Development of a Capability-Based Bidder Evaluation Tool for the Fixed-Wing Search and Rescue Replacement Project

Sean Bourdon
Bohdan L. Kaluzny

DRDC CORA TR 2013–182
October 2013

Defence R&D Canada
Centre for Operational Research and Analysis

Supporting C Air Force and ADM(Mat)

National Defence
Défense nationale

Canada

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Principal Author

Sean Bourdon and Bohdan L. Kaluzny

Approved by

Dr. Roy E. Mitchell
Head, Maritime and Air Systems Section

Approved for release by

Paul Comeau
Chief Scientist

Abstract

In 2010, the National Research Council released a report detailing their review of the Fixed-Wing Search and Rescue (FWSAR) Statement of Operational Requirement (SOR). The SOR is a Royal Canadian Air Force document that specifies the requirements that replacement aircraft must possess in order to be considered viable as search and rescue platforms. Subsequent to the review of the SOR, the Department of National Defence began reformulating this procurement process using a capability-based approach, specifying what effects were desired of the FWSAR aircraft rather than prescribing the fleet's characteristics, such as speed, basing, etc. This report describes a series of analyses done in support of the procurement process including the development of a response performance model and tool, along with assessments and characterization of the opportunities and risks in potential aircraft/basing solutions based on the output of the model.

The FWSAR Aircraft Performance Assessment Tool, or FWSAR APAT, is the culmination of DRDC Centre for Operational Research and Analysis efforts. This tool will be used as an integral part of the evaluation of bids when these are received. The FWSAR APAT has been released to industry as part of the Government's consultation process, in addition to having been independently reviewed and thoroughly tested.

Résumé

En 2010, le Conseil national de recherches (CNR) publiait un rapport sur son examen de l'énoncé des besoins opérationnels (EBO) du projet de remplacement d'aéronefs de recherche et sauvetage à voilure fixe (ARSVF). L'EBO est un document de l'Aviation royale canadienne qui précise ce que l'avion de remplacement doit posséder pour être jugé efficace comme plateforme de recherche et sauvetage. Comme suite à l'examen de l'EBO, le ministère de la Défense nationale a entrepris de reformuler ce processus d'acquisition à l'aide d'une approche axée sur les capacités, en précisant les répercussions attendues de l'ARSVF plutôt que de prescrire les caractéristiques du parc d'avions, comme la vitesse, le positionnement, etc. Ce rapport décrit une série d'analyses réalisées à l'appui du processus d'acquisition, y compris le développement d'un modèle et d'un outil d'évaluation des performances en matière d'intervention. En même temps, l'évaluation et la caractérisation des possibilités et des risques associés aux solutions potentielles de l'avion et du positionnement, fondées sur les résultats du modèle, sont présentées.

L'outil d'évaluation de la performance des aéronefs de ARSVF est l'aboutissement des efforts de RDDC Centre d'analyse et de recherche opérationnelle. Cet outil fera partie intégrante de l'évaluation des soumissions lors de la réception de ces dernières. L'outil d'évaluation de la performance des aéronefs de l'ARSVF a été transmis au secteur privé dans le cadre du processus de consultation du gouvernement, après avoir été examiné de manière indépendante et mis à l'essai sous tous les angles.

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Executive summary

Development of a Capability-Based Bidder Evaluation Tool for the Fixed-Wing Search and Rescue Replacement Project

Sean Bourdon, Bohdan L. Kaluzny; DRDC CORA TR 2013–182; Defence R&D Canada – CORA; October 2013.

Background: The Royal Canadian Air Force (RCAF) currently uses two fleets of fixed-wing aircraft to perform search and rescue missions: the CC-115 Buffalo and the CC-130H Hercules. The *Canada First* Defence Strategy addressed the need to replace these fleets. In 2009, Industry Canada asked the National Research Council (NRC) to review the latest Statement of Operational Requirement (SOR) in an effort to reinvigorate a procurement process that had long been plagued by delays. One of NRC's findings was that the SOR was overly prescriptive in its characterization of what constitutes a suitable replacement fleet. One of their primary recommendations was to redefine the requirements in a capability-based manner, describing the effects that are desired of replacement fixed-wing search and rescue (FWSAR) aircraft rather than specific performance minimums.

Objective: This report details several analyses conducted by Defence Research and Development Canada's Centre for Operational Research and Analysis in support of the Directorate of Air Requirements, which is responsible for producing the SOR, and the FWSAR Project Management Office, which is responsible for developing assessment criteria and determining the most suitable replacement option. The overall objective of these analyses is to define an assessment method to replace specific aircraft performance targets in order to allow industry more flexibility in defining potential replacement options, such as using a different number and different locations for the FWSAR main operating bases.

Methodology: The first step was to define an assessment framework to allow for a capability-based evaluation of potential FWSAR solutions. This phase of the overall study resulted in the Basing, Endurance, and Speed Tool (BEST) for FWSAR which was purpose-built to satisfy this need. The second step was to evaluate a number of hypothetical FWSAR fleets using BEST for FWSAR to demonstrate the opportunities and risks associated with these options. The final step consisted of increasing the fidelity of BEST for FWSAR in order to use it for the purposes of evaluating the capability of a hypothetical fleet as part of the formal procurement process. The FWSAR Aircraft Performance Assessment Tool (APAT) was created as a result of this activity.

Summary of principal results: The models and analyses developed as part of this effort were extremely successful in helping progress the FWSAR project. BEST for FWSAR showed NRC that the RCAF had recast the FWSAR project in a capability-based framework. The analysis of the benefits and risks associated with various hypothetical fleets evaluated using this framework was pivotal in demonstrating the validity of this approach to the senior leadership of Industry Canada, Public Works and Government Services Canada, and the Department of National Defence. Finally, FWSAR APAT is being integrated into the bid evaluation process as a key component and has been shared with industry as part of an ongoing engagement campaign.

Sommaire

Development of a Capability-Based Bidder Evaluation Tool for the Fixed-Wing Search and Rescue Replacement Project

Sean Bourdon, Bohdan L. Kaluzny ; DRDC CORA TR 2013–182 ; R & D pour la défense Canada – CARO ; octobre 2013.

Contexte : L'Aviation royale canadienne (ARC) utilise actuellement deux aéronefs pour exécuter ses missions de recherche et sauvetage : le CC115 Buffalo et le CC130 Hercules. La Stratégie de défense Le Canada d'abord a reconnu la nécessité de remplacer ces aéronefs. En 2009, Industrie Canada a demandé au Conseil national de recherches (CNR) d'examiner le dernier énoncé des besoins opérationnels (EBO) dans le but de revigorer un processus d'acquisition qui éprouve des problèmes de lenteur. Le CNR a conclu, notamment, que l'EBO était trop normatif dans sa caractérisation de ce qui constitue un aéronef de remplacement approprié. Une de ses principales recommandations était de redéfinir les exigences d'une façon axée sur les capacités, en décrivant les répercussions attendues d'un aéronef de recherche et sauvetage à voilure fixe (ARSVF) de remplacement plutôt que le rendement minimal particulier.

Objectif : Le rapport contient plusieurs analyses réalisées par le Centre d'analyse et de recherche opérationnelle de Recherche et développement pour la défense Canada (RDDC CARO) à l'appui de la direction des besoins en ressources aériennes (DBRA), responsable de la production de l'EBO, et du bureau de gestion de projet de l'ARSVF, responsable de la formulation de critères d'évaluation et de l'établissement du choix de remplacement le plus approprié. Ces analyses visent à définir une méthode d'évaluation qui remplace les objectifs de performance particuliers d'un aéronef afin d'accorder plus de souplesse à l'industrie pour définir des options de remplacement potentielles, comme l'utilisation d'un nombre et d'endroits différents relativement aux bases opérationnelles principales de l'ARSVF.

Méthodologie : La première étape consistait à définir un cadre d'évaluation qui permet une évaluation fondée sur les capacités d'éventuelles solutions liées à l'ARSVF. Cette étape de l'étude a permis de mettre au point l'outil de positionnement, d'autonomie et de vitesse (OPAV) de l'ARSVF. La deuxième étape visait à évaluer un certain nombre d'aéronefs hypothétiques de recherche et sauvetage (SAR) à l'aide de l'OPAV de l'ARSVF afin de démontrer les possibilités et les risques associés à ces options. L'étape finale consistait à renforcer la fidélité de l'OPAV de l'ARSVF dans le but de l'utiliser pour évaluer la capacité d'un aéronef hypothétique dans le cadre du processus d'acquisition officiel. L'outil d'évaluation de la performance des ARSVF a été l'aboutissement de cette activité.

Résumé des résultats principaux : Les analyses et les modèles élaborés dans le cadre de cette démarche ont été extrêmement utiles à l'avancement du projet de l'ARSVF. L'OPAV de l'ARSVF a permis de montrer au CNR que l'ARC avait refondu le projet en un cadre de travail axé sur les capacités. L'analyse des avantages et des risques associés aux divers aéronefs hypothétiques évalués à l'aide de ce cadre de travail a été un élément charnière pour démontrer la validité de cette démarche auprès de la haute direction d'Industrie Canada, de Travaux publics et Services gouvernementaux Canada et du ministère de la Défense nationale. Enfin, l'outil d'évaluation de la performance des ARSVF est intégré au processus d'évaluation des soumissions comme élément clé et a été partagé avec l'industrie dans le cadre d'une campagne de mobilisation permanente.

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1 Introduction

1.1 Background

The National Search and Rescue Secretariat (NSS), an independent agency of the Government of Canada, administers the National Search and Rescue Program (NSP), coordinating public policy for the provision of Search and Rescue (SAR) services. The primary goal of the NSP is to save lives at risk throughout Canada's SAR area of responsibility (AOR). Figure 1 depicts the entirety of the Canadian AOR. The area encompasses over $18,000,000\ \text{km}^2$ and includes all of Canada's land mass as well as areas of the Atlantic, Pacific and Arctic oceans as designated by the International Maritime Organization (IMO) and International Civil Aviation Organization (ICAO). For command and control purposes, the Canadian AOR is subdivided into three smaller search and rescue regions (SRRs), each with its own Joint Rescue Coordination Centre (JRCC): the Victoria SRR, Trenton SRR, and Halifax SRR.

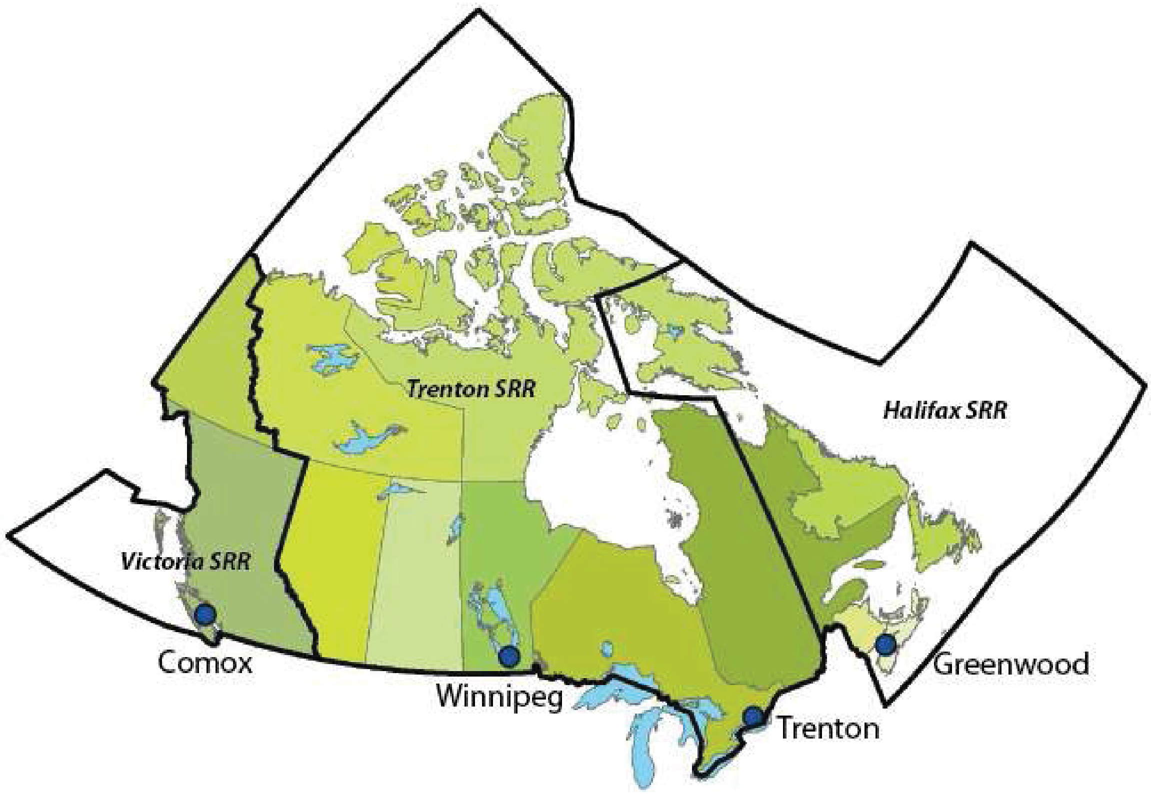


Figure 1: *Canadian AOR and the Victoria SRR, Trenton SRR, and Halifax SRR subdivisions.*

The NSP involves federal departments, provincial and territorial governments, municipalities, non-profit organizations, and volunteers working together to provide search and rescue in Canada. The Department of National Defence (DND) is the lead ministry responsible for providing and coordinating SAR response for incidents involving aircraft, and incidents involving vessels in federal or international waters. The Canadian Armed Forces (CAF) operate the three JRCCs as well as various dedicated SAR squadrons of helicopters and fixed-wing aircraft. The CAF currently use two types of primary fixed-wing search and rescue (FWSAR) aircraft: the CC-115 Buffalo fleet based in Comox and the CC-130 Hercules fleet based in Winnipeg, Trenton, and Greenwood. The aircraft are shown in Figure 2. The CC-115 aircraft are used to respond to incidents within the Victoria SRR, CC-130s out of Winnipeg and Trenton provide coverage of the Trenton SRR, and CC-130 aircraft in Greenwood respond to incidents in the Halifax SRR.

(a) CC-115 Buffalo (photo credit: Cpl Langgath, 9 Wing Imaging) (b) CC-130 Hercules (photo credit: Airliners.net)

Figure 2: *Current CAF FWSAR aircraft.*

As a part of the *Canada First* Defence Strategy (CFDS) issued in 2008 [1], the replacement of Canada's FWSAR fleet is a high priority for the Government of Canada. A FWSAR project office at DND was established; and, in 2004, a Statement of Operational Requirements (SOR) was drafted [2]. The SOR published in 2006 outlines the technical aspects that an aircraft requires to effectively carry out SAR missions in Canada's harsh operating environment [3]. In July 2009, in an effort to move forward with the FWSAR procurement, the Government of Canada requested industry's feedback on the high level considerations for FWSAR requirements, which were detailed during a FWSAR Industry Day. Industry was subsequently given the opportunity to submit comments. The submission period concluded on 15 September 2009 and DND, Public Works and Government Services Canada (PWGSC), and Industry Canada (IC) reviewed the industry feedback. Following consultation with the aerospace industry, the Government engaged the National Research Council (NRC) to conduct an independent review of the FWSAR SOR.

The Government received a report from the NRC in March 2010 [4]. NRC recommended revising the FWSAR SOR based on the CAF's current 'level-of-service.' Based on the NRC's findings and recommendations, the Royal Canadian Air Force (RCAF) worked to revise the FWSAR SOR [5]. The Chief of the Air Force Staff (C Air Force) Directorate of Air Requirements (DAR) tasked the Defence Research and Development Canada (DRDC) Centre for Operational Research and Analysis (CORA) Directorate of Air Staff Operational Research (DASOR) to develop a 'level-of-service' model to capture current response performance and provide a means to compare potential replacement fleets. In parallel, Director General Major Project Delivery Air (DGMPD(Air)) tasked the Directorate Materiel Group Operational Research (DMGOR) Acquisition Support Team (AST) to provide support to Project Management Office (PMO) FWSAR in assessing and characterizing the opportunities and risks in potential aircraft/basing solutions [6]. Results of DRDC CORA FWSAR analyses were briefed to Ministers of DND, PWGSC, and IC in November 2010 [7], and to the Associate Minister of National Defence in September 2011 [8]. The Government of Canada Cabinet approved the FWSAR purchase plan in January 2012.[1] Subsequently, PMO FWSAR requested analysis on historical SAR incidents (locations and trends) and the development of a robust bidder evaluation tool to evaluate the response performance of FWSAR solutions. Figure 3 illustrates a subset of the FWSAR replacement project timeline highlighting relevant departmental and government decisions and DRDC CORA decision support analyses (in blue) since receipt of NRC's report.

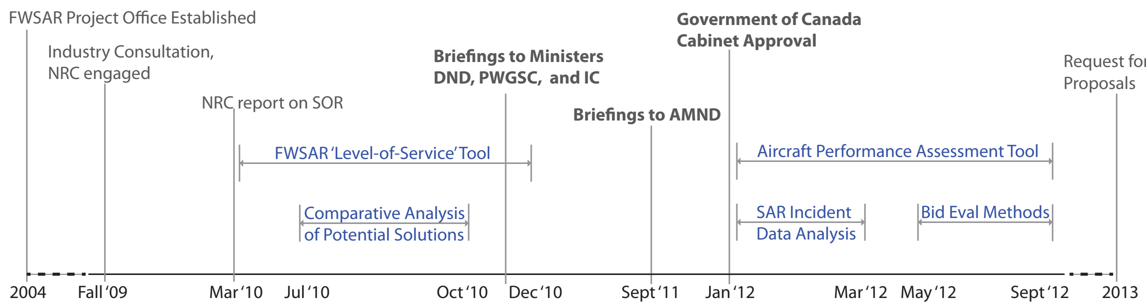


Figure 3: *Subset of FWSAR replacement project timeline with DRDC CORA contributions highlighted in blue.*

1.2 Previous Work

In support of an early SOR drafted by Project Director FWSAR project, Bourdon and Rempel [9] analyzed the fleet requirements for FWSAR replacement aircraft. The study looked at fleet size and structure, and on the cruise speed required to maintain the current level of SAR service. Their analysis first derived the number of aircraft required based on mission ready rates of individual aircraft. Factors including historical SAR incidents, base location, crew standby posture, and coverage of the entire Canadian SRR were considered.

Various other studies of note on SAR have been undertaken within DRDC CORA. Many of the studies can be clustered as follows: studies on asset positioning and base location [10, 11, 12, 13, 14, 15], asset performance/availability [16, 17, 18, 19, 20], training [21, 22], sensors, search patterns and communications [23, 24, 25, 26], and response postures [27, 28, 29]. With the exception of [24], these studies deal with rotary-wing SAR aircraft or more general aspects of search and rescue.

[1] *Cabinet quietly approves search plane purchase plan*, The Canadian Press, January 6, 2012 (`http://www.cbc.ca/news/politics/story/2012/01/06/pol-cp-search-planes-contract.html`).

1.3 Objective

This technical report compiles the research and analyses undertaken between 2010 and 2012 by DASOR and DMGOR AST for the Fixed-Wing Search and Rescue Replacement Project, supporting C Air Force and Assitant Deputy Minister (Materiel) (ADM(Mat)) decision makers. The report presents the individual work elements in the chronological order that they were completed. In some cases, the work elements were concurrent. Each work element was executed in response to a time-constrained client request, and was completed in reference to a particular objective (described in detail in the respective sections of the report).

The FWSAR Aircraft Performance Assessment Tool, or FWSAR APAT, is the culmination of the effort. This tool will be used as an integral part of the evaluation of bids when these are received. The FWSAR APAT has been released to industry as part of the Government's consultation process, in addition to having been independently reviewed and thoroughly tested.

1.4 Scope

This report is limited to capturing the decision support provided to C Air Force and ADM(Mat) in response to specific client requests. The assumptions and limitations of the various work elements are listed in the respective sections of the report. While certain sections of the report have been previously published informally [30, 31], an effort has been made to make the present report self-contained and seamless. Depending on client time constraints and problem requirements, study-specific assumptions were made at the time of the analysis. In certain instances early model shortcomings were addressed in subsequent iterations as models were refined. As a result, in this report, the reader can anticipate the evolution of assumptions/limitations, data sets, and lexicon from section to section.

1.5 Outline

Section 2 details a FWSAR response performance model modelling the CAF's current 'level-of-service.' Section 3 documents the comparative analysis of potential FWSAR solutions. Section 4 presents a performance assessment tool developed to evaluate the FWSAR aircraft/basing solutions proposed by industry. Section 5 details considerations that led to the development of scoring criteria used in the performance assessment tool described in Section 4. Section 6 concludes the paper. A self-contained analysis of the location and trends of historical search and rescue incidents is presented in Annex A.

2 A Response Performance Model

NRC [4] recommended revising the FWSAR SOR based on the CAF's current 'level-of-service.' In March 2010 DAR tasked DASOR to develop a 'level-of-service' model to capture current response performance and provide a means to compare potential replacement fleets. In order to objectively assess the 'level-of-service' of the current CAF FWSAR capabilities (aircraft and basing locations) and to compare it to potential alternative FWSAR solutions (new fleet of aircraft and suggested basing) a 'response performance' model was developed and is detailed herein. The term 'response performance' is used as any model can only partially capture the true 'level-of-service.'

Section 2.1 defines the set of measures and assumptions considered in the model. Section 2.2 provides the relevant specifications of the current CAF FWSAR aircraft and basing. Sections 2.3 and 2.4 define the search and rescue region in detail and historical distribution of incidents used to assess response performance. Section 2.5 details the model, and Section 2.6 discussed the implementation of the tool.

2.1 Performance Measures

There are two fundamental questions that address the level of service provided to the Canadian public by FWSAR aircraft:

Q1. How quickly can search and rescue (SAR) assistance be provided?

Q2. How much SAR service can be provided once the aircraft are on station?

The first question relates directly to the amount of time it takes to reach SAR incidents from the time of notification of potential distress. Given that any potential FWSAR replacement fleet would be subject to the same operating conditions as the current fleet (number of SAR crews, SAR standby posture, etc.) the time it takes to deliver SAR assistance is primarily a function of the proximity of SAR bases to the incident locations, the speed of the FWSAR aircraft, and for distant incidents, the aircraft endurance and locations of suitable en-route refuelling stops.

Assuming that all potential replacement FWSAR aircraft would be capable of carrying a SAR crew, the aircraft directly influences the amount of SAR assistance provided while on station in two ways. First, the amount of time the aircraft is capable of remaining on station to execute searches, establish communications, drop survival equipment and/or SAR technicians is of vital importance. Second, the size of the SAR payload onboard the aircraft affects the SAR crew's ability to airdrop survival equipment in order to effectuate change at the incident sites. Thus, Q2 above is refined as follows:

Q2a. How much time can FWSAR aircraft remain on station?

Q2b. How much SAR payload can be delivered to each incident location?

2.2 Current FWSAR Aircraft and Basing

As described earlier, the CAF currently use two types of primary FWSAR aircraft: the CC-115 Buffalo and the CC-130 Hercules. Table 1 provides a brief summary of the relevant performance specifications for both. Speed is expressed in knots (kts), endurance in hours (hrs) and payload in pounds (lbs).

