THE CURTIS PAPERS

CANADIAN AEROSPACE AND JOINT STUDIES

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Introduction

The Curtis Papers are named in honour of Air Marshal Wilfred Austin "Wilf" Curtis, Officer of the Order of Canada (OC), Companion of the Order of the Bath (CB), Commander of the Order of the British Empire (CBE), Distinguished Service Cross (DSC) and Bar, Efficiency Decoration (ED) and Canadian Forces Decoration (CD). Curtis was the Chief of the Air Staff of the Royal Canadian Air Force (RCAF) from 1947 until 1953 and was a strong supporter of the Canadian Forces College (CFC) in its early years as the RCAF Staff College. He firmly believed in the need for a well-trained and educated officer corps as a prerequisite for an efficient, effective and innovative military force.

The publication of *The Curtis Papers* supports the ongoing mandate of the Canadian Forces Aerospace Warfare Centre (CFAWC) to encourage the study of aerospace subjects of interest to both the RCAF and the joint defence community. One of the primary methods to achieve this goal is to publish, or to cause to have published, aerospace and joint material of a high professional and academic quality. The CFC, through its Master of Defence Studies (MDS) programme, produces on an annual basis a number of papers that meet these criteria. The papers contained herein were selected from amongst a multitude of fine papers produced by the students of the Joint Command and Staff Programme.

The Curtis Papers will be distributed to various Canadian and allied locations to serve as a resource for ongoing professional development and academic education. In this manner, they will increase aerospace awareness amongst broader civilian and military communities, while at the same time emphasizing the need for a joint perspective within aerospace forces.

Abbreviations

CFC	Canadian Forces College
RCAF	Royal Canadian Air Force

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Chapter 1 – Line Operational Simulation: Towards Optimizing Human Performance in the Canadian Air Force

Lieutenant-Colonel Colin R. Keiver

Abstract

The Canadian Air Force has begun a modernization programme that is unprecedented in its history. The findings and conclusions in this paper, as they relate to the synthetic environment and the optimization of human performance, are a means to ensure the Air Force is able to fully exploit the potential of not only the systems it possesses or will possess in the future but also the potential of its personnel. This paper proposes a road map to operational success and safety that fully exploits the synthetic environment to build upon what has always been one of the fundamental strengths of the Air Force—its people. To achieve these goals, it recommends the creation of behavioural performance markers within the Air Force that are taught and evaluated to the same level as technical skills. Once created, these skills are best taught in the synthetic environment in what the aviation industry refers to as line operational simulation (LOS).

While there are no quick answers to the human factors issues that the Air Force is wrestling with, this paper concludes that solving them is not difficult. It will take deliberate effort and resources. Once that effort is begun, and a common language of aviation human factors is established across the Air Force, other areas such as human performance in military aviation (HPMA) and the Human Factors Analysis and Classification System (HFACS) used by flight safety will also begin to deliver promised results that have yet to be achieved. There is significant potential to adopt other industry solutions, such as line operations safety audits (LOSA), once human factors are fully integrated into Air Force training and operations. Implementing LOS and maximizing the use of the synthetic environment across all fleets within the Canadian Air Force is a critical first step in that transformation.

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1. Introduction

The quality of the box matters little.
Success depends upon the man who sits in it.[1]

Manfred von Richthofen
The Red Baron

In the latter part of the 20th century, the introduction of simulators to aviation marked a dramatic evolution in the way the aviation community develops human potential. No longer restricted to conducting training with an actual aircraft, simulators have allowed the industry to teach and practice sequences and events considered too dangerous in a real aircraft while replicating, to a high level of fidelity, the actual operating environment. In modern aviation training systems, it is not uncommon for someone to achieve an initial qualification, and then maintain that qualification, without ever touching an actual aircraft except during the conduct of operations. While originally oriented towards training aircrew, the use of simulation has expanded to include all personnel involved in aviation. This includes both maintainers and air traffic controllers.

This movement towards the use of the synthetic environment to achieve training objectives has been mirrored within Canada's Air Force. It began with the introduction of the first Link trainers during the Second World War and continues to this day with highly capable simulators found in programmes like the Maritime Helicopter Project (MHP) and the Airlift Capability Project - Tactical (ACP-T), more commonly referred to as the C130J project. These projects will deliver more than modern aircraft to the inventory; they will also field numerous sophisticated training devices heavily reliant on simulation to achieve training objectives for both aircrew and maintainers. Today, most Canadian Forces (CF) aircraft fleets possess, or have access to, synthetic training devices used for the training and qualification of personnel within those fleets. In an effort to increase human performance, the Canadian Forces has expended significant resources on the acquisition of synthetic training devices.

The technological development that has been put into the aviation synthetic training environment has been significant—but, does it deliver corresponding increases in human performance? Research has shown that without significant investment in other critical areas, with a focus on behavioural and learning objectives, simply procuring the device will not achieve the desired results. As articulated by Eduardo Salas, Clint A. Bowers and Liza Rhodenizer, how a simulator is used is actually more important in the attainment of training objectives than the specific training technologies themselves.[2] Simply put, a simulator or a full suite of synthetic training devices is not a training programme. The fundamental issue then becomes how best to design the training so as to take full advantage of what the synthetic environment has to offer. Achieving optimization of human performance through the synthetic environment mandates the development of not only the devices but also the means by which they are employed, based on a solid understanding of the behavioural objectives to be achieved.

This study will demonstrate that the adoption of line operational simulation concepts, similar to those developed and implemented by the civilian aviation industry, will significantly contribute to an increase in human performance in the Canadian Air Force and allow it to fully exploit the potential of the synthetic environment. To do so, it will examine the following areas of human factors and simulation within industry and the Canadian Air Force:

1. Manfred von Richthofen, *The Red Fighter Pilot,* trans. J. Ellis Barker (London, UK, 1918), Chapter 12, http://www.richthofen.com/ (accessed July 3, 2012). Originally published as *Der Rote Kampfflieger* (1917).

2. Eduardo Salas, Clint A. Bowers, and Lori Rhodenizer, "It Is Not How Much You Have but How You Use It: Toward a Rational Use of Simulation to Support Aviation Training," *International Journal of Aviation Psychology* 8, no. 3 (1998): 197.

a. the critical role of human factors in aviation, in addition to traditional technical skills;

b. the rationale behind LOS to address human factors in aviation;

c. the critical role of the instructor in ensuring the development of appropriate human factors skills to reduce their impact on aviation mishaps; and

d. the current state of simulator utilization and human factors training within the Canadian Air Force.

The majority of the aviation regulatory and research material used in the development of this thesis will be taken from the United States Federal Aviation Administration (FAA). Although similar documentation has been published by Transport Canada, the majority of it uses FAA policy and guidance as a primary reference. As an example, Transport Canada guidance on the development and implementation of an advanced qualification programme (AQP), a training programme which incorporates extensive use of LOS, specifically refers to the fact that the FAA standards for AQP "have been used as the basic model for the Canadian AQP standards."[3] For that reason, FAA documentation will be used as the primary sources for the development of this paper.

This study will capture the delta that currently exists within the Canadian Air Force as it relates to the optimization of human performance and the use of the synthetic environment in comparison to the broader aviation industry. It will recommend that a comprehensive LOS programme be developed and implemented across all aircraft fleets to address identified deficiencies in fully integrating the field of aviation human factors into military training and operations. The development of behavioural performance markers and ensuring the instructor/evaluator cadre is prepared to deliver the required training and evaluations with those behavioural performance markers will be emphasized in this paper. Air Force instructors and evaluators are the front line of standards and operational effectiveness, and they are the engine by which the Air Force will achieve its synthetic environment and human factors goals. A dedicated human factors programme, delivered by qualified instructors and evaluators through a robust LOS programme, can have a significant impact. Finally, this study will discuss the ways in which simulator scenarios should be designed to fully integrate both behavioural and technical skills that can be taught and evaluated. As the Air Force develops a common language of human factors, essential to the development and maintenance of an effective LOS programme, other complementary areas will begin the transformation as well, and that will have significant benefit for the organization in both safety and operational effectiveness.

In keeping with the focus on the methods of employment, rather than the device itself, this study will not address the issue of motion in the synthetic environment and its applicability to aviation. While much of the study will focus on the development of aircrew specific training, the lessons contained within it are equally applicable to all aspects of the Air Force, if it is to optimize human performance across the spectrum of its activities.

Many aviators affectionately refer to the simulator as "the box." The aim of this paper is to identify, within the Canadian Air Force, the requirement for LOS and the means by which to implement it, thereby achieving a high level of human performance. It will demonstrate that the lesson offered by the Red Baron more than 90 years ago, and the importance of the human over the box, is as relevant today as it was when it was written. More importantly, it will also demonstrate that the heavy reliance on technology, which the Air Force has always exploited to its fullest, will only deliver its promised results if the human element is considered and fully integrated across all aspects

3. Government of Canada, Transport Canada, *Development and Implementation of an Advanced Qualification Program (AQP)* (Ottawa: Transport Canada, 2005).

of the military flight domain. How the Air Force uses its synthetic environment to address aviation human factors will play a significant role in how successful Air Force transformation really is.

2. Human factors in aviation

Introduction

Three years before the Red Baron identified the critical role of the human to achieving success in aviation, the first Canadian in uniform took to the air. Lieutenant William Sharpe enrolled in the Canadian Expeditionary Corps in September 1914 and, already possessing a pilot's licence, found himself the first and only pilot in the Canadian Aviation Corps.[4] With his Burgess Dunne aircraft still in pieces after being shipped to England, he began flying training with No 3 (Reserve) Squadron of the Royal Flying Corps. William Sharpe died on the 4th of February, 1915 when the aircraft he had taken up solo crashed, thereby earning the distinction of being not only the first Canadian military aviator but also the first to be killed while on service.[5]

Accidents in Canadian military aviation have been occurring ever since, just as they have in the broader aviation environment. This section will briefly examine that history and demonstrate the critical importance of human factors in aviation in not only understanding the causes of accidents but also developing potential solutions. It will provide an understanding of how best to shape training and operations to support the fundamental role of the human in aviation, and it will conclude with an emphasis on the development and introduction of LOS as a critical enabler to addressing the human factors issues embedded within aviation and which have been wrestled with since man first took to the air. The purpose of this section is to provide a contextual background to human factors in aviation as well as their significance and to clearly link human factors to the development of LOS as a critical enabler to reducing the attribution of human factors to aviation accidents.

Human factors defined

At its most fundamental level, human factors are about people. It is, as Frank Hawkins put it in 1987, about people in their living and working environments, their relationship with the technology in those environments as well as with the procedures they use to conduct activities and, most importantly, their interactions with other people.[6] In a more formal sense, it can best be defined as a science oriented to "optimise the relationship between people and their activities by systematic application of the human sciences, integrated within the framework of systems engineering."[7] Its objectives are articulated as achieving overall effectiveness of the system, in the areas of safety and efficiency, while maintaining the well-being of the individual within the system.[8]

The birth of aviation human factors

The International Air Transport Association Technical Conference held in Istanbul, Turkey, in 1975 is widely viewed as the turning point in the recognition of the importance of human factors in aviation.[9] By this point in time, aviation technology had reached a level of maturity that allowed for high levels of reliability, yet accidents were still occurring. The general consensus of the meeting was that "something was amiss related to the role and performance of man in civil aviation" and that a

4. Brereton Greenhous and Hugh A. Halliday, *Canada's Air Forces 1914–1999* (Montreal: Art Global, 1999), 14.

5. Ibid., 15.

6. Frank H. Hawkins, *Human Factors in Flight* (Aldershot: Gower Technical Press Ltd, 1987), 18.

7. Ibid.

8. Ibid.

9. Ibid., 17.

"basic Human Factors educational gap existed in air transport."[10] Thus was born the modern field of aviation human factors, and the catastrophic accident in Tenerife just 17 months later in which 695 people lost their lives due to crew error has been described by Frank Hawkins as a call to "aviation to put its Human Factors house in order."[11] With that recognition, the industry began moving forward on a number of initiatives. However, was this really a new problem within aviation?

The role of human factors in aviation

It has generally been accepted that airworthiness issues, such as mechanical unreliability and structural weaknesses in the aircraft, were primarily responsible for the majority of accidents through much of aviation history. The theory states that in the beginning more accidents were caused by technical failures than by human factors, and as the technical side has matured, human factors took on more prominence. Now that the technical problems have largely been solved, the general hypothesis of the theory is that human factors have emerged as the final frontier in addressing and solving aviation complexity.

This was not viewed as a trend unique to aviation and was observed in other areas such as the nuclear and manufacturing industries in which it has been noted that there has been an increase in the numbers of accidents attributed to human error.[12] While it is certainly possible that increases in mechanical reliability have led to these observations, it is also possible that changes in the focus of the investigation have led to these differences.[13] If that is in fact the case, then it is necessary to re-examine aviation accidents throughout history to determine whether the role of the human has changed or remained relatively constant.

The historical context

Several reviews of historical records have been conducted in which the role of human factors in aviation has been re-examined. One of the best was that conducted by Alan Hobbs in the latter part of the 20th century in which he examined accident records and statistics in Australia from 1921 to 1932.[14] What he uncovered represents a significant departure from the widely held belief on the evolving role of human factors in aviation.

Hobbs utilized causal factor categories employed by the Australian Bureau of Air Safety Investigation until the 1990s and was able to identify 84 accidents during the study period in which sufficient data was available to conduct an analysis. What his analysis showed was that the largest proportion of cause factors attributed to aviation accidents during the period was in fact personnel. While mechanical failures contributed to slightly more accidents, they did not do so to a degree that supports the widely held theory of mechanical versus human factors causes in aviation.[15]

What Hobbs also discovered in sifting through the historical record is that this finding was not unique to the early days of Australian aviation. He identified a study done by W. H. Wilmer in 1935 which stated that fully 90 per cent of all British aviators who lost their lives in the initial year of the First World War did so due to "individual deficiencies," 8 per cent due to mechanical defect, and only 2 per cent at the hands of the enemy.[16] He uncovered another study done by G. E. Anderson

10. Ibid., 18.
11. Ibid.
12. Alan Hobbs, "Human Factors: The Last Frontier of Aviation Safety?" *International Journal of Aviation Psychology* 14, no. 4 (Fall 2004): 336.
13. Ibid.
14. Ibid.
15. Ibid., 337–40.
16. Ibid., 338.

in 1918 on British Naval Aviation accidents during the same war in which fully 91 per cent were related to pilot factors which were primarily categorized as "error of judgement" but also included "loss of head" and "brain fatigue."[17] Finally, he uncovered German studies that revealed the same patterns, including one done by O. Selz in 1919 which analysed 300 German flight school accidents in 1918 and which identified that 66 per cent of all accidents "involved factors associated with the individual."[18]

What the Hobbs study clearly states is that human factors have played a dominant role in aviation, both military and civil, since its earliest days. In fact, what it demonstrates is that "the last frontier view of human factors is little more than a persistent myth."[19] The reality is that human factors have always played a dominant role in aviation. Considering the modern definition of human factors, in which the role of the human interacting with the external environment is the established baseline, that conclusion should come as no surprise.

The modern context

In not much more than 100 years, aircraft have evolved significantly, having a dramatic impact on the role of the pilot. Initial aircraft were very basic platforms in which the pilot obtained almost all vital flight information through the pilot's own senses and in which the principal goal of the pilot was "getting into the air and returning to earth safely."[20] Today's modern and complex aircraft have increasingly removed the pilot from direct contact with aircraft controls, while creating additional tasks in the realm of working with other crew members and interacting effectively with advanced technologies on the aircraft itself.[21] In reality, these changes have affected all aspects of aviation as systems move towards automation, with the human moving increasingly towards an input and monitor role as compared to a direct physical manipulation of controls.

Research has demonstrated that the introduction of complex systems, such as the flight management system, has had a significant impact on the ability of the operator to "grasp at the same level all the details of system architecture."[22] What this translates to in operations is that traditional skill sets associated with detailed systems knowledge to both analyse and correct emergency or abnormal situations creates high levels of task workload and reduced cognitive effectiveness.[23] This research has also shown that the modern cockpit is extremely sensitive to crew relationships, particularly conflict, and especially so when "intuitive and non-educated cooperation is required."[24]

This has a significant impact on training objectives in that the requirement for the crew to effectively interact with one another is greater than ever because of the need for more coordination, optimum task allocation and sharing, and the avoidance of conflict.[25] In short, the emphasis must shift from teaching the operators all the details of the system they are operating to teaching them to be more aware of what they do and do not know, supported by effective strategies and solutions to

17. Ibid.

18. Ibid., 339.

19. Ibid.

20. Pamela S. Tang and Michael A. Vidulich, *Principles and Practice of Aviation Psychology* (New Jersey: Lawrence Erlbaum Associates, 2003), 4.

21. Ibid., 8.

22. Rene Amalberti and others, "Human Factors in Aviation: An Introductory Course," in *Aviation Psychology: A Science and a Profession*, ed. Klaus-Martin Goeters (Aldershot: Ashgate Publishing, 1998), 27.

23. Ibid., 29.

24. Ibid.

25. Ibid.

regain control of any unexpected situations in which they find themselves.[26] The technological evolution that has occurred in aviation has placed even greater emphasis on the critical role of human factors, and as the International Civil Aviation Organization noted in 2005, "in the rush to embrace new technologies, the fallible mortals who must interface and use this equipment are often overlooked."[27] This is a significant lesson to organizations undergoing a significant revitalization of its equipment, especially if that revitalization involves transcending several developmental stages of technology.

Modern aviation incidents and occurrences

With the increased acceptance of human factors in the aviation industry, its overall impact has been much better articulated. In 2005, the International Civil Aviation Organization (ICAO) released the *ICAO Accident Prevention Manual*, in which it was noted that "at least three out of four accidents involve performance errors made by apparently healthy and qualified individuals."[28] In considering the reasons for this, the ICAO document states an intuitive approach to human factors misses the mark. It must be considered and deliberately applied to all facets of operation if accidents are to be reduced.[29] It is no longer sufficient to describe something as human error: it must be understood why that error occurred in the first place.[30]

In a comprehensive study of the airline industry, Boeing publishes an annual statistical summary of commercial jet airplane accidents. The data used in the study is derived from flight operations data; government accident reports; operators, manufacturers, various government and private information services; and press accounts.[31] During the period 1959–2008, it examined a total of 1,630 commercial accidents for causal factors. When refining the data specifically for the period 1999–2008 (the most recent ten-year period), it found that human factors were attributed to more than 80 per cent of all fatal accidents in aviation.[32] In military aviation, the same trends are observed. In a human factors study conducted by the United States Air Force in 2008 of all major accidents during the period 1992–2005, the report found that "most Air Force accidents are attributed to human error."[33] Other Western air forces are experiencing the same trends, and as recently as February 2010, the French Air Force identified the fact that fully 80 per cent of all accidents can be attributed to human factors.[34]

The nature of human factors incidents and occurrences

As already discussed in this section, the requirement to teach operators basic systems knowledge and how to deal with specific published emergencies and abnormalities is a long-established practice in aviation. Several studies have examined whether this training has translated into a reduction of error in operations, including the National Aeronautics and Space Administration (NASA). The results are surprising and challenge conventional thinking on not only what should be taught to aviators but also the methods in which it is taught.[35]

26. Ibid.

27. International Civil Aviation Organization, *ICAO Accident Prevention Manual* (Montreal: ICAO, 2005), 3–10.

28. Ibid.

29. Ibid.

30. Ibid.

31. Boeing Commercial Airplanes, "Statistical Summary of Commercial Jet Airplane Accidents: Worldwide Operations 1959–2008" (Seattle: Aviation Safety Boeing Commercial Airplanes, June 2011), http://www.boeing.com/news/techissues/pdf/statsum.pdf (accessed July 3, 2012).

32. Ibid., 23.

33. Randall W. Gibb and Wes Olson, "Classification of Air Force Aviation Accidents: Mishap Trends and Prevention," *International Journal of Aviation Psychology* 18, no. 4 (Fall 2008): 307.

34. France, Ministère de la défense, "Facteurs humain," *Air actualités* 628 (February 2010): 35.

35. Barbara K. Burian, Immanual Barshi, and Key Dismukes, *The Challenge of Aviation Emergency and Abnormal Situations*, report prepared for the National Aeronautics and Space Administration (Ames Research Center, Moffat Field, California: NASA, 2005), 1.

Utilizing data from the Aviation Safety Reporting System (ASRS), a team of researchers from NASA began examining the issue in 1999.[36] Using terms like "emergency" and "abnormal" within the ASRS database, which is populated anonymously by airline pilots across the United States, they were able to identify 107 reports for further analysis. What it revealed was that while aviators handle those specific situations for which they are trained, such as emergency procedures, they frequently were "ill-quipped and ill-prepared for what they had to face" in line operations. The general theme within the reports was that completion of the checklists led many pilots to conclude that the flight had returned to a normal status.[37] The study found that pilots generally oriented themselves from a systems perspective in which the focus was on responding to a specific checklist procedure for a systems abnormality as compared to appreciating what implications that abnormality might have on the remainder of the flight. While the majority of the "textbook" emergencies were well-handled, these only comprised 22 of the 107 incidents examined. In the remaining 85 reports, the incidents involved non-textbook situations which were generally poorly handled, with concerns noted in the way in "which the crew or others responded to the situation."[38] These findings are presented in Table 2.1.

	Textbook Emergency	Non-textbook Emergency	Total
Handled Well	19	6	25
Not Handled Well	3	79	82
Total	22	85	107

Table 1. Type of emergency and how it was managed

In a follow-up report published in 2005, the NASA researchers made several observations on why these differences appeared in relation to the type of emergencies crews encountered.[39] As it noted, many non-normal situations have no published procedures or checklist that the crew can rely upon for resolution, and this challenges the crew to "determine the appropriate response." When training is largely focused on the most common abnormalities and procedures, they rarely face a situation in which there is no published response.[40] As a result, in many cases the training that aircrew receives simply does not reflect the situations they are likely to encounter in the conduct of operations. Consequently, the quality of the response is hampered by the shortcomings in the quality of communication and coordination amongst all those involved.[41]

These findings are important and reinforce the assertion earlier in this section and published by Amalberti and others in 1998, that training must also focus on the need for more coordination, optimum task allocation and sharing, and the avoidance of conflict.[42] It is no longer enough to focus on systems knowledge and published procedures. Training must be shifted from teaching the operators all the details of the system they are operating to teaching them to be more aware of what they do and do not know. This must be supported by effective strategies and solutions to regain control of any unexpected situations in

36. Barbara K. Burian and Immanuel Barshi, "Emergency and Abnormal Situations: A Review of ASRS Reports," in *Proceedings of the 12th International Symposium on Aviation Psychology*, ed. R. Jensen (Dayton, Ohio: Wright State University Press, 2003), 1.

37. Ibid., 6.

38. Ibid.

39. Burian, Barshi, and Dismukes, *Challenge of Aviation Emergency*, 1.

40. Ibid., 2.

41. Ibid., 11.

42. Amalberti and others, "Human Factors in Aviation," 29.

which they find themselves.[43] Basic "stick and rudder" or "hands and feet" skills remain essential elements of any aviator's training, but the modern aviation environment demands additional skill sets that the training organization must provide if they are to be successful in the conduct of operations.

These are issues that have been identified within the aviation industry for some time now, and it is worthwhile to examine how the industry has addressed them. One particular strategy that has been adopted across the industry as a means of teaching and evaluating human factors areas (such as workload management, communication and decision making) is LOS.

The introduction of line operational simulation (LOS)

Concurrent with the breakthrough in human factors at the International Air Transport Association Istanbul conference in 1975, the concept of LOS was first introduced as line-oriented flight training (LOFT) in the same year when Northwest Airlines sought permission from the FAA in the United States for a new type of training. This was done for two major reasons. First, simulator technology had improved to the point that permitted the replication of the operational environment to a high level of fidelity.[44] Second, safety data showed that at the time over 70 per cent of all accidents and incidents over the previous 20 years could be attributed to "inadequacies in leadership qualities, communication skills, crew coordination, and decision making."[45] What the data was telling the industry was that accidents were primarily caused not by technical malfunctions but by the inadequate use of resources readily available to the crew. When combined, it was recognized that addressing the issues of human factors in aviation could be better accomplished through the use of the synthetic environment.[46]

At the same time that it received this request from Northwest Airlines, the FAA began to deal with the regulatory issues associated with the burgeoning synthetic environment. Recognizing that the new synthetic technologies were significantly enhanced and complex and at the request of the airline industry, the first step was for the FAA to address standards for the design of simulators. This effort culminated in the release of the Advanced Simulation Programme in 1980, and since that time, the FAA has been focused on addressing the second part of the equation, the training systems that use the synthetic environment.[47]

The delivery of LOS

Since the introduction of the first synthetic training device, significant effort has been put into the technological development of the devices. The inherent problem (as identified by Eduardo Salas, Clint Bowers, and Lori Rhodenizer) is that "aviation training has not evolved but simulations and simulators have."[48] As they described it, simulators are still largely used in the same manner they have been used since they were introduced without any consideration being given to the considerable amount of information learned about individual and team training.[49]

43. Ibid.

44. William R. Hamman and others, "The Future of LOFT Scenario Design and Validation," in *Proceedings of the Seventh International Symposium on Aviation Psychology*, ed. R. Jensen (Dayton, Ohio: Wright State University Press, 1993), 589.

45. Ibid.

46. Ibid.

47. United States, Federal Aviation Administration, *Developing Advanced Crew Resource Management (ACRM) Training: A Training Manual* (Washington, DC: Office of the Chief Scientific and Technical Advisor for Human Factors, 1998), ii.

48. Salas, Bowers, and Rhodenizer, "It Is Not How Much," 199.

49. Ibid.

To fully exploit the potential of simulators, organizations must shift focus from achieving optimum levels of realism to the "design of human-centered training systems that support the acquisition of complex skills."[50] In other words, training with simulators must embrace the fundamental concepts of training if it is to be successful. As Salas, Bowers and Rhodenizer pointed out, training must be a deliberate approach to learning that encompasses several phases and the design of the learning environment. It is "the instructional features embedded in the simulation" that will determine the success of the training rather than the device itself, and those tools must include "performance measurement, cognitive and task analysis, scenario design, and feedback and debriefing mechanisms."[51]

An additional consideration in relation to the synthetic environment that must be considered is that higher fidelity does not equal better training without corresponding improvements in the delivery of that training. The most capable devices in the world will not deliver the promised results, and in fact, less-capable devices can actually significantly improve training quality if used properly. With an industry predilection towards costly, high-fidelity devices, hard to obtain funding to support the development of a robust training system to support their utilization is often neglected.[52] The clear lesson to be taken from this is that it is not simply enough to invest in the devices; investment must also be put into the development of a training system that embraces the behavioural environment to increase training effectiveness.[53] Much of industry has now embraced this lesson, and this is reflected in the way in which LOS is delivered within aviation today.

LOS today

Beginning in the early 1980s, the FAA has issued significant guidance on the development of line-oriented flight training. The name itself has evolved to line operational simulation which includes traditional LOFT, special purpose operational training (SPOT) and line operational evaluation (LOE). As clearly stated in the FAA documentation, "due to the role of [c]rew [r]esource [m]anagement (CRM) issues in accident causation, it has become evident that training curriculums must develop pilot proficiency in both technical and CRM skills."[54] From a human factors perspective, if CRM-type training is to be effective, it must be deliberately built into all training steps and activities, and that is why LOS has been widely adopted across the aviation industry. The key to LOS is that it permits the development of a training environment that encourages the application of both technical and CRM concepts to a situation that "enables conceptual knowledge to become working knowledge."[55]

A key component of LOS is that rather than the training event being programmed with a single solution, the crew is allowed to manage the situation and the environment, while processing available information to arrive at a satisfactory resolution.[56] Emphasis is placed on the team developing a solution to the problem that satisfies the primary objectives of ensuring safety of flight and mission accomplishment. In order to do this, the crews must operate together at high levels of effectiveness while prioritizing and managing workload. With the majority of aviation incidents and accidents caused by "non-published" abnormalities or emergencies in which crews fail to properly use all of

50. Ibid.

51. Ibid., 201.

52. Ibid., 205.

53. Ibid.

54. United States, Federal Aviation Administration, Advisory Circular (AC) 120-35C, *Line Operational Simulations: Line Oriented Flight Training, Special Purpose Operational Training, Line Operational Evaluation* (Washington, DC: FAA Flight Standards, 2009), iv.

55. Ibid.

56. Ibid.

the resources available to them, the purpose of LOS is to give the crews the skill sets necessary to handle often ambiguous and contradictory situations. As stated by the FAA, the objective of LOS "is to improve total flight crew performance, thereby preventing incidents and accidents during operational flying."[57]

As already identified, the additional areas that have been added to LOFT to comprise what is today referred to as LOS are SPOT and LOE. Their specific purposes are described below:

a. **SPOT**. Used to introduce new training requirements, such as those associated with the introduction of a new aircraft subsystem as a result of modification; it is a specifically tailored training session that incorporates both technical and CRM skills. It can consist of "full or partial flight segments depending on the training objectives for the flight."[58]

b. **LOE**. This is the primary means of evaluation in which the individual is assessed for both technical and CRM proficiency in accordance with those identified as being required to safely and effectively operate in a mission environment.[59]

The basic elements of LOS

There are several key elements of LOS that must be considered during its design and implementation. If aviators are to fully develop CRM skills, which include techniques that facilitate better problem solving and resource management, any LOS event must be structured to "enable CRM behaviours to emerge and the crew to become aware of them; that is, the scenario must last long enough for crew traits to become evident and require crew skills to be displayed in response to specific circumstances."[60] This basic philosophy must be adhered to in the design of all LOS events if they are to deliver the desired effects.

A second key consideration is that any training conducted under the auspices of LOS should take place with the full crew complement or all of the actors that would be involved in line operations. This permits the full participation of all members of a crew or team to fully exploit available resources and employ creativity in the solving of complex and ambiguous situations. It is also critical that, to the maximum extent possible, the scenarios employed in LOS replicate the real-world environment that personnel will be exposed to in line operations. These scenarios need to progress in real time and need to be representative of segments where an entire operation can be completed. Finally, both LOFT and SPOT must be viewed as "no-jeopardy" training events, in which crews are allowed to make errors without fear of career implications. This ensures that the trainees are free to employ all of their resources and creativity.[61]

With the basic elements of LOS clearly established, scenario design and performance levels can be readily determined in both technical and CRM skill areas. The challenge from this point on moves towards implementation, and in this area, it is again the role of the human that is critical to the eventual success of a LOS programme. In this case, it is the instructors and evaluators who will determine whether or not the LOS programme achieves its aims.

57. Ibid., v.
58. Ibid.
59. Ibid., vi.
60. Ibid., 1.
61. Ibid., 2.

The critical role of the instructors and evaluators

Several industry papers have been written on the critical nature the instructors and evaluators play in both implementation and maintenance of any new programme. In 1998, the FAA published a guide to the integration of CRM into aviation operations entitled *Developing Advanced Crew Resource Management Training (ACRM): A Training Manual*. The document identified the fact that "instructors/evaluators represent the front line."[62] Only through early and continuous involvement of that critical cadre will a successful human factors programme be fully integrated into operations. Not only can they assist in the development of the training programmes, their early "buy-in" allows them to become a role model for the remainder of the organization, a critical first step in organizational change.[63]

Yet it is not enough to simply get instructors and evaluators involved in the process. They require substantial practice to develop adequate assessment skills, and that practice needs to be standardized as much as possible.[64] This is best delivered using "rater reliability" methods in which instructors/evaluators are given the training necessary to not only assess the individuals but also deliver assessments that are stable and consistent in relation to the rest of the instructor/evaluator (I/E) population. This stability and consistency becomes a critical factor in providing reliable data that allows the organization to measure the overall effectiveness of its various training programmes.[65] At a minimum, instructors and evaluators need to be trained "in the philosophy, skills, and conduct of LOS and CRM," and they "should be able to effectively observe and critique both individual and crew performance during the scenario."[66] If LOS is to be used effectively to address the human factors issues within aviation, then significant effort must be expended on training and standardizing the I/E cadre responsible for delivering that instruction.

The effectiveness and benefits of LOS

When developed in accordance with its basic, fundamental principles and recognizing the critical nature of the instructor cadre in delivering LOS, data within industry shows that it is effective at increasing CRM skills within aviators while maintaining traditional technical skills. A 2008 study published in the *International Journal of Aviation Psychology*, in which 16 empirical studies of CRM training effectiveness were subjected to meta-analysis, revealed that behavioural training like that conducted during LOS "had large effects on the participants' attitudes and behaviours."[67] These positive impacts were further enhanced when participants were allowed to practice in simulators the behaviours they had been taught in a classroom.[68]

Regulators outside of the United States and Canada have noted the effectiveness and benefits of a LOS programme. As early as 2002, the Civil Aviation Authority (CAA) in the United Kingdom commented extensively on this in Civil Air Publication (CAP) 720, *Flight Crew Training: Cockpit Resource Management (CRM) Training and Line-Oriented Flight Training (LOFT)* in which it was noted that "LOFT can have a significant impact on aviation safety through improved training and

62. FAA, *Developing ACRM Training*, 7.

63. Ibid., 14–15.

64. Ibid., 5.

65. Robert W. Holt, Jeffrey T. Hansberger, and Deborah A. Boehm-Davis, "Improving Rater Calibration in Aviation: A Case Study," *International Journal of Aviation Psychology* 12, no. 3 (2002): 305–6.

66. FAA, AC 120-35C, *LOS*, 23.

67. Paul O'Connor and others, "Crew Resource Management Training Effectiveness: A Meta-Analysis and Some Critical Needs," *International Journal of Aviation Psychology* 18, no. 4 (2008): 353.

68. Ibid., 364.

validation of operational procedures."[69] In short, what industry is discovering is that a well-developed LOS programme not only trains individuals to safely and successfully discharge their assigned duties but also provides a high degree of insight into the internal workings of the organization as well as its training programmes.[70] This is an incredibly powerful benefit that when fully utilized allows the organization to rapidly make changes and improvements to its crew procedures and training programmes. It becomes not just a check of the individual but "a validation of training programmes and operational procedures."[71] For organizations in the midst of significant change, LOS has the potential to identify and capture those policies and practices that are no longer relevant to its operating environment but are being maintained by its culture. When implemented properly, LOS can be a powerful engine of change.

Summary

Despite the long-held belief that human factors are a relatively recent development and they are widely considered the last frontier of aviation, an examination of the historical record dispels that assertion. Since the beginning of manned flight, the importance of the human in the system has always played a dominant role in whether or not aviation is successful. With current incident and accident statistics showing that human factors account for 70–80 per cent of all occurrences, there clearly remains much to be done in this field, and one of the key components within industry is the introduction of line operational simulation. Designed to specifically address shortcomings in leadership, communication, crew coordination and decision making, it represents an incredibly effective tool for addressing human factors.

Addressing human factors through training in the synthetic environment requires consideration of several key elements of the modern aviation environment. The first is the mandate to recognize that as technology evolves so too must the training. Traditional, well-proven training methodologies valid in systems in which the human was the exclusive actor have proven to be inadequate as increasing levels of automation are brought into the industry. Concurrently, it needs to be recognized that the majority of the incidents and accidents in aviation are as a result of crews failing to use all available resources in situations for which there is no "book" answer. The modern and sophisticated aviation environment has further complicated the ability of the crew to gather information and act deliberately and decisively. Finally, the research has demonstrated that the first line of defence, when it comes to human factors in aviation, is not just the training programme itself but the instructors and evaluators embedded within that programme. The training devices will deliver the potential to increase human effectiveness, but it is the humans conducting the training, within a deliberately designed training programme, which will make the difference and allow the organization to achieve optimized levels of human performance.

These are all aspects on which much has been written and discussed within the aviation industry. Various civil and military organizations have explored, to differing levels, the concepts and methodologies discussed in this section in an ongoing effort to address human factors. One of those organizations has been the Canadian Air Force. Therefore, to continue this study, it is necessary to examine the current state of affairs within the Canadian Air Force as it relates to the field of aviation human factors and LOS.

69. United Kingdom (UK), Civil Air Authority, CAP 720, *Flight Crew Training: Cockpit Resource Management (CRM) Training and Line-Oriented Flight Training (LOFT)* (Gatwick, UK: Safety Regulation Group, 2002), Chapter 5, page 1.

70. Ibid.

71. Ibid.

3. The Canadian Air Force

Introduction

While the aviation industry at large has recognized the critical nature of human factors in the safe and successful execution of operations (and the means by which to optimize them through the use of the synthetic environment), the Canadian Air Force struggles with fully implementing and adopting the same methodologies and focus. This section will examine, in detail, the desired end state the Air Force hopes to achieve with regards to human factors and the synthetic environment and will measure where it is in relation to that desired end state. This determination will be made through the use of research conducted in the Air Force under other auspices and through an examination of current Air Force publications related to human factors and the synthetic environment.

Desired end state

In 2004, the Chief of the Air Staff published *Strategic Vectors*. Considered a landmark document, it maps out the means by which the Air Force will achieve transformation "from a primarily static, platform-focused Air Force to an expeditionary, network-enabled, results-focused Aerospace Force for the 21st Century."[72] One of the critical enablers to achieving Air Force transformation is the creation of a "distributed synthetic environment for flying training and operational mission rehearsal."[73] In 2008, the Commander of 1 Canadian Air Division, the operational commander of all Canadian Forces aircraft, published a directive to the Air Mobility community in which he stated that "the use of simulation, to accomplish training objectives, both initial and recurrent, is to be exploited to the maximum extent possible to both reduce training requirements on the aircraft and increase pilot production."[74] Clearly, the Canadian Air Force views the exploitation of the synthetic environment as being a critical enabler to not only achieving transformation but also excellence in operations.

All predictions point to the continued growth of the synthetic environment to deliver training objectives in the Air Force. Whether influenced by industry developments or internal pressures to achieve increased cost effectiveness and improvements in quality with limited resources, the synthetic environment will continue to expand in importance. *Projecting Power: Canada's Air Force 2035* states that "the employment of virtual environments *will* be a key resource at all levels of training and education."[75] It also predicts that "superiority in the cognitive or human dimension *will* be essential if our values and prosperity are to remain viable in the future."[76] When viewed together, these two statements articulate the requirement for the Canadian Air Force to fully exploit the synthetic environment to achieve human superiority. If that is the desired end state, then it is necessary to examine the current status of the synthetic environment and the optimization of human performance to determine the delta that exists between the two. Only once that is completed can the Air Force begin to implement policies and resources that ensure it achieves the desired end state.

72. Canada, Department of National Defence (DND), *Strategic Vectors* (Ottawa: Department of National Defence, 2004), 2.

73. Ibid., 48.

74. Major-General J. A. J. Y. Blondin, 1 Canadian Air Division Headquarters message Comd 078, 101413Z Jul 08, "Air Mobility Training Directive FY 08/09 through 13/14."

75. Canada, Department of National Defence, *Projecting Power: Canada's Air Force: 2035* (Ottawa, Canadian Forces Aerospace Warfare Centre, 2009), 48.

76. Ibid.

The Canadian Air Force today

On the night of July 12, 2006, a CH149 Cormorant Search and Rescue helicopter from 413 Squadron, Greenwood, departed on a routine training mission. Its purpose was to operate in the vicinity of Sydney, Nova Scotia, in coordination with the Canadian Coast Guard to practice recovery operations, which was to include night boat hoists. Tragically, while approaching the hover, the aircraft impacted the water and three crewmembers lost their lives. The causes of the accident were thoroughly investigated by the Directorate of Flight Safety, and their findings clearly indicated several human factors causes, including a loss of situational awareness.[77]

Recognizing that the loss of the Cormorant potentially indicated wider, systemic failings, Commander 1 Canadian Air Division began a series of initiatives to identify those shortcomings against a clearly-defined desired end state and began defining the means by which to address them. These initiatives were based on the "Four P" model articulated by Drs. Asaf Degani and Earl Weiner, of the National Aeronautics and Space Administration, in 1994. The premise of the model is that in order to achieve the desired "practice" (the fourth *p*) in flight operations, it is necessary to first develop philosophy, policies, and procedures.[78] Only once these three have been aligned is it possible to achieve the desired levels of performance. With this in mind, the Commander of 1 Canadian Air Division published the "1 Canadian Air Division Automation Philosophy" in June 2007.[79] Included within the "Automation Philosophy" was clear direction to ensure that all "Flying Orders, flying training programmes, assessment and evaluation criterion …"[80] are aligned with the "Automation Philosophy."

The Automation Policy and Planning Development Project

With the publication of the "Automation Philosophy," the next logical step was the development of policy to support the philosophy. To this end, the Commander of 1 Canadian Air Division initiated the Automation Policy Planning and Development (APPD) Project in December 2007. The fundamental tenant of the project was the development of Air Force policy that instils and maintains a robust human factors programme to not only optimize human performance but also ensure that the performance is in alignment with the new technologies being delivered to the Air Force.[81] The critical first step in creating that policy was measuring the delta between the desired level of performance as articulated in the "Automation Philosophy" and the current state of the Air Force. To accomplish this, the APPD Project reviewed all existing Air Force documentation and orders and visited several wings and units across the country. When it was complete, the project delivered a report to the Air Force with several conclusions and recommendations. Some of those were directly related to the areas of human factors and the synthetic environment, and these will be discussed in depth in the following sections.

Simulation in the Air Force

Indications that the Air Force was not taking full advantage of the synthetic environment available to it were evident in the Cormorant investigation in which investigators concluded that "the overall proficiency of the CH149 crews was less than might have been achieved given a more

77. Canada, Department of National Defence, *Flight Safety Investigation Report (FSIR) 1010-149914* (Ottawa: Directorate of Flight Safety, 22 January 2008), 62.

78. Asaf Degani and Earl L. Weiner, *On the Design of Flight Deck Procedures* (Moffat, CA: NASA Contractor Report 177642, 1994), 6.

79. Major-General J. C. C. Bouchard, 1 Canadian Air Division Headquarters file 3030-1 (Comd), 12 December 2007, "Air Division Fleet Modernization and Aircraft Automation Philosophy."

