firms During and After the Cold War (master's thesis, University of Essex, 2013), accessed August 24, 2018, http://www.academia.edu/7170804/The_Rise_of_Privatised_Military_Firms_During_and_After_the_Cold_War.

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20. The term "the Crown" is used throughout this paper in lieu of the "Canadian government."

21. "Collapse of the Soviet Union," *Portulus.RU*, September 4, 2007, accessed on October 3, 2014, http://www.portalus.ru/modules/english_russia/print.php?subaction=showfull&id=1188915416&archive=&start_from=&ucat=11& [site discontinued].

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23. LCol Michael Rostek, "A Framework for Fundamental Change? The Management Command and Control Re-engineering Initiative," *Canadian Military Journal* 4, no, 5, 2005, accessed August 24, 2018, http://www.journal.forces.gc.ca/vo5/no4/manageme-gestion-eng.asp.

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28. Kamery, "Brief Review of the Recession of 1990–1991."

29. Rostek, "Framework for Fundamental Change?"

30. Beattie, "Hypothetical Most Efficient Organization."

31. Institute for Citizen-Centred Service, "Alternative Service Delivery," August 1999, accessed on July 21, 2014 [site discontinued], http://iccs-isac.org/en/clearinghouse/asd.htm.

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33. "Strategic, Core and Non-Core Activities: What to outsource for best results?" *intetics* (blog), April 2, 2017, accessed August 24, 2018, http://www.intetics.com/strategic-core-and-non-core-activities-what-to-outsource-for-best-results/.

34. Canada, DND, *1994 White Paper on Defence*, 3, accessed August 24, 2018, http://publications.gc.ca/collections/collection_2012/dn-nd/D3-6-1994-eng.pdf .

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41. Canada, DND, *1994 White Paper on Defence*, 17.

42. Beattie, "Hypothetical Most Efficient Organization."

43. Beattie, "Hypothetical Most Efficient Organization."

44. Beattie, "Hypothetical Most Efficient Organization."

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46. Canada, DND, *1994 White Paper on Defence*, 36.

47. Murray Brewster, "National Defence struggling to staff mental health positions in remote outposts," *The Globe and Mail*, November 30, 2014, accessed August 24, 2018, http://www.theglobeandmail.com/news/national/somnia/article21840761/.

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50. Canada, DND, *1994 White Paper on Defence*. 36.

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54. Beattie, "Hypothetical Most Efficient Organization," 3.

55. Beattie, "Hypothetical Most Efficient Organization."

56. Canada, DND, *1994 White Paper on Defence*.

57. Canada, DND, *1994 White Paper on Defence*, 65

58. During the NFTC program, Bombardier's military training division was renamed Bombardier Military Aviation Training (BMAT), but Bombardier Incorporated (Inc.) is referred to as BI throughout this paper.

59. Canada, DND, *Backgrounder: Contracted Flying Training and Support*, March 30, 2005, accessed August 24, 2018, http://www.forces.gc.ca/en/news/article.page?doc=contracted-flying-training-and-support-cfts/hnocfoke.

60. Rostek, "Framework for Fundamental Change?"

61. Colonel Glynne Hines, "Alternate Service Delivery: Managing to Get It Done Right," National Security Studies course paper, Canadian Forces College, 2000, 8, accessed August 24, 2018, http://www.cfc.forces.gc.ca/papers/nssc/nssc4/hines2.pdf.

62. Hines, "Alternate Service Delivery."

63. The two programs are NFTC and CFTS. NFTC consists of two operating sites: one in Moose Jaw, Saskatchewan, and one in Cold Lake, Alberta, which are part of 15 Wing Moose Jaw. 2 Canadian Forces Flying Training School (2 CFFTS) in Moose Jaw operates CT155 Hawk and CT156 Harvard II (Harvard) aircraft. 419 Squadron (Sqn) in Cold Lake operates Hawk aircraft. CFTS consists of one site at Southport, Manitoba. 3 CFFTS in Southport operates Grob 120A, CH139 Jet Ranger, Bell 412 CF Outlaw and C90B King Air aircraft. The two programs are highly interdependent. The training consists of several phases: Phase I (3 CFFTS/AW) is conducted on the Grob with successful students proceeding to Phase II (2 CFFTS) on the Harvard. Students are then selected for one of three training streams: Phase III Helicopter at 3 CFFTS utilizing CH139 Jet Ranger (Basic) and Bell 412 CF Outlaw (Advanced); and Phase III Multi-Engine at 3 CFFTS utilizing C90B King Air or Phase III Jet at 2 CFFTS for Phase III Jet/Fighter training on the Harvard. Students who continue in the Jet/Fighter stream complete Transition training (Phase IV T) on the Hawk at 2 CFFTS. Successful candidates then proceed to Fighter Lead-In Training (Phase IV FLIT) at 419 Sqn. See Appendix A: RCAF Pilot Training Phases (CFTS and NFTC).