Table 1: *Summary of current CAF FWSAR aircraft performance specifications.*

	CC-115 Buffalo	CC-130 Hercules
Location	Comox	Winnipeg, Trenton, Greenwood
Cruise Speed (kts)	220	300
Endurance (hrs)	6	5.7 to 11.5
SAR Payload (lbs)	4,000	10,000
Typical fuel load (lbs)	8,000	36,000 (40,000 in Winnipeg)
Max fuel capacity (lbs)	13,807	60,000

The CC-115 Buffalo aircraft are normally parked on the runway with 8,000 lbs of fuel [32]. Aircraft crews may opt to carry additional fuel, a larger SAR payload, or a combination of both depending on the circumstances surrounding a particular SAR incident. Because of restrictions on the total aircraft payload (SAR payload and fuel), crews must often trade off additional fuel for additional SAR payload. For this reason, an endurance of 6 hrs is considered representative of Buffalo performance for the majority of SAR incidents in the area serviced by CC-115 aircraft.

The CC-130 Hercules aircraft at Trenton and at Greenwood normally carry 36,000 lbs of fuel when parked on the runway, while those at Winnipeg carry 40,000 lbs of fuel [33]. This results in an endurance of approximately 5.7 hrs for the former and 6.6 hrs for the latter. For incidents beyond 600 nautical miles (nmi) from any of these SAR bases, it is assumed that the aircraft would depart from the base with a maximum fuel load, resulting in an endurance of approximately 11.5 hrs at cruise speed.

2.3 Canadian Area of Responsibility

Figure 1 depicts the entirety of the Canadian Area of Responsibility (AOR) for which the CAF is required to provide SAR assistance [34]. The point on the extreme eastern edge of the AOR at 51.6°N, 30°W (approximately at the midpoint of this edge of the AOR) is nearly equally distant to the three closest recovery airports at Shannon, Ireland; Keflavik, Iceland; and Lajes, in Portugal's Azores Islands, and represents the most challenging SAR location to reach using current basing from an aircraft endurance perspective. The most extreme point of the western edge of the AOR is at 48°20'N, 145°W. The extreme northern-most point is located at the North Pole and presents the greatest challenge from a crew day perspective in light of current FWSAR basing. For command and control purposes, the Canadian AOR is subdivided into three smaller Search and Rescue Regions (SRRs), each with its own Joint Rescue Coordination Centre (JRCC): the Victoria SRR, Trenton SRR, and Halifax SRR. Given their current basing, the CC-115 is used to respond to incidents within the Victoria SRR, CC-130s out of Winnipeg and Trenton provide coverage of the Trenton SRR, and CC-130 aircraft in Greenwood are responsible for incidents in the Halifax SRR. The number of SRRs and their boundaries are not tied to Government of Canada policy, they are adjustable depending on the infrastructure and resources available to the CAF.

2.4 Historical SAR Data

A historical record of SAR incidents was maintained in the Canadian Coast Guard's System of Information for Search and Rescue (SISAR) database. The most recent information in this database that is both accurate and complete spanned the years 1996-2004, inclusive. Annex A provides a more detailed analysis of historical SAR incidents, including a discussion on available historical data. The complete set of incidents that CAF FWSAR aircraft prosecuted during the 1996-2004 time period was used to benchmark FWSAR performance. Figure 4 depicts the locations (red dots) of the SAR incidents responded to by FWSAR aircraft between 1996 and 2004.[2] There were 3427 incidents. Also depicted are the three extreme points (yellow dots) of the Canadian AOR—there were no incidents at these locations between 1996-2004. Incident details, such as weather conditions or the nature of the incident, were not considered for simplification purposes.

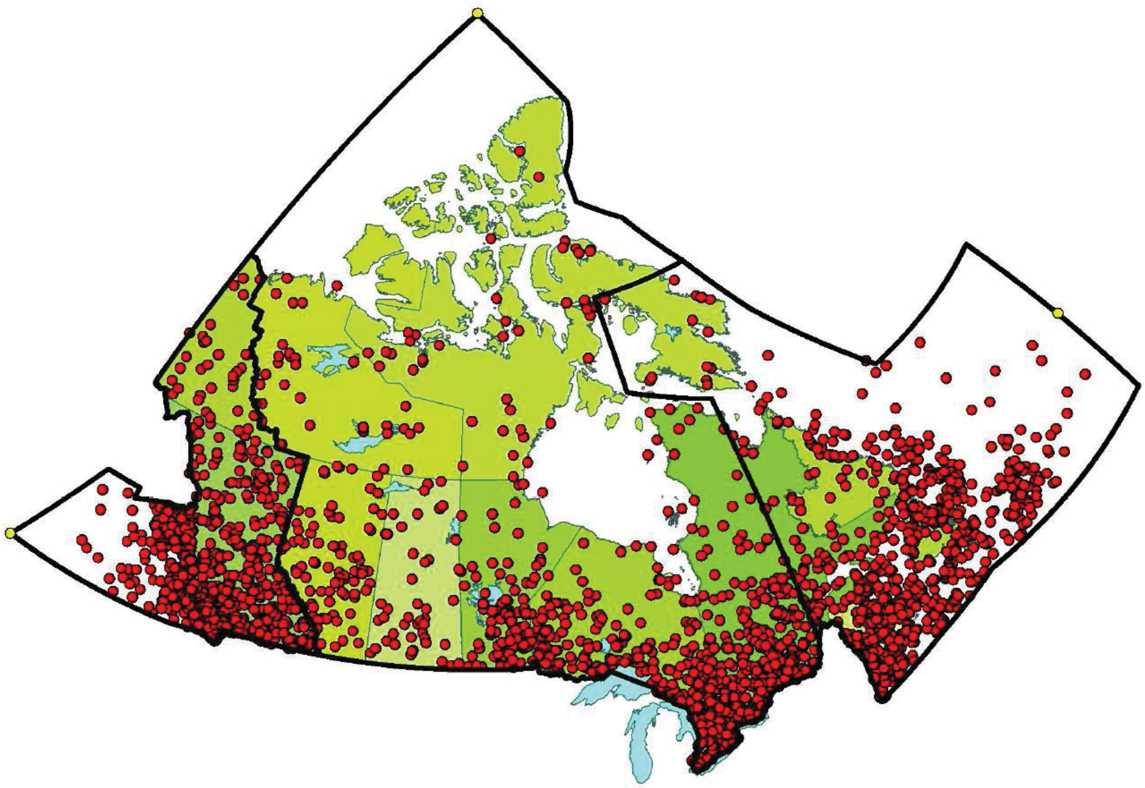


Figure 4: *Locations of historical (1996-2004) SAR incidents responded to by FWSAR aircraft.*

[2] Throughout this report Lambert Conformal Conic and Orthographic projections of spherical coordinates to the plane are applied to present maps of Canada's AOR. The Lambert Conformal Conic projection is a conic map projection often used for aeronautical charts. Local angles are preserved, and local circles are not deformed—at every point east/west scale is the same as north/south scale. A straight line drawn on a Lambert Conformal Conic projection approximates a great-circle route between endpoints as long as distances are not great. The Orthographic projection gives a view of the Earth as seen from space. Both were chosen to minimize distortion of the images presented. See www.radicalcartography.net for further information.

2.5 Model

A FWSAR solution is defined by the location of the main operating bases (MOBs) along with the cruise speed(s) and the endurance(s) at cruise speed of the aircraft stationed at each base. The general approach is to assess any hypothetical FWSAR solution against the set of historical incidents presented in Section 2.4 as well as the three extreme AOR points in order to provide an indication of performance in the most challenging of scenarios (with regard to distance traveled). For each of these incidents, the transit time (TT) and time on station (TOS) are computed for each possible aircraft/MOB combination. The results are compared against the response performance of the current FWSAR fleet, which is used as a baseline.

2.5.1 Capturing Current CAF FWSAR Response Performance

To capture current CAF FWSAR performance as a baseline, CAF FWSAR aircraft are limited to responding to incidents within the SRR in which their MOB lies. For example, the CC-115 Buffalo out of Comox responds to all incidents within the Victoria SRR, even if a CC-130 from Winnipeg may provide better response performance. Restricting assets to respond to incidents within a particular SRR is self-imposed but facilitates coordination. In addition, CAF FWSAR CC-130s based in Winnipeg respond to incidents within 600 nmi of Winnipeg with a partial fuel payload (providing 6.6 hrs of endurance), CC-130s based out of Trenton and Greenwood respond to incidents within 600 nmi of their MOBs similarly (providing 5.7 hrs of endurance). Incidents within the Trenton or Halifax SRR that lie beyond 600 nmi of a MOB are assumed to be responded to with full CC-130 fuel payload (11.5 hrs endurance). A maximum 15-hour SAR crew day limitation is enforced and it is pessimistically assumed that a 2-hour SAR standby posture is in effect at the time the JRCC is notified of the incident (reducing the effective crew day to 13 hours as of aircraft take-off). The constraint of operating exclusively within a particular SRR are relaxed for the extreme points: the current CAF FWSAR response to the western extreme point is assumed to be by a CC-130 from Winnipeg (refuelling at Comox) as the CC-115 Buffalo does not have the endurance to reach the point and recover.

To calculate the TT to each incident, a fixed cruise speed is used even though cruise speed will typically vary during the course of a flight. Great circle distances are calculated using the haversine formula [35]. An algorithm determines the base whose aircraft will arrive on station the soonest. If an aircraft does not have sufficient endurance to reach a SAR incident location with at least two hours of endurance remaining[3] [5], then a refuelling stop is assumed to take place at an ideal location (namely directly en route and just prior to arriving at the incident location). Similarly, if an aircraft does not have enough endurance to reach an incident then refuel stops are assumed to occur just as the aircraft runs out of fuel. This assumption was necessary at the time (due to the complexity of identifying a complete list of suitable airports at which various aircraft would be able to complete a refuelling stop—subsequent model development presented in Section 4 considered refuelling stops explicitly). Each refuelling stop is assumed to last one hour. For the calculation of TT to the three SRR extreme points, a minimum two-hour time on station constraint is not enforced since recovery time and fuel are explicitly considered, however any required or predefined refuelling stops are assumed to last one hour.

[3] A minimum of two hours of on station time was assumed to be necessary in order to ensure that a quick search of the area can be initiated and that there is sufficient fuel onboard to meet instrument flight rules (IFR) reserves [2]. This has since been revised to the one hour used in Section 4.

Once the aircraft arrives on station, endurance is computed assuming that any low-level flight activity will consume fuel at a rate similar to the aircraft's fuel consumption rate at cruise speed. Owing once again to the complexity of identifying airports suitable for each type of potential aircraft, aircraft recovery is not always explicitly accounted for. Rather, the endurance to "dry tanks" is used as a surrogate for the historical SAR incidents. While this does not accurately identify how much time on station the aircraft actually has, it is strongly indicative of an aircraft's ability to remain airborne on station for an extended time. For the extreme points of the SRR, the time to recover at Shannon (for the east), Sandspit (for the west), or Alert (for the north) is included.[4] However, the tool does not ensure that sufficient fuel reserves are available to land at a suitable alternate airport.

2.5.2 Assessing a Proposed FWSAR Solution's Response Performance

The assessment of a proposed FWSAR solution is determined by first computing the TT and TOS to each of the historical incidents and three extreme points and then by comparing these to the baseline CAF FWSAR response times. The calculations of a proposed FWSAR solution TT and TOS are similar to that of computing the baseline CAF FWSAR response performance, except that SRR boundaries and fuel payload constraints are relaxed.[5] For example, aircraft based in Comox (Victoria SRR) can respond to an incident in the Trenton SRR. If aircraft are based in Greenwood, then incidents within 600 nmi of Greenwood are responded to with maximum fuel payload.

To exemplify the calculation of TT and TOS, consider the scenario presented in Figure 5. The scenario consists of two bases in Winnipeg and Greenwood. Aircraft of type A1, capable cruising at 320 kts with an endurance of 8 hours, are based in Winnipeg. Aircraft of type A2, capable cruising at 280 kts with an endurance of 10 hours, are based in Greenwood.

- **SAR incident 1** is situated at the northern extreme of the SRR, the North Pole (90°N, 0°W). For the scenario, Resolute Bay is specified as the refuelling stop for the northern extreme of the SRR and Alert is the recovery base. Aircraft A1 would depart Winnipeg, arrive in Resolute Bay in 4 hours and 40 minutes, refuel (for an hour), and arrive at the incident a total of 8 hours after departure. Aircraft A1 could stay 3 hours on station until it would have to recover at Alert to respect the 13 hour effective crew day limitation. Aircraft A2 would depart Greenwood and take 7 hours to arrive in Resolute Bay, stop for an hour to refuel, then proceed to fly over 3 hours to arrive at the incident a total of 11 hours after departure. To respect the 13 hour effective crew day limitation and to ensure recovery time to Alert, aircraft A2 could only stay on station for 10 minutes prior to flying to Alert, which is less than the minimum acceptable time outlined in the SOR.

- **SAR incident 2** is located in northern British Columbia at coordinates 56°N, 120.74°W. An A1 aircraft from Winnipeg would reach the incident in 3 hours and remain on station for 5 hours until fuel was exhausted as the model does not allocate any reserve for return to a recovery base. An A2 aircraft from Greenwood would take 7.7 hours to reach the incident and could remain on station for 2.3 hours, exhausting its 10 hours of endurance.

[4] Subsequent model development presented in Section 4 considered primary and secondary recovery locations explicitly.

[5] Recall that the current practice of restricting assets to respond to incidents within a particular SRR is self-imposed and based on current infrastructure and aircraft fleets.

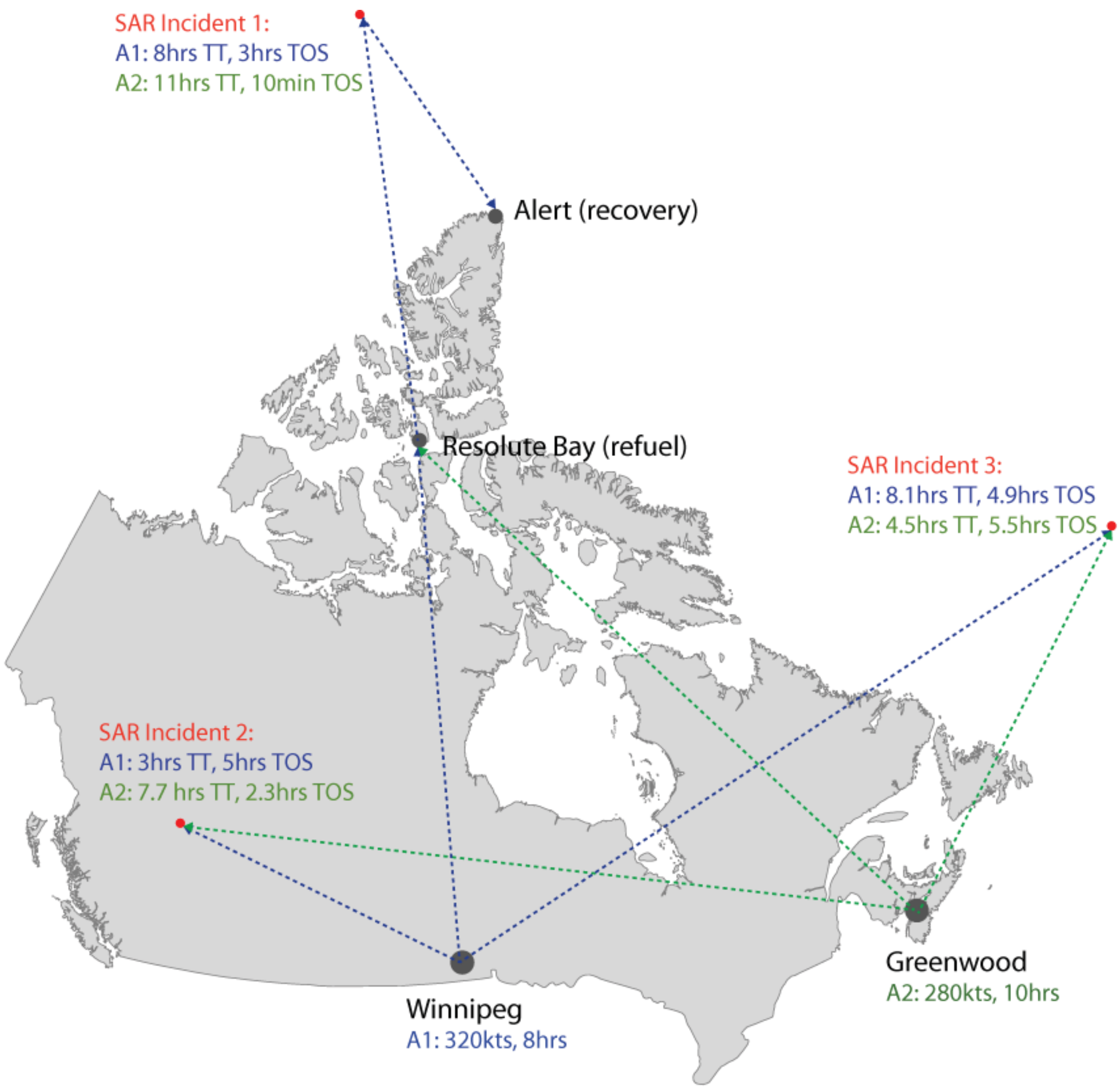


Figure 5: *Response performance model calculation examples.*

- **SAR incident 3** is located in the North Atlantic Ocean at coordinates 52.04°N, 34.88°W. An A1 aircraft from Winnipeg could reach the incident in 7.1 hours with enough reserve to remain on station for an additional hour. However, since the on station time is below the desired 2 hour threshold, the A1 aircraft is forced to refuel just prior to arriving to the incident. This results in a total transit time of 8.1 hours. Although there is enough fuel to stay on station for 8 hours, the 13 hour effective crew day limits the on station time to 4.9 hours. An A2 aircraft from Greenwood would reach the incident in 4.5 hours and remain on station for 5.5 hours until fuel was exhausted.

The model computes the average transit time and average time on station to the historical SAR incidents and breaks down the results by SRR (Halifax SRR, Trenton SRR, and Victoria SRR), and aggregates to overall averages. The cumulative transit time and time on station are also computed by SRR and overall. For the three extreme points, the model returns the individual transit and time on station times. The outputs allow for a high-level comparison of response performance of proposed FWSAR solutions to the current CAF capabilities.

2.5.3 Limitations

The response performance model does not provide a definitive assessment about a proposed FWSAR solution's ability to meet or exceed the current level of service. The goal of the model is to provide a good indication of a FWSAR solution's ability to do so. When the differences between the proposed FWSAR solution's performance statistics and the current CAF FWSAR level of service are large, the model correctly assesses the proposed FWSAR solution's performance as being above or below the standard set by the current FWSAR fleet. However, when these differences become small, a precise answer will necessitate a more in-depth investigation of the FWSAR solution's performance against the current level-of-service.[6] The assumptions listed below define the scope and limitations of the model.

- The payload of the aircraft is not explicitly accounted for in the response performance model. There is no way to aggregate the payload carried to each of the incidents in a meaningful way while ensuring that the current level of service is maintained. For example, a combination of aircraft that carries a 5,000 lb SAR payload to 80% of the incidents in the Victoria SRR and no payload to the remaining 20% of the incidents would provide an aggregate level of service equal to the 4,000 lb SAR payload of the CC-115 Buffalo. Clearly, this situation is unacceptable. Therefore, payload is treated separately as a simple pass/fail criterion. If the aircraft can carry the current SAR payload to the incident location, then it remains eligible.
- Apart from location, specifics of historical SAR incidents are not considered.
- Weather, time of day, or time of year are not accounted for.
- Concurrency of SAR incidents is not considered. It is assumed that aircraft from all bases are available when called on.
- The SAR stand-by posture is assumed to be 2 hours.
- The maximum SAR crew day is assumed to be 15 hours.
- It is assumed that refuelling occurs at ideal locations as required (including over water).
- It is assumed that aircraft can coast to a recovery base as required (including over water).

A number of the limitations in BEST for FWSAR will be revisited and addressed in Section 4 which details the FWSAR APAT model designed for bidder evaluation.

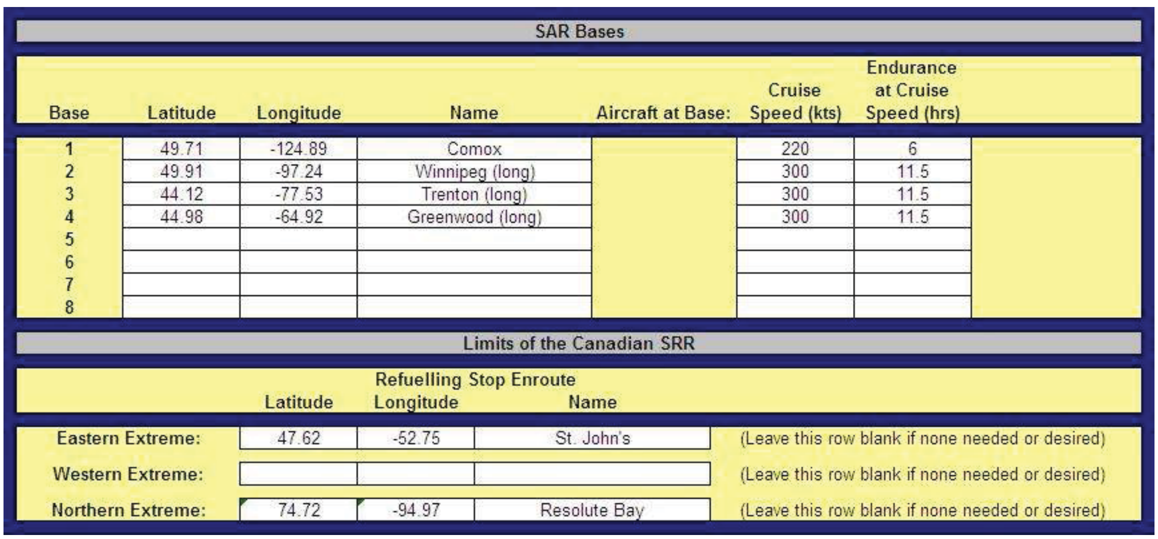
[6] Subsequent efforts, documented in Section 4, lead to a more refined model.

2.6 Implementation: Basing, Endurance, and Speed Tool

The response performance model was implemented in software named "Basing, Endurance, and Speed Tool (BEST) for FWSAR" [30]. The model was built in Microsoft Excel, using Visual Basic for Applications, to help assess whether or not a hypothetical fleet of FWSAR aircraft would be in position to meet or exceed the current level of service. The following outlines the use of the tool.

2.6.1 Input Data

The first two sheets of the workbook contain instructions on how to input the data necessary to run the tool and a glossary of terms. On the "Bases" sheet (Figure 6), users provide the latitude and longitude of any proposed FWSAR MOBs, along with the cruise speed and the endurance at cruise speed of the aircraft stationed there. Multiple aircraft can be located at the same MOB simply by adding coincident bases with different aircraft performance data. The tool allows the user to specify using the "Incidents" sheet (Figure 7) which base (and aircraft) will be dispatched to each incident location, which is particularly useful in a multi-fleet context. For the extreme points ("Bases" sheet - Figure 6), a preferred refuelling stop can be input by the user, if desired.