80. Ibid., 2/3.

81. Major-General M. Duval, 1 Canadian Air Division Headquarters file 3030-1 (Comdt CFS), 12 December 2007, "Aircraft Automation Philosophy," 1/3.

rigorous approach to simulator training, and training in general."[82] The APPD analysis confirmed that the use of the synthetic environment is lacking in almost all areas of the Air Force. It concluded that a strength of the Air Force is the synthetic devices it possesses; it is failing to take advantage of them to deliver training.[83] The impact of this, as summarized in the APPD report, is that "the tangible training benefits of access to high quality, high fidelity simulators are not being realized, and aircraft flight hours and their associated costs are being used to support training events in the aircraft that are better performed in the simulator."[84]

These findings should not be surprising given the Air Force policy framework related to the synthetic environment. After a complete review of 1 Canadian Air Division Orders applicable to the use of simulation, the APPD Project concluded that "the overall tone and final recommendations can best be described as *'SIM-Phobic*.'"[85] This is best captured in the 1 Canadian Air Division Orders statement that says "normally using the simulator as a platform for performing instrument rating tests (IRTs) will be approved as a backup to the IRT being flown in the actual aircraft."[86]

When viewed in light of industry advances in the use of the synthetic environment, and as discussed in the previous section, this is a significant finding. Most of the aviation industry, both civil and military, is exploring the limits of what can be accomplished with the synthetic environment, while the Canadian Air Force seeks to restrict its use. The policy issue was identified within the APPD report as a significant constraint on the ability of the Air Force to fully exploit the synthetic environment and one that needed to be changed immediately.[87] Like all organizational change, simply rewriting policy will not deliver the desired results. The culture of the organization will determine whether the policy is implemented, and again, the APPD analysis provides us insight into that culture, particularly as it relates to Air Force instructors and evaluators.

The practice of conducting single pilot training and evaluations is manifested in the Air Force use of simulation. Although the synthetic environment is a "vital piece to effective training in modern aircraft"[88] there are "limited applications"[89] of crew evaluations being conducted in Air Force simulators. Instead, there are "strongly embedded legacy Air Force training issues that are counterproductive to automated flight training and evaluation."[90] Air Force instructors and evaluators have created "a very strong culture of the single pilot being able to fly their aircraft to touchdown under all circumstances—'Hands and Feet.'"[91] The emphasis on traditional technical skills does so "to the detriment of other flying skills."[92] Again, when viewed within the context of what the aviation industry has learned in relation to the critical role of human factors in aviation incidents and accidents, "the current method of individual evaluation does not promote the requirement for close coordination of tasks."[93] The Air Force culture, manifested through its methods of training and evaluation, runs counter to what industry has learned are the most effective means of developing optimum levels of

82. DND, *FSIR 1010-149914*, 44/69.

83. R. D. Kobierski and C. Stickney, *Automation Analysis Report* (Ottawa: 1 Canadian Air Division, 29 September 2008), 4.25.

84. Ibid., 3.27.

85. Ibid., 3.26.

86. Canada, Department of National Defence, 1 Canadian Air Division Orders Vol. 2, 2-008, Annex A, "IRTs on Flight Simulators – Simulator Approval Process/Conduct of IRTs" (Winnipeg: 1 Canadian Air Division, 2008), A-3/5.

87. Kobierski and Stickney, *Automation Analysis Report*, 4.26.

88. Ibid., 3.27.

89. Ibid., 3.30.

90. Ibid., 3.26.

91. Ibid.

92. Ibid.

93. Ibid.

human performance in a team environment. To understand this culture, it is necessary to examine the human factors programmes within the Air Force as well as the standards by which Air Force instructors and evaluators are trained and qualified.

Human factors in the Air Force

In 2001, the Air Force created the Human Performance in Military Aviation programme to replace the Crew Resource Management programme. Designed for all personnel directly or indirectly involved in the operation of aircraft, the purpose of HPMA is "a systematic approach to [h]uman [p]erformance training with the aim of increasing operational effectiveness through individual and team performance training."[94] The development and implementation of the HPMA programme within the Air Force has been specifically designed to exploit "the strengths of the human factor" while "compensating for our individual limitations through high quality training" to ensure that Air Force personnel are equipped "with the superior skills necessary to accomplish their mission."[95] HPMA is viewed as a critical enabler to mission success and safety within the Air Force, and significant effort has been expended on its development and implementation.

The APPD Project analysis revealed that HPMA "has not migrated effectively into the cockpit either through flight procedures or daily flight operations" and that the absence "of an effective HPMA programme crossed virtually all communities observed during the APPD site visits."[96] The primary reason for this is that Air Force crews "are educated in the elements and skills of HPMA Programme but they are not *trained* in HPMA."[97] The Air Force has never developed HPMA performance measures. This shortcoming means that "although crews are exposed to the terms and concepts of HPMA, they are not measured or held accountable for HPMA knowledge and the ability to employ the skills in the cockpit."[98]

The lack of HPMA performance measures is reinforced through training and evaluation cultures within the Air Force that emphasize the individual at the expense of the team within which that individual is operating. Whether it is a CF18 lead and their wingman conducting an intercept over the high Arctic, the crew of a CC177 Globemaster III on approach into Kandahar, Afghanistan, or the maintenance crew repairing a CH124 Sea King at sea, their ability to function as a team at a high level of competency will be the eventual determinant of success. As the broader aviation industry has demonstrated and as discussed in the previous section, the focus on evaluating the individual "can reinforce negative training."[99]

As the APPD report states, "complex aircraft fail in complex ways, and without the flight crew's ability to (realistically) work together and process and organize the data presented by the aircraft during training and evaluation rides, crews lose the opportunity to maximize the value of training."[100] The same is true of any complex system in which groups of individuals are required to work together to deliver optimum levels of performance. If the Air Force is to fully develop its human potential, it must find the means to measure and evaluate the teams it employs to accomplish its tasks.

94. "Air Force's Human Performance in Military Aviation Program Enters New Phase," *Maple Leaf* 9, no. 12, 22 March 2006, 15, http://www.forces.gc.ca/site/commun/ml-fe/article-eng.asp?id=2424 (accessed July 3, 2012).

95. Ibid.

96. Kobierski and Stickney, *Automation Analysis Report*, 3.35.

97. Ibid., 3.36.

98. Ibid.

99. Ibid., 3.30.

100. Ibid.

The Flight Safety system

Within the APPD analysis, the Flight Safety system of the Canadian Forces was also examined. What it uncovered was that the Air Force struggles to capture the real causes of its incidents and accidents and, subsequently, learn from them. As a result, the Directorate of Flight Safety (DFS) is not able to maximize flight safety within the Canadian Forces.[101] This becomes evident when one considers that in the aviation industry at large, both military and civil, human factors play a role in 70–80 per cent of all aviation incidents and accidents yet within the CF, the *2008 Flight Safety Annual Report* states that personnel cause factors are attributed in 44.3 per cent of all air occurrences and 77.1 per cent of all ground occurrences.[102] As illustrated in Table 3.1, this difference has existed in all annual reports published since DFS began publishing annual reports in 2005.

Annual Report	Human Factors	
	Air Occurrences (%)	Ground Occurrences (%)
2005	39	68
2006	47.3	74.0
2007	47.9	82.4
2008	44.3	77.1

Table 2. Personnel cause factor attribution in CF[103]

This discrepancy was noted by the DFS with a statement in both the 2007[104] and 2008[105] annual reports that DFS "will investigate the cause of the marked difference." A review of the annual reports highlights the issue and offers potential solutions, as they relate to capturing human factors within the flight safety system.

The Human Factors Analysis and Classification System was introduced to the Canadian Forces in 2004. In its *2005 Annual Report*, DFS noted that the system was new and that flight safety staffs were struggling with its introduction and use. The report noted that feedback from the various units indicated that workload within the flight safety staffs prevented them from fully implementing HFACS. As a result, it was noted that only a year into the introduction of the programme, flight safety staffs were no longer investigating all occurrences and that the solution may lie in reducing HFACS investigations even further to manage workload. Within the investigations that HFACS was considered, the 2005 report noted with concern that the majority of the analysis was still focused on the active crew failures at the expense of the organizational, or latent, failures.[106] The *2005 Annual Report* actually begins to describe the very causes of the issues with HFACS and causal factors identified in subsequent reports. When considered against the backdrop of the lack of human factors integration into Air Force training and operations for all Air Force personnel, it should not be surprising that flight safety personnel are struggling to define and capture human factors issues within the organization.

101. Ibid., 4.27.

102. Canada, Department of National Defence, *2008 Annual Report on Flight Safety* (Ottawa: Directorate of Flight Safety, 24 August 2009), 32.

103. Canada, Department of National Defence, *DFS 2005 Annual Report on Flight Safety* (Ottawa: Directorate of Flight Safety, 27 July 2006); Canada, Department of National Defence, *2006 Annual Report on Flight Safety* (Ottawa: Directorate of Flight Safety, 22 August 2007); Canada, Department of National Defence, *2007 Annual Report on Flight Safety* (Ottawa: Directorate of Flight Safety, 4 July 2008); and DND, *2008 Annual Report on Flight Safety*, http://www.rcaf-arc.forces.gc.ca/dfs-dsv/page-eng.asp?id=1126 (accessed July 3, 2012).

104. DND, *2007 Annual Report on Flight Safety*, 22.

105. DND, *2008 Annual Report on Flight Safety*, 32.

106. DND, *DFS 2005 Annual Report on Flight Safety*, 18.

Notwithstanding the issues the flight safety system is having with human factors and the reasons why, the data has always demonstrated that the single largest proportion of causal factors has consistently been attributed to personnel since the *2006 Annual Report*. The 2005 numbers do not reflect this but that was also the first year in which HFACS data was collected. This is illustrated in Tables 3.2 and 3.3, and while the actual percentage of personnel cause factors is lower than industry for air occurrences, the fact that it constitutes the single largest attributed factor indicates that the Air Force has potential work to do in this area. The data confirms other observations, such as those within the APPD report, that the Air Force is struggling with introducing and maintaining a robust human factors programme. Of note, even though the HPMA programme was introduced in 2001, there has been no appreciable decline in personnel cause factors in either air or ground occurrences.

Causal Factor	**Flight Safety Annual Report Air Occurrences (%)**			
	2005	**2006**	**2007**	**2008**
Personnel	39	47.3	47.9	44.3
Materiel	43	32.2	33.7	36.6
Environment	8	13.0	12.2	13.1
Undetermined	9	7.1	6.1	5.4
Foreign Object Damage	1	0.2	0.1	0.05
Operational	0	0.2	0.1	0

Table 3. Air occurrence causal factors[107]

Causal Factor	**Flight Safety Annual Report Ground Occurrences (%)**			
	2005	**2006**	**2007**	**2008**
Personnel	68	74.0	82.4	77.1
Materiel	21	15.1	12.6	16.1
Environment	2	2.1	1.4	3.1
Undetermined	8	8.1	2.9	2.6
Foreign Object Damage	1	0.5	0.7	1.0
Operational	0	0.2	0	0

Table 4. Ground occurrence causal factors[108]

Air Force instructors and evaluators

As discussed in the previous section, the instructor and evaluator play a critical role in ensuring the desired levels of human performance are achieved during training. A review of Air Force manuals, outlining how flight instructors and evaluators are trained and qualified, confirms the legacy practices of single-pilot evaluation with little or no emphasis on HPMA skills.

107. DND, *DFS 2005 Annual Report on Flight Safety*; DND, *2006 Annual Report on Flight Safety*; DND, *2007 Annual Report on Flight Safety*; and DND, *2008 Annual Report on Flight Safety*,

108. Ibid.

Flight instructor standards

All Air Force personnel engaged in the conduct of flying training are required to be qualified as flight instructors. Personnel selected for evaluator responsibilities are generally selected from those already possessing a flight instructor qualification. In 2009, the Air Force released version 1.2 of the qualification standard for flight instructor.[109] The primary reference document for the flight instructor qualification standard is the *Flight Instructor's Handbook* released in 2005.[110] A review of these documents for reference to both HPMA and the synthetic environment is revealing.

Within the flight instructor qualification, there are only two references to HPMA. The first occurs in Performance Objective 404 – Conduct a Training Mission, in which the standard is articulated as "with due regard to HPMA, situational awareness and airmanship in accordance with applicable references … ."[111] The second is contained in Annex A – References which refers to the *Human Performance in Military Aviation Handbook*. With regards to prerequisites an individual must hold prior to being trained as a flight instructor, there is no requirement to be a qualified HPMA facilitator. There is no reference to the use of the synthetic environment at all within the qualification standard for flight instructors; furthermore, there is no acknowledgement that there are distinct skill sets required of simulator instructors and evaluators. The qualification standard is primarily oriented towards ensuring individuals are qualified to train individuals in traditional legacy type skill sets, thus reinforcing the prevalent culture that prevents the Air Force from fully exploiting the synthetic environment.

The primary reference document for flight instructors, the *Flight Instructor's Handbook*, includes limited references to both HPMA and the synthetic environment. Out of a total of 298 pages, the *Flight Instructor's Handbook* contains a single HPMA annex of 14 pages embedded within Module 9. Significantly, the annex begins with the statement that "up to 80% of all aviation accidents and incidents are the result of Human Performance issues"[112] notwithstanding the fact that this is not supported by Air Force safety data but is instead reflective of industry data. Included within this annex are references to the broad objectives of the HPMA programme, its policy, and general examples of HPMA procedures. It includes reference to the requirement for elevated levels of team performance and concludes with a statement that "Part 2 of the HPMA Handbook details effective HPMA behaviours and instructor guides for use in aviation instruction."[113] It must be emphasized again that there is no requirement for a flight instructor to be qualified as an HPMA facilitator and that any references to HPMA in the flight instructor syllabus or references are largely symbolic without well-developed HPMA performance measures against which all instructors are trained to and evaluated.

The *Flight Instructor's Handbook*, within its 298 pages, also contains a 2-page reference to simulation embedded within Module 4 – Instructional Methods. Making specific reference to the FAA Advisory Circular 120-35C on line operational simulations, it provides a short and concise summary of what LOS is and its benefits to aviation. Significantly, it describes the specialized nature of simulator instructor/facilitator training as a disadvantage of simulation.[114] Considered within the policy framework that currently exists within the Air Force, this statement does not come as

109. Canada, Department of National Defence, Air Force Training and Education Management System, *Qualification AIMB Flight Instructor* (Winnipeg: 1 Canadian Air Division, 2009), i. AIMB is the four-letter code that represents the CF-approved qualification for flight instructor.

110. Canada, Department of National Defence, Central Flying School, A-PD-050-001/PF-001, *Flight Instructor's Course Flight Instructor's Handbook* (Winnipeg: Canadian Forces Training Material Production Centre, 2005).

111. DND, *Qualification AIMB Flight Instructor*, 4-7.

112. DND, *Flight Instructor's Handbook*, Module 9, Annex A, 1.

113. DND, *Flight Instructor's Handbook*, Module 9, Annex A, 19.

114. Ibid., Module 4, 15–16.

a surprise and reinforces the desire of the Air Force to use the aircraft over the simulator as an effective training and evaluation tool. Notwithstanding the marginal attempt to include reference to simulation in the *Flight Instructor's Handbook*, it has been done in a way that ensures flight instructors do not view it as a primary means to achieve training objectives.

The reasons for the shortcomings

The problems within the Air Force are not unique and have been widely discussed within aviation industry literature. In 2001, the FAA issued a report in which Douglas Wiegmann and Scott Shappell noted similar issues in commercial aviation and identified their likely causes.

The FAA study examined all commercial air carrier accidents between 1990 and 1996 in which the accidents were attributable, to some extent, to the aircrew. In total, it considered 119 occurrences. What it discovered was that notwithstanding the significant effort expended on the development and introduction of CRM training and aeronautical decision making (ADM) strategies, these areas still account for the highest proportion of causal factors. It gave two reasons for this. The first was that most CRM and ADM training focuses on specific case studies rather than on the fundamental causes of these problems through the use of a systemic analysis of accident data. The second reason given was that most CRM and ADM training programmes involve classroom exercises that are not reinforced by simulator training in which the concepts are applied and evaluated.[115] As already discussed in this section, the problems with HPMA and the Air Force's approach to the synthetic environment are eerily similar and were explained in the same manner within the APPD report.

The FAA study also discovered that most accident investigations focused almost exclusively on the active failures in the cockpit, while ignoring the latent or organizational factors. Very few of the accident reports cited supervisory or organizational shortcomings as causes, and as a result, most of the reports held the aircrews almost exclusively responsible. In order to rectify this, the study made the observation that "more thorough accident investigations may need to be performed to identify possible supervisory and organizational issues associated with these events."[116] Again, the similarities to the Air Force HFACS programme and the issues identified with ensuring it achieves its aims are remarkably similar. Clearly, the Canadian Air Force is wrestling with the same issues the broader aviation industry is wrestling with.

The Air Force of tomorrow

The Canadian Air Force has begun a significant revitalization of its capability, and considering the technological leaps some of the communities are making, this is not without risk. There is, therefore, a requirement to make significant changes in training methodologies as identified by ICAO in 2005 and discussed in Section 2.[117] The CF18 and CP140 Aurora fleets are completing major upgrades; the CC177 Globemaster III has been delivered and is now flying operations around the world; the majority of the CC130 fleet is about to be replaced by the C130J; the Sea King is being replaced by the CH148 Cyclone; and CH147 Chinooks have been ordered for delivery. In all cases, the technology being delivered represents a significant leap forward over that it is replacing, and in some, such as the CC130 and Sea King, it firmly moves the roles of the systems operators from direct manipulation of the controls to the higher level functions of monitoring and interacting with others in the system as well as the aircraft itself. What is happening in military aviation today is

115. Douglass A. Wiegmann and Scott A. Shappell, DOT/FAA/AM-01/3, *A Human Error Analysis of Commercial Aviation Accidents Using the Human Factors Analysis and Classification System (HFACS)*, report prepared for the Federal Aviation Administration (Washington, DC: Office of Aviation Medicine, 2001), 11–13.

116. Ibid., 17.

117. ICAO, *ICAO Accident Prevention Manual,* 3-10.

reflective of what is happening in the broader aviation industry in which, increasingly, software and computers are being used to augment the human in the system and deliver supposed increased levels of efficiency and safety across the spectrum of aviation activities. As an example, the Boeing 777 utilizes more than "2.6 million lines of code to support the autopilot, flight management, navigation, and maintenance functions."[118]

What this means for the Air Force are the same lessons the rest of the aviation industry has learned during this evolution. The traditional, "legacy" style of training, which focuses primarily on aircraft handling skills, must be expanded to include a deliberate human factors element that includes critical areas such as "attitude development, stress management, risk management, flight deck management, crew-coordination, and psycho-motor skills."[119] Without a deliberate effort to develop, introduce and maintain these new essential skill sets, the Canadian Air Force will not be able to fully exploit the technical potential it either possesses or will soon possess.

Summary

The organizational pressures being exerted on the Air Force through the introduction of new platforms, from a human factors perspective, are significant. While the Air Force aspires to optimize human performance through the creation of the HPMA Programme, the use of the synthetic environment in training and evaluation, the implementation of HFACS, the policy framework it has created and the tools it has given its instructors and evaluators ensure it will never achieve the desired end state. There exists a significant delta between the Air Force ideal and the current situation, and addressing that delta will take a deliberate and dedicated effort to overcome. Critical to that effort will be a focus on the flight instructors and evaluators so that they are not only conversant but also highly proficient with the methods by which human performance is taught and evaluated.

The delta that has been identified is not insurmountable and reflects problems common to those experienced by many other operators within the aviation industry. For that reason, the lessons of industry, and its "best practices" in the exploitation of the synthetic environment to address the area of human factors, are useful in determining how best to implement an effective LOS programme. By considering what has and has not worked for those organizations, both military and civil, it is possible for a plan to be developed that systemically develops and implements a robust training programme centred on the synthetic environment that is not only viable but also sustainable and delivers the promised benefits in the realm of aviation human factors.

4. Solving human factors with LOS

Introduction

Considering the role that human factors play in aviation, including within the Canadian Air Force, there can be little doubt that efforts aimed at addressing them will yield increases in both safety and operational effectiveness. As discussed in Section 2, several aviation regulatory authorities, including the United Kingdom's Civil Aviation Authority, have concluded that training, such as LOS in which both technical and behavioural skills are emphasized and evaluated, "can have a significant impact on aviation safety through improved training and validation of operational procedures."[120] The question, then, becomes how best to implement these concepts to ensure they achieve their aims.

118. Pamela S. Tsang and Michael A. Vidulish, eds., *Principles and Practice of Aviation Psychology* (New Jersey: Lawrence Erlbaum Associates Inc., 2003) 7.

119. R. D. Campbell and M. Bagshaw, *Human Performance and Limitations in Aviation*, 3rd ed. (London: Blackwell Science, 2002), 5.

120. UK, CAP 720, *Flight Crew Training*, Chapter 5, page 1.

As discussed in the previous section, the Canadian Air Force struggles with its human factors programmes. Issues identified by the APPD analysis in relation to the synthetic environment and HPMA as well as the inability of the CF flight safety system to deliver an effective HFACS programme are symptoms of a broader failure to fully integrate human factors into all aspects of training and operations. Rather than complement existing processes, they have become additive, and when combined with already overworked and undermanned staff, they fail to live up to their promises.

While there are several potential areas of aviation human factors that the Canadian Air Force could address, this section will specifically target LOS as the means by which the CF can improve its human factors programmes to deliver significant improvements in safety and effectiveness. It will first consider the critical requirement to clearly define and articulate behavioural performance markers that capture the required behavioural skills to the same level in which the Air Force currently captures technical skills. This section will include examples of behavioural markers developed by industry that can be used as a template for the development of behavioural markers in the CF. With those performance markers created, the next logical step is ensuring the instructor/evaluator cadre within the Air Force is capable of employing them across the spectrum of Air Force activities. As this section will demonstrate, doing so will require dedicated effort and resources. Once those two areas are addressed, the design of LOS scenarios will be briefly explained as well as the potential additional benefits the Air Force can derive from a well-developed LOS programme.

By focusing on these specific elements, the Air Force will begin the long process of cultural change and will transform human factors into a fully integrated method of approaching training and operations. Areas like HPMA and HFACS, currently identified as needing attention, will begin to be addressed within the broader framework of an organization that clearly understands what its goals and objectives are in relation to human factors and that refers to them in a common language. Only then will the Air Force begin to move towards its transformational goals.

Behavioural markers

There is widespread agreement within the aviation industry on the importance of incorporating reliable and valid measures for assessing an individual or crew's non-technical skills. Within the United States, the adoption of the Advanced Qualification Programme has driven many organizations to conduct a comprehensive technical and non-technical skills analysis as part of instructional system design, to provide specific human factors training (i.e., CRM) and LOFT to all flight crews, and to evaluate their CRM skills through the use of LOE. To accomplish these goals, many have developed substantial and detailed lists of required CRM knowledge and skills, and some have even begun to incorporate critical CRM behaviours into their cockpit checklists.[121] In Europe, licensing requirements now mandate the evaluation of CRM skills in multicrew operations, and robust behavioural markers have been developed to facilitate this assessment.[122] While there are several variances, they generally share common characteristics.

The vast majority of CRM skills "are complex cognitive skills that involve problem solving, efficient chunking or grouping of information, or utilize specialized forms of mental representations."[123] A behavioural marker can be described as a "prescribed set of behaviours indicative of some aspect

121. Rhona Flin and Lynne Martin, "Behavioural Markers for Crew Resource Management: A Review of Current Practice," *International Journal of Aviation Psychology* 11, no. 1 (2001): 96.

122. Ibid.

123. Thomas L. Seamster, Frank A. Pretiss, and Eleana S. Edens, "Implementing CRM Skills within Crew Training Programs," Neil Krey's CRM Developers, http://s92270093.onlinehome.us/CRM-Devel/resources/paper/Training%20CRM%20skills%20seametal99.pdf (accessed July 3, 2012), 5.

of performance" and are generally listed in relation to component skills.[124] Most behavioural markers developed across the industry have fallen into three clusters, two of which are related to CRM performance. The two CRM clusters are cognitive (problem solving, task prioritization, and workload management), which make up a large percentage of crew performance, and interpersonal (teamwork, communication, group dynamics, and leadership–followership). The third cluster relates to technical assessment: skills already identified in traditional aviation training systems. This has significant implications for the design of training and evaluation scenarios that will be discussed later in this section. Finally, extensive research has revealed that it is extremely important that the wording of the markers is as concise and simple as possible and that the verb used to describe the marker is clearly observable.[125]

FAA behavioural markers

In the 1990s, the University of Texas, working in conjunction with NASA and the FAA, produced what is generally considered the seminal work on behavioural markers in aviation referred to as the *Line/LOS Checklist: A behavioural based checklist for CRM skills in assessment.* This work has been widely used throughout the aviation industry.[126] Developed through an in-depth analysis of incidents and accidents that have clear human factors causation, and relying on extensive psychological research, the checklist invokes ratings for four distinct phases of flight (preflight/taxi, departure, en route and arrival) within six categories of behaviour. These behaviours are described as "team management and crew communications, situational awareness and decision making, automation management, special situations, technical proficiency, and overall observations."[127]

The behavioural markers developed by the University of Texas have been incorporated into line operations safety audit programmes widely adopted across the aviation industry as a means of assessing crew performance during the conduct of line operations. LOSA is a deliberate and systematic programme of line observations "to provide safety data on the way an airline's flight operations system is functioning."[128] Data generated during the conduct of LOSA provides an organization with diagnostic indicators of its strengths and weaknesses as well as crew performance. With this data, the organization is then able to develop and implement countermeasures to operational threats and errors.[129]

European behavioural markers

The Europeans have developed a behavioural marker system referred to as NOTECHS (non-technical skills). NOTECHS was developed as a generic system to permit the evaluation of individual pilots' non-technical skills to enable individual licensing events which the original FAA criteria were not designed to support. Although designed for different purposes, the behavioural elements of NOTECHS are very similar to the University of Texas model. Fundamental to the development of NOTECHS was the belief that the system should contain the minimum number of categories and elements required to capture the required behaviours, that it would use simple language, and that the skills listed should be directly observable, in the case of social skills, or able to be inferred from communication, in the realm of cognitive skills. NOTECHS consists of three levels: elements, categories, and pass/fail. By beginning at the element level and applying clearly

124. Flin and Martin, "Behavioural Markers for CRM," 96.

125. Seamster, Pretiss, and Edens, "Implementing CRM Skills," 5.

126. Flin and Martin, "Behavioural Markers for CRM," 97.

127. Ibid.

128. International Civil Aviation Organization, DOC 9803, *Line Operations Safety Audit* (Montreal: ICAO, 2002), 16.

129. Ibid.

articulated ratings at the category level, the instructor/evaluator is able to determine if the candidate has passed or failed.[130]

The category level of NOTECHS has been "divided into two social skills (cooperation as well as leadership and management skills) and two cognitive skills (situation awareness and decision making)." The four categories are then divided into three or four elements. Attached to each element are several examples of both positive and negative behaviour.[131] It should be noted that NOTECHS does not capture communication as a separate category like the FAA model does. The view within NOTECHS is that communication is in fact an observable within all categories and cannot be separated on its own.

In 1998, a project team was created to conduct tests on the reliability, usability and adaptability of NOTECHS to the European culture. This team conducted a literature review, a small group study with 105 training captains and a final study in which several airlines were examined. In all cases, the NOTECHS model has proven to be a reliable and valid method of assessing behavioural skills in individuals.[132]

Behavioural markers used in the APPD Project

As in LOSA, some models have taken the basic behavioural markers framework and merged them with the required technical skills to create a comprehensive approach to defining the skills and knowledge required on the modern, complex flight deck. Although they share basic similarities with other behavioural models, the incorporation of technical skill sets makes them an extremely powerful tool in assessing an aviator's comprehensive ability to manage the complex and demanding environment of the modern flight deck.

For example, the APPD analysis used a model developed by Convergent Performance, LLC, referred to as the Advanced Technology Skills Inventory (ATSI)©. Developed in 2004 and utilized as performance measures in several other military organizations (including the United States Marine Corps and the United States Coast Guard), the ATSI© examines 12 discreet flight crew skills "in which automation plays a significant role."[133] The 12 performance measures used in ATSI© during the conduct of line observations were as follows:

a. mission preparation best practices;

b. briefing and debriefing best practices;

c. crew communication best practices;

d. data entry best practices;

e. authority management best practices;

f. task and workload management best practices;

g. situation and mode awareness best practices;

130. Paul O'Connor and others, "Developing a Method for Evaluating Crew Resource Management Skills: A European Perspective," *International Journal of Aviation Psychology* 12, no. 3 (July 2002): 266–67.

131. Ibid., 267–68.

132. B. Klampfer and others, "Behavioural Markers Workshop" (workshop notes, Group Interaction in High Risk Environments (GIHRE) – Aviation / Swiss Federal Institute of Technology, Zurich, 5–6 July 2001), 25.

133. Kobierski and Stickney, *Automation Analysis Report*, 3.4.

h. automation transition best practices;

i. alert and warning management best practices;

j. failure and deviation response best practices;

k. automation confidence best practices; and

l. automation systems and logic knowledge.[134]

These 12 areas were targeted during the APPD Project and formed the baseline for the conclusions and recommendations contained in the APPD report. By directly measuring the skill levels of several Air Force crews conducting both line operations and training in these functional areas (in addition to examining Air Force policies and procedures that facilitated or enabled that crew performance), the APPD report was able to capture the current state of the Air Force.[135] In effect, the APPD Project conducted a LOSA on the Air Force with emphasis on advanced technology aircraft and the implications of their introduction into the inventory.

These are but three examples of models employed within the aviation industry for measuring behavioural skills; there are several others in use throughout the world.[136] One of them, the ATSI©, has already been used in the Canadian Air Force to conduct the APPD analysis. Clearly, it is possible to develop behavioural markers that allow an organization to effectively evaluate behavioural skills to the same level as traditional skills.

The development of behavioural markers in the CF

The Group Interaction in High Risk Environments – Aviation, Behavioural Markers Workshop, held in Zurich, Switzerland, in 2001 published an excellent guide to the development and implementation of behavioural markers. Published as a simple guide, it focuses on general concepts and their application vice a specific behavioural marker system. The intent of the workshop was to publish a set of guidelines useful to those either employing, or considering employing, behavioural markers. It consists of questions and answers to 17 frequently asked questions on the subject.[137] Many of the details in the publication relate directly to what constitutes good behavioural markers and how to develop them, much of which has already been discussed in this section. Where the publication is particularly strong is in its discussion of the change management requirements and resource implications an organization will have to contend with when considering the implementation of behavioural markers. It is these that will be specifically discussed in this section.

The adoption of behavioural markers within the Canadian Air Force will require a deliberate effort, and while the ATSI© has already been employed, its full-scale implementation would require some effort to align it with organizational culture and terminology. As stated in the "Behavioural Markers Workshop," "behavioural marker systems do not transfer across domains and cultures without adaptation."[138] The workshop also noted that the adoption of any behavioural marker system must be properly introduced into an organization, with the addition of management and workforce to support the system, through a phased approach. This enables the building of confidence in both trainers and trainees in the system being implemented. Finally, any introduction of a behavioural

134. Ibid., 3.4–3.5.

135. Ibid., 2.2.

136. Flin and Martin, "Behavioural Markers for CRM," 95.

137. B. Klampfer and others, "Behavioural Markers Workshop," 7–8.

138. Ibid., 12.

marker system must be sensitive to the level of professional development of not only the individuals that will be subject to the behavioural markers but also the maturity and professional culture of the organization.[139]

When this last consideration is weighed against the APPD Project, it can be concluded that the ATSI© was successfully used as a diagnostic tool within the Canadian Air Force by a small pool of individuals expert in its use. Utilizing it as an internal training and/or evaluation tool would require a correspondingly higher level of effort across the organization to ensure policies and procedures are aligned to support it and, more importantly, personnel are able to use it. This is the most significant consideration within the "Behavioural Markers Workshop" and one that the Canadian Air Force will have to contend with if it is to develop and implement behavioural performance markers to address human factors in aviation.

The criticality of the instructor

As already mentioned in Section 2, instructors and evaluators are the "front-line" in any efforts to either introduce or maintain new methodologies, and as such, they are critical to the eventual success of any attempt to introduce behavioural markers. Without this group of individuals being given appropriate training, any efforts to apply behavioural markers will not deliver the desired results. This training must consist of formal training in: human factors skills, the use and limitations of performance marker systems, and the use of the specific behavioural marker system adopted by the organization. It must include a formal assessment, calibration in the environment in which the training or evaluation will be delivered (i.e., simulator), and periodic recalibration to ensure the instructor/evaluator is still conducting training and evaluations in accordance with organizational performance standards.[140]

The FAA LOS advisory circular, AC 120-35C, expands upon the general requirements of an effective LOS instructor/evaluator in several key areas, including defining minimum qualifications. Fundamental to their ability to execute LOS is their ability to "effectively observe and critique both individual and crew performance during the scenario."[141] Minimum requirements for an effective LOS instructor include being line familiar; qualified as a LOS instructor; trained in CRM skills (HPMA in the CF context); and trained in methods for briefing, debriefing and critique. The primary role of the instructor in LOS should be viewed as communicator, observer and moderator. They are not an instructor in the traditional sense and must resist the temptation to instruct or intrude in any way into the training scenario. Rather, the instructor is the facilitator of the flight and must be "prepared to accept and manage alternate courses of action that the crew may wish to follow."[142]

Instructors as facilitators

As discussed in Section 2, the purpose of LOFT is to expose the crews to complex situations that cannot be solved simply by consulting a checklist but rather force them into problems that are ambiguous and for which there is no set solution.[143] This mandates that instructor training be focused on being able to manage and assess ambiguous situations as compared to measuring compliance against a standard solution. A critical component to an effective LOS programme is the instructor's/evaluator's ability to facilitate "self-discovery and self-critique by the crew rather than lecture on

139. Ibid., 13.
140. Ibid.
141. FAA, AC 120-35C, *LOS*, 23.
142. Ibid., 23–24.
143. Hamman and others, "The Future of LOFT Scenario," 590.

what they did right and wrong," the latter being something technical-oriented programmes tend to focus on delivering.[144] These areas represent skill sets that legacy training systems do not develop in instructors and are the primary reasons why specific LOS instructor training programmes and standards must be developed and implemented.

Facilitation, when conducted properly, significantly enhances the overall training experience. In 1956, B. S. Bloom argued in his *Taxonomy of Educational Objectives* that there are "six levels of mastery, arranged hierarchically by the level of mental complexity involved."[145] In ascending order of complexity, these six levels are knowledge, comprehension, application, analysis, synthesis and evaluation. A LOS event and its debrief should provide an opportunity for individuals to achieve the highest levels of mastery: analysis, synthesis and evaluation. Through facilitation, the crews analyse what happened during the simulation event, synthesize their ideas on how to deal with complex situations in the line environment, and evaluate their own actions. In short, it develops skill sets critical to the modern and complex aviation environment. As a facilitator, the instructor becomes a "catalyst, one who uses skilled questioning techniques to help students draw their own conclusions from their personal experiences and create their own prescription for change."[146]

Traditional instruction is oriented towards information flowing to the student from the instructor, who generally has significantly more knowledge on the subject. Facilitation draws on knowledge already resident within the trainee, such as HPMA concepts taught in a classroom, to gain insight into the concepts and master them. A NASA study entitled *LOFT Debriefings: An Analysis of Instructor Techniques and Crew Participation* conducted on several airlines in the 1990s revealed that instructors who have not been taught facilitation methods, but are familiar with traditional instructional techniques, run a debrief session that revolves almost exclusively around themselves rather than the students. In these cases, the debrief is approached from a "teacher tell" perspective, and as a result, there is little benefit to it. The NASA study provided empirical evidence of the benefit of facilitation in crew training but noted that instructors "need additional training in facilitation."[147] Concurrent with the 1997 study, NASA released *Facilitating LOS Debriefings: A Training Manual* to assist aviation organizations with improving facilitation.[148] The *Training Manual* release was driven by one particularly significant finding in the study related to instructor standardization.

LOFT Debriefings revealed that there was a significant discrepancy amongst LOS instructors at all five airlines examined. From effectiveness as facilitators to the emphasis they placed on various CRM skill sets and crew participation, the instructors crossed the entire spectrum from very good to poor. As argued in the study, this indicates "an urgent need for additional training and standardization within each airline."[149] To address this issue, the aviation industry has adopted programmes aimed at instructor standardization, commonly referred to as "rater reliability."

144. R. Key Dismukes, Kimberly K. Jobe, and Lori K. McDonnel, *LOFT Debriefings: An Analysis of Instructor Techniques and Crew Participation*, NASA Technical Memorandum 110442 DOT/FAA/AR-96/126 (Moffat, CA: NASA Ames Research, 1997), 1.

145. R. Key Dismukes and others, "What is Facilitation and Why Use It?" in *Facilitation and Debriefing in Aviation Training and Operations*, eds. R. K. Dismukes and G. M. Smith (Aldershot, UK: Ashgate, 2000), 4.

146. Ibid., 4–5.

147. Dismukes, Jobe, and McDonnel, *LOFT Debriefings*, 4.

148. R. Key Dismukes, Kimberly K. Jobe, and Lori K. McDonnel, *Facilitating LOFT Debriefings: A Training Manual*, NASA Technical Memorandum 112192 DOT/FAA/AR-96/126 (Moffat, CA: NASA Ames Research, 1997). Readers are encouraged to consult this manual when considering developing a LOS program. It is a comprehensive document that clearly outlines how to effectively implement and maintain facilitation within an aviation organization.

149. Dismukes, Jobe, and McDonnel, *LOFT Debriefings*, 14.

Rater reliability

Within any training and evaluation system, "the assessment of individual performance relies on systematic observation and assessment by a trained rater or instructor/evaluator (I/E)."[150] Only through standardization can the rating and evaluation process used by the I/Es provide reliable and valid data from which to address individual and organizational deficiencies. This mandates that rating criteria remain stable over time and that ratings are consistent across the instructor/evaluator population. Given the traditionally subjective nature of behavioural measurements, the aviation industry has turned to psychometric methods of assessment in which reliability is a precondition for validity.[151]

The aviation industry has generally adopted two types of rater-reliability methodologies; inter-rater reliability (IRR) and referent-rater reliability (RRR). The first method, IRR, relies on achieving inter-rater consistency or inter-rater agreement. In this method, groups of I/Es conduct observations on the same event and rate them. Upon completion of the rating, the various I/E ratings are then analysed, compared and discussed to achieve a high level of congruency amongst the I/Es. IRR establishes a group norm that I/Es can then utilize in their own evaluations as a baseline. The second method, RRR, seeks to achieve rater consistency with an already developed standard of measurement. While generally more reliable, and therefore more valid, RRR demands a higher level of effort to develop the referent against which I/Es are trained.[152]

Regardless of the methodology chosen to achieve reliability and validity, training generally employs the same methods. Potential instructors and evaluators are provided with formal training in CRM concepts and applications, training in the specific behavioural markers to be used, practice in observing specific behaviours, and practice in utilizing all performance markers concurrently to develop a rating. Included within this training must be behavioural observation training (BOT) which teaches raters "to accurately detect, perceive, recall, and recognize specific behavioural events" as well as training in note-taking skills.[153] Generally, this is conducted through formal classroom training and the observation of prepared videos in which multiple observers rate the same crew performance. Feedback and discussion throughout the training, particularly with regards to how individual grades compare with peers, is critical to developing a common baseline in the trainees through the use of both traditional instruction and facilitation.[154]

Studies into the effectiveness of reliability training have shown that IRR evaluation standards can be obtained in an environment of "constrained resources of personnel and training time."[155] Generally, both IRR and RRR deliver high values of correlation to referent grades. The distinction between the two is that while a high level of referent reliability implies inter-rater reliability, high levels of inter-rater reliability do not imply referent reliability. It is quite possible for a group of instructors/evaluators to come to agreement amongst themselves while disagreeing with the published standard. For this reason, RRR is deemed the more valid of the two methods. What this means for the Air Force is that the "gold standard" is RRR, but reliability can still be achieved

150. Holt, Hansberger, and Boehm-Davis, "Improving Rater Calibration," 305.

151. Ibid., 306.

152. Robert W. Holt and Peder J. Johnson, *Application of Psychometrics to the Calibration of Air Carrier Evaluators*, report prepared for Chief Scientist for Human Factors (Federal Aviation Administration, Washington: FAA, 1998), 2–3.

153. J. Matthew Beaubien, David P. Baker, and Amy Nicole Salvaggio, "Improving the Construct Validity of Line Operational Simulation (LOS) Ratings: Lessons Learned from the Assessment Center," *International Journal of Aviation Psychology* 14, no. 1 (2004): 12.

154. Michael T. Brannick, Carolyn Prince, and Eduardo Salas, "The Reliability of Instructor Evaluations of Crew Performance: Good News and Not So Good News," *International Journal of Aviation Psychology* 12, no. 3 (2002): 250.

155. Holt, Hansberger, and Boehm-Davis, "Improving Rater Calibration in Aviation," 323.

through the implementation of IRR. Another advantage to RRR is that "because it is based on qualification standards, it provides an explicit training objective for evaluators."[156] Regardless of the method chosen, achieving an ability to teach and assess behavioural skills within the Canadian Air Force is entirely in the realm of possibility: all that is required is a dedication to implementing it and ensuring the resources required to support it are put in place.

With behavioural markers developed and an instructor cadre trained and prepared to teach and assess behavioural performance, the last step is the development of the training scenarios in which that performance will be assessed in the synthetic environment. Again, industry provides significant insight on how best to design training scenarios that support the attainment of both technical and behavioural objectives.

Simulator scenario design

The baseline for all LOS scenario development is that it must create "a functional environment which provides the opportunity to combine CRM and technical skills."[157] The basic framework of LOS scenario design is to integrate technical and CRM objectives into a single training programme that elicits the desired responses.[158] These are then matched with primary technical objectives to complete overall scenario development. The FAA advisory circular on LOS, AC 120-35C, discusses scenario design at length.

For LOS to be effective, it must be as realistic as possible. This makes the scenarios operationally relevant, believable, and a valid test of the crew's ability to execute an actual mission. The purpose is to simulate operational situations that require good CRM and technical skills to successfully resolve, while creating the requirement for decision making. They need to create an open atmosphere in which all crewmembers are able to engage in free and open communication, as required and when appropriate. LOS scenarios are most effective when they are straightforward, and the crew should live with the situation until it is either resolved or the aircraft has been safely landed. Any disruption of a LOS event, for comments or instruction, significantly detracts from its overall effectiveness.[159]

Scenario design process

Specific training objectives should be developed for each LOS scenario. These objectives are generally related to items identified as being required within the organization such as winter operations or the incorporation of new systems. Operational deficiencies identified through evaluations or LOSA are also included in scenario development. Generally, scenarios in the commercial aviation industry are comprised of some or all of the elements below:

a. preflight activities such as icing or cargo loading anomalies that the crew must address;

b. taxi operations;

c. origin, routing and destination;

d.revised arrival procedures, such as an unexpected runway change;

e. alternate operation of flight management systems;

156. Timothy E. Goldsmith and Peder J. Johnson, "Assessing and Improving Evaluation of Aircrew Performance," *International Journal of Aviation Psychology* 12, no. 3 (2002): 231.