64. Canada, OAG, *1999 November Report of the Auditor General of Canada*.

65. Hines, "Alternate Service Delivery."

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72. Canada, DND, *Backgrounder: Canada's Flying Training History*.

73. Canada, OAG, *1999 November Report of the Auditor General of Canada*.

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76. Canada, PACC, *Eighteenth Report*.

77. Canada, OAG, *1999 November Report of the Auditor General of Canada*.

78. Bombardier Aerospace, "Military Training", accessed on October 17, 2014, http://www.bombardier.com/en/aerospace/specialized-aircraft/military-training.html.

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80. Canada, OAG, *1999 November Report of the Auditor General of Canada*.

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82. The original purchase included 18 Hawk, 24 Harvard aircraft, as well as 2 Hawk FTDs and 3 Harvard II FTDs. This number included 1 Hawk and 2 Harvard II airframes as spare parts aircraft. These are termed Series 1 Assets, as defined in Schedule R-14 of the CSA.

83. The bonds were Series 1 Amortizing Secured Bonds, which paid 5.75% per annum and were rated AA by the Canadian Bond Rating Service (CBRS).

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88. Canada, OAG, *2006 May Status Report of the Auditor General of Canada*, Chapter 3 – National Defence – NATO Flying Training in Canada, accessed on August 24, 2018, http://www.oag-bvg.gc.ca/internet/English/parl_oag_200605_e_1118.html.

89. Canada, OAG, *2002 September Status Report of the Auditor General of Canada*.

90. The NFTC contract was designed and business cased from the start to include sales to customer air forces. It is important to note that BI made no direct sales to any party other than to the Crown. Sales were made through Memoranda of Understanding (MOU) between the RCAF and the customer air force. The Crown would then purchase the required training to fulfill the MOU through the CSA with BI.

91. Canada, DND, *NATO Flying Training in Canada*, 30.

92. Canada, PWGSC, *Statement of Work SOW 9177 for the NATO Flying Training in Canada (NFTC) Program*, April 30, 1998 and incorporating revisions to December 19, 2008.

93. Participating nations are required to provide QFIs in a ratio of QFI to students depending on the phase of training. If the nation either cannot or does not wish to provide QFIs, then it must reimburse the program financially so that the required numbers of QFIs can be sourced from another nation at no financial cost to the nation that provides the QFIs. This is the "Hired Gun" concept used in NFTC.

94. As a result, Milit-Air purchased three Hawk and two Harvard aircraft, valued at $106M through an additional bond sale at 5.87%. These aircraft were known as Series 2 assets, i.e., assets required as a result of the training demand of a new program signatory. These are differentiated from the initial purchase of assets and the associated bond sale, which were called Series 1 assets as per the CSA, Schedule R-14 Series 1 Assets and Series R-15-1 Series 2-1 Assets Amendment 7 (2002).

95. Canada, PWGSC, *Canada Services Agreement*.

96. Canada, OAG, *2002 September Status Report*.

97. In addition, aircraft fatigue life and engine thermal cycle impacts and wear and tear resulted in varying costs per training phase, such that a Hawk jet training aircraft hour flown at 15 Wing Moose Jaw was charged at a different rate than the same hour flown at 4 Wing Cold Lake.

98. These items included the following: housing, rations, ALSE, ground school, FTD hours, flying hour-related costs and several others.

99. Canada, OAG, *2002 September Status Report*.

100. This list is not complete because there are other examples of flawed assumptions. Additional examples are the following: differences between weather at the Jimmy Lake weapons range and at 4 Wing Cold Lake; lack of winter daylight hours at 4 Wing, thus limiting 419 Sqn to a three-wave operation during the winter months; and MAPLE FLAG, which limits 419 Sqn to three waves during this major May–June exercise.

101. Canada, DND, DAOD 5001-2, *Maternity and Parental Benefits,* accessed August 24, 2018, http://www.forces.gc.ca/en/about-policies-standards-defence-admin-orders-directives-5000/5001-2.page.

102. Canada, OAG, *2002 September Status Report*.

103. Canada, PWGSC, *Statement of Work SOW 9177*.

104. Canada, OAG, *1999 November Report*.

105. Canada, OAG, *1999 November Report*.

106. Major-General (MGen) C. Bouchard, *NATO Flying Training in Canada (NFTC) Program Performance,* 17 Wing Winnipeg, File Number 2455-3 (A1 Trg), June 8, 2005.