SAR Bases

Base	Latitude	Longitude	Name	Aircraft at Base:	Cruise Speed (kts)	Endurance at Cruise Speed (hrs)
1	49.71	-124.89	Comox		220	6
2	49.91	-97.24	Winnipeg (long)		300	11.5
3	44.12	-77.53	Trenton (long)		300	11.5
4	44.98	-64.92	Greenwood (long)		300	11.5
5						
6						
7						
8						

Limits of the Canadian SRR

	Latitude	Refuelling Stop Enroute Longitude	Name	
Eastern Extreme:	47.62	-52.75	St. John's	(Leave this row blank if none needed or desired)
Western Extreme:				(Leave this row blank if none needed or desired)
Northern Extreme:	74.72	-94.97	Resolute Bay	(Leave this row blank if none needed or desired)

Figure 6: *BEST for FWSAR 'Bases' sheet.*

The "Current Bases" sheet (Figure 8) provides details of the current CAF FWSAR MOBs and aircraft.

2.6.2 Assessment

Once the "Calculate!" button has been pressed, the tool finds the base whose aircraft will arrive on station (incident location) the soonest for each incident. The remaining endurance is then computed and is reported as the potential time on station for each SRR. The average and cumulative transit times and potential time on station for each SRR are presented in the "Results" sheet (Figure 9). The

Latitude	Longitude	Base	Fly-Out Time Improvement (hrs)	Time on Scene Improvement (hrs)	Best Base
50.17	-114.82		0:00:00	0:00:00	1
50.61	-127.23		0:00:00	0:00:00	1
48.79	-123.04		0:00:00	0:00:00	1
52.83	-129.16		0:00:00	0:00:00	1
52.43	-134.66		0:00:00	0:00:00	1
54.22	-130.42		0:00:00	0:00:00	1
49.88	-119.48		0:00:00	0:00:00	1
50.00	-125.00		0:00:00	0:00:00	1
52.23	-131.51		0:00:00	0:00:00	1
54.13	-131.37		0:00:00	0:00:00	1
53.35	-129.18		0:00:00	0:00:00	1
53.88	-122.68		0:00:00	0:00:00	1
49.53	-123.33		0:00:00	0:00:00	1
49.26	-124.93		0:00:00	0:00:00	1
49.88	-124.00		0:00:00	0:00:00	1
54.17	-132.50		0:00:00	0:00:00	1
49.40	-122.93		0:00:00	0:00:00	1
49.86	-125.01		0:00:00	0:00:00	1
49.92	-126.92		0:00:00	0:00:00	1
62.33	-132.00		0:00:00	0:00:00	1
50.76	-127.43		0:00:00	0:00:00	1
50.50	-126.55		0:00:00	0:00:00	1
50.05	-125.23		0:00:00	0:00:00	1
50.45	-126.00		0:00:00	0:00:00	1
49.42	-123.65		0:00:00	0:00:00	1
49.45	-123.80		0:00:00	0:00:00	1
48.83	-125.42		0:00:00	0:00:00	1
49.43	-124.20		0:00:00	0:00:00	1
51.09	-122.60		0:00:00	0:00:00	1

Figure 7: *Partial snapshot of BEST for FWSAR 'Incidents' sheet.*

SAR Bases

Base	Latitude	Longitude	Name	Aircraft at Base:	Cruise Speed (kts)	Endurance at Cruise Speed (hrs)	
1	49.71	-124.89	Comox		220	6	
2	49.91	-97.24	Winnipeg		300	11.5	(reduces to 6.6 for incidents within 600 nm)
3	44.12	-77.53	Trenton		300	11.5	(reduces to 5.7 for incidents within 600 nm)
4	44.98	-64.92	Greenwood		300	11.5	(reduces to 5.7 for incidents within 600 nm)
5							
6							
7							
8							

Limits of the Canadian SRR

	Refuelling Stop Enroute Latitude	Longitude	Name	
Eastern Extreme:	47.62	-52.75	St. John's	(Leave this row blank if none needed or desired)
Western Extreme:				(Leave this row blank if none needed or desired)
Northern Extreme:	74.72	-94.97	Resolute Bay	(Leave this row blank if none needed or desired)

Figure 8: *BEST for FWSAR 'Current Bases' sheet.*

performance against the three extreme points of the AOR is also assessed. The "Results" sheet also shows the current response performance that FWSAR aircraft provide for comparative purposes.

SAR Cases		Average		Cumulative	
		Fly-Out Time	Potential Time on Scene	Fly-Out Time	Potential Time on Scene
Victoria SRR	Current:	0:51:58	5:11:23	1104:09:51	6616:57:21
	Proposed:	0:51:58	5:11:23	1104:09:51	6616:57:21
Trenton SRR	Current:	1:00:15	5:29:54	1234:16:00	6757:20:00
	Proposed:	1:00:15	10:17:40	1234:16:00	12651:44:00
Halifax SRR	Current:	1:19:36	5:57:02	1224:32:58	5492:21:02
	Proposed:	1:19:36	10:10:24	1224:32:58	9389:57:02
Overall	Current:	1:02:23	5:30:19	3562:58:49	18866:38:23
	Proposed:	1:02:23	8:21:45	3562:58:49	28658:38:23

Extreme Limits of SRR		Fly-Out Time	Potential Time on Scene
Eastern Edge of SRR	Current:	5:47:59	4:37:00
	Proposed:	5:47:59	4:37:00
Western Tip of SRR	Current:	6:09:07	3:25:00
	Proposed:	6:09:07	3:25:00
Northern Tip of SRR	Current:	9:01:17	2:28:55
	Proposed:	9:01:17	2:28:55

Calculate!

Figure 9: *BEST for FWSAR 'Results' sheet.*

The BEST for FWSAR model described herein is a small, simple application that will predict a hypothetical fleet's ability to maintain or improve upon the current level of service. In cases where the assessed performance is very close to the current level of service, a more sophisticated analysis should be undertaken if a precise answer is desired. BEST for FWSAR was reviewed by the NRC [36]. Their key recommendation stated that the "tool has considerable utility for comparison of capabilities expressed in terms of speed, endurance and basing with reference to historical incident locations" [36].

3 Comparative Analysis of FWSAR Solutions

Concurrent to the development of BEST for FWSAR, in July 2010 PMO FWSAR requested support from DMGOR AST in assessing and characterizing the opportunities and risks in potential aircraft/basing solutions. A graphical comparative analysis tool was developed based on the outputs of BEST for FWSAR. The goal was to synthesize the response performance statistics in a concise fashion allowing senior DND leadership and other government stakeholders to begin to understand the opportunities and risks of possible FWSAR solutions (aircraft speed, endurance, basing). The graphical comparative analysis tool also partially addressed the final NRC report [36] recommendation that "graphical outputs [be used to] improve the tool's utility and usability."

3.1 Implementation

BEST for FWSAR was modified to output the transit time, and on station time for each historical SAR incident given a proposed FWSAR solution. Similarly, the transit time and on station time for each historical SAR incident for the current CAF FWSAR basing and aircraft was outputted. Hence, for each incident $i = 1, \ldots, 3427$ of the historical data presented in Section 2.4, BEST for FWSAR was modified to output:

- F_i^c transit time to incident i for the current CAF FWSAR solution
- F_i^p transit time to incident i for the proposed FWSAR solution
- O_i^c on station time at incident i for the current CAF FWSAR solution
- O_i^p on station time at incident i for the proposed CAF FWSAR solution

For each incident, the transit time percent change, ΔF_i, (between the current and proposed solutions) is computed, simply $\Delta F_i = 100 \times \left(F_i^p - F_i^c\right)/F_i^c$. For each incident, the proposed FWSAR solution transit time is qualitatively better, the same, or worse than the current CAF FWSAR solution. Similarly, the on station time percent change, ΔO_i is computed as $\Delta O_i = 100 \times \left(O_i^p - O_i^c\right)/O_i^c$. For each incident, the proposed FWSAR solution on station time is qualitatively better, the same, or worse than the current CAF FWSAR solution. Combining the two metrics, there are nine qualitative possible response performance outcomes as per the first two columns of Table 2. Incidents out-of-range for a particular proposed solution are considered separate from the 'worse' category, and are labelled 'no service.'

The difficulty with synthesizing the comparison of a proposed FWSAR solution to the current CAF solution in a concise graphical manner is depicting the response performance outcomes for each incident on a map of the Canadian SRR. To maintain an information granularity that depicts the ten possible outcomes requires a corresponding combination of symbols and/or colours. Initial attempts to maintain the maximum qualitative granularity yielded graphs requiring expert interpretation—Deputy Ministers of Industry Canada, and Public Works and Government Services Canada expressed preference to simplify [37]. To comply, the potential response performance outcomes were aggregated into four categories: 'BETTER' indicating that performance was at worst maintained but improved for at least one metric, 'SAME' indicating that performance was maintained for both metrics (no improvement or degradation), 'TRADE-OFF' indicating that one metric improved while the other degraded, 'WORSE' indicating that the performance was at best maintained but degraded for at least one metric. 'NO SERVICE' was handled separately. Based on a tolerance defined by the PMO FWSAR staff, the 'SAME' category was quantified as being within 10% of current, i.e., $-10\% \leq \Delta F_i \leq 10\%$ and $-10\% \leq \Delta O_i \leq 10\%$.

The third column of Table 2 lists the aggregate performance outcome as well as the colour or shade chosen to depict it graphically. Aggregating the potential performance outcomes results in information loss, in particular the grouping suggests that TT and TOS are of equal importance.

Table 2: *Possible response performance outcomes for transit and on station time metrics.*

Transit Time	Time on Station	Aggregate & Colour/Shade
Better	Better	BETTER
Better	Same	BETTER
Better	Worse	TRADE-OFF
Same	Better	BETTER
Same	Same	SAME
Same	Worse	WORSE
Worse	Better	TRADE-OFF
Worse	Same	WORSE
Worse	Worse	WORSE
No Service	No Service	**NO SERVICE**

It is stressed that BEST for FWSAR and solution-specific comparative graphical analysis provide the means to compare response performance of a proposed FWSAR solution to the response performance of the current CAF FWSAR solution (with SRR constraints). Comparison of different FWSAR solutions is indirect—the analysis is always relative to the current CAF FWSAR solution. Setting the baseline, Figure 10 depicts the output of the graphical comparative analysis when inputting current CAF FWSAR solution (with SRR constraints)—as expected there is no change so all incidents are coloured green.

Using the performance outcome aggregation and respective colour coding, potential FWSAR solution scenarios were generated and presented to senior decision makers [7, 8]. Section 3.2 provides comparative graphical analysis of several examples along with accompanying explanations.

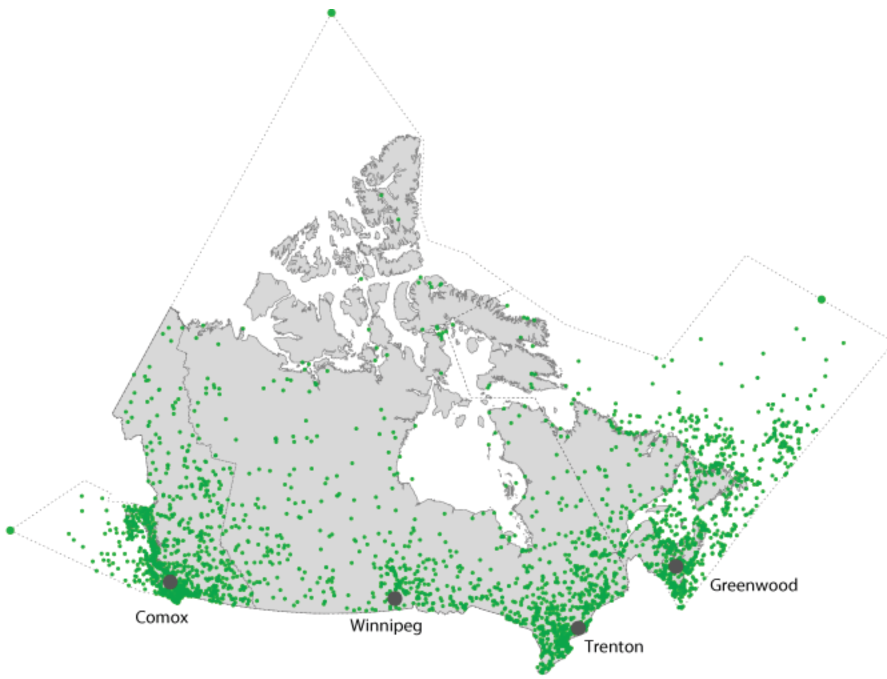


Figure 10: *Graphical depiction of current CAF FWSAR response performance.*

3.2 Hypothetical FWSAR Solution Scenarios

Table 3 lists five hypothetical FWSAR solution proposals (which are subsequently graphically illustrated and the comparative analysis explained). The proposals are fictional and not meant to represent any particular real aircraft. Rather, the proposed solutions were chosen to highlight the modelling assumptions of BEST for FWSAR. Proposals A-D are homogeneous (single aircraft) fleets and proposal E is a mixed-fleet solution. Proposal A maintains the existing MOBs, proposal B adds additional basing in Yellowknife and Gander, and proposals C-E are reduced-basing solutions. All proposals except B are shown to be able to provide service to the entire Canadian SRR.

Proposal A

FWSAR proposal A provides an aircraft with 320 kts cruising speed and 10 hrs endurance based out of the existing four MOBs. Figure 11 compares the response performance of the BEST for FWSAR solution to that of the current CAF FWSAR solution. The reader is referred to Table 2 for a legend. Roughly 90% of the incidents show improvement, 9% show degradation, and 1% indicate a trade-off. Incidents within 600 nmi of Winnipeg, Trenton, and Greenwood are coloured blue since BEST assumes that current CAF aircraft would respond to these incidents with a reduced fuel payload—the proposed aircraft are faster than the CC-130 Hercules and are given the benefit-of-doubt full fuel payload at take-off. The incident at the most northwest corner of the Halifax SRR is coloured blue since BEST compares the response performance of a CC-130 from Greenwood to the proposed aircraft from Trenton (recall that BEST for FWSAR relaxes SRR sub-divisions constraints). It is also interesting to note the scatter of yellow-coloured incidents occuring in a north-south line nearly equidistance

Table 3: *Example FWSAR solutions.*

	Cruise Speed	Endurance	Basing
Proposal A	320 kts	10 hrs	Comox, Winnipeg, Trenton, Greenwood
Proposal B	235 kts	7 hrs	Comox, Winnipeg, Trenton, Greenwood, Yellowknife, Gander
Proposal C	315 kts	8 hrs	Comox, Winnipeg, Greenwood
Proposal D	315 kts	13 hrs	Trenton
Proposal E	315 kts 235 kts	13 hrs 7 hrs	Greenwood Comox

(longitudinally) from Comox and Winnipeg. Again, this is a result of the proposed solution benefitting from relaxing SRR subdivision constraints. The proposed aircraft departing from Comox arrives more than 10% sooner than the CC-130 out of Winnipeg, but its reduced endurance results in at least 10% less on station time. This is a trade-off in service (yellow-coloured).

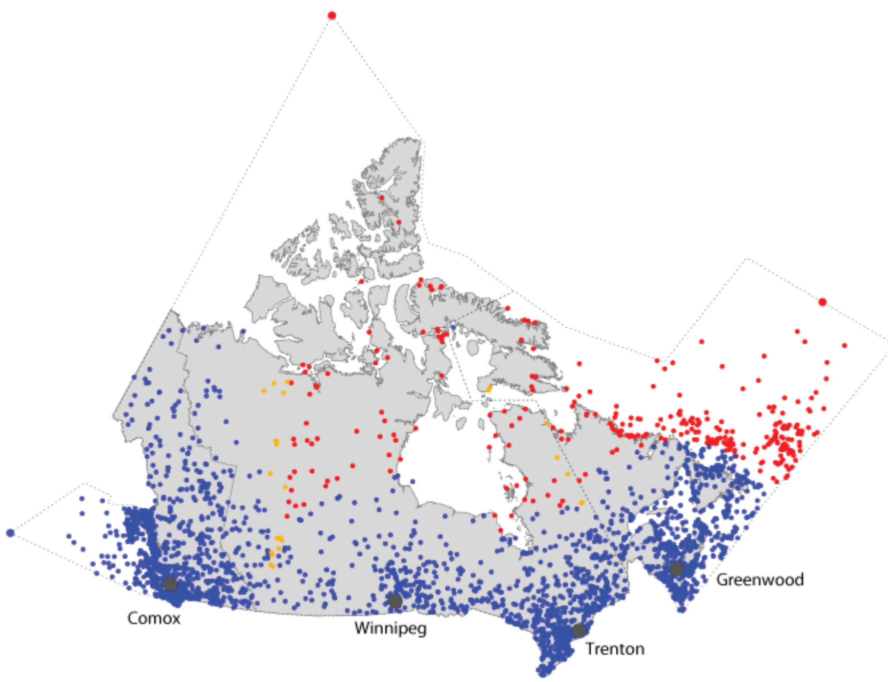


Figure 11: *Comparative response performance of FWSAR proposal A.*

Proposal B

FWSAR proposal B provides an aircraft with 235 kts cruising speed and 7 hrs endurance based out of six MOBs: the existing four MOBs of Comox, Winnipeg, Trenton, Greenwood, as well as additional basing in Yellowknife and Gander. Figure 12 depicts the response performance comparison to the current CAF FWSAR solution as per BEST for FWSAR. While roughly 43% of the incidents show improvement, 12% show degradation, and 45% indicate a trade-off, the proposed solution is not able to provide service to the eastern-most extreme edge of the Canadian SRR (illustrated by a black dot). As expected, incidents around Gander are coloured blue as the response time is faster and the on station time is calculated based on 7 hours of endurance (compared to a CC-130 departing Greenwood with only a partial fuel load as Gander is within 600 nmi of Greenwood). Incidents around Yellowknife are coloured yellow—while the response time is quicker, the 7 hours of endurance is worse in comparison to a CC-130 leaving Winnipeg with 11.5 hours of endurance (since the area is more than 600 nmi outside of Winnipeg). The collection of blue-coloured incidents between Yellowknife and Winnipeg highlight the limit of the 600 nmi radius—these points are less than 600 nmi from Winnipeg, hence the 7 hours of endurance from Yellowknife is deemed to be superior to the endurance of a CC-130 with reduced fuel payload from Winnipeg. A similar explanation applies to the sliver of blue-coloured incidents along the Trenton SRR and Halifax SRR boundary. The analysis of proposal B highlights

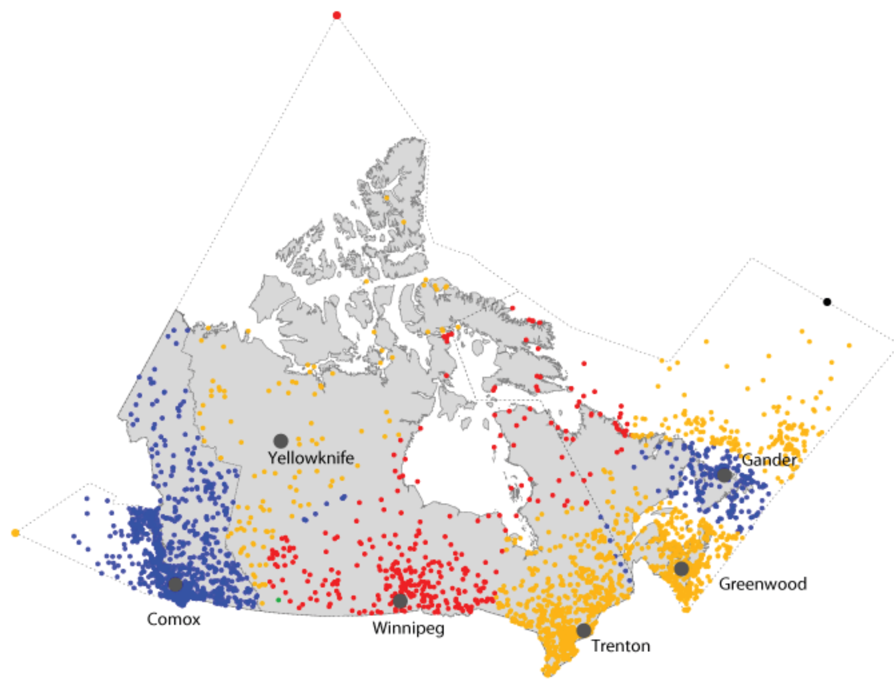


Figure 12: *Comparative response performance of FWSAR proposal B.*

another assumption of BEST: time on station for historical incidents is calculated to dry tanks and assumes that the aircraft can recover to an ideally located runway. This is assumed for incidents over water as well. As a result, all the historical incidents off the coast of British Columbia are coloured blue as the proposed aircraft provides better response than the CC-115 from Comox. However, the extreme western point of the Canadian SRR is coloured yellow as the proposed aircraft from Comox would achieve a faster transit time but reduced on station time compared to a fully fuelled CC-130 from Winnipeg.

Proposal C

FWSAR proposal C provides an aircraft with 315 kts cruising speed and 8 hrs endurance based out of Comox, Winnipeg, and Greenwood. Figure 13 depicts the response performance comparison to the current CAF FWSAR solution as per BEST for FWSAR. Roughly 68% of the incidents show

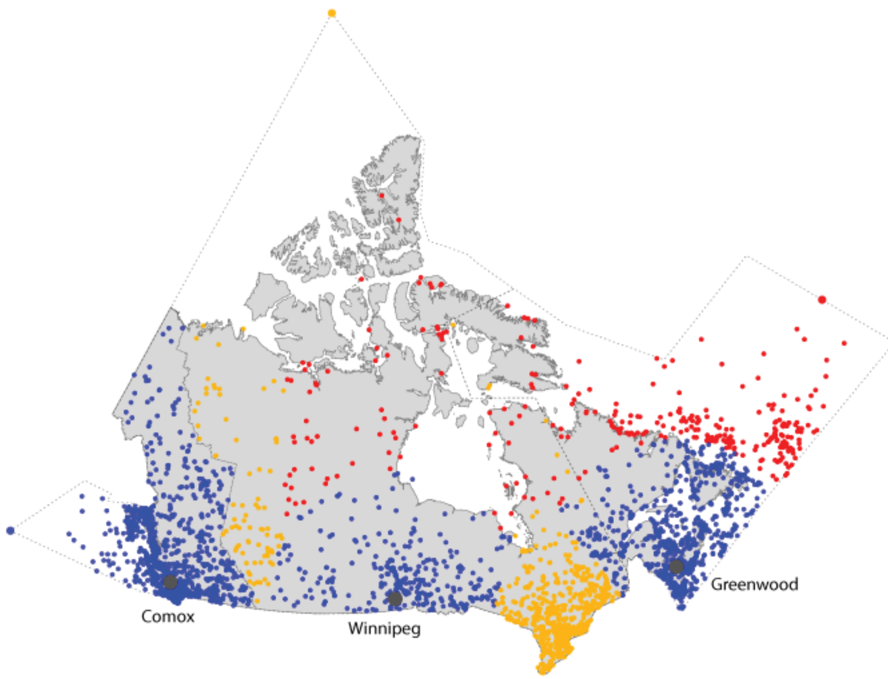


Figure 13: *Comparative response performance of FWSAR proposal C.*

improvement, 9% show degradation, and 21% indicate a trade-off. The proposed solution is able to provide degraded service to the eastern extreme of the Canadian SRR, trade-off performance with respect to service to the northern extreme (faster transit, shorter on station time), and improve on performance to the western extreme. Some historical incidents at the most northwest corner of the Halifax SRR are coloured yellow since BEST compares the response performance of a CC-130 from Greenwood to the proposed aircraft from Trenton (SRR sub-division constraints are relaxed for proposals). The reason for the yellow-coloured historical incidents along the Canadian Rockies is that the proposed aircraft departing from Comox is compared to a CC-130 responding from Winnipeg: the proposed aircraft will arrive more than 10% faster than the CC-130 from Winnipeg, but will have at least 10% less on station time. The historical incidents within 600 nmi of the former base of Trenton are coloured yellow as the response time to these incidents will be worse than the current setup. However, the time on station for the proposal is deemed to be an improvement (by at least 10%) since the baseline solution limits the endurance of the CC-130 to 5.7 hours for response to incidents within

600 nmi of Trenton. There is also an interesting mix of yellow-, red-, and blue-coloured historical incidents in mid-western Quebec. These are a result of the intersection of boundaries (Halifax-Trenton SRR, MOB 600 nmi reduced fuel payload radius).