157. Hamman and others, "The Future of LOFT Scenario," 589.

158. FAA, AC 120-35C, *LOS*, 30.

159. Ibid., 4.

f. abnormal and emergency conditions, including simple conditions (i.e., a hot start) and complex conditions that continue for the entire flight (i.e., a failed essential alternating current bus);

g. adverse weather conditions; and

h. partial or full loss of integrated flight management systems.[160]

As stated in AC 120-35C, "one misconception is the belief that LOS training should continuously increase crew workload until the crew becomes overloaded. This is not the purpose or intent of LOS and can actually help to defeat its effectiveness."[161] A well-designed LOS scenario does not need to be technically complex, it needs to be ambiguous to force desired crew behaviours to exhibit themselves. As discussed at length in Section 2, the majority of accidents are not caused by complex technical failures but rather seemingly minor discrepancies that lead to crew errors.[162] With these basic principles in mind, it is possible to build an appropriate LOS scenario.

The event set

The primary design component of LOS is referred to as the "event set," a group of related events that are part of the scenario and which achieve specific training objectives.[163] Each event set is comprised of triggers, distracters and supporting events. The event trigger is the condition which initiates the event; distracters are conditions inserted into the training period to divert the trainee's attention from events that are occurring or about to occur; supporting events are other elements taking place within the event set that further both technical and CRM training objectives.[164] The purpose of the event set is to provide a reference source for specific items to be accomplished during the conduct of the LOS and ensure all training objectives are achieved.[165] Breaking the training event into specific sets, or timeframes, allows observable behaviours to be focused "if a clearly definable unit of action or time is specified and used to delimit the observable crew behaviours." This has the added benefit of reducing instructor workload through focusing on key CRM behaviours for that specific event set rather than having to monitor for all categories.[166] Event set-based scenarios require the coordinated and effective actions of all crewmembers to successfully complete.[167]

As each event set is built, with its specific technical and CRM training objective, the overall scenario will eventually be captured in an event set matrix. This matrix allows the organization to categorize the levels of complexity the crew will have to contend with throughout the scenario.[168]

Optimizing LOS effectiveness

LOS has been in use throughout the aviation industry for several years. As a result, several studies have been done into methods to increase its overall effectiveness. The majority of these measures relate to either "reducing the cognitive demands of the rating task" or "selecting, training,

160. Ibid., 3.
161. Ibid., 25.
162. Hamman and others, "The Future of LOFT Scenario," 591.
163. Ibid., 590.
164. Ibid.
165. FAA, AC 120-35C, *LOS*, 35.
166. Flin and Martin, "Behavioural Markers for CRM," 100.
167. FAA, AC 120-35C, *LOS*, 26.
168. Ibid., 35.

and retaining qualified pilot instructors."[169] The instructor areas have been previously covered in this section, so this part will focus exclusively on increasing the ability of the rater to effectively rate the event.

In order to increase rater effectiveness from a cognitive perspective, the workload of the instructor must be considered in the design of the scenarios. As experience with LOS has increased across the industry, several strategies have been developed that can be employed to reduce that workload. These include the following:

a. evaluating fewer skills per event set;

b. increasing the length of each set;

c. creating a user-friendly evaluation form;

d. automating the simulator as much as possible to run the scenario;

e. using a behavioural checklist instead of rating scales;

f. clearly specifying skill definitions and example behaviours;

g. providing multiple opportunities for the instructor to observe required skills;

h. videotaping the crew performance;

i. providing decision tools to help instructors make their final ratings; and

j. documenting all skill ratings, not just those above or below average.[170]

All of these strategies, when implemented, have proven to significantly increase overall rater effectiveness in LOS. While they are all relatively straightforward, three of them will be examined in some detail to further develop an understanding of how they increase overall LOS effectiveness.

Increase the length of the event set

Increasing the length of the event set provides additional time for the instructor to complete ratings, make notes, compare performance on the current event set to previous event sets, and prepare for the next set. However, this needs to be deliberately managed against the requirement to maintain a high level of realism in the scenario. Increasing time within the event set may impact the ability of the scenario to manipulate stress in the crew being observed through the introduction of time pressures.[171] The FAA has regulated that each LOS scenario be scheduled for at least four hours to include cockpit preparation, preflight activities, crew briefings and interactions with agencies such as air traffic control (ATC).[172] Clearly, the design of any LOS scenario mandates deliberate consideration and weighing of training objectives against time available to optimize instructor workload and ensure a high level of rater reliability.

169. Beaubien, Baker, and Salvaggio, "Improving the Construct Validity," 8.

170. Ibid., 8–11. Readers are encouraged to consult the reference document for a full explanation of all rater workload mitigation strategies.

171. Ibid., 8.

172. FAA, AC 120-35C, *LOS*, 3.

Create a user-friendly LOS evaluation form

Simulator instructors are located at the back of the simulator, often in cramped conditions with low light. This mandates the creation of forms that employ large print and brightly coloured paper to increase contrast, and they should be contained in a spiral-bound booklet that can be easily folded to mitigate the cramped space. The form itself should be designed to provide background information, such as skill definitions or simulator manipulations, on the left-hand page while the right-hand page contains the rating form. Simple "check in the box" formats should be used instead of formats that require extensive input.[173] Evaluation sheets play a critical role in the ability of the evaluator to rate the crew's performance. The Air Force will have to wrestle with fundamental questions (such as how the ratings are worded, whether they are general or specific, and whether to use a numerical rating scale or behavioural checklists) if it is to develop an effective LOS programme.[174]

Document all skill ratings

Research has shown that evaluators tend to rate crews as "average" when the grade sheet only requires justification or amplification for ratings of above or below average. Including ratings of average performance reduces this probability and also creates a significantly larger data set with which to grade the overall effectiveness of the LOS programme. Adopting this methodology requires deliberate effort in clearly articulating rating skills that are easy for the instructor to use to avoid other potential issues, such as instructor workload.[175]

The conduct of LOS

The FAA recommends that all LOS scenarios contain four distinct phases: briefing, preflight planning documents and activities, the flight segment, and the debriefing.[176] Research into the effectiveness of LOS has shown that weaknesses in the debriefing phase are the most significant contributors to a weak or ineffective LOS programme.[177] A brief explanation of each phase is included below:

a. **Briefing**. The instructor will brief the LOS scenario, including the training objectives and the role of the instructor and flight crew during the scenario. Background information, such as the environmental setting of the scenario, will also be discussed. Frequently, inadequate LOS briefings result in poor LOS events. The most common problem is a failure to convince the crew that the instructor is not present during the event and cannot be used as a resource by the crew. The brief should also include a review of the CRM (HPMA) concepts to be covered in the scenario, with the crew taking the lead in this part of the briefing.[178]

b. **Preflight activities**. The instructor will provide the crew with all preflight documentation required to complete a flight. Weather sequences, weight and balance, and other normal preflight documentation should be the same as that provided for a real flight. The crew needs to be in the simulator early enough to properly set up the aircraft in accordance with established preflight procedures.[179]

173. Beaubien, Baker, and Salvaggio, "Improving the Construct Validity," 9.
174. Goldsmith and Johnson, "Assessing and Improving Evaluation," 235.
175. Beaubien, Baker, and Salvaggio, "Improving the Construct Validity," 11.
176. FAA, AC 120-35C, *LOS*, 2.
177. Dismukes, Jobe, and McDonnel, *LOFT Debriefings*, 4.
178. FAA, AC 120-35C, *LOS*, 4–8.
179. Ibid., 8–9.

c. **Flight segment**. As already mentioned, the flight segment unfolds in real time with the crew performing their normal duties. The only exception to this is during the conduct of SPOT, which can be interrupted for the purposes of accomplishing specific training objectives. Realism must be adhered to at all times, to include the crew donning headsets, emergency breathing equipment or any other piece of equipment necessary for the conduct of flight.[180]

d. **Debriefing**. This is the most critical component of the LOS session. The instructor must resist the urge to instruct and allow the crew to explore their own strengths and weaknesses. Research has shown that crews will not all be capable of conducting this type of activity to the same level, depending on experience and maturity. This means that instructors must be prepared to facilitate to varying levels depending on the crew they are dealing with. Instructor requirements during LOE are different than those of LOFT and SPOT, and this must be taken into account during instructor development.[181]

Scenario validation and update

Developing an effective LOS programme requires deliberate effort and the consideration of several key factors as articulated in this section. One additional requirement relates to the validation of the scenario prior to its use with line aircrew. In the United States, all commercial operators are required to submit their scenarios to the FAA for approval prior to their use. Approval is based on compliance with Advisory Circular 120-35C, *Line Operations Simulations*.[182] Once validated, LOS instructors are then trained in the conduct of the new LOS scenarios. The development of LOS within the Air Force would mandate a similar regulatory approach to ensure that various fleets are complying with Air Force objectives related to teaching and evaluating behavioural skills.

The last item to consider in the implementation of LOS is a recognition that the scenario design effort does not stop with the delivery of the first scenarios. Scenarios need to be updated regularly (the FAA recommends at least annually) to ensure that students do not become overly familiar with them. This final step would ensure that Air Force crews are exposed to "new technologies, procedures, and current operational problems."[183]

Once these various methodologies and considerations have been completed, the Air Force would find itself in a position to implement and sustain an effective LOS programme. As this section has demonstrated, it is simply not enough to state that the Air Force is going to fully exploit the synthetic environment while optimizing human performance without ensuring the appropriate level of resources and effort are in place to support the attainment of that goal. The APPD report, discussed in Section 3, summarizes the result when that does not happen and has clearly indicated that the Air Force has yet to optimize its training and operations for aviation human factors. Implementing and sustaining an effective LOS programme is within the reach of the Air Force if the lessons of industry are considered. While LOS is a single component of a broader human factors effort, the deliberate effort required to successfully introduce it into the Air Force would have significant "ripple" effects across the organization.

180. Ibid., 9 and 12.

181. Dismukes, Jobe, and McDonnel, *LOFT Debriefings*, 20.

182. FAA, AC 120-35C, *LOS*, 4. For a detailed breakdown of LOS design methodology, readers are encouraged to consult Table 6-1 of this reference. It provides a step-by-step process that organizations can follow to develop LOS.

183. Ibid., 13.

Additional benefits of a LOS programme for the Air Force

The implementation of LOS throughout the Air Force mandates that certain critical activities take place as discussed in this section. First, the Air Force will have to clearly define the behavioural skills it expects its personnel to achieve and publish the behavioural markers it will measure their performance against. Second, it will have to teach its instructors and evaluators to use those behavioural markers during the conduct of training and operations to ensure the Air Force is achieving its goals. Finally, deliberate effort will be required to develop and implement LOS scenarios that capture both the technical and behavioural skills the Air Force wants to enforce and evaluate. All of these activities will cause the organization to develop a common language of aviation human factors. Out of that common language will develop the means by which the Air Force begins to address its other human factors related challenges such as HPMA and HFACS. In the case of HPMA, which already contains the foundation and concepts of a robust human factors programme, all that is really missing is the evaluation portion. HFACS, although a flight safety function, will also begin to correct itself as the organization develops a broader appreciation of what it is that it wants to achieve in the field of aviation human factors. These two areas are relatively straightforward to address when considered within the context of developing and implementing a LOS programme across the Air Force.

There are other potential benefits that have already been briefly discussed in this paper. One of the most important benefits that would logically follow the implementation of a LOS programme would be the introduction of a line operations safety audit or flight operations quality assurance programme. With clearly defined technical and behavioural performance markers already in place to support a LOSA programme, it would become relatively simple for the Air Force to begin wide-scale safety audits of its operations. As described in the ICAO LOSA manual, "LOSA uses expert and highly trained observers to collect data about flight crew behaviour and situational factors on 'normal' flights."[184] With LOS teaching and evaluating the baseline expectations, LOSA operates on a non-jeopardy basis in which flight crews are not held accountable for their actions and errors that are observed. Rather, the purpose of LOSA is to assist the organization in identifying potential shortcomings in its training and operational procedures.[185] LOSA becomes to the operational community what HFACS is designed to be to the flight safety system—the means by which the organization identifies and addresses deficiencies in the way it conducts operations from a human factors and technical perspective. LOSA represents an organizational maturity that can only be achieved by taking the first critical step. That critical first step is the development and implementation of a robust and effective LOS programme.

Summary

LOS is a thoroughly researched and highly substantiated means of optimizing human factors in aviation. Several regulatory agencies (including those in Canada, the United States and Europe) advocate, and in some cases mandate, its implementation to reduce the attribution of human factors in aviation incidents and accidents. Multiple manuals and research papers have been written on its effectiveness, how to develop it, and how to introduce it: they have been continually refined as the concept has matured. What the APPD report demonstrated is that the Canadian Air Force has yet to optimize either its human factors programmes or its use of the synthetic environment. It is simply not enough to say that the Air Force is going to fully exploit the synthetic environment and optimize human performance. It must provide the resources and dedicate the effort required in the areas of behavioural marker definition, training of the instructor/evaluator cadre, and scenario design and validation if it is to achieve its goals.

184. ICAO, *Line Operations Safety Audit*, vii.

185. Ibid.

The adoption of a robust and effective LOS programme can effectively address the issues of HPMA and the synthetic environment identified in the APPD report and, in so doing, will begin to address other issues the Air Force is wrestling with. This is the real benefit of introducing a LOS programme to the Canadian Air Force—the follow-on capabilities that become achievable once behavioural markers are defined and evaluated to the same level as today's technical skills. As the LOS programme matures across the Air Force and its personnel start to speak in a common language in relation to behavioural skills, the flight safety system would find itself in a position to begin full implementation of HFACS. Follow-on programmes, like LOSA, would allow the Air Force to truly become a learning organization.

5. Conclusion

William Sharpe and Manfred von Richthofen were aviators at a time when simulators and the synthetic environment were distant years in the future. The first met his fate in an accident in 1915, and the second finally fell in battle in 1918. Would better training have prevented the accident which took William Sharpe's life? Would the synthetic environment have allowed the Red Baron to teach his deadly skills to a wider cross section of the German Air Force in First World War, thereby potentially altering the outcome of that conflict? There can be no answers to those questions, but perhaps the most pressing question that comes to mind when thinking of those two today is whether they would have something to tell us about what they learned so long ago. Is the message on the importance of the human in aviation that was passed on to us by the Red Baron in 1917 still valid?

This paper began with a demonstration of the enduring prevalence of the role that human factors play in aviation. Since man first took to the air, it is the human spirit that has sustained it and kept it aloft. As the historical record shows, it is also the human that has played a significant role in bringing it to earth when least expected. While the aircraft matured and achieved high levels of reliability in little more than half a century, aviation continues to find itself wrestling with the way in which the human functions as a result of thousands of years of evolution. It has been argued in this paper that the field of aviation human factors did not really come into being until the latter part of the 20^{th} century. Since that time, the field has expanded rapidly and begun to systematically address the role of human factors in aviation. Recent statistics show that between 70 and 80 per cent of all aviation incidents and accidents are attributed to human factors. Even more significant, the research shows that many of those accidents are not a result of complex technical problems with the aircraft but are caused by fundamental breakdowns in leadership, crew coordination, communication and decision making. The introduction of advanced technology aircraft, with sophisticated onboard systems, has further elevated the criticality of the role of the human and the need to ensure that aviators are properly trained to deal with the increasingly complex environment of aviation.

One of the most significant developments in aviation in recent years has been the incorporation of the synthetic environment to address aviation human factors. Significant research has been conducted into how best to structure the exploitation of the synthetic environment to achieve high levels of human performance which, in turn, deliver higher levels of operational effectiveness and safety. Referred to as line operational simulation, the development and implementation of a robust simulator training programme to teach crew resource management is widespread across the industry. This paper has captured the development of LOS and the means by which it is delivered. It has also highlighted the critical role that instructors and evaluators play in any effort to optimize the synthetic environment. Without training and standards firmly rooted in clearly defined behavioural performance markers, the ability of the instructor and evaluator cadre to properly teach and assess behavioural skills is severely impacted. Industry has recognized the relationship between these elements and many of the aviators in today's civilian world are exposed to levels of training and evaluation in behavioural skill sets that the Canadian Air Force aspires to now and in the future.

This study also considered the current state of the Canadian Air Force in relation to aviation human factors and the synthetic environment. What it concluded was that there remains much to be done if human performance is to be optimized and the long term vision for transformation achieved. The APPD Project uncovered several issues linked to the areas of human factors and the synthetics environment that are not insurmountable considering the lessons from industry. It must be remembered that the Air Force already possesses a robust suite of synthetic training devices, but it is simply failing to use them to their full potential. As Eduardo Salas, Clint A. Bowers and Lori Rhodenizer said in 1998, "it is not how much you have but how you use it" and in this regard, the Air Force needs some work.[186] This study also uncovered other areas directly linked to human factors that are hindering the ability of the Air Force to sufficiently capture the true causes of its accidents and learn from them. Again, the lessons of industry, if applied properly, can be used to make the Human Factors Analysis and Classification System, currently employed by the Directorate of Flight Safety, a useful tool. Most importantly, this paper demonstrated that these problems are not unique to the Canadian Forces and that others have been able to address them.

The final section of this paper discussed the specific ways in which the Air Force can begin to comprehensively optimize its approach to aviation human factors through the use of the synthetic environment. By focusing on the development of behavioural markers, creating instructors and evaluators that are able to use them, and implementing a robust LOS programme across the Air Force, the Air Force can begin to move towards its transformational goals. Dedicated resources and personnel will be required, as it is no longer sufficient to simply state that it is going to be done.

With those resources and personnel in place, and utilizing the lessons of industry, it is entirely possible for the Air Force to create a LOS programme that is both sustainable and operationally relevant. In so doing, it will set the conditions for success in other areas related to human performance, such as the HPMA and the HFACS programmes. As the organization creates a common language and culture of human performance, the implementation of programmes like line operations safety audits become achievable as well. All that is required is for the Air Force to take that first critical step of creating markers to teach and evaluate behavioural performance in the same way that it already teaches and evaluates technical skills.

Manfred von Richthofen's recognition of the criticality of the human to achieving success in aviation is as true today as when it was written in 1917. While the box he was referring to was the aircraft, today the Canadian Air Force finds itself with the opportunity to fully exploit another box, the simulator. Doing so will allow it to optimize not only the human sitting in the aircraft but also achieve levels of operational effectiveness and safety not previously known. It will also ensure that it is able to fully exploit the technology it either currently possesses or will possess in the future. Air Force strategy clearly indicates that the will exists. All that remains is for the Air Force to dedicate the resources and the effort to making it happen; optimization of the synthetic environment to deliver optimized human performance is entirely within its grasp.

186. Salas, Bowers, and Rhodenizer, "It Is Not How Much," 197.

Abbreviations

AC	advisory circular
ACRM	Advanced Crew Resource Management Training
ADM	aeronautical decision making
APPD	Automation Policy and Planning Development
AQP	advanced qualification programme
ASRS	Aviation Safety Reporting System
ATSI	Advanced Technology Skills Inventory
CAP	Civil Air Publication (United Kingdom)
CF	Canadian Forces
CRM	Crew Resource Management
DFS	Directorate of Flight Safety
DND	Department of National Defence
FAA	Federal Aviation Administration (United States)
FSIR	flight safety investigation report
HFACS	Human Factors Analysis and Classification System
HPMA	human performance in military aviation
ICAO	International Civil Aviation Organization
I/E	instructor/evaluator
IRR	inter-rater reliability
IRT	instrument rating test
LOE	line operational evaluation
LOFT	line-oriented flight training
LOS	line operational simulation
LOSA	line operations safety audit
NASA	National Aeronautics and Space Administration
NOTECHS	non-technical skills
RRR	referent-rater reliability
SPOT	special purpose operational training
UK	United Kingdom

Chapter 2 – Canadian Special Operations Aviation: A Strategically Relevant Force

Major Richard Morris

Abstract

In today's international security environment, special operations forces (SOF) have often become a force of choice for governments who possess them. They offer economy of force and provide flexibility when dealing with crises that require swift action and are often politically sensitive. SOF, however, are only as effective as the sum of their parts. With this in mind, the paper argues that special operations aviation (SOA) is a strategically relevant force for Canada but that it in its current state, it is unable to provide the desired effect. The argument is made through an examination of the current and future international security environments' challenges and how SOF, through theory and practice, provide effective solutions. In addition, historical examples of the strategic relevance of SOA to special operations are examined. This is followed by an analysis of Canadian SOA and how it needs to develop in the future to achieve its strategic and required potential.

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1. Introduction

Modern special operations forces, as typically understood by today's standards, have existed in some form or another since World War II in order to provide national governments and their military commanders with unique skill sets that can be called upon in times of need. SOF's uniqueness (in addition to the employment of non-conventional tactics and equipment, as William McRaven notes) stems from their ability to succeed in the face of normally numerically superior forces.[1] The inherent high levels of readiness of SOF units and their ability to operate both covertly and overtly have made them an extremely attractive and cost effective strategic military asset. This was only accentuated in the post cold war economic and strategic environments where there was the expectation of a "peace dividend" and the probability of massive conventional state-on-state warfare declined considerably. The former never really materialized, and the latter was largely replaced by internal or smaller regional conflicts resulting from failed or failing states. Under these economic and global strategic environments, SOF became an attractive asset to enable national governments to shape their policies abroad.

The tragic events of September 11, 2001, (9/11) again dramatically changed the global strategic environment. The value of SOF was reinforced and increased in the ensuing "global war on terrorism" where:

> [t]heir inherent responsiveness, small footprint, cultural and regional awareness, and impressive suite of capabilities made them a force multiplier with an impact on operations far in excess of the numbers actually employed.[2]

The Canadian military was not blind to the changing nature of global security. Consequently, under the direction of then Chief of Defence Staff General Rick Hillier, a sweeping command and control transformation was initiated. This included the creation of the Canadian Special Operations Forces Command (CANSOFCOM) in February 2006.[3] The envisioned purpose of this command was to generate SOF task forces in support of Canadian Forces (CF) operations, both domestically and abroad.[4] To accomplish its missions and tasks, CANSOFCOM was comprised of four units: Joint Task Force 2 (JTF 2); the new Canadian Special Operations Regiment (CSOR); an expanded Joint Nuclear, Biological and Chemical Defence Company (JNBCDC);[5] and 427 Tactical Helicopter Squadron (THS), under operational command (OPCOM).[6] SOF was now embedded as an integral element of the CF alongside traditional land, sea and air components.

Like CSOR and the JNBC units, the aviation unit represented a new development in SOF capabilities for Canada. Until 2006, 427 THS had only provided limited dedicated support to the domestic counterterrorism mission of JTF 2. It had now been officially designated as 427 Special Operations Aviation Squadron (SOA Sqn), and the whole of the unit was tasked to provide integral dedicated aviation support to Canadian SOF.[7] Canada had now joined a small handful of nations that possessed highly trained special operations forces, along with critical, integral and enabling elements such as aviation.

1. William H. McRaven, *Spec Ops: Case Studies in Special Operations Warfare: Theory and Practice* (Novato: Presidio Press, 1996), 4.
2. Colonel Bernd Horn and Major Tony Balasevicius, eds., *Casting Light on the Shadows: Canadian Perspectives on Special Operations* (Toronto: The Dundurn Group; Kingston, ON: Canadian Defence Academy Press, 2007), 13.
3. Canada, Department of National Defence (DND), *Canadian Special Operations Forces Command: An Overview* (Ottawa: DND, 2008), 2.
4. Ibid.
5. This unit would later be renamed the Canadian Joint Incident Response Unit (CJIRU).
6. Canada, DND, *Canadian Special Operations Forces Command*, 10.
7. Ibid., 11.

However, the mere change in command relationships and the function of 427 THS only represented the first steps in the development of a true SOA capacity for CANSOFCOM and the Canadian Forces. The equipment, airframes and personnel establishment in 2006 still largely reflected legacy cold war and conventional force organization and concepts. In four years there have been some incremental changes which have been made to facilitate the development of SOA; nevertheless, the overall capability is still nascent. Consequently, this paper will show that SOA is a relevant strategic capability for Canada but that it is currently insufficient, requiring further development to ensure a mature, sustainable and effective competency for the Canadian Forces.

In order to accomplish this, the contemporary and future security environment will be outlined. This will be followed by a brief look at the existing theory of SOF and their roles. The next two sections will provide context and an understanding of the relevance of SOF in the present and future operating environments. This will then provide the reader a framework or background to better comprehend the two SOA case studies in Section 4. These case studies examine special operations conducted by the United States and the United Kingdom, where SOA held a key role as a strategic enabler. Finally, Section 5 will examine Canadian SOA against the backdrop of the three previous sections in order to determine its current capacity and where it needs to be in the future to secure its place as a relevant force.

Author's note

In addition, the information that will be presented in this paper will be kept at an unclassified level. The result will be that some topics and subsequent discussions may appear to be somewhat general in nature. However, I have decided to do this in order to facilitate the potential for broader dissemination with the hope of generating a greater level of thought and discussion.

The reader will also likely take note that, in discussing SOF and SOA, I have avoided discussing the roles that each may have in domestic operations. This was a conscious decision on my part. This is a result of what I call the "idea of last response versus first response." That is to say, generally, in the domestic role SOF is a force of last resort called upon when the civil authorities are unable to deal with the crisis at hand. Conversely, with respect to international operations, SOF is often able to provide a first response, giving those governments and militaries that employ them strategic flexibility. It is this idea of the strategic flexibility that SOF/SOA can provide that will be explored.

2. The contemporary and future security environments

There can be little doubt that the events of 9/11 caused a monumental shift in the global security environment. Since that marked day, there has been much study and thought applied to the circumstances that now shape the international security environment and those that will affect it as we move forward into the future. Though it is not a new phenomenon to attempt to analyse current and future international trends, there has been an increased emphasis placed on the criticality of understanding the global landscape due to its now inherent complexity. Put into context:

> … it is important to understand the potential operational challenges generated by the future security environment in order to ensure the CF has the ability to carry out the roles set for it by Government policy.[8]

8. Peter Johnston and Dr. Michael Roi, *Future Security Environment 2025* (Ottawa: Operational Research Division Directorate of Operational Research [CORP], 2005), 1, http://cradpdf.drdc-rddc.gc.ca/PDFS/unc35/p520084.pdf (accessed July 9, 2012).

Key trends

Though the post-9/11 focus has been on global terrorism and combating it, there are additional and important factors that exist which are shaping the world today and that of tomorrow. This section will outline key security trends that have been identified and seem to be commonly recognized, at least by Canada and its key allies. Globalization, rapid scientific and technological innovation, geopolitical shifts, resource scarcity, demographic changes, urbanization, the threat of pandemic disease, failed and failing states and the growing significance of non-state actors will be outlined in order to understand the shifting security environment of the world today.[9] This will provide the background to frame the relevancy of the theory and roles of SOF that will be explored in the next section.

Globalization

Globalization, though it is a popular expression in use today, is not necessarily a new trend.[10] "The term globalization refers to the increased mobility of goods, services, labo[u]r, technology and capital throughout the world."[11] The rapid expansion of telecommunications technology has been the main catalyst for this phenomenon in most recent years. It has not only resulted in a significant interdependent global economy, as noted above, but it has also integrated societies, increasing the exchange of information (both quantity and speed) exponentially.[12] Globalization is somewhat unavoidable in terms of international economic and social evolution. It has had several major international economic and other benefits. However, there are some inherent disadvantages, and to date, the advantages of globalization have not been universally realized nor universally accepted. It is for these reasons that the effects of globalization must be understood from a security perspective.

The globalization process has, as previously mentioned, resulted not only in the ease and speed of movement of people, information and technology worldwide but almost necessitated it. For instance, in terms of people, the need to sufficiently screen the large numbers of cross-border movements conflicts with the requirement to do it in an efficient manner, so as to not unnecessarily disrupt the economic activity driven by these persons. Also, information and knowledge can now be easily and widely accessed and disseminated. This makes it complicated to restrict the availability of information to, and disrupt its passage within, elements that pose a security threat. The World Wide Web and the "CNN"[13] effect represent difficult entities to monitor and control effectively. The speed at which communications technology, in particular, has developed and become available globally has only compounded the difficulty of this situation. In summary:

> [The] growing access to information and technology is dramatically heightening the potential, both among state and non-state entities, to acquire the means to succeed (e.g., [weapons of mass destruction] WMD and their means of delivery).[14]

9. These trends are common to numerous global security assessments from Australia, Canada, the United States and the United Kingdom.

10. Johnston and Roi, *Future Security Environment 2025*. Figures 1 and 2 in the reference clearly show the significant increase of integration of the global economy from 1970 to 2000.

11. Ibid., 1.

12. Canada, Department of National Defence, *Future Force: Concepts for Future Army Capabilities* (Kingston: Directorate of Land Startegic Concepts, 2003), 2, http://www.army.forces.gc.ca/DLCD-DCSFT/pubs/special/futureforce/FPAC_eng.pdf (accessed July 9, 2012).

13. The Cable News Network (CNN) is a United States cable news channel founded in 1980. It was the first channel to provide 24-hour television news coverage and was the first all-news television channel in the United States.

14. Canada, DND, *Future Force*, 3.

We will see the impact that this has on the relevancy of the roles and missions of SOF in the next section.

Globalization has seen significant benefits realized by some; however, there is the risk of a widening of the gap between the "haves" and the "have-nots." The challenges for contemporary policy makers and those of the future will be to ensure that the benefits of globalization are realized by developing nations and regions of the world.[15] The likely consequences of not succeeding in this endeavour would be a backlash from those who have been largely excluded from the material benefits of globalization.[16] The potential risk, if not appropriately addressed, is that in the increasingly interconnected and complex economic environment there will be "stable" and "unstable" states. Stable states will be those who have the ability to comply with the demands and scrutiny of the international economic structure, thus securing continued and further investment. Unstable states will not be able to meet these conditions and, consequently, may be caught in a vicious circle of poverty, leading to potential failure.

> In other words, globalization will play a large role in determining the future trouble spots and, if the economic benefits of the global trading system do not spread to the developing world, may sow the seeds of future conflicts.[17]

As we will see in the coming section, SOF will have a role to play in warning of and shaping some of these potential conflicts arising from globalization.

The international integration due to globalization has resulted in particular in an economic interdependence. This interconnectedness has encouraged participants to take a shared interest in the continued health and welfare of the system.[18] The consequence of this has been the reduction of the likelihood of traditional state-on-state warfare. This is in part due to the resultant greater uniformity across cultures and societies.[19] Though this has benefitted nations and regions that have like-minded societies, governments or cultures, there is definitely not a universal acceptance of this order. The reality is that there will be others in the world that will feel threatened by the norms and values promoted by globalization. This may result in significant resentment and violent reaction from entities such as theocratic states and traditional cultures.[20] For evidence of this, one just has to look at the apparent clash between the ideals of "the West" and Islam, of which ongoing conflicts in Iraq, Afghanistan and the Middle East are all representative.

The impact that globalization has had and will continue to have on the international security environment is very real and will require foresight and planning to minimize its effect. People, money, and ideas now move faster around the world, not always for the good.[21] Ultimately, events abroad now have the potential to have a profound impact on Canada and its interests.[22]

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15. Johnston and Roi, *Future Security Environment 2025*, part III.

16. Canada, DND, *Future Force*, 3.

17. Johnston and Roi, *Future Security Environment 2025*, part III.

18. Canada, DND, *Future Force*, 3.

19. Ibid.

20. Peter Gizewski, "The Future Security Environment: Threats, Risks and Responses," *Canadian Institute of International Affairs International Security Series* (March 2007): 1, http://www.opencanada.org/wp-content/uploads/2011/05/ISS-Future-Security-Environment.pdf (accessed July 9, 2012).

21. Australia, Department of Defence, *Australia's National Security: A Defence Update 2007* (Canberra: Department of Defence, 2007), 14, http://www.defence.gov.au/oscdf/ans/2007/ (accessed July 9, 2012).

22. Canada, Department of National Defence, *Canada First* Defence Strategy (Ottawa: Department of National Defence, 2008), 6, http://www.forces.gc.ca/site/pri/first-premier/index-eng.asp (accessed July 9, 2012).

Rapid scientific and technological innovation

The rate of change and innovation in a number of technological areas has the potential for being very beneficial politically, socially, economically and militarily. This stems from a number of recent advancements in the fields such as information technology, robotics as well as nano and biotechnologies.[23] Societies stand to benefit from increased efficiencies (like more effective communications and information management technology), to more effective and new health procedures, to increased efficiencies in business and industrial practices. For the military, advances in information management systems; enhanced sensing equipment; and the precision, range and lethality of weapons may allow for the possibility of increasing the effectiveness of applying proportional levels of force.[24]

However, there are also dangers associated with these rapid advances in technology. Militarily, there are developments underway focussed on high-yield weapons. Advancements in enhanced blast, thermobaric and fuel-air explosives are but a few examples. This kind of weaponry is in direct contrast to the precision targeting and the scalability of effects inherent in other technologies. The security threat that exists in this circumstance is that, given the nature of globalization, it is likely only a matter of time before proliferation of such weaponry becomes an issue.[25] The challenge for Canada and other nations will be to prevent proliferation of this technology and to mitigate the threat of its use as much as possible without entering a technological "arms" race.

Geopolitical shift

It is generally accepted that United States' (US) predominance will prevail for the foreseeable future. "To put it another way, the role played by the United States in global affairs remains the most important geopolitical factor shaping the international security environment."[26] The current gap between the military capabilities of the US and its potential adversaries is such that there is little doubt that the US will retain its position of unrivalled military might, for at least the next two decades. In fact, this capability gap will likely widen over the near term, as a result of unmatched US investment in defence research and development. Despite this outlook, it would be naive to assume that US hegemony, as it exists today, will remain unchanged into the future.

The international landscape is already showing signs of transformation. Countries such as China, India and Russia, who all have regional interests and goals, have shown interest in expanding their influence beyond their traditional spheres.[27] The consequence of this is that US/Western policies and interests will likely be increasingly at odds with those of these emerging powers.[28] In addition, the presence of states with unpredictable regimes or "rogue" states that have or are attempting to acquire advanced weaponry and nuclear capabilities increases the potential for conflict.[29] In either case, the risk of armed conflict could rise, making Western influence and presence in many regions problematic and risk prone.[30] The military power of the US and its allies is likely sufficient to counter most threats for now. However, as time goes on can the US sustain the fiscal and political costs of policing global conflict? Or will they adopt a semi-isolationist posture only acting and committing

23. Gizewski, "The Future Security Environment," 2.

24. Ibid.

25. Ibid., 5.

26. Johnston and Roi, *Future Security Environment 2025*, part IV, para 30.

27. Gizewski, "The Future Security Environment," 2.

28. Canada, DND, *Future Force*, 6.

29. Canada, DND, *Canada First* Defence Strategy, 6.

30. Gizewski, "The Future Security Environment," 3.

resources and American lives when their key national interests are at stake? Though relatively stable for the foreseeable future, it is evident that the global geopolitical situation will shift, bringing new challenges to international security with it.

Resource scarcity

Climate change, burgeoning regional population growth and environmental degradation will lead to significant shortages of resources in the coming years. While some key non-renewable resources such as cropland and timber will be adversely affected, it is water and oil that are forecasted to pose the greatest threat to global security. The potential is such that a reduction of availability of these key resources will contribute to regional/state weakness, economic decline and societal instability.[31]

The increasing decline in the availability of water resources is of particular concern. Three billion people, from 48 countries, are in jeopardy of facing significant freshwater shortages by 2025. There are approximately 20 countries of the Near East and North Africa that stand to suffer the worst shortages. In these areas, supplies are currently predicted to run dry by 2100 if per capita consumption and inefficient agriculture practices are not controlled or curtailed.[32] In some areas (such as the Middle East, Central Asia, parts of Africa and South America) the control of access to water resources will become a source of power. Consequently, this essential strategic resource has significant potential to be a basis for conflict in the future.[33]

In addition to water, oil will remain a resource of great strategic interest, as demand continues to grow exponentially due to the increasing requirements of the developing world's economies. Regions such as the Middle East will remain vital due to their developed oil production and reserves. Other regions stand to increase in strategic importance (such as parts of Africa, the Caspian region, the South China Seas, numerous equatorial regions and, in the Western hemisphere, Canada and Venezuela).[34] Much like the case with water, disputes may arise over "issues of control and access … pos[ing] a growing source of tension between developed and developing nations, as well as within the developing world itself."[35] The increased demand for oil may be mitigated somewhat if a viable alternative fuel source is discovered. However, this would also have a strategic impact as current oil rich areas would be diminished in strategic importance and could potentially be marginalized economically. The consequences of this would be marked, as many of these regions and countries depend almost exclusively on the economic benefits of the oil industry. Some of these nations are already breeding grounds for extremist ideologies, and if their economies were to be significantly adversely affected, there is great risk of an increase in instability and violence.[36]

Demographic changes

There are several demographic trends that will affect global security in the coming decades.[37] In particular, the two trends of note and in stark contrast to one another are: the declining birth rates / ageing populations of the developed world and the apparent "youth bulge" of the developing world. Both of these trends are expected to place significant strain on their respective societies and economies.

31. Canada, DND, *Future Force*, 9.

32. United States, Central Intelligence Agency (CIA), "Long Term Demographic Trends: Reshaping the Geopolitical Landscape," (July 2001), 77, https://www.cia.gov/library/reports/general-reports-1/Demo_Trends_For_Web.pdf, (accessed July 9, 2012).

33. Canada, DND, *Future Force*, 9.

34. Johnston and Roi, *Future Security Environment 2025*, part V, para 54.

35. Gizewski, "The Future Security Environment," 4.

36. Johnston and Roi, *Future Security Environment 2025*, part V, para 55.

37. Ibid., para 50.

Demographically, the developed world is characterized by ageing and stagnant populations. "Specifically, current birth rates in much of the industrialized world are at, or below, the replacement rate of 2.1 children per woman."[38] As a result, the ratio of tax-paying workers to non-working pensioners is expected to be reduced by half by the year 2050.[39] This may cause significant economic strain, as the tax bases of developed nations decrease and the demand for social services increases. Industrialized nations may see a sharp decline in their economic prosperity and ability to contribute to global economic stability and security.

In the developing world, the demographic changes are of a different nature. In many developing regions, there is a significant growth in the youth cohort, persons of the ages 15–29.[40] Afghanistan, Pakistan, Colombia, Iraq, Gaza and Yemen (which are amongst some of the poorest and most politically unstable nations in the world) are forecasted to have the largest youth populations through 2020. Most of these countries will lack the economic, institutional and political means to effectively integrate the youth into society.[41] This will lead to high demands for employment and essential services in these nations that will not be able to be satisfied; the results of which will be widespread disenchantment. This has already been experienced in countries such as Algeria, Sri Lanka, Turkey and Iran, where youth cohorts have been the source of political unrest and civil strife.[42]

In both instances, the demographic shifts will potentially threaten global security through economic stressors and social turmoil.

Urbanization

Closely linked to the previous security trend, demographic changes, is the trend in the developing world towards continued population growth and subsequent rapid urbanization. It is projected that by 2015, for the first time in human history, that the majority of people in the world will reside in urban centres. By 2025 it is expected that two thirds of the developing world's population will be in cities.[43] "Historically, urbanization has correlated to increased economic growth."[44] This has not necessarily been the case in the developing world. For many developing nations the massive and rapid migration of people into existing urban centres has overwhelmed the available services and infrastructure.[45] This has often resulted in the inability to effectively manage the rapid influx to these cities.[46] The potential consequences of this trend in the developing world will be continued mass poverty, social unrest and discontent. These conditions may prove to be overpowering for already tenuous governments, leading to political collapse and, thereby, destabilizing national and regional security environments.

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38. Ibid.
39. US, CIA, "Long Term Demographic Trends," 23.
40. Gizewski, "The Future Security Environment," 3.
41. US, CIA, "Long Term Demographic Trends," 36.
42. Gizewski, "The Future Security Environment," 3.
43. US, CIA, "Long Term Demographic Trends," 55.
44. Johnston and Roi, *Future Security Environment 2025*, part V, para 61.
45. Canada, DND, *Future Force*, 7.
46. Johnston and Roi, *Future Security Environment 2025*, part V, para 61.

The threat of pandemic disease

Pandemic disease is generally viewed purely as a health issue; however, it also has the potential to affect the global security environment. Once again, it is the developing world that is most vulnerable to pandemic disease and its possible destabilizing effects. This vulnerability stems largely from the developing world's lack of adequate health care systems, due to insufficient funding and education.[47] The widespread poverty, lack of basic services and appropriate infrastructure due to overpopulation and rapid urbanization will only exacerbate the problem. The consequences are such that:

> [t]hese diseases are likely to aggravate and, in some cases, may even provoke economic decay, social fragmentation, and political destabilization in the hardest hit countries … whose health systems are ill-prepared to deal with them.[48]

Industrialized nations with well established health care systems may not suffer the same human toll of pandemic disease as the developing world; however, they are not invulnerable to possible destabilizing effects. In the developed world, infectious disease rates have fallen, but lifestyle induced diseases are on the rise. Combined with ageing populations, this often results in costly long-term care and rising fiscal strain on social systems.[49] "In short, disease will likely destabilize many regions of the world in the years ahead."[50]

Failed and failing states

In most instances, the previously noted trends do not become the direct cause of conflict, but in combination, they may lead to state failure and subsequent instability. In most instances of failed states, they lack the ability to provide economic stability, let alone the prospect of bettering the economy. In addition, these states are unable to provide for the basic welfare of their citizens. Given that economic development and infrastructure improvements normally take decades to achieve, it is unlikely, given the low starting point of many of the nations of the developing world, that the governments will be able to improve conditions without significant aid. The consequences of this often manifest themselves in discontent of the populaces, providing breeding grounds for extremism and violence.[51] There are many regions with states that already exhibit the kind of weakness and instability noted above (such as the Middle East, Latin America, Africa, South Asia, Eurasia and Central Asia).[52] The widespread existence of failed or failing states has resulted in this phenomenon becoming a central security concern, and arguably, it may be the primary source of current international instability.[53]

Growing significance of non-state actors

Though states remain the key international players, so-called non-state actors are increasingly having a significant influence on the global stage. These entities include non-governmental organizations (NGOs) that monitor the performance of governments and advocate policies as well as multinational corporations seeking a greater profit. More importantly from a security perspective, they also include criminal organizations (such as armed irregulars, insurgents, warlords and terrorist groups) who frequently resort to violence to achieve their aims and who are ever increasingly

47. Gizewski, "The Future Security Environment," 5.

48. US, CIA, "Long Term Demographic Trends," 69.

49. Ibid.

50. Johnston and Roi, *Future Security Environment 2025*, part V, para 76.

51. Ibid., para 78.

52. Gizewski, "The Future Security Environment," 5.

53. Johnston and Roi, *Future Security Environment 2025*, part V, para 79.

transnational in nature. Failed or failing states and globalization exasperate the problem as weak states often provide safe havens and operating bases for these dangerous groups.[54] "Defence against the threats posed by such groups will be increasingly complex and burdensome, especially in open societies such as the United States and Canada."[55] This is exemplified by both the global war on terrorism (and its operations in Iraq and Afghanistan) and the complexities of efforts to secure North America.

