National Defence	Défense nationale

SÉCURITÉ DES VOLS FLIGHT SAFETY

ON TARGET

NEW TECHNOLOGY

Canada

DIRECTORATE OF FLIGHT SAFETY

DIRECTOR OF FLIGHT SAFETY
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ON TARGET

Photo: MCpl Colin Aitken

Editors Note

DFS would like to thank all of those who submitted articles for this magazine. The articles contained in this magazine reflect the opinions of the authors.

Cover: The design highlights the new technological fifth generation F-35 fighter overshadowing a mathematical fractal (an infinitely complex geometric shape which can be split into sections, each of which is a smaller sized copy of the whole). The rising sun infers that technology is still at its infancy and its use will expand like the fractal figure. The aircrew head silhouette lingers in the background to signify the human versus technology interface with the associated challenges.

Photo cover: Created by Corporal Raulley Parks, DFS Image Technician

Published October 2011

TABLE OF CONTENTS

Colonel J.C.Y. Choinière
Director of Flight Safety, Ottawa

Director's Foreword

As the incoming Director of Flight Safety, it is my pleasure to welcome you to the 2011 Issue of *On Target – New Technology*. The issue is divided into two parts, "Accident Investigation" and "Operations". Both areas have been significantly affected by technological improvements that will continue to impact safety in aviation.

PART ONE – ACCIDENT INVESTIGATION

The investigation of incidents and accidents has been an integral part of our Flight Safety Program since its creation after the Second World War. It is essential that within this system, analysis of these occurrences be as accurate as possible such that practical preventive measures and risk management techniques minimize chances of reoccurrence.

Part One looks at some of the options available, or becoming available, to support accident investigation including the use of satellite imagery, video tracking, spatial imaging, and other technologies. One challenge facing our investigators includes the lack of a Flight Data Recorders (FDR) on aircraft. New technologies are developing portable FDRs that are effective yet relatively inexpensive.

An essential part of any Flight Safety Program is to be proactive rather than reactive. Flight Operations Quality Assurance (FOQA) employs technology that has been in use within the civil airline industry for years but is noticeably absent from our aircraft. The concept is to routinely download flight data to find out what we don't know about recent flight operations, but should. The article analyzing this topic was kindly provided by the USAF and provides some insight as to how developing a system within the RCAF might improve our Flight Safety Program.

PART TWO – OPERATIONS

Technology relating to all aspects of air operations has undergone dramatic improvements since the Second World War. Engine, instrumentation, systems, avionics and infrastructure, have all contributed to steadily falling accident rates. It is hoped that carefully introducing new technologies, such as the potentially significant "Synthetic Vision", will continue to contribute to this positive trend.

Training technologies have also markedly improved for both operations and maintenance such that transition from training courses to operations becomes as seamless and safe as possible. This technology becomes particularly important as average experience levels are reduced. The enclosed article "Out of Harm's Way: 3-D and Aircraft Maintenance" describes one of the successful training programs currently in use.

As world experiences increases in air traffic, cost effective technologies to effectively control this traffic are being developed. Capabilities such as ADS-B and Intelligent Video are things to watch for in the near future.

Introducing new technology, however, is not always a safety enhancer. Accidents like the 2006 *Cormorant* (CH149914) crash and several in the civil sector, highlight concerns between high technological flight decks and human factors. This concern becomes particularly relevant when examining the integration of new fleets of aircraft into the RCAF as older fleets are retired. The creation of the Air Standards, Training, Readiness and Automation (ASTRA) project identified some of the flight safety risks associated with introducing new technologies in our aircraft. The interface between the human element and technology remains as the significant flight safety challenge. In response, new training techniques and operational procedures are being developed and implemented as new aircraft become operational.

THE WAY AHEAD

It is imperative that our Flight Safety Program, while well respected within the global aviation community, never remains static. As new technologies are introduced to the RCAF towards improving effectiveness, efficiency and safety, new challenges will emerge. Although technological improvements are helping to make aviation safer, we must be ever cognizant of how this technology interfaces with the human element.

> "If we continue to develop our technology without wisdom or prudence, our servant may prove to be our executioner."
>
> – Oman N. Bradley

PART ONE
ACCIDENT INVESTIGATION

Visualization

By Major Adam Cybanski, Deputy Section Head Promotion and Information, Directorate of Flight Safety, Ottawa

Major Adam Cybanski

Major Cybanski is a tactical helicopter pilot with over 20 years and 2500 hours on fixed and rotary wing aircraft including the CT114 Tutor, CH139 Jet Ranger, CH135 Twin Huey and CH146 Griffon. He completed a tour in Haiti as Night Vision Goggle Specialist and Maintenance Test Pilot, and has managed the CH146 Griffon Full Flight Simulator. He is a graduate of the Aerospace Systems Course and holds a BSc in Computer Mathematics from Carleton University.

Overview

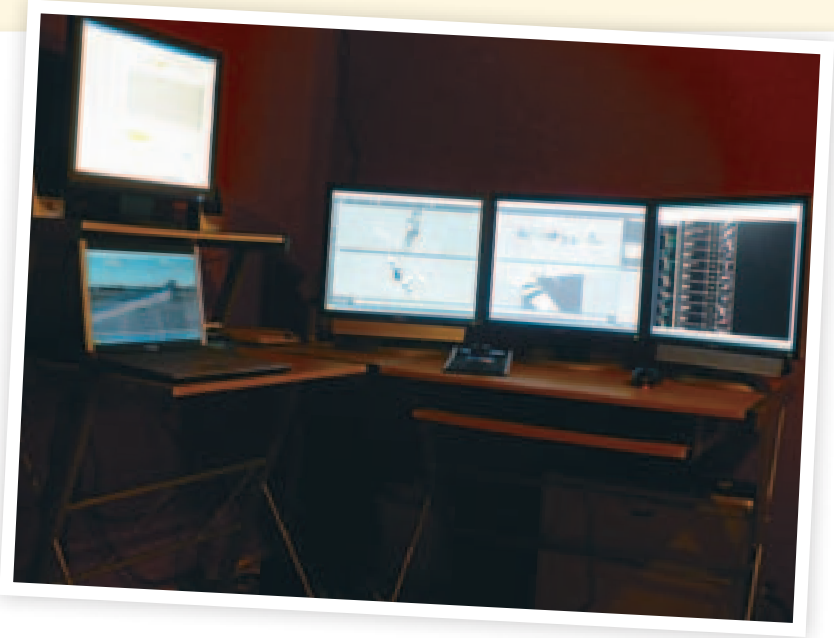
Visualization is a modern, cost-effective method of training, passing lessons learned, and documenting significant events. Flight-path reconstruction employing simulation of both inside and outside the aircraft can help greatly in understanding why an occurrence took place. These types of videos can quickly integrate different aspects of an investigation and effectively communicate the findings.

There are two types of visualization: investigative and promotional. Investigative depicts detailed data for the investigator in a way that is intuitive and relevant to flight operations. Promotional is aimed at showing an audience unfamiliar with an occurrence the sequence of events and contributing factors.

The volumous amounts of data generated by modern aircraft are best analyzed through automated parameter extraction and visualization. In an investigative visualization based on a *Griffon* Flight Data Recorder (FDR), the animation was used by pilots in order to figure out what manoeuvres were being conducted, something that could not be judged by looking solely at the data. FDR information was synchronized with the visualization and shown at the bottom left. The information was colour coded, depicted in yellow when cautionary ranges were reached and red during exceedances.

Animations depicting aircraft accidents and serious incidents have been employed at DFS for several years now. The videos have been shown at air bases across Canada so that aircrew, groundcrew, and everyone else involved in air operations could understand the factors leading up to the accidents. This is critical in preventing future re-occurrences.

FDR Visualization



Visualization Station

A virtual-reality capable laptop system was assembled at DFS to facilitate flight path validation with investigators, and to produce visualizations of accidents. It is able to play back actual and derived FDRs from any angle, including inside the cockpit or from an observation point on the ground. All the associated tools and resources needed were assembled into a visualization lab, which dramatically decreases visualization time. The system is able to replicate any aircraft flown by the CF, and was employed on several investigations, including the validation of a flight path of a fatal aircraft crash which did not have a FDR (CT114 *Tutor*).

Traditional film making processes are employed within the simulator in order to produce visualizations. This includes the sets, characters and sequence of events. The characters (aircraft) are controlled in the simulation to emulate the flight path in an environment that resembles the actual occurrence. The sequences are filmed from different angles with virtual movie cameras. The footage is edited into a final visualization, and then the sequence is viewed in the simulator for validation, ensuring it matches witness testimony or recorded video of the occurrence. Special effects such as night vision goggles (NVG), dust, snow, fog and others may be added.

Sets/Flight Environment

Replicating the airspace that the aircraft fly through can be simple or very involved. High-level flights can employ the default simulator imagery and look quite convincing. On the other hand, low-level flight requires that custom ground textures be imported, and background objects be created and accurately placed on the terrain map. Ground textures are collected from many sources. They can be obtained from an imagery providers such as *Google Earth, Virtual Earth,* from aerial photos, and from other sources such as Mapping and Charting.

Satellite or other ground imagery is staged into one complete image of the subject area. The resulting image may need to be rotated in order to match latitude longitude coordinates. Satellite spectral bands blue, green, and infrared may need to be mixed in order to produce imagery that looks realistic. In cases where black-and-white imagery is at a higher resolution than the colour information, special processing can produce a higher-resolution colour image. The end product is then split into tiles that the flight simulator can import.

Satellite-based Ground Texture

The set can be populated with models from the simulator library, or ones derived from photos through photogrammetry. These include aircraft, ground vehicles, buildings, structures, and even stationary people. Buildings and landmarks at airports, towns and cities may be available on the Internet, or may need to be created from scratch

Satellite-based Ground Texture

using a 3-D modeling application. Photogrammetry and videogrammetry applications have been employed to extract 3-D models with textures from photographs and video of the occurrence location. The number of models is extensive, but have been assembled into object libraries.

Object Library

Models can be placed into location and scaled in the simulator using a reference map, or even from a perspective view in the simulator. This can produce a realistic set, but must be validated from several different viewpoints.

Characters/Aircraft

Many RCAF aircraft are available from third-party developers for a low price. As the aircraft are controlled to replicate a flight path, the simulation aspects of the models are irrelevant. The visual representations of the exterior and cockpit are what is important. When an aircraft type is commercially unavailable, it has been created in a 3-D modeling application using orthogonal view diagrams and photographs. Advances in photogrammetric model/texture extraction have made this even easier.

Watching the aircraft perform the flight path within the simulated environment will usually reveal problems with the flight path analysis. Viewing the aircraft from the cockpit, chase plane, or ground observer perspectives, any unnatural or unrealistic manoeuvres become evident. At this point, the flight path analysis calculations will have to be revisited, perhaps to account for wind, or address a mathematical error.

Model Parameter Visualization

Object Library

Near-Miss Distance Validation

Visualizations from assorted perspectives can be studied by witnesses to produce a validated flight path. In one case, by showing different versions of a near-miss visualization to the pilot concerned, investigators were able to estimate the distance between the two aircraft. A visualization of the event was subsequently produced to warn aircrew of the near-miss risks.

Special Effects

There are two main types of effects, integrated simulation effects and post-production effects. Integrated effects are controlled in the simulation itself, and include weather (cloud types and coverage, visibility, rain, snow, fog), scenery detail, water effects, dust balls, airport traffic, road traffic, and time of day/night lighting.

Post-production effects can include NVG simulation, additional weather effects, instrument panel simulation and personnel simulations. In order to show high levels of detail, the visualization may require non-realtime rendering.

Filming

Once a validated flight path is working in the simulator, virtual cameras are placed in the simulator, either inside the cockpit, following or fixed to the subject aircraft, or at some arbitrary location (tower, runway button, observer position). Footage of the sequence is captured from these cameras, archived, and then synchronized in preparation for editing.

Dustball Effects

> "…it can reveal relevant issues hidden in millions of lines of data,…"

Editing

The virtual camera footage is assembled in an editing application such as *Premier* or *AfterEffects*. If the aim is to produce a promotional video providing an overview of the occurrence, movies can be made by cutting together the footage. Critical incidents in the film can be shown in slow motion. No more than two camera views are displayed simultaneously. For an investigative visualization, the sequence is rendered with as many as four camera views simultaneously, as well as FDR or other synchronized flight data. Overwhelming for the casual viewer, this allows the investigator to integrate many aspects of the investigation into a common picture and perhaps extract new findings or find problems in the investigation analysis. The final videos are rendered then saved in a usable video format, currently WMV2.

Visualization Production Speed

The visualization workflow is very involved and time-consuming. That said, the goal from the start of the project was to be able to produce a first draft of a video within a single eight hour period. In order to achieve this, much work must be done upfront, before an incident occurs. This is done by integrating libraries into a single visualization station. The libraries include aircraft, airport, object, flight path, and terrain libraries. All RCAF aircraft are ready for use at a moments notice. Similarity, RCAF airfields and other Canadian airports have been collected and are available for use in the simulator. Satellite imagery of most Canadian bases has been collected and is available. Libraries of common airport objects, trees, buildings, other aircraft, people, and other objects can also be employed.

Currently the bulk of time for visualization consists of flight path analysis. Each aircraft and accident poses their own challenges. The workflows and techniques of FDR, flight path and acceleration analysis, photogrammetry and videogrammetry have each taken a significant amount of time to develop, but subsequent investigations should prove to be an order of magnitude quicker. A library of sample flight path analysis for each aircraft type would further expedite future analysis/investigation.

Other air forces are discovering the benefits and capabilities of visualization. The USAF is using it to depict dangerous events found through their Flight Operations Quality Assurance (FOQA) program. Other nations are using visualization to show the circumstances behind crashes, and for aircrew training.

Follow on

Visualization is proving to be a powerful tool, for both investigation and promotion. As part of an investigation, it can reveal relevant issues hidden in millions of lines of data, or it can illustrate the dangers of a certain aerial manoeuvre to the aircrew. This capability requires special tools, and significantly trained individuals to operate these tools. Visualization represents a potent capability for accident prevention and training, and should be maintained.

QETE –
Engineering Support and More

By Mr Vince Horne and Captain Hani Mustafa, Quality Engineering Test Establishment, Gatineau, Quebec

Mr Vince Horne is the Group Leader for Flight Safety & Vehicle Systems in QETE and is a retired Aerospace Engineering Officer. Captain Hani Mustafa is an Aerospace Engineering Officer who is working in the capacity of Aircraft Accident Investigation at QETE.

The Quality Engineering Test Establishment (QETE) is a Department of National Defence (DND) unit that serves an important role in the Canadian Forces. QETE's mandate is to provide investigation, evaluation, advice, and representation for DND and the Canadian Forces (CF) throughout the life cycle of equipment, from a technology versus platform perspective, to ensure performance requirements are met, and issues of safety, reliability and operational readiness are addressed. QETE delivers multi-disciplinary engineering and applied science services, thus ensuring that materiel and services used by DND and the CF satisfy their operational and performance requirements throughout their life cycle. QETE's mandate and mission ties in well with the objectives of the Directorate of Flight Safety (DFS), the Directorate of Technical Airworthiness Engineering Support (DTAES) and the Weapon System Managers (WSMs).

> "QETE's mandate is to provide investigation, evaluation, advice, and representation for DND and the Canadian Forces (CF)..."

Photo: Mr Julien Dupuis

QETE is comprised of five technical sections: Mechanical & Materials Engineering, Applied Chemistry, Electrical Engineering, Metrology & Test Equipment Services, and Land Engineering. The Flight Safety group (part of the Mechanical & Materials Engineering section) is QETE's primary contact for technical investigative services related to flight safety investigations, and utilizes the expertise of other

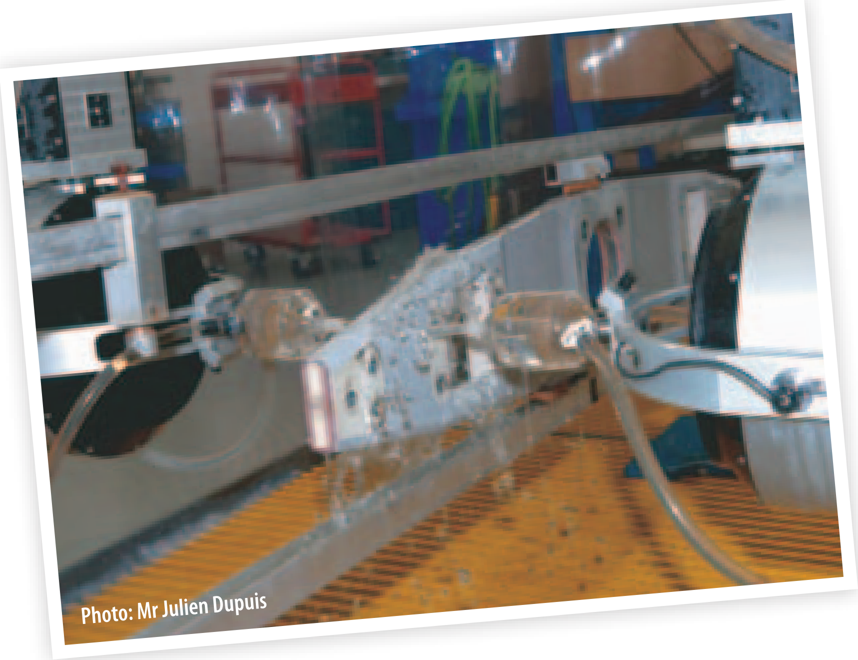


Photo: Mr Julien Dupuis

sections within QETE to conduct its work. This is what makes QETE a unique entity, almost all the diverse technical capabilities required for independent system and component level failure investigation are housed under one roof. With the support of all the QETE laboratories, aircraft systems such as engines, flight controls, avionics, and aviation fluids can be studied in detail to determine if equipment failure contributed to an accident or incident. In addition, expertise in areas such as non-destructive inspection and testing allows QETE to make recommendations on potential inspection techniques, risk mitigation and preventative measures.

The Flight Safety group is staffed with both civilian and military engineers and technologists. The civilian staff have extensive experience and expertise in aviation fields such as aviation life support equipment and aircraft engines. The military positions include an Aerospace Engineering Officer (Lt/Capt), an Aviation Systems Non Commissioned Member (WO) and, along with technical expertise, they bring a detailed knowledge of current military training, maintenance and operational practices.

Similar to the practices of civilian aircraft accident investigations, QETE's Flight Safety group works both in the field (where applicable) and laboratory settings. The Flight Safety group has a "crash lab" facility that permits aircraft wreckage reassembly and detailed analysis of damaged aircraft structure. In this controlled environment, features such as fracture surfaces, material deformation, the location of damaged components, debris, trace evidence, and/or soot patterns provide clues which could help in determining the sequence of events, as well as the cause of an accident or incident.

As part of an investigation, QETE investigators inform DFS of not only how a component failed but also likely why it failed. In many cases, an individual component failure results from a sequence of other system failures that interact with that component.

One example would be the failure of a gas turbine blade. A gas turbine blade may ultimately fail due to a crack that propagates in the blade's root, reducing its structural integrity, causing it to separate from the turbine wheel and resulting in damage to surrounding components. As part of the investigation the failure mechanism might be identified as fatigue but the investigation does not end there. The blade may have failed in fatigue for many different reasons.

> "One example would be the failure of a gas turbine blade."


Photo: Mr Julien Dupuis

It may have been that the turbine blade was not installed properly or that there was a flaw in the geometry of the blade due to a problem with the manufacturing process. Material deficiencies may have rendered the blade incapable of withstanding the harsh operating environment or the operating environment itself may have changed due to another failure elsewhere in the engine. One can see how a single component failure investigation can branch into multiple investigative thrusts in an attempt to determine the cause(s) and identify preventative measures.

QETE has an extensive library of archived failure investigation reports completed on behalf of DFS and other agencies which it uses to assist with new investigations. As aviation technology is constantly evolving, QETE is continuously researching and collecting information on new materials and manufacturing processes, changing maintenance practices as well as advancing investigative techniques. In most cases, however, the most critical information required to complete a failure investigation comes from the users and maintainers themselves.

All of the technical information including imagery/audio, maintenance records, drawings, and eye witness testimony is gathered from stakeholders including (but not limited to) DFS, the WSMs, the Air Maintenance

> "...the most critical information required to complete a failure investigation comes from the users and maintainers themselves."

Squadrons (AMSs), the Original Equipment Manufacturers (OEMs), and most importantly the CF field units. Those units are the ones that experience a flight safety occurrence first hand and, as a result, have first-hand knowledge as to the details of what took place. As thorough research is required to understand the sometimes complex systems and the failure occurrences themselves, an open exchange of information between QETE and stakeholders ensures that the failure investigation is both efficient and effective in yielding plausible explanations for the cause(s) of a failure.

Coordination in the conduct of a failure investigation is crucial when there are multiple investigative thrusts and there are points (lessons learned) that should be considered by anyone that becomes involved in a failure investigation. Key evidence could be lost at every stage of an investigation if proper precautions are not taken to preserve it. Photographs need to be taken as soon as possible and must include not only the failed component but also any other system components it interacts with. Environmental conditions including weather, dirt, dust or other contaminants such as oil or grease should also be documented and photographed. Witness statements should be taken as soon as possible and all observations should be recorded, whether they are considered likely to be relevant or not. Finally, care must be taken to prevent additional damage or contamination of failed components (something that frequently occurs during disassembly) prior to shipment to QETE labs.