Proposal D

FWSAR proposal D provides an aircraft with 315 kts cruising speed and 13 hrs endurance based only out of Trenton. Figure 14 depicts the response performance comparison to the current CAF FWSAR solution as per BEST for FWSAR. Roughly 24% of the incidents show improvement, 10% show degradation, and 66% indicate a trade-off. The proposed solution is able to provide degraded service to the extremes of the Canadian SRR. As expected, incidents around Trenton are coloured blue as the response time is faster and the on station time is calculated based on 13 hours of endurance (compared to a CC-130 departing Trenton with only a partial fuel load). Incidents around former MOBs of Comox, Winnipeg, and Greenwood are coloured yellow since the transit time is slower but the on station time is longer (compared to existing CAF aircraft restricted to reduced fuel payloads within 600 nmi of the MOB). The plethora of red-coloured incidents in the Northwest Territories and northern Alberta/Saskatchewan/Manitoba show that the proposed FWSAR solution cannot make up for reduced basing in comparison to the existing CC-130s based in Winnipeg. The historical incidents are coloured yellow in the Victoria SRR as the proposed aircraft is now being compared to the current CC-115 responding out of Comox. While the transit time is worse, the 13 hour endurance of the proposed aircraft improves the on station time despite the longer travel time to an incident.

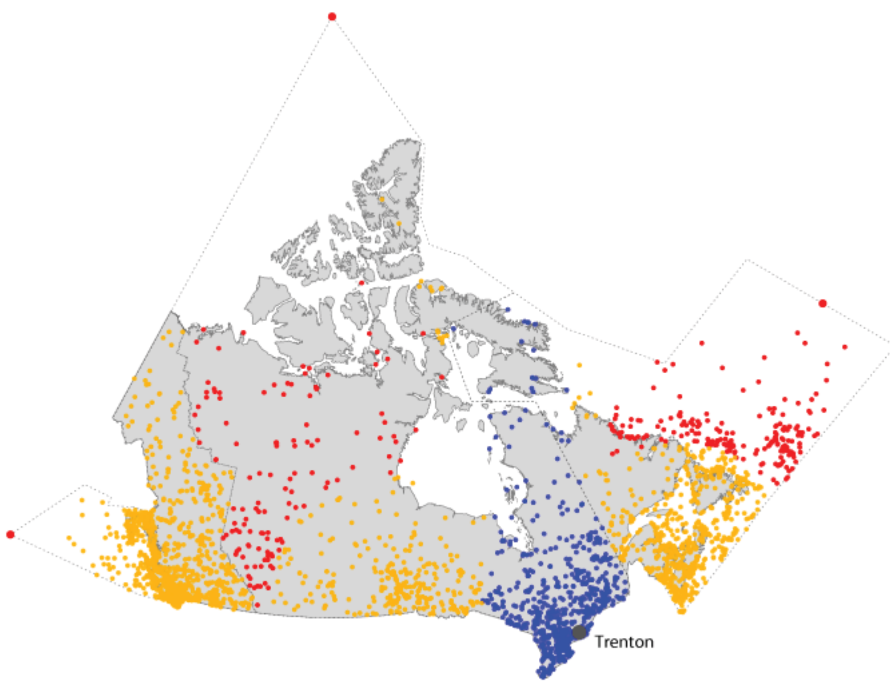


Figure 14: *Comparative response performance of FWSAR proposal D.*

Proposal E

FWSAR proposal E is a mixed-fleet, reduced basing proposal consisting of aircraft with 315 kts cruising speed and 13 hrs endurance based out of Greenwood, and aircraft with 235 kts and 7 hrs endurance based out of Comox. Figure 15 depicts the response performance comparison to the current CAF FWSAR solution as per BEST for FWSAR. Roughly 65% of the incidents show improvement, 5%

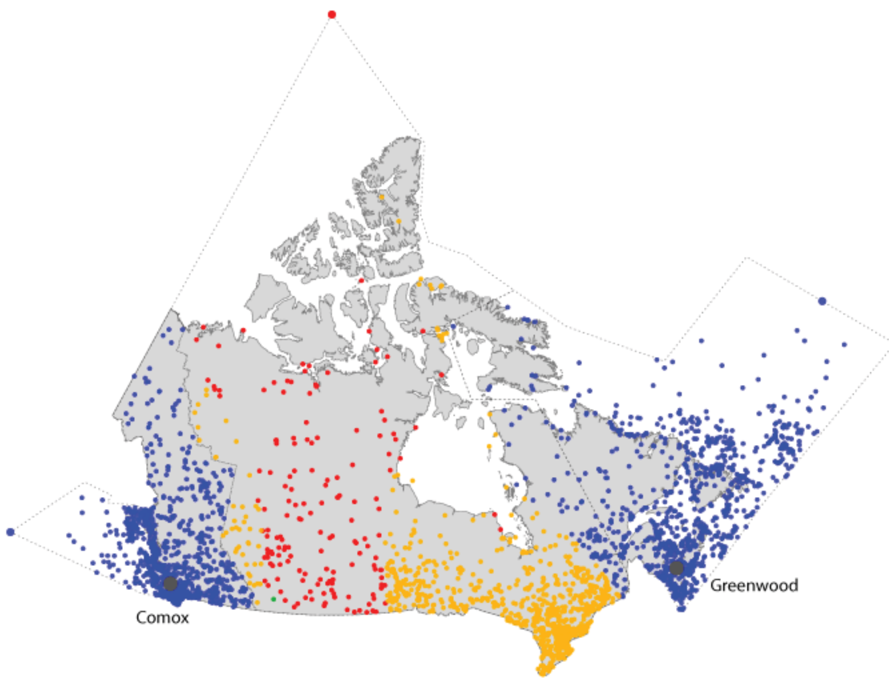


Figure 15: *Comparative response performance of FWSAR proposal E.*

show degradation, and 29% indicate a trade-off. In this case, most of the yellow-coloured incidents occur around the current bases of Winnipeg and Trenton and the trade-off is a result of the modelling assumption of the current CAF FWSAR solution where the CC-130 Hercules depart Winnipeg or Trenton with a reduced fuel payload for incidents within 600 nmi, whereas in the proposed solution the aircraft from Greenwood would take longer to reach an incident near Trenton, but would depart with a full fuel payload and have longer endurance. It is interesting to note the green-coloured incident between Comox and Winnipeg. The incident is closer to Comox than to Winnipeg: the aircraft from Comox respond quickest. The baseline response is from Winnipeg with a CC-130 Hercules (since in the baseline Comox aircraft are constrained to the Victoria SRR). The incident is just barely within 600 nmi of Winnipeg (the CC-130 is assumed to depart with 5.7 hrs of fuel). So the comparison is between the proposed aircraft from Comox (235 kts, 7 hrs) and a CC-130 from Winnipeg (300 kts, 5.7 hrs). The proposed aircraft from Comox is slow but still manages to get to the incident within the 10% margin in comparison to the CC-130 (which covers a greater distance quickly from Winnipeg). The time on station is also comparable (within 10%).[7] The reason for the yellow-coloured (tradeoff) incidents to the left is that these are outside the 600 nmi range from Winnipeg so the CC-130 departs with 11.5 hrs endurance but the proposed aircraft from Comox still has a faster response. The reason for the red-coloured incidents to the left is that now it takes more than 10% longer to get to the incident with the proposed aircraft from Comox.

Table 4 shows the relative performance of the five example proposals presented. The table entries list the percentage incidents that scored 'BETTER', 'SAME', 'TRADE-OFF', and 'WORSE'.

Table 4: *Comparison of example FWSAR solution performance.*

	Historical Incidents				SRR Extremes		
	Better	Same	Trade-off	Worse	Western	Northern	Eastern
Proposal A	90%	0%	1%	9%	Better	Worse	Worse
Proposal B	43%	0%	45%	12%	Trade-off	Worse	**No Service**
Proposal C	69%	0%	22%	9%	Better	Trade-off	Worse
Proposal D	24%	0%	66%	10%	Worse	Worse	Worse
Proposal E	65%	0%	29%	5%	Better	Worse	Better

[7] The green-coloured incident occurs at $50^\circ N, 112.5^\circ W$. The proposed aircraft from Comox responds in 126 min. The current CC-130 Hercules would respond from Winnipeg in 115 min. Time on station is 294 min (proposed aircraft) vs. 281 min (CC-130).

4 An Improved Response Performance Tool: The FWSAR Aircraft Performance Assessment Tool (APAT)

BEST for FWSAR was a successful tool in that it helped the FWSAR Project regain traction with the FWSAR Secretariat (represented by DND, PWGSC, and IC). Using the outputs of BEST, it was possible for members of the Secretariat to understand how potential FWSAR fleets compare relative to the capability delivered by the CAF's Hercules and Buffalo aircraft. PMO FWSAR saw the potential to advance this idea further and use a similar approach to evaluate potential bids in a capability-based assessment framework. However, as with NRC [36], PMO FWSAR saw limitations in the applicability of BEST in this task [38]. BEST's lack of fidelity for solutions whose performance is similar to the current fleet was an area of particular concern since it likely precluded using BEST to discriminate between fleets offering similar, albeit slightly different, levels of capability. The FWSAR APAT was borne out of the discussions on how to administer enough improvements to the fidelity of BEST for FWSAR to enable its use as a bid evaluation quality tool.

Section 4.1 describes how the assumptions used in developing BEST for FWSAR were modified for the purposes of creating FWSAR APAT. Section 4.2 describes a few simple measures that were taken to improve the run time of APAT. Section 4.3 shows the implementation of the tool and outlines its use. Finally, Section 4.4 shows how the examples from Section 3.2 change as a result of the new assumptions that have been included as part of APAT.

4.1 Assumptions and Implementation Issues

The intent behind FWSAR APAT is identical to that of BEST for FWSAR. However, there are nonetheless several fundamental differences in their implementations. First among these is a slight change in assessment philosophy; namely, bids in APAT are not assessed against the standard set by the current fleet, but rather they are given a score[8] based solely on their own merit. This results in choices that are optimized relative to the scoring criteria as opposed to being optimized relative to current performance, which is more consistent with capability-based assessment. It also treats all SAR incidents equally, rather than assessing based on the deviation from existing performance.

The FWSAR SOR [5] requires that at least one aircraft be available to prosecute incidents within each of the three SRRs at all times. Under the set of BEST for FWSAR assumptions, this aircraft can be located anywhere in Canada. This allows, for example, the possibility of having aircraft servicing two or all three SRRs from a single location, which could result in efficiencies resulting from reduced infrastructure. On the other hand, under the current CAF FWSAR practice only the aircraft dedicated to a particular SRR are allowed to prosecute a given SAR incident within that SRR. As APAT cycles through the SAR incidents, this change limits the set of eligible squadrons that can send aircraft to provide assistance.

The incidents used to assess hypothetical FWSAR fleets in APAT are those coming directly from the SAR Mission Management System (SMMS) [39] described in Annex A. The dataset spans multiple

[8] The development of an appropriate scoring function is the subject of the next section of this report.

years and is representative of typical demand on FWSAR assets. Annex A shows that this data has geostatistical properties similar to those of the SISAR data used in BEST. It represents the most up-to-date SAR data available at the time APAT was developed.

The most easily identifiable set of differences between BEST and APAT relate to the precision with which transit time and time on station are computed. BEST required the aircraft to spend at least two hours on station, while this time was later reduced to the one hour used in APAT based on Version 6.0 of the SOR [5]. BEST assumed a simplified best case scenario when computing both transit time and time on station. On the other hand, the flight profiles in APAT, while still very much simplified compared to any real-world scenario, are corrected on a number of fronts. The bulk of these changes are captured in the typical flight profile used in APAT, which is similar to the one shown in Figure 16 (the dashed lines represent additions to the potential flight profiles for a subset of the incidents).

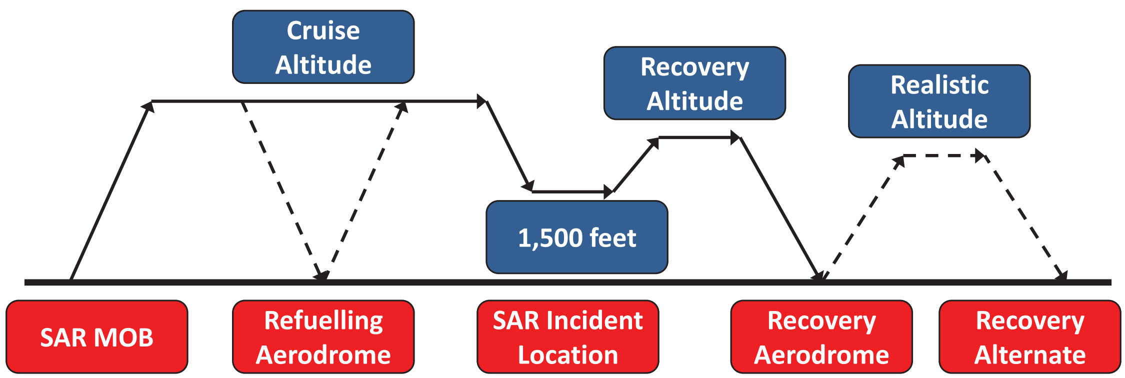


Figure 16: *Typical SAR flight profile.*

In order to algorithmically implement this type of flight profile, several new inputs are required. A constant aircraft endurance is no longer an input to the calculations. Rather, the amount of fuel that the aircraft is capable of carrying along with the aircraft's fuel consumption rates (on ascent, cruising, etc.) are used to determine how long it can remain airborne and how far it can fly.

Another significant deficiency that was addressed in APAT is the use of both refuelling and recovery aerodromes. Users are asked to input up to 75 potential recovery locations and up to 50 potential refuelling locations. Annex B maps the predefined list of 288 refuelling and 404 recovery aerodromes. The user must additionally provide the refuelling rate that the selected aerodromes are capable of providing, and the minimum of these values and the rate at which the aircraft are capable of accepting fuel is used to determine the duration of a refuelling stop. Recall that BEST assumed that refuelling took place in an idealized fashion, with a constant refuelling time, and ran the aircraft to dry tanks as a proxy to determining time on station. Moreover, if a multi-aircraft fleet is proposed, APAT users must identify which of the refuelling and recovery aerodromes are usable by each of the aircraft.

Based on the proximity of the SAR incidents, two different cruise profiles to the incident locations are defined by the user. The first applies to incidents that are within the immediate vicinity of the MOBs. For these, the aircraft are allowed to use a *short range cruise* flight profile, which is optimized for speed. This type of profile is typically lower in altitude and results in a higher rate of fuel consumption, thereby reducing the aircraft's ability to remain on station. This flight profile is used for all incidents within a distance equal to the distance covered by the aircraft in one hour of flight at short range cruise. For example, if the short range cruise speed is 300 kts, then this flight profile is used whenever the SAR incidents are within 300 nmi of an MOB. Whenever the distance to the SAR incidents exceeds this threshold, a second flight profile, *endurance cruise*, optimized for aircraft endurance is applied instead. This flight profile allows aircraft to climb to higher altitude which typically results in decreased fuel consumption and slower transit speeds. The cruise speeds, altitudes, and fuel consumption rates for both of these profiles are used to calculate how quickly the aircraft can arrive on station and how long it can remain there once it has arrived.

Two additional flight profiles are defined in APAT: one is used to track the aircraft's performance while on station and the other is a *recovery cruise* profile which can take advantage of reduced urgency in getting the aircraft to a suitable recovery aerodrome once it has visited the SAR incident location for at least one hour. Similarly to the short range and endurance cruise profiles, the user must specify cruise speeds, altitudes, and fuel consumption rates for both of these two additional flight profiles, notwithstanding the assumption that the aircraft flies at 1500 ft in altitude while on station.

Unlike BEST, APAT requires user-specified climb and descent information to increase the precision with which transit time and time on station are computed. Specifically, the tool requires the time, horizontal distance, and fuel consumption required to perform the full climb from an aerodrome[9] or the SAR incident location to the appropriate cruise altitude for each profile, with the exception of the on station profile. Similar numbers are required for the descent portion of the short range, endurance, and recovery cruise profiles.

In the event that the distance between the start and end of a climb/cruise/descent portion of a flight profile is too small to allow a full climb and descent, the cruise portion of the profile is eliminated and the climb and descent are linearly interpolated to find the point at which the aircraft instantaneously transitions from climb to descent, loosely approximating a parabolic flight arc (see [40] for details). The situation where the distances involved are so short as to not allow a full climb/descent to/from the on-station altitude of 1500 ft is also accommodated in APAT. The time on station is started as soon as the aircraft arrives on station, irrespective of whether or not it has climbed to 1500 ft. However, the aircraft is still made to continue its climb while on station and so the fuel consumption is still predicated by the climb rate until the climb is completed. At a minimum, the time required to complete descent to sea level is applied to reach a refuelling or recovery aerodrome in the case that the aerodrome is in close proximity.

The final major component to the computation of transit time and time on station that was embedded in APAT is the addition of a more explicit determination of the fuel required to land at an aerodrome while maintaining sufficient fuel to reach a suitable recovery alternate. PMO FWSAR analyzed the distances between Canadian aerodromes and fixed a reasonable value for the distance to an alternate, based on the proximity of aerodromes in three distinct bands of latitude. See [40] for additional details. For foreign aerodromes a fixed alternate recovery aerodrome (hence the distance to this

[9] For simplicity, it is assumed that all MOBs, and refuelling and recovery aerodromes are at sea level.

alternate) was explicitly identified.[10]

Using all of the information described above, it is possible to determine if an aircraft can fly from an MOB, provide at least one hour on station, and have sufficient endurance to reach the closest recovery location, all while maintaining sufficient fuel reserves to reach an alternate recovery location. If this can be done, then APAT determines how much time on station the aircraft is able to provide. If this is not possible, then APAT determines whether hops from the MOB to the refuelling aerodromes and from the refuelling aerodromes to the recovery location, via the SAR incident location are feasible within 13 hours.[11] APAT cycles through all SAR incidents and determines the combination of eligible MOBs, refuelling aerodromes,[12] and recovery aerodromes that maximizes the score that the proposed FWSAR solution receives. Note that APAT will additionally identify cases where adding a refuelling stop provides a higher score even if the refuelling stop is not necessary to provide the minimum one hour time on station.

APAT provides a level of detail that exceeds that of BEST. However, there is one calculation that BEST performed that is not provided in APAT. BEST was used to verify if the extreme points in the SRR are reachable from the chosen set of MOBs. APAT does not provide this verification as the PMO has decided that this can more accurately be confirmed through other means.

4.2 Improving Computational Efficiency

In a worst case scenario, APAT could potentially check a few billion scenarios, which could result in excessive run times. APAT was programmed using a little additional logic and some common Microsoft Excel tips to help mitigate against this possibility. For example, APAT temporarily turns off two inherent Excel functions which can significantly slow execution for even a modest sized workbook: screen updating and automatic recalculation of cell values. These are re-enabled when APAT execution is complete.

For the sake of simplicity, APAT uses an exhaustive search of all possible combinations to search for the one that provides the highest possible score. There are a few places where the search is restricted to help speed it up a little. For example, when checking for refuelling aerodromes, it is unnecessary to verify those that are farther from the incident location than the last aerodrome that the aircraft visited (whether it is an MOB or another refuelling location). So, these locations are excluded from the check.

Similarly, the best recovery locations are computed at the outset, for each aircraft type if necessary, and stored for later use, since these do not depend on where the aircraft come from. In each case, two potential recovery aerodromes are identified: the one that is closest to the SAR incident and the one that minimizes the transit from the incident location to the recovery aerodrome and then to its alternate. For most cases, these two recovery locations will be the same. However, when they are different, the latter aerodrome is found because it can potentially allow the aircraft to provide more

[10] The only exception is the aerodrome at St. Pierre, France, which was treated as though it were in Canada, given its proximity to Newfoundland.

[11] This value is the result of subtracting a worst case two-hour standby posture from the normal 15 hour maximum crew day.

[12] Given the maximum crew day constraint, it is assumed that no more than two refuelling stops are reasonable for the types of aircraft that will be competing to provide Canada's future FWSAR capability.

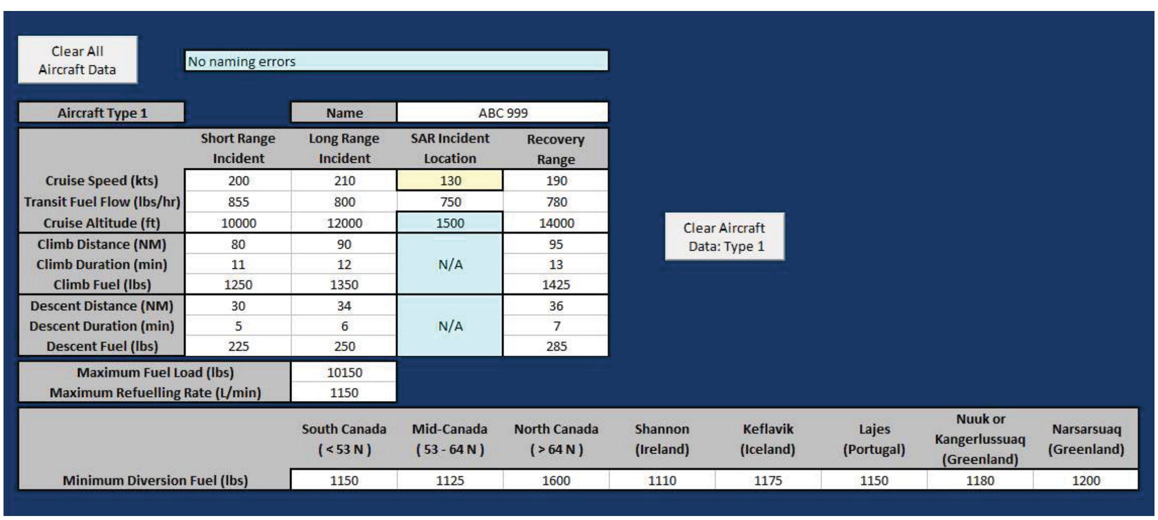
time on station in situations where fuel is the limiting factor. (Recall that aircraft need to land at a recovery aerodrome with sufficient fuel to reach their alternate.) If time is the limiting factor, then the nearest recovery location is used since the time it takes to transit from the recovery aerodrome to its alternate is not accounted for in the 13 hour maximum time allowance.