Implications

It is clear from the current trends that the world will remain a dangerous place and that conflict will continue to be a threat to international security. State-on-state conflict of a conventional and high-tempo nature may occur, but chances are that this type of scenario will not manifest itself. What are likely to be more prevalent will be clashes of an asymmetric nature, often initiated by non-state actors.[56] They will favour indirect engagements, thereby avoiding direct confrontations against regular forces that they are unlikely to win. They will focus their attacks on the vulnerabilities of the target states in an attempt to undermine those states' power, authority and, in some cases, their ideology and will to fight. What is most disturbing is the possibility that these asymmetric attacks may include the use of WMD such as crude nuclear, biological and chemical weapons.[57] To defend against such threats will be complicated and will require robust security apparatus.

The military implications of being able to effectively meet the challenges posed by the global security environment are complex, to say the least. Domestically, this demands constant vigilance in terms of surveillance and the monitoring of national borders and airspace to prevent and protect against attack. In addition, a more effective and increased capacity to support civil power in case of national emergencies is required. Abroad there will be the requirement to be able to conduct effective counterinsurgency operations as well as stabilization and reconstruction missions.[58] This implies the need for robust capabilities:

> … in the form of lighter, lethal, more precise, mobile and networked forces, [s]pecial [f]orces, enhanced capabilities to operate in complex terrain and the possession of tactical and strategic lift for rapid deployment into and within theatre.[59]

All of this will require a delicate balance of force structures, equipment and training that will be difficult for most governments and militaries to effectively accomplish with limited resources.

It is undoubtedly difficult, if not impossible, to predict the future accurately. Despite this fact, it is imperative that strategic planners look ahead in an attempt to anticipate future threats and challenges that may arise.[60] For Canada, its large territory and relatively small population pose a unique and challenging context where military force planning becomes critical.[61] In the coming section, we will see how SOF, including its aviation component, may provide an attractive solution to a significant part of this security challenge.

54. Canada, DND, *Future Force*, 11.
55. Ibid., 12.
56. Ibid., 17.
57. Gizewski, "The Future Security Environment," 7.
58. Ibid.
59. Ibid.
60. Johnston and Roi, *Future Security Environment 2025*, part V, paragraph 82.
61. Canada, DND, *Future Force*, 1.

3. SOF: Theory, roles and relevance

> How are we to counter the highly sophisticated theory that supposes it possible for a particularly ingenious method of inflicting minor damage on the enemy's forces to lead to major indirect destruction; or that claim to produce by means of limited but skilfully applied blows, such paralysis of the enemy's force and control of his will-power [sic] as to constitute a significant shortcut to victory?[62]
>
> Carl von Clausewitz

Clausewitz posed this question, seemingly rhetorically, in his exploration on the strategy of war. He ultimately concluded that the only appropriate strategy was the direct annihilation of the enemy's forces.[63] Even though he does not investigate this idea further in his writings, it does acknowledge that there could be alternative means, theories or strategies to pursue in the art of war. Clausewitz had unwittingly outlined the context within which modern special operations and SOF would ultimately be conceived and designed. Accordingly, in this section the existing theory and roles of SOF will be examined along with their continued relevancy to operations in light of the current and future security environments described in the preceding section.

The theory

To date, there is a notable absence of a solid foundation of well-developed and widely-accepted theory of special operations. This is especially evident when compared to more traditional elements such as air, land and sea. Not surprisingly therefore, there is a general lack of theoretical understanding of special operations.[64] However, it is vital to understand the existing thoughts behind them in order to grasp how the component parts, such as SOA, fit in the larger picture. To provide a basic comprehension, special operations and SOF will be defined. In addition, current theoretical ideas on SOF will be briefly explored.

Over the years there have been many opinions on, and subsequent definitions of, special operations. Part of the problem in defining special operations has been the question of what makes them unique among other forms of warfare. In the early cold war, for example, the popular view was that special operations were those carried out within and behind enemy lines.[65] This rather simplistic idea of special operations was expanded and developed over the years. For example, in his report to congress in 1987, John M. Collins defined special operations as:

> … embrac[ing] a wide range of unorthodox, comparatively low-cost, potentially high-payoff, often covert or clandestine methods that national, subnational, and theat[re] leaders may employ independently in "peacetime" or to support nuclear, biological, chemical, and/or conventional warfare of low-, mid-, and high-intensity.[66]

This definition, though admittedly very broad in nature, does encapsulate the main theme of more recent thoughts on special operations, where the basic concept is that strategic effect is achieved through the use of limited resources and unconventional means. For example, as former United

62. Carl von Clausewitz, *On War*, eds. Michael Howard and Peter Paret (Princeton: Princeton University Press, 1976), 228.

63. Ibid.

64. James D. Kiras, *Special Operations and Strategy: From World War II to the War on Terrorism* (New York: Routledge, 2006), 115.

65. Bernd Horn, "Special Operations Forces: Uncloaking an Enigma," in *Casting Light on the Shadows: Canadian Perspectives on Special Operations* (see note 2), 21.

66. John M. Collins, *Green Berets, Seals and Spetsnaz: U.S. and Soviet Special Military Operations* (Toronto: Pergamon Press, 1987), 2.

States Navy Sea, Air and Land (SEAL) commander, William H. McRaven suggests: "… what defines a special operation is the strategic environment in which it is conducted; that is, one in which a nation's freedom of action is extremely limited and economy of force essential."[67] Or in other words, it is one where conventional forces would be at a strategic or operational disadvantage. The theory being that effectively executed special operations are those that provide decision makers greater flexibility in implementing national policy.[68] US joint doctrine further differentiates special operations from:

> … conventional operations in degree of physical and political risk, operational techniques, mode of employment, independence from friendly support, and dependence on detailed operational intelligence and indigenous assets.[69]

It is this notion of special operations as suggested by McRaven and the difference from conventional operations, as defined in US doctrine, that will be used throughout the rest of the paper.

If the previously stated definition of special operations is accepted, how then are the forces who conduct them defined? Similar to special operations, there are many variations on the definition of SOF. For example, the North Atlantic Treaty Organization's (NATO's) definition is quite broad, as it states that SOF provide:

> … a flexible, versatile and unique capability, whether employed alone or complementing other forces or agencies, to attain military-strategic or operational objectives.[70]

The Canadian definition is more specific, as it states:

> Special [o]perations [f]orces are organizations containing specially selected personnel that are organized, equipped and trained to conduct high-risk, high-value special operations to achieve military, political, economic or informational objectives by using special and unique operational methodologies in hostile, denied or politically sensitive areas to achieve desired tactical, operational and/or strategic effects in times of peace, conflict or war.[71]

This definition incorporates the key characteristics of the previously accepted definition of special operations, and additionally, it reflects current thought on the characteristics of SOF.[72] Distilled to its simplest form, special operations, and the forces who conduct them, provide military options when the risk is high and the lower profile of smaller forces is required for stealth and/or political reasons in order to achieve operational or strategic effects.

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67. William H. McRaven, "Special Operations: The Perfect Grand Strategy?" in *Force of Choice: Perspectives on Special Operations*, eds. Bernd Horn, J. Paul de B. Taillon, and David Last (Kingston: McGill-Queen's University Press, 2004), 64.

68. Ibid. This definition is also in line with the definition of special operations in the US Joint Publication (JP) 3-05, *Doctrine for Joint Special Operations*, where special operations are defined as: "…operations conducted in hostile, denied, or politically sensitive environments to achieve military, diplomatic, informational, and/or economic objectives employing military capabilities for which there is no broad conventional force requirement."

69. United States, Department of Defense, JP 3-05, *Doctrine for Joint Special Operations* (Washington: US Government Printing Office, 2003), 1-1.

70. North Atlantic Treaty Organization, AJP-1(A), *Combined SOF Concept 3200* (Brussels, Belgium: North Atlantic Treaty Organization, March 1997).

71. Canada, DND, *Canadian Special Forces Command*, 7.

72. Similar definitions appear in contemporary writing on SOF as seen in: Susan Marquis, *Unconventional Warfare: Rebuilding U.S. Special Operations Forces* (Washington, DC: The Brookings Institute, 1997); Alastair Finlan, *Special Forces, Strategy and the War on Terror: Warfare by Other Means* (New York: Routledge, 2008); and US, Department of Defense, JP 3-05, *Doctrine for Joint Special Operations.*

Despite the many varied definitions of special operations and SOF over the years, there are some tenets that have emerged. These were originally articulated by John Collins in his report to the US Senate in 1987 on US and Soviet special operations, and they have since become internationally recognized as SOF truths.[73] They are:

a. Humans are more important than hardware.

b. Quality is better than quantity.

c. SOF cannot be mass produced.

d. Competent SOF cannot be created after emergencies occur.[74]

These widely acknowledged tenets, along with the previously described concepts of special operations and SOF, will be used to frame analysis in the coming sections in order to put SOA into perspective.

From a purely theoretical viewpoint, there is a recurring theme that surfaces in the examination of SOF. It is the fact that SOF are generally expected to succeed against numerically superior forces. As Major General Hindmarsh, the former commander of the Australian Special Operations Command, suggested:

> Economy of force is what I would refer to as the "hydraulics" of unconventional operations. That is, for relatively minor tactical effort or expenditure, the operational, strategic or indeed political effect or dividends can be substantial.[75]

How is SOF, then, able to achieve this? If one were to follow the conventional wisdom of Clausewitz (where he states that superiority in numbers should be brought to bear at the decisive point to ensure victory) it would seem that SOF would be at a disadvantage in most instances.[76] In an attempt to explain this phenomenon, McRaven suggests the theory of relative superiority.[77] He proposes that relative superiority exists when a smaller attacking force is able to create the conditions that give them a decisive advantage over a larger, and normally defending, force. He further argues that through minimizing what are commonly referred to as the frictions of war, special operations forces are able to achieve relative superiority over an enemy. The key to managing the frictions of war are what McRaven calls the six principles of special operations: simplicity, security, repetition, surprise, speed and purpose.[78] These principles work "because they seek to reduce warfare to its simplest level and thereby limit the negative effects of chance, uncertainty, and the enemy's will."[79] In the conduct of special operations, achieving the condition of relative superiority does not guarantee success; however, it is suggested that it is necessary for success.[80] This theory of relative superiority goes a long way in describing how SOF is able to defeat numerically superior forces. However, it is limited to a tactical and kinetic focus. How, then, do special operations forces fit within the realm of strategic theory?

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73. US, Department of Defense, JP 3-05, *Doctrine for Joint Special Operations*, 7.

74. Collins, *Green Berets, Seals and Spetsnaz*, xiii. The first four tenets have generally been recognized internationally. Collins had penned a fifth that tends to be omitted. It stated: "Most special operations require non-SOF assistance."

75. Major General Mike Hindmarsh, "The Philosophy of Special Operations," *Australian Army Journal* III, no. 3 (Summer 2006): 20, http://www.army.gov.au/Our-future/DARA/Our-publications/Australian-Army-Journal/Past-issues (accessed July 9, 2012).

76. von Clausewitz, *On War*, 195.

77. For further reading and information on the theory of relative superiority, see McRaven, *Spec Ops*.

78. McRaven, *Spec Ops*, 1, 4 and 9.

79. Ibid., 9.

80. Ibid., 1.

The existing strategic thoughts on SOF, while limited in scope and quantity, are fairly consistent in their approach. The focus is generally on the idea found widely in contemporary strategic doctrine of targeting the centre(s) of gravity of the enemy.[81] The centre of gravity, as defined by Canadian doctrine, is "… that characteristic, capability, or locality from which a military force, nation or alliance derives its freedom of action, physical strength, or will to fight."[82] This concept is not necessarily a new one, as Sun Tzu expounded that one who was skilled in the art of war would be able to defeat the enemy without engaging in battle and lengthy operations.[83] This suggests that he felt that if an enemy's critical vulnerabilities were targeted in an effective manner, one could possibly achieve victory through innovation and economy of effort.

An important development in relatively recent history has been the ability to target centres of gravity or key nodes with a much higher probability of success. As Alastair Finlan argues, modern technology (such as advanced battlefield helicopters for reliable tactical mobility), along with state of the art navigation and communications systems, allow for unprecedented accuracy and coordination of special forces in the conduct of these types of focused missions.[84] In essence, he suggests that SOF, enabled by modern technology, provide strategic military planners with the ability to target enemy centres of gravity, while reducing the requirement for force-on-force attrition style warfare. Of course, one should not be left with the idea that SOF is, therefore, the magic military panacea to ensure defeat of an enemy. Strategically, special operations should be designed as part of a wider campaign, with the aim of undermining an adversary's resources and moral resolve through a series of comparatively smaller activities.[85] As James Kiras suggests:

> [s]pecial operations combine the effects of striking or threatening what an adversary fears or values the most, or using force in unexpected ways, by shaping an adversary's behaviour and perceptions in ways that make one's style of warfare more effective.[86]

Therefore, from a theoretical perspective, SOF is viewed as a strategic tool to be employed in attacking an adversary's weaknesses in order to influence and complement the overall campaign.

Roles

Even though there are differing definitions of special operations and SOF as well as limited supporting theory, the roles assigned to special operations forces are quite consistent, especially within Western militaries. This consistency is not surprising from the point of view that many nations place compatibility and interoperability with US forces as a priority. For example, the core tasks for Canadian Special Operations Forces Command are listed as: counterterrorism (CT) operations and high value tasks (HVT). Counterterrorism operations are described as both offensive and defensive actions conducted domestically and internationally to prevent and respond to terrorism. High value tasks refer to other tasks spanning the spectrum of conflict that may be assigned by the Government of Canada, which include but are not limited to: counter-proliferation (CP); special reconnaissance

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81. This concept is widespread especially within Western doctrine. For further elaboration see: US Army, Headquarters Department of the Army, Field Manual 3-0, *Operations* (Washington, DC: Department of the Army, 2008); United Kingdom, Ministry of Defence, Joint Warfare Publication (JWP) 0-01, *British Defence Doctrine*, 2nd ed. (Shrivenham, UK: The Joint Doctrine and Concepts Centre, 2001); and Canada, Department of National Defence, Canadian Forces Joint Publication 5.0 (CFJP 5.0), *The Canadian Forces Operational Planning Process (OPP)*, change 2, (Ottawa: Department of National Defence, April 2008).

82. Canada, DND, CFJP 5.0, *Canadian Forces OPP*, GL-1.

83. Sun Tzu, *The Art of War*, trans. Samuel B. Griffith (New York: Oxford University Press, 1963), 79.

84. Finlan, *Special Forces, Strategy*, 19.

85. Kiras, *Special Operations and Strategy*, 115.

86. Ibid.

(SR); direct action (DA); and defence, diplomacy and military assistance (DDMA).[87] These tasks essentially mirror those listed for US SOF in their doctrine for joint special operations, with the exception that the US also includes civil affairs, psychological and information operations.[88] These roles are important to keep in mind, as the capabilities of SOF should be centred on the ability to effectively conduct the types of tasks allocated or assigned.

Relevance

The true value of SOF and their roles began to materialize in the post cold war period, as the global security environment shifted when failed and failing states became the most prominent threat to international stability. Within this environment, their scalability, small organizational footprint and unique capabilities afforded governments the flexibility to take military action where it was normally too politically sensitive to deploy large scale conventional forces.[89] Following the unimaginable events of 9/11, there has been a further increased reliance on SOF in order to achieve military effect. Again, the international security environment had shifted dramatically to include non-state actors in the form of terrorist groups with global membership and reach. In this environment, SOF has become a "force of choice."[90] Special operations in Afghanistan and Iraq post 9/11 have demonstrated this, where SOF have shown their value in countering asymmetric threats to the security of the international community.

The response of the United States to the attacks of 9/11 was swift and sure. By October 19, 2001, US SOF was conducting raids in southern Afghanistan and had deployed to the north to train, equip and advise the Northern Alliance and other indigenous forces. The Taliban now faced the power of the United States Air Force (USAF) being directed by SOF combat controllers on the ground. On 7 December, the key Taliban stronghold of Kandahar was taken. At the time, there were still less than 300 US SOF personnel on the ground in Afghanistan, making their contribution to the successful outcome of operations all out of proportion to their relatively few numbers.[91] The overall results were dramatic.[92] Afghan indigenous forces, now supported by US SOF and the USAF, were able to topple the Taliban regime in a matter of weeks, a feat they had been attempting to achieve for the previous six years. US SOF, supported by the USAF, succeeded in providing relevant and effective economy of force for the US government and military in the initial Afghan campaign. As a result, this period of the war in Afghanistan has often been referred to as a special operations war.[93] This effort, however, was just a foreshadowing of what would be expected of SOF in 2003 during the war in Iraq.

The war in Iraq, in contrast to the early stages of Afghanistan, was largely a conventional campaign. However, due to the lessons learned from Afghanistan, SOF was accorded a much greater role than it had been 10 years earlier. This role, much like in Afghanistan, was a transformational

87. Canada, DND, *Canadian Special Forces Command*, 9. For further elaboration on each of the core tasks see the reference.

88. US, Department of Defense, JP 3-05, *Doctrine for Joint Special Operations*, II-5.

89. Bernd Horn, "'Avenging Angels': The Ascent of SOF as the Force of Choice in the New Security Environment," in *Casting Light on the Shadows* (see note 2), 157–180, 158.

90. Ibid.

91. Jamie W. Hammond, "Special Operations Forces: Relevant, Ready, and Precise," in *Casting Light on the Shadows* (see note 2), 209–236, 217.

92. In fact, the results of the initial Afghan operations to oust the Taliban were so successful that the "Afghan model" is now a subject of study, in order to determine its future applicability to military operations. For more on the Afghan model, see: Stephen D. Biddle, *Afghanistan and the Future of Warfare: Implications for Army and Defense Policy* (Carlisle Barracks, PA: US Army War College, Strategic Studies Institute, 2002); and Stephen D. Biddle, "Allies, Airpower, and Modern Warfare: The Afghan Model in Afghanistan and Iraq," *International Security* 30, no. 3 (Winter 2005/06).

93. Hammond, "Special Operations Forces," 218.

one.[94] During Operation IRAQI FREEDOM, US and coalition SOF were given the responsibility of securing the vast western Iraqi desert, in order to protect the left flank of conventional coalition forces advancing from the south. In addition, they were to deny missile launch sites to the Iraqis and search for WMDs. In northern Iraq, SOF linked up with Kurdish peshmerga militia and was successful in fixing Iraqi conventional divisions in a very effective economy of force action. Their actions in the north were so successful that they were able to secure the northern cities of Kirkuk and Mosul along with the northern oil fields.[95] SOF operations to the south were no less important, as they seized offshore oil platforms and conducted personnel recovery operations such as the rescue of Private Jessica Lynch.[96] Much like in Afghanistan, SOF was able to achieve effective results far in excess of what their limited numbers would have suggested from a conventional viewpoint.

In the previous examples, SOF played key and critical roles in the initial stages of the campaigns. However, their contributions did not end there, as both of these operations are still ongoing today, and SOF are still making vital contributions. Their roles have transitioned somewhat, and they are now providing critical capabilities in combating insurgents and hunting down terrorists.[97] Afghanistan and Iraq have demonstrated the value of SOF to recent and current military operations, through their ability to provide governments and their military significant economy of force options in the contemporary operating environment.

Currently, the future would seem to hold much of the same for SOF. As noted in Section 2, the expectation is that the global security environment will largely be impacted by asymmetric threats. These will likely be generated, for the most part, by non-state actors or insurgencies within failed or failing states and have international implications, due to the ever increasing effects of globalization. As SOF operations in both Afghanistan and Iraq have demonstrated:

> [u]nconventional warfare / SOF activities have been elevated from being a satellite activity within the scope of conventional organization missions, to a primary means of warfare for accomplishing national security objectives.[98]

In other words, SOF will continue to provide nations with vital military capabilities into the future.

The post 9/11 operating environment has seen a marked strategic shift in the employment of SOF by the US and its allies. The dramatic results that special operations have achieved with significant economies of force in both Afghanistan and Iraq have certainly demonstrated their worth and relevance to current and future military operations—whether it be in support, in concert with, or supported by conventional forces. They have secured their position alongside traditional army, air and naval forces.

Summary

In comparison to conventional land, sea and air forces, there exists an absence of doctrine and theory for SOF. McRaven's tactical theory of relative superiority explains how SOF is able to be successful against normally numerically superior foes. Strategically, there is also very little SOF theory other than they are considered to be an effective capability to use in targeting what contemporary conventional doctrine defines as an enemy's centre(s) of gravity or critical vulnerabilities. This lack

94. Ibid., 219.

95. Stephen D. Biddle, "Special Forces and the Future of Warfare," *Military Technology* 30, no. 3 (2006): 12.

96. Hammond, "Special Operations Forces," 220.

97. Biddle, "Special Forces and the Future of Warfare," 12.

98. Marvin Leibstone, "Special Operations Forces & 21st Century Warfare," *Military Technology* (Special Issue 2009): 30.

of substantial strategic theory has led Finlan to suggest that the true potential of SOF has not yet been fully explored or realized.[99] There certainly have been significant shifts in the ideas and actual employment of SOF in recent campaigns in Afghanistan and Iraq, but this is likely just the beginning of special operations coming into their own. Canada has recognized the implications and lessons for SOF from the post-9/11 military campaigns, as is evident by the creation of the Canadian Special Operations Forces Command along with its component parts in 2006. What remains now is for Canada to consider SOF's relative strategic and operational priority within the Canadian Forces force structure.[100] This also includes the place of special operations aviation. In order to provide a benchmark for this, the next section will explore the strategic importance of a formed ready and skilled SOA capability.

4. Special operations aviation strategic relevance: Case studies

> Competent SOF cannot be created [rapidly] after emergencies occur.[101]
>
> John Collins

The real strategic value and relevance of SOF, both in theory and practice, has begun to emerge in the past nine years. Recent operations, as a result of the shifting international security environment, have demonstrated this. It follows then that integral capabilities such as SOA are just as critical with respect to enabling SOF to achieve strategic effect. The roles of aviation (aerial firepower, reconnaissance and mobility)[102] are well understood, valued and, indeed, often required for special operations to succeed in the contemporary operating environment. When effectively integrated into special operations, SOA provides increased reach, mobility and fire support for SOF, who is generally small and light organizations. In this section two historical case studies will be used to demonstrate the strategic requirement for robust SOA that is able to support special operations, whenever and wherever required. The first will be an example of what occurs when Collins' above fourth tenet is not heeded and will examine the hard lessons learned by the US from the ill-fated hostage rescue mission in the Iranian desert—Operation EAGLE CLAW. The second will focus on the successful British hostage rescue mission conducted in Sierra Leone—Operation BARRAS. From these examinations, the strategic importance of formed, ready and effective special operations aviation will become evident.

Operation EAGLE CLAW

In November 1979, the American embassy in Tehran was seized, along with 63 US hostages, by armed Iranian students who were followers of the Shiite Muslim leader the Ayatollah Khomeini. The Ayatollah and his followers held deep resentment for the United States as a result of its long time association and support to the ousted Shah. The students had seized the US embassy in an effort to force the US to extradite the exiled Shah back to Iran, as he had recently been granted permission by President Carter to enter the US for cancer treatment. Many questions immediately arose within

99. Finlan, *Special Forces, Strategy*, 13.

100. Hammond, "Special Operations Forces," 221.

101. John M. Collins, "U.S. Special Operations – Personal Opinions" (lecture, 1st Special Warfare Training Group, Camp Mackall, NC, 11 December 2008), http://smallwarsjournal.com/mag/docs-temp/148-collins.pdf (accessed July 9, 2012). In this presentation John Collins indicated that the SOF truths he penned in 1987 were still very relevant, but if he could start from scratch, he would add the word "rapidly" to the fourth bullet.

102. Canada, Department of National Defence, B-GA-441-001/FP-001, *Tactical Level Aviation Doctrine* (Ottawa: DND, 2000), 1-1.

the US government, as to whether the hostages could be rescued or if the US even had the means to do it? Nevertheless, National Security Advisor Zbigniew Brzezhinski ordered the Pentagon to prepare contingency plans for a rescue mission and retaliatory strikes if the hostages were harmed.[103] Consequently, a joint task force was appointed and began to plan and prepare for a rescue mission.

The problem facing the task force was a daunting one to say the least. How was the military going to rescue and extract 63 US hostages from the US embassy in the middle of a major urban centre, hundreds of miles deep inside "hostile" territory? Fortunately, the US military Joint Chiefs of Staff had authorized the formation of an elite counterterrorist unit two years previously, commonly known as Delta Force. This unit had just been declared operational around the same time that the embassy was seized.[104] Delta force would, subsequently, be tasked with the assault on the embassy. However, the rest of the task force, which would be responsible for the ingress and egress of the Delta operators, needed to be assembled and would eventually be comprised of Army, Air Force, Navy and Marine assets, all of whom had to be brought together and trained to conduct the rescue. Joint training, therefore, commenced almost immediately and carried through to March 1980.

Despite the hopes of the Carter administration for a diplomatic solution to the crisis, it became apparent after six months that negotiations had failed. Consequently, the president ordered the execution of the rescue plan now called Operation EAGLE CLAW on April 24, 1980.[105] A detailed examination of the operational plan and subsequent events that took place is beyond the scope of this paper and has been described and analysed in many subsequent books and articles.[106] What follows, therefore, is a simplified account of the overall plan and the events that occurred in the early morning hours of April 25.

The operation that had been developed was a complex joint effort. It called for eight Navy RH-53D helicopters to launch from United States Ship (USS) *Nimitz*, an aircraft carrier in the Arabian Sea, and rendezvous with the assault force and C130 Hercules tanker aircraft that had landed at an improvised landing strip in the Iranian desert (code named Desert One). Here the helicopters would refuel from the C130s, load the assault force and proceed to another forward site inside Iran approximately 50 miles (80.5 kilometres) southeast of Tehran. The following night, the Delta operators would make their way to the embassy to secure the hostages. The helicopters would then extract the assault force and hostages from the embassy under the cover of AC-130 gunships and proceed to an abandoned Iranian airstrip which was to be seized and secured by a company of Army Rangers. The helicopters would then be destroyed, and the rescue force and hostages would be extracted by two C-141 Starlifters to US bases in Europe.[107]

On the night of April 24, the eight RH-53D helicopters lifted off the USS *Nimitz* as planned. However, just a few hours into the mission two of the helicopters were forced to abort due to mechanical failures. To make matters worse, the remaining six helicopters were delayed in arriving at Desert One as a result of an unexpected dust storm, known as a haboob. After arriving at the improvised refuelling site, another of the helicopters suffered a hydraulic malfunction and was deemed unable to continue with the mission. This meant that the operation was now down to five helicopters, which was one less than the minimum six that had been determined essential to

103. Otto Kreisher, "Desert One Disaster," *MHQ: The Quarterly Journal of Military History* 13, no. 1 (Autumn 2000): 44.

104. Ibid.

105. Fred J. Pushies, *Night Stalkers: 160th Special Operations Aviation Regiment (Airborne)* (St. Paul: Zenith Press, 2005), 10.

106. For a more detailed account of Operation EAGLE CLAW as well as the planning and training leading up to it, read: Colonel James H. Kyle, USAF (Retired), *The Guts to Try* (New York: Orion Books, 1990). Colonel Kyle was the air force commander of the mission and the on-scene commander at Desert One.

107. Kreisher, "Desert One Disaster," 48.

complete the task. Consequently, the decision to abort the rescue attempt was made by the on-scene commander. It was then that tragedy struck. One of the helicopters was engulfed in a dust cloud while attempting to reposition and taxied into the C130 it had been refuelling from. The subsequent explosion and fireball killed eight personnel and injured many others. The site was quickly evacuated thereafter, leaving behind five undamaged helicopters, the burning wreckage and the unrecovered bodies of the eight dead. The ambitious Operation EAGLE CLAW had ended in failure in the middle of the Iraqi desert.

The tragic events at Desert One had tarnished the honour of the United States and the credibility of US special operations.[108] This prompted the establishment of a government review committee known as the Holloway Commission to examine the circumstances of the ill-fated mission and, more importantly, problems within US special operations.[109]

While not necessarily directly attributable to the failure of the mission, there are some notable and, in hindsight, obvious weaknesses that are revealed in the examination of the helicopters and the selection of crews. The Navy RH-53D helicopters had been chosen for two main reasons. The first was that they possessed the range and payload requirements to conduct the mission. The second was for operational security (OPSEC), which was considered an extremely high priority for this operation. Since the helicopters would be departing from an aircraft carrier, it was felt that the presence of the eight Navy helicopters would not attract any unwanted attention. Additionally, they could easily be stored below decks due to their ability to fold the rotor blades and tail sections, unlike Air Force or Army airframes.[110] Consequently, Navy crews familiar with these particular aircraft were initially selected to fly the mission.

These crews, however, were not suitably qualified for the tasks assigned and expected of them. The Navy aircrew of the RH-53Ds were trained for daytime mine sweeping missions of relatively short duration over water. As a result, they had no experience in night, low-level, overland tactics, nor did they have any crews with special operations experience.[111] This inexperience was revealed very early on, when the Navy pilots had great difficulty in adapting to the demanding, low-level, night environment using night vision goggles (NVG), with which they had no previous training. Not only did this situation jeopardize the safety of the mission, it was undermining the confidence of other members of the team. As one Delta operator was heard to remark during an early desert training mission after a harrowing flight on one of the helicopters: "I'll be damned if I'm riding back on this thing—I'll walk home first!"[112] The planners quickly realized that the Navy pilots were not progressing fast enough and decided to replace the majority of them with Marine CH-53 pilots who were experienced in low-level, overland tactics. Despite the fact that Marine pilots also lacked experience in the night environment, the training for the rescue mission began to progress more rapidly with the new crews.[113] Yet in hindsight, this decision was also less than ideal.

In examining the helicopter crewing decisions, the *Holloway Report* revealed that during the period leading up to the mission there were 96 H-53 qualified USAF pilots, who were current in long-range mission profiles, including air-to-air refuelling. In addition, there were 86 former H-53 qualified pilots, most of whom had recent special operations or rescue experience which was more

108. Pushies, *Night Stalkers*, 12.

109. The results of the review committee's findings were subsequently published in the now famous *Holloway Report*. This report made several recommendations to improve US special operations capabilities.

110. Kyle, *The Guts to Try*, 47.

111. Ibid., 81.

112. Ibid., 94.

113. United States, Department of Defense, *The Holloway Report* (Washington, DC: Department of Defense, 1980), 35.

ideally suited for the mission demands of Operation EAGLE CLAW.[114] This raises the question as to why these pilots were not enlisted to conduct the mission. Part of the answer lies in the desire of the planners to maintain operational security, since recalling pilots from many different assignments would have raised unwanted questions. There was a key flaw in the planners' assumptions though. They believed that the pilots who were qualified on the aircraft variant chosen for the mission would be able to adapt quickly and effectively to a new and highly complex mission set. However, previous experience from developing air force special operations capabilities for Vietnam had clearly demonstrated that it was far more difficult for pilots to learn new complex mission skills than to transition to another airframe of similar design and performance characteristics.[115] This ultimately underscored the import of having a formed helicopter unit trained and proficient in special operations aviation skill sets. This point was highlighted by the final evaluation on the helicopter crew compositions by the Holloway Commission.[116]

The purpose of examining this case study was not to rehash arguments as to whom or what may be to blame for Operation EAGLE CLAW's ultimate failure. The idea that a special-forces operation could be mounted to rescue the hostages was legitimate. For example, the *Holloway Report* did conclude that:

> [t]he concept of a small clandestine operation was valid and consistent with national policy and objectives. It offered the best chance of getting the hostages out alive and the least danger of starting a war with Iran.[117]

In other words, the United States could have achieved its strategic goals through a focussed special operation while achieving suitable economy of force. At the time of the crisis, the US military did have at its disposal the newly formed and highly capable counterterrorist unit Delta Force. However, they had no means to achieve a covert insertion to the American embassy. As Charles Cogan noted:

> [t]he United States had a glaring lack of a centralized command that could conduct a turn-key [sic] operation, having under its control all the necessary support elements—air transport, intelligence, logistics, and combat air support.[118]

This highlights the strategic military impotence the US experienced in being able to deal rapidly and appropriately with the crisis. This impotence was in large part due to the lack of a developed SOA capability. Additionally, the pitfalls associated with disregarding the fourth SOF tenet became evident from the difficulties encountered in attempting to develop a suitable aviation force package after the crisis had occurred.

Operation BARRAS[119]

On August 25, 2000, while on patrol in Sierra Leone near Freetown, 11 British soldiers of the Royal Irish Regiment and their liaison officer from the Sierra Leone Army were captured and detained by members of the rebel group the West Side Boys. United Kingdom (UK) forces had been

114. Ibid.

115. Ibid.

116. Ibid., 36.

117. Ibid., v.

118. Charles G. Cogan, "Desert One and its Disorders," *The Journal of Military History* 67, no. 1 (January 2003): 204.

119. For a more detailed account of Operation BARRAS read: William Fowler, *Operation Barras: The SAS Rescue Mission, Sierra Leone 2000* (London: Weidenfeld & Nicolson, 2004).

in Sierra Leone since early May, when rebel forces had seriously threatened the city of Freetown and the government. They had initially been deployed to secure the evacuation of British citizens but had since been assisting in stabilizing the situation after UN and government forces had succeeded in beating back the rebel factions. The West Side Boys were a smaller, but troublesome, faction. They were more of a criminal gang than an organized rebel force, as they were commonly referred to as a "self-provisioning" group.[120] They had (leading up to the detainment of the British soldiers) been conducting roadblocks and essentially robbing those who they stopped. The British patrol had been given information at a meeting with UN forces that the West Side Boys had begun to disarm and had gone to Magbeni to investigate this further. The West Side Boys' leader Foday Kallay (upset that the British soldiers had not asked permission to enter "his" territory) ordered his troops to disarm them and detain them. After being taken hostage, the captives were immediately moved from Rokel Creek to the rebel headquarters at Gberi Bana.

The UK government's reaction was swift, as the SAS was alerted and began planning preparations within 12 hours of the hostages being detained.[121] Fortunately for the planners, intelligence on the situation had subsequently been forthcoming rather quickly. Within two days of the detention, the Royal Irish Commanding Officer (CO) was meeting with Kallay to negotiate the possible release of the hostages. On 29 August, Kallay allowed one of the hostages to accompany him to one of the negotiation meetings as a show of good faith. The soldier managed to pass a detailed map of where they were being held along with rebel dispositions and weapons emplacements hidden inside of a ball point pen to his CO. In addition, two days later, five of the captured soldiers were released in exchange for a satellite phone and medical supplies. Unbeknownst to the rebels, the British were now able to track precisely where they were through the satellite phone. As well, the rescue planners had now garnered a significant amount of valuable information on the West Side Boys' numbers and capabilities in Gberi Bana and south across the river in Magbeni.

It had been determined early on in planning that the SAS team would not be sufficient to conduct the assault alone. They would be the assault force on Gberi Bana to rescue and secure the hostages. However, there was a significant concentration of rebels and heavy weaponry 1000 yards (914 metres) to the south across the creek at Magbeni and within effective engagement range of where the hostages were being held. Therefore, a company group from the 1st Battalion Parachute Regiment was brought in and assigned the task of finding and fixing the rebels in Magbeni in order to cover the SAS rescue assault at Gberi Bana.

Initially, three options for the assault had been developed: an overland assault, an air assault and a favoured river approach. By 5 September, the SAS had two observation posts established, one outside of Gberi Bana and the other outside of Magbeni. These two teams had used the river to approach the target areas and had subsequently determined that this would not be feasible for the main assault, as the river was too shallow. In addition, the overland option would also have to be abandoned due to the density of the jungle. Consequently, the only remaining viable option was an air assault.

The rescue plan was now taking shape. Three Chinook helicopters flown by Royal Air Force crews from 7 Squadron (Sqn), which were dedicated to special forces operations, would provide the airlift.[122] Two Army Air Corps Lynx attack helicopters would support the assault and concentrate

120. Ibid., 109.

121. Dr. Christine Coker, "Planning in Hostage Rescue Missions, US Operation Eagle Claw and UK Operation Barras," *Military Technology* 30, no. 9 (2006): 67.

122. Ibid.

initially on neutralizing the heavy weapons emplacements in order to protect the Chinooks. Two of the Chinooks would insert the SAS hostage rescue team into Gberi Bana, where they would secure the hostages and then move them approximately 200 metres to a soccer field to be extracted by one of the insert helicopters. The Para company would be simultaneously inserted by the third Chinook into Magbeni to fix the rebel fighters and prevent them from interfering with the rescue operation across the river. In order to maintain the advantage of surprise and to provide the best chance of securing the hostages safely, the SAS teams would have to be inserted by "fast rope" in close proximity to where the hostages were being held. This technique of sliding down a rope from the rear of the helicopter allows the assault troops to be very quickly inserted from the hover into an area that the helicopter cannot physically land.

By 9 September, 16 days after the hostages had been detained, negotiations had reached an impasse and the rescue mission was given the go-ahead. Just prior to first light the following morning the assault was launched at 0615 hours. Less than a minute after being inserted, the hostages had been secured by the SAS, and by 0700 hours the hostages and wounded from the assault were aboard the extraction Chinook headed for the safety and medical care on board the Royal Fleet Auxiliary ship SIR PERCIVAL. By 1045 hours, the last of the assault group had left the rebel areas and the mission was a complete success—with all of the hostages safely rescued, a small number of Paras wounded, and the loss of one SAS trooper.

The significance of this particular case study is that it highlights the strategic flexibility that the British government and military possessed to respond effectively and rapidly to this crisis. As it was eventually discovered, the only viable tactical option was for an air assault on the rebel strongholds. The fact that the UK already possessed a formed special operations aviation unit in 7 Sqn Royal Air Force (RAF) provided them with the capacity to confidently proceed with a direct action plan. The question in this case may be asked: Why would conventional Chinook aircrew not have been capable of effectively supporting the mission? The answer lies in the proficiency of the aircrew in special operations tactics: both aviation tactics and those of the supported forces such as the SAS. In this situation, it had been determined that the advantage of surprise would be fleeting but critical to safely securing the hostages in the opening moments of the assault. As Dr. Christine Coker notes: the SAS train and work with the special operations aviation crews regularly.[123] Therefore, the Chinook crews were already familiar with and proficient in the fast rope technique. This allowed the SAS and the aircrew to focus on preparing for the specific circumstances of the tactical situation and not the actual insertion technique. Essentially, this meant that all the key players were mission ready from the outset, less being briefed on the plan and rehearsing it. This meant that a minimum amount of preparation time was required prior to being in a position to carry out the mission. In the end, having a formed SOA capability proved fundamental in executing the rescue mission with confidence and in a timely manner.

Summary

The two case studies demonstrated from opposite aspects how special operations aviation can be a critical component in enabling special operations. In the case of Operation EAGLE CLAW, the lack of mission-ready helicopters, and more specifically aircrew, demonstrated the significant difficulties of developing a special operations capability for a complex mission skill set after it is required. This lesson was learned rather quickly by the US military. Following the failure at Desert One, a second rescue plan was developed. However, this time planners decided to form the aviation task force (TF) from US army aviation assets of the 101st Airborne Division (Air Assault).

123. Ibid., 69.

This task force, known as TF158, was comprised of OH-6 scout helicopters, the recently fielded UH-60 Blackhawk medium assault helicopter, and the heavy lift CH-47C Chinook. The hostages were finally released in January 1981, and the second rescue operation was subsequently cancelled. However, TF158 was not disbanded and would retain the specialist aviation skills that they had developed. The unit would eventually become what is now known as the 160th Special Operations Aviation Regiment (SOAR). In contrast, Operation BARRAS exemplified how quickly effective special operations can be mounted when ready, trained and integrated units already exist. The RAF SOA aircrew not only made the UK rescue mission possible but also facilitated a rapid response within 17 days of the onset of the crisis. In both instances, special operations aviation played a critical role in the respective national government's ability to create strategic effect through the use of special operations.

5. Canadian special operations aviation: To be or not to be?

Introduction

Earlier sections identified the strategic role and importance of SOF in the current and future global security environment. In addition, the case studies of the last section demonstrated that SOA can often be an essential enabler of special operations. The creation of Canadian Special Operations Forces Command in 2006, along with its component parts to include 427 SOA Sqn, acknowledged that Canada had recognized the strategic importance of SOF and SOA in the contemporary operating environment. However, where are we now with respect to the development of a robust SOA competency? Canadian SOA is not a completely new capability, as it has existed in a limited fashion in a domestic counterterrorism role since the early 1990s. But, despite the recognition four years ago for the need of a more robust SOA capability, the ability of CANSOFCOM to generate strategic SOA capacity remains insufficient. Therefore, in this section the current status of Canadian SOA will be examined, along with what manner of capabilities it should have. This will be followed by an exploration of possible options available to meet these requirements for a sustainable and effective Canadian SOA capability.

Current status

Since 2006, the overall capacity of 427 SOA Sqn to be able to provide critical support to Canadian special operations has been, and remains, somewhat limited. While it is readily acknowledged by the author, and demonstrated by the example of Operation EAGLE CLAW in the previous section that a mature and sustainable SOA capability cannot be created "overnight," there are some inherent limitations which continue to hinder the ability of the squadron to develop and generate an appropriate level of SOA effect. This is in large part due to the unit having been simply changed from a conventional tactical helicopter squadron to special operations with seemingly little initial consideration given, other than a shift in command relationship.[124] Consequently, with the exception of the previously developed small domestic counterterrorism capability, the unit's organization, training and equipment reflected contemporary conventional requirements of the time. What follows is a brief examination of the current state of 427 SOA Sqn's organization, training, equipment and personnel management and how they are affecting continued growth and development of SOA capability.

124. In accordance with the transfer of command authority (TOCA), the Air Force transferred operational command of 427 SOA Sqn to CANSOFCOM in February, 2006.