107. Canada, DND, CRS, *Evaluation of Aerospace Training and Readiness*.

108. Approval required for funding from Program Management Board (PMB) and spending authority from Treasury Board (TB).

109. The Contracted Flying Training and Support contract.

110. Paul Samyn, "Portage Contract $2.3B Windfall," *Winnipeg Free Press*, March 22, 2005, accessed August 24, 2018, http://www.shindico.com/index.php?option=com_content&view=article&id=115&catid=5&Itemid=26.

111. Canada, OAG, *2002 September Status Report*.

112. The Honourable Michael H. Wilson, *The Budget Speech 1989*, April 27, 1989, accessed August 24, 2018, http://www.budget.gc.ca/pdfarch/1989-sd-eng.pdf.

113. Canada, DND, *Backgrounder: Contracted Flying Training and Support*.

114. Canada, DND, *Backgrounder: Contracted Flying Training and Support*.

115. "Canadian Forces Seek to Build Excellence in Foreign Flight Training," Defence Industry Daily, February 22, 2011, accessed August 24, 2018, http://www.defenseindustrydaily.com/canadian-forces-seek-to-build-excellence-in-foreign-flight-training-01537/.

116. "Canadian Forces Seek," 2011.

117. Samyn, "Portage Contract $2.3B Windfall."

118. Kevin Rollason, "Aviation Training Centre Takes Flight," *Winnipeg Free Press*, September 14, 2007, accessed August 24, 2018, http://www.winnipegfreepress.com/historic/32410714.html.

119. Canada, DND, CRS, *Evaluation of Aerospace Training and Readiness*.

120. Canada, PWGSC, *Contracted Flying Training and Support*.

121. This was a result of the TP analysis done by the Tiger Team in 2011.

122. The number of Phase I slots has since been increased under contract to 155.

123. Canada, PWGSC, *Contracted Flying Training and Support*.

124. The CFTS contract has been amended 48 times, from the start date of the contract to the end date in 2014.

125. In the CFTS and NFTC contracts, there are four authorities responsible for various aspects of quality assurance and quality control. The training authority (TA) works at the strategic level in Ottawa at the RCAF Directorate of Air Simulation and Training. The TA is responsible for matters concerning the technical content of the work under this requirement. In addition, any desired changes must be discussed with the TA prior to implementation. The Training Management Authority (TMA) works in Winnipeg at the RCAF Headquarters, A3 Training. The TMA is responsible for the training standard, the qualification standard and the qualifications of instructor personnel. Any changes to training plans must be discussed with the TMA prior to implementation. DND Procurement Authority was responsible for all procurement and financial activity related to the contract on behalf of DND. Lastly, the CA is PWGSC. It is responsible for managing the contract on behalf of the Crown. Any change to the contract or the work must be authorized by PWGSC, and the contractor is not to undertake any work in excess of or beyond the scope of the contract without the CA's prior agreement. If this appears complex, it must be understood that on top of this structure were DND Legal and PWGSC Legal, which provide advice to their respective customer agencies and the Contractor Representative, AW, which must also consider its parent company, KFL, their legal advisor and their insurers. The process to introduce a change was lengthy because of the presence of so many stakeholders.

126. Canada, PWGSC, *Contracted Flying Training and Support*.

127. Canada, PWGSC, *Annex D Performance Incentive Fee Plan Revision-2, Goose Bay Support Services Contract*, October 1, 2006.

128. Canada, PWGSC, *Annex D Performance Incentive Fee Plan Revision-2*, Section 10.7

129. Canada, PWGSC, *Contracted Flying Training and Support*.

130. This fact was confirmed in the results of a Contractor Survey of the prime contractors for CFTS and NFTC.

131. The PIFB is a Director-level group (Colonel equivalent) made up of several representatives of various government stakeholders. The PIFB is co-chaired by the Director, Air Simulation Training and the Director Major Procurement Services. Other members include PWGSC, the Director, Air Force Training and the Commander 15 Wing.

132. The PET Chair is the Program Director CFTS. This is the responsibility of DAST 2, which is a Lieutenant-Colonel position.