Implementing these basic improvements, APAT is capable of providing its output on a realistic scenario (e.g. using the current SAR aircraft at their current MOBs) in a matter of a few seconds, even when run on an ordinary laptop. Given this result, it was deemed unnecessary to explore more sophisticated algorithms for finding the best solutions.

4.3 User Interface

In addition to the functionality of FWSAR APAT, the user interface has been significantly modified from the one that was used in BEST. The tool is still implemented using Microsoft Excel, bolstered by macros programmed using Visual Basic for Applications. Throughout all of the tool's worksheets, cells are colour coded in order to more easily understand their roles. White cells represent areas where user input is accepted. Light blue cells are locked and cannot be modified by the user. They present error messages or values that have been fixed by PMO FWSAR. Bright yellow cells show results or display warnings. The light yellow cells capture user data that is not required for proper APAT functioning, but will be required during the flight testing portion of the bid evaluation process. There are also a number of buttons that the user can press; these are all light grey.

Figure 17 shows the revised area where users must enter their aircraft performance specifications. A few of these inputs overlap with those of BEST, but most are new. As described earlier, they relate primarily to aircraft flight profiles including climb and descent data, aircraft fuel and refuelling capacity, and aircraft recovery. APAT allows users to enter data for at most two aircraft types. Buttons give users the option to delete the data for either or both aircraft types.


Clear All Aircraft Data

No naming errors

Aircraft Type 1 — Name: ABC 999

	Short Range Incident	Long Range Incident	SAR Incident Location	Recovery Range
Cruise Speed (kts)	200	210	130	190
Transit Fuel Flow (lbs/hr)	855	800	750	780
Cruise Altitude (ft)	10000	12000	1500	14000
Climb Distance (NM)	80	90	N/A	95
Climb Duration (min)	11	12		13
Climb Fuel (lbs)	1250	1350		1425
Descent Distance (NM)	30	34	N/A	36
Descent Duration (min)	5	6		7
Descent Fuel (lbs)	225	250		285

Clear Aircraft Data: Type 1

Maximum Fuel Load (lbs)	10150
Maximum Refuelling Rate (L/min)	1150

	South Canada (< 53 N)	Mid-Canada (53 - 64 N)	North Canada (> 64 N)	Shannon (Ireland)	Keflavik (Iceland)	Lajes (Portugal)	Nuuk or Kangerlussuaq (Greenland)	Narsarsuaq (Greenland)
Minimum Diversion Fuel (lbs)	1150	1125	1600	1110	1175	1150	1180	1200

Figure 17: *FWSAR aircraft parameter input worksheet.*

The next worksheet in APAT is shown in Figure 18. It allows users to choose the locations of a set of FWSAR squadrons and then allocate aircraft to each one. In addition, users must specify to which SRR the SAR squadron is dedicated to. APAT improves upon BEST by standardizing the inputs; the aircraft types, MOBs, and SRRs are all selected from dropdown menus. The remaining aerodrome data in the blue cells is automatically populated based on the choice of MOBs. There are no restrictions on the combinations that are eligible at this stage. For example, users can choose to collocate different types of aircraft at the same MOB (in different squadrons) and have them provide SAR service to different SRRs. The only button on this worksheet simply provides a mechanism for quickly deleting all user input data on the worksheet.

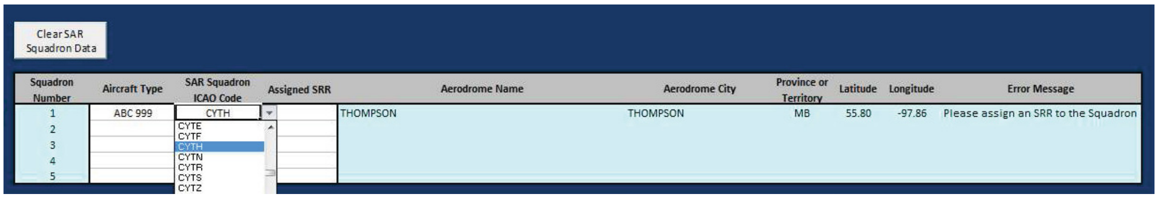


Figure 18: *FWSAR squadrons input worksheet.*

The “Refuelling Aerodromes” worksheet, shown in Figure 19, captures the data necessary to determine the best choices of refuelling locations as the SAR incident locations are visited by the aircraft. Users must specify which aircraft types are capable of using the selected aerodromes. In addition, users must provide the rate at which the facility is capable of replenishing aircraft fuel. The values for many commonly used aerodromes have been pre-specified by PMO FWSAR based on information they collected during the development of APAT. This worksheet provides users with the number of remaining refuelling aerodrome choices still available, to a maximum of 50.[13] Users are allowed to choose more than 50, although the program will not run if they have done so. There are separate buttons that clear the refuelling aerodrome selections and the refuelling rate data.

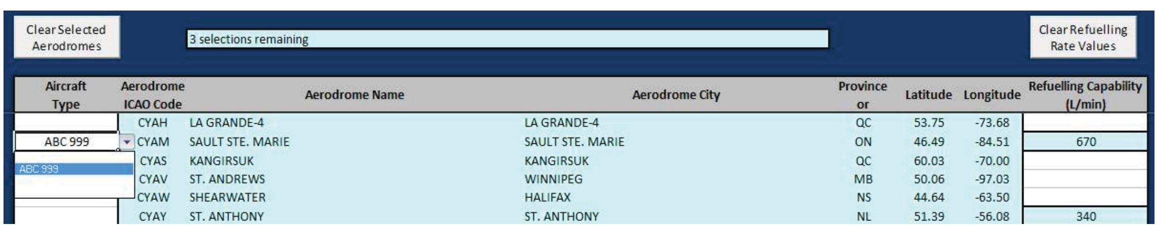
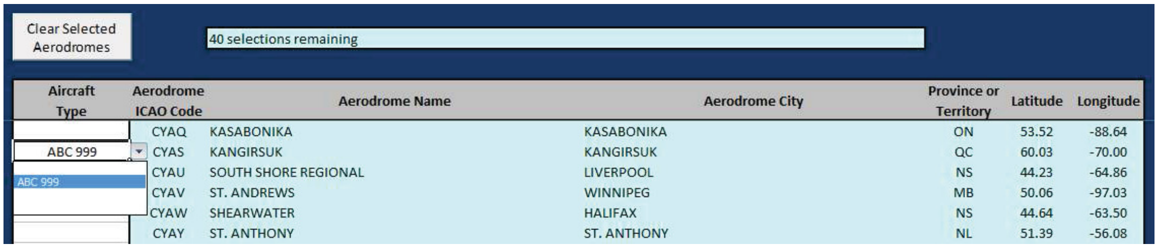


Figure 19: *FWSAR aircraft refuelling aerodromes worksheet.*

Figure 20 displays the “Recovery Aerodromes” worksheet, which is very similar to “Refuelling Aerodromes” worksheet. In this case, a maximum of 75 locations can be chosen and no refuelling rate data is required.

[13] The maximum number of refuelling and recovery bases was determined by SAR subject matter experts to reduce computational time.



Clear Selected Aerodromes

40 selections remaining

Aircraft Type	Aerodrome ICAO Code	Aerodrome Name	Aerodrome City	Province or Territory	Latitude	Longitude
	CYAQ	KASABONIKA	KASABONIKA	ON	53.52	-88.64
ABC 999	CYAS	KANGIRSUK	KANGIRSUK	QC	60.03	-70.00
ABC 999	CYAU	SOUTH SHORE REGIONAL	LIVERPOOL	NS	44.23	-64.86
	CYAV	ST. ANDREWS	WINNIPEG	MB	50.06	-97.03
	CYAW	SHEARWATER	HALIFAX	NS	44.64	-63.50
	CYAY	ST. ANTHONY	ST. ANTHONY	NL	51.39	-56.08

Figure 20: *FWSAR aircraft recovery aerodromes worksheet.*

The "Results" worksheet provides the tool's main outputs. As can be seen in Figure 21, it displays the average transit time and time on station for each SRR and for the entire AOR, in addition to providing the average score that results from these performance values. It is on this basis that the response performance component of a bid's overall score will be determined. The determination of the score is discussed in detail in Section 5.

The "Results" worksheet contains a number of buttons. The most important of these is marked "Calculate!" and is responsible for starting the execution of the tool. Once this button is pressed, it turns bright yellow to indicate that APAT is performing its calculations. During this time, APAT performs some error checks before executing the main part of its algorithm. These checks are designed mainly to ensure that the user-entered data is consistent throughout and is complete. The core of APAT's functionality cycles through all incidents, finding the available squadron that provides the best score possible. Any choice must be able to provide at least one hour on station and land at its recovery aerodrome within 13 hours of having first taken off. If this is not possible within a single aircraft hop (i.e. without refuelling), then APAT adds as many as two refuelling stops along the way. The algorithm used is visually depicted in [40]. When APAT is running, the status field is updated to let the user know which part of the code is being executed. Once APAT's algorithm has finished running, the button returns to its normal light grey colour.

The "Toggle Diagnostics" button offers users the choice to see the best scoring path to each incident. This is meant to provide users with a better understanding of the choices APAT has made. For example, a user can use this diagnostic information to analyze refuelling patterns, such as which refuelling aerodromes are being used and how often. This could help iteratively make better refuelling aerodrome selections, if they are available.

The "Results" worksheet also contains a button to reset the status of the "Calculate!" button. It is mainly used in situations where execution is halted unexpectedly. Pressing this button results in a few actions taking place. First, it changes the colour of the "Calculate!" button back to its normal light grey colour. It also clears the results from the "Results" worksheet. Additionally, it resets Microsoft Excel so that cell values are automatically calculated.

The remaining buttons are rather straightforward in their use. The "Clear All User Data" button erases the contents of all white cells in all worksheets. The import and export buttons allow users to store scenarios they have run and re-load them at a later time if desired. Exported data is stored in a text

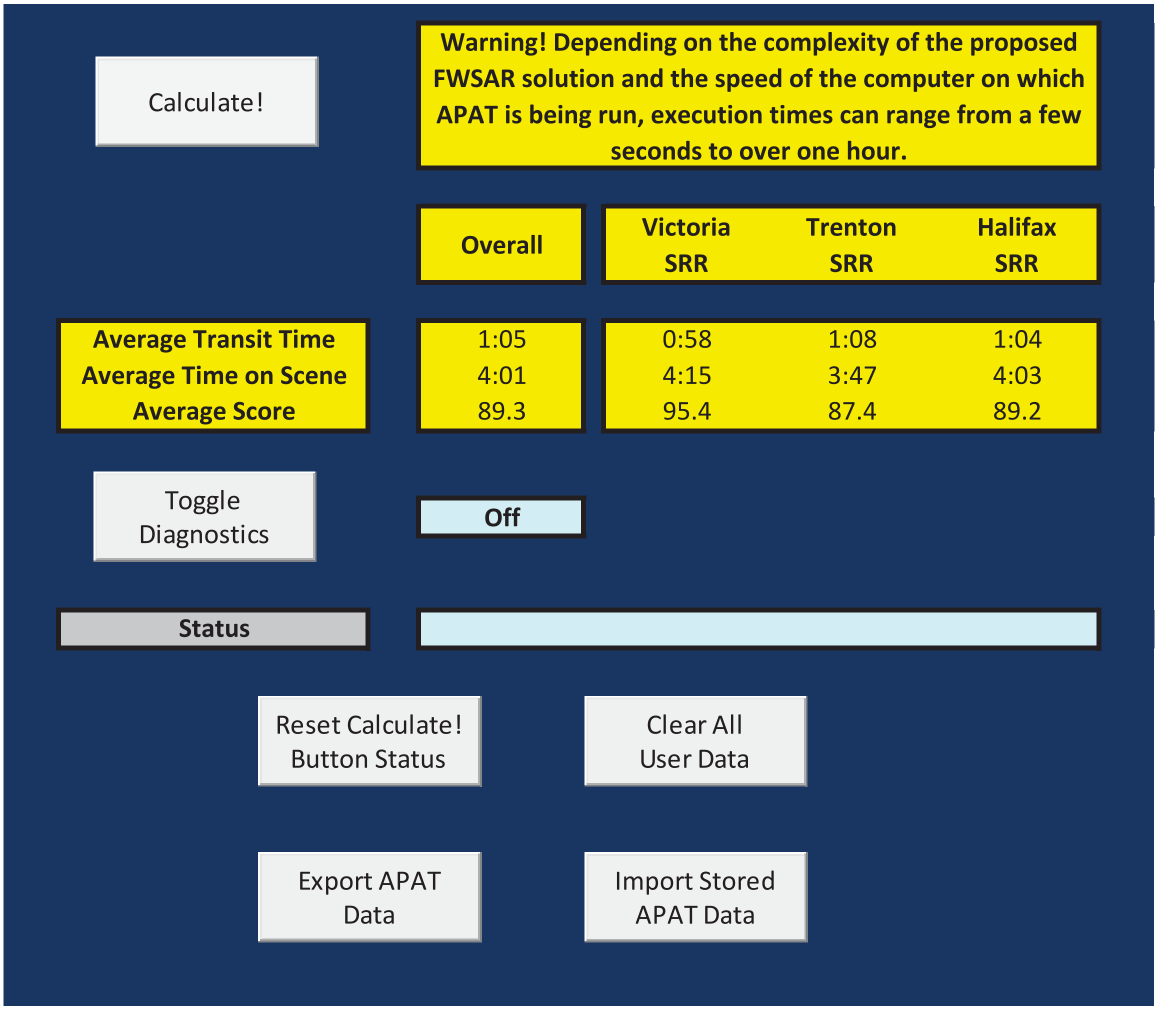


Figure 21: *FWSAR APAT results worksheet.*

file with a .apat extension. This functionality can also be used for bid submission as vendors need only send a small text file to PMO FWSAR who will then verify the overall response performance score that a bid receives.

The last worksheet in APAT is labelled “SAR Incidents”. It provides the latitudes and longitudes of the 2674 SAR incidents used in APAT. The left part of the worksheet (shown in Figure 22) allows users to override any choice APAT makes by specifying which squadron will travel to the incident location as well as which refuelling and recovery aerodromes to use, provided these choices do not result in inconsistencies. For example, if an incident lies in the Victoria SRR, users cannot use aircraft from the Trenton SRR to prosecute the incident, even if they happen to be able to reach the SAR incident location faster. The right part of the worksheet (shown in Figure 23) shows the diagnostic information if the users have toggled it to “On.” In this case, the aircraft used to prosecute each incident along with the path it took (MOB, refuelling, recovery) are displayed. The transit time, time on station, and score are also shown for each case.

Clear User Overrides

Number	Latitude	Longitude	Preferred SAR Squadron (Number)	Preferred Refuelling Aerodrome 1 (ICAO Code)	Preferred Refuelling Aerodrome 2 (ICAO Code)	Preferred Recovery Aerodrome (ICAO Code)	Error Messages
742	60.02	-69.99	1	CYAS		CYTS	Chosen Squadron not assigned to Halifax SRR
743	52.61	-68.14					
744	47.51	-64.82					
745	47.52	-64.80					
746	49.45	-69.90					
747	55.36	-65.71					
748	60.03	-70.16					

CYTQ
CYTR
CYTS
CYTZ
CYUB
CYUL
CYUT
CYUX

Figure 22: *FWSAR incidents worksheet.*

Diagnostic Information

Clear Diagnostic Information

SAR Squadron ICAO Code	Aircraft Type	Refuelling Aerodrome 1	Refuelling Aerodrome 2	Recovery Aerodrome	Transit Time (hrs)	Time on Scene (hrs)	Score	SAR Squadron Latitude	SAR Squadron Longitude	Refuel 1 Latitude	Refuel 1 Longitude	Refuel 2 Latitude	Refuel 2 Longitude	Recovery Latitude	Recovery Longitude
CYTH	ABC 999	CYZT		CYZT	6:35	5:57	0.53	55.80	-97.86	50.68	-127.37			50.68	-127.37
CYTH	ABC 999			CYPR	4:04	4:07	0.58	55.80	-97.86					54.29	-130.44
CYTH	ABC 999			CYYJ	4:24	4:28	0.60	55.80	-97.86					48.65	-123.43
CYTH	ABC 999			CYWL	3:07	5:05	0.65	55.80	-97.86					52.18	-122.05
CYTH	ABC 999	CYKA		CYYJ	3:49	5:59	0.60	55.80	-97.86	50.70	-120.45			48.65	-123.43
CYTH	ABC 999			CYQQ	4:47	3:55	0.55	55.80	-97.86					49.71	-124.89
CYTH	ABC 999	CYZP		CYZP	5:45	7:02	0.52	55.80	-97.86	53.25	-131.81			53.25	-131.81
CYTH	ABC 999			CYQQ	4:42	4:00	0.55	55.80	-97.86					49.71	-124.89
CYTH	ABC 999	CYKA		CYYJ	4:51	7:57	0.59	55.80	-97.86	50.70	-120.45			48.65	-123.43

Figure 23: *FWSAR diagnostics from the incidents worksheet.*

4.4 Comparison of Previous Cases

To exemplify the calculation of transit time and time on station, consider the scenario presented in Figure 24 based on the example initially presented in Section 2.5.2. The scenario consists of two bases in Winnipeg and Greenwood. The SAR Squadrons input worksheet of APAT was used to input aircraft/MOB/SRR combinations enabling A1 or A2 type aircraft to respond to SAR incidents in all three SRRs. Aircraft of type A1 are based in Winnipeg. Aircraft A2 are based in Greenwood. Tables 5, 6, and 7 list the aircraft specifications inputted to APAT, modelling in detail the specification of hypothetical aircraft A1 and A2. For the example illustrating BEST in Section 2.5.2, only the aircraft cruising speed (320 kts and 280 kts respectively) and endurance (8 hours and 10 hours respectively) were required as input.

The figure illustrates the response to three SAR incidents whose locations are denoted by red dots. The aircraft bases are denoted as larger gray dots. Fifty potential refuelling stops (green dots) were specified, subjectively chosen based on the possible flight paths from the bases to the incidents. A refuelling rate of 745 L/min was inputted for refuelling stops for which APAT required input (745 is the average refuelling rate of the aerodromes for which this information is known). Nine recovery

Table 5: *Hypothetical aircraft parameter specifications for APAT input.*

	Short Range Incident	Long Range Incident	SAR Incident Location	Recovery Range
Aircraft A1				
Cruise Speed (kts)	320	300	150	280
Transit Fuel Flow (lbs/hr)	1500	1200	1300	1100
Cruise Altitude (ft)	15000	25000	1500	22000
Climb Distance (nmi)	35	80	—	80
Climb Duration (min)	10	30	—	30
Climb Fuel (lbs)	350	900	—	900
Descent Distance (nmi)	32	60	—	60
Descent Duration (min)	8	25	—	25
Descent Fuel (lbs)	125	250	—	125
Aircraft A2				
Cruise Speed (kts)	295	280	130	260
Transit Fuel Flow (lbs/hr)	1400	1100	1200	1000
Cruise Altitude (ft)	13000	22000	1500	20000
Climb Distance (nmi)	30	65	—	65
Climb Duration (min)	8	25	—	25
Climb Fuel (lbs)	310	790	—	790
Descent Distance (nmi)	25	50	—	50
Descent Duration (min)	7	22	—	22
Descent Fuel (lbs)	110	215	—	215

Table 6: *Hypothetical aircraft fuel parameters.*

	Maximum Fuel Load (lbs)	Maximum Refuelling Rate (L/min)
Aircraft A1	11000	1500
Aircraft A2	13000	1350

Table 7: *Hypothetical aircraft minimum diversion fuel (lbs).*

	South Canada (<53N)	Mid-Canada (53-64N)	North Canada (>64N)	Shannon (Ireland)	Keflavik (Iceland)	Lajes (Portugal)	Greenland
Aircraft A1	1800	2200	3000	1750	1900	1900	2000
Aircraft A2	1700	2000	2750	1600	1800	1800	1850

aerodromes were specified (blue dots). Brown dots represent locations which serve as both refuelling and recovery aerodromes.

- **SAR incident 1** is situated at the northern extreme of the SRR, the North Pole (90°N, 0°W). APAT determines that Aircraft A1 would depart Winnipeg, stop to refuel in Resolute Bay, and arrive at the incident a total of 9.5 hours after departure. Aircraft A1 could stay 1 hour and 10 minutes on station until it would have to recover at Alert to respect the 13 hour effective crew day limitation. APAT determines that aircraft A2, based in Greenwood, could not provide service to this location within the alloted 13-hour effective crew day: it would take 9.5 hours to get to Resolute Bay and refuel, another 3 hours and 40 minutes to get to the incident and 3 hours and 10 minutes to recover to Alert.

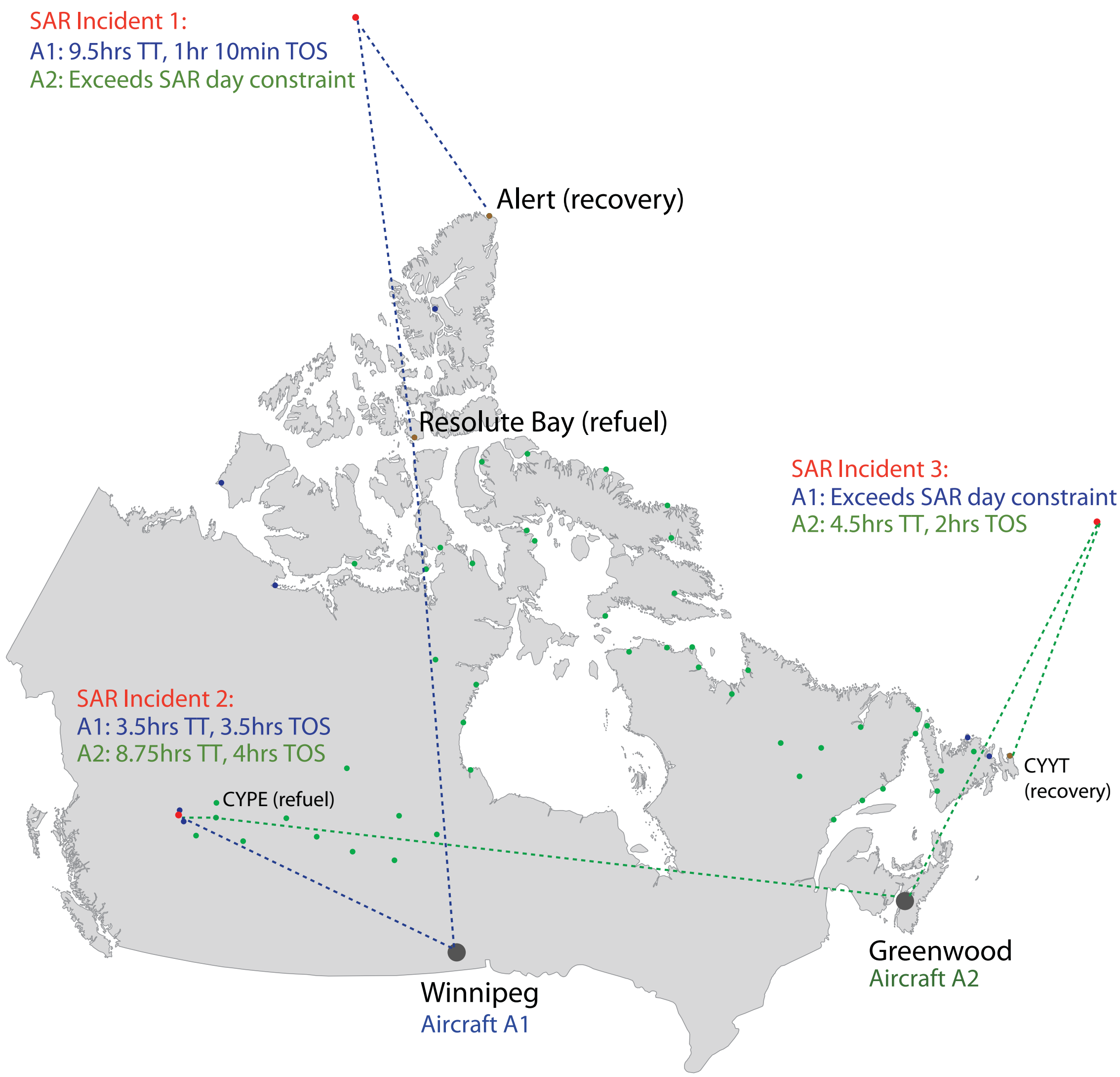


Figure 24: *APAT calculation examples.*

- **SAR incident 2** is located in northern British Columbia at coordinates 56°N,120.74°W. An A1 aircraft from Winnipeg would reach the incident in 3.5 hours and remain on station for 3.5 hours recovering at the nearby Fort St. John aerodrome. An A2 aircraft from Greenwood would take 8 hours and 40 minutes to reach the incident, stopping to refuel enroute at Peace River (ICAO code CYPE), and could then remain on station for 4 hours before recovering to Fort St. John (identified in the figure as the dark blue dot adjacent to the red dot locating incident 2) to respect the maximum effective crew day constraint.