The current establishment of 427 SOA Sqn has not incurred any significant changes since 1996, when a third operational flight (responsible for support to JTF 2 in the domestic counterterrorism role) was added. Otherwise, the establishment represents a legacy cold war utility helicopter squadron, doctrinally designed to be a conventional Land Force divisional asset.[125] This organization reflected two operational flights established to operate eight helicopters each as well as a headquarters, logistical support and aviation maintenance flights.[126] The manning and equipment of the unit was designed to be able to deploy the organization, as a whole, into the battlespace, where it would be able to operate, move and sustain itself while having the capacity to forward deploy its two operational flights for short durations. While this organization was effective for the types of operations it was conceived for, it has proven limiting for support to special operations.

One of the significant limitations or stressors that the current establishment has placed on the ability to generate SOA has been a critical shortage of support trades. While this problem is not unique to special operations or 427 SOA Sqn specifically, it is magnified due to the nature of current operations. The unit no longer deploys as a whole, and typically, it is common to have several small detachments deployed simultaneously. Each of these detachments requires support while they are deployed to include functions such as intelligence, signals/communications, supply, mobile support equipment operators (MSE Ops, i.e., drivers), etc. The current support manning structure was designed to facilitate the deployment of the unit in its entirety or only a portion thereof at any given time. To support multiple detachments requires, in many cases, an increased number of these vital support trades since there can be no efficiency achieved from all of the squadron's subunits operating from one base or in close proximity to one another.

Additionally, the nature of the new mission and roles for 427 SOA Sqn coupled with its legacy personnel establishment have significantly challenged its ability to generate and sustain operations with a sufficient amount of qualified aircrew. This is primarily due to the diversity of skill sets that are now required by the unit's aviators. The mission of 427 Sqn is: [t]o provide CANSOFCOM agile, high-readiness special operations aviation forces capable of conducting special operations across the spectrum of conflict at home and abroad.[127] The currently assigned roles for 427 Sqn are: counterterrorism; direct action; special reconnaissance; and defence, diplomacy and military assistance.[128] Both the mission and assigned roles have domestic and international facets inherent to them, which demand, in many cases, different skill sets from the aircrew. For example, the training requirement for aircrew to develop proficiency in skill sets for domestic maritime CT is quite significant in terms of resources and time. Similarly, the preparation to conduct CT or DA missions abroad in a high threat environment is just as demanding and intensive. Due to the significant resource and time requirements, aircrew are unable to develop and maintain required levels of proficiency in both types of skill sets. Despite there being a common baseline for all SOA aircrew, the diversity of missions and the consequent training requirements have led to a division of operational roles within the squadron, and they are split, generally, along domestic and international lines.

125. Previous conventional land force and tactical aviation doctrine, for which 427 Squadron's establishment was originally designed, called for a utility helicopter squadron (originally equipped with the CH135 Twin Huey, replaced in the 1990s by the CH146 Griffon) to be controlled at divisional level while each of the division's brigades would have a reconnaissance helicopter squadron (equipped with the CH136 Kiowa) in support.

126. Canada, Department of National Defence, "427 SOA Sqn Establishment Report" (01 April 2010).

127. Canada, DND, *Canadian Special Forces Command*, 11.

128. Ibid. CT refers to the offensive and defensive measures taken to prevent, deter, pre-empt and respond to terrorism, both domestically and internationally. CT measures are mostly offensive actions such as hostage rescue, recovery of sensitive material or strikes at infrastructure but additionally include mitigation and deterrent activities. DA are short duration strikes and other precise small-scale offensive actions conducted by SOF to seize, destroy, capture, exploit, recover or damage designated targets. SR missions are conducted to collect or verify information of strategic or operational significance. DDMA refers to operations that contribute to nation building through assistance to select states through the provision of specialized military advice, training and assistance.

To further complicate the ability to force generate SOA aircrew, the aircrew training system that 427 Sqn depends upon to produce qualified pilots and flight engineers (FEs) is designed to meet the needs of conventional aviation units. In other words, graduates of this training system, upon arrival at a conventional aviation unit, are theoretically considered "combat ready." However, once aircrew arrive at 427 Sqn, there is a requirement to conduct further training to acquire basic SOA skill sets prior to being ready to conduct special operations. Currently, this training must be accomplished by 427 Sqn. Since this is a relatively new functional requirement generated by the unit's revised roles and mission, the personnel structure does not account for adequate numbers of instructor pilots and instructor FEs to accomplish the task. This is just another example of the fact that the personnel establishment was never designed to meet the current demands of it.

Similarly, the current airframe employed was never intended nor envisioned to fulfill the SOA roles now assigned to 427 Sqn with the exception of the domestic CT task. The platform presently in use is the CH146 Griffon helicopter. This is a militarized version of the Bell 412 helicopter. It is a twin-engine, light-utility helicopter, capable of transporting up to 10 passengers at speeds of 220 kilometres per hour, with an operating range of 656 kilometres.[129] While it has proved a suitable platform for domestic special operations, it is widely accepted that it is severely limited in being able to support the wider range of roles required of SOA.[130] Its greatest drawback is its limited lift capacity, thereby reducing its usefulness to effectively provide mobility for SOF.

The second SOF truth is: "Quality is better than quantity."[131] This truth is very relevant with respect to the personnel selection and management process that is currently in place for SOA. Presently of the four units within CANSOFCOM, only 427 Sqn does not have a formal personnel selection and screening procedure in place. While a detailed examination of screening and selection of personnel for Canadian SOA is beyond the scope of this paper, it is worth noting the drawbacks of the current process.[132] As has been previously identified, SOF are specially selected, trained and organized to conduct high risk and/or politically sensitive operations. The argument for SOF, and equally applicable to SOA personnel selection, is that the cost of failure of special operations is much higher than the cost of ensuring that the most appropriate personnel have been chosen for the task.[133] This point, in particular, was highlighted by the Operation EAGLE CLAW case study in the previous section. At the present time, not all personnel at 427 Sqn are volunteers, and the majority of manning requirements are subject to the current Air Force personnel management process. In essence, without a formal selection process in place, there is very little that can be done to ensure the overall suitability of the personnel assigned to 427 Sqn. While it is understood that it will take time to develop a proper SOA selection process, in its absence Canadian SOA will be prevented from reaching its full and required potential.

It is evident, as a result of the manner in which 427 SOA Sqn was transitioned to special operations, that there are some continuing challenges to developing a flexible and robust SOA capability. The brief overview of some of the issues posed by the dated nature of 427 Sqn's present personnel establishment reveal insufficiencies that will need to be addressed over the long term in

129. Canada, Department of National Defence, "CH-146 Griffon Technical Specifications," Royal Canadian Air Force, http://www.airforce.forces.gc.ca/v2/equip/ch146/specs-eng.asp (accessed July 9, 2012).

130. Bernard Brister, "Canadian Special Operations Mobility – Getting the Right Tools," *Canadian Military Journal* 9, no. 2 (n.d.): 53, http://www.journal.forces.gc.ca/vo9/no2/07-brister-eng.asp (accessed July 9, 2012).

131. Collins, *Green Berets, Seals and Spetsnaz*, xiii.

132. For a more in-depth look at this issue see: Major T. A. Morehen, "A Selection Process for SOF Aviation in Canada" (master of defence studies research project, Canadian Forces College, 27 April 2009) http://www.cfc.forces.gc.ca/259/290/295/286/morehen.pdf (accessed July 9, 2012).

133. Ibid., 33.

order to facilitate continued development and growth. However, under the auspices of the current Canadian Forces Strategic Review, CANSOFCOM should have the opportunity to provide a remit on its overall force structure requirements and, therefore, possibly rectify some of these establishment deficiencies. Much like the current force structure, the CH146 was not envisioned to be employed within the spectrum of special operations, and consequently, the ability for SOA to effectively fulfill some of its assigned roles will continue to be hampered until more suitable platforms are available. In addition, the lack of a formal personnel screening and selection process will prolong the development of a credible and experienced SOA competency. What does this mean for now and the near future? Essentially, the strategic capability of SOA in CANSOFCOM will remain limited until such time that the previously discussed issues are suitably dealt with. This will, in turn, reduce flexibility for the Canadian government to respond militarily to politically sensitive emergencies or crises abroad.

What we should have

Having assessed the current status of Canadian SOA and some of the existing challenges to continued growth, what capacity should it have in order to ensure it is able to provide strategic effect into the future? SOF, despite having specialized requirements, still requires aviation to fulfill its basic doctrinal roles of: aerial firepower, reconnaissance and mobility.[134] This would suggest the need for a balanced SOA force that is able to provide adequate support to all three roles. In other words: [t]o be effective, the Canadian rotary wing [sic] SOA community needs … a range of suitably equipped aircraft able to satisfy the unique requirements of Canadian [s]pecial [o]perations [f]orces … .[135] Therefore, in order to develop an ideal capability for the future, it would seem that Canadian SOA should be able to fulfill the three doctrinal roles of aviation in support of SOF. However, given the resources available, this ideal force structure is unrealistic for Canada, and therefore, tactical mobility should be the focus for Canadian SOA development. This emphasis would ensure that, as a minimum, SOF has the integral strategic enablers they require to effectively operate at home and abroad. To explore these ideas, the concept of a balanced special operations aviation force will be investigated along with the critical requirement for tactical mobility.

Balance, when used in reference to force structure, may be defined as the combination of force elements that will provide the most flexibility in order to accomplish the greatest number of tasks across the spectrum of conflict. For example, a force comprised of one aircraft type would likely provide ample capacity but over a very narrow task set. Conversely, a force structure of similar size consisting of a broader number of airframe types would have the ability to accomplish a wider range of tasks but have a reduced capability to sustain them. In this context, SOA is no different than conventional tactical aviation, where balance becomes the search for the correct amount of diversity in the types of airframes in order to best accomplish the tasks assigned.[136]

The simplest way to determine an appropriate level of balance would be to examine what others have discovered to be a functional and flexible force structure, thus making use of their valuable experience. With respect to SOA force structures, it is essentially only the US 160th SOAR that demonstrates any significant level of balance. Each of the four battalions of the unit is comprised of a "strategic composition of light, medium and heavy helicopters, all highly modified in design to

134. Canada, DND, B-GA-441-001/FP-001, *Tactical Level Aviation Doctrine,* 1-1.

135. Jim Dorschner, "Instructions Not Included – Thoughts on Building a Canadian Special Operations Aviation (SOA) Capability," *Canadian Military Journal* 9, no. 3 (2009): 92, http://www.journal.forces.gc.ca/vo9/no3/13-dorschner-eng.asp (accessed July 9, 2012).

136. Thierry Gongora and Slawomir Wesolkowski, "What does a Balanced Tactical Helicopter Force Look Like: An International Comparison," *Canadian Air Force Journal* 1, no. 2 (Summer 2008): 14, http://www.rcaf-arc.forces.gc.ca/CFAWC/eLibrary/Journal/Vol1-2008/Iss2-Summer_e.asp (accessed July 9, 2012).

meet the unit's unique mission requirements."[137] The light helicopters are a mix of AH-6 (attack) and MH-6 little birds.[138] The medium helicopters are MH-60 Black Hawks, and the heavy helicopters are the MH-47 Chinooks. In the case of the 160th SOAR, each of the three doctrinal roles of aviation can be effectively supported by assets integral to the unit. The AH-6s provide a reconnaissance and aerial firepower capability. In addition, some MH-60L Black Hawks are modified to carry different weapons packages, to also fulfill the firepower role. However, the bulk of the unit's capabilities (the MH-6s, MH-60 Black Hawks and the MH-47 Chinooks) are focussed on varying degrees of mobility. The overall result is a very flexible SOA unit that is able to provide robust support to SOF.

In contrast, 7 Sqn RAF in the UK only operates the Chinook heavy transport helicopter, and Australia only the S-70A Black Hawk,[139] a medium transport helicopter in a dedicated SOA role. Even with what is considered to be a balanced force, the US 160th SOAR employs assets of which the majority are used to provide mobility. If one is to heed these examples of Canadian allies, one would have to conclude that effective tactical mobility is the priority task for a dedicated SOA organization. This is also supported by the two case studies of the previous section. For the Iranian hostage rescue operation, the critical requirement for SOA was to provide the tactical mobility for the Delta Force assault team from Desert One to the embassy and, subsequently, back to the evacuation airfield with the rescued hostages. In Operation BARRAS, the vital requirement for aviation support was for the transport and insertion of the SAS rescue assault force. In both situations, the requirement for tactical mobility proved to be decisive in terms of being able to achieve the overall strategic effect of the operation.

This point is also emphasized by recent operational experience. For example, in assessing Canadian special operations mobility requirements in a recent article, Bernard Brister points out that operations in Iraq highlighted that a SOF task force's overall effectiveness was vitally linked to its ability to address its own mobility requirements. There exists the option, under these kinds of circumstances, for a nation to rely on coalition partners to provide mobility support to its SOF TF. However, this is not an effective option, as recent operations in Afghanistan and Iraq demonstrate that there is very little guarantee that aviation support will be forthcoming in a timely manner, if at all.[140] This is due to the high demand in general for aviation support and the limited availability of SOA in theatre. Additionally, any coalition SOA would likely only be provided to support another nation's SOF if the operation falls within the coalition partners' national interest and priorities.[141] This has been a critical issue plaguing Canadian SOF, as they have dealt with this particular circumstance while conducting operations in Afghanistan.

In light of the fact that Canada has not been able to provide tactical mobility for SOF abroad, it will not likely be capable of fielding a balanced SOA force any time soon. The Canadian Forces are often compared to the Australian Defence Force as they are very similar in terms of overall size and resources available. The British, on the other hand, represent a force structure and resource base of a greater order of magnitude somewhere between the Canadian/Australian example and that of the US. The UK and Australians to date have only concentrated on tactical mobility with their dedicated SOA. Therefore, it would seem logical that for Canada the idea of a balanced SOA force is

137. United States, Department of Defense, "The 160th Special Operations Aviation Regiment (Airborne): Fact Sheet," US Department of Defense, http://www.soc.mil/160soar/160soar.html (site discontinued).

138. These are modified military versions of the more commonly known Hughes 500 helicopter.

139. Australia, Australian Defence Force, *Capability Fact Book* (Canberra: Department of Defence, April 2003), 23, http://www.defence.gov.au/publications/cfb.pdf (accessed July 9, 2012).

140. Brister, "Canadian Special Operations Mobility, 54.

141. Ibid.

not within the realm of possibility from an overall resource perspective. This becomes apparent from a simple comparison of the US 160th force structure and that of 427 SOA Sqn. In terms of relative size, 427 SOA Sqn, as a whole, can be compared to one of the four battalions of the 160th SOAR. In addition, as was already highlighted, the 160th operates highly modified airframes different from those employed by conventional aviation forces. This implies that the 160th requires specialized maintenance and logistical support for its fleets. Currently, 427 SOA Sqn's small fleet of CH146 Griffons only have minor modifications that are for the most part found in the form of modular mission kits. The result is that there is no requirement for unique or specialized maintenance for the aircraft. This also allows 427 SOA Sqn to achieve a level of synergy with the rest of the CH146 fleet with respect to such things as basic aircrew and maintenance training as well as a common supply chain. Therefore, regardless of what types of aircraft are employed by 427 SOA Sqn in the future, the flexibility in support and training achieved in operating a common platform with the rest of the Air Force cannot be underestimated.

Does this, then, suggest that balanced aviation support to special operations cannot be practically achieved? Experience or historical examples would demonstrate that this balance can be accomplished through the employment of conventional aviation forces in certain roles. For example, in Operation BARRAS, aerial fire support was arguably a critical requirement for mission success due to the requirement to suppress rebel heavy weapons systems able to engage the Chinooks during the assault. In this case, the task was effectively executed by conventional UK Army Air Corp Lynx attack helicopters. This merely exemplifies that there are acceptable and effective means available to mitigate the lack of integral abilities of a SOA organization to support all three doctrinal aviation roles.

In summary, what is evident from allied examples and experience is that tactical mobility needs to be the focal point for capability development of Canadian SOA. The ideal of a balanced force along the lines of the US 160th SOAR is neither realistically attainable nor an absolute necessity in the Canadian context. What will be critical, however, will be the continued growth of a credible and competent SOA organization able to provide Canadian SOF with effective tactical mobility. Only if this occurs will CANSOFCOM have a SOA capability that will provide the necessary strategic enablers to provide flexibility to Canadian special operations.

Possible options

Knowing that developing a strategically relevant SOA capability should be centred around providing effective mobility to SOF, there are several options available given current helicopter fleets and capital acquisition projects that are underway. There is the CH148 Cyclone, a medium-lift capable helicopter, which is set to replace the Sea King in the near future. There is also the CH147F Chinook project which will deliver 15 of the heavy transport helicopters starting in 2013. In addition, Canada is currently operating six CH147D model Chinooks in Afghanistan to bridge the capability gap until the delivery of the new aircraft. Each of these airframes, in the right numbers and organized appropriately, has the potential to effectively improve mobility for SOF.

The status quo of continuing to operate with only the CH146 Griffon is not viable over the long term. The lift capacity is inadequate to be able to provide an effective mobility capacity to SOF. While its characteristics make it well suited to the domestic CT role, it is of limited value in a deployed high-threat environment where SOF often require range and payload capacities in excess of the Griffon's capabilities. Therefore, maintaining the status quo will not suffice if Canadian SOA is to be developed into a true enabling strategic capability.

The ideal solution would be to equip 427 SOA Sqn with a capable medium or heavy transport helicopter. However, this is unlikely to occur in the near term due to the availability of capital acquisition funds and given the current departmental procurement priorities. In addition, the aforementioned capital projects only represent conventional force requirements and, in the case of the CH148 Cyclone, do not include the requirement for a tactical mobility task. Assuming that for the foreseeable future the lack of incremental procurement funds will persist, the Canadian government in concert with CF leadership will be forced to prioritize force structure requirements. If SOA is assigned a strategic priority under these circumstances, it would be possible to redirect some of the airframes to provide a mobility capability. The downside to this is that another conventional force will suffer as a result.

A possible resolution to this issue would be allocating the six D model Chinooks to SOA. The cost of this endeavour would have to be explored in greater depth, since there is currently no announced plan to repatriate these helicopters once the Afghanistan mission is complete. The D model Chinook is also a significantly different aircraft from the F model such that, as previously indicated, there would be increased costs with respect to maintenance, training and parts from operating a unique fleet. While equipping 427 SOA Sqn with an appropriate medium-to-heavy transport helicopter would be ideal, fiscal realities would seem to indicate that there is little chance of this being a viable option for the near future.

What is possible and may be manageable within currently planned resource levels is having SOA qualified aircrew embedded in other units. For example, when the new Chinook squadron is activated, a certain number of crews in the unit could be trained and SOA qualified. There would be an incremental training cost associated with this option since a SOA qualification implies the maintenance of a constant state of high readiness and the acquisition of some skills above and beyond a conventional skill set. However, this factor can be mitigated if 427 SOA Sqn retains the responsibility to lead SOA mission planning, coordination, liaison, etc. This would mean that only the aircrew qualifications and flying proficiency would become an incremental task for the designated Chinook crews. In this case, for a comparatively small training investment an exponential strategic return would be realized.

Each of the above suggested options would have to be explored in more depth to determine whether they are viable with respect to currently planned resource allocations. Furthermore, it is not an exhaustive examination of all the courses available to further develop a mature and robust SOA mobility capacity. It is hoped that this brief overview of some potential solutions is enough to spark further thought and debate in the SOF and Air Force communities at large.

Summary

Despite having been recognized as a critical component to Canadian SOF, 427 SOA Sqn remains limited in its ability to provide a truly robust SOA capability. This is in part due to inherent issues which are the direct result of a legacy personnel establishment and aircraft fleet that were never designed or intended to fulfill the current roles and tasks now expected of the unit. Additionally, personnel management continues to be a concern that has reached the point where it will begin to hamper efforts to establish an effective and credible SOA community until such time that a suitable screening and selection process is instituted. With the exception of the aircraft fleet, these issues can be addressed directly and rectified if there is a collective desire to move SOA development forward. It is also evident, from allied experience and Canadian operational experience, that continued SOA development efforts must be focussed on fulfilling the mobility role. It is this aspect that, once achieved, will truly provide Canadian SOA the ability to fulfill its strategic role in enabling SOF operations in a robust and credible manner.

6. Conclusion

> … I am a member of the fastest deployable task force in the world—ready to move at a moment's notice anytime, anywhere, arriving on target plus or minus 30 seconds.[142]
>
> Unknown Author, *Night Stalker's Creed*

The security landscape has shifted considerably over the past 20 years. From the end of the cold war to the tragic events of 9/11, the international community has struggled to adapt to, and understand, the circumstances of the world they live in. One remaining constant is that the world continues to be a dangerous place. The negative effects of trends (such as globalization, failed and failing states, and the transnational nature of non-state actors like criminal and terrorist groups) have resulted in an environment where traditional, conventional force-on-force military responses are often no longer practical or appropriate. The ever-increasing development of theory and strategic thoughts on SOF, coupled with recent employment on operations in Afghanistan and Iraq support this. As a result, SOF has become increasingly more relevant and often the preferred choice for strategic military actions deemed necessary by their governments to shape or project their national policies abroad. The Canadian military has not been blind to this evolution and has taken steps to adapt to this environment with the creation of CANSOFCOM, along with its component parts to include SOA.

However, like other organizations, SOF is only as effective as the sum of its parts. The two historical examples of Operation EAGLE CLAW and Operation BARRAS clearly demonstrated the critical requirement for SOA to be integrated into SOF and the possible consequences if it is not. These lessons are as valid today as they were in the past, thus confirming the need for Canadian SOA as a relevant and strategic SOF capability now and into the future. Despite this realization, Canadian SOA capabilities need to be further developed in order to effectively enable special operations. Inherent institutional insufficiencies and current equipment limitations will need to be addressed along with a focus on developing in the short term an effective SOA mobility capability for Canadian SOF. It is not until these issues are suitably addressed that Canadian SOA will begin to reach its full potential as a strategically relevant force.

142. Pushies, *Night Stalkers*, 69.

Abbreviations

CANSOFCOM	Canadian Special Operations Forces Command
CF	Canadian Forces
CIA	Central Intelligence Agency
CO	commanding officer
CSOR	Canadian Special Operations Regiment
CT	counterterrorism
DA	direct action
DDMA	defence, diplomacy and military assistance
DND	Department of National Defence
FE	flight engineer
HVT	high value task
JNBC	Joint Nuclear Biological Chemical Company
JP	Joint Publication
JTF 2	Joint Task Force 2
OPP	operational planning process
RAF	Royal Air Force
SOA	special operations aviation
SOAR	special operations aviation regiment
SOF	special operations forces
sqn	squadron
SR	special reconnaissance
TF	task force
THS	tactical helicopter squadron
UK	United Kingdom
US	United States
USAF	United States Air Force
WMD	weapon of mass destruction

Chapter 3 – Protection of Canadian Space-Based Assets: A Policy Void

Major Walter S. F. Norquay

Abstract

Canada's reliance on space assets puts it in a precarious position in terms of the threats to space operations. The reliance on space-based systems is critical to the economy and security of Canada; accordingly, Canada should have a national policy that ensures its access to this crucial domain. Other space-faring nations, aware of the threats, have developed their own strategic security policy for space, while Canada has not. Several departments are developing space agendas within their areas of responsibility, but there is simply no unifying guidance or policy to shape and synchronize their efforts. This paper intends to prove that Canada currently has no strategic space policy to defend Canadian space systems and, in the absence of an immediate threat or crisis, will not likely be moved to develop one.

The topic is broken out over four sections. To start, the operating environment for space assets will be discussed to provide background on the risks to space operations. Second, the international space treaty regime will be examined followed by a look at the examples of three key international space-faring nations. Third, an exploration of Canada's documented security, defence, and space policy will be conducted. This is done with an eye to defining Canada's national space security policy and will look at both the activities of the Government of Canada as well as the departments and agencies that have a mandate which overlaps the space security issue. Finally, the paper will look at our current situation in comparison to past security issues, namely the nuclear debate, ballistic missile defence, and the proposed sale of Radarsat.

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1. Introduction

Space has become an integral component of world infrastructure that facilitates the functioning of a modern information-based society. The systems now in orbit provide fundamental services such as communications, earth observation, geographic location, and timing. These are services that permit the high-speed movement of knowledge and goods that drive modern economies. They also provide an invaluable knowledge of events around the world. Responses to natural disasters, tracking of weather systems, the conveyance of news and, ultimately, the functioning of an armed force has become reliant on the capability space affords. The advantage of space is its ability to bypass the limitations and obstacles of terrestrial systems. Considered within military circles as the ultimate high ground, the vantage point of space all but eliminates the effects of terrain and synchronizes action. These advantages to space operations come at a cost. Space is a difficult environment in which to operate, specifically in Earth orbit.

Space is naturally a hostile environment. Life on Earth is protected from the ravages of space by the atmosphere and magnetic field of the planet. Objects in orbit are outside of this protective barrier and must function with minimal natural protection. The solar wind and flares that provide a constant rain of charged particles, the ambient radiation of space as well as the impact of meteoroids can all have an impact on orbital systems. These space conditions, although difficult, are simply part of the cost of working in space. As hard as space operations already are, human orbital activities are making things worse.

In addition, the actions of human space activity have significantly increased the threat to space systems. Putting objects in space creates orbital debris that is a threat to future missions. Dead satellites, either after their useful life or by failure, often remain in orbit adding to the debris obstacle course. These systems, as they stand, are a sufficiently concerning threat made worse when they collide with other defunct or possibly active systems, such as the Iridium-Cosmos satellite collision in 2009, creating additional debris clouds that threaten the environment. Even with an appreciation of these threats, nations have found ways to make orbiting more difficult through antisatellite (ASAT) weapons. The ASAT threat goes beyond an attack on the targeted system to the debris generated and the consequences for all systems in affected orbits.

In response to the threats, an international body of law is being built around treaty work conducted under the United Nations (UN). Over time, it has become apparent that the law that has developed is vague or lacking in key areas such as the weaponization of space. In response, some nations have begun to fill in the blanks by extending concepts of existing international norms in other environments or simply establishing their own space security direction. Those nations without their own direction may be left out of the decision-making process when it comes to defining future norms and legislations for space operations.

Canada's reliance on space assets puts it in a precarious position in terms of the threats to space operations. The reliance on space-based systems is critical to the economy and security of Canada; accordingly, Canada should have a national policy that ensures its access to this crucial domain. Other space-faring nations, aware of the threats, have developed their own strategic security policies for space, while Canada has not. That is not to say there has not been work in this area. Several departments are pushing forward individual space agendas within their areas of responsibility, but there is simply no unifying guidance or policy to shape and synchronize their actions. This paper intends to prove that Canada currently has no strategic space policy to defend Canadian space systems and, in the absence of an immediate threat or crisis, will not likely be moved to develop one.

The focus of this paper will be on the orbital portion of space systems or the space segment. The terrestrial portion, while essential, will be considered part of standard physical protection measures. These would include standard security practices such as fences and policing. The concern is that there is no single government policy to tackle the protection of the space segment.

2. The threat environment

Introduction

Operations in space are exceedingly difficult due to the physics of orbiting satellite systems. At the same time, "because of its remoteness and difficulty of access it provides a relatively safe sanctuary for global operations."[1] For this reason as well as the benefits of using space as a high ground for a number of capabilities, space is being pursued by a number of actors. All those involved in space need to be prepared for the space threats in order to extract the benefits. Concern for space operations is derived from three main threats to the satellite. On orbit "satellites are vulnerable to natural hazards, to inadvertent harm caused by other space users' activities and potentially also to deliberate interference for strategic or tactical military advantage."[2] The following discussion of threats will, therefore, consider three areas: natural threats, man-made passive threats, and man-made active threats intended to neutralize space systems.

Natural threats

Space is a hostile environment that must be understood if satellite operations are to be effective. Understanding the natural threats in the environment and mitigating their effects is key. The following will provide a basic understanding of the threat through basic definitions and a couple of examples. Before going further, it should be noted that the focus of this paper is on those systems in orbit of Earth in service to Canada and its populations. There are three predominant types of orbits used in space operations: low earth orbit (LEO), medium earth orbit (MEO) and geosynchronous earth orbit (GEO). LEO extends to 3,100 nautical miles [5,741 kilometres] and is generally used for navigation and earth observation. MEO, defined simply as between the other orbits, is optimal for applications such as navigation. GEO is found at 22,300 nautical miles [41,300 kilometres] and provides a 24-hour period which allows satellites to appear unmoving relative the Earth's equator. GEO orbits are suited to communications and missile warnings.[3] All these orbits, while advantageous to the provision of certain services, also expose systems to a number of natural threats.

The natural effects of space do not generally come to mind when considering the void of space. It is a consideration for any nation that is involved in any type of space operations. These aspects include temperature, radiation, solar wind, and meteoroids. In terms of temperature, a satellite must be able to withstand changes from 200 Kelvin to 350 Kelvin (or -73 to +77°Celsius) in the conduct of operations. Satellites in orbit must be able to withstand and operate at these extremes over their lifespan. Systems must also be able to contend with a constant barrage of electromagnetic radiation in the form of visible light, ultra-violet, X-rays, infra-red, radio, and others across the electromagnetic spectrum. The solar wind, a flow of high-energy particles ejected from the sun, can also have significant effect on satellite electronics. Its density and its speed are dependent on the

1. Stephen James, "Space Is Becoming Crucial: We Need to Pick Up the Pace [the Canadian-American Defence Relationship: Where Next?]," *Policy Options* 23, no. 3 (Apr, 2002): 66.

2. Nancy Gallagher, *A Reassurance-based Approach to Space Security* (Ottawa: Foreign Affairs and International Trade Canada, 2009), 7, http://www.international.gc.ca/arms-armes/assets/pdfs/a_reassurance_based_approach_to_space_security.pdf (accessed October 5, 2012).

3. Steven R. Petersen, *Space Control and the Role of Antisatellite Weapons* (Maxwell Air Force Base Alabama: Air University Press, 1991), 1.

degree of solar activity in terms of flares and sunspots. Finally, the threat from meteoroids / natural space debris is a constant concern for all activities in space. Collisions can have significant impact on physical integrity and system functions.[4] Each of these threats can have an impact on space operations.

These natural threats are the price of working in a space environment. All space actors will have to deal with their effects, as Canada is well aware. In 1994, Canadian communications satellites Anik E1 and E2 were disabled by the effects of increased solar activity. Their flight controls were damaged, but control of the satellites was eventually regained.[5] Anik E1 and E2 were a significant portion of Canada's telecommunications infrastructure, and replacement systems would have been costly in terms of alternative services and new satellites. Acknowledging the natural threats of space itself, it is now important to look at the effect human activities have on the space environment. The primary issue is one of debris. By connection, the natural effects on man-made systems "under the influence of extreme ultraviolet radiation, impinging atomic oxygen and impacting micro particles, surfaces of space objects start to erode."[6] These results of natural effects are only the beginning of the debris issue.

Man-made passive threats

Beyond the naturally occurring threats of the space environment itself, there are additional considerations attributable to the space operations themselves. More accurately, the remnants of previous activities are forming an increasingly dangerous and costly threat for current and future operations. Be it discarded rocket bodies, defunct satellites or associated refuse, these items have become a hazard to all activities in space. It is a hazard that is getting worse, generated as a function of the launch and space systems.

Numbers put out by the European Space Agency show the development of the space debris issue over the past 50 years. Of approximately 6,000 satellites placed into orbit, only 800 are still functioning with a majority of the defunct satellites remaining in orbit. The functioning satellites comprise 8 per cent of the total objects being tracked. Proportionally, 36 per cent of the objects tracked are non-functioning satellites, spent rockets and other mission related items. The remaining 56 per cent contains objects generated through collisions and explosions that have occurred in orbit.[7] It should be noted that these numbers represent objects of a size that can be tracked with current technology. Related to each action there are untold numbers of smaller objects that still constitute a hazard. In perspective, "even a paint flake, traveling at orbital velocities, can crack the space shuttle's windshield."[8] The issue only gets worse as operations continue.

As more space operations occur, more debris will be generated. This, along with existing debris, is but one factor that contributes to the number of objects in orbit. As the number of objects in orbit increases so does the chance of a collision that ultimately creates more, if smaller, debris. This increase in debris then increases the probability of additional inter-debris collisions. In fact, "NASA [National Aeronautics and Space Administration] has shown that, in LEO, inter-debris-debris

4. Canadian Forces School of Aerospace Studies, *Space Indoctrination Handbook 5th Ed.* (Winnipeg: Canadian Forces School of Aerospace Studies, 1996), 1-2/3.

5. James Fergusson and Stephen James, *Report on Canada, National Security and Outer Space* (Calgary: Canadian Defence & Foreign Affairs Institute, 2007), 69.

6. European Space Agency, "Space Debris Environment," http://www.esa.int/SPECIALS/Space_Debris/SEMQQ8VPXPF_0.html (accessed October 11, 2012).

7. Ibid.

8. Robert L. Hotz, "Harmless Debris on Earth is Devastating in Orbit," http://online.wsj.com/article/SB123568403874486701.html#printMode (accessed October 11, 2012).

collisions will become the dominant source of debris production within the next 50 years."[9] Allowed to continue, this self-producing debris would be a threat to space access.[10] At such a stage, all space assets and the nations they support would be impacted. As if to underscore how simply this could occur, there have been several impacts between complete satellites.

On 10 February 2009, a collision occurred between the United States' (US) Iridium 33 communications satellite and the decommissioned Russian COSMOS 2251 communications satellite. The impact turned two stable space objects into debris clouds totalling, as of March 2009, some 823 space objects, with more being recorded.[11] The incident, while significant for the two nations involved, is now also a concern for all operators in related orbits. This is a simple example of how quickly the debris issue could get out of hand. Each of the new objects could, if not monitored, create more debris should they collide with other objects. Assessments made in the US indicate the debris from this incident alone will threaten operations for decades. The event was accidental and only the fourth known collision to occur between two catalogued space objects.[12] However, it is an indicator of problems to come.

On the positive side, this event and others like it have pushed a greater appreciation of the collision and debris threats. This has put a greater emphasis on space surveillance to ensure objects are monitored and possible collisions identified. In specific response to the Iridium-COSMOS collision, the US Joint Space Operations Center "now conducts conjunction assessments for all operational spacecraft in Earth orbit, regardless of ownership nationality."[13] Such actions show a maturing understanding of the debris problem. The concern is that space is "populated with ever-increasing new owners and defunct or expiring satellites, the problem is uncontrolled and becoming unmanageable."[14] A cooperative approach appears to be the current solution to managing these man-made but passive concerns, as there are no borders in Earth orbit. The action (or inaction) of one can affect all.

Man-made active threats

The active threat to space operations is different, but only in terms of intent. There is the obvious impact to the system targeted, but much like the concerns over collisions discussed above, there could be a much broader impact to all space users. The key concern that comes out of the idea of neutralizing space systems is again one of debris. A single system destroyed could create the same space hazards as a satellite collision. Considering this point, the intent now is to look at the concept of ASAT systems, their considered usefulness, and the possible repercussions of their use.

The acronym "ASAT" will be used here to describe systems used to damage or incapacitate orbital systems. These weapons come in three broad categories: kinetic, directed energy, and electromagnetic/radiation. Kinetic systems rely on the impact of the ASAT weapon and the target to generate sufficient destructive power. Because there is essentially a collision in space, such systems can generate a significant amount of debris in taking out a target. Directed-energy weapons use high-intensity light (laser) or radio frequencies in an attempt to blind or physically damage a

9. Jessica West ed., *Space Security 2009* (Kitchener, Ontario: Pandora Press, 2009), 27.

10. Ibid.

11. National Aeronautics and Space Administration, "Satellite Collision Leaves Significant Debris Clouds," *Orbital Debris Quarterly News* 13, issue 2 (April 2009): 1, http://www.orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv13i2.pdf (accessed October 11, 2012).

12. Ibid., 2.

13. Leonard David, "Space Junk Getting Messier in Orbit," http://www.space.com/missionlaunches/space-debris-getting-messier-100223.html (accessed October 11, 2012).

14. J. Vernikos, "Space Assets Under Attack," *Defense & Foreign Affairs Strategic Policy* 37, no. 3 (2009): 12.

satellite. Finally, electromagnetic weapons generate radiation or electromagnetic pulses meant to destroy unprotected electronics.[15] In addition to the immediate impact to electronics, these last systems, also referred to as High Altitude Nuclear Detonation (HAND), leave long-term radiation that would continue to have an effect on other systems beyond the original attack.[16] In each case, these systems create debris or additional effects to future space operations. Even when the effects are not fragmentary, a disabled satellite is as much a threat as COSMOS 2251 was to Iridium 33.

The US and Russia appreciate these issues. These nations having "a common interest in protecting their respective military systems in space lead them to develop costly and technological anti-satellite systems to limit damage to other satellites."[17] In doing so, they have led the way in ASAT technology that localizes the effect. The issue remains that they have the capacity to neutralize a satellite should the need arise. In response, other nations may feel a need to demonstrate a comparable capability, a recent example being the case of China's ASAT tests. On 11 January 2007, China launched an ASAT missile at one of its aging satellites.[18] In demonstrating their ASAT capability, China also underscored the key concern with such systems. "The Chinese Feng-Yun 1C engagement … alone increased the trackable space object population by 25 percent."[19] In a single action China had greatly increased the odds of debris collision by adding a debris cloud of 300,000 pieces that affected "orbits as low as 200 kilometers (124 miles) and as high as 3,800 kilometers (2,360 miles)."[20] This debris cloud will have consequences for years to come, consequences Chinese authorities have begun to recognize as a threat to their own activities.

Returning to the aftermath of the COSMOS-Iridium accident, China was concerned about the effects of debris. "Chinese authorities worry that the new debris may hit their nearby weather and maritime surveillance satellites. At least 17 commercial communication satellites pass directly through the heart of the debris cloud … ."[21] This understanding is coming as China increases its reliance on the space effects for both its security and prosperity. In terms of threats to satellite operations, the concern over nations like China may be misplaced. The true threat comes from nations that have little reliance or concern for space operations. Fundamentally, "if a state is not concerned about collateral damage and can launch a payload or deliver a weapon, especially a nuclear weapon, to a target thousands of kilometers away, it can also strike satellites."[22] As the cost and technological barriers to space access are lowered, the threat could become more unpredictable. With that said, "there are no reported cases of use of ASAT weapons during international conflict. Nonetheless ASAT technology has been tested."[23] Should a nation feel sufficiently threatened, even one that understands the impact, "sustainability of the space environment can potentially conflict with security from threats posed by objects in space."[24]

15. Michel Bourbonnière, *LOAC and the Neutralization of Satellites or IUS in Bello Satellitis* (Ottawa: Foreign Affairs and International Trade Canada, 2003), 15.

16. West, 142.

17. James Fergusson, "Out of Sight, Out of Mind: Canada, Outer Space & National Security," *Fraser Forum* (May 2004): 16.

18. A. Frey, "Defense of US Space Assets: A Legal Perspective," *Air & Space Power Journal* 22, no. 4 (Winter 2008): 76.

19. European Space Agency.

20. Frey, 78.

21. Hotz.

22. Fergusson, "Out of Sight," 16.

23. Bourbonnière, 14.

24. West, 31.

Summary

Space is an unforgiving environment which creates unique challenges for the operation of satellites. Human activity in space further exacerbates these difficulties. All space operations need to take these issues into consideration. Whether it is the effects of solar winds, radiation or meteoroids, space systems must be prepared. The true difficulty that burdens orbiting systems is the increasing amount of debris that comes from the space missions themselves. "Dead or alive, these orbiting satellites or their debris are a challenge to other spacecraft … ."[25] Satellite operators need to be aware of and be able to react to the existing threats to space systems. They must also be mindful of the effect the byproducts of today's systems will have on the space needs of future generations. This line of reasoning extends to the impact security and space activities could have on the orbital environment. The Chinese ASAT test and the Iridium-COSMOS collision clearly demonstrate the impact even a single incident can have for all players in the space environment. The question that is left is how much of tomorrow's space environment can or should be sacrificed for the security of today? This is a question being considered by a number of nations individually and collectively.

3. International context

Introduction

Space is a resource that is common to the entire world and, therefore, belongs to no single nation. Space, being a shared environment, requires that nations come to common understandings on how to operate in this domain. This understanding in theory allows the space actors to achieve their goals in space while limiting any interference from, or with, the activities of another. The core of modern international law as it applies to space is coordinated through the UN under the United Nations Office for Outer Space Affairs (UNOOSA). For this discussion, it is important to understand the international framework, its origins, and limitations in order to appreciate the implications for Canada. It should be noted that this discussion will focus on the nation state. The international body of law that exists today holds the nation state accountable for its actions in space. It is acknowledged this may change based on the evolving role of organizations like the European Union (EU) and commercial space interests.[26] After a review of international law, the activities of select prominent and rising space users will be looked at, namely the United States, Russia, and China.

International law

International space law is based on a series of treaties administered under the UN and currently constitutes the only international legal regime for space. The foundational treaty is the 1967 Outer Space Treaty (OST), as it defined the key concepts for space explorations. The fundamental ideas of the treaty are that space should be used for the benefit of all mankind and that space "is not to be the subject of national appropriation."[27] In addition, the OST specifically prohibits the deployment of weapons of mass destruction (WMDs) in space. Subsequent treaties and statements of principle are extensions of the core ideas in the OST.[28] These additional treaties are the Rescue Agreement, Liability Convention, Registration Convention, and the Moon Agreement.

25. Vernikos, 12.

26. International space law holds the state responsible for its actions and its impact on other nations. This framework may have to evolve to accommodate commercial interests. Virgin Group's Virgin Galactic, which is selling suborbital travel, is likely the beginning of a significantly more complex legal environment.

27. Brian MacDonald, ed., *Space Strategy: Three Dimensions* (Toronto: Canadian Institute of Strategic Studies, 1989), 95.

28. Ibid.

The 1968 Rescue Agreement defines the requirement for signatory nations to provide notification of, and assistance to astronauts and spacecraft in distress. It also contains provisions for the return of space objects and personnel aboard to the appropriate country.[29] The 1972 Liability Convention is an extension of the OST and Rescue Agreement with a focus on responsibility for damage caused by space objects. The convention makes the launching state responsible for damages caused "to people and property on earth or in its atmosphere."[30] Interestingly, Canada was not happy with the lack of binding arbitration in the convention and abstained. In 1975, the country acceded, indicating that it was, in the end, a step in the right direction.[31] Next, the 1974 Registration Convention provided a requirement for nations to provide details to the UN on any object launch into orbit or beyond. The details would become part of records held at the UN.[32] This most obviously is an extension of the Liability Convention, as liability would be hard to assert without a record of the launching state. The final treaty is the Moon Agreement, which attempted to define a legal framework for usage of the moon and its resources. Unfortunately, the treaty is so broad that it creates "ambiguity about the right and obligations of states and fail[s] to establish effective rules."[33] As of March 2010, there are only 4 signatories and 13 other parties to the treaty.[34] Aside from perhaps France, the nations listed are marginal players in space. In terms of Canada's involvement, the country is party to four of the five treaties.