"Environmental conditions including weather, dirt, dust or other contaminants such as oil or grease should also be documented and photographed."

At QETE the employment of optical and scanning electron microscopes as well as other highly sensitive equipment allows detailed analysis of often pertinent evidence that is not even visible to the naked eye.

Whether in support of accident investigation with significant operational implications or a routine incident investigation that highlights potential product improvements for future acquisitions, the Quality Engineering Test Establishment is dedicated to providing the best possible engineering support to its clients and the CF as a whole.


Photo: Mr Julien Dupuis

Safety by the Numbers –

The USAF MFOQA Programme

By Antonio Cortés, Headquarters U.S. Air Force Safety Center, Albuquerque, New Mexico

Mr Cortés started his career flying the C-21 and C-141 for the USAF, where he was also a flight safety officer. He worked safety issues with the Air Line Pilots Association while flying MD-80s for Midwest Airlines and went on to teach flight safety as a professor at Embry-Riddle Aeronautical University. He is currently a Federal civil servant working as an MFOQA Manager at the Headquarters USAF Safety Center.

Can you imagine what it would be like to fly your next mission without any cockpit instruments? You would have to rely on gut-instinct and perception, guessing your altitude, airspeed, and thrust settings. I suspect the sortie would end quickly and painfully, particularly if at night or in the weather. Pilots have come to rely so extensively on quantitative feedback during flight that many years ago we coined the expression, "Flying by the numbers." The expression today is often used to signify the precise control of an aircraft in accordance with performance targets.

> "...the expression, "Flying by the numbers." The expression today is often used to signify the precise control of an aircraft in accordance with performance targets."

Have you ever heard of managing a flight safety programme by the numbers? Aviators take great pride in flying by the numbers, but when we don safety hats and try to manage a flight safety programme, all too often we rely on gut instinct and on the anecdotal perception of hazards. As safety managers we try our best to detect all significant risk, but often neglect invisible threats because we are focused on those obvious hazards that appear imminent and dangerous. Psychologists tell us that what holds our attention is what determines action. Unfortunately, what holds our attention isn't always what should determine our action. Our attention is easily seduced by

"Philosophically, the great challenge of mishap prevention is that safety is often defined by the intensity of its absence."

what we believe are pressing issues, but in reality we often don't know the gravest safety threats. "We don't know what we don't know." Invisible hazards often inflict more harm than the obvious hazards.

Leaders are often unaware that a mission is drifting towards disaster because they lack the means to detect the numerous weak signals of failure that precede most mishaps. For example, let's contemplate the difference that a few millimeters can make in our profession. An aircraft can come within a few millimeters of striking a wingtip on landing, but not scrape, and no one will hear of the event. However, if that same wing actually scrapes on landing, even if by just a few millimeters, maximum dissemination of the event will occur. How can we ethically allow a few millimeters to determine whether an event recedes into obscurity or flashes across a commander's desk? After all, the unsafe acts and conditions that went into the near-scrape are probably identical to those that resulted in the actual scrape. The only difference between both scenarios is luck. Can we call ourselves safety professionals if we allow luck to dictate the terms of our hazard reporting?

Over the past decade the U.S. Air Force has implemented a scientific approach to uncover the weak signals that precede mishaps. We have implemented safety by the numbers in an effort to proactively take control of hazard reporting. The initiative is called Military Flight Operations Quality Assurance (MFOQA), a military version of the civilian Flight Operational Quality Assurance (FOQA) and Flight Data Management (FDM) programmes. Whatever we choose to call it, the idea is to routinely download flight data in order to detect mishap precursors. Philosophically, the great challenge of mishap prevention is that safety is often defined by the intensity of its absence. In other words, we often try to manage safety by measuring the rates of mishaps. Smoking holes are, rather tragically, the traditional metric used to measure safety. Unfortunately, they are trailing indicators of safety. Managing safety by using mishap

> "With the data from the "almost mishaps" we can measure our drift towards failure instead of just the actual failures."

metrics is like driving a car solely by looking in the rearview mirror. MFOQA allows us to actually measure the leading indicators of safety by examining close calls, which we know occur in far greater numbers than actual mishaps, and thus furnish our analyses with far more data than what our infrequent mishaps provide. With the data from the "almost mishaps" we can measure our drift towards failure instead of just the actual failures.

Our MFOQA programme is overseen and promoted by the USAF Safety Center at Kirtland Air Force Base in Albuquerque, New Mexico. Currently the following 9 fleets of aircraft participate in the programme, in some form or fashion: F-16, C-17, T-6, KC-135, C-130J, C-32, RC-135, C-37, and C-40. The C-5M will be the next fleet to join. Four prerequisites must be met in order to participate in MFOQA: an aircraft must have the ability to record the proper types of flight data, an experienced pilot trained in the MFOQA processes must analyze the data to detect mishap precursors, the command structure must know how to use the resulting analyses to manage risk, and a safety culture must exist that protects aircrew when errors are made.

In order to promote the proper use of flight data and prevent using the programme to punish aircrew, the U.S. Secretary of Defense dictated in 2005 that data generated from the MFOQA process shall not be used for monitoring aircrew performance to initiate punitive or adverse action, except for cases of suspected willful disregard of regulations and procedures. We go to great lengths to ensure that MFOQA is a "white hat" programme. We accumulate data from many flights and de-identify the data before we try to detect instances where aircraft operated outside of preset parameters. We are especially interested in finding unsafe latent conditions such as normalization of deviance that may point to poorly designed procedures. We work closely with our human factors experts to determine the root causes of the mishap precursors detected by MFOQA.

In the decade since commencing our MFOQA initiative, the USAF has learned to value the analyses produced from flight data. Aircrew flying MFOQA aircraft can learn the latest hazards at deployed locations and use such information to brief threats and errors germane to airfields, terrain, ATC, and navigation. MFOQA analyses can be used to validate the effectiveness of tactics, training, and procedures by measuring what actually happens during flight operations, versus what we think is happening. Actual aircraft performance data can be used to validate or correct calculated performance figures. Insights can be gleaned on how tightly flights are following mission profiles. Safety officers can learn what airfields are associated with high numbers of unstable approaches and what locations are triggering the most stall warnings, TCAS activations, or GPWS alerts. Flight profiles can be examined to discern where over-Gs and over-temps are most likely to occur. Analysts are able to determine whether procedural changes have improved operations or made things worse. Mission planners can optimize flight profiles to save time and fuel. In a nutshell, MFOQA allows us to make information-based decisions, instead of relying on our gut instinct, which is often wrong.

> "Analysts are able to determine whether procedural changes have improved operations or made things worse."

I wish the USAF could take credit for coming up with MFOQA, but we are only one voice in a chorus of organizations that tout the value of flight data analysis. The idea originated with British Airways in the 1960s. Academic researchers have documented significant decreases in mishap rates and maintenance costs at those airlines that have started flight data programmes when compared to other air carriers that do not analyze flight data. The U.S. Federal Aviation Administration estimates a net savings of $892,000 per year for each 50 aircraft flown in FOQA programmes. Such a calculation partly explains why over 40 civilian companies in the U.S. have FOQA programmes and why all International Civil Aiation Organization airlines operating aircraft with maximum takeoff weights in excess of 27,000 kg are required by law to have flight data programmes. Commercial operators can also save significantly from reduced insurance premiums. One British air carrier achieves $8 million CAD a year from insurance savings by showing that flight data analysis makes their operations safer every year. Such a savings proves that insurance companies striving to reduce payouts believe FOQA is a "best practice."

In closing I will quote Captain W.D. Lowe, former Concorde pilot and Chief Pilot of British Airways, who complimented FOQA by claiming, "It is the most important way to dramatically improve flight safety." From where I am sitting, I can safely say that I wholeheartedly agree with Captain Lowe. As professional aviators we should fly by the numbers. As safety officers we should be equally professional and also practice safety by the numbers.

Aircraft Accident Investigation

Using Commercial Satellite Imagery

Dr Matthew Greaves and Professor Graham Braithwaite
Cranfield Safety and Accident Investigation Centre, Cranfield University

Matthew Greaves is a Lecturer in the Safety and Accident Investigation Centre at Cranfield University. Prior to joining Cranfield he worked for the science and technology organisation QinetiQ. He holds an engineering degree and a PhD in aircraft engine noise and vibration. His research deals with the application of technology to the accident investigation process.

Graham Braithwaite is Head of the Department of Air Transport at Cranfield University, UK. He was appointed as Director of the Safety and Accident Investigation Centre in 2003 and awarded a Chair in Safety and Accident Investigation in 2006. Prior to this, he worked as a Lecturer at the University of New South Wales, Sydney. Graham holds a PhD in aviation safety management from Loughborough University and his research has focused on issues of safety, culture, and investigator training.

Introduction

In the majority of aircraft accidents, the wreckage is easily located and is accessible to investigators; however, there are notable exceptions. The loss of Air France Flight 447 over the Atlantic Ocean in 2009 and Adam Air Flight 574 which crashed near Indonesia in 2007 show the difficulty that can be experienced in locating aircraft wreckage. Similarly, the RAF *Nimrod* that crashed in Afghanistan in 2006 and UTA Flight 772 which broke up over the Sahara Desert in 1989 both show that wreckage can be difficult or even impossible to access due to either political or geographical constraints.

For these reasons, there has been an increasing interest in the use of general aerial imagery for the location, and subsequent analysis of aircraft accidents. In more populated areas this may come from police, air ambulance or even news helicopters, but again, this will be absent in more remote regions. Some agencies and organisations may have arrangements which allow access to imagery from military satellites, which may have different capabilities to commercial satellites. Following the loss of Flight 447, a request was made for the US Government to use satellite technology to assist in the search for wreckage. However, there are often issues surrounding the priority of acquiring this imagery and its subsequent access and use in the civilian domain. As a result, attention has turned to the use of commercial satellite imagery for accident location and investigation. This paper evaluates the current state of the art focusing on the needs and priorities of an accident investigation and reporting upon live trials conducted in Cyprus in 2009.

> "Some agencies and organisations may have arrangements which allow access to imagery from military satellites, which may have different capabilities to commercial satellites."

Commercial Satellite Imaging

The availability and use of commercial satellite imagery has grown markedly in recent years with no better demonstrator than the ubiquitous *Google Earth*. However, acquiring this imagery on demand is not cheap and therefore it is useful for investigators to know what can potentially be achieved by this technology. For example, it would be helpful to know whether, say, a flight data recorder can be identified by a particular satellite before spending many thousands of pounds acquiring the image to order. Whilst the published specifications of the imaging satellite can provide some of this information, they are not the whole picture!

Satellite	Panchromatic (m)	Multispectral (m)
OrbView-3	1	4
IKONOS	0.82	4
EROS-B	0.7	–
QuickBird	0.61	2.44
WorldView-1	0.5	–
WorldView-2	0.46*	1.84*
GeoEye-1	0.41*	1.64*

* Subject to restrictions – see below

Table 1 – Available resolutions of commercial satellites

Satellite	Resolution (m)
ADARSAT-2	3
COSMO-SkyMed	1
TerraSAR-X	1

Table 2 – Available resolutions of commercial radar satellites

There is a wide range of satellites offering images in the visible spectrum, all with different resolutions and characteristics. Table 1 shows some of the higher resolution satellites and the best resolution available from each. This indicates the smallest dimension that can be resolved and hence a lower number is better. Resolutions are shown for both panchromatic images (black and white) and multispectral (colour and other bands). Clearly, the panchromatic resolutions are much greater than the multispectral. One useful concept when dealing with satellite imagery is that of ground sample distance (GSD) which is the size of area on the ground represented as a pixel at nadir (i.e. overhead). As the viewing angle changes from directly overhead, i.e. increasing off-nadir angle (ONA), the available resolution reduces.

Whilst satellite resolutions continue to improve, the distribution and use of imagery from US-owned satellites at better than 0.50m GSD panchromatic and 2.0m GSD multispectral is subject to prior approval by the U.S. Government. Without this approval, images at resolutions better than 0.5m will be resampled to give 0.5m resolution. Whilst this approval may be granted in the case of accident investigation and resolutions will continue to improve, it is at least feasible that resolutions better than those currently offered will not be available in the near future.

One useful technique aimed at maximising the information available from electro-optical (EO) imagery is that of pan-sharpening, which can often be specified when requesting the imagery. This involves fusing the colour information from a multispectral image with the geometric information from the panchromatic image, essentially yielding a high-resolution colour image.

Commensurate with this growth in EO satellites has been an increase in the availability of commercial radar imagery, albeit at slightly lower resolutions. Table 2 shows three of the commercial radar satellites available and their associated resolutions. EO satellites are unable to image through thick cloud, whereas radar does not suffer from the same limitation. This is particularly relevant when considering that poor weather is a factor in many accidents.

In general when obtaining satellite imagery of a particular location, it is possible either to purchase a pre-existing 'library' image or to task the satellite to acquire a new image. Clearly, whilst library imagery is useful for planning, recovery, visualisation, etc. it offers little to support the process of investigating the accident. Therefore, if up-to-date imagery of the accident site is required, it will be necessary to task the satellite to acquire specific imagery. The speed with which this can be done depends on a number of factors including budget, priority and satellite orbit. However, as a general guideline, the minimum time it would take to task a specific image, from point of request to having the image would generally be between 1 and 2 days.

Imaging satellites are scientific instruments with a wide range of parameters that need to be specified before acquiring an image. An analogy can be drawn with SLR cameras where there are many modes and settings, some of which will drastically affect the outcome of the image. Whilst it is beyond the scope of this paper to discuss the specifics of acquiring an image, parameters that can be adjusted include: file type; imaging mode (related to imaged area and resolution); datum and projection; post-processing; dynamic range, etc. It should be noted that just like the zoom lens on a camera, most satellites can image a range of areas (e.g. 5km x 5km, 10km x 10km, etc.) but that an increase in area will often lead to a reduction in resolution.

Once an image has been acquired, it is usually delivered as a digital file. Dependent upon the size of the imaged area, the file size involved can be significant e.g. 1GB for a 10km x 10km image, which has implications with respect to file handling. The majority of current handheld devices will not deal with a file of this size. An additional complication arises from the file format. Whilst it is often possible to specify the delivered format, the default format can be, say, the National Imagery Transmission Format (NITF) rather than the more common TIFF or JPEG. This means that the processing chain should also be considered when acquiring imagery as specialist software may be required to view the image. In some cases, further post-processing is required before anything resembling an image is produced.

These points are not raised to discourage the investigator, but rather to highlight the need to prepare for the possibility of a need to utilise imagery in the future.

> "The speed with which this can be done depends on a number of factors including budget, priority and satellite orbit."

Attempting to understand the different satellite parameters should not be done whilst searching for a lost aircraft. Therefore, it may be appropriate for a representative to engage with a satellite imagery provider to establish a 'standard' set of parameters and a processing workflow before it is needed in anger.

Trial configuration

In order to assess the potential utility of satellite imagery in aircraft accident investigation, a trial was conducted in which known targets were set out and imaged. The trial was conducted in collaboration with the UK Ministry of Defence (MoD), the UK Air Accidents Investigation Branch (AAIB) and the Defence Science and Technology Laboratory (dstl). Cyprus was chosen as a location for the trial due to the generally clear skies and the availability of open space.

Three test sites were set up: the first used accident-damaged aircraft components (metallic, carbon fibre and mixed materials) in representative terrain and the second used a helicopter door and tail boom floating at sea. The third site consisted of a grid of objects of various sizes and materials including metal squares ranging from 0.5m x 0.5m to 4m x 4m and real wreckage, all for use as a 'testcard' for the satellite. These sites offered an array of problems at the more challenging end of wreckage location and plotting. Clearly, finding an intact 50m fuselage will be easier than a 4m x 4m square panel. All three sites were also surveyed by the Joint Aircraft Recovery and Transportation Squadron (JARTS) using differential GPS mapping.

Two images were acquired of the site; an electro-optical image from the *QuickBird* satellite and a radar image from the *TerraSAR-X* synthetic aperture radar satellite (courtesy of *infoterra GmbH*).

The *QuickBird* image was of a 10km x 10km area, taken with a 0.6m (panchromatic) and 2.4m (multispectral) ground sample distance at an average off-nadir angle of 3°. The file was supplied in NITF 2.1 format with a file size of 960MB. The image was requested at 'Assured' tasking level for a time window of 17th – 21st August 2009 and was acquired on Monday 17th August at 08:42 GMT. (This is relevant because painting of the target was completed at approximately 10:00 GMT; comparison of Figures 1a and 1b show that the orange 4m x 4m orange square is only three-quarters completed and the other two 'orange' squares are unpainted and not raised!) The file was viewed using *GeoGenesis Lite*, a free NITF viewer from IAVO. The commercial cost of tasking this image, given the Assured tasking level and relatively narrow acquisition window, would be in the region of £10,000.

The *TerraSAR-X* image was acquired of a 10km x 10km area in 'Spotlight' mode giving a 1m GSD. However, by the nature of its operation, the preferred range of acquisition angles for this satellite is 20° to 55° with the trial image being acquired at 48°. This acquisition angle results in a reduction in resolution to approximately 1.5m. The file was delivered as a Complex SAR image and was approximately 220MB in size. Analysis was performed using *Radar Tools*, an open source application. The commercial cost of tasking this image would be in the region of £7,000.

Figures 1 – 3 show handheld imagery of the three sites taken from a helicopter, corresponding pan-sharpened electro-optical images extracted from the *QuickBird* image and two images extracted from the *TerraSAR-X* image.


Figure 1a – Handheld image from helicopter of the grid

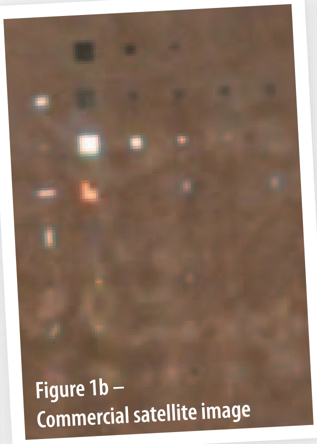


Figure 1b – Commercial satellite image

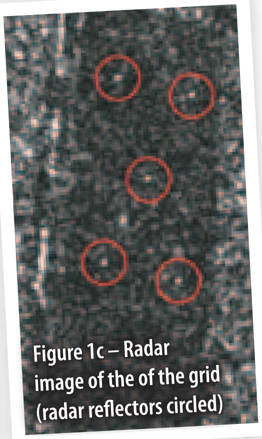


Figure 1c – Radar image of the of the grid (radar reflectors circled)

Figure 2a – Handheld image from helicopter of the *'Harrier'* site (Both wings and tailplane circled)

Figure 2b – Commercial satellite image of the *'Harrier'* site

Figure 3a – Handheld image from helicopter of the sea site

Figure 3b – Commercial satellite image of the sea site

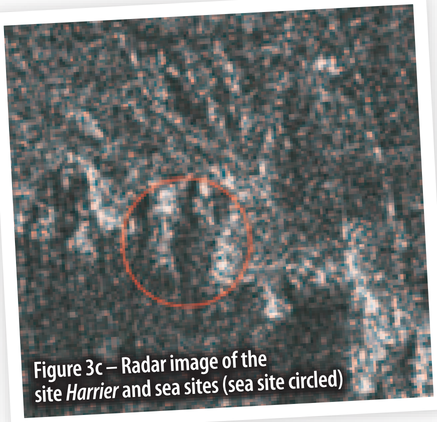


Figure 3c – Radar image of the site *Harrier* and sea sites (sea site circled)

Analysis

Each of the items in the grid was analysed for interpretability by examining the image and deciding whether it was distinct from the background, i.e. whether there was "something there". No attempt was made to interpret the detail of the item.

Of the 50 targets that were in the grid, 20 were clearly visible, 7 were marginal and 23 were undetectable. The clearly visible targets included: a 2m x 2m black square; a 1m x 1m white square; a tail panel and a bulkhead (each 2m x 1m approximately). The marginal targets included: a 1m x 1m black square; a 0.5m x 0.5m white square; a canopy section and a pair of seats. Those targets which were deemed undetectable included: a 0.5m x 0.5m black square; a 4m x 4m Perspex square; a helicopter rotor blade and a flight data recorder.

These results highlight the other factors that impinge upon the interpretability of an image. Whilst the panchromatic GSD of 0.6m gives an indication of the results that might be available, the results are also heavily affected by other factors such as the surrounding area, object colour, viewing geometry, etc. It is interesting to note for example, that the 2m x 2m black square is clearly visible occupying approximately 4 pixels by 4 pixels, but also is the 1m x 1m white square occupying 2 pixels by 2 pixels, whilst the 1m x 1m black square is considered marginal. Because of the colours present in the surrounding area, a white

> "This involves taking a 'before' image and comparing it to the 'after' image in order to highlight any differences."

pixel is much higher contrast than a black pixel, making it more prominent.

In order to test the geolocational accuracy of the satellite image, 20 items were chosen from the grid, the location of the item's centre was estimated and the coordinates noted, as displayed by the software based on the geographical information embedded within the image. These coordinates were then compared with the surveyed data.

Comparing the coordinates for absolute accuracy (i.e. comparing merely the precise coordinates) the average error was 10.25m for the Easting and 3.56m for the Northing with a maximum error of 10.80m and 3.75m respectively. Assessing the relative accuracy (i.e. the distance between items) the average error was 0.20m for the Easting and 0.08m for the Northing with a maximum error of 1.05m and 0.23m respectively.