- **SAR incident 3** is located in the North Atlantic Ocean at coordinates 52.04°N, 34.88°W. APAT determines that an A1 aircraft from Winnipeg could not provide service to the incident within the alloted 13-hour effective crew day: it would take 6 hours to reach St. John's (ICAO code CYYT), refuel, and transit for another three hours to reach the incident. Given at least another 3 hours to recover to St. John's, the 13-hour effective crew day is maximized, leaving insufficient time on station. An A2 aircraft departing Greenwood would take 4.5 hours to transit to the incident and could remain on station for 2 hours prior to recovering to St. John's.

5 Scoring Response Performance in APAT

Response performance of any hypothetical FWSAR fleet is a combination of transit time and time on station. The scoring in BEST and APAT are based on distinct philosophies. Whereas BEST was designed to assess response performance against the standard set by the current FWSAR fleet, APAT is meant to assess it independently of any standard, consistent with a capability-based approach to procurement.

BEST optimizes response performance through a two-step process. First, the total transit time needed to prosecute the full set of SAR incidents is minimized. Then, different MOBs are used to prosecute incidents in an effort to maximize total time on station, all while ensuring that the transit time does not exceed the transit time of the current fleet. The remainder of this section describes how APAT scores FWSAR fleets.

The goal of this section is to define a function of average transit time and average time on station to score a fleet of FWSAR aircraft. Clearly, such a function should increase as transit times get lower and as time on station gets higher. There are an infinite number of possible functions which satisfy these requirements, however it was decided to simplify the problem space by defining a function that is a linear combination of two scoring functions: one for the average transit time and one for the average time on station. Doing so reduces the problem to that of finding appropriate scoring functions for each of the two inputs, and then deciding what fraction of the score is directly attributable to transit time (and therefore the fraction that is linked to time on station).

5.1 Transit Time

Three types of monotone decreasing functions were tested as candidates for scoring transit time: linear, concave up, and concave down. Examples of these generic types of functions are shown in Figure 25. The nonlinear concave up functions are meant to put a premium on the shortest transit times without providing much distinction on long transit times. The intent is that long transit times should not score well irrespective of their values; for example, a ten-hour transit, while better than an eleven-hour transit, should not obtain a much better score since both times are quite long. The nonlinear concave down family of functions provide less distinction amongst short transit times, but tail off rapidly as the transit time increases. The intent is to severely discourage longer transit times. The linear function simply results from the interpolation of an instantaneous transit (score: 1) and the maximum allowable transit of twelve hours (score: 0). The intent is to treat all delays equally; delaying a 30-minute transit to refuel along the way results in the same decrease in score as the same delay during a 9-hour transit.

The concave functions were rejected for two main reasons. First, they encouraged unnecessary refuelling stops near the incident locations, as the resultant decrease in score for increased transit time was usually more than offset by the gain in score for the increase in time on station. Second, there is no defensible basis on which to decide the specific form of the function. Namely, there is no reasonable grounds for determining whether, say, an exponential form better captures the intent than a polynomial form. Ultimately, the linear function was chosen as it represents the most unbiased attribution of score resulting from transit time. Applying the linear scoring function and setting a

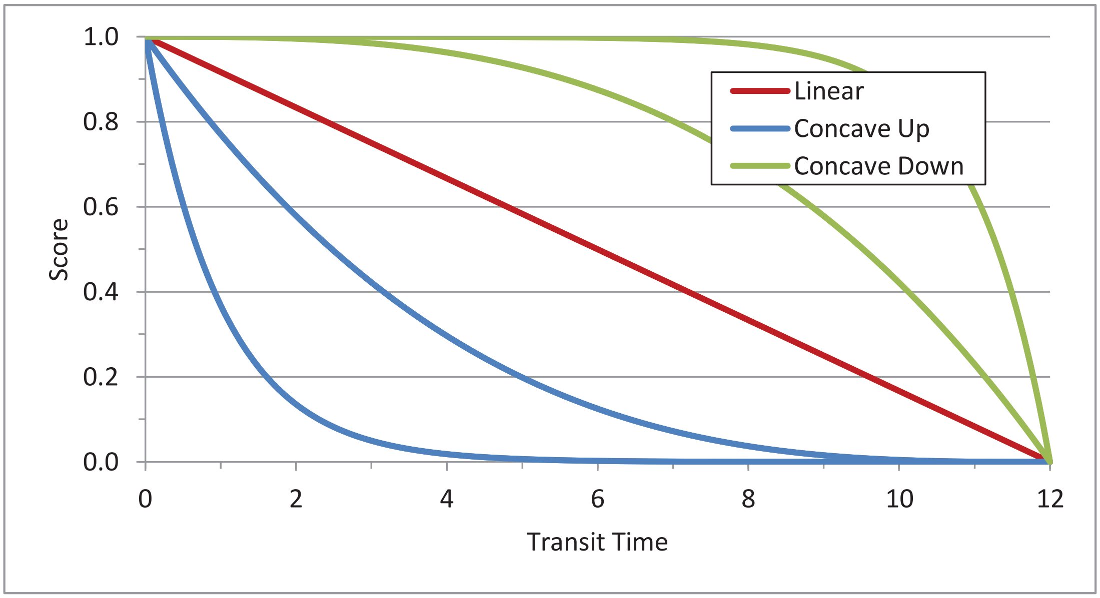


Figure 25: *Test functions for transit time scoring.*

range from 0 to 100, the specific equation used for the transit time component of the score, S_{TT}, is

$$S_{TT}(TT) = \max\left\{100 \times \frac{12 - TT}{12}, 0\right\}, \quad (1)$$

where TT represents the transit time in hours. If the transit time exceeds twelve hours, then $S_{TT} = 0$ automatically.

5.2 Time on Station

The same three generic types of functions were considered for scoring time on station, examples of which are shown in Figure 26. There are two principle differences from the case of transit time. First, the functions are monotone increasing in this case, since more time on station is better. Second, given that the SOR mandates a minimum of one hour on station, a score of 0 is awarded when the time on station is less than one hour and is maximized at 1 when the time on station reaches the maximum possible of 13 hours.

The functions engender slightly different philosophies in scoring time on station. The concave up functions increase in value rapidly and saturate as the time on station increases, thereby providing little discrimination between large values of time on station. The concave down function treats shorter time on station values fairly equally and then quickly increases to provide incentive to maximize time on station as much as possible. The linear function simply rewards additional time on station in the same fashion, whether the increment is above the minimum of one hour or above a period of eight hours.

In this case, there was operational data that could be used to determine the appropriate function to score time on station. Using the historical data on which APAT is based, it was possible to determine

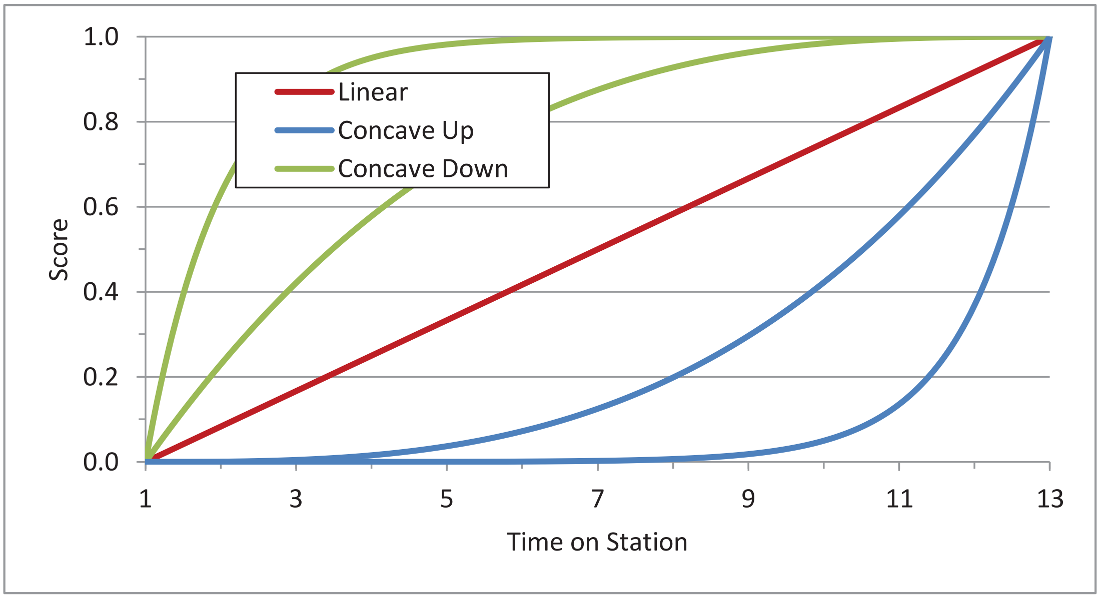


Figure 26: *Test functions for scoring time on station.*

how long SAR crews typically remained on station when prosecuting an incident. Removing any obvious outliers (e.g. time on station that exceeds aircraft endurance), Figure 27 shows the cumulative distribution of incidents which had a FWSAR aircraft overhead for at least one hour. The data was deemed to not present any bias given that the vast majority of incidents had times that fell well below the endurance of both the CC-130 Hercules and CC-115 Buffalo aircraft currently in service. In that respect, the data clearly showed that in terms of providing time on station there is a point of diminishing returns; this is expected to be particularly true of the FWSAR replacement aircraft as they will be required to have an onboard sensor suite that will reduce search times. A curve fitting algorithm [41] was used to determine a function that best fit the data, in addition to scoring 0 at one hour and 1 at thirteen hours. The resulting function, S_{TOS}, has the following form:

$$S_{TOS}(TOS) = 100 \times \left(1 - e^{-0.72187(TOS-1)}\right), \tag{2}$$

where TOS represents the time on station in hours. If the time on station exceeds thirteen hours, then $S_{TOS} = 100$. Strictly speaking, $S_{TOS} \approx 99.9827 < 1$ when $TOS = 13$ and should be normalized by this value. However, the simplified form shown in Equation (2) is sufficient for computational purposes.

5.3 Combining Transit Time and Time on Station

Having established scoring functions for transit time and time on station, the remaining task is that of deciding how much each one contributes to the overall score. There were two ways in which this was accomplished: through subject matter expert consultation and through experimentation. The FWSAR PMO developed various realistic FWSAR missions and polled several SAR operators to determine their thoughts on the appropriate balance in each case. The consensus was that the most appropriate balance was approximately 85% for transit time and 15% for time on station.

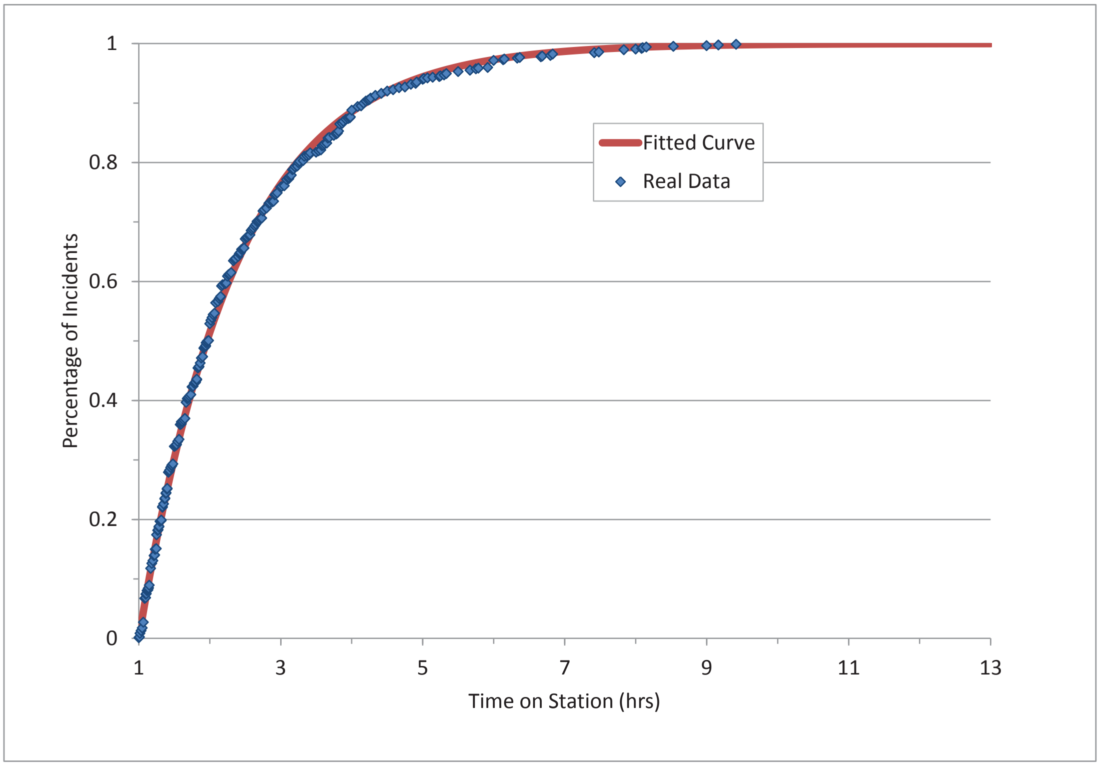


Figure 27: *Curve fitting results for scoring time on station.*

Afterwards, a number of hypothetical fleets were evaluated using APAT, with the aim of identifying how many refuelling stops were required as the ratio of the two scores was varied. While necessary in some cases, operators prefer to avoid excessive refuelling stops owing to the hazards these entail. For example, every refuelling stop introduces the possibility of aircraft becoming unserviceable after landing due to failure of one or more of its components. There is a possibility that contaminated fuel may be added to the aircraft, the risk of bird strikes increases, and the runway could wind up being closed before the FWSAR aircraft leaves the aerodrome. In addition, landing may introduce additional delays due to de-icing requirements, provided the aerodrome has the equipment necessary to provide this service.

Once again, operator input was used to determine an appropriate number of refuelling stops for the hypothetical fleets that were tested. APAT was run several times, varying the ratio of S_{TT} and S_{TOS} every time. In general, fleets with fast, long endurance aircraft were not sensitive to changes in the ratio. Not surprisingly, slower aircraft with lesser endurance positioned at only a few MOBs saw the number of refuelling stops increase significantly as more emphasis was placed on time on station. PMO staff examined APAT output to see when and where the refuelling stops were taking place to compare against their operational experience. In the end, the experimentation reaffirmed that the 85 : 15 ratio was a reasonable choice, as it prevented unnecessary refuelling stops without discouraging them altogether. Therefore, the scoring function that is used in APAT (normalized to the 0 to 100 range) is as follows:

$$S(TT, TOS) = 0.85 \times S_{TT}(TT) + 0.15 \times S_{TOS}(TOS)$$
$$= 100 \times \left(0.85 \times \max\left\{\frac{12 - TT}{12}, 0\right\} + 0.15 \times e^{-0.72187(TOS-1)}\right). \quad (3)$$

5.4 Additional Considerations

There are two additional points to bear in mind when using the function in Equation (3). The first is that the scores it produces tend to be fairly high for reasonable FWSAR fleets. For example, the existing fleet receives a score of approximately 90.9 out of a possible 100.[14] This is because its average transit time is approximately 1:13 with an approximate average time on station of 8:20. A fleet that is 50% slower will still have transit times that are on average around 2:26, which is nowhere near the maximum allowable time of 12 hours. Similarly, aircraft would have to be impossibly fast to achieve scores in excess of 95. For this reason, small differences in APAT scores matter and it is best, for the purposes of scoring bids from industry, to concentrate the points awarded for response performance based on fleets whose APAT score is within a few points of 91.

The last point to note is that if $\overline{TT}$ and $\overline{TOS}$ represent the average transit time and time on station respectively, then in general

$$S(\overline{TT}, \overline{TOS}) \neq \overline{S}(TT, TOS), \quad (4)$$

where $\overline{S}(TT, TOS)$ is the average of the APAT scores over all incidents. Using the current fleet, it is indeed seen that $S(1{:}13, 8{:}20) = 91.3 \neq 90.9$. APAT, as currently implemented, computes a score for each incident based on its transit time and time on station and returns the average of this as the overall score, as opposed to providing the score of the averages for transit time and time on station. Given that Equation (3) is non-linear, in general $S(\overline{TT}, \overline{TOS}) \neq \overline{S}(TT, TOS)$.

5.5 Comparison of Previous Cases

To better understand how $S(TT, TOS)$ works, the hypothetical proposals introduced in Section 3.2 are re-evaluated and compared using APAT. Table 3 summarizes the approximate cruise speed, endurance, and basing for each proposal.

Since the proposals being evaluated are hypothetical, many of the performance characteristics required to run APAT, such as climb and descent data, were unavailable. In order to circumvent this difficulty, the data for Aircraft A1 in Table 5 were simply scaled based on cruise speed and rounded to the nearest ten to approximate the missing data. For example, the transit fuel flow is 1200 lbs/hr in the long-range incident flight profile for aircraft A1 and its cruise speed in this profile is 300 kts. Proposal B consists of aircraft with a cruise speed of 235 kts, with an endurance of 7 hrs. Thus, its descent fuel was obtained by computing $1200 \times \frac{235}{300}$, which is equal to 940 lbs/hr when rounded to the nearest ten. This procedure is applied to all parameters except the cruise altitude for the SAR incident location flight profile, which

[14] Because APAT is restricted to at most 5 SAR squadrons, it is impossible to model the situation described in Section 3.2 which has the aircraft in Greenwood, Trenton, and Winnipeg sitting on the runway with less than maximum fuel, but capable of maximizing fuel for more distant incidents. The score of 90.9 is obtained by assuming that each aircraft departs from its MOB with full fuel.

is fixed at 1500 ft for all aircraft, and the maximum fuel load. The latter is adjusted to ensure that each aircraft has enough fuel to fly the full amount of time specified in its endurance using the long-range incident flight profile and with fuel reserves sufficient to recover at the mid-Canada recovery distance. Using the aircraft from proposal B once again yields a maximum fuel load of

$$7 \text{ hrs} \times \left[1200 \text{ lbs/hr} \times \frac{235 \text{ kts}}{300 \text{ kts}}\right]_{10} + \left[2200 \text{ lbs} \times \frac{235 \text{ kts}}{300 \text{ kts}}\right]_{10} = 8300 \text{ lbs},$$

where 2200 lbs is the recovery fuel required for aircraft A1 at mid-Canadian latitudes and $[\cdot]_{10}$ denotes the operation of rounding to the nearest ten.

Table 8 shows how each of the hypothetical proposals scores using APAT. Refuelling and recovery aerodromes were selected to provide reasonable coverage across the country and overseas, and the same locations were used for all proposals. The score for the current FWSAR fleets is also included. The APAT scores below paint a slightly different picture for the current fleet than the comparative analysis of Section 3.2 for two reasons: the first is the five squadron limitation described in the previous section and the second is that its parameters were approximated using the technique described above. The approximation technique reduces the current fleet's score to 90.3, whereas more realistic values yield an APAT score of 90.9 as discussed in the previous section. This does not affect the ordering of the proposals amongst themselves, but does affect the ordering of the current FWSAR fleet within the set of proposals.

Table 8: *APAT scores for hypothetical FWSAR proposals.*

FWSAR Squadrons	APAT Score
Proposal A	91.5
Proposal B	No score; unreachable incidents
Proposal C	88.4
Proposal D	74.5
Proposal E	85.2
Current	90.3

The analysis of APAT scores shows that Proposal A is the only proposal that fares better than the current FWSAR fleet. The marginal improvement is due mostly to improved SAR service in the Victoria SRR. Proposals C and E are the next best, but suffer due to degraded service in the Trenton SRR. Proposal D scores poorly due to reduced SAR service in every SRR, with the most pronounced degradation of service occurring in the Victoria SRR. Proposal B is not scored by APAT, since there are incidents in the Halifax SRR that are unreachable by the aircraft. Once one of these incidents is encountered, APAT execution is halted. The ordering of the proposals is consistent with the results of Section 3.2.

6 Conclusion

As discussed at the outset of this report, DRDC CORA has provided analyses in support of the FWSAR Project for many years. These studies have been pivotal in helping the project move forward, including the development of criteria on which to base the Statement of Operational Requirement [9], in the establishment of a 'level-of-service' model to compare potential fleet options [42] and using it to characterize the opportunities and risks in these options [7, 8, 37], and in the refinement of this model so it could be used as part of the eventual bid evaluation process [43]. This report describes the contributions made since the review of the FWSAR SOR in 2010.

The FWSAR Aircraft Performance Assessment Tool, or FWSAR APAT, is the culmination of DRDC CORA's effort. This tool will be used as an integral part of the evaluation of bids when these are received, as part of "the first-ever, capability-based procurement of an aircraft fleet by the Government of Canada", according to the PMO [44]. The PMO additionally indicated that "APAT represents a significant innovation in the way the Materiel Group conducts major procurements."

The FWSAR APAT has been released to industry as part of the Government's consultation process, in addition to having been independently reviewed and thoroughly tested. The DMGOR team continues to support ADM(Mat) on the FWSAR replacement project, including analyzing the evaluation of the full set of criteria in support of the project's bidder evaluation plan [45].