The only treaty that Canada is not a part of is the Moon Agreement, for the reasons discussed above. Canada's agreement to these treaties, either by ratification or accession, defines the nation's baseline policy in terms of space. For the specific question of defending space-based assets, the key document for Canada remains the OST, but the OST is limited. Since the signing of the OST, there has been an internationally "powerful norm" against the placement of weapons in space. This is supported by an almost annual resolution in the UN General Assembly on this point, which is without dissent; however, a small number of nations such as the US abstain from the votes.[35] The problem is that the actual OST does not go as far as the resolutions. "Currently the only legal restraint against space weapons is [that] … the OST bans weapons of mass destruction in space, on the moon, or on other celestial bodies, [but] it doesn't ban the kind of weapons systems now being developed … ."[36] The OST is a product of the times when it was created.

The OST was formed during the cold-war era, where two superpowers with significant space programs were sufficiently concerned about mutual deterrence and maintenance of a strategic balance.[37] The OST was, therefore, influenced by the compromises required in this environment. While this made an effective document for the time, it is also one lacking the guidance needed today. Compounding the question of weapons in space is the 13 June 2002 withdrawal by the US from the US-Russia antiballistic missile (ABM) treaty. With the end of this treaty, there ceased to be any treaty specifically prohibiting the deployment of space weapons aside from the WMDs included in

29. Ibid., 96.

30. James Fergusson and Stephen James, *Space Appreciation 2000* (Ottawa: Directorate of Space Development, National Defence Headquarters, 2000), F-7.

31. Brian MacDonald, 97.

32. Fergusson and James, *Space Appreciation 2000*, F-7.

33. Brian MacDonald, 99.

34. United Nations Office of Outer Space Affairs, "OOSA Treaty Database," http://www.oosa.unvienna.org/oosatdb/showTreatySignatures.do (accessed Ocober 11, 2012).

35. Jonathan Dean, "Defenses in Space: Treaty Issues," in *Future Security in Space: Commercial, Military, and Arms Control Trade-Offs*, ed. James Clay Moltz (Monterey, CA: Center for Nonproliferation Studies, Monterey Institute of International Studies, 2002), 5.

36. Paul Webster, "The Ultimate High Ground: The US is Weaponizing Space. Canada is Firmly Opposed … But Not Necessarily," *The Walrus* 1, no. 5 (June 2004): 54. http://walrusmagazine.com/articles/2004.06--weapon-in-space/3/ (accessed October 11, 2012).

37. Gallagher, 15–16.

the OST.[38] In the absence of defined international law, the concept of space weapons and defence is being considered through the lens of existing regimes.

Space is both a national and an international interest, as no one country owns it, but a great many recognize its strategic value. In comparison to existing international regimes, the Law of the Sea and Law of Armed Conflict (LOAC) are the most relevant. Orbital space is not a satellite's destination but a medium to be transited. Orbit, by its definition, is a state of motion. It is a fluid environment, unlike the static nature of Antarctica or the sea floor. This links well with the concepts within the Law of the Sea, specifically the high seas. No one owns it, vessels remain sovereign in it, and the actions of private or commercial interests are the responsibility of the launching nation.[39] These ideas are captured in the OST; however, there is currently no basis for the right of safe passage or the right of self defence.[40] These ideas may come from an extension of the existing concepts within LOAC. Beyond the physics, aggression in space is simply aggression.

The LOAC can provide insight into acceptable practice should human conflict enter space. In the interpretations of some, the LOAC, if applied, would allow for an attack on military space assets if the "military advantage outweighed the collateral harm."[41] In this line of reasoning, the concept of dual-use systems becomes a concern.[42] These are systems with both a civil and military purpose. For example, some communications or earth observation systems provide service to the public and can also be used for military advantage. The concept of dual use could make these systems legitimate targets under the LOAC. If so, all nations may need to consider these systems a possible target and act accordingly. As international laws and customs evolve, a number of nations are concurrently developing their own approaches to space. These activities have significant consequences for space security.

National approaches

The following will review the activities of a number of space-faring nations as examples of the growing complexity of space security. The intent is to briefly look at the countries' involvement in space and their national views on ensuring their right to space. In any such discussion, starting with the largest player can provide broad insight on the domain as well as provide context to the actions of other players. In terms of spending, the US space budget made up 75 per cent of the world's total public (vice commercial) budget on space in 2008.[43] Due to this disproportionate investment the US is the starting point for space operations and concepts of space security.

United States

The US has acknowledged its heavy reliance on space capabilities and is well aware of the threats that exist. Economically, space is seen as an essential utility to the functioning of the country. This appreciation comes via technical issues that have demonstrated the nation's reliance on space. In one case in 1996, an error was transmitted by a single global positioning system (GPS) satellite for only six seconds. The result was an outage of over 100 cellular networks in the eastern US. In 1998, the loss of a single satellite caused pagers, banks, and news outlets to lose the ability to send data.[44] From a military standpoint, the US appreciates that "severe degradation or loss of space-based

38. Dean, 4.

39. Fergusson and James, *Space Appreciation 2000,* F-6.

40. Gallagher, 20.

41. Ibid.

42. Ibid.

43. Wolfgang Rathgeber, *Space Policies, Issues and Trends in 2008/2009* (Vienna, Austria: ESPI European Space Policy Institute, 2009), 14.

44. Peter L. Hays, "Military Space Cooperation: Opportunities and Challenges," in *Future Security in Space: Commercial, Military, and Arms Control Trade-Offs,* ed. James Clay Moltz, 32–43 (Monterey, CA: Center for Nonproliferation Studies, Monterey Institute of International Studies, 2002), 39–40.

communications and intelligence would have a major and growing impact on global US capabilities and operations, making the prevention of such an occurrence an ever more urgent priority."[45] To further protect US interests, the 2006 National Space Policy directs US opposition to "all new legal regimes or other restrictions on U.S. access to or use of space… ."[46] Understanding the need to be ready, the US military has developed fundamental concepts that capture the core tenets of military operations in space. These tenets extend the international legal concepts to space security.

Two doctrinal concepts have become core to the US discussion of space power. They are space situational awareness (SSA) and space control. The former is the monitoring of space to generate a comprehensive understanding "of [the] objects, activities and the environment" to provide commanders a foundation for planning.[47] The core of SSA is a requirement for commanders to understand the battlespace before engaging in any action.[48] From awareness and the ability to act, space control, which is the "operations to ensure freedom of action in space for the United States and its allies and, when directed, deny an adversary freedom of action in space,"[49] can be established. This idea of space control is derived from the naval concept of sea control, which shares the same goals. "As the United States, in conjunction with allies, defends the sea lines of communication, supporting freedom of passage on the high seas, so the United States and its allies can serve the same function of defending the space lines of information and supporting freedom of passage on orbit."50 This concept of space control has also spurred capability development.

The US is expending significant sums of money in relation to the rest of the world and is developing significant new space capability. A number of the experimental capabilities could be considered space weapons. The 2009 budget, beyond missile defence, contained funding for manoeuvring satellites, proximity operations, localized SSA as well as high-energy laser research and development.[51] While these capabilities are intended to provide for the defence of the US and its allies, it may be having the opposite effect. The concern is that the US will continue to under-appreciate the response of other nations, including key allies, to its actions. This concern applies even when US legal advisors consider an action permissible under current space laws.[52] More specifically, with US "efforts to achieve comprehensive space dominance," other nations, including Russia and China, will not guarantee they will not target satellites "without legally binding reassurances" on how the US will use its space forces.[53] US dominance may be setting up a classic spiral of distrust.

Russia

During the cold war, the US and the then Soviet Union remained on par with one another in terms of military space capability. With the fall of the Soviet Union, Russia has fallen behind the

45. Lincoln P. Bloomfield Jr., "A Space Doctrine for Soldier, Scientist, and Citizen: What It Will Take to Secure the Space Domain," *High Frontier: The Journal for Space & Missile Professionals* 5, no. 4 (August 2009): 18.

46. Gallagher, 12.

47. United States Department of Defense, *Air Force Doctrine Document 2-2.1 Counterspace Operations* (Washington, DC: United States Air Force, 2004), 54.

48. "A greater capability to monitor satellites in GEO is expected from Canada's space-based space surveillance satellite Sapphire, which will contribute data to the US Space Surveillance Network. The US refers to this capability as Space Situational Awareness, which the US government viewed as having greater importance after the 2007 Chinese satellite intercept. European Union (EU) member states have also discussed the feasibility of developing an independent space surveillance system, based on the existing national capabilities of a few members." West, 127.

49. United States Department of Defence, *Air Force Doctrine Document 2-2.1*, 54.

50. Fergusson and James, *Report on Canada*, 40.

51. Rathgeber, 42.

52. Bloomfield, 17.

53. Gallagher,12.

US but remains a significant space power.[54] In terms of military satellites in orbit, it is second only to the US, with a focus on strategic capability vice support to the tactical level.[55] It has also maintained a significant launch capability, and in terms of total orbital launches, it bests the world.[56] These assets and capabilities, in conjunction with its international partnerships such as the EU-Russia partnership "on launcher development and uses,"[57] have ensured Russia's role as a prominent player with significant interests in shaping the international space regime.

With a continued interest in space, and recognition of the US's space dominance, Russia has been working on the diplomatic front to ensure its security. Most notably is the Russia-China proposed Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects (PPWT). The proposal would extend a prohibition on "any type of hostile action that interferes with a space object's normal functioning."[58] This proposal, in its very name, is a direct challenge to the concepts and systems being considered by the US; systems that Russia and China believe would be "highly destabilizing."[59] Although Russia has significant military space power, it sees its security, in part, through international venues.

People's Republic of China

The official policy in the People's Republic of China (PRC) in terms of space is that its activities and technology are intended "for exclusively peaceful purposes."[60] This direction for its space program, admittedly, does not negate the military importance of space. In 2009, China released a White Paper on the modernization of its military, which included direction for its military space activities. The core idea of the PRC military space strategy is termed "active defence"; its intent is to ensure the country maintains "space and electromagnetic security." At the same time, the White Paper also makes clear China's belief that the current international space regime, based on the OST, is insufficient and indicates the PRC's support for the PPWT.[61] In the end, the purpose of the PPWT and China's role in supporting it is for security, not for protection of the environment. In terms of its support of the treaty, it should be noted that PPWT, as it stands, does not prohibit the "testing or possession of debris-generating ASAT weapons" other than those based in space.[62] Where does this place China in terms of space security?

China understands the risk to space operations from debris but is still willing to test an ASAT capability that creates significant debris, as discussed previously. China also supports the idea of making space weapons-free, and at the same time, the proposed PPWT does not prohibit ground-based ASAT systems. China's space program is defined as one of peace, but the PRC does not draw a line between its military and civilian activities that lead to activities that are dual use (military-civilian) in nature.[63] These observations form a picture of a nation that knows it does not have the capability to be a peer to a nation like the US on space capability. Accordingly, limiting this advantage in space-based ASAT is key to security. At the same time, China has developed a credible ASAT threat, be it asymmetrical in nature and damaging to the space environment, but still a

54. West, 104.
55. Ibid., 108.
56. Rathgeber, 53.
57. West, 75.
58. Gallagher, 10.
59. Ibid., 11.
60. West, 92.
61. Ibid., 61.
62. Gallagher, 11.
63. West, 92.

credible deterrent. As the US develops new capabilities, China and Russia will find a way to respond. In the end, it may be this US-Russia-China relationship that will shape the future of space law.

Summary

"The etymology of the word 'satellite' shows the Latin origin of the word, namely satellitis, which in its incipient use in antiquity meant 'garde du corps' or bodyguard."[64] Yet the discussion being held internationally by space-faring nations revolves around the threat to and from these "bodyguards." The body of law that surrounds these systems and their function is out of date or simply lacking. Weapons in space may be discouraged, but they are not strictly illegal (aside from WMDs). While similar concepts in terms of the sea and LOAC may show the future for space law, these ideas have never been tested or agreed to. Ultimately, it is the interaction of individual nations that may be forming the de facto law in terms of space operations. Those nations ill-prepared or simply not involved may have the rules written for them.

4. Canadian situation

Introduction

In Section 2, the near-Earth space environment was discussed with a particular focus on the threats to space operations, both natural and man-made. The discussion in Section 3 added the current international space policy framework, with a focus on the work being conducted through the UN, followed by an exploration of the specific space endeavors of several key countries. This section will now explore the efforts of the Canadian government and Canadian policy makers in the space domain. What will be argued is that in spite of Canada's long history and modern dependence on space-derived capability, there is no single national policy that captures the fullness of its need and intentions. Without such a policy, it is not clear how Canada will guarantee it retains access to this finite and increasingly crowded resource.

Canada has had a long history in space, which started not long after the Russian launch of the world's first man-made satellite, Sputnik. Canada's foray into space began with the launch of Alouette I in 1962, making Canada only the third nation to have a satellite in orbit. In doing so, it also set the standard for success; "in an era when satellite lifetimes were measured in months, Alouette I continued to work until it was turned off 10 years later." Subsequent systems developed by Canada helped to extend the nation's "international reputation and credibility in space."[65] A number of the systems that followed were also world firsts. These included the first national communications satellite and the first direct broadcast satellite. Subsequently, the country has developed a well-earned reputation for space robotics, astronautics, earth observation and remote sensing. In addition, Canada has contributed greatly to scientific disciplines "as diverse as astrophysics, life sciences and the dynamics of the atmosphere."[66] Canada's history of success in these space activities stems in part from government intervention early on that continues to shape the Canadian space program.

A report entitled the *Upper Atmosphere and Space Programs in Canada* of 1967, was a report commissioned by the government to look at the impact emerging space capabilities would have on Canada. Commonly referred to as the *Chapman Report* for its chair, John Chapman, it argued that the Canadian space program should be refocused on communications and natural resource

64. Bourbonnière, 1.

65. W. M. Evans, "The Canadian Space Program - Past, Present, and Future [A History of the Development of Space Policy in Canada]," *Canadian Aeronautics and Space Journal* 50, no. 1 (March 2004): 21.

66. Canadian Space Agency, *The Canadian Space Strategy: Serving and Inspiring the Nation* (Ottawa: Canadian Space Agency, 2005), 10.

surveying. The reasoning went that space infrastructure would be crucial to the future of the country, much as the railroad had been before. Complementary to the *Chapman Report* that same year, an independent report from the Science Council made the same case for focusing Canada's space efforts. In addition to the points from Chapman, the latter report included the need for industrial benefit and international cooperation and reinforced a need for a coordinating agency.[67] The ideas contained in these two reports became the very basis of Canadian space activity, and their legacy is still the conceptual basis of the program today.

A search of the outer space registry managed by UNOOSA currently lists Canada as the country/organization responsible for 30 satellites[68] launched since 1972.[69] A review of the systems listed in the register by the "function of space object" underscores the role the *Chapman Report* has had on the very function of Canadian space assets. As registered through the UNOOSA registry's period of record, a significant majority are listed as telecommunications or direct broadcast systems. Even today, a majority of the current, active Canadian satellites are telecommunication or direct broadcast systems.[70] These systems provide a core capability to Canadians and, when complemented by the systems of other nations, play a vital role in modern society.

In Canada's case, the benefit derived from space is even more important. Canada's increased space requirements are a direct result of the size of the Canadian land mass. Due to the size of the country, the curvature of the Earth itself creates a natural obstacle.[71] No nation on the Earth's surface is perfectly flat, but due to the size of Canada—both east and west, north and south—the curvature has a significant impact. The value of space is the height Earth orbit provides. From a carefully selected orbit and the right satellite configuration, the constraints dictated by the curvature of the planet are rendered moot.

The capabilities and conveniences derived from space are requisite parts of a knowledge-based society. Whether it is the functioning of international finance, the core of worldwide navigation, the time synchronization of the critical systems, or the remote sensing of world events, space is critical to Canada.[72] The value to the country can be broken out into three key areas: remote sensing, satellite communications, and satellite navigation and timing. First, remote sensing is crucial, as it permits the monitoring of the environmental conditions. Nationwide weather prediction, as it exists today, would not be possible without the view from space. Additionally, the ability to monitor ice floes, forest fires, or crop damage would be extremely limited. The accuracy of modern cartography would also not exist across large, uninhabited expanses within the country. Finally, from a military and security perspective, satellites provide the unique ability to gather intelligence, monitor coastlines and borders, and even conduct arms verifications that would be otherwise impossible without them.[73]

The second key area where space is critical is in the provision of satellite communications. Satellite operations are an essential component of global communications and are incredibly important to Canada. As evidence of their importance, "Canada has the largest space transponder use per capita

67. Evans, 21.

68. United Nations Office of Outer Space Affairs, "Online Index of Objects Launched into Outer Space," http://www.oosa.unvienna.org/oosa/osoindex.html (accessed October 11, 2012).

69. The Convention on Registration of Objects Launched into Outer Space did not come into effect until 1976. Space objects are self-reported by the registering and/or launching nation.

70. Union of Concerned Scientists, "UCS Satellite Database," http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/technical_issues/ucs-satellite-database.html (accessed October 11, 2012).

71. Fergusson and James, *Report on Canada*, 6.

72. Fergusson, "Out of Sight," 16.

73. Fergusson and James, *Report on Canada*, 54. Examples are taken from Table 4.9.

of any country in the world," except for the US.[74] Satellite communications afford an opportunity to extend the reach of information anywhere in the country, regardless of the infrastructure. For example, this facilitates the provision of specialist medical or educational services; where in the past, they would otherwise not be available. Satellite communications also ensure a link in times of emergency or natural disaster. These uses are in addition to the equally important bulk transmission of communications in support of telephone, data, radio, and television. This same ability to move information rapidly, independent of terrestrial capacity, makes space communications an essential component of military operations.[75]

The third and final key area where space is critical to Canadian interests is satellite navigation and timing. These services are derived primarily from the current US GPS. The satellites of GPS use a synchronized and highly accurate time signal in the process of calculating a location on the Earth's surface. Due to the accuracy of the time signal across the global fleet of satellites, it is often used in situations where an accurate and consistent time stamp is required. Today, for example, communications and financial activities around the world are reliant on GPS time for synchronization of individual transactions. More traditionally, GPS facilitates the flow of everyday life. The capacity for worldwide navigation, tracking (i.e., animals, vehicle fleets, or packages) and the increased accuracy for mapping and surveying make GPS invaluable to a modern society.[76]

The area of navigation and timing is unique in the Canadian context, as it is an area that the country currently has no national capacity to replicate. What this means for Canada is that these critical services are provided by another nation. Therefore, the functions of the country that rely on these services are intimately linked to the actions and interests of the US. This is not to infer that the US would use GPS to influence Canada, but it is important to recognize that a dependency exists. A failing of the GPS service, as highlighted by the previously mentioned 1996 timing error, has equally significant consequences for Canada. There may be alternative sources of timing and location in the future to mitigate any risks. These sources could include the Russian Global Navigation Satellite System (GLONASS), once restored, or the European Galileo project, once completed.[77] Of note, Canada is participating in the development of the European project.[78] Having access to an alternative source for such a key service is simply prudent.

Existing policy within the Government of Canada

At this point it is important to appreciate that Canada is a modern, information-based society, with a heavy dependance on space technologies required in order to function. Due to the level of integration of space-derived capabilities, a loss of these services would have significant economic, industrial, and societal impacts. The difficulty with space assets is that their presence is invisible to daily life. Therefore, the ubiquitous nature and importance of these systems is often overlooked. "Overall, space-based systems have become the unseen and poorly understood backbone of a modern information-based … society."[79] With this idea taken in concert with an understanding of the hazards to space operations developed in previous sections, it is now appropriate to look at Canada's space-policy base. Of particular importance to this discussion is policy that exists to ensure a defence of Canada's space services and access.

74. Ibid., 54–55. Examples are taken from Table 4.10.

75. Ibid., 55. Examples are taken from Table 4.11.

76. Ibid., 56.

77. Ibid., 55.

78. Canadian Space Agency, *Canadian Space Agency Departmental Performance Report- Detailed Performance Information* (Ottawa: Canadian Space Agency, 2009), 84.

79. Fergusson, "Out of Sight," 16.

Government of Canada

The exploration of Canada's policy framework for space activities will begin with the direction provided by the Government of Canada. The focus here is the political direction that is in place to guide the departments, agencies, and bureaucracy in their related space functions. It is acknowledged that the individual departments and agencies have a hand in the development of government strategy, but it is ultimately the agreement of the government that makes the strategy a valid direction. Starting from a broad perspective, acknowledgement of Canada's current status with respect to international treaties on space is essential. Canada's relationship to these treaties defines a key aspect of any national space-policy framework.

In Section 3 of this paper, the five UN treaties on space were discussed and Canada's status in relation to them was presented. These treaties provide an international framework that defines where Canada is legally constrained and restrained in terms of its activities in space. In the review of the treaties it was clear that the key in terms of defining Canada's policy limits for defending its space capabilities is the OST, which "established the fundamental premise on which all law in outer space is based, that outer space should be utilized for the benefit of mankind generally and is not to be the subject of national appropriation."[80] In terms of defending space assets, this guiding international space document has little to say. The OST has its limits, in part due to its origins at a time when there were primarily two nations in space focused on mutual deterrence.[81] Ultimately, there is "no clear-cut guidance about where the right of safe passage for peaceful purposes ends and the right of self defenses takes over." Some space-faring nations have also noted that the only specific prohibition is on "orbiting weapons of mass destruction."[82] Canada has taken a more general interpretation.

Canada has made it very clear that it does not see the weaponization of space as a way forward for the nation. Most recently, in 2004, during discussions on whether Canada should participate in the US National Missile Defense program, then Prime Minister Paul Martin made it clear in Parliament that Canada would not participate in the weaponization of space. Additionally, Canada's lead negotiator on the file, Jim Wright, stated before a Senate committee in February 2004 that "Canada makes 'a clear distinction between the military in space and the weaponization of space,'" and that government policy was to ensure it remained a "weapons-free environment."[83] Beyond ratification, these statements reinforce Canada's current support for the contents of the treaties. Accordingly, the treaties provide a basis for Canada's principles on the usage of space. Policy developed within Canada with respect to space must ensure compliance with these treaties. From here the discussion moves to identifying what government policies or strategies currently define how it will ensure access to space now and into the future. To do so, the *Canada Firs*t Defence Strategy (*CFDS*) and the Canadian Space Strategy will be discussed.

The *CFDS* was announced by Prime Minister Stephen Harper on 12 May 2008, and was followed up with the release of the written document on 19 June 2008. The intent of the *CFDS* was to provide the Department of National Defence (DND) and the Canadian Forces (CF) renewed direction along three main priorities. These priorities were to strengthen domestic capability, meet North American defence commitments, and contribute in a meaningful way to international security.[84] The actions designed to meet these priorities were broken out over four pillars, seen in

80. Brian MacDonald, 95.

81. Gallagher, 15.

82. Ibid., 20.

83. Webster, "The Ultimate High Ground," 49.

84. George MacDonald, *The Canada First* Defence Strategy – *One Year Later* (Calgary, Alberta: Canadian Defence & Foreign Affairs Institute, 2009), 1.

the *CFDS* as the basis of military capability. The pillars were personnel, equipment, readiness and infrastructure.[85] Overall, the document provided a plan for reinvesting in Defence, provided general guidance to the department, and defined a way forward. The *CFDS* also served as notification of investment in the "industrial, knowledge and technology sectors." The deliverables from the *CFDS* were intended to contribute to the development of those sectors over the plan's 20 year lifespan.[86] In providing this direction, what did the Strategy have to say about space?

Simply put, space, as an issue or area of concern, is not in the *CFDS*. That is not to say it is not there at all, but its inclusion is tangential to the other activities outlined. To find space in the document, one has to be looking with it in mind. The *CFDS* states that it will allow the CF to "address the full range of defence and security challenges facing Canada now and into the future."[87] This statement would seem to point to space as one of many future challenges the CF will face, but only if the reader has knowledge of space operations. The *CFDS*, in its discussion of the level of ambition, states that Canada requires "core capabilities … to successfully address both conventional and asymmetrical threats, including terrorism, insurgencies and cyber attacks."[88] Again, conventional and asymmetrical attacks could be directed at Canadian or partner space segments, but the threat to space is not explicit.

Within the *CFDS* there is only one explicit statement on space capability and no reference to space as an area of concern. The only point where it addresses space directly is through the stated need for "radars and satellites to improve surveillance capabilities, especially in the arctic."[89] While this is valid direction in terms of achieving a greater degree of visibility over the arctic or, more generally, terrestrial surveillance, as an example, it also highlights the current perception of space. Space, at the moment, is thought of in terms of being a solution to other interests or concerns, not as an issue itself. Fundamentally, the *CFDS*, through its terrestrial focus, does not provide the guidance or strategy necessary for Canada to address defending access to its space-based assets. The *CFDS* has moved the CF forward in a number of areas, but space and, more importantly, the defence of space are not among them.

The Canadian Space Policy Framework, on the other hand, is keenly focused on Canada's involvement in space. The framework was put in place in 1994 by the Government of Canada to guide the Canadian Space Program. In its narrative, it acknowledges space as strategically important to Canada's economy and interests. The focus of the framework is on the social, economic, regional, and industrial benefits space can provide to the country. To achieve this a program of specialized capabilities was put in place to derive maximum benefit in areas that best fit Canada's "needs and policy objectives." The four areas of the programme are robotics, remote sensing, communications, and science. Other areas that were resource intensive or did not fit the selected niches, such as launch and satellite navigation, were to be accessed through international partnership.[90] The intent of the framework was to provide a capable space sector that could meet Canadian needs and compete commercially. As a comparison to the *CFDS*, what does the framework have to say about defending space capability?

85. Privy Council Office, *Canada First* Defence Strategy (Ottawa: Privy Council Office, 2008), 14.

86. Ibid., 20.

87. Ibid., 4.

88. Ibid., 7.

89. Ibid., 18.

90. Canadian Space Agency, "The Canadian Space Policy Framework," http://www.asc-csa.gc.ca/eng/industry.policy.asp (accessed January 26, 2010, site discontinued).

Much as the *CFDS* spoke little of space, the Canadian Space Policy Framework speaks little of defence, let alone defence of space. The framework's focus on industry, science, and niche capabilities make for a well-thought-out approach to develop interest and capacity in Canada. At its heart, it is a practical document which defined a way ahead for Canada to exploit value in space and technology, while remaining focused on Canadian interests. What it lacks is acknowledgment of the threats-in-space environment that can impact any and all activities in space. Ultimately, the Canadian Space Policy Framework has moved the Canadian Space Agency (CSA) forward in a number of areas, but defence and, more importantly, the defence of Canada's space activities are not among them. As the implications of space protection or defence are profoundly national security concerns, it is important to consider Canada's national security policy.

Securing an Open Society: Canada's National Security Policy was developed in 2004 to provide "an integrated approach to security issues across the government."[91] In doing so, it became a consolidation document for high-level threats and corresponding responses of the Government of Canada. This consolidated policy defined eight threats to Canada and Canadians. The threats as listed were terrorism, proliferation of weapons of mass destruction, failed and failing states, foreign espionage, natural disasters, critical infrastructure vulnerability, organized crime, and pandemics.[92] Throughout the entire policy, there was only one reference to space, and it was to reaffirm Canada's "long-standing opposition to the weaponization of space," specifically in relation to the country's role in national missile defence.[93] Outside this single reference to space, its threats and impact on society did not make the document. Even in the consideration of critical infrastructure—an area of concern—space was not included. What was included was an action item for the Government of Canada to begin development of a critical infrastructure protection strategy that would involve all levels of government, industry, and international partners. Progress on the action items contained within the national security policy was released in a follow-on document the next year.

Securing an Open Society: One Year Later was produced by the Government of Canada to document the progress on initiatives created under *Securing an Open Society: Canada's National Security Policy*.[94] With little in the initial policy on the matter of space protection, there was similarly scant discussion of the subject within the follow-on report. In this latter document, the only mention of the word "space" was in terms of cyberspace. Canada's decision to stay out of national missile defence was not mentioned in the report, as it had been in the original policy. The only area of interest in this discussion of space asset protection was an update on critical infrastructure, though again space was not specifically mentioned. Simply, the government was making progress in terms of developing a national critical infrastructure protection strategy. A position paper on the proposed strategy was produced by Public Safety and Emergency Preparedness Canada (now known as Public Safety Canada), and this paper was used in discussions that were happening across the depth and breadth of government.[95] The issue of critical infrastructure would continue within Public Safety Canada, but *Securing an Open Society: One Year Later* was the last direct evaluation of progress against the national security policy.

The three current national policies that border the concept of space asset protection are disconnected and provide no guidance when it comes to the defence of Canadian space assets. The *CFDS* provides Canada's defence focus for the next 20 years but, for the most part, excludes the

91. Privy Council Office, *Securing an Open Society: Canada's National Security Policy* (Ottawa: Privy Council Office, 2004), vii.

92. Ibid., 6–8.

93. Ibid., 49.

94. Privy Council Office, *Securing an Open Society: One Year Later* (Ottawa: Privy Council Office, 2005), 2.

95. Ibid., 22.

protection of space. The Canadian Space Policy Framework, on the opposite extreme, provides the clear objectives for the nation's involvement in space but excludes consideration of protecting the country's capability. Finally, the national security policy provides no detail on space infrastructure as a critical infrastructure or otherwise. Essentially, there is a national strategic gap, made clear by the lack of a single definitive policy or reference to Canada's approach to ensuring Canadians' access to space-derived services. This point was echoed by former astronaut and former head of the Canadian Space Agency Marc Garneau, when concerns were raised about the sale of Canada's Radarsat-2 and the associated technology to a US company. Fundamentally, Canada has no national space policy.[96] With the acknowledgement of the fact that there is no national policy umbrella for space, it is important to look at the work being done within the individual departments.

Canadian Space Agency

The Canadian Space Strategy was developed and approved by the CSA in 2003 as its internal guidance for the management of Canada's space program. It was designed to capture in one document the details needed by planners, stakeholders, and partners on Canada's strategic space direction.[97] In February 2005, the strategy was subsequently approved by the Government of Canada so it could be used "in focusing decision making at CSA and aligning all space related program activities through its strategic outcome and long term priorities."[98] The strategy largely followed in the footsteps of the Space Capability Framework. The strategy's main thrusts were now termed earth observation, space science, communications, and education. The document, like the framework, has at its heart a focus on the development of and support for the Canadian space sector. That said, beyond the ideas it shares with the framework, it does expand and refine the vision of the Canadian Space Program.

The CSA vision articulated within the Strategy is expanded to include a role in bringing the value of space to the rest of government. Specifically, the CSA will "integrate space fully and completely in Government of Canada Departments and Agencies as an invaluable tool to help fulfill their mandates … ."[99] From the perspective of defence, the strategy goes so far as to provide "target results" that focus on security and foreign policy. The CSA sees as part of its role support for surveillance related to national security and sovereignty as well as surveillance in support of Canada's foreign policy initiatives around the world.[100] That is where the expanded vision and the strategy end in terms of defence. Security continues to be defined exclusively as an application of space, but even then, it is only touched on briefly. Protection of Canada's space segment seems to remain outside the CSA mandate.

Within the CSA guiding documents there is a keen focus on commercialization, building industry, and technology spinoffs. Some have suggested that this is likely due to the agency's subordination to Industry Canada,[101] as the Industry portfolio of the government would have significant influence on decisions and approvals within the CSA. Recognizing this relationship, the question still remains how to best protect Canadian industry, which includes its interests and the space assets it relies upon. Such considerations are not clear in the strategy. Going beyond the strategy documents to the departmental performance reports provides a more detailed insight into

96. Canadian Broadcasting Corporation, "Sale of MDA Units Leaves Canada's Space Ambitions in the Air: Garneau," http://www.cbc.ca/technology/story/2008/01/11/tech-mda-space.html (accessed October 11, 2012).

97. Canadian Space Agency, *The Canadian Space Strategy*, 5.

98. Canadian Space Agency, *Canadian Space Agency 2008–2009 Departmental Performance Report* (Ottawa: Canadian Space Agency, 2009), 4.

99. Ibid., 7.

100. Canadian Space Agency, *The Canadian Space Strategy*, 7.

101. Fergusson and James, *Report on Canada*, 65.

the activities of the CSA. What is clear within the CSA's *2008–2009 Departmental Performance Report* is that some threats to space operations are being considered.

Debris in space is the main standout in the *Performance Report*. The document recognizes it as a concern for space operations that "favour[s] increased cooperation between nations with common goals."[102] The report is also clear on the significant rise in the use of space, stating that there are an increasing number of countries using space with "close to a thousand satellites … expected to be launched in the next ten years."[103] While the document does not go to great lengths to detail the current efforts on these issues, it is important to recognize that they are part of the considerations within the CSA. A further appreciation of the CSA's activities can be gained by reviewing the missions listed in the 2009 detailed *Performance Report*.

There are a number of missions listed in the *Performance Report* that demonstrate there is activity within the CSA to look at the protection of space-based assets. Their presence highlights that some protection issues are being considered. None of the missions listed are exclusively defensive in nature; they are more appropriately labeled dual use, but that does not negate their value in this area. Of particular note are the Outer Radiation Belt Injection, Transport Acceleration and Loss Satellite (ORBITALS), Near-Earth Object Surveillance Satellite (NEOSSat) and Canadian Satellite Operations Centre (CANSOC) missions. ORBITALS is a satellite-based physics mission that will explore the space weather and radiation of near-Earth space. This mission is of value to all space operators, as the knowledge gained will help to minimize the impact of space weather in the future. The second mission, NEOSSat, is a joint venture between CSA and DND. Its purpose is the tracking of asteroids in the inner solar systems as well as the tracking of satellites in high-Earth orbit to update their orbit details.[104] NEOSSat provides an excellent example of what cooperation between government organizations can provide. A final example on the horizon is CANSOC. The value in this mission is that it affords Canada a facility "for end-to-end operations and management of satellite missions."[105] While still a concept under review,[106] its implementation would also provide a capability that could unify space operations across the government.

Taking the activities within CSA into account, it is clear that the agency has the awareness and the capacity to help address the issue of defending Canadian space assets. What is lacking is a specific mandate which defines its role in relation to defence of space assets. From the time of its creation, the CSA's mission was defined in terms of "the peaceful use and development of space."[107] This philosophy has worked for Canada and the agency and would continue to as long as space remained a new frontier. Now, with space becoming congested and contested, the requirement to defend space assets is becoming an essential ingredient of space operations. This burden is not the CSA's alone. In the current portfolio structure, the defence of space falls into the territory of a number of government organizations.

Department of Foreign Affairs and International Trade

The Department of Foreign Affairs and International Trade (DFAIT) is Canada's face to the world. It exists to project Canada's influence. Its mandate, in part, is to ensure "that Canada's foreign policy reflects true Canadian values and advances Canada's national interests." It does this by working

102. Canadian Space Agency, *Canadian Space Agency 2008–2009 Departmental Performance Report,* 16.

103. Ibid., 8.

104. Canadian Space Agency, *Canadian Space Agency Departmental Performance Report- Detailed Performance Information,* 94.

105. Ibid., 81.

106. Ibid., 6.

107. Canadian Space Agency, *The Canadian Space Strategy,* 3.

with "partners inside and outside government to achieve … enhanced security for Canada … ."[108] This responsibility extends equally to the department's involvement in space and space defence, just as it would to any other area of Canadian interest. As an outward facing department, what role does DFAIT play in terms of policy for defence of Canadian space assets?

While DFAIT, by mandate, would not define a national space policy itself, its activities in international fora as well as its research activities make it an important player in national policy development. Canada has a history of involvement in the development of space law. DFAIT has been Canada's voice in the negotiation of the international space treaties. It effectively targeted areas where the country can make the greatest contribution, but also areas of great national interest. One such example was the advancement of principles on nuclear power sources in space, where Canada took a lead role in response to the crash of the nuclear powered COSMOS 954 on Canadian soil.[109] The work being conducted in the area of treaties and international agreements on space is important. By signing on to any one, Canada is essentially defining its space policy both internationally and domestically. With that said, it must be understood that international agreements are about compromise and, therefore, may not reflect the totality, but only a threshold of a nation's position in an applicable field. Accordingly, while they do shape it, Canada's acceptance of international agreements does not replace a need for national policy.

DFAIT has provided a litmus test in terms of a national space policy. Its work in the past on international space treaties is but one aspect. The 2005-released *Canada's International Policy Statement: A Role of Pride and Influence in the World* provides some insight into the international interests of the government. In terms of space, its focus is on two aspects: the weaponization of space and the space application in surveillance. The latter is discussed as part of its terrestrial role in the defence of Canada and North America with the US. Meanwhile, Canada's "policy against the weaponization of space"[110] is a traditional role that relates back to its past treaty work and focuses on arms control and disarmament.[111] In the end, the most recent policy statement provides no clear direction on space outside of these traditional concerns.

In acknowledging the contents of the policy statement, it should be made clear that DFAIT is going beyond what is contained within it and is considering the broader issues of space and space defence. In part, it has begun to promote "multi-lateral measures to manage a range of pressing space security questions, such as launch notification, debris mitigation and orbital slots."[112] These additional activities will help further the discussion on these key areas and develop a body of knowledge on the issues. Additionally, the department has been developing policy ideas and discussions through its International Security Research and Outreach Programme, which, through the engagement of academic organizations and think tanks, has developed policy ideas in a number of areas including space security.[113] This work is important to developing knowledge of the issues and in DFAIT's role being able to address the international considerations of space. The activities of DFAIT could play a role in the development of a national policy, but they do not replace one.

108. Department of Foreign Affairs and International Trade, "About the Department," http://www.international.gc.ca/about-a_propos/index.aspx (accessed October 11, 2012).

109. MacDonald, *Space Strategy*,108–109.

110. Department of Foreign Affairs and International Trade, *Canada's International Policy Statement [A Role of Pride and Influence in the World]* (Ottawa: Department of Foreign Affairs and International Trade, 2005), 8–9.

111. Fergusson and James, *Report on Canada*, 64.

112. Ibid., 65.

113. Department of Foreign Affairs and International Trade, "International Security Research and Outreach Programme (ISROP)," http://www.international.gc.ca/arms-armes/isrop-prisi/ (accessed October 11, 2012).

Public Safety Canada

Public Safety Canada is the lead department for domestic security in Canada. Its role is to unify and coordinate the efforts of "federal organizations dealing with national security, emergency management, law enforcement, corrections, crime prevention and borders."[114] Through this function, the Minister of Public Safety defines the policy and mechanisms used to protect the country. This role includes the policy for and the protection of Canadian infrastructure. Having recognized above the importance of space assets or space infrastructure, what is the role that Public Safety Canada plays in terms of protecting these assets?

To answer this question, one has to go back to the national security policy discussed above and recognize that space is not defined as a security issue. The closest the policy comes to touching the issues of space operations is in consideration of critical infrastructure. At the time, critical infrastructure was not specified except as an action item to develop a National Critical Infrastructure Protection Strategy. That strategy is still not published, but a Public Safety Canada draft document entitled *Working Towards a National Strategy and Action Plan for Critical Infrastructure (2008)* underscores by its absence that space as a domain is not a consideration in critical infrastructure. The sectors that are listed in the draft are: energy and utilities, communications and information technology, finance, health care, food, water, transportation, safety, government, and manufacturing.[115] Each of these areas is then assigned to a responsible federal department. The departments are the federal lead in terms of advancing a "collective national approach to protecting critical infrastructure."[116] As close as this draft gets to the protection of space assets is through the assignment of the communications and information technology sector to Industry Canada. In consideration of the complexity and implications of operations and protection in the space environment, this allocation of communications only captures a portion of the space-derived services. The implications of losing space assets or space capability are significant to all the defined sectors, when the breadth of space-derived services is considered. That is not to say other aspects are not being taken into account, but the breadth of the space capability is too large to not be a specifically documented area of concern.

In terms of space infrastructure, what is left for Public Safety Canada is a role for "coordinating and facilitating" should an incident arise. What is lacking is the capture of all the space services and infrastructure that are critical to the country.[117] It is important to acknowledge that communications is not the sole space-based capability and that space services, in their entirety, need to be managed as a whole. If that is not well understood, Public Safety Canada will not be able to fulfill its emergency management mandate. Interestingly, the equally broad concerns of cyberspace warrant significant consideration in the national security policy and related documents. In response, Public Safety Canada operates the Canadian Cyber Incident Response Centre, which monitors and coordinates Canada's response to cyber incidents against critical infrastructure.[118] A similar function in support of space infrastructure would be a logical extension, but only when space becomes critical infrastructure in its own right. Until that occurs, Public Safety Canada's role in protection of space assets will be limited.

114. Public Safety Canada, "Who we are" http://www.publicsafety.gc.ca/abt/wwa/index-eng.aspx (accessed October 11, 2012).

115. Public Safety Canada, *Working Towards a National Strategy and Action Plan for Critical Infrastructure - Draft for Consultation* (Ottawa: Public Safety Canada, 2008), 23.

116. Ibid., 15.

117. Ferguson, *Report on Canada*, 61.

118. Public Safety Canada, "Canadian Cyber Incident Response Centre," http://www.publicsafety.gc.ca/prg/em/circ/index-eng.aspx (accessed February 24, 2010, site discontinued).

Department of National Defence

The Department of National Defence had a significant role in space very early on. As time went on, however, the government increased its focus on space and the military benefits decreased in priority. The origins of Canada's space program can be traced to DND. In fact, Alouette was produced through the work of the Defence Research Telecommunications Establishment (DRTE), then a part of DND. The reductions in DND involvement occurred over a number of years starting in the late 1960s. Through the years, "Canada's space programs were transferred to civilian and private-sector organizations … except for a handful of personnel assignments within the North American Aerospace Defence [Command (NORAD)] … ."[119] The withdrawal of DND from space began with the removal of DRTE from Defence, placing it instead within the newly formed, civilian-run Department of Communications as the Communications Research Centre.[120] This, and subsequent changes, clearly signaled Canada's involvement in space would be primarily a civilian endeavour. This decrease in military programmes continued on through to the 1980s, where military involvement was "only 10 per cent of the Canadian government's space-related spending."[121] As seen in previous sections, space is becoming an increasingly contested and congested domain. Canada has enjoyed the benefits of space through an increasing number of systems and services and accordingly has a national interest in maintaining access.