Given the distances involved from sensor to object and the potential errors due to pixellation and centre estimation, these accuracies are exceptional. Notwithstanding the issues of interpretability above, a typical maximum error of 20cm would be deemed more than accurate enough for wreckage plotting from a distance.

One technique that is often referred to in imagery analysis is that of change detection. This involves taking a 'before' image and comparing it to the 'after' image in order to highlight any differences. This can either be done manually or in software. The manual approach may be as simple as viewing the two images on the screen simultaneously and moving around them in a synchronised way looking for differences or anomalies. Whilst this method is labour intensive, it can be extremely effective.

The software approach uses algorithms to compare the before and after image. However, this technique works most effectively when using 'matched' images i.e. images taken from the same sensor, at the same resolution, with the same geometry with only differences of interest present. Clearly, since the next accident location is unknown, the likelihood of matched imagery being available is low. Therefore, automated change detection was attempted on the *QuickBird* image of the grid, with an image from the *GeoEye* satellite providing the reference from which to detect change. Whilst it would be possible to adjust the detection parameters in order to highlight the areas of known change, the point of using this technology is to detect change where it is unknown. Therefore, the change detection was performed using standard parameters.

A piece of software called Matisse, written by dstl, was used in an attempt to detect change. After performing the change detection, one of the panels in the grid was highlighted by the software as the most prominent change in an area of 700m x 700m around the grid. Expanding this to a 4km x 3km area resulted in the software highlighting the same panel as being one of the 50 most prominent changes in the scene.

Clearly, this technique will not be used as a totally automated process, but rather as a way of highlighting possible areas of interest to an

> "Clearly, this technique will not be used as a totally automated process, but rather as a way of highlighting possible areas of interest to an imagery analyst."

imagery analyst. Therefore, given the results above, it is feasible that an analyst may be able to process the changes highlighted in, say, a 10km x 10km scene in a day although as the algorithm ranks possible detections, the more highly ranked a find is, the more likely it will be found by the analyst early in the process.

Examination of the radar image of the grid highlights some of the difficulties of working with radar. The five radar reflectors (laid out like the face of a die) are visible and circled in Figure 1c, as are some of the other components including the tail plane. However the resolution is such that each item occupies no more than one pixel in size. This makes it very difficult to interpret the image.

Figures 2a and 2b show the *'Harrier'* site. Whilst the bright blue parachute in the top left hand corner of the image is clearly visible, comparison of the two images clearly highlights the difficulties in distinguishing the wreckage from the surrounding scrubland. The wreckage visible in this image includes both wings, the rear fuselage and both drop tanks from a *Harrier*. There are also many other smaller parts in the images, such as pipes and a nose gear leg, but these are only visible from the helicopter image when zoomed and are not visible on the satellite image.

> "WorldView-2 is a high-resolution multi-spectral satellite and is one of the most recent commercial satellites available."

Figures 3a and 3b show the helicopter and satellite image of the sea site. The handheld image shows a helicopter tailboom floating in the water and a red door on the beach. However, it is not possible to distinguish any of the wreckage from the surrounding land or the sea. Similarly, the resolution offered by the radar image in Figure 3c, coupled with the noise and returns from the surrounding area make it impossible to identify any wreckage and difficult to even identify the local geography.

Practical Example

On April 10th 2010, a *Tupolev* 154 aircraft crashed near Smolensk, Russia killing all 96 people onboard including the Polish President. Satellite imagery of the accident site was acquired from the *WorldView-2* satellite and archived. This imagery was then provided to Cranfield courtesy of *DigitalGlobe* for research purposes.

WorldView-2 is a high-resolution multi-spectral satellite and is one of the most recent commercial satellites available. It was launched in October 2009 and is capable of producing high quality images with a resolution 0.46m for panchromatic and 1.84m for multispectral. In addition to the traditional Red, Green and Blue bands, it also offers two near-infrared bands, a red-edge band, a yellow band and a coastal band. Using the latter band, *WorldView-2* has the ability to perform bathymetry (measurement of depth in water).

The image in Figure 4a clearly shows the wreckage trail in the top right corner. It also shows the vehicles, tents and access routes being used by emergency services and investigators. It is clear from this figure that at this resolution, a trained analyst could easily identify this wreckage trail as the location of an accident. However, this image represents an area of approximately 150m by 100m. Clearly, at this magnification, the analyst time taken to manually search, say, 20km by 20km would be considerable, although not completely impractical.

Figure 4b shows the same image zoomed on the wreckage trail with the rear section of the aircraft in the centre of the image. Other footage of the accident site suggests this piece is of the order of 10m in

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Figure 4a – Wreckage trail and surrounding area

© DigitalGlobe, Inc. All Rights Reserved. Imagery provided by the WorldView Global Alliance

Figure 4b – Wreckage trail enlarged

length, which is consistent with the number of pixels depicting it. However, unfortunately, this is clearly a high-energy accident resulting in significant destruction of the aircraft and hence it is difficult to distinguish many other parts of the aircraft.

Although satellite imagery had no role to play in the analysis of this specific accident, it provides a valuable proof of concept, particularly because it uses one of the highest resolution commercial satellites available, *WorldView-2*.

Concluding Remarks

The growth in commercial satellite imagery means that access to imagery is widely available. However, as the discussion has outlined, the tasking and acquisition of this imagery is not trivial, with a wide range of factors and parameters to be taken into account. It would be prudent for organisations who may wish to acquire commercial satellite imagery to make contact with an imagery provider in order to establish their typical requirements in advance of requesting imagery. This is particularly important if imagery is required quickly, say, in response to an accident at sea where buoyancy may be time-limited.

Commercial satellite imagery is not yet of a quality to replace ground imagery or handheld imagery taken from a helicopter. However, the results of this trial and example have shown that there is potential utility in commercial satellite imagery for both wreckage location and wreckage plotting in specific situations. However, there are a wide range of factors affecting performance which are outside the control of the investigator including wreckage and scene colour, wreckage size, acquisition geometry, etc. The perceived risk of a wasted collection posed by these factors will obviously depend upon the situation faced by the investigator.

Future plans for research in this area include further trials into higher resolution multispectral satellites and the possible use of radar and hyperspectral sensors for detection of fuel and oil patches for location of accidents at sea.

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Spatial Imaging as a Site Recording Technique in

Air Accident Investigation

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Introduction

Traditionally, aircraft accident site dimensions have been recorded using tape and offset measuring procedures and techniques to produce hand-drawn site and wreckage plots. However, modern technologies such as photogrammetry and laser scanning now offer viable alternatives to this technique. This paper, drawn from an MSc research thesis, examines the potential of these technologies using a simulated accident site.

Technologies

Cameras have been used by investigators for many years to record evidence at a crash site. The Air Accidents Investigation Branch (AAIB), in its guidance to the police, emergency services and airfield operators, states that "coverage should include an overall view of the site and close-up of wreckage, especially the cockpit area, and of the bodies"[1].

Hand-held cameras are ideally suited to this requirement as they are light, inexpensive, and relatively easy to use. Not only do they record in colour and in high resolution but with the advent of digital cameras with large memory storage capacities, they can also record hundreds of high quality images. Furthermore, with advances in digital photography and data analysis programs, in-depth data can be gained from such images. Using photogrammetry, which Mikhail defines as "the process of deriving metric information about objects through measurements made on photographs of the object"[2], accurate measurements can be derived from photographs. This process has been simplified through photogrammetry software such as *PhotoModeler*™ which allows accurate measurements to be obtained away from the accident site.

Total stations (precision surveying instruments which measure range and angles to targets) are routinely used by UK police collision investigation teams and are increasingly being seen at some larger scale air accident sites. These total stations allow

> "Hand-held cameras are ideally suited to this requirement as they are light, inexpensive, and relatively easy to use."

operators to plot accident sites using laser beams to calculate the angles and distances to a target from a known position.

Laser scanning is a technology which on its own does not create an accurate wreckage plot however scanners do produce accurate 3-D models and are being used to a greater extent in accident investigation. Indeed, a recent initiative has provided funds for UK police collision investigation teams to purchase laser scanners.

Spatial Imaging is the name given by *Trimble*™ to its systems which use 3-D and positioning measurements captured at eye-level. In simple terms, they are total stations, laser scanners and digital cameras rolled into one precision surveying instrument. Whilst not currently being used as a site recording technique for air accident investigation, Spatial Imaging systems are being used in other investigation sectors and may have the capability and functionality required by an air accident investigator to record the site .

Evaluation Scenario

The aim of this research was to establish whether Spatial Imaging is an appropriate site recording technique for air accident investigation. In order to do this, a controlled scenario was created so that *Spatial* Imaging and photogrammetry techniques could be used to record the site and the results compared against measurements taken using traditional site recording techniques.

In order to produce credible data for evaluation, a simulated crash site was created at Cranfield Airport in the UK. Using the Safety and Accident Investigation Centre at Cranfield University, a small, typical, general aviation accident site involving the wreckage of a *Piper Saratoga* was constructed on the airfield adjacent to the main runway. Whilst the wreckage was that of an aircraft involved in a real accident, it was used merely to provide credible wreckage associated with a small general aviation accident.

To assess the accuracy of the two systems on test, a number of reference measurements were taken from the wreckage. These reference measurements were taken prior to scanning and photography, and were achieved using traditional tape and offset measuring techniques. These measurements were independently checked and verified and the scanning technicians and the photogrammetry photographer were aware of neither the location nor the measurement results.


Main Wreckage Trail

Photography

Gathering images for the digital photogrammetry was the easiest technique on trial. The trial assistant merely used a standard *Canon* EOS 400D camera set on automatic and took a series of images around the accident site, both from eye-level and from a raised position. The assistant had a rudimentary grasp of photography and photogrammetric principles. In total over 100 images were captured, but only 12 images were imported into *PhotoModeler* to allow measurements to be extracted. The time taken to capture these images was 20 minutes, and despite the relatively cold temperatures (+4°C), the standard battery was sufficient for the duration of the trial.

Laser Scanning

The scanning technicians took approximately 20 minutes to assess the site and setup the equipment for the first scan. They chose to complete three scans of the site from three different angles to

Surveying Equipment

ensure a full 3-D cloud was created. The area to be scanned took approximately 5 minutes to programme into the scanner using the portable controller before it was left in automatic mode to capture each scan. Each scan took 20 minutes to capture the data. A further 15 minutes was required between scans to relocate the scanner. The total time on site to capture the scans and capture the site/wreckage plot was two and a half hours.

Whilst two technicians carried out the scans, it was clear that this operation could have been carried out by a single, trained operative. Although apparently complex, the process is highly automated and an individual would be able to carry out scans with as little as one day of training.

Results

Both techniques on test were able to record the site but to differing standards. Both were able to produce accurate measurements although the photogrammetry technique required 10 times as long in the post-processing phase.

Capturing images for photogrammetry analysis was quick and required very little effort, a handheld digital camera and little or no training for the operator.

A major constraint of the photogrammetry technique is that it was not possible to convert the data into a wreckage plot. The images did capture some of the wreckage trail, and photogrammetry is capable of measuring the positions of some of the large debris but it could not produce a plot to the standard achieved using Spatial Imaging systems. Photogrammetry is principally designed to allow measurements to be extracted from photographs away from the accident site.

Due to the accuracy of the GNSS receiver, the Spatial Imaging plot was exceptionally accurate. According to the positional data recorded, positions were within 20mm horizontally. This technique not only allowed the wreckage to be plotted with positional accuracy but also allowed the shape and relief of the wreckage to be recorded. This feature could be extremely useful to an investigator operating in terrain. The technicians were able to allocate codes to each individual piece of wreckage with a *Bluetooth* enabled camera and would have been able to automatically upload a photograph, to an associated file. This type of recording using a *Bluetooth* camera was not assessed during this trial.

Once on the computer, *RealWorks*™, the associated software, automatically created the 3-D point clouds and within a very short space of time the investigator was able to use the software to view and extract useful data.

Screenshot from PhotoModeler 6.5

Wreckage plot achieved through Spatial Imaging

The measurements presented for the Spatial Imaging station in Table 1 were very easy to obtain and the whole process of extracting measurements took less than 30 minutes. The photogrammetry took an order of magnitude longer.

Conclusions

Spatial Imaging does have a number of advantages over standard digital photography and photogrammetry. It captures the site in extreme detail and by overlaying the digital images that are captured with the cloud data it provides the investigator with a real three-dimensional representation of the accident site. The scanner can operate with very limited input from the investigator once set up and the scanner can capture the scene whilst the investigator maps the wreckage plot using a GNSS receiver. The wreckage plot created using this system is exceptionally accurate. It is questionable whether this kind of accuracy is absolutely necessary for air accident investigation but the system does give a wreckage plot which is more accurate than the traditional tape and offset measuring techniques in use today[3].

One disadvantage of Spatial Imaging is that the system is not as portable as using a standard digital camera and photogrammetry analysis. Without good access it would be difficult for investigators to get all the equipment required to the accident site. Whilst scanning,

> "It captures the site in extreme detail and by overlaying the digital images that are captured with the cloud data it provides the investigator with a real three-dimensional representation of the accident site."

Set Criteria	Measurement taken on Site (m)	Measurements from Multi-Image Photogrammetric Project (PhotoModeler™) With Camera Calibration(m)	Measurements from Trimble™ VX Spatial Imaging Station
A	0.5000	0.532 (+0.032) or +6%	0.517 (+0.017) or +3.2%
B	0.250	0.264 (+0.014) or +5.3%	0.261 (+0.011) or +4.1%
C	0.500	0.499 (-0.001) or -0.2%	0.498 (-0.002) or -0.4%
D	0.250	0.274 (+0.024) or +8.7%	0.262 (+0.012) or +4.5%
E	0.500	0.515 (+0.015) or +2.9%	0.492 (-0.008) or -1.6%
F	0.860	0.867(+0.007) or +0.8%	0.867 (+0.007) or +0.8%
G	1.060	1.073 (+0.013) or +1.2%	1.064 (+0.004) or +0.3%
		Mean percentage error: 3.5%	Mean percentage error: 1.55%

Table 1 – Comparison of site measurements with results from multi-image photogrammetry

the unit needs to be free from any external influences. During the trial the investigator accidentally touched the tripod leg of the scanner. This small movement of the tripod leg rendered the scan unusable and that particular scan had to be restarted.

Spatial Imaging is not a cheap technology and units such as the one used for this research cost around about £80,000. It is unlikely that many air accident investigation units would be able to procure sufficient units to enable them to be used for all aviation accidents[4]. Systems like this are however exceptionally capable and would provide an investigator with additional capability on large scale land-based accident sites.

Digital photogrammetry is not ideally suited to creating a site/wreckage plot and is generally only used when the investigator requires a measurement which was not recorded at the accident site.

> "Spatial Imaging is not a cheap technology and units such as the one used for this research cost around about £80,000."

In situations such as this, where the investigator knows which measurement is required and a good collection of photographs is available, photogrammetry is an ideal solution; and in some situations it may be the only available solution. Unlike Spatial Imaging where measurements can be taken from any point with minimal processing, the operator using photogrammetry techniques needs to know what measurement is required before starting to build a picture. As a result of this constraint, photogrammetry is likely to continue to be used to provide the investigator with measurements which were not recorded in the field.

It can be seen that both Spatial Imaging and digital photogrammetry have their place in air accident investigation. Given unlimited resources, Spatial Imaging has been shown to produce accurate models enabling precise measurements to be achieved and has the added advantage over photogrammetry in that it can create a highly accurate wreckage plot. Whilst not always suitable for all accident sites, Spatial Imaging is a technology that provides the investigator with many advantages over traditional site recording techniques. Rather than replacing traditional tape and offset measuring and photogrammetry, Spatial Imaging should be seen as a complimentary technology which provides considerable advantages over traditional techniques in certain accident scenarios.

> "...the operator using photogrammetry techniques needs to know what measurement is required before starting to build a picture."

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Flight Path Analysis Based on Video Tracking and Matchmoving

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Major Adam Cybanski is a tactical helicopter pilot with over 20 years and 2500 hours on fixed and rotary wing aircraft including the CT114 Tutor, CH139 Jet Ranger, CH135 Twin Huey and CH146 Griffon. He completed a tour in Haiti as Night Vision Goggle Specialist and Maintenance Test Pilot, and has managed the CH146 Griffon Full Flight Simulator. He is a graduate of the Aerospace Systems Course and holds a BSc in Computer Mathematics from Carleton University.

Visualizations of Flight Data Recorder (FDR) flight paths can be used in accident investigation to validate witness testimony, determine flight profiles, calculate ground tracks, harmonize radar data, witness information, and FDR data, and to provide quick and intuitive lessons learned to a much larger audience than just the pilots of the aircraft type. Unfortunately, many aircraft are not equipped with comprehensive FDRs, and only employ Heads Up Display (HUD) or cockpit video to document aircraft flights. A new capability has been developed at the Canadian Forces Directorate of Flight Safety to extract 3-D positional data from such video footage through photogrammetry and match moving and employ it in investigative and promotional visualizations.

Original HUD Imagery

CT155 *Hawk* Formation Landing, Sioux Falls, South Dakota

This mission was a two ship *Hawk* formation from Moose Jaw landing in Sioux Falls, SD for fuel. Just prior to flare during the final phase of landing, the number two aircraft flew into turbulence from the first aircraft. Its wingtip then struck the runway. The aircrew executed an overshoot, declared an emergency, and continued around the traffic pattern for a safe landing.

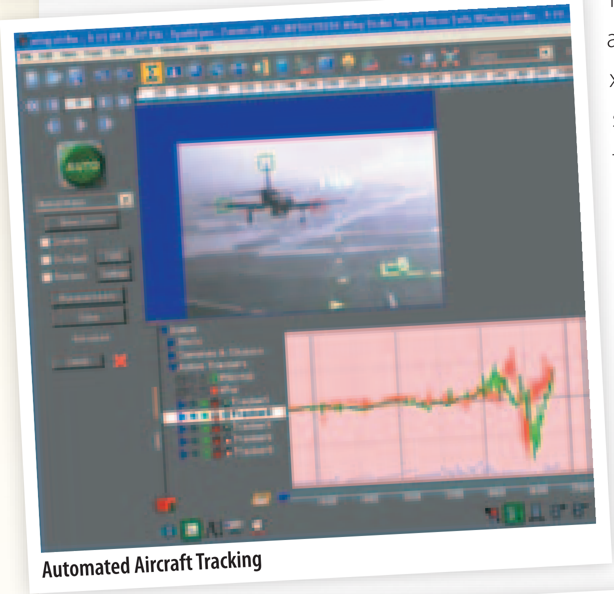
The CT155 *Hawk* is not equipped with an FDR, but fortunately a HUD recording of the incident was available. The HUD video could be useful for demonstrating the dangers of wake turbulence in formation, but an animation showing the incident from the chase, top-down, and tower as well as cockpit perspective would better demonstrate the conditions, situation and responses involved in the incident. As a result, this occurrence was chosen for further video analysis.

> "Just prior to flare during the final phase of landing, the number two aircraft flew into the turbulence from the first aircraft."

Automated Data Extraction from HUD

SynthEyes software was employed for video analysis. Trackers were placed at the -45, -30, -15, -5, 0, 5, 15, 30 and 45 degree bank indicators, and their x-y positions were exported from the software. Next, a moving tracker was placed on the tip of the triangular bank indicator, which resulted in a spreadsheet depicting the position of the triangular indicator for each frame of the video. Using a mathematical formula that took into account the curve of the bank scale, interpolated bank values were calculated for each frame of the video. Other HUD symbology was also tracked in order to provide frame-by-frame FDR-type parameters of the aircraft.


Tracking Angle of Bank


Automated Aircraft Tracking


Final Visualization

Trackers were also placed on the tail and flap/wing intersections of the lead aircraft, and the resulting x-y data was reviewed. In some portions of the video, the aircraft could not be completely discerned because of blooming, which caused the trackers to lose lock. By enhancing the contrast and gamma of the video, successful tracking of the aircraft components was achieved. A 3-D *Hawk* model was imported into the software and matched to the aircraft in the video. Although the aircraft was not close enough to the camera to derive its distance and orientation throughout the sequence, there was some success which indicated that this methodology could be useful in deriving an aircraft's position and orientation in space based solely on video.

Upon visualization in the flight simulator, the pilot's perspective closely matched that of the HUD video. The visualization was recorded from several camera perspectives in the simulator, including a top-down view, a chase plane view, a tower view, and from a virtual camera located at the touchdown point on the airfield. The footage was synchronized and mixed with the original HUD footage in Adobe *AfterEffects*. It became clear that analysis of a video could result in a 3-D visualization that gave much more insight into the event than the original HUD video.

CF188738 *Hornet*, Lethbridge, Alberta

During an air show practice at Lethbridge County Airport, CF188738 experienced a loss of thrust from its right engine while conducting a high alpha pass at 300 ft above ground level. Unaware of the problem but feeling the aircraft sink, the pilot selected military power on both throttles to arrest descent. The aircraft continued to sink and the pilot selected maximum afterburner on both throttles. The aircraft immediately started

Witness Photo

Tracking Features in Video #1

Selection of Ground Features

to yaw right and continued to rapidly yaw/roll right despite compensating control column and rudder pedals inputs. With the aircraft at approximately 150 feet AGL and about 90 degrees of right bank, the pilot ejected from the aircraft. The aircraft continued to yaw/roll right with its nose descending in a tight right descending corkscrew prior to hitting the ground nose first. The ejection and seat man separation worked flawlessly, but the pilot landed firmly under a fully inflated parachute and was injured when he touched down.