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Annex A: SAR Data Analysis

In December 2011 Project Management Office (PMO) FWSAR began scrutinizing BEST for FWSAR as a potential tool for bidder evaluation [38]. As part of this effort, PMO FWSAR requested an analysis of historical SAR incident data. This section presents the preliminary analysis of historical SAR incidents that was undertaken; it presents where incidents have occurred, when incidents have occurred, and discusses corresponding trends.

The annex is structured as follows. In Section A.1 the sources of data are discussed and compared. Section A.2 continues the comparison in graphical format and in particular presents heat density maps indicating the typical locations of SAR incidents. Section A.3 provides preliminary insight into SAR incident location and seasonal trends. Finally, Section A.4 concludes by highlighting results.

A.1 Historical SAR Incident Data

The three JRCCs are responsible for planning, co-ordinating, and controlling aeronautical and maritime search and rescue operations within their respective SRR (Victoria SRR, Trenton SRR, and Halifax SRR). The SAR Mission Management System (SMMS)[39] was developed to provide an integrated and comprehensive means for JRCCs and Marine Rescue Sub Centres (MRSCs) to effectively and efficiently prosecute aviation and marine distress cases. SARMaster is the primary SMMS client-server software. Information for each incident is recorded in SAR databases. Two SAR databases were available to DRDC CORA in early 2012:

1. SARMaster SM3, and
2. Canadian Coast Guard's System of Information for Search and Rescue (SISAR).

The SARMaster SM3 database is a raw database used to collect SAR incident information. The SISAR database is generated from SARMaster data that has undergone validation (often resulting in a 2-3 years of lag) [46]. While neither should be considered fully authoritative for SAR incident details, both are considered to accurately depict the spatiotemporal distribution of SAR incident locations. Table A.1 highlights the comparison of the datasets drawn from the two databases.

Table A.1: *SAR incident dataset comparison.*

	SISAR	SARMaster SM3
Span:	1996–2004	2003–2011
Incident Set:	Response by FWSAR (CAF or other)	All SAR
Temporal Granularity:	Year	Second
Notes:	Used in other DRDC studies	Incomplete for 2003 and 2004

The dataset from the SISAR database spans the years 1996-2004, inclusive. The query was restricted to this span of the database since it provided the best available snapshot that has been validated across all of Canada [47]. While the database contains information for all SAR cases with temporal granularity down to the second, the dataset requested by DASOR focused exclusively on all SAR cases prosecuted by fixed-wing aircraft, sorted by the year of the incident. The complete set of incidents that CAF FWSAR aircraft prosecuted during this time period, roughly 3400 incidents, was used for BEST (Section 2) to benchmark CAF FWSAR response performance. The SISAR database was also used in previous DRDC CORA studies (e.g., [48]).

The SARMaster SM3 database spans 2003-2011. The entries in this database are continuously undergoing validation and review. However, it is deemed to be incomplete for 2003, 2004, and potentially the early part of 2005, while the system was still in its testing phase [47]. SARMaster SM3 records all SAR incidents (marine or land, rotary-wing or fixed-wing, CAF or other, etc.). The database contains roughly 48000 unique entries. Incident report times are recorded down to the second. Figure A.1 graphs the location of all ≈ 48000 SAR incidents recorded in the SARMaster SM3 database between 2003 and 2011. It is noted that several incidents reported were outside the Canadian SRR. It has not been verified if the locations of these incidents were accurately recorded in the database.

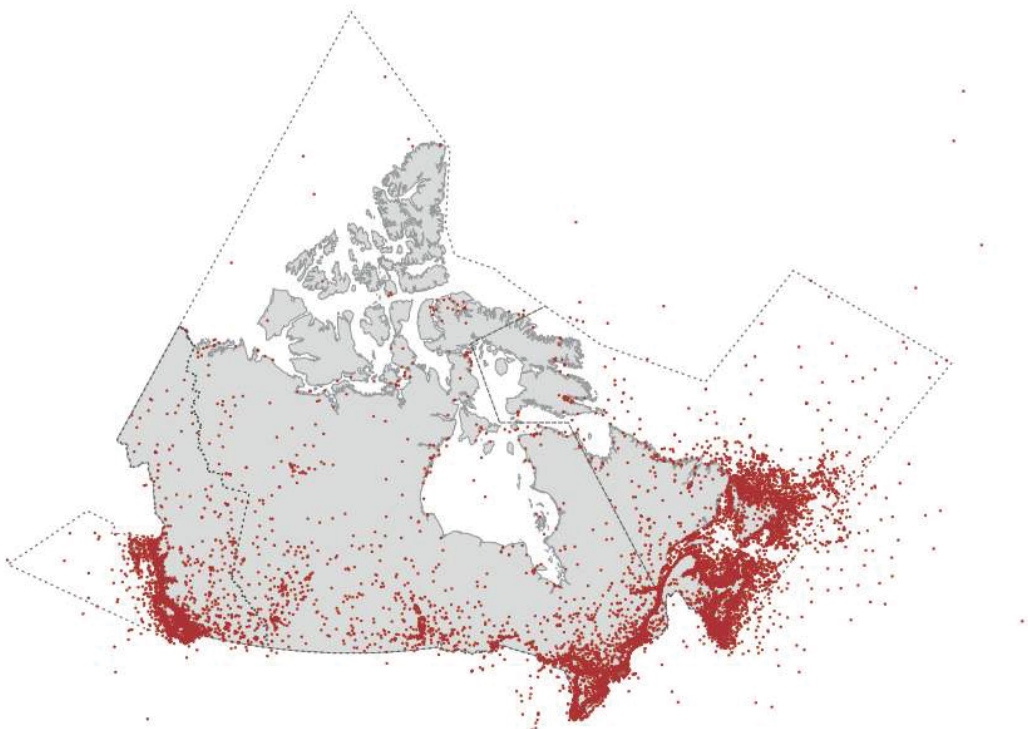


Figure A.1: *Location of SAR incidents between 2003-2011 recorded in SARMaster SM3 database.*

A.2 SAR Incident Location

To further compare the SISAR and SARMaster SM3 databases, both databases were filtered to consider only those incidents that were responded to by CAF FWSAR aircraft within the SRR. Figure A.2a depicts the locations (red dots) of the SAR incidents responded to by CAF FWSAR aircraft between 1996 and 2004 (approximately 3400 incidents as per SISAR), and Figure A.2b depicts the locations of the SAR incidents responded to by CAF FWSAR aircraft between 2003 and 2011 (approximately 2900 as per SARMaster SM3).

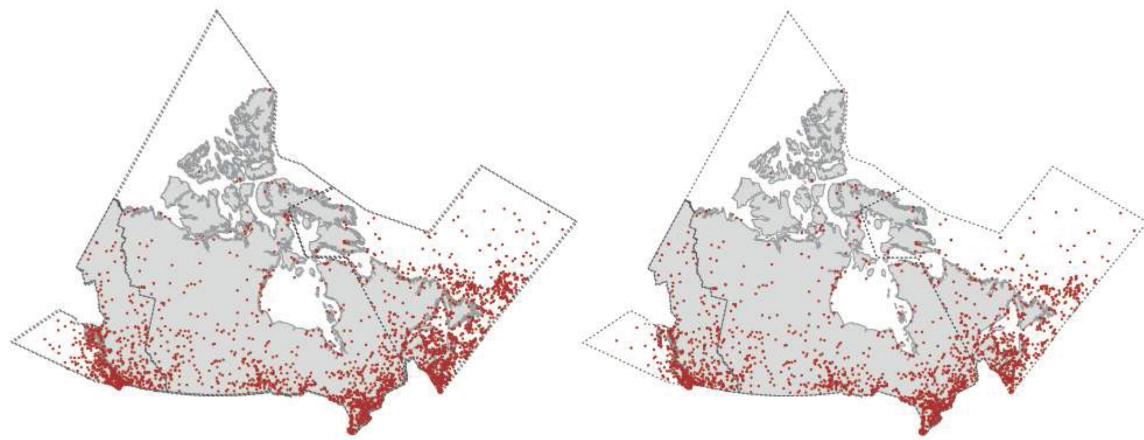
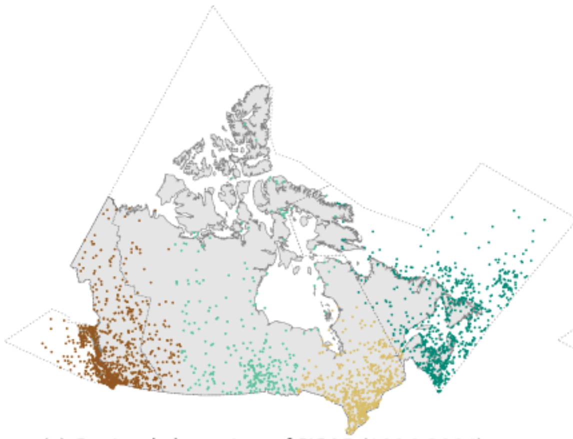


Figure A.2: *Locations of SAR incidents responded to by CAF FWSAR aircraft as recorded in (a) SISAR and (b) SARMaster SM3 databases.*

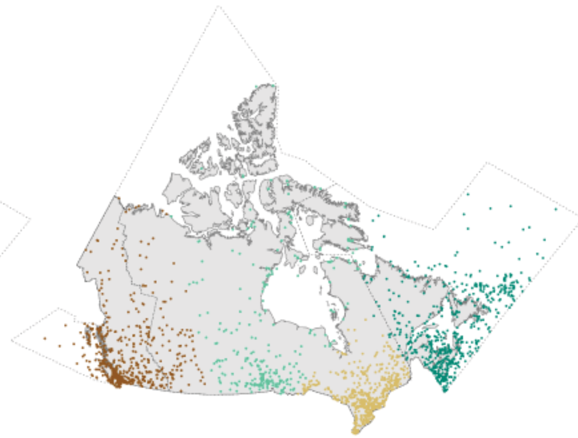
Cluster analysis provides a means to compare the similarity of the distribution of SAR incident locations recorded in SISAR and SARMaster SM3. The *k-medoids* clustering algorithm[15] implemented with the haversine formula for great-circle distances was applied to the SISAR database (1996-2004) and the SARMaster SM3 database (2005-2011). The incidents recorded in SARMaster SM3 between 2003 and 2004 were omitted to prevent overlap. Figure A.3a illustrates the optimal set of clusters for the SISAR data—the algorithm determined that four clusters are optimal (in the figure the points are coloured by cluster). Figure A.3b illustrates the optimal set of clusters for the SARMaster SM3 data. Figure A.3c shows the similarity of the location of the respective medoids (for the four optimal clusters), indicating that the distribution of the incident locations is quite similar. While it is interesting to note that the medoids are located near the current set of CAF FWSAR bases (indicated by larger gray dots in Figure A.3c, the clustering results should not be used to promote optimal FWSAR base locations as the clustering algorithm does not take into consideration numerous other factors [48].

Heat density contour maps accentuate the distribution of SAR incidents recorded in a given year. Figure A.4 illustrates the heat density maps for SAR incidents responded to by CAF FWSAR aircraft every three years starting with 1996 (as recorded by the respective databases). The colours indicate the relative (probability) distribution of the incidents: no colour indicating a minimal probability of incident occurrence, subsequent color steps (green, yellow, orange, red) each indicate more than

[15] The k-medoid clustering algorithm breaks the dataset up into groups and attempts to minimize squared error, the distance between points labeled to be in a cluster and a point designated as the center of that cluster. The k-medoids algorithm chooses data points as centers (medoids)—it is more robust to noise and outliers as compared to the traditional k-means algorithm. For further details see [49].



(a) Optimal clustering of SISAR (1996-2004)



(b) Optimal clustering of SARMaster SM3 (2005-2011)

(c) Optimal clustering mediods for SISAR and SARMaster SM3

Figure A.3: *K-medoids clustering analysis for (a) SISAR data and (b) SM3 data, and the set of cluster medoids determined (SISAR medoids in orange and SARMaster SM3 medoids in brown).*

three times the probability of incident occurrence than the lower color region.[16]. Year-to-year it is interesting to note the consistency of orange and red regions. Northern Canada is marked with some green and yellow regions, but differing in location year-to-year.

Figure A.5 illustrates the heat density maps for all SAR incidents (including those responded to by CAF FWSAR) for years 2005, 2008, and 2011. Similarly to Figure A.4, the colours indicate the relative (probability) distribution of the incidents (more than three times more for each color step). In particular, by visual inspection these figures seem to indicate that the concentration of incidents responded to by CAF FWSAR does not differ greatly from the concentration of all SAR incidents.

[16] Kernel density estimation, a non-parametric way of estimating the probability density function of a random variable based on a finite data sample, was applied to generate the probabilities. In Figure A.4 the five colour steps correspond to the probabilities: white$< \frac{3}{20000}$, $\frac{3}{20000} \leq$ green $< \frac{10}{20000}$, $\frac{10}{20000} \leq$ yellow $< \frac{30}{20000}$, $\frac{30}{20000} \leq$ orange $< \frac{100}{20000}$, and red$\geq \frac{100}{20000}$ To generate Figure A.5 the probability thresholds were multiplied by 20 (i.e., white$< \frac{20\times3}{20000}$ etc.)

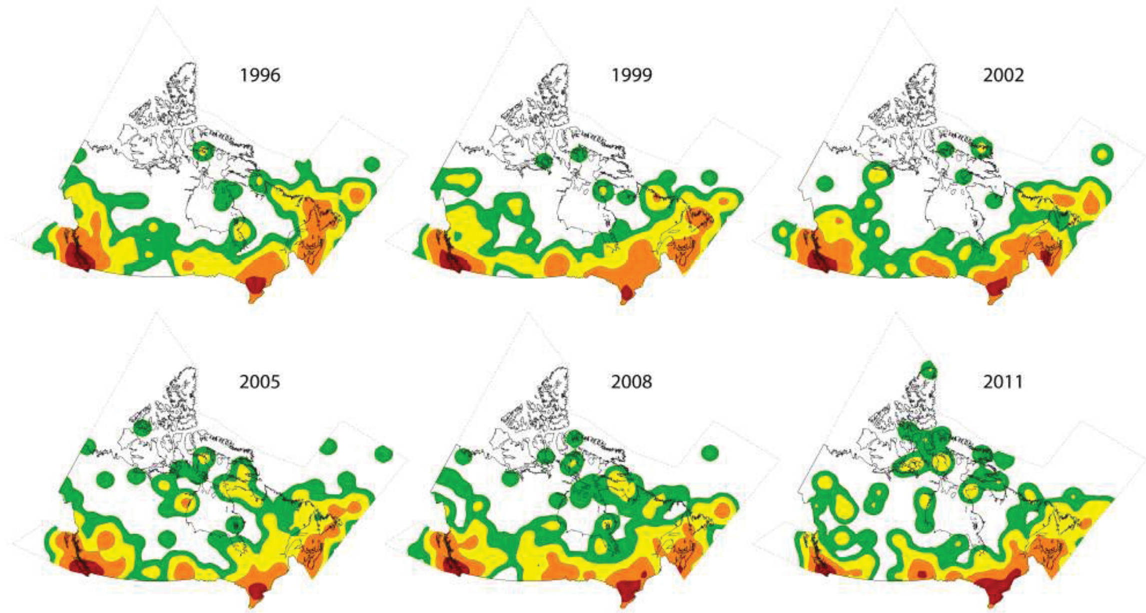


Figure A.4: *Density maps of SAR incidents responded to by CAF FWSAR for 1996, 1999, 2002, 2005, 2008, 2011.*

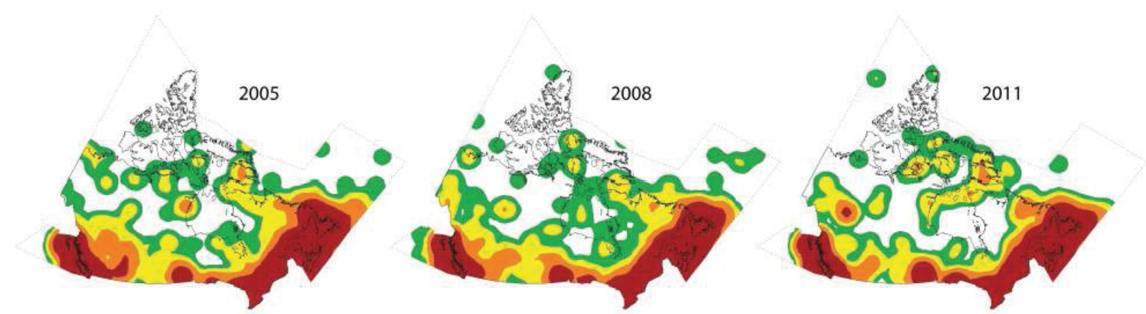


Figure A.5: *Density maps of all SAR incidents for 2005, 2008, and 2011.*

The SARMaster SM3 database was filtered to determine the percentage of marine vs. land incidents. It was found that roughly 60-70% of all SAR incidents were marine. However, around 30% of incidents that prompted a response by CAF FWSAR were marine.

A.3 SAR Incident Trends

The time of incidents recorded in the SARMaster SM3 database was analyzed. Figure A.6 shows the distribution of the number of SAR incidents by day of year and Figure A.7 shows the distribution of the number of SAR incidents (a) by day of week, and (b) by hour of day (counting incidents between 2004 and 2011). Figure A.6 shows a clear seasonal trend with a larger number of SAR incidents occurring during the summer months. Discernible peaks are observed near Victoria Day weekend (third weekend in May corresponding to days 140-145), Canada Day (July 1—day 181 or 182), the Civic holiday on the first Monday in August (around days 210-220), and a drop-off after Labour Day weekend (days 240-250). Figure A.7 illustrates that more incidents are reported during weekends than weekdays.

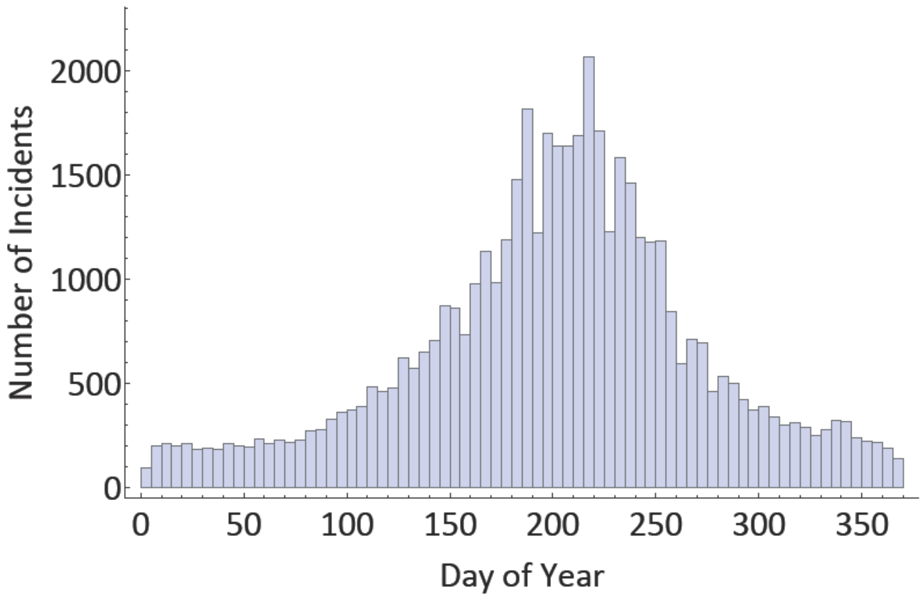


Figure A.6: *SAR incidents by day of year.*

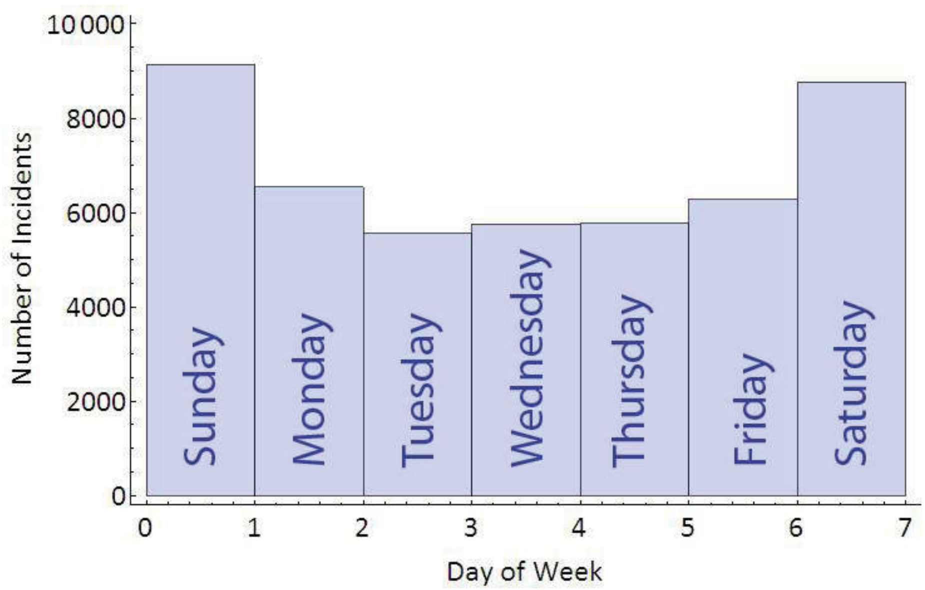


Figure A.7: *Time of SAR incidents by day of week.*

Figure A.8 shows the number of incidents per year that prompted a response by CAF FWSAR aircraft.

The chart combines both the SISAR and SARMaster SM3 data sets to span 1996-2011. The two data sets overlap for 2003 and 2004—the incompleteness of the SARMaster SM3 data during these years is evident. Also graphed are the number of incidents whose latitude was greater or equal to 60°N. Less than 5% of all incidents prompting response by CAF FWSAR are north of 60°N.

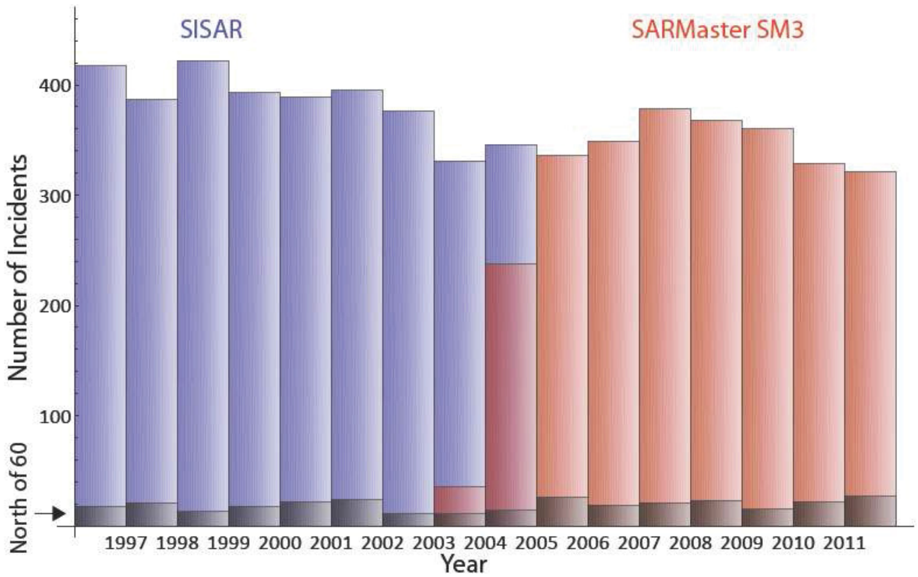


Figure A.8: *Number of incidents per year that prompted a response by CAF FWSAR aircraft.*

Figure A.9 zooms in to show the number of incidents per year north of 60°N that prompted a response by CAF FWSAR aircraft (the chart combines both the SISAR and SARMaster SM3 data sets to span 1996-2011). The average yearly number of such incidents is 20 and ranges from a low of 11 in 2002 and 2003 to a high of 27 in 2011.