133. Canada, PWGSC, *Contracted Flying Training and Support*.

134. Canada, PWGSC, *Contracted Flying Training and Support*.

135. Defence Industry Daily, 2011.

136. Defence Industry Daily, 2011.

137. Canada, PWGSC, *Contracted Flying Training and Support*.

138. Canada, PWGSC, *Contracted Flying Training and Support*, Article 22.1.1.

139. In the case of a desired sale of ten Phase I training slots to the Royal Saudi Air Force (RSAAF is the abbreviation used in this paper instead of RSAF, the usual abbreviation, to distinguish it from the Republic of Singapore Air Force [RSAF]) in 2011, it took 18 months to come up with a definition of excess capacity with TB. This CFTS element, amounting to less than $1M, was the linchpin in a $43M sale of training to the RSAAF that included training slots in NFTC and technician training at the BC Institute of Technology. Therefore, the lack of an expansion mechanism was detrimental to the overall goal of the sale of training services to Allied countries. The agreed definition of excess capacity was restricted to only that capacity in CFTS available to the RCAF that was not included in the fulfillment of the 113. The RCAF paid for the Phase I training and VIQ.

140. Allied Wings Director CFTS, series of emails with the author, November 24–26, 2014; and, Director Programs and Business Operations, BMAT, personal conversation with the author, November 27, 2014.

141. For a complete list of questions, see Appendix B.

142. All material discussed in this chapter was taken from the contractor's answers.

143. Canada, PWGSC, *Procurement Management Manual*, January 2011, accessed August 24, 2018, http://www.tpsgc-pwgsc.gc.ca/biens-property/sngp-npms/bi-rp/conn-know/approv-procure/manuelga-pmmanual-2-eng.html.

144. It is noteworthy that the RCAF has maintained a pilot shortage for the duration, thus far, of the NFTC contract. Therefore, the RCAF has been attempting to balance operational and FG manning demands.

145. This is exemplified in the very nature of 20-year, firm, fixed-price contracts.

146. A weather model is used to calculate averages over a span of years that includes yearly statistical variances from the long-term average. Therefore, the model calculates resources based on the long-term average and not on the statistical variances.

147. As a reminder, the RCAF is only one of the four Crown authorities involved in the contract.

148. For example, should a tactical level user (2 CFFTS, 3 CFFTS or 419 Sqn) want a change to be made to a TP, they would staff a change to the TMA at the operational level; the TMA would then forward the request to the TA at the strategic level in Ottawa. The TA would then examine the impact of the TP change on the work as defined in the SOW and the contract. The request would then be packaged per staffing procedures to the Procurement Authority, who would then forward the change to the CA. The CA would then either verify whether the work was in- or out-of-scope with its legal team. At this point, the CA would negotiate with the contractor's representative to price the required work. Once satisfied, the contractor's representative would then verify with its legal team and lenders, at which point, the contract amendment would be signed and the work could begin.

149. Rostek, "Framework for Fundamental Change?;" ASD savings had amounted to a mere $60M per year rather than the intended $300M per year targeted by the year 2000.

150. Beattie, "Hypothetical Most Efficient Organization."

151. Canada, DND, CRS, *Evaluation of Air Force Training and Readiness Part 1 – Air Force Initial Occupational Training*, November 2012, accessed August 24, 2018, http://www.forces.gc.ca/en/about-reports-pubs-audit-eval/187p0940.page.

152. Canada, OAG, *1999 November Report of the Auditor General of Canada*, Chapter 27 – National Defence – Alternate Service Delivery, 27-17, accessed August 24, 2018, http://publications.gc.ca/collections/collection_2016/bvg-oag/FA1-1999-3-27-eng.pdf

153. $1.5M minus a $100,000 residual value assigned by the contractor.

154. $5.3M minus a $2M residual value assigned by the contractor.

155. The cost of privately financed Grob and King Air Fleet was $126M amortized over 20 years versus $40.5M if DND had purchased the aircraft directly.

156. Canada, Department of Finance, *Government of Canada Lending Rates: Consolidated Revenue Fund (CRF) Lending Rates*, October 23, 2008, accessed August 24, 2018, http://www.fin.gc.ca/admin/len/crf-tid-eng.asp?year=2005&month=06.

157. Cost of private financing in the amount of $126M amortized over 20 years versus a cost of $62M if DND purchased at the mid-2007 Central Revenue Fund 20-year lending rate of 4.43%.

158. $85.5M in savings versus an original unescalated CFTS program cost of $1.77B.

159. The cost of private financing of the original Series 1 NFTC fleet was $1.258B versus $740M if the aircraft had been purchased and made available as GFE. The total, including additional assets, was $871M financed for $1.381B.

160. The Royal Air Force left NFTC in 2008, although under contract to 2010; the Royal Danish Air Force left in 2010, although under contract to 2020; and the Italian Air Force left the program in 2011, although its planned departure was in 2020.