The CF188 *Hornet* is not equipped with an FDR, and was not carrying an ACMI pod. Much of the recorded maintenance data was lost with the destruction of the aircraft. External video and photos of the subject flight were the only record of its flight path prior to the accident. Luckily, it was media day at the airport, and the crash was caught from several different angles. It was decided that the aircraft position throughout the incident would be determined through triangulation.

Triangulation

Webster's defines triangulation as "A trigonometric method of determining the position of a fixed point from the angles to it from two fixed points a known distance apart." In our case we knew where two videographers were located, and the bearing from each to the aircraft could be calculated by interpolating between known ground references.

The first step was to review Video #1 in *Syntheyes,* and track the centre of the aircraft. Major ground features, such as the TwoTrees, and the SmallBush were tracked throughout the whole video.

The camera positions, as well as the tracked major ground features were marked on a satellite image.

In order to calculate a bearing to the aircraft, its position had to be interpolated between two known bearings in each frame. Unfortunately,

"Webster's defines triangulation as "A trigonometric method of determining the position of a fixed point from the angles to it from two fixed points a known distance apart."

Selection of Features in First Panorama

Tracking Features in Video #2

the video rarely showed two prominent ground features in the frame. As a result, prominent cloud features were chosen that could act as a bearing reference for the aircraft. As the clouds did not move significantly during the 30 second video, they could be used as a relatively stationary reference. These cloud features were also tracked within *Syntheyes*.

Sample video frames were stitched together in *Photoshop* to form a panorama covering all the ground and cloud references. The bearing to the aircraft could then be calculated by interpolating between ground or cloud features.

Similarly, Video #2 was reviewed, and prominent ground and cloud features were tracked. The tracker position data was saved and imported into *Excel*.

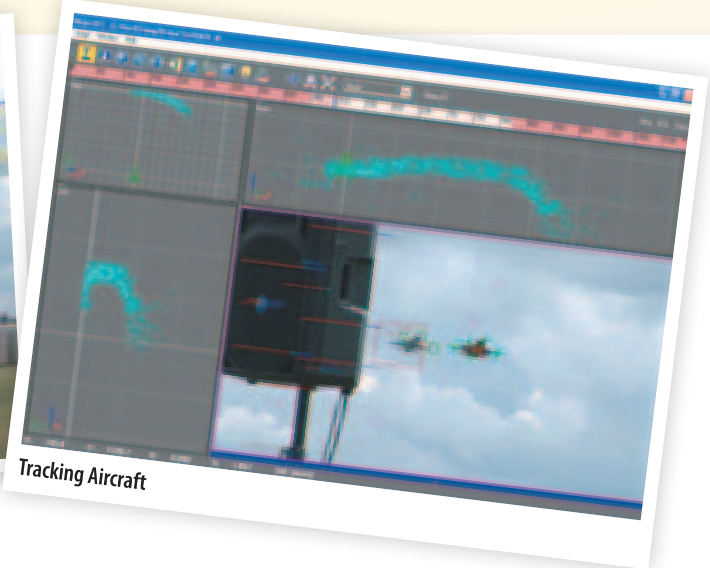
The data was transferred into a spreadsheet that contained the horizontal and vertical position of the aircraft, the position of a ground/cloud reference to the left of the aircraft along with its associated bearing, and the position and bearing of a ground/cloud reference to the right of the aircraft for each frame of video. The bearing to the aircraft was found by interpolating between the ground or cloud reference bearings.

The data from the two cameras was synchronized. At frame 1574 of Video #1, and frame 800 of Video #2, the pilot's ejection seat was clearly firing. Using the lat and long and bearing of the two camera positions, the lat and long of the aircraft was calculated at each frame, using the Intersecting Radials formula, based on the spherical law of cosines.

The data, including timestamp, lat/long, and heading were input into the flight simulator (Microsoft *Flight Simulator X*). A recording of the flight was made in a top-down view. In post-processing (Adobe *AfterEffects*), an orange line was drawn between the aircraft and the Video #1

> "Sample video frames were stitched together in Photoshop to form a panorama covering all the ground and cloud references."


Tracking Camera Movement


Tracking Aircraft

camera, and a yellow line was drawn between the aircraft and the Video #2 camera position. The synchronized videos from each camera were also displayed in the corners, surrounded by a colour-coded frame. The resulting flight path looked reasonable, and matched the southwest trajectory of the actual aircraft.

Matchmoving

Much more than the position and altitude can be derived from videos. Hollywood has long employed a technique called matchmoving in films, in order to realistically add digital effects to a hand-held camera shot. In this process, the individual pixels in the film/video are tracked and the pan, tilt, zoom, and movement of the camera relative to the scene is mathematically calculated. This matchmoving process was conducted on footage of the crash to derive the height, position, pitch, bank, and heading of the aircraft for the duration of the footage.

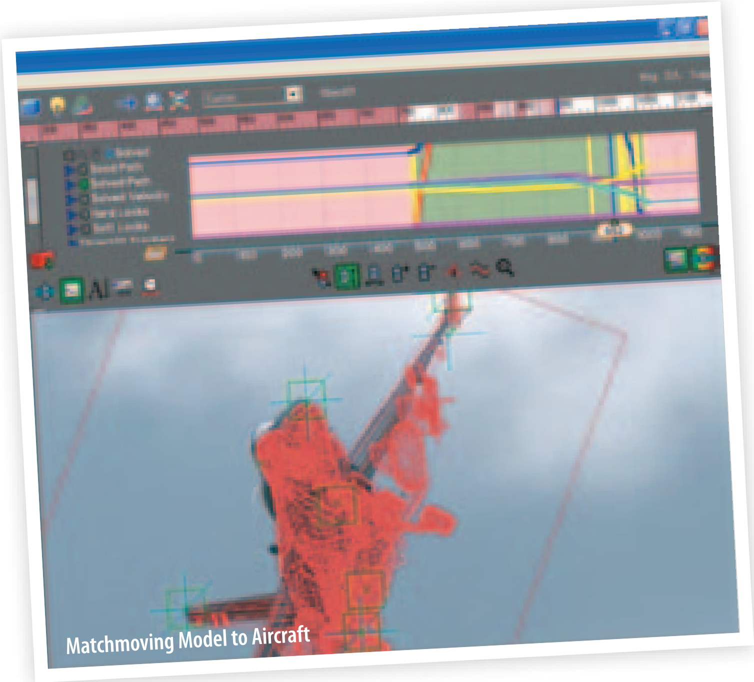
> "Hollywood has long employed a technique called matchmoving in films, in order to realistically add digital effects to a hand-held camera shot."

Before the motion of the aircraft can be calculated, the movement of the camera must be derived. This ensures that a shake of the camera is not interpreted as a vertical jump of the aircraft. As the aircraft is moving independently of the camera and background, an exclusion rectangle is drawn around it so that it does not influence the trackers which are trying to derive camera movement.

Once camera analysis is complete, the software knows exactly how the camera moved during the video – vertically, horizontally, forward/back, pan, tilt, roll and zoom. With these parameters determined, analysis of the aircraft (object tracking) can begin.

This time, the scene is not tracked, but trackers are placed on the nose, tail, wingtips, exhausts, and other discernable points of the aircraft. A 3-D model of the aircraft is imported, and the aircraft trackers are matched to the corresponding nose, tail, wingtips, etc on the model. The software is instructed to adjust the position, height, pitch, roll and yaw of the model to match that of the aircraft in the video.

The software superimposes the wireframe model over the aircraft in the video so that the tracking and matchmoving can be visually validated. The resulting position, height and attitude calculated by the software can be employed as an FDR, and analyzed to



Matchmoving Model to Aircraft

calculate flight parameters such as groundspeed, heading, roll rate and other information.

Triangulation and matchmoving are complementary. Triangulation is useful for modeling the flight path when the aircraft is very small in the frame. At these types of distances, matchmoving software is unable to detect changes in attitude or distance of an aircraft. Matchmoving is useful when the aircraft fills the screen, and is relatively close to the camera. It can provide detailed attitude information that can be used in visualization or fused with other data, such as simulation.

> "Triangulation and matchmoving are complementary. Triangulation is useful for modeling the flight path when the aircraft is very small in the frame."

Conclusion

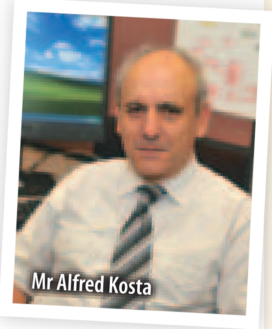
There are ever-increasing sources of video which may capture a flight incident: cameras, smartphones, Ipods, as well as security and airport ground surveillance systems. Many aircraft have on-board systems that record HUD or cockpit imagery. Analysis of even a single video can produce massive amounts of data which could be useful in an investigation. Analysis of this video imagery can be used to validate FDR flight path data, and in its absence, can even replace it.

One video can provide a significant amount of information, but additional videos or photographs taken from a different location can reveal, by triangulation or other processes, more than could otherwise be found. This fusion of data from multiple sources can be further improved by combining it with data from an FDR, radar, or simulation to produce an optimal collaborative representation of the event.

Even a single video can reveal the final flight parameters of an aircraft through the process of matchmoving. This data can be played back in a simulator to visualize the event from any perspective, including the aircraft cockpit. Visualization can be critical in understanding why an accident took place, and to help others understand in order to prevent reoccurrence. Video analysis and visualization are capabilities that are complementary and have great potential to support investigation and improve flight safety.

Trend Analysis and

Statistical Methods in Flight Safety



By Mr Alfred Kosta, Statistician, Directorate of Flight Safety, Ottawa

Mr Kosta is currently working as Statistician at DFS. He has a M.Sc. Mathematics from "Ottawa-Carleton Graduate Institute of Mathematics and Statistics". His previous experience includes teaching mathematics and statistics at Tirana University, and was a Quality Control Analyst with Business Intelligence Software at Cognos IBM.

Occurrence information is provided from FSOMS (Flight Safety Occurrence Management System) and other database sources. This paper describes some methods of descriptive and inferential statistics used by DFS. Descriptive statistics is the part of statistics that seeks only to describe and analyze a given group without drawing any conclusions about a larger group. Graphical methods and numerical descriptive measures are part of descriptive statistics. If important conclusions about a population are inferred from the analysis of a finite subset of the population (the sample), then this part of statistics is called inferential statistics. Confidence interval estimates, statistical tests and the level of randomness of a series of data are part of inferential statistics.

The following statistics have been derived from actual data from FSOMS.

Graphical Methods

Some graphical techniques used in Flight Safety are: pie charts, bar charts, time series, histograms, etc.

Pie Charts

The data within a pie chart should be arranged in such a way that each observation can fall into only one category of the variable. Example:

	Status 'Initial'
Previous 3 months	134
Previous 6 months	46
Previous 9 months	48
Previous 12 months	26
Total	**254**

Table 1 – Number of Reports with status 'Initial'

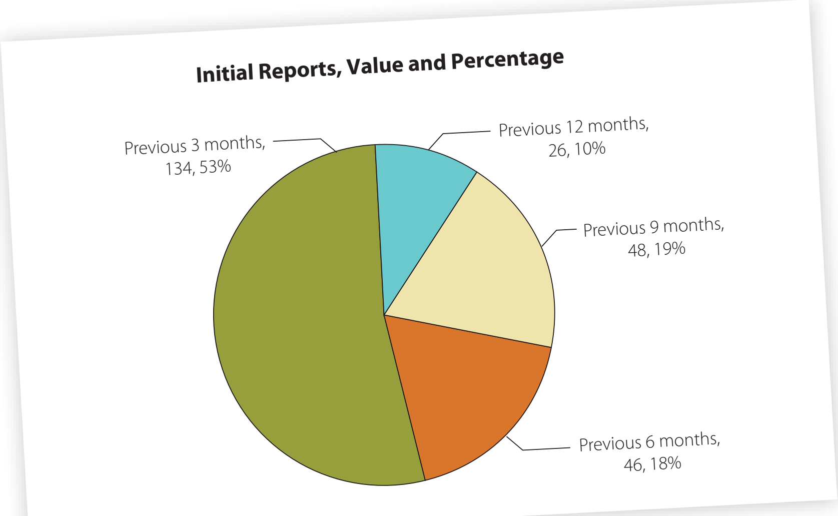


Figure 1 – Pie chart of 'Initial' reports

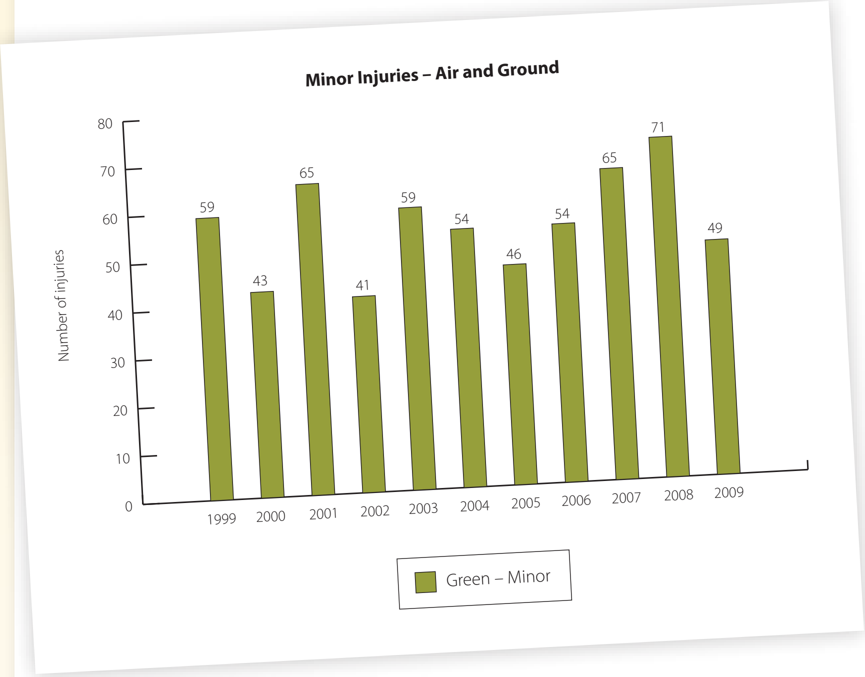


Figure 2 – Minor Injuries 1999-2009

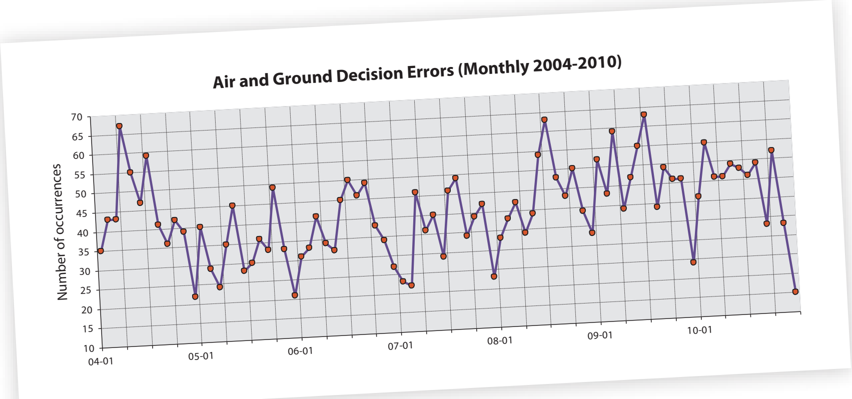


Figure 3 – Monthly occurrences due to decision errors (Air and Ground)

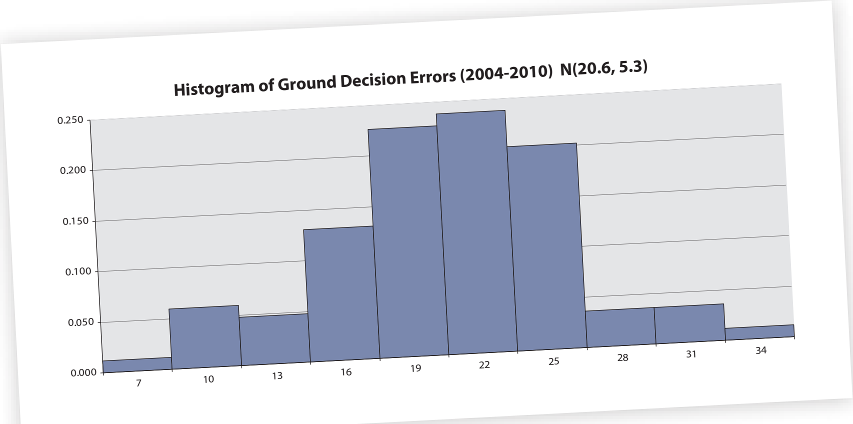


Figure 4 – Histogram of monthly ground occurrences due to decision errors (2004-2010)

Bar Charts

Bar charts are frequently used in annual reports. Figure 2 displays Minor Injuries for the 1999-2009 period.

Time Series Charts

A time series chart is a pictorial method of presenting changes in a variable over time (Figure 3).

Histograms

A histogram is built by separating data in intervals and calculating the relative frequency for each interval. With the centers of intervals as the X axis and relative frequency as the Y axis, a bar-chart with the gap-width 0 is created. The histogram can be an approximation of a probability distribution. It could be bell-shaped, symmetric, asymmetric, skewed, etc. Based on the histogram, previous studies, or theoretic considerations, hypothesis about probability distribution is raised and tested. Figure 4 displays a histogram related to a Normal Distribution N(20.6, 5.3).

Measures of Central Tendency and Variability

Descriptive statistics also includes numerical descriptive measures like *averages* or *measures of central tendency* and *measures of variability*.

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Mean
Reports Filed	2774	2811	3045	2904	2786	2844	2990	2637	2691	2931	**2841**

Mean = (2774 + 2811 + . . . + 2931) / 10 = 2841

The set of numbers 5, 5, 7, 9, 11, 12, 15, 18 has median (9+11)/2=10, mode 5 (which has the greatest frequency) and mean 10.25.

Table 2 – Statistical averages

Several types of averages can be defined, the most common being the *(arithmetic) mean*, the *median* and the *mode*. The definitions of these concepts can be seen in Table 2 above.

There are many types of measures of variability: *range, percentiles, variance, standard deviation,* etc. The variance and standard deviation are the most useful ones.

The *variance* of a set of *n* measurements $y_1, y_2, \ldots, y_n$ with mean $\overline{y}$ is given by:

$$s^2 = \frac{1}{n-1}\sum_i (y_i - \overline{y})^2$$

The *standard deviation* of a set of measurements is defined to be the positive square root of the variance, i.e. the number *s*.

DFS mainly uses the mean and standard deviation in the annual report. The *Empirical Rule* is often applied in the interpretation of data. For a set of measurements with roughly a mound-shaped histogram:

The interval $\overline{y} \pm s$ contains approximately 68% of the measurements

The interval $\overline{y} \pm 2s$ contains approximately 95% of the measurements

The interval $\overline{y} \pm 3s$ contains approximately all the measurements

> "There are many types of measures of variability: range, percentiles, variance, standard deviation, etc."

We retrieve information for the year we want to estimate (2009) and the previous ten years (see the example of Table 3). Then we calculate the mean and standard deviation of the ten value sample and determine the value of D-coefficient by the formula:

D = (Value of 2009 - $\overline{y}$) / *s*

Occurrences by Stage Operations	99	00	01	02	03	04	05	06	07	08	09	$\overline{y}$	S	D
Towing	46	46	60	48	47	43	44	44	46	55	**65**	48	5.4	**3.2**
Taxi	92	115	95	92	87	82	105	91	92	89	**121**	94	9.4	**2.9**
Take-Off	128	180	182	164	124	148	165	144	125	140	**163**	150	21.8	**0.6**
Parked	192	197	264	254	218	248	326	242	275	323	**362**	254	46.0	**2.3**
											🟨			**1.3**

Table 3 – Occurrences by stage of operations

The 2009 value for *Towing* is outside the interval $\overline{y} \pm 3s$. According to the Empirical Rule, almost all values must be inside this interval, so this value is very unexpected. It is recommended to further investigate and perhaps take action. We colour the 2009 values that are greater than $\overline{y} + 3s$ brown. For *Taxi* we have $\overline{y} + 2s <$ (2009 value) $< \overline{y} + 3s$. We expect approximately 95% of data to be in the interval $\overline{y} \pm 2s$, thus the 2009 value has a probability (100%-95%)/2=2.5%; however, this is still a rare event. Investigation and/or further analysis are recommended. We colour these values orange. The same argument goes for *Parked*. If, say D=1.3, then we colour the value yellow and caution is recommended. The approximate probability in this case would be: (95% -68%)/2 ≈ 14%. For 0 < D < 1 as it is the case for *Take-Off* operation, we have a probability (68/2)% = 34% and we colour the value dark green.