Accordingly, "space interest inside DND is on the rise."[122] Knowledge of the importance of space in terms of its economic, scientific, and military importance "now resonate within Canada's Department of National Defence."[123] "Space is also of growing importance to the Canadian Forces …" itself, as nations who cannot use it will be left behind, unable to exploit the capability for their own needs, and, ultimately, will find it exceedingly difficult to remain interoperable with partner nations, in particular the US.[124] As well, DND recognized that the threat goes beyond military operations and includes risks to Canada's domestic infrastructure. In response to the increasing concern over space operations, the department has developed an updated National Defence Space Policy and an associated National Defence Space Strategy. As of the writing of this paper, both were still in draft, but permission from Directorate Space Development was received to use the material.

The *2009 National Defence Space Policy*[125] is a significant document, as it addresses the key issues that affect space operations. It is also careful to make clear the department's role relative to others in government. From the beginning, the document underscores the importance of the space environment to both the CF and the Canadian public. It also points out a number of threats that must be addressed, including the space environment itself, collisions and debris, and the vulnerability of the systems to attack. In response to the current environment, DND has set out three goals: to ensure access to space, to use the unique capabilities afforded by space, and to protect critical space systems. Interestingly, the protection of space systems is specifically limited to those assets that are "critical to National Defence, both national and allied … ."[126] To achieve these goals, the policy defines a series of capabilities required by the department, a number of which have application to the protection of Canadian space assets.

119. James, "Space is Becoming Crucial," 65.

120. Evans, 22.

121. James, "Space Is Becoming Crucial," 65.

122. Ibid., 65.

123. François Malo, "Schriever V: Lessons Learned - A Canadian Perspective," *High Frontier: The Journal for Space & Missile Professionals* 5, no. 4 (2009): 30.

124. James, "Space is Becoming Crucial," 66

125. Department of National Defence, *National Defence Space Policy 2009 - DRAFT* (D Space D Version 5), 1.

126. Ibid., 3.

The two key capabilities in the space policy that will contribute to the protection of space assets are space domain awareness and command and control. First, space domain awareness will provide the CF with the capacity to monitor objects in Earth orbit, be they natural or manmade, in order to avoid collisions. This capability would also extend an awareness of "man-made interference" that would allow for the determination of the actors involved. The second capability is the development of a "comprehensive command and control system" with the associate infrastructure required to track, manage and control systems in orbit. This capability is acknowledged to require a partnership with the other government users.[127]

Beyond the discussion of threats and capability, the policy recognizes the larger framework within which it must function, at the same time providing focus to DND's efforts. Explicit in the document is that the policy is the centrepiece of DND's efforts in space, and all space-related initiatives will be governed by it. It is also clearly stated in the document that DND's space capabilities "will be in accordance with this policy and relevant international law, including space treaties and international space agreements ratified by Canada or otherwise supported as part of Government of Canada policy … ."[128] It is also clear in the document that interdepartmental cooperation is essential to DND efforts to maximize the value of "versatile multi-purpose missions" but also to ensure national defence and security aspects are part of any discussion. This need for cooperation is further extended in the guidance to include Canada's international partners, predominantly the US (including NORAD), North Atlantic Treaty Organization (NATO) and traditional allies such as "the United Kingdom, Australia and New Zealand."[129] The National Defence Space Strategy adds specifics to the concepts in the policy.

The *National Defence Space Strategy*[130] starts out by again reaffirming the importance of the space-derived services, the natural difficulty of the environment, and the threat posed by ease of space access for an increasing number of actors. It then makes the policy connection to the *CFDS* and National Defence Space Policy. Access to space-derived capability is an essential component to the success of the CF mission. The focus is on what space delivers terrestrial operations, and again, there is no mention of a requirement to protect space systems in relation to the *CFDS*.[131] That said, the real heart of the strategy is in its assignment of key tasks and activities. This is where DND's space actions over the next couple years are defined and where ideas on addressing the defence of space assets are contained.

The department believes there is a need to strengthen the CSA's infrastructure and capabilities from a launch capacity through to the management of space assets. To do this, DND will build on the existing relationship between the departments defined in a series of memoranda of understanding and update the relationship to demonstrate this strategic focus for the two.[132] As an extension of the need to strengthen space infrastructure, the strategy outlines the CF need for a Canadian Space Operations Centre whose functions would "apportion, control and protect" Canadian capability.[133] Complementary to the needs for command and control of space assets is the requirement for space domain awareness. The strategy lays out a need for a Canadian capability to bring together information on space weather and systems status, along with detection, tracking, and analysis. This would be done again in concert with other government departments and allies.[134]

127. Ibid., 4–5.

128. Ibid., 2.

129. Ibid., 7–8.

130. Department of National Defence, *National Defence Space Strategy - DRAFT* (D Space D Version 4.4), 1.

131. Ibid., 2.

132. Ibid., 5–6.

133. Ibid., 7.

134. Ibid., 8.

Ensuring access to space-derived services has also been identified within the National Defence Space Strategy. The department will work with US partners to ensure that information on threats to space assets are disseminated. In addition, the strategy notes there is an active threat from other nations that "field offensive counterspace [sic] capabilities" and that critical national satellites "will need to possess self-defence capabilities." Taken to its logical conclusion, the strategy also provides for DND to explore "active protection measures" that would deny space capability to others. This concept would be restricted to actions "that are temporary, reversible and localized."[135]

While hitting the high notes on protection of Canadian infrastructure, the restriction to those that are specifically necessary to the CF highlights the issue in government. There is no single organization charged with taking a holistic approach to the defence of Canadian space infrastructure. In its policy and strategy, DND makes it clear there is a need for a focused whole-of-government approach to space activities, including defence of national infrastructure. Canadian Forces documents acknowledge this by outlining the need for cooperation with other agencies, departments, and allies. The missing component seems to be simply one of mandate. The fact that the National Defence Space Policy goals specifically focus on DND is likely an intentional decision. The statement leaves questions that point to a need to engage other departments. It should not be taken as a statement that the department is not interested in the protection of the other departments and commercial assets. The statements of the former Director Space Development, Colonel François Malo, show this is simply not the case. He states, "the military mandate is to protect the homeland—that now includes Canadian civil, commercial and military space."[136] So where does the sum of Canadian policy leave the concept of protecting space assets?

Canada's policy situation

After a review of Canada's space-related policies and strategies, it is clear that Canada currently has no comprehensive national strategy for space. By extension, the government has no core policy or strategy to deal with the protection of its space assets or of ensuring national access to space-derived services from industry and allies. Government-level documents view space as a solution to other, mainly terrestrial, concerns, not as a problem space unto itself. What is clear is that some government departments are involved in defining Canada's role in space but do so exclusively within their area of responsibility. The point is not to condemn or condone these activities, as they are important in their own right, but to simply highlight the lack of a singular national focus on space. Due to the gaps between initiatives, key issues such as ensured safety and access to national (including commercial) space assets are missing from the discussion. Canada is not alone in terms of not having a comprehensive strategy. Even the US, arguably the most advanced nation in this regard, has had difficulty in generating a truly comprehensive space strategy that captures all facets of space as a strategic asset.[137] What the US has that Canada lacks is a national strategy that includes protection of its space assets.

What is clear is that this is an area the Canadian government needs to consider. In military parlance, space has become a centre of gravity (COG), which is both a national strength and a weakness.[138] A COG is defined as "characteristics, capabilities or localities from which a nation, an alliance, a military force or other grouping derives its freedom of action, physical strength or will

135. Ibid., 9.

136. Malo, "Schriever V: Lessons Learned," 31.

137. Joan Johnson-Freese, *Space as a Strategic Asset* (New York: Columbia University Press, 2007), ix.

138. James, "Space is becoming crucial," 67.

to fight."[139] The increasing space dependency of information-based societies and their militaries has provided significant advantages to nations, but that same dependence has also become an Achilles heel. Protection of this weak spot is absolutely vital to the well-being of the nation as a whole as much as it is for the success of a modern armed force.

"We cannot afford a day without space—our global economy is fuelled by space effects." Infrastructure and economies would take the brunt of the impact, as it would take months or years to replace what was lost.[140] A pan-government approach is needed to bring the issue of space protection in from the periphery of policy, but this will require recognition of the threat and genuine interest in meeting that threat.

Canadian space policies, as they stand, will not protect the nation's interests in space until the reasons behind them move beyond satellite effects to a full appreciation of the space environment. There is no explicit or unifying guidance from the Government of Canada that deals with the specific aspects of ensuring the safety of these systems and the vital functions they support. The problem is that space as an area of concern is "out of sight and out of mind," which will require a strategic re-think by the whole of government.[141] This is a tall order, considering the dynamics of current Canadian politics, the state of the economy, and a general lack of interest from the Canadian people. The implications of losing space assets are simply not a concern to the public nor, therefore, to the government. Without an impetus to change, space will remain "buried within the governmental process itself, its access to cabinet constrained and its message diluted."[142] Acknowledging the need for a spark for the government to rethink space, where would one come from?

In the most severe circumstances such motivation could come in the form of destruction of, or damage to, a country's infrastructure. Attacks like those in New York, Washington, and rural Pennsylvania on September 11, 2001 can have a profound effect on government. The attacks motivated governments in the US and Canada to change the way they viewed domestic threats. Further back, the Japanese attack on Pearl Harbor had a similar effect on the US government, causing it to react and, ultimately, led to the US involvement in World War II. The US has learned from the past and has recognized the threat to space operations. "As early as 2001 the Report of the Commission to Assess United States National Security Space Management and Organization warned that US dependence on space systems made it uniquely vulnerable to a 'space Pearl Harbor' . . . ."[143] The US has been looking at space as a threat environment of equal importance to terrestrial concerns and is reacting accordingly. The threat to space assets is real, and Canada is equally dependent on space-derived services.

Canada needs to focus its divergent departmental efforts in part on ensuring the national space assets and services are not disturbed. An attack on or major outage of space systems, whether national or shared, would have a significant and immediate effect on the country. In addition, collateral damage from new debris that could result from such an event would have a longer-term impact on all space users in that orbit and lower, regardless of nation. These issues do not stop with active targeting of space assets but also include accidental collisions with existing debris, other satellites, and the natural effects of the space environment itself. If the effect of any such damage to space segments on which Canadians depend is significant enough, the population, commercial industry and, ultimately, the Government will be interested, but by then all solutions will be reactions.

139. Department of National Defence, B-GJ-005-500/FP-000 *Canadian Forces Operational Planning Process (OPP)* (Ottawa: DND/MDN Canada, 2008), 2-1, http://publications.gc.ca/collections/collection_2010/forces/D2-252-500-2008-eng.pdf (accessed October 11, 2012).

140. Malo, 31.

141. Fergusson and James, *Report on Canada*, 59.

142. Ibid., 60.

143. West, 107.

Without a definitive statement from the Government of Canada that defines Canadian intentions in space, it is exceedingly difficult for the various departments and agencies to synchronize their efforts. Furthermore, without clearly defined roles or leads in this domain, important areas of policy and action will be hindered or remain dormant, because it is not clear where the authority lies. Often it is only when crisis strikes or a problem lands in their backyard that nations react. Canada itself is an excellent example. In 1978, then Soviet COSMOS 954 returned to Earth scattering debris and radioactive material across the Canadian North. Only then did Canada react to space-based nuclear power sources and take an international lead role in this area.[144] Hopefully, the development of a comprehensive national space policy will not require such an event. In considering the future of Canadian space policy, whatever its engendering spark, the best answers may come from a review of the past. The intent is not to provide a definitive answer but to define the outer limits by which a Canadian policy would be bound in terms of protecting national space interests.

5. Options for Canada

Introduction

It is exceedingly difficult to predict, with any degree of accuracy, the direction a nation will go in terms of policy. The political consequences of unforeseen events such as recession, natural disaster or terrorism can lead governments in directions not anticipated. Beyond the reaction to such events, there are ideas or concepts that are relatively constant throughout a nation's policy. These are often revealed through the lens of past government action and may help define the likely limits of future policy. Canada's nuclear debate from 1963 and the ballistic missile defence (BMD) debate in 2003 will be used to discuss the broader defence and security considerations that arise. The issues surrounding the CSA's Radarsat program will also be discussed, as they show the effect some alliances can have in terms of shaping Canada's defence and security policy as well as the interplay of globalization. These situations will be evaluated through the lens of Douglas Bland's five ideas that define Canada's national interest, and the results will be extended to the space environment. This approach will help define key aspects and the likely limits of Canadian space policy.

Nuclear

"The election of 1963, in which [John] Diefenbaker's Conservatives were defeated by [Lester B.] Pearson's Liberals, was essentially a referendum on Diefenbaker's handling of the questions of nuclear weapons."[145] The end result of the nuclear question in Canada was not a debate on the weapons themselves but on the government's handling of the Canada-US relationship. The debate began in the late 1950s, when the Canadian government purchased the CF104 Starfighters, CF101 Voodoo fighters, Honest John rockets, and the BOMARC-B missile system for use by Canadian forces. Each of these systems was designed to be used with nuclear warheads. It was felt at the time that these nuclear weapons systems were necessary for Canada to meet its NATO and NORAD commitments to help defend North America and Europe from the Soviets.[146]

So important was the perceived need for nuclear capable forces that US President John F. Kennedy was directly involved in the discussions. He was concerned that NORAD's defence would be weakened if Canada did not also have a nuclear capability to thwart an attack over the

144. MacDonald, *Space Strategy*, 101.

145. Brian Bow, "Parties and Partnership in Canadian Defence Policy," *International Journal* 64, no. 1 (Winter 2008–09): 71.

146. Mark A. Eaton, "Canadian Editorial Opinion and the 1963 Nuclear Weapons Acquisition Debate," *The American Review of Canadian Studies* 35, no. 4 (Winter 2005): 643.

North Pole.[147] For the Canadian government, the US pressure was in addition to that coming from within the bureaucracy itself. "Diefenbaker later wrote that bureaucrats had railroaded him into accepting the BOMARC and that the defence establishment conspired with its American counterparts to push him into deploying nuclear weapons."[148] As the pressure mounted, the situation became worse for the Prime Minister, as a rift was also forming within his party over the issue.

Diefenbaker's reluctance to make a definitive decision on the deployment of nuclear weapons was in part due to a fundamental division in his party. This division was personified in his Defence and External Affairs ministers. In Defence, Douglas Harkness saw the acceptance of nuclear weapons as the fulfillment of a commitment Canada had made under NORAD. On the other side of the debate, Secretary of State for External Affairs Howard Green opposed the move, because it might damage "Canada's international reputation as a leading advocate of nuclear arms control."[149] It should be acknowledged that the warheads, although available to compatible Canadian systems, would remain in US custody.[150] This nuance was insufficient to change the views of those against the nuclear warheads and, therefore, left the Prime Minister little room to manoeuvre. Then, with a minority government handed to him in the June 1962 election, Diefenbaker decided that making no decision was in the best interest of staying in power.[151] This approach did little to appease everyone.

In January 1963, the US, fed up with delays from the Canadian government openly questioned Canada's sincerity in terms of NORAD and NATO. The US's public statements brought the issue to a head in cabinet, and in the end, the Minster of National Defence and two other ministers resigned. Pearson, then leader of the opposition, put forward a non-confidence vote that brought down the Diefenbaker government.[152] What had occurred was the misreading of the public's interest. In 1962, a small majority of Canadians supported the deployment of nuclear weapons. This was not from an increased interest in the weapons system but over concerns the country was not living up "to alliance obligations, and the damage evidently done to the bilateral relationship with the US."[153] In the end, under the new Liberal government, an agreement was reached that saw Canadian systems with nuclear warheads.[154]

Missile defence

In December 2002, then President Bush announced the US would deploy a BMD[155] to protect the country from new nuclear threats such as China, North Korea, and possibly Iran.[156] This announcement obviously created a great deal of discussion within Canada on the merits of the systems. The particular areas of concern were (1) a new arms race and the weaponization of space, balanced against the security BMD could provide and (2) Canada's security relationship with the US. Initially, on the political front, Canada's support and likely involvement seemed assured. Paul Martin, prior to becoming the Liberal Party leader, had supported the idea of BMD.[157]

147. Ibid., 644.

148. Bow, 81.

149. Ibid.

150. Eaton, 646.

151. Bow, 81.

152. Eaton, 646–47.

153. Bow, 82.

154. Eaton, 647.

155. James Fergusson, "Shall We Dance? The Missile Defence Decision, NORAD Renewal, and the Future of Canada-US Defence Relations," *Canadian Military Journal* 6, no. 2 (Summer 2005): 18.

156. Eaton, 659.

157. Kim Richard Nossal, "Defence Policy and the Atmospherics of Canada-US Relations: The Case of the Harper Conservatives," *The American Review of Canadian Studies* 37, no. 1 (Spring 2007): 25.

More broadly, a motion was passed in the House of Commons in 2003 that expressed Canada's desire to have NORAD involved in BMD.[158]

In August 2004, Prime Minister Paul Martin approved the signature of an amendment to the NORAD agreement that would allow the organization to share its missile warning information in support of missile defence activities. At the time of the signing, the Canadian government made clear that this only permitted the sharing of tracking data and did not mean that NORAD was going to take on missile defence responsibilities.[159] More importantly, this also did not mean that Canada had committed itself to BMD. Then Minister of National Defence Bill Graham stated that the decision on the sharing of information had been made to ensure the relevance of the bi-national NORAD partnership because "the Americans were on the verge of building an airspace defence system that would have made Norad [sic] obsolete."[160] In essence, the change in the NORAD agreement had less to do with the BMD, and more to do with preserving a politically important defence relationship.

At the time of the original 2003 motion in the House, some Liberals voted against because they felt the wording of the motion could allow for weapons in space as part of the BMD initiative. At the time, "Paul Martin said Canada should be involved in missile defence to represent Canadian interests, but that he didn't support putting weapons in space."[161] These statements defined the position of the government and underscored the difficulty the Prime Minister faced as he tried to move this file forward. In the end, he could not overcome interests in caucus that included strong opposition to BMD from his Quebec MPs.[162] In February 2005, without prior warning, Martin announced that BMD was simply "not in Canada's interests," much to the surprise and dismay of the US government.[163]

Radarsat

The development and launch of the Canadian Radarsat satellites provides another crucial piece of Canada's unwritten space policy. In particular, it highlights the potential pitfalls that exclusive dependency can bring. In defence and security matters, such dependency could have another nation determining Canadian capabilities or defining tenets of national policy. The Radarsat scenario demonstrates the fine balance that often must be struck in the Canadian defence and security arena. Two aspects will be highlighted: the first is the US's concern over the system's capability and second is Canada's concern over the possible sale of the Canadian parent company to a US firm.

The Radarsat satellites were perceived as a threat to US interests; the threat being derived from concerns over the imaging resolution of the system. The Radarsat satellites are based on a version of synthetic aperture radar technology developed in Canada that provides "all weather, day and night imagery" at resolutions from 100 metres down to 10 metres.[164] This resolution increases to 3 metres for Radarsat-2.[165] It was ultimately the level of detail these systems could provide, in conjunction with the fact that imagery would be sold commercially, that had the US concerned. Two reasons are given for the US concern: national security and commercial interests.

158. Canadian Broadcasting Corporation, "In Depth: Canada's Military – NORAD," http://www.cbc.ca/news/background/cdnmilitary/norad.html (accessed October 11, 2012).

159. Nossal, 25.

160. Canadian Broadcasting Corporation, "In Depth: Canada's Military."

161. Ibid.

162. Nossal, 25.

163. Ibid., 26.

164. Roger Handberg, "Dancing with the Elephants: Canadian Space Policy in Constant Transition," *Technology in Society* 25, no. 1 (January 2003): 36.

165. MacDonald, Dettwiler and Associates Ltd., "Radarsat 2: Features and Benefits," http://www.radarsat2.info/about/features_benefits.asp (accessed March 19, 2010, site discontinued).

In terms of national security, the US was concerned the resolution of the system provided too much detail. In addition, the commercial availability of the imagery could facilitate it falling into the wrong hands. The US was so concerned about this fact that domestic US law prohibited non-military or non-intelligence imaging satellites from having resolutions comparable to those of the Radarsat satellites. This may have also led to industry concerns in the US over the Canadian project. In fact, a lobby was formed by US aerospace companies who felt that their country's involvement in Radarsat amounted to support of foreign competition in Earth imagery.[166] The implications of these concerns were significant to the Radarsat-2 project.

Although the Canadian-made imaging technology was immune, other parts of the project were affected. The main satellite structure (known as a bus) was denied export to Canada by the US State Department on the grounds "that sensitive technology could fall into non-American hands." Additionally, NASA, at the request of intelligence agencies, would also not facilitate the launch of the system.[167] In response to the US closing the door on the project, CSA and MacDonald, Dettwiler and Associates Ltd. (MDA), the prime contractor, worked with the Europeans to acquire a satellite bus and to have the systems launched.[168] If this option had not been open, the project would likely not have been completed.

The US had tried to stop the system from achieving flight, but once in place recognized the importance of the capability. "In 2008 the US Department of Defense bought $5-million worth of commercial synthetic aperture radar imagery from the Canadian Radarsat system."[169] This recognition also attracted attention from US companies interested in the technology and in 2008, MDA announced it had decided to sell its aerospace division to US weapon maker Alliant Techsystems. This sale would have included the ownership of Radarsat-2. The sale caused a stir in space circles and opposition to the sale was fronted by former astronaut and head of CSA Marc Garneau.[170] In the end, after significant debate within government, Industry Minister Jim Prentice blocked the sale stating that it was not of benefit to Canada and that concerns over the "application of foreign law" would affect operation of the satellite in terms of Canada's interests.[171]

Lessons learned

In his article "Canada's National Interest: Alliance with the United States," Douglas Bland examines five ideas that have been at the core of Canada's defence and security policy. Although this title describes his conclusion, the following will use the five ideas he has proposed and arrive at its own conclusion using the examples above and extend the idea to the concept of space defence. The ideas that define Canada's national interest, as proposed by Bland, are: Canada as a sovereign country, Canada as naturally secure, Canadians' belief in the traditional concept of war, Canada's national interests are best served by alliances, and, finally, Canada's competing visions and directions.[172]

Bland's ideas are a valuable approach, as they capture the thoughts of a number of other authors in this area and provide a guide to the discussion. In addition, the concepts proposed by

166. Peter Calamai, "Canada Ready to Dump NASA for Space Launch; May Go to Europe to Build and Send $305 Million Radar Satellite into Orbit." *Toronto Star,* December 8, 1999.

167. William Boei, "Radarsat Launch Delayed a Year After US Security Concern Forces Canadian Firm to Find New Contractor," *Canadian Press Newswire*, December 17, 1999.

168. Handberg, 36.

169. West, 99.

170. Canadian Broadcasting Corporation, "Sale of MDA unit leaves Canada's space ambitions in the air: Garneau."

171. Canadian Broadcasting Corporation, "Govt. Confirms Decision to Block Sale of MDA Space Division," http://www.cbc.ca/money/story/2008/05/09/alliant-sale.html (accessed October 11, 2012).

172. Douglas L. Bland, "Canada's National Interest: Alliance with the United States," *Policy Options* 28, no. 10 (November 2007): 63

Justin Massie will be included. In particular his idea of "three concurrent and coexistent strategic cultures: continental soft-bandwagoning, defensive internationalism, and soft-balancing Atlanticism."[173] The value of Massie's work in this area is that it is a counterbalance to the realist perspective put forward by Bland. Massie's article "Making Sense of Canada's 'Irrational' International Security Policy" introduces the "importance of constructivist, or cultural, factors" and the way they shape the national interests.[174] The following will explore the three cases above and then extend the ideas to Canada's interests in space. Bland's five ideas that define the national interest will be used as a structure for the discussion.

The first idea proposed by Bland is that "Canada as a sovereign country—is the cardinal idea that underlies all aspects of our national interest." In this idea he captures the protection of the physical entity, political freedom and ideals of the nation.[175] During the nuclear debate, the issue was first about protecting the nation, but beyond that, it was about a perception of Canada in the world. The sticking point was between commitments made and a reputation for arms control. In terms of BMD, it became a cost-benefit analysis of the security offered against domestic and world perception. "The benefits of formal participation in missile defence would be marginal, but the political costs of appearing subservient to the United States would be high." The missile warning role alone, that Canada was able to keep under NORAD, at the same time maintained Canada's relevance in the aerospace defence of North America.[176]

These events show the constant balance required between sovereignty and the Canada-US relationship. Massie terms this "continental soft-bandwagoning." The concept goes beyond the exclusive concern over Canada as a sovereign state. Instead, it is the importance of the friction between sovereignty and the need to be a "reliable neighbour to the United States."[177] It is this friction that defines the decisions taken in the BMD and in the nuclear debate. They were not exclusive matters of Canada's physical security. In each case, Canada had to decide on the balance between sovereignty and ensuring the country played a sufficient security role to satisfy the US. In striking the correct balance, the country is able to achieve both aims.

The events surrounding the Radarsat satellites also demonstrated the sovereignty balance and led to the fundamental issues that space brought to that discussion. Radarsat, at first, was hampered by US restrictions on imaging resolutions. These restrictions, due to Canada's dependence on the US for both the satellite bus and launch services, could have changed the capability the nation wanted in the system. This was a system designed in part to monitor Canada's sovereignty. Additionally, the possible sale of the system to a US company highlights the issue that comes with international companies. Outside the concerns of access restrictions on imaging, the purchase of the system would bring to light questions on who would be responsible to protect the system. This becomes more concerning the greater a country's reliance on the space asset. If a system was essential to the national interest, would that nation not want to protect it? How is this done when the asset belongs to another nation?

The US, on the other hand, sees space as a sovereignty issue and is reacting to it accordingly. As space becomes increasingly crucial to the functioning of the US, it will see "space as a vital

173. J. Massie, "Making Sense of Canada's 'Irrational' International Security Policy: A Tale of Three Strategic Cultures," *International Journal* 64, no. 3 (Summer 2009): 627.

174. Ibid., 626–27.

175. Bland, 63.

176. Massie, 635.

177. Ibid., 632.

and vulnerable medium to be controlled and defended." This change will make space a prominent security issue in the Canada-US relationship.[178] Canada needs to be prepared for this discussion or it may lose fundamental control over its space capabilities. This will be another debate that will require the balancing of sovereignty with reassuring the US. In the absence of a Canadian government that appreciates the importance of space, the nation's interest will rest exclusively with the decisions of the US.[179]

The second idea put forward by Bland is that Canada is naturally secure. Bland considers both the geographical aspect and Canada's need for others to assist in the nation's defence. Bland singles out the Canada-US relationship and the security it provides the nation.[180] Again, the explanation fits Massie's concept of continental soft-bandwagoning. The nuclear and BMD debates emphasize his point. In both cases they centred on how much defence responsibility Canada needed to take on to convince American interests that Canada was sufficiently involved in continental defence. In essence, "Canada benefits from America's involuntary security guarantee, provided it contributes only modestly to continental defence and security."[181] How do the ideas of being naturally secure and soft-bandwagoning now apply to space?

Domestically, understanding space in terms of security is important. "Protected by three oceans, the only feasible means by which nations can realistically threaten the safety of Canadians is by using the medium of air, or space."[182] Space is an access point into Canada that needs to be protected, not only in terms of systems transiting space to get to Canada but also in terms of securing the space systems the nation relies on. There is also no need to hit a nation directly if you can achieve sufficient effect by attacking critical services in space.

The landscape of strategic defence has changed with a refocus on space that will require Canada's attention. Simply, Canada needs to offset the decline in importance of air defence to the US, relative to space.[183] The country, therefore, needs to find new defence aspects to contribute to and maintain relevance to the US. One current example is the DND's Sapphire satellite project which is intended to contribute to the US Space Surveillance network by tracking objects in higher orbits. This is a necessary part of both nations' SSA. The project is an important step in redefining Canada's contribution and maintaining its relationship with the US. But it is only one step.

The third idea is that Canadians believe in traditional ideas of war and thus security interests are tailored accordingly. War is between two states; its actions are controlled and scheduled.[184] In 1963, the concern was the Soviet Union, and in 2003, the concern was "rogue" states. These defence concepts were based on known threats by state controlled activities. As time moves on there is an increasing presence of asymmetrical or irregular warfare, a label generally put on war fighting that does "not follow regular patterns and Western doctrine … ." Ultimately, Bland states, these will be the regular wars of tomorrow.[185] In terms of space, the opening position is that a war has never been fought there.

178. James, "Space Is Becoming Crucial," 65.

179. Fergusson, "Out of Sight," 17.

180. Bland, 64.

181. Massie, 633.

182. Fergusson and James, *Report on Canada*, 6.

183. James, "Space Is Becoming Crucial," 67.

184. Bland, 64.

185. Ibid., 65.

The fact that there has not been a war in space to this point is fortuitous, but as the technology becomes more commercialized and readily available, the option opens to a greater number of actors. This means space needs to be considered in terms of defence, including the assets in it. The only guidance on war in space comes from the OST, but it is lacking when it comes to acknowledging broader space threats. The treaty is limited, by its age, to the prohibition of WMDs, providing no guidance on the systems envisioned today.[186] The OST, as addressed earlier, also does not provide for the concepts of safe passage and self-defence. Even "customary international laws … most relevant to space conflict are also very subjective and permissive."[187]

With that said, Canada has been clear, when confronted, that there should be no weapons in space. Most recently, the BMD debate brought this affirmation temporarily back into the public discourse. Politically and philosophically, the country cannot accept the idea of placing weapons in space or being part of a system that does. Ultimately, that may be in the interest of all concerned with space operations. Nations that have space programmes have come to understand that the implications of space warfare to existing and future space operations may simply not make it worthwhile.[188] While valid for those who rely on it, the threat remains that space is just as vulnerable to attack from those with nothing to lose.

The fourth idea of what drives Canadian policy is that Canada's national interests are best served through alliances. Be they binational or multinational, Canada has a history of seeking out these alliances.[189] The essence of the nuclear and BMD issues was predicated on this same assertion. The debate over the Radarsat build, launch, and purchase, on the other hand, alludes to the downside of alliances when one party becomes exclusively dependent on another. In Canada's case, the need for alliances is clear. Canada has always taken a more collaborative approach to defence and security matters to offset its relatively small size in terms of population and economic output.

Massie also agrees with Canada's need for alliances in terms of national security, but he sees a strategy of soft-balancing Atlanticism. Due to the country's historical identity derived from Britain, France, and the US, the truth behind its decisions are based on the balancing of this North Atlantic quadrangle. He uses the example of the Iraq invasion, where Canada did significant work in trying to bridge the gap between France and the others. It is postulated that had there been an agreement with France, Canada would have been in Iraq.[190] Applying soft-balancing Atlanticism to space is significantly more difficult, as there is currently no immediate crisis affecting all four nations to drive the narrative. These specific relationships may shape Canada's take on the defence of space, as it does terrestrial issues, but they are currently not a substantial influence. At the moment, it is Canada's geographic isolation and proximity to the US that has instead shaped a "profound dependence on its southern neighbour."[191] This dependence leads to areas of safety and concern in terms of space defence.

The US sees space as a national centre of gravity that requires "legitimate monitoring and security measures" to ensure its protection. Accordingly, "Canada will cautiously support [US] controls because it will ultimately be in its interest to do so." By doing so, it maintains two national interests: the safeguarding of allied and civilian assets and maintaining security relevance in areas where it

186. Webster, 54.
187. Gallagher, 20.
188. Bloomfield, 17.
189. Bland, 66.
190. Massie, 641.
191. Bow, 69.

cannot or will not follow. Canada's influence in this bilateral relationship is light. Canada "will seek to safeguard [its] national interests by investing a requisite amount in national capability and then trying to leverage the capability inside a larger bilateral arrangement."[192] The US relationship remains key to Canadian space interests even after events such as Radarsat. A tangible example again is Canada's return to participate in space monitoring under the US Space Surveillance Network by DND's Sapphire System. In the end, collective engagement and space control are essential to Canada's interest,[193] an interest best served through alliance.

The fifth and final defining idea put forward by Bland is that Canada has a number of competing visions and directions. The competition is based on where Canada can best find its security. Is it in a close relationship with the US, Europe, or within the broader construct of the UN?[194] Just as in the discussion of alliances, the crux of each example is a debate on where Canada could derive the security it needs. Space makes this same discussion exceedingly difficult. As stated before, space law—be it the OST or customary international law—has significant latitude. At the same time, space has moved from a pristine environment to one crowded by a number of state and commercial players seeking its benefits. "Space was once perceived as a sanctuary but is increasingly like the high seas in the 1900s— an international territory … ."[195] Accordingly, an international approach to regulations and security will be required.

"Canada has been caught between two conflicting roles: as a world leader in disarmament efforts, and as a player in the drive for continental military integration."[196] These pressures have generated a great deal of tension within the country, as evidenced in the effects on government during the nuclear and BMD debates. This pressure has created a climate where "Canadian officials seek to formulate policy that satisfies Washington, that is not perceived as destabilizing by other members of the international community, and also that assuages domestic anxiety about the unavoidable relationship with the [US]"[197] These ideas, for better or for worse, have become the fundamental tenets of Canadian defence and security policy. To achieve true balance on many of these issues, Canada has to maintain good standing in both the continental and international arenas.

This posits well with the Canadian external identity of being a "good international citizen" through Massie's concept of "a defensive internationalist strategic culture." This identity is defined by "multilateralism (negotiation, compromises), humanitarian interventions, reluctant uses of forces, and economic aid and sanctions."[198] This approach has allowed Canada to balance its interests with those of its allies, with sufficient success for the country. It has also built Canada a reputation on the diplomatic front, one that the country could use to advance its own goals. In terms of space, Canada understands the Russian and Chinese concerns over space weapons, European concerns on protecting the orbital environment and US interest in space for legitimate military purposes.[199] From a purely realist perspective this need not be out of genuine concern for other nations' interests but simply a manner of managing Canada's dependence on other nations. Canada may best find its security in maintaining this multiforum approach. This leaves Canada not completely beholden to anyone and, therefore, able to leverage multiple fronts in advancing its goals.

192. James, "Space Is Becoming Crucial," 68.
193. Malo, 30.
194. Bland, 66.
195. James, "Space Is Becoming Crucial," 68.
196. Webster, 52.
197. Eaton, 641.
198. Massie, 637.
199. Gallagher, 9.

Summary

Space defence policy is about what the country is willing to accept and what it is willing to risk. The fundamental question in the policy domain is if there will be a trade-off between defence and values. By extension, in the Canadian context, it is also a discussion of the trade-off between autonomy and security. The answer will never be a simple yes or no; it is an appreciation of balance. In the review of the 1963 nuclear debate, the 2003 BMD debate, the issues surrounding Radarsat and, by extension, the lessons in terms of space defence, a number of concepts are highlighted. The first and foremost is Canada's crucial relationship with the US. While this relationship magnifies Canada's defence, it often comes as a trade-off in terms of sovereignty or autonomy. Canada's autonomy and credibility in international fora also has significant influence in decisions in terms of defence. The Canada-US relationship and Canada's perception in the world have specific implications to space.

Canada can really only achieve a depth in space defence through strong partnerships with the US. Canada's contributions to these partnerships also provide a voice in continental defence and extend the umbrella of US security over Canada's interests. There are limits to this for Canada, as some US policy would not be permissible in the Canadian context. Much like the Radarsat solutions, Canada also needs to maintain international involvement in the areas it holds important, in part to influence the domestic security construct. The best example is the question of the weaponization of space, which Canada has been consistently opposed to. Bilaterally, there is little Canada can do. It can participate to a point, such as its involvement in space surveillance, or simply opt out. Internationally, though, it may have greater influence to strengthen international law when working with like minded nations. Additionally, if Canada cannot deploy weapons in space, even defensive weapons, then the international multilateral approach is the only way to go.[200] Where this leaves Canada in terms of space defence options is best summarized by Dr. James Fergusson and Stephen James when they state: "in the end, looking is fine, but acting is not. The same may be said about space itself. Looking into space is fine, but acting upon the information is up to the United States."[201]

6. Conclusion

There is a significant national security policy gap for Canada in terms of space that needs consideration. Canada, as an advanced information-based economy, is highly dependent on the effects derived from space-based technologies, yet the country has no central government policy on how to protect these systems. More generally, the country has no single policy that defines Canada's approach to ensuring the nation simply retains access to this crucial environment. This is an environment on which the prosperity and security of the country deeply depends. In the absence of a clearly articulated whole-of-government approach, individual departments are exploring the issues of space within the silos of their mandates. The problem is that space security transcends these unique mandates. Even considering the sum of the departmental mandates, there are still gaps that remain. This occurs when issues fall outside individual mandates or, just as concerning, when mandates overlap and it is not clear who has the lead.

The requirement remains for broad national guidance to synchronize government efforts. Without this pan-government approach, the activities of individual departments will either miss or ignore crucial aspects in the defence of Canada's space capabilities and goals. However, this will not be an easy task for a government to achieve. The fact that space is not generally perceived as a threatened domain in part ensures there will be little movement in this area. This is because

200. Fergusson, "Out of Sight," 16.

201. Fergusson and James, *Report on Canada*, 41.

space-derived effects are not readily visible to the public; although, they are a driving factor in everyday life. So long as the infrastructure functions and the capabilities are delivered, space security will not be an issue the government will be encouraged to address. Fundamentally, Canada has no capstone space security policy to defend its interests in space and, without an igniting spark in the form of a crisis or significant external pressure, is unlikely to develop one.

Regardless of the existence of a Canadian security policy on space, international developments will continue to shape the way space is used. These actions may ultimately define the rules for Canada. The UN treaties on space currently provide the only international legal regime that exists for space, and nations have already begun to explore the limits. Countries, like the US, read the OST literally, inferring that its only prohibition is on the placement of WMDs in orbit. Other nations take a broader view in interpreting the documents and see in them a restriction on all weapons in space. Nations, like China and Russia, see the future in additional frameworks beyond the OST that explicitly eliminate aggressive acts in space, while at the same time ensuring their own offensive capability. In attempting to define concepts of acceptable practice in space, the Law of the Sea and the LOAC are being considered. These frameworks may help develop parallel concepts such as the right of safe passage in space as well as concerns over dual-use systems. Beyond these ideas, future consideration will need to be given to the burgeoning private space industry, which is currently offering LEO tourism, and may develop additional capacities in the future. The role of larger political unions or regional interests, such as the European Union, may also shape the way space law is interpreted as currently all responsibility remains with the nation state.

Regardless of the legal framework, what remains certain is that space is an environment under threat. The mere act of accessing space threatens future operations in terms of debris. ASAT systems, defunct satellites and human error further complicate the environment. If these issues are not specifically addressed, future access to space could be lost to all. Unfortunately, this is an issue that is out of sight and out of mind and is not currently a public or government concern. With a threat that is hard to demonstrate, it becomes exceedingly difficult to have a policy generated that reflects the reality of space security. The public mindset needs to change. Space is no longer a pristine sanctuary but is a finite resource and an environment in need of protection. These considerations are essential if Canada and the rest of the world are going to continue to benefit from space, now and into the future.

Abbreviations

ASAT	antisatellite
BMD	ballistic missile defence
CANSOC	Canadian Satellite Operations Centre
CF	Canadian Forces
CFDS	*Canada First* Defence Strategy
CSA	Canadian Space Agency
DFAIT	Department of Foreign Affairs and International Trade
DND	Department of National Defence
DRTE	Defence Research Telecommunications Establishment
EU	European Union
GEO	geosynchronous earth orbit
GPS	global positioning system
LEO	low earth orbit
LOAC	law of armed conflict
MDA	MacDonald, Dettwiler and Associates Ltd.
MEO	medium earth orbit
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NEOSSat	Near-Earth Object Surveillance Satellite
NORAD	North American Aerospace Defence Command
ORBITALS	Outer Radiation Belt Injection, Transport Acceleration and Loss Satellite
OST	Outer Space Treaty
PPWT	Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Space Objects
PRC	People's Republic of China
SSA	space situational awareness
UN	United Nations
UNOOSA	United Nations Office for Outer Space Affairs
US	United States
WMD	weapon of mass destruction

Chapter 4 – Motion: Is There A Requirement in Large Fixed-Wing Aviation Simulators?

Major Jason Stark

Abstract

In a June 2008 appearance before the Senate Defence Committee, the Chief of the Air Staff stated that the Air Force was developing initiatives to resolve pilot production and absorption deficiencies, including the increased use of flight simulators.[1] Most would agree that the increased use of flight simulators can increase pilot production and, more importantly, significantly assist trained pilots in maintaining learned skills through simulator continuation training. However, few can agree on the type of flight simulator required to achieve this effective continuation training. Namely, is full motion required to achieve effective training in Canadian Forces air mobility fixed-wing aircraft full flight simulators? The author's opinion is no.

This analysis examines how humans process motion and applies that knowledge to the modern use of the Stewart-Gough simulator motion platform. Although pilots appear to prefer full motion in transport aircraft flight simulators, science indicates that the motion is not required. The military and civilian professional aviation communities are expending a significant amount of money on full-motion platforms when there is no need. The future of flight simulators for continuation flight training requires a change in the status quo and an investment in alternative technologies, such as immersive simulators with dynamic motion seats.

1. Lieutenant-General Angus Watt, "Appearance before the Senate Defence Committee, 9 June 2008," as reported by David Pugliese, "Air Force Short 250 Pilots But Getting A Handle On Retention," *Defence Watch* (June 2008), http://communities.canada.com/ottawacitizen/blogs/ defencewatch/ archive/2008/06/13/air-force-short-250-pilots-but-getting-a-handle-on-retention.aspx (accessed July 9, 2012).

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1. Introduction

Almost since the invention of powered flight in 1903, simulation has been an integral part of flight training. During the ensuing 107 years, there have been drastic and remarkable improvements in the level of simulation. Aircraft cockpits are now accurately represented with all of the pertinent display panels, controls, and instrumentation. Visual display systems, with the advent of computer-generated imagery, are able to recreate realistic environmental scenes. Modern aircraft simulators look, sound, feel, and act almost like real aircraft. However, "almost" is the operative word. Throughout the history of aviation simulation, scientists and pilots have sought the unattainable: the *absolute* recreation of flight in land-based simulators. A significant by-product of this quest has been the heated and contested debate about the importance of simulator motion. Specifically, is simulator platform motion required in flight simulators?