Figure A.10 further analyzes the number of incidents per year per season north of 60°N that prompted a response by CAF FWSAR aircraft (using SARMaster SM3 data between 2005-2011). The figure is consistent with the seasonal trend displayed in Figure A.6 for all SAR incidents over the entire Canadian SRR.

Between 2003 and 2011 there were roughly 360 SAR incidents that were reported north of 60°N. This represents less than 1% of the ≈ 48000 incidents recorded in the SARMaster SM3 database. While CAF FWSAR aircraft responded to around 6% of all SAR incidents across the entire SRR, it is interesting to note that CAF FWSAR aircraft responded to 45% of all incidents located north of 60°N. Figure A.11 graphs the number of incidents per year north of 60°N inclusive of all response types (based on SARMaster SM3 data between 2003-2011). While the figure highlights the seasonal trend (as was presented in Figures A.6 and A.10), no discernible increasing or decreasing trend of the number of incidents is evident.

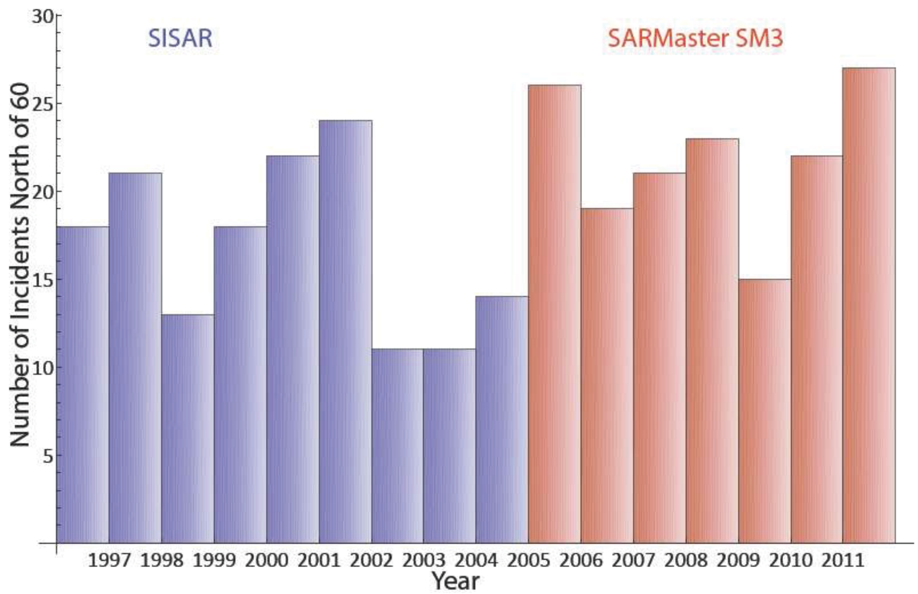


Figure A.9: *Number of incidents north of* 60°N *per year that prompted a response by CAF FWSAR aircraft.*

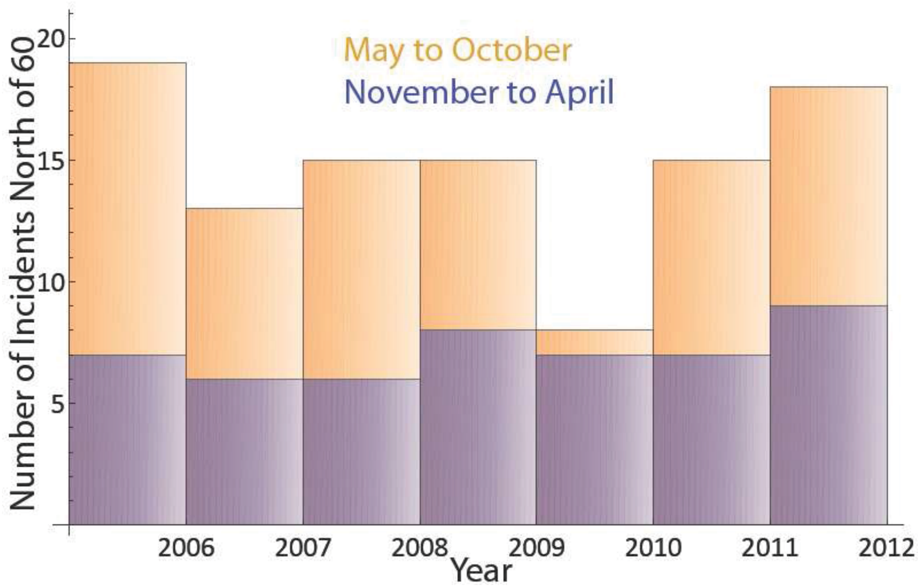


Figure A.10: *Number of incidents north of* 60°N *per year per season that prompted a response by CAF FWSAR aircraft.*

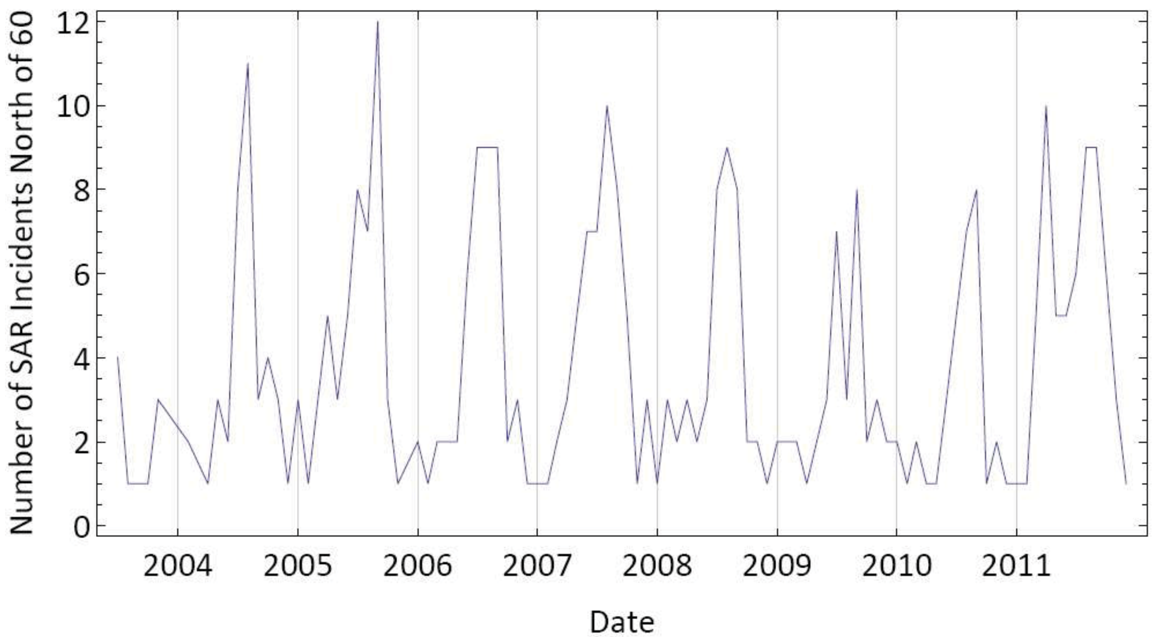


Figure A.11: *Number of incidents north of* 60°N *inclusive of all response types.*

A.4 SAR Data Analysis Summary

- The distribution of incident locations responded to by CAF FWSAR between 2005-2011 (SARMaster SM3 database) is deemed to be similar to the distribution of incident locations responded to by CAF FWSAR between 1996-2004 (SISAR database).
- Roughly 6% of all SAR incidents noted prompted a response by CAF FWSAR.
- While 60% of all SAR incidents are marine, 30% of incidents responded to by CAF FWSAR are marine.
- Less than 1% (typically under 60 per year) of all SAR incidents recorded were located north of 60°N. CAF FWSAR responded to 45% of these (between 10-30 per year).
- There is a clear seasonal pattern of when SAR incidents occur. The majority of incidents occur in summer months (with noted spikes near long weekends/holidays and a significant drop-off is noted after Labour Day weekend). The seasonal pattern also holds for SAR incidents north of 60°N.
- Preliminary analysis of the number of SAR incidents reported north of 60°N shows no discernible increasing or decreasing trend.
- The SARMaster SM3 data can be further analyzed, e.g., with respect to incident classification, type or resource deployed, times between alert/tasking/deployment, transit time to station, time spent on station, time spent off-station, and transit time to return.

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Annex B: Refuelling and Recovery Aerodromes

APAT users are required to select up to 75 potential recovery locations from a predefined list of 404 possible recovery locations, and up to 50 potential refuelling locations from a predefined list of 289 refuelling locations. Figure B.1 maps the list of 404 possible recovery aerodromes identified by their International Civil Aviation Organization (ICAO) codes. Figure B.2 overlays a Voronoi diagram of the recovery aerodrome locations—each cell contains a single recovery aerodrome which is the closest aerodrome to every point within that cell.

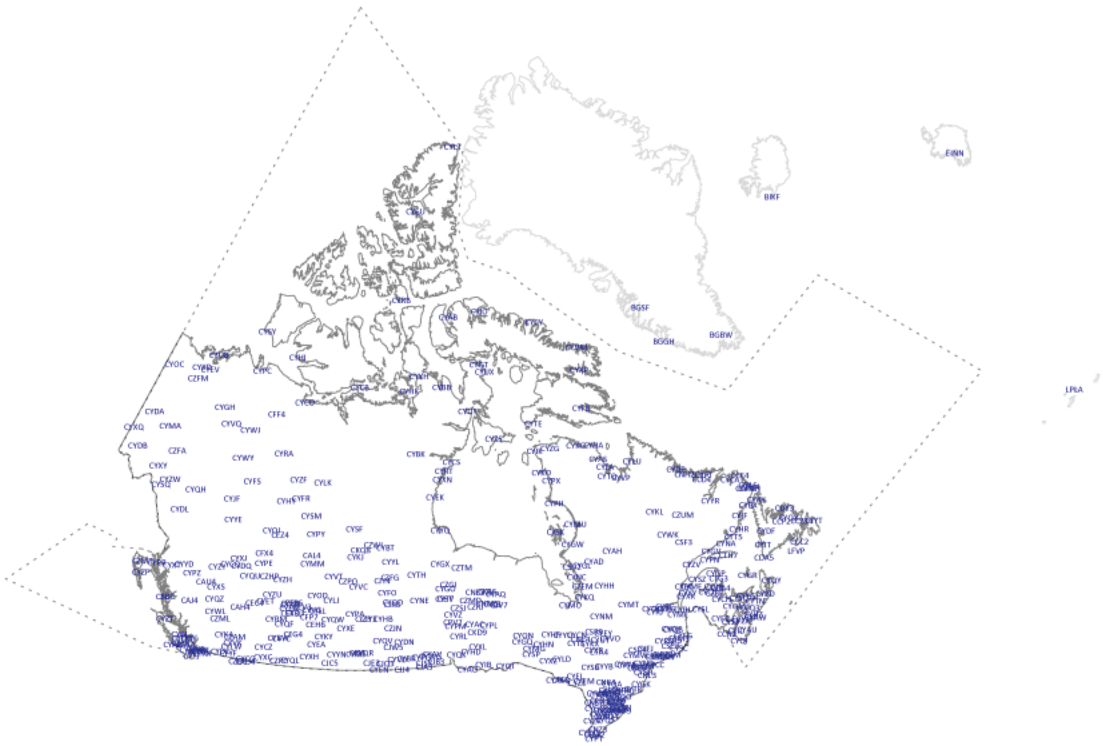

Figure B.1: *Identified recovery aerodromes and associated ICAO codes.*

Figure B.3 maps the list of 288 possible refuelling aerodromes identified by their ICAO codes. Figure B.4 overlays a Voronoi diagram of the refuelling aerodrome locations—each cell contains a single refuelling aerodrome which is the closest aerodrome to every point within that cell.

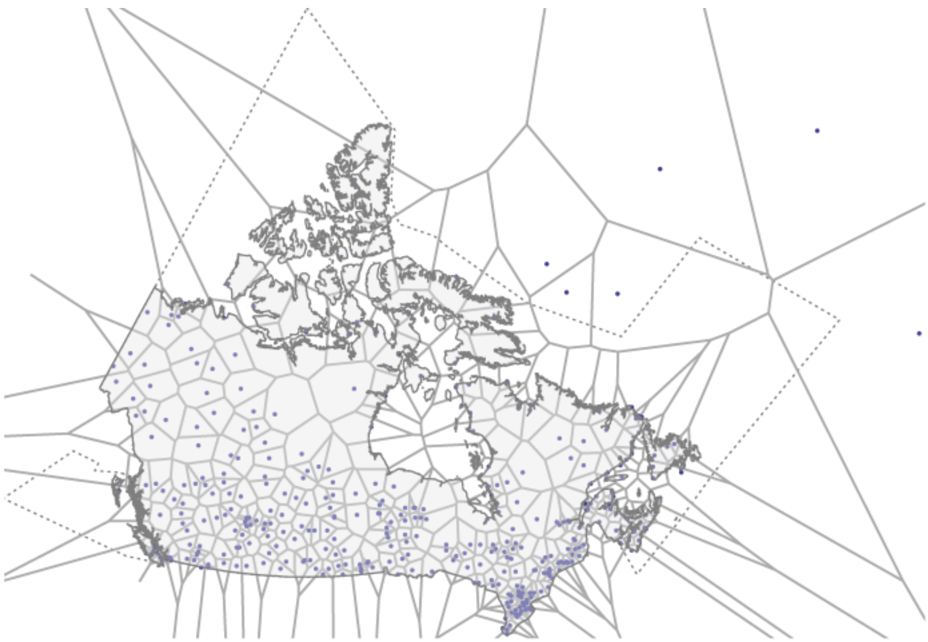

Figure B.2: *Identified recovery aerodromes and associated Voronoi diagram.*

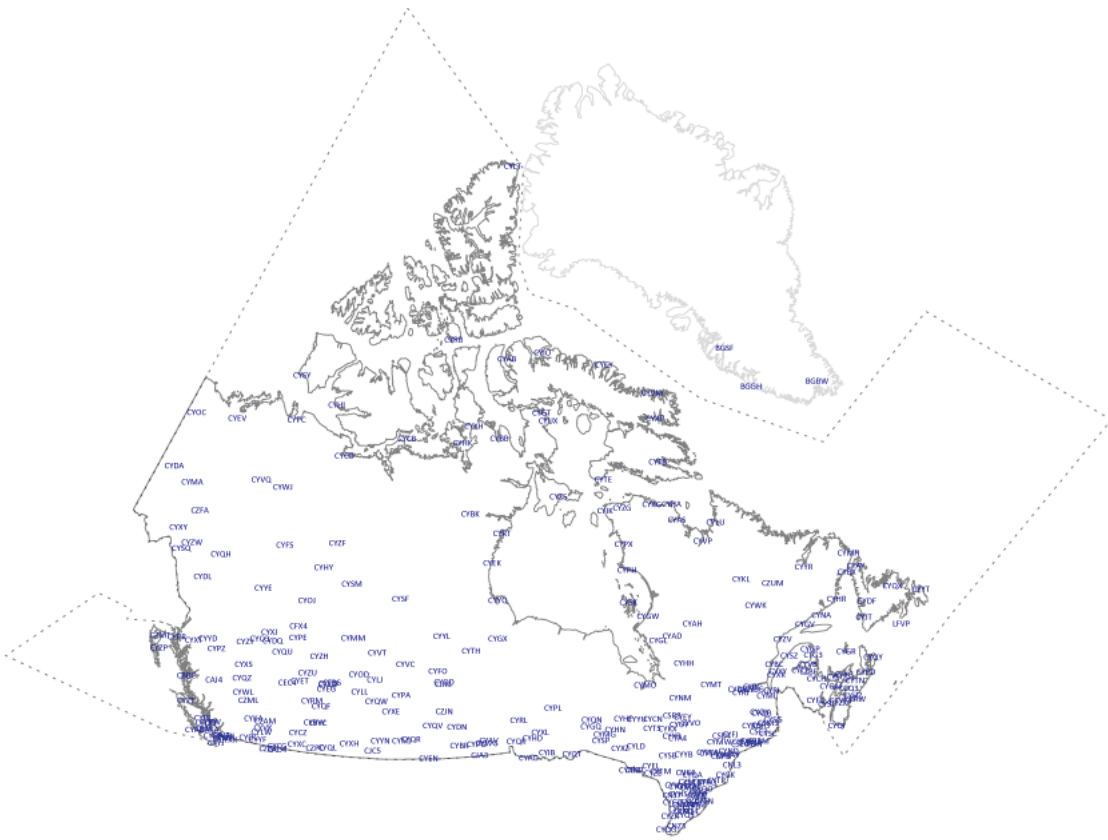

Figure B.3: *Identified refuelling aerodromes and associated ICAO codes.*

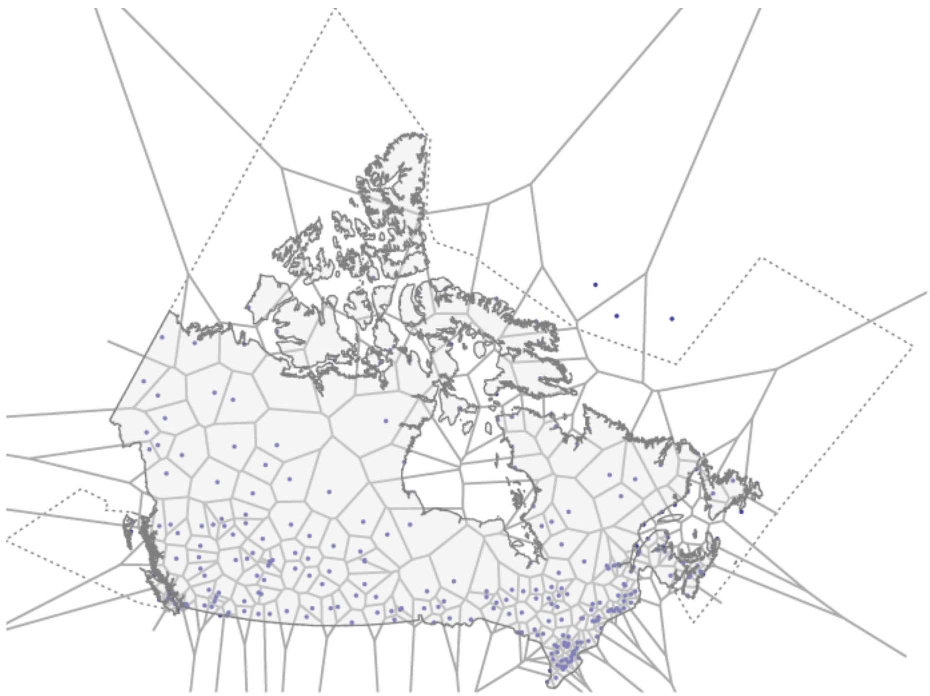

Figure B.4: *Identified refuelling aerodromes and associated Voronoi diagram.*

List of symbols/abbreviations/acronyms/initialisms

ADM(Mat)	Assistant Deputy Minister (Materiel)
AOR	Area of Responsibility
APAT	Aircraft Performance Assessment Tool
ARC	l'aviation royale canadienne (ARC)
ARSVF	aéronefs de recherche et sauvetage à voilure fixe
AST	Acquisition Support Team
BEST	Basing, Endurance, and Speed Tool
C Air Force	Chief of the Air Force Staff
CAF	Canadian Armed Forces
CFDS	*Canada First* Defence Strategy
CNR	Conseil national de recherches
CORA	Centre for Operational Research & Analysis
DAR	Directorate of Air Requirements
DASOR	Directorate of Air Staff Operational Research
DGMPD	Director General Major Procurement Delivery
DGRGP	Direction générale - Réalisation des grands projets
DMGOR	Directorate Materiel Group Operational Research
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DROGM	Direction recherche opérationnelle du Groupe des matériels
EBO	énoncé des besoins opérationnels
ESA	Équipe de soutien d'acquistion
FWSAR	Fixed-Wing Search and Recue
hrs	hours
IC	Industry Canada
IFR	Instrument Flight Rules
IMO	International Maritime Organization
ICAO	International Civil Aviation Organization
JRCC	Joint Rescue Coordination Centre
kts	knots
L	litres
lbs	pounds
min	minutes
MOB	Main Operating Base
MRSC	Marine Rescue Sub Centres
nmi	nautical miles
NRC	National Research Council
NSP	National Search and Rescue Program
NSS	National Search and Rescue Secretariat
OPAV	outil de positionnement, d'autonomie et de vitesse
PMO	Project Management Office
PWGSC	Public Works and Government Services Canada

RCAF	Royal Canadian Air Force
RDDC	Recherche et développement pour la défense Canada
RFP	Request for Proposal
SAR	Search and Rescue
SISAR	System of Information for Search and Rescue
SMMS	SAR Mission Management System
SOR	Statement of Operational Requirements
SRR	Search and Rescue Region
TOS	Time on Station
TT	Transit Time
UTC	Coordinated Universal Time

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1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence R&D Canada – CORA Dept. of National Defence, MGen G. R. Pearkes Bldg., 101 Colonel By Drive, Ottawa ON K1A 0K2, Canada	2a. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED 2b. CONTROLLED GOODS (NON-CONTROLLED GOODS) DMC A REVIEW: GCEC APRIL 2011

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Development of a Capability-Based Bidder Evaluation Tool for the Fixed-Wing Search and Rescue Replacement Project

4. AUTHORS (Last name, followed by initials – ranks, titles, etc. not to be used.)

Bourdon, S.; Kaluzny, B. L.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information. Include Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
October 2013	76	49

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Report

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

Defence R&D Canada – CORA
Dept. of National Defence, MGen G. R. Pearkes Bldg., 101 Colonel By Drive, Ottawa ON K1A 0K2, Canada

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
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In 2010, the National Research Council released a report detailing their review of the Fixed-Wing Search and Rescue (FWSAR) Statement of Operational Requirement (SOR). The SOR is a Royal Canadian Air Force document that specifies the requirements that replacement aircraft must possess in order to be considered viable as search and rescue platforms. Subsequent to the review of the SOR, the Department of National Defence began reformulating this procurement process using a capability-based approach, specifying what effects were desired of the FWSAR aircraft rather than prescribing the fleet's characteristics, such as speed, basing, etc. This report describes a series of analyses done in support of the procurement process including the development of a response performance model and tool, along with assessments and characterization of the opportunities and risks in potential aircraft/basing solutions based on the output of the model.

The FWSAR Aircraft Performance Assessment Tool, or FWSAR APAT, is the culmination of DRDC Centre for Operational Research and Analysis efforts. This tool will be used as an integral part of the evaluation of bids when these are received. The FWSAR APAT has been released to industry as part of the Government's consultation process, in addition to having been independently reviewed and thoroughly tested.

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Bidder Evaluation
FWSAR
Level of Service
Simulation
Risk Analysis

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