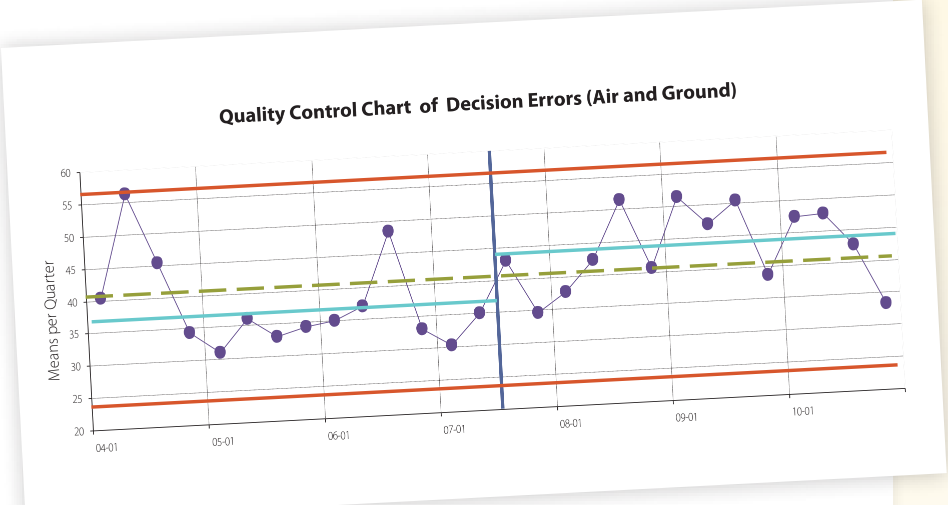


Figure 5 – Quality Control chart of occurrences due to decision errors (Air and Ground)

Quality Control Charts (QC)

Figure 5 shows a QC chart for the dataset of occurrences due to decision errors for the time period 2004-2010. Typically a control chart consists of three lines: a *center line* (average dot dark-green line), an *upper control line* and a *lower control line* (both red lines). The center line represents the average of k sample means, each based on n samples. In this example n=3 (three months sample) and k=28 quarters in 7 years. The process is considered *under control* when data falls within lower and upper control line and out of control otherwise. The *upper control limit (UCL)* and the *lower control limit (LCL)* are computed as follows:

$$UCL = \bar{y}_c + 3\frac{s}{\sqrt{n}}$$

$$LCL = \bar{y}_c - 3\frac{s}{\sqrt{n}}$$

where s is the standard deviation of the sample means. From the Empirical Rule, the interval

$$\bar{y}_c \pm (3s/\sqrt{n})$$

should contain nearly all the sample means in repeated sampling. If a sample mean falls outside this interval, we have either observed an extremely unlikely event or the process quality has changed and is no longer an accurate measure of the actual mean.

The consistency of HFACS was also analyzed. By testing the statistical hypothesis $H_0 : \mu_1 = \mu_2$

> "The 2009 value for Towing is outside the interval $\overline{y} \pm 3s$. According to the Empirical Rule, almost all values must be inside this interval, so this value is very unexpected."

that the mean for 2004-2007(June) is the same as the mean for 2007(July)-2010 we test the difference for these two time periods. The hypothesis H_0 might be accepted or rejected with a confidence level 95% (significance level 0.05). If accepted we have consistency for the two time periods. If the hypothesis $H_0{:}\mu_1 = \mu_2$ is rejected, two light blue lines are added in the charts, which signify the sample means of two periods, respectively. Further investigations and discussions are recommended when two time periods are statistically different. The causes of this difference have to be explained and understood.

> "Further investigations and discussions are recommended when two time periods are statistically different. The causes of this difference have to be explained and understood."

Ground Skill-Based Errors (2004-2010)	
Null hypothesis Ho:	The series is random
Alternative hypothesis Ha:	The series is not random
Series Mean:	53.16667
Series Median:	53
Series St. Dev:	11.88786
Number of runs V:	35
Runs Mean:	41.49382716
Runs Standard Deviation:	4.4711
z-test:	-1.22874
Confidence to reject Ho:	78.08%
Randomness Level:	**21.92% Medium**

Table 4 – Statistical Report on Randomness Level

Randomness Level of a series of data

The Randomness Level (RL) is a measure that has been introduced in DFS Annual Reports for the last two years. The RL is defined in statistical/probabilistic terms.

Our first intuitive view of randomness is an inverse of a pattern or a trend. The lower the RL the greater the chance for detecting a pattern or a trend and vice versa. Note that the existence of a pattern or of a trend does not necessarily mean a problem. For instance, if we are fully aware that the number of reported occurrences is increased only because of improvement of reporting culture, then we have increased trend and therefore low RL, but would not constitute a problem.

The test version used by DFS is: *'Above and Below Median Test for Randomness of Numerical Data'.* First we place the data in the same order in which they were collected. Then we find the median of the data and replace each entry with the sign + or - according to whether the value is greater or smaller than median. These are defined groups called *runs*. A program in Visual Basic was written for the computations. It generates a report as seen in Table 4.

> "These are defined groups called runs. A program in Visual Basic is written for the computations."

Confidence Level p (%) to reject H_0	RL	Decision/Interpretation
$p < 70\%$	High	There is poor evidence to reject randomness
$70\% \leq p < 90\%$	Medium	There is not enough evidence to reject randomness
$90\% \leq p < 95\%$	Low	There is strong evidence to reject randomness
$p \geq 95\%$	Very Low	There is very strong evidence to reject randomness

Table 5 – Determination of Randomness Level

Randomness Level (RL) is determined based on the probability to reject the hypothesis H_o (in this case 78.08%) according to the following criteria (see Table 5).

Note that the analytical method to determine RL is more powerful in detecting trend/pattern in a series of data than the graphical time-series chart method. The pattern may not be always visually obvious in the chart but the RL is always decidable. This is also an example demonstrating the importance and advantage of inferential statistics.

"This is also an example demonstrating the importance and advantage of inferential statistics."

Statistical methods are applied in Flight Safety to detect problems and provide recommendations. We provided a few examples to illustrate their potential to make sense of data. Between descriptive and inferential statistics, descriptive methods are more popular and easier to understand, especially graphical depictions. Statistical inference is more powerful and goes deeper in data analysis and interpretation. There is no question that sound statistical methodology will continue to provide much needed information towards constantly improving our Flight Safety Program.

"Between descriptive and inferential statistics, the descriptive methods are more popular and easier to understand, especially graphical depictions."

Portable Flight Data Recorders

By Major Adam Cybanski, Deputy Section Head Promotion and Information, Directorate of Flight Safety, Ottawa

Major Adam Cybanski is a pilot with over 20 years and 2500 hours on fixed and rotary wing aircraft including the CT114 Tutor, CH139 Jet Ranger, CH135 Twin Huey and CH146 Griffon. He completed a tour in Haiti as Night Vision Goggle Specialist and Maintenance Test Pilot, and has managed the CH146 Griffon Full Flight Simulator. He is a graduate of the Aerospace Systems Course and holds a BSc in Computer Mathematics from Carleton University.

Overview

A Flight Data Recorder (FDR) is an electronic device that records aircraft parameters in flight. It is typically used not only for accident investigations but for tracking aircraft component life and wear and for monitoring operations as part of a flight operations quality assurance program (FOQA). These "Black Boxes" are comprised of a recording medium (photographic film, magnetic tape, solid-state memory), and connections to the aircraft sensors and systems. Completely integrating a FDR into a legacy aircraft can be complex and difficult, as any changes to an aircraft configuration necessitates airworthiness testing and certification.

Many CF aircraft do not have complete FDRs, or provide FDR data that is limited (the CH146 *Griffon* helicopter FDR is unreliable for hovering manoeuvres). Some aircraft like the SZ-2 glider employed by the Air Cadets, and the CT114 *Tutor* used by Snowbirds, do not have any recording capability whatsoever. Without a doubt, FDR systems can improve safety, operational capability, and reduce life cycle costs. Notwithstanding, the implementation costs of a full fledged integral FDR may be unaffordable for many fleets.

One of the most crucial components of an FDR is the flight path information. Knowing the location, altitude, and attitude of an aircraft immediately prior to an accident can be critical in the subsequent investigation. Video footage of the cockpit and instruments can be invaluable, showing the investigator what was taking place during the incident, and perhaps showing why critical decisions were made. Recently, technology has started providing effective alternatives to costly and complex FDR systems, for recording flight path data. These are called Portable FDRs, or self-contained inertial movement /GPS recorders.

> "… "Black Boxes" are comprised of a recording medium (photographic film, magnetic tape, solid-state memory), and connections to the aircraft sensors and systems."

Portable FDR Components

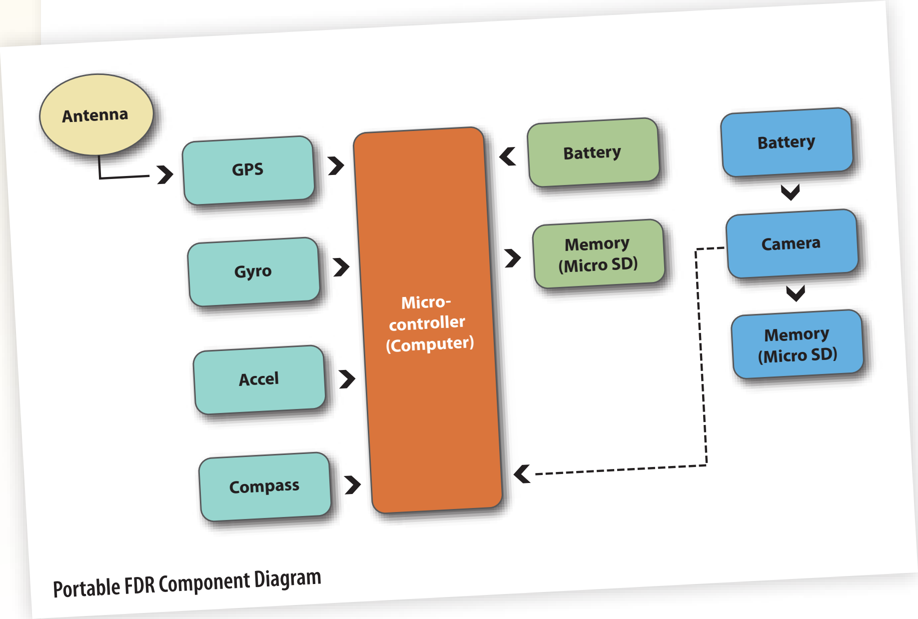
A portable FDR has three primary components: sensors, a computer, and a battery. Sensors can include inertial accelerometers and gyros, a magnetic compass, GPS, a camera, a barometer, and numerous other portable stand-alone sensors. The computer collects the data from the numerous sensors, formats and integrates it, then saves the results, along with timing information into a memory chip or other medium such as micro-SD card. The battery powers everything.

Commercial aircraft flight data recorders are engineered within hardened cases to withstand high impact forces, fire and water immersion. While portable FDRs usually have none of this, memory chips have shown a significantly high tolerance to these threats, and data has been recovered from SD cards that have been subject to intense heat, great impact forces, and even saltwater immersion.

Portable FDR Version 1 (V1)

A prototype portable palmtop-based Flight Data Recorder was assembled at DFS, and included sensors for attitude, altitude, and position as well as cockpit video (for validation of collected data). It was comprised of a small palmtop PC, tethered to a sensor package that included a GPS, altimeter, Inertial Movement Unit, and a USB video camera. The concept for employment was to place the unit into a pocket and strap into an aircraft for a day VFR flight. The system would record aircraft position, altitude, attitude, as well as cockpit video. A project Airworthiness Clearance was granted to test the unit, classified as a Personal Electronic Device in gliders and tow planes. The equipment (Portable FDR V1) was form and fit-tested, then employed in a proof of concept flight in an SZ-2 glider at the Smith's Falls airport. Collected data was found to be valid.


Portable FDR V1

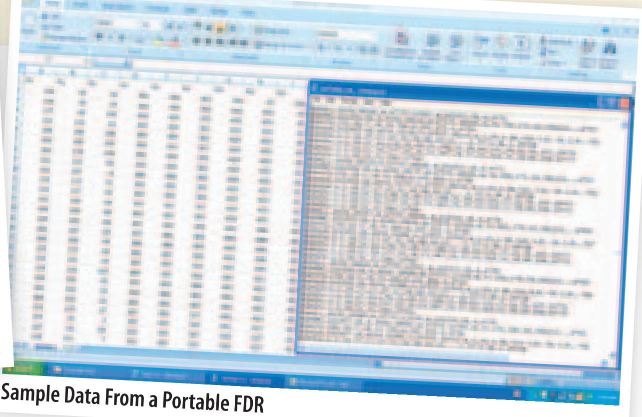


Portable FDR Component Diagram

Portable FDR V3

Three versions of the portable FDR were made. Each was simpler and less expensive than the previous one. One of the limitations of the initial Portable FDR was the tether wire. The sensor package had to be secured to the aircraft with Velcro and a tie-wrap. This posed a threat as a projectile in event of a crash, and could be an obstacle to egress. The fragile connection between sensors and the recording device was vulnerable to disconnection, and caused a system failure on one occasion. Second and

Camera and Portable FDR V3



Sample Data From a Portable FDR

third, self contained miniature FDRs were developed, assembled, and programmed. They consisted of a micro SD recorder, an inertial navigation system, a 50 channel GPS, and a battery all in a small 4cm x 4cm package that could be secured in a pocket. They were ccompanied by a 2cm x 7cm micro video camera, which could also be secured to a jacket, helmet, or inside a pocket.

The latest portable FDR is a Sparkfun Ultimate IMU, which has gyros and accelerometers in all directions, a 3-D magnetometer, a LPC2148 programmable microcontroller (miniature computer), and a micro SD socket to save the data to. Its functions are programmed in the C language, and uploaded from a PC through a mini-USB cable. The unit can save attitude and acceleration data at 30Hz. The GPS is a 66 channel GPS that runs at 10Hz, but only updates position at 2 Hz. The unit has not yet been tested in an actual aircraft, but trials in a radio control aircraft have been promising.

Data Analysis

Capturing FDR data is only one step. The data subsequently needs to be analyzed and utilized. The data from the different sources is multiplexed into a single text file on the micro SD card. After a flight, the result is separated back into individual acceleration, attitude, magnetic attitude, and GPS files. These files are merged into a single flight path file which denotes the basic parameters Latitude, Longitude, Altitude, Pitch, Roll, and Heading. This file can be analyzed graphically or visualized in a simulator such as *Google Earth* or Microsoft *Flight Simulator*.

GPS data is relatively easy to employ. It provides Latitude, Longitude, and altitude at a reduced accuracy. Heading is usually approximated by the aircraft track. To calculate aircraft pitch, roll, or even position to a higher level of accuracy, analysis of inertial data is required.

On a strap-down inertial system, the orientation of the sensors with respect to the aircraft body are known, thus it is easy to determine the pitch, roll, and heading. A portable system that is simply secured in a pocket has an unknown initial orientation: the sensor could be sideways, upside-down, or backwards. As a result, a post-flight calibration of the sensor must be conducted, so that readings noted when the aircraft is straight and level are subtracted from all subsequent readings. This can reveal the aircraft's true attitude, but as inertial sensors are prone to drift, they must be periodically corrected to maintain quality readings.

> "They consisted of a micro SD recorder, an inertial navigation system, a 50 channel GPS, and a battery all in a small 9cm x 7cm package that could be secured in a pocket."

Visualization in a Flight Simulator

Commercial Portable FDR

GPS only provides an approximate position, at a low update rate. Accelerometers can provide very high resolution and high frequency data over a small area but are also susceptible to drift. Luckily, positional data from a GPS can be used to correct the accelerometer data over the long term. Specialized filters such Kahlman and PI controllers fuse the data together into an integrated solution that is much more accurate than any of the individual components.

The visualization of flight path data is when the value of Portable FDRs truly can be seen. An accident flight can be played back from the cockpit perspective, or from a ground observer position. A marginal flight can be replayed over and over again, and compared to a "textbook" approach and landing. Flight path angle and visual references can be shown to pilots well before they go flying, so that there is an immediate sense of familiarity once they are in the air. We are just beginning to explore the ways that capturing flight path data can enhance safety and improve operational capability.

Commercial Alternatives

Companies are starting to release commercial portable FDRs with similar capabilities. *Appereo* Systems, LLC has a completely self-contained system that is mounted draws power from the aircraft. *Wi-Flight* by the General Aviation Safety Network has a simple and intuitive portable system that can be carried in a pocket during flight, then automatically synchronizes over the internet once on the ground, to provide playback of the flight through *Google Earth* on any internet computer.

Summary

The once cost-prohibitive capabilities of a Flight Data Recorder can now be procured at a cost similar to a cell phone. The basic components of sensors, battery, and computer are even resident on most phones sold today, and the capabilities of future portable FDRs promise to increase, while costs decrease. Portable FDRs represent new capabilities that can be employed to address current deficiencies for flight path recording. They can provide benefits to flight safety investigations by revealing how an aircraft was flown prior to an accident, and can enhance operational capability by providing a flight debrief system for aircrew under training. Portable FDRs will be examined by the RCAF in the future for use in small aircraft or those without comprehensive FDRs.

PART TWO
OPERATIONS

Photos: Cpl Willie Langer, Cpl Pierre Habib and Sgt Rick Ruthven

The ASTRA Project

By Major Darryl Shyiak, 1 Canadian Air Division Headquarters, Air Force Standards, Winnipeg

After serving in the CF for over 32 years, the author recently retired to become an airline pilot at WestJet. During his career, LCol Shyiak accumulated almost 5800 flying hours in helicopters, jets and multi-engine aircraft. His appointments included CO/Team of the Snowbirds, Comdt 3 CFFTS, Comdt CFS and O i/c AF Stds. He has been intimately involved in the ASTRA project since it started in 2009 and will continue project management activities as part-time Reservist (at the Maj rank level) for the foreseeable future.

The Air Standards, Training, Readiness and Automation (ASTRA) Project is a 1 Canadian Air Division (1 Cdn Air Div) initiative to make the RCAF a highly capable, tightly integrated and extremely modern air force that is able to fully exploit its increasingly advanced technology. Due to the combined effects of decreasing experience levels, personnel shortages, a high operational tempo and the introduction of new fleets of highly automated aircraft, RCAF-wide standardization with respect to training, flight publications, automation procedures and practices, and Human Performance in Military Aviation (HPMA) measures and standards is needed on an urgent basis – to enhance the safety of flight operations.

"On 22 June 2007, the Comd 1 Cdn Air Div signed a milestone letter on the subject of Air Division Fleet Modernization and Aircraft Automation Philosophy..."

The genesis of the ASTRA Project was the tragic loss of *Cormorant* 914 in July 2006. The flight safety investigation into Tusker 914 identified many human factors issues and "systemic deficiencies in how modern aircraft are fielded by the air force and the standards to which crews fly them." In response to the challenges that came to light after Tusker 914, 1 Cdn Air Div adopted NASA Ames Research Center's "Four Ps" approach to aviation operations with highly automated aircraft: philosophy, policies, procedures and practices. In order to achieve the desired practices in the cockpit, an organization's philosophy, policies and procedures must be developed (and/or revised) deliberately and sequentially so that all three are properly aligned to provide aircrew with comprehensive and consistent direction on how to conduct flying training and operational missions.

On 22 June 2007, the Comd 1 Cdn Air Div signed a milestone letter on the subject of Air Division Fleet Modernization and Aircraft Automation Philosophy:

> A number of recent accidents and incidents have highlighted a requirement for a fundamental review of the operating procedures and practices employed by Air Force aviators in all aircraft, as well as the policies and philosophies that Air Force leadership is guided by in determining them...
>
> Modern aircraft rely on a high level of automation and technical integration to create tactical advantage and achieve operational effectiveness. The acquisition of modern aircraft, and the modernization of legacy aircraft, demands new skills, knowledge, and attitudes to effectively and safely achieve mission success. Adherence to legacy


Photo: Cpl James Nightingale

operating practices on highly automated aircraft is ineffective and unsafe.

The employment of cockpit automation must be standardized, disciplined, and fully integrated in all phases of flight. Because the aviator retains authority in determining the optimal use of automation, the aviator must be proficient in operating the aircraft in all levels of automation and be fully knowledgeable in the selection of the most appropriate level of automation for the situation.

All Flying Orders, flying training programs, assessment and evaluation criterion, standard operating procedures, briefing guides, checklists, flight manuals, and flying operations shall be in accordance with this automation philosophy.

In the fall of 2007, 1 Cdn Air Div initiated the Automation Policy and Planning Development (APPD) project to determine the state and effectiveness of the policies, procedures and practices in effect at that time throughout the Air Force. Two civilian companies with extensive human factors engineering and Automation Airmanship expertise – CMC Electronics and Convergent Performance – were contracted to critically examine how our Air Force was conducting flight operations and training. Industry experts flew with training and operational crews (in simulators and aircraft), interviewed a significant number of aircrew and staff officers, and thoroughly reviewed all flying publications and manuals to assess the overall state of readiness for adopting highly automated aircraft. The comprehensive APPD Project Automation Analysis Report, delivered on 29 Sep 08, presented many findings and ecommendations. A summary of the findings is as follows:

- Automation Performance Measures
  - No consistent automation performance measures in the Air Force
  - No common automation measures across all communities
  - The Air Force lacks a common "Language of Automation"
- Training and Evaluation
  - Over-emphasis on single pilot evaluations
  - Negative training with regards to two piloted aircraft
  - Limited Crew Concept Evaluations
  - Inconsistent simulator utilization
  - Lack of standardization leads to training inefficiencies and impacts ability to absorb new pilots
- HPMA
  - Team observed limited use of HPMA principles in the cockpit
  - Why has HPMA stalled?
    - *Taught, not trained"*
    - *No HPMA Performance Measures"*

- *HPMA is not evaluated"*
  - *Culture of single pilot evaluations"*
- "Stovepipes of Excellence"
  - Great work being done in many areas, but much of it in isolation
  - Lack of standardization between aircraft communities

The APPD report and the follow-up APPD Project Draft Automation Implementation Plan, provided detailed recommendations to address the challenges that the contractors had identified. A summary of the top level work items in the proposed implementation plan is as follows:

- Create an Air Force Standards Organization
- Integrate New Automation Policies into Flying Orders
- Develop Implementation Guide and Standards
- Develop Cockpit Automation Task Definitions
- Develop Automation and HPMA Performance Measures
- Produce Writing Style and Content Guide for SMM's
- Upgrade Aircraft and Simulator Training
- Incorporate Best Practices into Flight Evaluations
- Produce Procedures and Manuals for Each Fleet
- Disseminate New Measures and Standards
- Restructure Flying Orders

Photo: MCpl Rebecca Bell

The Comd 1 Cdn Air Div and DComd FG read the entire APPD report and were briefed on the most important findings and recommendations. On 4 Dec 08, the Comd released a message (Comd 143) about the APPD project and the restructure of Central Flying School (CFS):

> 2. THE AUTOMATION ANALYSIS REPORT HAS BEEN COMPLETED AND I HAVE ACCEPTED ITS FINDINGS, CONCLUSIONS AND RECOMMENDATIONS IN THEIR ENTIRETY. IT PRESENTS A COMPREHENSIVE REVIEW OF THE CURRENT AIR FORCE CULTURE AS IT RELATES TO AUTOMATION PRACTICES, AND CLEARLY IDENTIFIES AREAS OF STRENGTH AND AREAS REQUIRING ATTENTION TO EFFECT A SUCCESSFUL TRANSITION TO UPGRADED OR NEW AIRCRAFT...