161. Canada, OAG, *1999 November Report of the Auditor General of Canada*.

162. An example of this was the removal of introductory Basic Fighter Manoeuvres and Air to Surface Tactics from the Phase III Hawk TP in 2006. These changes reduced both aircraft fatigue and engine thermal cycles, but had to be introduced as a trial until contractor acceptance could be achieved. This reality limited the flexibility of the TP from an RCAF perspective.

163. The organization related to training aircraft is Director General Air Engineering and Program (Fighter/Trainers), which is a subcomponent of the Assistant Deputy Minister (Materiel) [ADM (MAT)] section of DND.

164. One of the interesting dichotomies of NFTC is that DND is responsible for the provision of all ALSE (NFTC SOW, Book One, Article 8.4, Aviation Life Support Equipment); however,

until the creation of the Technical Support Manager (TSM) NFTC position in 2011 under a service-level agreement between the RCAF and the ADM (Mat), there was no dedicated DND engineering support allocated to NFTC. The ADM (Mat) created the NFTC TSM position after recognizing that despite the civilian ownership of the NFTC CFE fleets, these aircraft required DND oversight and support.

165. An example of this is the desire to upgrade the Harvard fleet with a Traffic Avoidance System (TAS). Because this system is outside the scope of the NFTC contract, the RCAF is responsible for the funding. In addition, even if the TAS were funded, the RCAF could also be liable for sorties lost on aircraft because they were taken offline to proceed through the upgrade process.

166. This issue became apparent when Hawker Beechcraft Corporation (HBC), the OEM for the Harvard, filed voluntary petitions under Chapter 11 bankruptcy on May 3, 2012. During this period, engineering work on the Harvard was brought to a standstill. This issue only abated when HBC exited bankruptcy on February 19, 2013, as the rebranded Beechcraft Corporation.

167. 15 Wing units belonged to 1 Cdn Air Div until the establishment of 2 Cdn Air Div in 2009, which focused on training and doctrine.

168. Renamed the Deputy Commander RCAF in 2011.

169. Commander 1 Cdn Air Div, RCAF, letter to Assistant Chief of the Air Staff, 2005.

170. Serviceability issues related to the low-pressure turbine blades of the Adour engine began in 2006 and had a negative program impact after 2008, and continue even today. This issue required a two-year redesign by Rolls Royce, the engine OEM. This redesign, while offering improved reliability, has not yet successfully eliminated all the availability issues.

171. This direction was included in the Implementation Plan following a meeting between the contractor and the RCAF on November 22, 2011.

172. X count refers to the number of completed sorties versus the ideal number of completed sorties necessary for the students to graduate from their courses on time. A positive X count means that the program is ahead of schedule, and conversely, a negative X count means that the program is behind schedule. Staff proficiency refers to the number of staff proficiency hours completed, which is compared with the end year requirement, and YFR refers to the number of hours flown versus the monthly plan to achieve the yearly YFR goals. As discussed, the contractor financials are closely tied to the YFR.

173. Brigadier-General M. P. Galvin, *Visit Report – Royal [sic] Singapore Air Force (RSAF) and Royal Australian Air Force (RAAF) Pilot Screening and Trg Systems*, 17 Wing Winnipeg: File Number

1776-1 [AF AOT], January 3, 2013. The positive contribution of operationally focused KPIs was specifically noted during the 2012 visit of the RCAF to the RAAF and RSAF training systems in Australia. In the observed system, there is a high degree of devolution of authority and responsibility to the tactical level. Overall, while the KPI concept was introduced to NFTC as a component of the training system paradigm update in late 2011 and early 2012, the observed KPI structure operates with a much higher degree of operational focus than that employed in NFTC.

174. At times in the NFTC program, the RCAF delayed its own training to ensure that Allied training, which was tied to fixed follow-on course start dates, was completed. This was especially evident during times of limited training resources.

175. Prior to the training purchased by the RSAAF, other customer nations had only purchased NFTC slots, i.e. those related to fighter training. These allied students arrived at NFTC having already completed Phase I training and sometimes Phase II training as well. In the case of the RSAAF, there was a desire to fully embrace RCAF training, such that Phase I training at CFTS was also purchased.

176. The Hawk Mk 115 is the version of the Hawk family of aircraft employed in the NFTC program.

177. Beattie, "The Hypothetical Most Efficient Organization."

178. Canada, DND, *1994 White Paper on Defence*.

179. Canada, OAG, *1999 November Report*.

180. When compared to resourcing to the mean in the case of CFTS and NFTC.

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