"The Comd 1 Cdn Air Div and DComd FG read the entire APPD report and were briefed on the most important findings and recommendations."

> 4.G. ...THE MAJORITY OF THE RECOMMENDATIONS WITHIN THE APPD PROJECT REVOLVE AROUND THE OPPORTUNITY TO DEFINE AND APPLY A SINGLE AUTOMATION PHILOSOPHY SUPPORTED BY CLEARLY DEFINED AND ARTICULATED AUTOMATION PERFORMANCE MEASURES AND STANDARDS. THE CREATION OF AN AFSET, THROUGH THE OPPORTUNITY CREATED BY THE RESTRUCTURE OF CFS, WILL CREAT A CENTRAL AIR FORCE ORGANIZATION THAT ASSUMES RESPONSIBILITY FOR THE RECOMMENDATIONS CONTAINED IN THE APPD REPORT AS WELL AS ANY FOLLOW-ON ACTIVITIES.

The Comd directed the continued use of contracted personnel to begin implementing the plan that the APPD project had produced. Although work was delayed a number of times due to contract-related difficulties, experts from CMC Electronics and Convergent Performance eventually began their work to execute the implementation plan. Adhering to the Four Ps model that 1 Cdn Air Div had adopted, contractor personnel worked closely with CFS and the Standards and Evaluation Teams (SETs) at the SET conference in Mar 09, and then a follow-on automation policy working group meeting in Jun 09, to draft new automation policies for B-GA-100 and the Air Div Orders. In addition, the contractors provided expertise to LRPSET for the important work they were doing on the CP-140 *Aurora* Incremental Modernization Program (AIMP) Block II aircraft, and to senior Project Management Office (PMO) staff working on the Maritime Helicopter Project (MHP).

By the spring of 2009, the APPD project had evolved into the Air Standards, Training, Readiness and Automation (ASTRA) project. The Commander's Intent for ASTRA is as follows:

> The ASTRA Project will deliver to the Air Force new policies, flying orders, training programs, assessment and evaluation criteria, standard operating procedures, briefing guides, checklists and flight manuals to implement and sustain flying operations that are consistent with the Automation Philosophy and achieve a high level of automation airmanship.

ASTRA Project Objectives:

- Transform Air Force Policies, Procedures and Practices to strengthen commonality of practice among communities, harmonize expectations for flight crew performance, and achieve robust adaptability to technological change.

- Four principal areas with strategic objectives:

  1. Streamline and reorganize Air Force **Standards** while unifying Air Force operations and management functions;
  2. Update **Training** programs with instructional systems design and simulation capabilities required for 21st Century operations;
  3. Strengthen performance measures, evaluation mechanisms and unit assessment programs to achieve high levels of operational **Readiness**; and
  4. Instil an **Automation** culture to ensure safe and efficient operation of modern, highly automated weapon systems.

While automation was the catalyst and remains one of ASTRA's four strategic objectives, the project is now a more comprehensive, broadly transformative effort for the Air Force.

"While automation was the catalyst and remains one of ASTRA's four strategic objectives, the project is now a more comprehensive, broadly transformative effort for the Air Force."

As the scope expanded, ASTRA provided personnel and expertise to form three separate integrated project teams (IPTs): the AF Stds IPT, the CP-140 IPT and the MHP IPT. The AF Stds IPT provided 1 Cdn Air Div with an interim AF Stds capability to lead and coordinate the ASTRA project. The focal point for standardization efforts to begin across the various communities, the AF Stds IPT worked with the SETs to finalize new automation policies for B-GA-100 and the Air Div Orders, provided oversight and coordination of the other IPTs, presented numerous briefings about the project, provided SETs with guidance on automation related matters, and developed a website for ASTRA. The CP-140 IPT examined the procedures and practices in use with the AIMP Block II aircraft and then drafted an Automation Procedures Baseline Report to "identify areas of emphasis to bring the aircraft into compliance with the 1 Cdn Air Div automation philosophy and new ASTRA automation policy statements." Guidance and assistance was then provided to begin the work required to revise checklists and standard operating procedures (SOPs) for the CP-140. The MHP IPT's work was extensive and focused on three key areas: flight publications (AOI, Checklist and SMM), a review of MHP mission and task analyses, and development of a training and evaluation program.

"The AF Stds IPT provided 1 Cdn Air Div with an interim AF Stds capability to lead and coordinate the ASTRA project."

Although contract-related difficulties prevented ASTRA from providing support for an extended period, a considerable amount of work was accomplished from the summer of 2010 to the summer of 2011. A new AF Stds cell was formally established in the DComd FG Branch of 1 Cdn Air Div on 1 Jun 10 "to provide 1 Cdn Air Div with Air Force-wide standardization with respect to training, flight publications, automation procedures and practices, and HPMA performance measures and standards." Due to manning pressures in AF Stds from the fall of 2010 to the summer of 2011, ASTRA provided manpower and expertise to accomplish short-term AF Stds goals and objectives. Following the Four Ps model adopted by 1 Cdn Air Div and the implementation plan that the APPD project had produced, ASTRA focused its efforts on finalizing new policies and producing the guidance needed to develop and/or refine aircraft procedures being used throughout the Air Force.

ASTRA contractors worked closely with AF Stds personnel to plan and host the AF Stds conference in Oct 10, where new automation-related policies were reviewed and finalized with representatives from all the SETs. In Dec 10, proposed changes for B-GA-100 and the Air Div Orders were submitted for approval. Automation-related changes to B-GA-100 were approved and came into effect in Jan 11 and changes to the Air Div Orders were promulgated in Feb 11.

To obtain feedback on the work ASTRA was doing and have discussions with key standards personnel about the new automation policies, ASTRA visits were conducted to MHSET and the OTU/OTF conference in Oct 10, LRPSET in Nov 10, and TRSET and TASET in Mar 11. These visits were highly productive as they provided everyone involved with a better understanding of the unique challenges in specific communities.


Photo: Sikorsky Aircraft Corporation

ASTRA's CP-140 and MHP IPTs continued work started in 2009 and developed guidance to be used by other fleets. The CP-140 Automation Procedures Baseline Report was finalized and delivered in Oct 10, a draft CP-140 cockpit Normal Checklist was produced in Feb 11, a review and update of Emergency Procedures for the Block II aircraft was conducted in Mar 11, and a review of tactical compartment procedures was completed in May 11. In addition to progressing tasks that began the previous year, the MHP IPT produced a comprehensive *Cyclone* Instrument Flight Procedures Manual for conducting instrument flight procedures that are fully compliant with the 1 Cdn Air Div automation philosophy and the new automation-related policies in B-GA-100 and the Air Div Orders. This manual was distributed to all SETs responsible for a helicopter fleet as it serves as a good reference for conducting instrument flight procedures in any highly automated helicopter. ASTRA's MHP IPT also provided an automation expert to support a MHLH crew-station working group meeting in Mar 11.

Considerable progress was made by ASTRA with the critical task of developing new automation and HPMA performance measures and standards for the Air Force. Work on this task began at the AF Stds conference in Oct 10, where over 300 statements identifying the skills and attributes displayed by our best performing aircrews were provided by representatives from all the SETs. This information and the fundamental modules of our HPMA program were used by ASTRA and AF Stds personnel at a working group meeting in Dec 10 to develop performance statements and specific behavioural markers for 18 different Automation & HPMA non-technical skills (NTS) unique to our Air Force. Draft performance measures and standards for the NTS were then developed in Feb 11. The 18 Automation & HPMA NTS, which will soon be introduced throughout the RCAF, are as follows:

- Individual Factors
- Mission Preparation

- Briefings and Debriefings
- Communications
- Policies and Standard Operating Procedures
- Decision Making
- Task and Workload Management
- Automation Communications
- Programming and Data Input
- Automation Authority Management
- Automation Task and Workload Management
- Automation Situation and Mode Awareness
- Automation Transitions
- Alert and Warning Management
- Failure and Deviation Response
- Situational Awareness
- Team Performance
- Threat and Error Management

As ASTRA's work on a 'writing style and content guide' for SMMs progressed, it was determined that similar guidance was needed for other aircraft publications, including Flight Manuals (FMs), AOIs, Checklists, and Quick Response Handbooks (QRHs). As a result, work began on the AF Stds Flight Publication Development Manual (FPDM) with the objective of providing style, content and formatting guidance for FMs/AOIs, Checklists/QRHs and SMMs. ASTRA personnel met with senior engineers from Directorate of Technical Airworthiness (DTA) to get their input regarding the handling of technical airworthiness data in flight publications. ASTRA personnel also met with senior staff at the CF Air Warfare Centre (CFAWC) to discuss the purpose of a SMM – as it relates to Air Force doctrine – and the differences between a SMM and a tactics, techniques and procedures (TTP) manual. As a result of these discussions, detailed descriptions for a SMM and TTP manual were developed:

> The SMM is a detailed "how to operate" manual that directs the crew to operate a weapon system as expected by the Air Force. The SMM incorporates aircraft manufacturer data (FM/AOI/Checklist), integrates automation and HPMA principles, and is aligned with Air Force doctrine and terminology. The SMM specifies to each crew member – in terms of actions and callouts – exactly what to do and say, and when to do it and say it.
>
> The TTP manual is a "how to employ" manual that guides the crew to employ a weapons system according to Air Force doctrine.

As the first draft of the FPDM was being finalized, ASTRA experts determined that guidance for developing/refining SOPs should be provided in the manual. With this in mind, the contractors added detailed information on the recommended procedures


Photo: WO Carole Morisette

> "The ASTRA project has completed a lot of important work for 1 Cdn Air Div, but there is still much more to be done."

development processes to be used when developing or refining comprehensive and robust SOPs.

ASTRA contractors worked closely with AF Stds personnel to plan and host the AF Stds conference in Jun 11. At the conference, work continued on automation policies and procedures. The first draft of the FPDM and the 18 new Automation & HPMA NTS that ASTRA had produced were also presented and discussed with the SETs for the first time. The FPDM and the new Automation & HPMA NTS received strong support from all the SETs. After some discussion, everyone agreed that guidance provided in the FPDM on procedures development/refinement should be beta-tested before the manual would be ready for operational airworthiness authority (OAA) approval. Conference attendees also agreed that the training community, specifically the multi-engine and rotary-wing programs in Portage, would be the best location for introducing the 18 new Automation & HPMA NTS that have been developed for the Air Force.

The ASTRA project has completed a lot of important work for 1 Cdn Air Div, but there is still much more to be done. Although contract-related problems continue to be an issue, it is hoped that an extension to the current contract will soon be approved and a contract for multi-year ASTRA support will come into effect in the spring of 2012. Current plans are for the following project activities during the next six months:

- Continued automation assistance to AF Stds & SETs
- Complete work on Automation & HPMA performance measures & standards
- Draft validation plan for new automation policies and procedures
- Draft plan for implementing Automation & HPMA performance measures
- Evaluate procedures development/refinement processes from FPDM in a test community
- Evaluate implementation of Automation & HPMA performance measures in test community
- Provide input to 2 Cdn Air Div Optimization of Simulation & Technology project
- Maintain and update ASTRA website
- Continue support to priority fleets (MHP, CP-140, MHLH, *Cormorant,* TALE, and BALE)
- Finalize FPDM and submit for approval

Long-term plans for the ASTRA project are as follows:

- Continue procedures/manuals development support
- Assist units to achieve ASTRA-compliant aircraft and simulator training programs
- Incorporate best practices in all flight evaluations
- Assist SETs with implementation of new Automation & HPMA performance measures & standards
- Restructure Air Force Flying Orders (RCAF Flight Operations Manual)

The ASTRA project is essential to the RCAF. As MGen Blondin stated when he was Comd 1 Cdn Air Div, ASTRA is "the glue that will hold us together" during a time of tremendous change and challenge, and it will ensure that we are well prepared for the demands of the 21^{st} Century.

For additional information about the ASTRA project, please visit the website that the contractors have developed at *www.astraproject.ca*

Synthetic Vision

By Captain Richard Granger, Canadian Forces Support Unit, Ottawa

Captain Grainger has served in both the UK Royal Air Force and the Royal Canadian Air Force as an AERE officer, with fast jet, maritime, trainer and large aircraft experience, plus flight safety duties. He is currently undergoing training as a medical officer at the University of Ottawa.


Photo: Cpl Alex Roy

Synthetic Vision (SV) is essentially virtual reality display for pilots. As a concept to improve operational safety and effectiveness it has been around since the 1990s, but systems are now starting to appear in aircraft. This article explores some of the history of SV, outlines the current and likely future state of military systems, and discusses some of the safety, operational and procedural challenges and opportunities surrounding SV systems.

The basic purpose of flight instruments and related displays is to provide pilots with information they need to safely operate their aircraft but cannot reliably or accurately sense themselves. Early in aviation, flight was almost exclusively a visual affair. Very rapidly the need for systems to sense and display flight-critical information became apparent, both to make flight safer and to extend the operational envelope of aircraft – for instance flight in cloud and at night.

Instrument and display development was initially driven by military aviation during WWI when there was a dramatic proliferation and change in a relatively brief period. By 1918, instrument night flight was quite common. Most flight instruments initially displayed a single parameter. There was little standardization of style, symbology or size and most were simple black and white dials. As displays and instruments became more complex, pilots were required to deal with an increasing interpretive workload. Cockpits became festooned with dials, switches and displays with little commonality.

Fast forward through the increasingly faster and complex aircraft and systems, the workload and interpretation problem grew rapidly. Secondary to the complexity of information in the cockpit, distraction became a common accident cause, as did lack of overall situational awareness. However, solutions were being developed. The standard 'T' layout of the key flight instruments was developed in the 1930s to make transition between aircraft easier. Later, a primary aim of the Head-up Display (HUD) was to keep pilots 'head-up' and aware of their speed, attitude and surrounding terrain. Multi-function displays give a single, more integrated and easier to read picture of desired information. Developments such as these, when properly designed and integrated into the aircraft and procedures, mitigate many of the human factors issues caused by multiple and competing streams of information being delivered to pilots through many different formats.

The concept of SV for aircraft is a logical continuation of this 'arms race' between input and pilot information processing capacity. Since the late 1990s, the concepts have become well established, enabling technology has raced ahead, and many systems are in development with a small number in services.

Photo: Pte Lori Geneau

POINT TO PONDER – FLIGHT INSTRUMENTS: NO LONGER THE SOLUTION?

A pilot needs to know a lot of flight information that cannot easily be directly sensed. A well-designed flight instrument is the best way to display it. Is this true, false, or somewhere in between? Has sensing and display technology now almost freed us from needing any single instruments, or do we still need a basic panel? Will SV be the tipping point where most if not all of the 'traditional' instruments start disappearing?

POINT TO PONDER – FLIGHT INFORMATION: VISUAL VERSUS CONCEPTUAL DISPLAY

Humans generally interact with the world in an overwhelmingly visual sense. Ride a bike down a steep hill and you can usually visually sense if you are going too fast from experience. However, we are also outstanding at conceptualization. One may not directly sense 600 knots at FL330, but looking at an altimeter and ASI will allow us to rapidly conceptualize the situation.

While airspeed has no real visual counterpart, traditional instrument flying involves co-ordinating at least three relatively complex display instruments while maintaining a mental picture of physical position, attitude and airspeed.

The best visual representation of airspeed may be a figure, but the best representation of position may be a picture relative to the ground and known features. SV allows such a picture to be directly presented, reducing workload and the need to refer to multiple displays or indicators.

Photo: Cpl James Nightingale

So what is SV?

The main aim of SV is to enhance operational safety, effectiveness and efficiency by providing a visual display of all relevant information while reducing pilot distraction, omission and workload. Key to this is enhanced attitude and positional awareness in a single display area. In addition, SV systems are extremely flexible in format, content and presentation; the 'ground' can be made feature-rich with terrain and obstacle information, and the 'air' populated with airways, restricted airspace, additional aircraft and other useful flight information. Below are just a few characteristics and possible impacts of SV:

Display anywhere: The SV picture can be shown on any suitable display, in any desired format (for instance incorporated into the AI in one view and simultaneously on an MFD in navigation mode in another view or in a HUD transparent overlay). Textured and tailored SV information can be displayed on the AI in place of the standard brown/blue hemispheres, with all of the standard aircraft attitude and flight information symbology retained.

> "The main aim of SV is to enhance operational safety, effectiveness and efficiency by providing a visual display of all relevant information while reducing pilot distraction, omission and workload."

Flight information: Sets of flight direction symbols can be incorporated into the SV picture, allowing direct visual cues and feedback for instrument and precision flying. When slaved to ILS glideslopes and markers, ILS approaches can be flown visually. Airways and safe or restricted airspace can be represented, as can almost any other useful flight information. Live update of relevant NOTAMS is also possible.

See the ground: The ground and obstacles can easily be 'seen' in the display. With overlays, an SV HUD enhances a poorly visible scene. SV overlay parameters, such as transparency and brightness, can be varied to suit the conditions.

Threat information: For military operations, threat zones can be incorporated into the display. On-board threat detectors can be slaved into the display for a live picture and alerts.

Mission specificity: The display can be programmed or adapted to specific types of missions.

External connectivity: External input can be piped direct to the display, and the SV display or key parameters can be also be linked externally.

Flight safety: A 'pilot's eye view' can be recorded to enhance investigations.

Training: A recorded SV sortie can be analysed or viewed from any angle or external viewpoint.

"Flight safety: a 'pilot's eye view' can be recorded to enhance investigations."

While the above characteristics have potential to affect many areas of operations, (one example might be lower approach minimums on landing with the anticipated increased accuracy), there are a number of associated human factors and safety issues. A few of these are:

Display from any viewpoint: Although current systems fit with the philosophy of current displays (for instance everything in an AI is a pilot-eyes view), SV can be projected from any point in space, just as a personal computer flight simulator pilot can select an external view. For example, a formation lead could view the formation from any point in space.

Zoom in zoom out: Just as variable viewpoints are possible, so are scaling and zoom in/out. It is by no means clear that these are desirable features from a human factors flight safety point of view.

Symbology changes: There is little if any standardized symbology for many of the new items that are being displayed in SV systems, but changing symbols is relatively easy. Pilot-selectable symbols are possible; this capability introduces potential unsafe human factors considerations.

Failure and/or degradation conditions: In a complete SV picture, for instance on an AI screen, there is no visible comparison with the actual external world. In this case, an automated 'failure' condition must be defined and annunciated. Some procedural reaction – perhaps return to 'true' instrument flight – would then be required.
In partial or blended SV systems, an overlay on some view of the real world is presented (for instance via a HUD) and there is some comparison possible so that inconsistencies can be spotted by the pilot.

Criticality: Is SV a flight safety critical function? If so, is it critical during all flight phases or just some? How should these systems be certified?

Type of flight: Does SV flight fit into the current categorization of instrument or visual flying, or is it some hybrid type?

POINT TO PONDER – SV SYSTEMS – IFR, VFR OR SOMETHING ELSE?

The current relationship between VFR, IFR, VMC and IFC is clearly understood, but it is not yet clear where using SV systems to their full military potential falls. With a full helmet mounted SV system, is it 'instrument' flight, even with the pilot 'VMC' following VFR? What are the minima for reversion to 'traditional' IFR in the case of system degradation or failure?

Pilot Psychology: Flight and simulator testing of various systems to date show that pilots adapt rapidly to both complete and partial synthetic vision pictures. However, does this rapid adaptation to the virtual result in a neglect of the real world, and if so, what are the 'symptoms'? What about a blended picture – will pilots tend to fixate on the virtual overlay?

"It is by no means clear that these are desirable features from a human factors flight safety point of view."

POINT TO PONDER – SV: REAL WORLD PICTURE OR NOT?

Although at present the graphics in complete SV pictures are obviously not 'real' and the pilot is able to distinguish this, with future improvements in rendering, it is possible that relatively soon the picture could be good enough to fool the human eye. Would it be safer to keep it obviously 'unreal', or better to improve the resolution and detail? Is there a need to see the 'join' between real and digital?

POINT TO PONDER – SV SYSTEMS: REDUCED STANDARDIZATION = REDUCED SAFETY?

If the full customization potential (pilot symbology, colour, mission type, external viewpoint, connectivity, etc) of SV is realized, do we leverage flexibility at the expense of safety? How do we assess where the optimum balance is?

SV also has potential to be a comprehensive visual substitute in conditions of sudden and complete loss of visual cues such as during 'brown out' in helicopter landings in dusty conditions. Loss of situational awareness in the final seconds of landing in these circumstances is both predictable and hazardous. Although instruments, GPS and a terrain database give accurate spatial information for landing, many obstacles such as buildings, antennae, vehicles, personnel and cables may not be represented, and pilots must currently interpret different displays and integrate the information themselves during a complex phase of flight. The resulting inadequate information and high workload increases the risk to the aircraft, so either operational flexibility is compromised by modifying the mission or an undesired risk to crew and helicopter must be accepted.

Combining information from live-feed on-board sensor with instruments, GPS and terrain maps and displaying it in a SV picture dramatically improves the situation. With suitable resolution in detection and display, obstacles and hazards become 'visible' and also represented in a suitable context for landing.

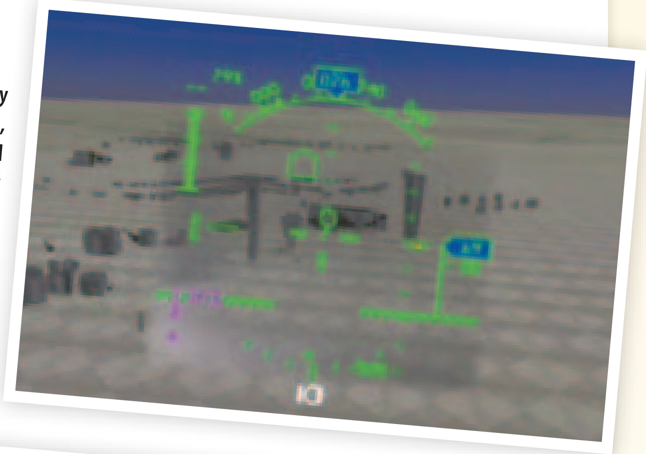
An SV display intended to minimize interpretation workload and reduce distraction (similar to looking thorough the cockpit windscreen with no dust present) should optimize situation awareness.

SV systems also offer the opportunity to widen the pilot's field of view to provide a complete 'through aircraft' view in any direction. Helmet mounted displays slaved to the direction of view, combined with multiple fuselage mounted sensors will allow the pilot to look and see anywhere. The integration of these systems into operations, tactics and training will be challenging. There are also additional human factors questions such as how do you cope psychologically with the virtual disappearance of your airframe if you can fade it out? Other issues, such as possible long term skeletal health effects associated with pilot's visual display systems, remain to be assessed.


Photo: Cpl David Cribb

POINT TO PONDER – SV SYSTEMS: TOWARDS A VIRTUAL COCKPIT?

While not on the immediate horizon (except perhaps in the UAV world), would a helmet-mounted SV system allow the creation of a virtual cockpit with only a throttle, stick and switches?



Head down SV display with fused LiDAR, IR, and terrain database and flight instrument input for helicopter landing in brownout/poor visibility (used with permission from Mr. G Laflamme, CAE Inc.).

L-3 Avionics Systems *SmartDeck* primary flight SV display depicting terrain in the Reno/Lake Tahoe area (used with permission Mr. R Bowes L-3 Communications MAS Canada).

In conclusion, SV systems are an extension of developments to combine the presentation of flight information in a single view and to improve operational safety, efficiency and effectiveness. Visual flight direction and airspace information is being added to attitude, terrain and standard flight parameters, bringing the required information to a single display and providing specific solutions to issues such as brown-out. In future, the incorporation of multiple sensor inputs will potentially allow pilots to 'see' in any direction through the airframe, and integration with other sensors and systems (both on-board and external) will significantly impact military capability.

> *"SV systems are an extension of developments to combine the presentation of flight information in a single view and so to improve operational safety, efficiency and effectiveness."*

The SV picture can be displayed on any suitable display including cockpit MFDs, AI, HUD and helmet-mounted systems. While the potential benefits and human factors issues remain to be fully researched, there is emerging evidence that the safety benefits are real. As the systems increase in capability and resolution we must be aware of and address the potential safety pitfalls as well as the obvious benefits. Processing and display technology is maturing and is now beginning to appear in the aerospace market; further potential applications and operational uses abound. We are in the early days of using SV to gain the maximum operational and safety advantages. One thing is certain – we will be seeing more of SV systems in the future.

Increased Automation –

Help or Hindrance?

By Captain John Dixon, Directorate of Flight Safety, Ottawa

Over a "mixed' career in aviation, Captain Dixon has flown almost 14,000 flight hours on a variety of aircraft including the CC138, CC130, A310, A320, B707, B737, B757 and B767. He is currently Editor of Flight Comment magazine as DFS 3-3.

"In recent years, the single biggest cause of accidents has become loss of control. ...It has raised the question about whether the situation is actually being made worse by the increasing automation, whereby crews don't get a great deal of opportunity to manually fly the aircraft."[1]

I remember hearing of a flight crew that was new to flying the high technological (at the time) aircraft Airbus 320. The aircraft Flight Management System (FMS) directed the autopilot to enter the holding pattern, corrected for wind throughout and continued to fly the pattern to perfection. When ATC directed the crew to cancel the hold and proceed with the approach, the aircraft continued in the pattern. When queried by ATC, the crew admitted that they were trying to figure out how to tell the FMS to exit the hold.

Back in 1992, another crew of an A320 impacted the side of a mountain at a high rate of descent. With the autopilot connected, the flying pilot had set a descent of 3.3 degrees flight path angle for the approach – or at least they thought they had. What the crew had actually selected was a 3,300 feet per minute descent.


Photo: Cpl Marc-André Gaudreault

Advances in aviation technology, whether fixed wing or rotary, have contributed to steadily declining accident rates since the end of the Second World War. Engines are incredibly reliable, airframes are constructed to exacting specifications while avionics and instruments have improved in reliability, readability and safety features. Why then would high tech features meant to prevent accidents, contribute to causing them?

There are a number of examples where largely serviceable aircraft have had incidents and accidents attributable, at least in part, to incorrect use of automation in the flight deck. For the purposes of this article, I have highlighted three such examples out of the plethora available.

12 JULY 2006, *CORMORANT* CH149914, CHEDABUCTO BAY, NEAR CANSO, NOVA SCOTIA

The accident occurred during an attempted go-around from a night approach to a fishing vessel. During the go-around the helicopter entered a nose-low attitude and seconds later the aircraft impacted the water with 69 knots forward speed in an 18 degree nose-down attitude. The three pilots and the SAR Tech TL were injured but survived the crash. The two flight engineers and the SAR Tech TM were unable to exit the aircraft and did not survive. The aircraft sustained damage beyond economical repair.

No evidence was found that any system malfunction contributed to the accident. The investigation determined that the flying pilot's trim technique caused the flight control pitch actuators to become saturated, which in turn caused the loss of the helicopter's automatic stabilization system. In this condition, the helicopter's inherent instability combined with the pilot's inputs to create a large but unrecognized nose down attitude and descending flight path.

The environmental conditions (darkness, distant dim horizon and calm water) were not suitable for continued flight using outside references only. The nose down attitude and descent were not noticed by any of the three pilots in the low visual cueing environment because they did not adequately reference their flight instruments.

25 FEBRUARY 2009, BOEING 737-800, AMSTERDAM-SCHIPHOL AIRPORT

Five passengers, a flight attendant and the three pilots were killed, and 117 passengers and 3 flight attendants were injured when the aircraft struck the ground 1.5 km short of the runway.

The aircraft had been vectored for an Instrument Landing System (ILS) approach to a position above the glide slope. One of the autopilots and the auto thrust were engaged. A number of automation related errors were made, but the result was that once the aircraft intercepted the glide path, the auto thrust commanded idle power due to the failure of the left radar altimeter. With decreasing airspeed, the autopilot commanded increasing pitch to remain on the glide path. Not one of the three pilots in the flight deck noticed the decaying airspeed until the "stick shaker" activated. The aircraft aerodynamically stalled and the aircraft crashed.

01 JUNE 2009, AIRBUS 330, ATLANTIC OCEAN

The A330 aircraft crashed into the Atlantic Ocean with the loss of all 228 people on board. It appears that the aircraft was flyable throughout with engines operating normally, but it was aerodynamically stalled, nose high, from 38,000 feet to the surface of the water. It was determined that minutes prior to the crash, the pitot tubes (speed sensors) gave inconsistent readings.

What do these accidents, and many others in recent years have in common? Largely that situational awareness in modern, technologically advanced aircraft can be lost to such a degree that very flyable and serviceable aircraft are crashed. Why is this happening when our aircraft are equipped with many more workload reducing, 'helpful', safety-enhancing technologies?

If we look back a generation (in aircraft terms), there were often 4 flight deck crew members: pilot, co-pilot, navigator and flight engineer. Generally speaking, one of the pilots was flying, the other pilot was working the radios and monitoring the instruments, the navigator assisted the flying pilot with directional input and the flight engineer (FE) handled the aircraft systems, sometimes including thrust management. When an emergency occurred, there were memory items followed by a paper checklist. Depending on the situation, the duties were shared to minimize the workload on one individual. As an example, the Aircraft Commander (AC) could take control, complete the memory items of the checklist with the assistance of the First Officer, have the Navigator take over the radios and obtain a clearance to the nearest airport and direct the FE to read the paper checklist. Therefore, almost all the attention of both pilots was concentrated on *flying the aircraft*.

"The next call over the intercom was "bank!" as the aircraft was by now inadvertently in a descending turn with almost 90 degrees of bank."

Back in the late 80's, I remember an incident that occurred in the CF with one of our CC130s. While on departure with a low weather ceiling, the aircraft entered cloud at 200 feet above ground level. At this point, the AC was told over the intercom that there was a fire. Thinking that the Loadmaster was suggesting an engine fire, both pilots and the FE became channelized, looking for indications of a fire (actually, the fire was a small incendiary in the back of the aircraft that was quickly extinguished). The next call over the intercom was "bank!" as the aircraft was by now inadvertently in a descending turn with almost 90 degrees of bank. The aircraft was recovered safely around 400 feet above ground. The Navigator had been the one to make the call that likely saved the aircraft.

In many of today's flight decks, there is one pilot who flies the aircraft and ensures proper navigation while the other pilot is responsible for communication, normal checklist and non-normal checklist completion as well as monitoring for possible errors of the flying pilot. When workloads increase, as they inevitably do from time to time, there are only the two crewmembers to share the load.

Many of the technological innovations that have led to 2 crew flight decks are indeed labour-saving and add to the safe operation of the aircraft. But what if the pilots learn to rely on these innovations, and for whatever reason, they suddenly become unavailable? What if these innovations begin to give erroneous indications such that the technological feature becomes part of the problem instead of the solution? What if the technical innovations become complicated to the point that pilots no longer fully understand the full implications of certain failures?

There are many safety innovations on the Air France A330 that crashed, which are designed to avoid entering and thereafter remaining in a stall. It appears that in this instance there were multiple warnings, both auditory and visual, which likely confused and distracted the flight crew as to what the real problem was. In an older aircraft without these safety innovations, it would have been second nature to set a specified power setting and attitude while assessing the problem. Since this accident, loss of airspeed indications in flight has once again become required training in spite of the technological advances.

One of the most basic parameters to monitor when flying an aircraft is airspeed. On a mostly serviceable

Photo: Cpl Tom Parker

B737 aircraft, how could an experienced crew with 3 pilots in the flight deck manage to stall the aircraft with two perfectly operating engines, on approach into Amsterdam? Before the normal use of auto thrust, this would not have resulted in a problem. This technical innovation, which pilots counted on and which failed to work properly, actually hindered the recovery. At one point during the approach, the FO pushed the thrust levers forward against the auto throttle to gain thrust to maintain airspeed. Because of the left radar altimeter reading negative 8 feet, the aircraft computers considered the aircraft to be on the ground and the auto thrust reverted to "retard" mode and automatically repositioned the thrust levers to idle. It seems almost certain that this aircraft would not have crashed had the flying pilot been hand flying the aircraft with manual thrust.

So what can we do to minimize the problems when transitioning to a more technologically advanced aircraft?

As a member of 437 Squadron when the unit was first converting from the B707 to the A310, I saw the squadron initially attempt to utilize the former aircraft's standard operating procedures (SOP) and adapt it to the A310 – a decision not supported by Airbus. I will not go into detail here, but suffice to say that the methodology to fly a much older technological aircraft was very different and it quickly became obvious that Airbus was correct. A large part of their SOPs were adopted for our use.

The other main lesson learned was that it is more vital than ever to fully understand the aircraft systems, the varying levels of technology and the interface with the operations of the aircraft. This kind of in-depth knowledge will minimize the now famous quote: "What's it doing now?" Knowing what will happen before it occurs is key to avoiding surprises on the flight deck.

Early in my A310 tour, we had a clearance to depart over a specific fix and then turn left 120 degrees on course. We dutifully programmed the fix and the turn and departed in NAV mode to follow the clearance. What we didn't know at the time was that in order to make the 120 degree turn on track, the aircraft "decided" to start the turn 3 miles before the fix, thereby not acurately following the clearance. The lesson learned here is if the aircraft isn't doing what you want, change it. You always have the option of disconnecting the automatics and you have control!

On that note, how many pilots regularly practice flying without the technological advances connected? At some airlines, it is encouraged to hand fly with the autopilot and auto thrust disconnected on a regular basis, particularly in good weather and in low traffic areas. This has the effect of maintaining an effective cross check and improving confidence in the event of multiple systems failure.

In the final analysis, effective technology should contribute towards safer flight. The weak link is the human element, and that is where each of us can make a difference by ensuring we are in every sense ready for the challenge.

Reference

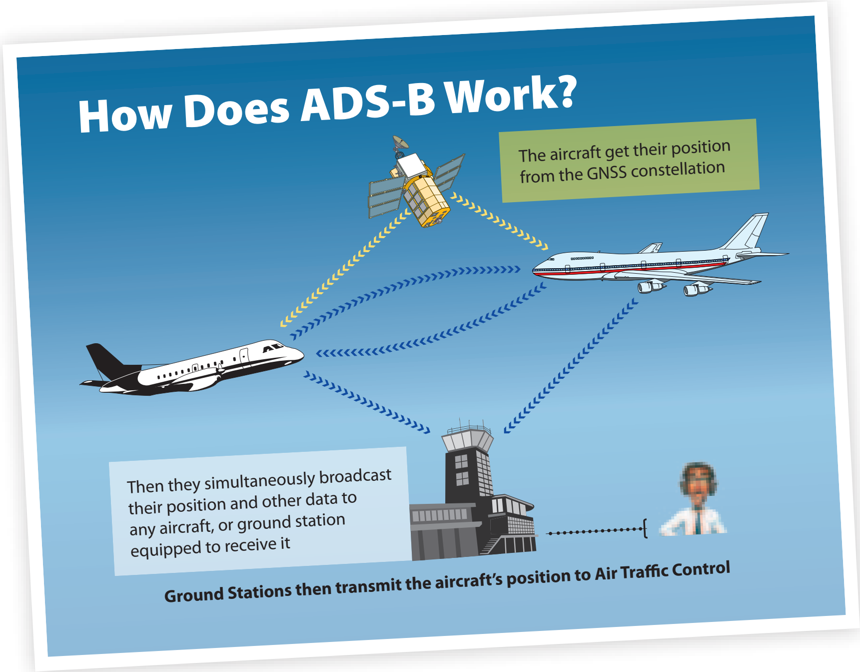
1. *Aero Safety World*, September 2010, "Inside Air France 447", p54, attributed to Mr Tony Cable.

ADS-B. Great...

Four More Letters I Gotta Know

By Captain Scott Anningson, Instrument Check Pilot Flight, 1 Canadian Air Division, Winnipeg, Manitoba

Captain Anningson is an instructor and Instrument Procedure Designer in the ICP Flight at the Air Force Standards Advanced Performance Centre in Winnipeg.

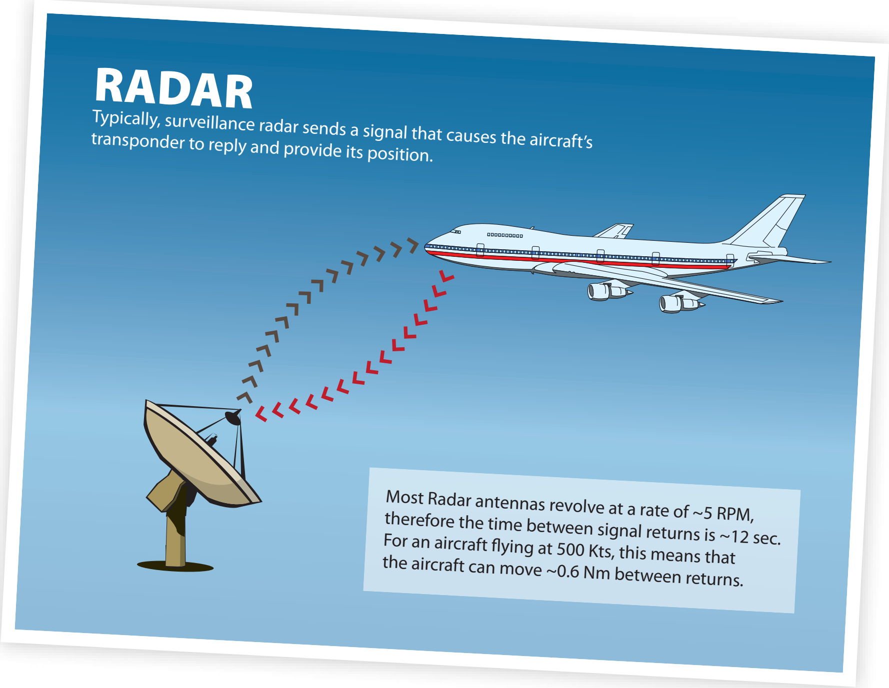


I brought my daughter in to work for "Bring Your Kids to Work" day. Although she had fun, she said she didn't understand much of what was being said amongst the other pilots in conversation – "VOR, shooting the ILS, GPS, go-around, NDB, torque, bleed air, PFL, boots, auto-rotate, ICAO, ED, bug smasher, RNAV, RNP, etc." She called it *aviationese*. Now we have another 4-letter to add to the lexicon: ADS-B. Anyone remember *aural null* by any chance?

> "Now we have another 4-letter to add to the lexicon: ADS-B."

ADS-B is a new ATC (Air Traffic Control) surveillance system that will replace traditional radar. It's already in operation over Hudson Bay. There are plans to expand this system throughout Northern Domestic Airspace in Canada.

Recent rulemaking in the United States mandates that all aircraft operating in airspace that now requires Mode C or Mode S transponders shall be equipped with ADS-B (Out) by 1 January 2020. Europe is proposing and mulling over mandatory ADS-B equipage for all aircraft by 2015. We will have to wait and see what Canada will require. Because the nature of Air Force operations is often



RADAR

Typically, surveillance radar sends a signal that causes the aircraft's transponder to reply and provide its position.

Most Radar antennas revolve at a rate of ~5 RPM, therefore the time between signal returns is ~12 sec. For an aircraft flying at 500 Kts, this means that the aircraft can move ~0.6 Nm between returns.

expeditionary and involves transiting U.S. and European airspace, this is equipment we will have to get a handle on.

What's In a Name?

ADS-B stands for *Automatic Dependent Surveillance – Broadcast.* Conveniently, the name defines the system.

Automatic – It's all automatic. It's a "box" in an airplane that broadcasts data about the airplane. It periodically transmits information with no pilot or ATC input required.

Dependent – It's dependent on aircraft sources of information. It takes WAAS (Wide Area Augmentation System)/GPS (Global Positioning System), possibly FMS (Flight Management System) and/or INS (Inertial Navigation System) positions, velocity vectors, altitudes, distances, and packages it with other stuff like call sign, aircraft type or category into digital form.

Surveillance – This information is used to determine the position and likely track of aircraft, vehicles, ships or anything else with this equipment.

Broadcast – This transmitted data is available to anyone with the appropriate receiving equipment. This usually includes other aircraft and ATC, but ships, the Ops desk or a CAOC (Combined Air Operations Center) can be in the loop as well with their own receiving equipment.

There are two parts to it – ADS-B In and ADS-B Out. ADS-B Out is the outward broadcast of your data. ADS-B In is the receiving of other ADS-B broadcasts, from the ground and from the air. Three link solutions are available. The first option is through the traditional Mode S transponder 1090 MHz squitter and is called an Extended Squitter. More data is added to a longer pulse and transmitted through the transponder. Another option uses the 978 MHz UAT (Universal Access Transceiver) spectrum reserved for ADS-B and requires the acquisition of associated transceivers. Finally, there may also be a VHF Data Link (VDL) mode 4 option using available aviation VHF frequencies.

> "Another option uses the 978 MHz UAT (Universal Access Transceiver) spectrum reserved for ADS-B and requires the acquisition of associated transceivers."

> "In contrast, ATC radar surveillance requires ground-based radar sweeps and bursts."

The ADS-B system in an airplane will update and broadcast information at a rate of about once per second or faster. It works on the ground and in the air.

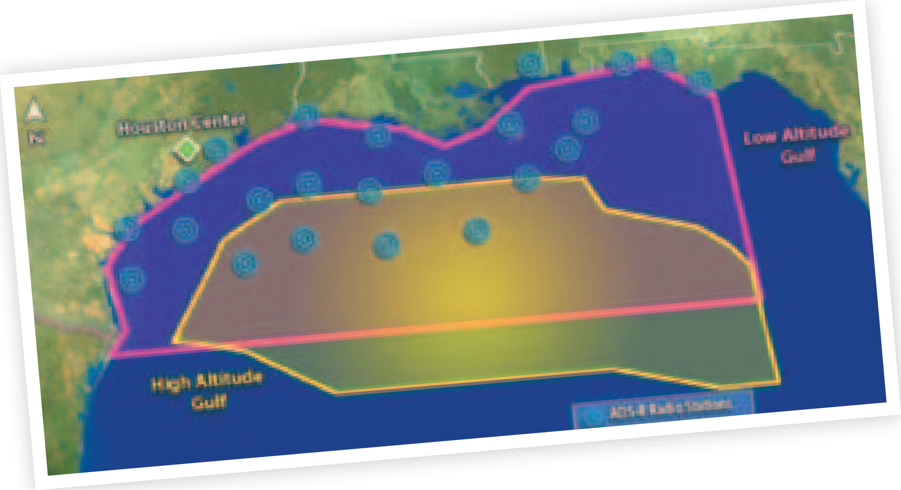
In contrast, ATC radar surveillance requires ground-based radar sweeps and bursts. Mode A or Mode C or Mode S transponders are interrogated and then reply with a "squawk." Perhaps after a few sweeps and some fancy ground-based computer calculations, a pretty accurate aircraft position, flight direction and speed are then depicted on a controller's screen. But given system flaws and range errors, ATC radar is only accurate enough to allow IFR aircraft to be within no less than 3 to 5 miles of each other.

Due to the automatic and more frequent broadcast of ADS-B data from the airplane, aircraft position accuracy is measured within a few hundred feet and not miles. Altitude and velocity accuracy is also much better and more reliable than traditional ATC radar. Because of this much improved standard of accuracy, ADS-B is the basis for reducing ATC separation and the narrowing of some other standards as well, namely on arrivals and departures.

Safety and Benefits of ADS-B

- Reduced and more common separation standards in all classes of airspace (horizontal and vertical).

- Radar-like or better separation standards in remote, non-radar areas. It provides surveillance for areas that currently lack it, and provides it cheaper and more effectively than installing radar.



- More flexible for direct routings contributing to fuel savings.
- Better ability to manage traffic flow and monitor aircraft fleets.
- Improved ATC ability to plan and project arrivals and departures.
- Low cost infrastructure for national airspace.
- More detailed air-to-air surveillance capability than TCAS (Traffic Alert and Collision Avoidance System)/ACAS (Airborne Collision Avoidance System) alone.

> "ADS-B is designed to allow more comprehensive and detailed coverage, eliminated gaps in coverage, and support the resolution of traffic down..."

- More detailed ground-to-air surveillance than radar.
- Availability of real-time, in-cockpit traffic and aeronautical information. This includes weather, temporary flight restrictions, special use airspace, aircraft call sign and class of proximal traffic and much more. Therefore, there is more data in real-time and less reliance on voice R/T (radio-telephony).

ADS-B has been in development and testing for years. It has now been selected as the foundation technology by the U.S. and Europe for the Next Generation Air Traffic Management System. This is commonly called NextGen. You can learn more about it by visiting the FAA Website *http://www.faa.gov/nextgen/* and the European Website *http://www.eurocontrol.int/cascade/public/subsite_homepage/homepage.html*. Useful information on joint U.S. military and civilian implementation can be had at the Joint Planning and Implementation Office at *http://www.jpdo.gov/index.asp*.

By 2013, there will be a grid of almost 800 ADS-B ground stations in the U.S. Most of the Gulf of Mexico is covered now, starting from below 1800 MSL.

ADS-B is designed to allow more comprehensive and detailed coverage, eliminated gaps in coverage, and support the resolution of traffic down to very fine tolerances in altitude, heading, airspeed and ETA (estimated time of arrival). It will also be a network of shared weather, aviation and traffic information in real-time. And it's supposed to be inexpensive, at least when compared to the cost of radar.

The future is now. Are we ready?

Out of Harm's Way:

3-D and Aircraft Maintenance

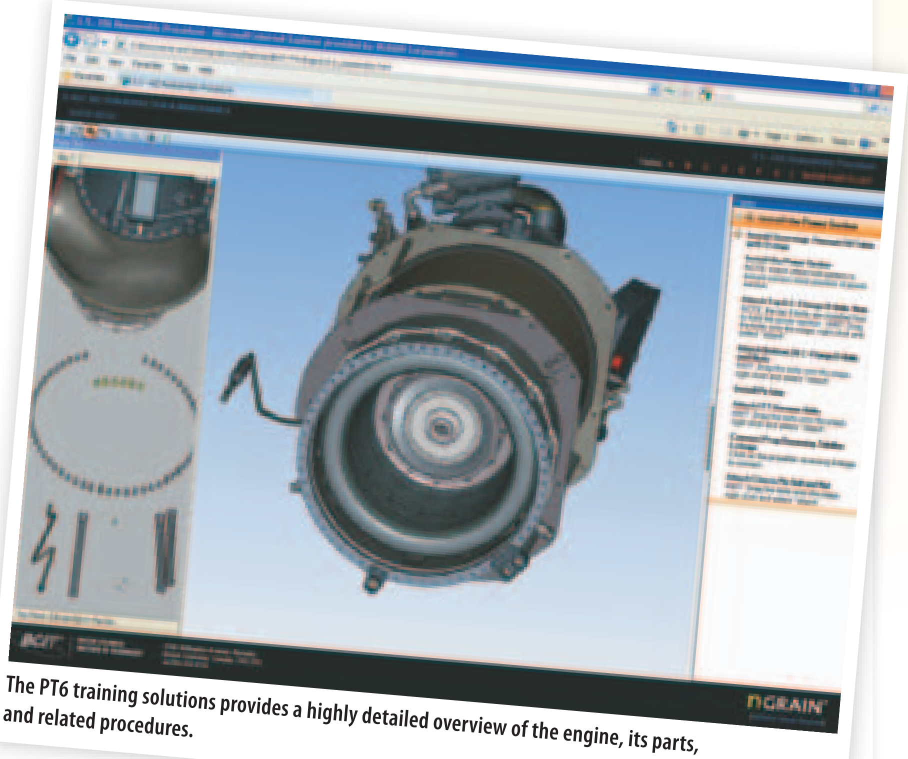
By Mr Arnold van den Hoeven, Director of Canadian Defence, NGRAIN

Mr Arnold van den Hoeven

Mr Van den Hoeven worked in the Aerospace & Defence (A&D) sector for more than 25 years, beginning with a 15 year career as a pilot and Aeronautical Engineering (AERE) officer in the CF. He held a wide variety of positions, including Mechanical Systems Project Officer at the Aerospace Engineering Test Establishment in Cold Lake, CC130 Structures Engineer, and CC130 Aircraft Structural Integrity Program (ASIP) officer at NDHQ in Ottawa. Since leaving the CAF in 1998, he has been active in the A&D industry working for companies such as Mxi Technologies, Air Canada and KLM. Now at NGRAIN, he is the Director of Canadian Defence helping to transform maintenance training with interactive 3-D simulation solutions.

The advance of simulation technologies plows ahead and is being applied to more areas of training and research than ever before. One area of significant growth over the past decade has been the application of simulation for equipment maintenance training and maintenance support solutions. Traditionally used in classrooms to increase training throughput, reduce the need to take equipment out of service for training purposes, and avoid costs of acquiring equipment for training, this type of solution is now also being leveraged on-the-job to make maintenance safer.

Maintenance of complex equipment – particularly aircraft and their systems – requires specialized knowledge of each system and their interrelation



The PT6 training solutions provides a highly detailed overview of the engine, its parts, and related procedures.

The interactive 3-D NGRAIN CP140 training solution has been approved for use on AFIILE and is currently used in instructor-led environments within the Air Force.

with one another. In addition, there are inherent risks to personal safety when working around toxic chemicals likes fuels and solvents as well as electrical and pressurized systems. One report by the Federal Aviation Administration found that almost 50 percent of maintenance accidents were related to the improper installation, maintenance and maintenance inspection procedures of an aircraft. The same report found that 76 percent of those injuries were a result of incorrectly attaching/connecting a part or omitting an installation procedure; particularly when working with powerplant, landing gear and rotor systems[1]. This was echoed in a more recent report conducted by the University of Illinois, which identified incorrect procedures and parts installation was often a result of incorrect interpretation of procedural information[2]. Simulation-based training can help to reduce maintenance-related incidents by improving the proficiency with which tasks are completed, as well as by providing just-in-time maintenance support so that airmen can review and practice tasks prior to carrying them out.

> *"One report by the Federal Aviation Administration found that almost 50 percent of maintenance accidents were related to the improper installation, maintenance and maintenance inspection procedures of an aircraft."*

Incorporating interactive 3-D simulations into training and on-the-job performance support provides maintainers with a visual representation of tasks related to key procedures. Step by step, maintainers and technicians can review parts, procedures, and even troubleshooting methods. Deployable on a common desktop, laptop or tablet computer,

> "The NGRAIN Virtual Task Trainer™ (VTT™) is a commercial-off-the-shelf (COTS) software-based solution that leverages interactive 3-D simulation to deliver maintenance procedure training in a Web browser-based environment."

simulation-based solutions from NGRAIN can help reduce the risk of personal injury by increasing the level of proficiency with which tasks are completed, providing a safe computer-based learning environment, as well as providing procedural knowledge at the time of need.

The NGRAIN *Virtual Task Trainer*™ (VTT™) is a commercial-off-the-shelf (COTS) software-based solution that leverages interactive 3-D simulation to deliver maintenance procedure training in a Web browser-based environment. SCORM- conformant and approved for use on the Air Force Integrated Information Learning Environment (AFIILE), VTT solutions from NGRAIN are being used as part of a blended learning solution to improve student knowledge and skill retention, while at the same time increasing classroom throughput.

Over the past decade, the average technician's experience on any given fleet in the Air Force has diminished significantly. This can increase the risk of incorrectly performing a procedure and thus the risk of injury. The NGRAIN *Virtual Task Refresher*™ (VTR™) is being used to provide just-in-time job support and helps to ensure airmen can complete specific tasks correctly. Locally deployed to a desktop, laptop or mobile computing device, the *Virtual Task Refresher* delivers task-specific information to maintainers so that they can prereview and practice procedures virtually before working on the aircraft. This improves task performance, maintenance resolution, and increases safety.

In a recent study commissioned by the Air Force, NGRAIN solutions were proven to improve levels of proficiency by up to 22 percent. The study found that when incorporated into Advanced Interactive Electronic Technical manuals (A-IETM) developed by Standard Aero, NGRAIN performance support solutions enable novice maintainers to perform at the same level, and in some cases better than, expert maintainers. The same study found that maintainers were able to complete tasks 23 percent faster when using NGRAIN than when using a traditional technical manual.

Today's Air Force face reduced budgets and manpower. It is critical that our airmen are given the tools needed to complete tasks properly and without incident. In a time when pure fleeting is no longer possible, NGRAIN solutions provide maintainers with the information they need to transition between any number of aircraft safely and efficiently.

References

1. Scott Goldman, et al, General Aviation Maintenance-Related Accidents: A review of Ten Years of NTSB Data (Washington: Office of Aerospace Medicine, 2002)

2. Takahiro Suzuki, et al, Coordination and Safety Behaviors in Commercial Aircraft Maintenance (University of Illinois at Urbana Champaign, 2008)

> "The same study found that maintainers were able to complete tasks 23 percent faster when using NGRAIN than when using a traditional technical manual."

Intelligent Video –

Improving safety in defence operations and enabling the future of automation

By Fadi Ghourani, Director, ATM/Airport Technology, Searidge Technologies

Mr. Ghourani specializes in providing comprehensive consulting services to airports and air navigation service providers (ANSPs) to assist in the deployment of surveillance technology to improve airport efficiencies and operations. His understanding of day-to-day operational and technical challenges encountered by airports has been instrumental in the adoption of intelligent video surveillance systems by leading airports and ANSPs throughout North America, Europe, and the Middle East.

Intelligent video is enabling a fast growing number of military surveillance applications with automated capabilities that can augment and in some cases replace human monitoring. Built from the ground up for use in airfield environments, *Defense-Grade* Video systems employ mil-grade sensors, ruggedized hardware, and leading edge computer processing tools.

Video Analytics, the underlying technology powering intelligent video applications, builds upon research in computer vision, pattern analysis and machine intelligence, and has been widely adopted in a wide variety of airfield management and command and control centre tasks ranging from remote airfield management used in prevention of runway incursions, to security applications such as restricted zone and perimeter intrusion detection, and Foreign Object Debris (FOD) detection.

Under the hood – Video Analytics

Similar to human vision, video analytics employs algorithms to perceive or see, and machine intelligence to interpret, learn and draw inferences; to understand a given scene and issue alerts and alarms that would typically be flagged by a human observer.

> "Video Analytics, the underlying technology powering intelligent video applications, builds upon research in computer vision, pattern analysis and machine intelligence..."

Benefits – Overview

Intelligent video allows for sharing of information with multiple users and stakeholders, and therefore is a key enabler of collaboration; multiple applications can be derived from a single sensor, or single set of sensors, allowing for ease of sharing of mission-critical information to be simultaneously distributed to the people that depend on it, in real time. Automation affords military operations personnel numerous advantages, including elimination of human error, reduction in, and in some cases, elimination of required manpower, more accurate and consistent performance of operational duties, and ultimately a systemic improvement in safety.

Intelligent video applied to automation of runway lighting; improving safety in all weather conditions.

Applications

- ***Remote Airfield Management***
  Modernizing Command and Control Centres

- ***Security***
  Perimeter Protection and Intrusion Detection

- ***Foreign Object Debris Detection***
  Safer runways, reduced manual labour

Remote Airfield Management – Modernizing Command and Control Centres

A remote airfield management solution equips military controllers with an advanced set of decision support tools that enable them to provide advisory or control services to aircraft and vehicles at geographically independent airfields.

Enabling military personnel to monitor restricted areas, intelligent video systems can both improve safety for operations staff and easily allow for surveillance of locations that are inaccessible or too harmful or dangerous for humans to enter into. With the emergence of drones being used in missions, and safety being of paramount importance, virtual tower solutions/remote surveillance is becoming increasingly accepted and adopted by defence organizations around the globe.

Under the hood – *Remote management solutions*

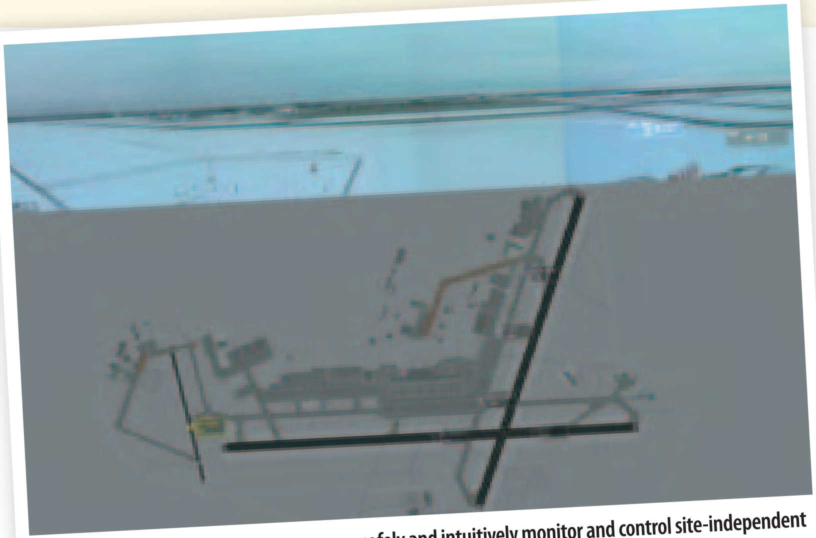
Using advanced video-stitching techniques, a remote monitoring video solution provides command centre personnel with an intuitive consolidated view of the airfield under surveillance; as opposed to a traditional tiled-CCTV view. In addition, an intelligent video module converts the standard mil-grade sensor outputs into a radar-like view of the surface.

Benefits – *Remote management solutions*

Automation affords military operations personnel numerous advantages, including elimination of human error, reduction in, and in some cases elimination of required manpower, more accurate and consistent performance of operational duties, and ultimately a systemic improvement in safety.

Security – Perimeter Protection and Intrusion Detection

Military personnel are responsible for maintaining safe and secure airfields and airfield perimeters. Various systems and methods are employed by defence organizations to monitor for and detect intrusions by vehicles, humans and animals. The most popular methods today include standard CCTV networks with manual monitoring procedures, as well as manual human observation procedures. Both of these options used for monitoring of and detecting intrusions can be labour intensive, cost-ineffective, and prone to error.



Command and Control Centre operators can safely and intuitively monitor and control site-independent airfields by using the latest advances in video technology.

The Intelligent Intrusion Detection solution is a scalable system that automatically monitors for and depicts and reports all targets in an area of interest to security personnel with real-world LAT/LONG positions via an intuitive 2-D map display. Suspicious activities such as a human entering into an unauthorized area is immediately flagged and sent to security personnel. Rather than having to continuously and simultaneously look at and scan numerous CCTV screens for possible intrusions, the system produces audible and visual alerts to the security operator such that no intrusions go undetected.

> "Various systems and methods are employed by defence organizations to monitor for and detect intrusions by vehicles, humans and animals."

Under the Hood – *Intelligent Security*

With an advanced software suite, operations personnel can configure a system to meet local operational needs. For example, operations staff can draw (on-the-fly) a virtual restricted zone, or a virtual trip-line alongside a runway entry point; an alert can then be issued to the user when the tripwire is breached, and because the system understands target velocity, heading, size and shape, alarm discrimination can be used based on predefined business rules such that they system automatically performs a task exactly as the human operator would otherwise perform it manually.

Benefits – *Intelligent Security*

Semi-automation or full automation in security affords the operator more time to perform auxiliary tasks, and handle only the exceptions as intrusions take place. All video and contextual map data is recorded and archived to be accessed for incident review, investigations, and mission training.

FOD Detection – Safer runways, reduced manual labour

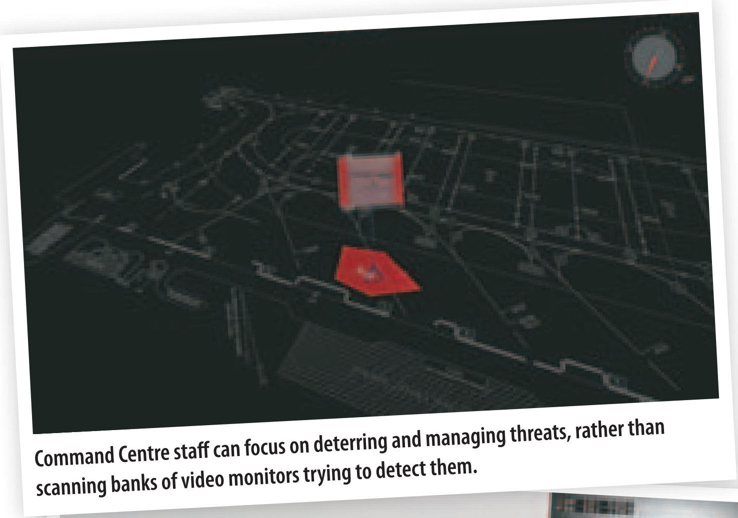
Foreign object debris (FOD) at airfields includes any object found in an inappropriate location that, as a result of being in that location, can damage equipment or injure airplane or airport personnel. The resulting damage is introduces significant cost; which in many cases could be avoided.

FOD includes a wide range of material, including loose hardware, building materials, rocks, wildlife, or other. It causes damage through direct contact with airplanes, such as by cutting aircraft tires or being ingested into engines, or as a result of being thrown by jet blast and damaging airplanes or injuring people.

Intelligent video systems can automatically scan runways and taxiways and alert support personnel to FOD and its location on the airfield surface. A traditional FOD prevention program involves teams of humans walking the length of a runway and looking for FOD and picking it up; a labour intensive process.

Under the Hood – *FOD Detection*

Intelligent video systems used to detect and report FOD can be configured to alert for specific sizes of objects left behind on a runway or taxiway. The system 'learns' the behaviours of standard objects within the scene, and alarms only for objects that do not fit within the 'normal' background and movement patterns within the field of view.



Command Centre staff can focus on deterring and managing threats, rather than scanning banks of video monitors trying to detect them.

Intelligent video can help automatically detect, identify and locate FOD on the airfield.

Benefits – *FOD Detection*

Operations personnel can be alerted to FOD in real time and can use the camera view to visually confirm the alert and quickly assess the risk of the FOD, and if necessary, dispatch support staff to retrieve it in an expeditious manner. By adding automation to a portion of the process, a defence organization can better utilize human resources, increase safety, and reduce costs, both direct and indirect, that result from FOD damage.

Conclusion

Advances in intelligent video technology are enabling a host of surveillance and command and control applications relevant to modernizing the way defence organizations conduct operations; the paramount implication being an increase of safety for military personnel. From remote airfield management to automation of previously manual processes and procedures, intelligent video can be applied to a wide variety of challenges and greatly aid in improving organizational safety, efficiency, and collaboration amongst stakeholders.

Intelligent video can safely and efficiently address a multitude of operational challenges; too many to list here; so a good starting point is to look at the organization as a whole and identify safety gaps and how video can help fill those gaps.