The question does not merit a simple yes or no answer. Nor is it a matter of whether full aircraft motion simulation is scientifically achievable. Many solutions to complex engineering problems have been resolved with enough research and financial commitment. Mankind has visited the moon, traveled to the bottom of the oceans and conquered heavier-than-air flight. Consequently, it is conceivable that thoroughly realistic land-based flight simulation is achievable. After sufficient investment, land-based flight simulators should eventually be able to recreate full flight motion, including sustained gravitational (G) force. However, the real question is whether a 100 per cent simulation of flight is actually required for pilot training and proficiency. The best type of flight simulation currently available to aircrew is the Level D, six degrees-of-freedom, full-motion simulator. Unfortunately, these simulators are very expensive, in the order of $15–30 million depending on the included options.[2] A significant portion of that cost is associated with the level of articulation required on the platform in order to simulate aircraft motion. The question is a matter of return of contribution. Is the cost associated with six degrees-of-freedom motion justified and does it provide a significant return on pilot proficiency? Is full motion required for accurate flight simulation?

The goal of this paper is to take an in-depth look at the aircraft simulator motion debate. However, this analysis is not focused on ab initio flight training where pilots obtain the initial "stick and rudder" skills required for flying. Rather, it will focus on the continuation training of qualified pilots. In today's complex world of aviation, simulators are required to train pilots holistically. This does not mean simple "stick and rudder skills" but rather communications, crew resource management, flight management, fuel management, regulations, airspace procedures, and aircraft systems. The Canadian Air Force, unlike the airline industry, will never be able to achieve zero flight time training (ZFTT) due to the complex nature of its flight roles, nor should it try. Military pilots complete a multitude of flight profiles that are outside of the normal civilian flight envelope. Low-level flight, attack, airdrop, tactical arrivals and departures at hostile airfields, and mountain flying are but a few examples of high-intensity, task-specific operations for which training in the actual aircraft will remain a requirement. However, once trained to operational status in the fixed-wing air mobility world, pilots can complete better continuation training at lower cost by using less expensive flight simulators to create a virtual flight "environment."

The complex aviation environment

As aviation has evolved, so has the complexity of the aviation environment. In the world of professional and military aviation, there is no longer such a thing as "basic" flight. Modern aircraft are extremely complex machines that require pilots to have a commensurate level of complex

2. Email Major Jason Stark and Nathalie Bourque, Vice President, Public Affairs and Global Communications, 2 February 2010.

management skills. The number of critical emergencies requiring an immediate reaction from the pilot of a CC130E/H Hercules aircraft is 22, whereas the number of critical emergencies in the CC177 Globemaster III is only 4.[3] However, this does not mean that the CC177 is a less complex aircraft. Rather, where the CC130E/H flight crew checklist has a list of 61 possible malfunctions, the CC177 flight crew checklist has over 500 listed possible malfunctions.[4] This is indicative of the complex nature of modern aircraft. Aircraft and the world of aviation are changing. Often, the task of piloting an aircraft from point A to point B is now referred to as "managing the flight" vice flying the aircraft.[5]

The airspace in which modern pilots operate their aircraft has also increased in complexity due to increased air traffic density. To regulate the traffic, and avoid mid-air collisions, intricate rules and procedures have been imposed. Nonetheless, even with the current technology and regulations, the air traffic control environment is rapidly approaching maximum capacity. Ground-based and satellite navigational systems are poised to increase traffic density further by allowing aircraft to complete more efficient direct routings between destinations.[6] The expected increases in technological capabilities and traffic density will require pilots to grasp more complicated rules of flight while the margin of error continues to decrease.

The modern aviation environment combines complex aircraft systems with an equally complex air traffic control framework. Often, aside from take-off and landing, standard long-haul air mobility missions are flown through the use of on-board computers and automation that are managed by the aircrew. The risks and hazards associated with system failures resulting in catastrophic emergencies have been significantly reduced due to the increased mean time between failures (MTBF) of modern aircraft.[7] Although aircrews need to train for the catastrophic failures that could result in loss of life and equipment, it is imperative that they are also trained to deal with the new emergencies and failures that are a result of the new human-machine interface hazards. These new hazards are at the core of continuation pilot training and need to be the focus of aviation simulators.

The application of aviation simulation

Aircraft simulators fulfil three vital functions in the aviation community. First, flight simulators are a critical component of pilot training. It is safe to assume that there are no professional military or civilian pilots who have not logged hours in an appropriate simulator. If not used in ab initio flight training, it is a foregone conclusion that simulators are used in the continuation training of qualified pilots. Secondly, simulators have found a niche roll in the acquisition and testing of both pre-production and established aircraft fleets. Finally, simulators are the platform of choice for aviation research. Although this section is predominantly focused on pilot training, it is important to note that all three applications play important roles in aviation.

Training simulators offer the opportunity to depart from reality in such a way that more cost-effective and applicable training can be achieved. Simulators allow aircrew to fly without burning

3. Canadian Air Division, C-12-130-00/MB-005, *CC130 Hercules Flight Crew Checklist Change 2000-02-18* (Ottawa: Department of National Defence, 1998) and United States Air Force, 1C-17A-1, *C-17 Flight Manual Change 4* (Wright Patterson Air Force Base: Department of Defense, 2006).

4. Ibid.

5. Matthew W. Blake, "The NASA Advanced Concepts Flight Simulator: AIAA Paper 96-3518," *AIAA Meeting Papers on Disc* (San Diego, CA: AAIA Flight Simulation Technologies Conference, 29-31 July 1996), 385.

6. Ibid.

7. Boeing Aviation Safety, *Statistical Summary of Commercial Jet Airplane Accidents* (Seattle, WA: Aviation Safety Boeing Commercial Airplanes, July 2009), Slide 23. http://www.boeing.com/aboutus/govt_ops/reports_white_papers/commercial_jet_airplane_accidents_statistical_summary.pdf(accessed July 9, 2012).

fuel, conduct engine and flight control failures with no threat of injury, and change the time of day and geography instantaneously to achieve specific training objectives. Simulators even permit crews to pause the flight in order to discuss a course of action or anticipated aircraft response.[8] Training simulators grant pilot instructors the ability to control all of these external factors. This, in turn, allows the instructor to increase and decrease pilot workloads, as applicable, allowing the students to concentrate on the current lesson. It is this ability to control "reality" that makes simulators an invaluable tool in pilot training. Simulator training is so widely accepted and effective that the CC177 initial pilot qualification consists of 41 missions (113 hours) in simulators and only 3 missions (19 hours) in the actual aircraft prior to certification.[9]

As mentioned, pilot training is only one facet of flight simulation. Of equal importance is the use of flight simulators in aircraft acquisition and testing. The ability to simulate an aircraft allows engineers and pilots to evaluate new systems, equipment, or procedures without risk to aviation safety. Simulation allowed pilots to train on the new Boeing 777 prior to the aircraft ever being built.[10] Simulation allowed for pre-production testing of pilot ergonomics, control panels, and information presentation. Moreover, simulation allows for the safe testing and evaluation of potential aerodynamic changes in post-production aircraft. In 2007, Boeing engineers wanted to adjust the algorithmic formulas controlling the CC177 fly-by-wire flight control system. The new algorithms were tested and evaluated in the simulator prior to being applied in the actual aircraft.

The final application of aircraft simulation is in the field of aviation research. Aviation psychologists are able to use flight simulators to recreate previous aircraft accidents or incidents in order to assess where breakdowns in communication and/or coordination may have occurred. Additionally, researchers are able to use simulators to assess and evaluate how crews behave under various stressors and stimuli. For example, the effects of sleep deprivation on aircrew performance can be safely evaluated in a simulator, not so in the actual aircraft.[11] The Volpe Institute in the United States has used simulators to test pilot performance in a myriad of piloting tasks. In an ironic spin, full flight simulators allow behavioural psychologists to assess the effectiveness of simulators themselves! Simulators enable researchers to evaluate skills transfer from simulators to aircraft in a safe and controlled fashion.

The outline

In order to demonstrate that six degrees-of-freedom full-motion aircraft simulation is not necessary to affect successful continuation pilot training in fixed-wing air mobility aircraft, this paper is divided into six sections. First, it is critical to understand how flight simulation evolved in order to predict where it will proceed in the future. Hence, Section 2 will address the history and evolution of flight simulation. In addition, it will define the various levels of simulator fidelity. Finally, it will establish the framework in which the various levels of aircraft simulators are categorized and labelled.

In order to assess the importance of motion to flight simulation, it is imperative to delve into methods by which humans process motion. This is the focus of Section 3. The human processing of

8. Michael E. McCauley, *Do Army Helicopter Training Simulators Need Motion Bases*? (Arlington, Virginia: US Army Research Institute for the Behavioral and Social Sciences, Army Project Number 622785A790, 2006), 4.

9. Email Major Jason Stark and Major Jean Maisoneuve, Transport and Rescue Standards Evaluation Team (TRSET) for C17, reference Canadian C17 Initial Training Plan, 27 January 27, 2010.

10. Jonathan Gabbai, "The Art of Flight Simulation," Section 1.2, http://gabbai.com/academic/the-art-of-flight-simulation (accessed July 9, 2012).

11. Gregory D. Roach and others, *The Effects of Fatigue on the Operational Performance of Flight Crew in a B747-400 Simulator* (Adelaide: Centre for Sleep Research, University of South Australia, 2006).

motion sensations is a complex process that combines many different systems. Some are obvious, such as the visual and vestibular systems. Others, such as the proprioceptive and auditory systems are much more subtle. Nonetheless, all senses contribute and are crucial to the sense of immersion required to effectively simulate reality.

Section 4 is focused on how motion is physically created in flight simulators. In this section, the latest studies conducted in the field will be reviewed and assessed. The importance of motion will be evaluated in terms of tracking and disturbance cues. Finally, the effectiveness of motion on skills acquisition and the subsequent effectiveness of transfer of training to the aircraft will be discussed.

Section 5 will examine how civilian industry and regulating authorities are approaching the simulator motion debate. As alluded to earlier, the modern aviation environment is sufficiently complex and only becoming more so. Consequently, this section will focus on how the challenges of this new environment can best be met and in the most cost-effective manner.

Finally, Section 6 will conclude the analysis and present thoughts on the future of military flight simulation. The military is a unique aerospace user and not all advances in civilian aviation are transferable. Nonetheless, the goal is similar in that both wish to create safe, effective, and professional aircrew in a cost-effective manner.

2. Simulation and simulators

Introduction

An analysis into the requirement for motion in aviation flight simulators requires the reader to have a solid foundation in the evolution of the modern simulator. Moreover, there is a baseline of knowledge and terminology that is required in order to understand the intricacies of modern simulator nomenclature. This section will establish the required historical context within which the motion requirement debate is framed.

The section is divided into three parts. The first part will explain the evolution of the modern motion flight simulator. In the past century the aviation industry has witnessed incredible leaps in technology resulting in the mainstream use of flight simulators. The history of simulation will explain where we came from and demonstrate where we appear to be headed. The second part will provide the baseline definitions of simulator fidelity. The entire motion debate is hinged on a solid understanding of the concepts of fidelity and the various types of fidelity referred to by the simulation industry. Lastly, the current simulator classification and nomenclature system will be explained and defined. This will allow the reader to appreciate how different levels of fidelity result in the full spectrum of flight simulator classifications.

The history of flight simulation

In the era of modern aviation, simulation is an established technique used to recreate the man-machine interface required to safely and effectively operate aircraft. The principal task of a simulator is "to model the dynamic behaviour of the flight vehicle."[12] Throughout the history of aviation, this has been the overarching goal of simulators. The modern flight simulators used today are the culmination of a century of technological, psychological, and engineering evolution.

12. Gabbai, "The Art of Flight Simulation."

Man learns to fly

The year 2009 marked Canada's centennial anniversary of flight. On 23 February 1909, Douglas McCurdy completed the first powered flight in Canada when he took off from Bras d'Or Lake in Baddeck, Nova Scotia. His first flight in the famed biplane *Silver Dart* lasted only a few minutes, but he achieved speeds of 65 kilometres per hour and soared to a height of over nine metres.[13] This was an incredible improvement over the Wright brother's first flight at Kitty Hawk, North Carolina, a mere five years earlier. Heavier-than-air flight was evolving quickly. Accordingly, these early days of aviation were fraught with accidents, injuries, and deaths.[14] Flying was immediately recognized as a dangerous endeavour, and the quest to improve training by developing a safe simulated environment began.

The Wright brothers immediately recognized that the pilot was central in the control of an aircraft. While other scientists and inventors of the time believed that aircraft would be fundamentally stable with only minor inputs required by the pilot, the Wright brothers understood that "the pilot of an aircraft [was] a skilled active controller of an unstable vehicle."[15] They became advocates of training pilots to be active participants instead of passive observers. With this realization, the evolution of pilot training began in earnest. The human dimension of pilot training has since become so important that an entire field of psychology has been dedicated to learning how pilots process information and react to the stresses associated with flight. This focus on the human element of pilot training has been the underlying driving factor behind flight simulation development. As early as 1910, there were already two dominant flight simulators used to assess and identify potential piloting skills in prospective candidates: the Sanders Teacher and the Antoinette Apprenticeship Barrel.

Simulator pioneers

The Sanders Teacher was a modified aeroplane mounted on a universal joint. The concept of simulation was to orient the Teacher into the prevailing wind.[16] With sufficient wind, the pilot could experience how aircraft controls functioned, much like a pilot in a ground-based glider can practice keeping the wings level in a strong headwind.

The 10 December 1910 issue of *Flight Magazine* heralded the Sanders Teacher as a "device which will enable the novice to obtain a clear conception of the workings of the control of an aeroplane, and of the conditions existent in the air, without any risk personally or otherwise."[17] Unfortunately, the Teacher was completely dependent on prevailing wind and, as such, was not an overwhelming success.

The Antoinette Apprenticeship Barrel approached the concept of flight simulation from a different perspective. To preclude any dependence on the natural "real" environment, the Antoinette was reliant on instructor inputs. It consisted of two half-barrels mounted and moved manually in order to reproduce pitch and roll motions. The student pilot sat in the top barrel and was expected to align a lateral reference bar with the horizon.[18]

13. Centennial Celebration Baddeck 2009, "The Flight of the Silver Dart," http://www.flightofthesilverdart.ca/ (accessed July 9, 2012).

14. On September 17, 1908, the aircraft flown by Orville Wright crashed. He survived, but his passenger, Lieutenant Thomas Sulfridge, died. This is recorded as one of the first passenger deaths in aviation. See http://inventors.about.com/library/inventors/bl_wright_brothers.htm (accessed July 9, 2012).

15. Pamela S. Tsang and Michael A. Vidulich, "Introduction to Aviation Psychology," in *Principles and Practice of Aviation Psychology*, eds. Pamela S. Tsang and Michael A. Vidulich, 1–19 (New York: CRC Press, 2003), 2.

16. J. M. Rolfe and K. J. Staples, *Flight Simulation* (Cambridge: Cambridge University Press, 1986), 15.

17. D. M. Howard, "The Sanders Teacher," *Flight* 2, no. 50 (10 December 1910): 1006, http://www.flightglobal.com/pdfarchive/view/1910/1910%20-%201008.html (accessed July 9, 2010).

18. Walter F. Ullrich, "A History of Simulation: Part II – Early Days," *MS&T Magazine* 5 (2008) http://www.halldale.com/MST_DigitalIssues.aspx (accessed July 9, 2012).

Both the Sanders Teacher and the Antoinette Apprenticeship Barrel shared the same problem; neither simulator produced any marked improvement or ability to train pilots to fly actual aircraft. With the advent of the First World War, there arose a need to produce a large number of pilots in limited time. Consequently, simulators were used primarily as selection tests for prospective pilots. Many of these devices were developed to assess pilot aptitude. For example, some devices were designed to measure pilot reaction to correcting vehicle equilibrium disturbances.[19] Other forays into flight simulation were based on false assumptions of how humans process motion and orient themselves to their surroundings. The Ruggles Orientator was one such device.

The Ruggles Orientator was developed based on a theory that the vestibular system would be equally effective in the air as on the ground. The idea was that disorientation in flight could be prevented through training. The "Orientator" was a seat mounted in a gimbal ring assembly that was capable of rotating the occupant in all three axes.[20] Its stated purpose was to train aviators "to accustom themselves to any possible position in which they may be moved by the action of an aeroplane while in flight."[21]

The claims for the Ruggles Orientator would later be proven to be unattainable. Scientists and inventors had yet to develop a complete picture of how simulators could be used and how humans process motion. As the First World War started, simulator devices had virtually no impact on pilot training because it was in its infancy.[22]

The interwar period

There were no frontrunners in the development of flight simulation until the arrival of inventor Edwin Link and his patented Link Trainer. An aviation enthusiast, Link was disappointed with the quality of flight instruction available. As a remedy, between 1927 and 1929, he turned his attentions toward the creation of the Link Trainer.

An engineer in his father's Link Piano and Organ Company, Link developed his trainer by using his expertise in organ making to create "a machine with a pneumatic motion platform driven by bellows."[23] The bellows were used to create pitch, roll, and yaw movements. The original trainer had no cockpit instrumentation but was equipped with flight controls. Movements of the control stick and rudder were transmitted to an electrically driven suction pump located in the fixed base. The pump actuated various control valves resulting in platform motion.[24] Motion accuracy was extremely subjective and achieved through trial and error. The Link Trainer was designed to give student pilots a feel for how an aircraft responds to its flight controls. However, the flight controls worked independently of each other and the resultant motion indicated aircraft attitude vice providing accurate motion cues.

Aviation in the late 1920s experienced a painful evolution as the requirement for "blind flying" became readily apparent. Aircraft were becoming all-weather vehicles, as Lieutenant Colonel James "Jimmy" Doolittle demonstrated in 1929 when he completed a flight from take-off to landing without

19. Ray L. Page, "Brief History of Flight Simulation," *SimTechT 2000 Proceedings* (Sydney: The SimtechT 2000 Organizing and Technical Committee, 2000), 2, http://citeseerx.ist.psu.edu/viewdoc/ download?do i=10.1.1.132.5428&rep=rep1&type=pdf (accessed July 9, 2012).

20. Kevin Moore, "A Brief History of Aircraft Flight Simulation," http://homepage.ntlworld.com/ bleep/SimHist1.html (accessed July 9, 2012).

21. Rolfe and Staples, 17.

22. Ibid., 16.

23. Ascent-UK, "History of Flight Simulators" (2007), http://www.ascent-uk.co.uk/history.htm (accessed July 9, 2012).

24. Ibid.

visual reference to the horizon.[25] However, this type of flying required special instrument training. A lack of such training proved to be fatal for pilots of the United States Army Air Corps. In February 1934, the United States Army Air Corps assumed responsibility for the delivery of domestic mail, and the United States (US) Army Air Corps Mail Operations (AACMO) was formed. Sadly, the AACMO suffered 66 crashes and 12 fatalities before the operation was cancelled by April of the same year.[26] Many of these crashes were due to loss of aircraft control in weather.

Military flying operations were forever changed by the failed AACMO. As a result, the US Army purchased Link Trainers upgraded with full instrumentation.[27] The concept of "flying by the seat of the pants" was dead, and simulators found a niche in training pilots to fly their aircraft through the use of their instrumentation. Hence, the need for simulators to recreate the motion of aircraft was brought into question. Link, himself, had difficulty convincing people that motion was even a requirement. Consequently, with the exception of the Link Trainer, the requirement to train for instrument flying resulted in the use and development of fixed-base simulators until "the era of true motion cue simulation."[28]

The Second World War

Although flight simulation was not instrumental in pilot training during the First World War, the Second World War witnessed the rapid expansion of the use of training simulators. The role of aviation had indeed changed dramatically during the interwar period. The US AACMO experience resulted in a strong desire for improved training. Between 1939 and 1945, over 10,000 Link Trainers were used to train Allied pilots.[29] Increased aircraft range required pilots to learn new skills in navigation. The increasing complexity of aircraft required crews to learn complex procedures and crew management. For these roles, fixed-base simulators were ideal.

The Second World War witnessed the creation and invention of a myriad of fixed-base simulators in addition to the use of the Link Trainer. Early developments consisted of instructional fuselages housed in hangars. There was no associated motion, but all the instrumentation, indicators, controls, and systems were made to work in the same manner as the real aircraft.[30] These fixed-base, no motion simulators allowed crews to train both normal and emergency procedures, such as bomb-dropping and bailout procedures, respectively. The Silloth trainer was one such training device.

Developed in 1941, the Silloth trainer originated at Royal Air Force Station Silloth, hence the name. The original trainer was a Lockheed Hudson light bomber and aerial reconnaissance aircraft mounted on an immovable base. The fuselage was equipped with electrics and pneumatics used to "simulate instrument readings, engine sound, and movement for 'realistic' training."[31] It was designed to train aircraft procedures and is considered by some to be the precursor to the modern aircraft simulator. Other aircraft types—such as the Wellington, Lancaster, Halifax, and Dakota—were all made into Silloth trainers prior to the end of the war.[32]

25. US Centennial of Flight Commission, "Jimmy Doolittle – Avation Star," http://www.centennialofflight.gov/essay/Air_Power/doolittle/AP17.htm (accessed July 9, 2012).

26. John T. Correll, "The Air Mail Fiasco," *Air Force Magazine* 91, no. 3 (March 2008), http://www.airforce-magazine.com/MagazineArchive/Pages/2008/March%202008/ 0308airmail.aspx (accessed July 9, 2012).

27. Moore.

28. Rolfe and Staples, 20.

29. Ascent-UK.

30. Rolfe and Staples, 27.

31. Wartime Memories Project, "Information," http://www.wartimememories.co.uk/ airfields/silloth.html (accessed July 9. 2012).

32. John M. Rolfe, "Two Cambridge Inventors," *Royal Aeronautical Society: Flight Simulation Group*, http://www.raes-fsg.org.uk/18/The_Cambridge_Cockpit (accessed July 9, 2012).

Despite the questionable significance of motion, Link motion trainers continued to dominate the aviation simulation industry. In 1941, the Link Corporation included a rudimentary visual system when it delivered the first Celestial Navigation Trainer to the Royal Air Force. Designed to train aircrew in the fundamentals of celestial navigation, it was comprised of a large Link motion platform flown by the pilot with crew positions for the bombardier and navigator. The navigator was provided with a large collimated view of 12 stars that moved across a domed ceiling and could be used to plot his position. The entire simulator was massive by the standards of the era and housed in a 45-foot-high silo-shaped building.[33]

Post-Second World War and the new motion platform

The Second World War proved the validity of simulation in flight crew training. The military dominated the initial era of aviation and simulation development. However, as large commercial aviation became a viable business model, civilian airlines became initially interested and then enamoured with simulation. The Curtis-Wright Corporation entered the flight simulation field in 1943 and developed the first Boeing 377 Stratocruiser full aircraft simulator. Another company, Rediffusion, was contracted by British Overseas Airways Corporation (the precursor to British Airways) to build a similar simulator. However, motion simulators remained in the minority until the late 1950s and early 1960s. Despite their predominant use as procedural trainers, the concept of full-motion flight training remained and manufacturers continued to develop motion proposals. However, it was not until 1958 that the airlines decided to purchase them. Rediffusion produced the first motion simulator in the form of pitch motion.[34]

In the arena of the simulator motion debate, 1966 marks the next technological leap. That year, while working for the Space and Weapons Research Establishment for aviation, D. Stewart published a proposal for "a flight simulator motion base in which a moveable triangular platform was supported by three articulate legs."[35] This proposal, when combined with research completed by researcher V. E. Gough, led to the invention of the Stewart-Gough Platform (commonly referred to as merely the Stewart Platform). The Stewart-Gough Platform permitted an aircraft cockpit to be placed on top of a moveable platform to allow for the experience of motion in six degrees-of-freedom.

At this point, it is important to clearly define "six degrees-of-freedom." All aircraft movement in flight occurs either around (rotational) or along (translational) the lateral, longitudinal, and vertical axes (see Table 2.1). Rotational motion *around* the lateral axis is referred to as pitch, while motion around the longitudinal axis is referred to as roll, and motion around the vertical axis is yaw. Translational motion *along* the lateral axis is referred to as sway, while motion along the longitudinal axis is referred to as surge, and motion along the vertical axis is heave. Aircraft in flight are subjected to all six motions and the quest for accurate motion simulation needs to replicate these movements—hence the term "six degrees-of-freedom" motion simulator platforms.[36]

33. Rolfe and Staples, 26.

34. Ibid., 33.

35. E. F. Fichter, D. R. Kerr, and J. Rees-Jones, "The Gough-Stewart Platform Parallel Manipulator: A Retrospective Appreciation," *Journal of Mechanical Engineering Science* 223, no. 1 (January 2009), 243.

36. This explanation of the six types of motion is derived from the field of applied physics and aerodynamics. See William F. Moroney and Brian W. Moroney, "Flight Simulation," in *Handbook of Aviation Factors*, eds. Daniel J. Garland, John A. Wise, and V. David Hopkin (Mahwah, New Jersey: Lawrence Erlbaum Associates, 1999), 366–67. For additional information about rotational and translational motion, see John D. Anderson, *Introduction to Flight* (New York: McGraw-Hill, 2000).

Axes	Rotational Motion	Translational Motion
Lateral	Pitch	Sway
Longitudinal	Roll	Surge
Vertical	Yaw	Heave

Table 1. Rotational and translational motion

Simulation in the modern age and the future

While researchers like Stewart and Gough were developing a platform to simulate the six degrees-of-motion, others were improving other areas of simulation such as visual systems. Prior to the computer age, simulators used a closed-circuit television (CCTV) screen mounted outside of the cockpit simulator windows. A camera was then moved over a terrain board in coordination with simulator inputs to provide the pilot with a visual representation of flight.[37] The advent of the computer age and computer-generated imagery replaced this technology, as it removed the requirement for a terrain board and opened up an endless possibility of scene generation. The computer images were projected on collimated (infinity-focused) screens and allowed pilots to be further immersed in the virtual reality of simulation. As technology has evolved, it has permitted "for continuous viewing in excess of 180 degrees,"[38] allowing users to be exposed to both direct and peripheral visual cues.

Modern simulators currently employ advanced visual systems and complicated motion-base systems. The future of simulation will continue to reap the benefits of evolving technologies. Visual systems currently replicate extremely accurate scene detail. The weakness in modern simulators continues to be the motion base. Although the conundrum of six degrees-of-freedom has been resolved, the acceleration motion problem remains unsolved. Acceleration requires the movement of mass over distance. This is not feasible within housing constraints. However, the simulator with the greatest level of promise is the Desdemona simulator in the Netherlands.

Developed by the independent research organization TNO, Desdemona is heralded as the next step in simulation. The cockpit is mounted on a Stewart-Gough platform. However, the platform is mounted in a sliding cage mounted on a rotating base. The base rotates like a centrifuge, allowing the occupant to experience up to 3 G of sustained force.[39] The issue with Desdemona is a matter of cost. Although not releasable, the cost is estimated to be well in excess of $60 million. This places Desdemona in a class of its own; it is not something that is attainable for either commercial or military simulation. Desdemona was developed primarily for aviation research; a task for which it is ideally suited.

Simulator fidelity

The fuel crisis during the 1970s resulted in the airline industry searching for more cost-effective ways to train aircrew without the high costs associated with flight in real aircraft.[40] Whereas the military had previously been the driving force behind simulator development, economics drove the

37. Rolfe and Staples, 131.

38. Page, 10.

39. Bernd de Graaf and others, "MSC: Vehicle Validation of Military Flight Simulation," http://ftp.rta.nato.int/Public/PubFullText/RTO/MP/RTO-MP-HFM-136/MP-HFM-136-16.pdf (accessed July 9, 2012).

40. Wei L. Chen, "Simulation for Training and Decision-Making in Large-Scale Control Systems: Part 2: Civil Aircraft Pilot Trainers," *Simulation* 35, no. 2 (August 1980): 42–44.

commercial industry to fund and develop better simulators.[41] Increases in technology, the advent of digital computers, and computer generated graphics urged the airlines to seek a higher level of accuracy in flight simulators. Finally, the invention of the now industry standard Stewart-Gough Platform, with its ability to simulate limited acceleration cues, propelled motion simulation into mainstream industry by the 1980s.[42] The subsequent increased use of flight simulators in pilot training added new fuel to the simulator motion debate. Central to the debate is simulator fidelity. Many researchers have defined fidelity and continue to debate an all encompassing meaning. By strict definition, the *Oxford English Dictionary* defines fidelity as "the degree of exactness with which something is copied or reproduced."[43] For the simplicity of this analysis, flight simulator fidelity means the degree to which flight is accurately reproduced. In broad terms, fidelity can be subdivided into two broad categories: objective and perceptual.[44]

Objective fidelity is easily explained and defined. It refers "to the physical correspondence between the flight simulator and the aircraft."[45] Objective fidelity is concerned with the physical realm and requires the exact reproduction of switches, controls, and instrumentation. The level of objective or physical fidelity can be easily compared to the real aircraft. The elusive perceptual fidelity is much more complicated to assess and involves subjective interpretation. *Perceptual fidelity* refers to the pilot's perception or comparison of simulator and aircraft performance.[46] Perceptual fidelity is the domain of the motion debate. For the purpose of this analysis, perceptual fidelity can be further subdivided into *motion fidelity*, *visual fidelity*, and *cognitive fidelity*.

Motion fidelity is very difficult to perfect in land-based flight simulators. As the name implies, it refers to the "extent to which the motion-induced forces experienced in the simulator reflect those of the actual flight environment."[47] The Stewart-Gough Platform allowed these forces to be replicated better than ever before, but it is still limited by an inability to simulate sustained G forces. In 1989, researchers concluded that without an unforeseen technological breakthrough, it was "hopeless to provide realistic force and motion stimuli in the sense that acceleration forces produced by aircraft can be replicated in a simulator."[48] As will be explained in a later section, the Stewart-Gough Platform manipulates the gravity force vector on the occupants and can simulate basic acceleration and decelerations. However, these forces are limited in nature, and modern engineering is used to trick the human motion processing system. Consequently, since 100 per cent motion fidelity is unattainable, science should focus on the "perceptions associated with force and motion."[49]

Visual fidelity refers to the accuracy of the scene detail in relation to the real world. Although visual technology has resulted in great advancements in scene generation, there still exist limitations

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41. The military, especially the Canadian Air Force, has lagged behind the commercial industry in the use of flight simulators. The Air Force Automation Policy and Planning Development (APPD) *Automation Analysis Report* conducted in 2008 referred to the Air Force as "sim-phobic," citing that 1 Canadian Air Division orders state that "normally using the simulator for performing [instrument rating tests] will be approved as a backup to the IRT being flown in the actual aircraft." Page 3.26.

42. Dave Higdon, "Flight Training – Simulators Review," *AV Buyer* (March 2008), http://www.avbuyer.com/articles/detail.asp?Id=1072 (accessed July 9, 2012).

43. Catherine Soanes, *Pocket Oxford English Dictionary* (New York: Oxford University Press, 2002), 332.

44. McCauley, 4.

45. Ibid.

46. Ibid.

47. Mary K. Kaiser and Jeffrey A. Schroeder, "Flights of Fancy: The Art and Science of Flight Simulation," in *Principles and Practice of Aviation Psychology*, eds. Pamela S. Tsang and Michael A. Vidulich, 435–71 (New York: CRC Press, 2003), 439.

48. Yorke Brown, Frank Cardullo, and John Sinacori, "Need-Based Evaluation of Simulator Force and Motion Cueing Devices," *Flight Simulation Technology Conference and Exhibit* (Boston: American Institute of Aeronautics and Astronautics, 14–16 August 1989), 79.

49. Judith Bürki-Cohen, Nancy Soja, and Thomas Longridge, "Simulator Platform Motion – The Need Revisited," *The International Journal of Aviation Psychology* 8, no. 3 (Fall 1998): 299.

of computer generated images used in flight simulation. The current technology cannot fully recreate "the richness and complexity of the visual world."[50] The amount of computer processing power required to depict both fine detail and large pictures currently surpasses what is available. However, simulator visual systems continue to evolve, and Moore's Law (computing processing power doubling every two years) gives reason to have high expectations for future improved visual systems at reasonable cost.[51] One of the greatest breakthroughs in visual technology is the wide field of view now available in simulators. This provides critical visual inputs to both the peripheral and focused visions.

Cognitive fidelity is the last, yet perhaps the most complicated, subcomponent of perceptual fidelity. Cognitive fidelity combines all fidelity types to create operator "buy-in" to the simulation. It refers to the engagement of the pilot's cognitive skills such as situational awareness, decision making, and problem solving.[52] Historically, flight simulators have sought the other forms of fidelity without much appreciation for cognitive fidelity. However, in the modern age of flight simulation, cognitive fidelity has arguably become the most important. It requires full immersion in the simulated environment. Increases in aircraft complexity and the use of flight automation systems have created a need for high cognitive fidelity simulators in order to train crew and teach flight management skills.[53]

In the final analysis, it is important to acknowledge that simulator fidelity types are not mutually exclusive and that a significant amount of overlap exists. Visual fidelity can affect motion fidelity which can affect cognitive fidelity, and so on. Although high-cost and high-fidelity simulators are used for pilot training, research "has shown that high fidelity simulators may not be necessary to produce effective training results."[54]

Modern simulation classification system

The level of fidelity, both objective and perceptual, is critical in the industry standard for the classification of flight training devices. It is assumed that the more sophisticated the simulator, the more training can be transferred to the aircraft. North America shares the same classification system after Canada adopted the same nomenclature as the Federal Aviation Authority's Aviation Circular 120–40C in January 1998. Europe's classification is also similar in accordance with regulations established by the Joint Aviation Authority (JAA) in Joint Aviation Regulation–FSTD A, issued in May 2008.[55]

When discussing the various types of flight simulators, it is important to establish a baseline of definitions. The term "flight simulation training device" (FSTD) is an all-encompassing term for all simulator training devices. Underneath the umbrella of FSTD are full flight simulators (FFS) and flight training devices. An FFS is a full size replication of an aircraft's flight deck. It consists of all instrumentation and the computer programming required for the duplication of the aircraft in

50. Kaiser and Schroeder, 453.

51. Gordon Moore was the founder of Intel. In 1965, he postulated that the processing power of computer chips would double every two years based on the assumption that the number of transistors on an integrated circuit would continue to grow exponentially. This would drive the cost down and quality up in computer power for the foreseeable future. His prediction has been proven correct for over 40 years. See S. Furber, "The Future of Computer Technology and its Implications for the Computer Industry," *The Computer Journal* 51, no. 6 (November 2008): 735–40.

52. Kaiser and Schroeder, 440.

53. Alfred T. Lee, *Flight Simulation: Virtual Environments in Aviation* (Burlington: Ashgate Publishing Company, 2005), 71.

54. Beth Blickensderfer, Dahai Liu, and Angelica Hernandez, *Simulation-Based Training: Applying Lessons Learned from Aviation to Surface Transportation Modes* (Daytona Beach: Emery Riddle Aeronautical University, 2005), 21.

55. Joint Aviation Authority, "JAR-FSTD A: Aeroplane Flight Simulation Training Devices," http://www.jaa.nl/publications/jars/JAR-FSTD-A_sec1_0508.pdf (accessed July 9, 2012).

ground and flight operations as well as a visual system providing the out of the flight deck view and a force cueing motion system. The major difference in a flight training device is that it does not require the visual or force cueing motion systems.[56]

There are four levels of FFS spanning a range from Level A to Level D, with the latter being the most sophisticated level of simulation. In accordance with Transport Canada, "the more sophisticated the simulator, the more training and checking may be approved for that simulator."[57] Transport Canada publication TP 9685 clearly defines the levels of required fidelity in each level of simulator.

At the low end of the spectrum, Level A and B simulators require a minimum of four degrees-of-freedom of motion. The major difference between the two levels is the quality of the visual system. A Level B simulator is required to be able to reproduce visual cues such as sink rate and depth perception during landing, whereas a Level A simulator is not.[58]

There is a significant technological and monetary jump to Level C and D simulators. Mainly, both levels require six degrees-of-freedom of motion. This, by default, requires the use of a Stewart-Gough full-motion platform. This results in second- and third-order associated costs that include the construction of a suitable building and a higher level of maintenance and computer support. Again, similar to the difference between Level A and B simulators, the major difference between Level C and D simulators is the quality of the visual system. Where both levels require the ability to replicate night and dusk scenes, Level D simulators are required to replicate daylight visual scenes. Level D simulators are required to reproduce all scenery "with sufficient content to recognize airport, terrain and major landmarks."[59] Additionally, Level D simulator daylight visual scenes need to include sufficient cockpit lighting to replicate the actual cockpit lighting on an overcast day.

Summary

The history of the development of aviation simulators is nearly as long as the history of flight itself. Flying is an inherently dangerous act for mankind. The purpose of simulators has been to recreate this unsafe act in a safe environment. As technology has evolved so has the quality of simulation available to pilots and aircrew.

Central to the motion requirement debate for flight simulators is a solid understanding of simulator fidelity types and subtypes. The ability to accurately recreate the aviation environment has led to an internationally adopted simulator classification system. The two major delineators in the classification system are the visual and motion systems, where the motion system is the more expensive of the two.

Establishing a baseline of knowledge is crucial prior to examining the merits of motion in aviation flight simulators. However, understanding the history and nomenclature is only one minor facet of the motion debate. It merely provides the framework for the discussion. In order to evaluate the need and requirement for motion in aircraft simulators, it is important to understand how humans process motion and motion cues. This is the focus of the next section.

56. Ibid., 1-B-1.

57. Transport Canada, "TP 9685," http://www.tc.gc.ca/civilaviation/publications/tp9685/ chapter2/menu.htm; (accessed July 9, 2012).

58. Ibid., 2-A-7.

59. Ibid., 2-A-8.

3. How humans process motion

Introduction

The most important trait required for human survival is our ability to orient ourselves to our surroundings. Spatial orientation is "a fundamental and primitive need for humans."[60] It is this ability that governs human interaction with the rest of the physical realm. Children develop this ability over time, and as their sense of balance and spatial orientation improves, they develop the ability to first crawl and then walk. Early humans required this ability in order to hunt and stalk prey. Modern humans require this ability to carry on with our everyday activities, from walking to the bus stop to flying aircraft.

Embedded in the human ability of orientation is our ability to process motion. There exist only two types of physical motion: translational (linear) motion and rotational (angular) motion.[61] As humans have evolved, we have developed overlapping and redundant systems to identify these motions. Motion perception is "built up by the central nervous system at various levels of consciousness by synthesizing the nervous signals from a wide variety of sensory organs."[62] Weaknesses in one system are often compensated for by the remaining systems. Much in the same manner that a blind person's sense of hearing is improved as a compensatory reaction, when humans are deprived of a motion sensing system the other systems will compensate. The human ability to identify and process motion is derived mainly from the visual, vestibular, proprioceptive, and aural systems.

Understanding how humans process motion is critical to understanding the significance of motion, both in actual and simulated flight. Once a solid understanding is achieved of how the human motion sensing systems interact, it will be possible to explain how modern simulators are able to trick the human brain into believing it is experiencing something it is not. To achieve this understanding, this section is divided into four parts. First, the visual system will be examined in depth. Second, the inner workings along with the strengths and weaknesses of the vestibular system will be explained. Third, this section will explain how secondary sensing systems like the auditory and proprioceptive systems indirectly contribute to motion sensing. Lastly, how all the systems combine to create total motion sensing will be explored.

The visual system

The visual system is arguably the most important human system for the accurate and correct processing of motion. It is critical to spatial orientation, especially in moving vehicles. Consequently, flight would be impossible without it, whereas "this would not necessarily be the case in the absence of the vestibular or other sensory systems."[63] Human vision is a complex process, habitually taken for granted. The human eye is often compared to a camera, and although the construction may be similar, the operation is very different. Unlike a camera, the human eye does not capture a picture and then transmit that picture to the brain. Rather, the brain uses signals detected by the optic nerve to "infer a concept of the physical space surrounding a person."[64]

60. McCauley, 8.

61. Kent K. Gellingham and James W. Wolfe, "Spatial Orientation in Flight," in *Fundamentals of Aerospace Medicine*, ed. Roy L. DeHart (Philadelphia: Lea and Febiger, 1985), 299.

62. Yorke J. Brown, Frank M. Cardullo, and John B. Sinacori, *Effects of Motion on Skill Acquisition in Future Simulators, Study Report 2006-07* (Arlington, VA: United States Army Research Institute for the Behavioral and Social Sciences, May 2006), 78.

63. Gellingham and Wolfe, 308.

64. Brown, Cardullo, and Sinacori, 79.

The human visual system is an extremely sensitive detection system. In fact, the sheer volume of information which can be processed by the visual system "exceeds that of any other sensory mechanism by several orders of magnitude."[65] In order to process the sheer magnitude of sensory cues, Dr. Laurence R. Young, Apollo Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology (MIT), determined that the human eye differentiates between two types of visual cues: central field (foveal) cues and wide field (peripheral) cues.[66] To process these cues, vision must be considered as two separate systems. The first vision system is focal vision, whereas the second system is ambient vision.

Vision types: focal and ambient vision

Foveal cues are the high acuity, high information density, central focal vision cues. These cues must be read in order to be processed by the human brain. In aviation, these vision cues are presented to the pilot through instruments, runway markings, approach / en route charts, and checklists. Focal vision is the domain of fine detail. When a pilot is flying in instrument conditions with no reference to the outside world, focal vision is used to read instruments such as the artificial horizon. In this manner, the pilot uses his focal vision to combat miscues from the vestibular system that could lead to spatial disorientation, such as the "leans."[67] In this situation, focal vision does not directly contribute to a sense of motion, but it does provide visual information to assist orientation.[68]

Focal vision is not limited to reading instruments. The foveal cues used in focal vision are critical for the judgment of both depth and distance.[69] This makes focal vision critical for high intensity tasks, such as low-level contour flying and landing manoeuvres. Accordingly, focal vision typically requires specific effort and attention, whereas ambient or peripheral vision is more reflexive in nature.[70]

Ambient vision is the visual system that directly affects how humans process motion and is integral to spatial orientation. It is regularly referred to as peripheral vision and is often processed directly by our subconscious vice requiring specific effort. It is generally accepted that ambient vision plays the dominant role in spatial orientation.[71] The function of ambient vision is independent of the function of focal vision. A person who has fully engaged their focal vision with a task such as reading is capable of simultaneously walking down the street, oriented by their peripheral vision.

Ambient vision is primarily concerned with the detection of large object motion within a wide field of view and the detection of "self-motion with respect to the visual environment."[72] Imagine sitting in a train reading a book. Outside the window is a stationary freight train on the adjacent track. As you continue to read your book, the flanking freight train starts to slowly advance. Your ambient vision system detects this motion and you jerk your head up thinking that *your* train has

65. A. R. Buffett, "Visual Cueing Requirements in Flight Simulation," *Advances in Flight Simulation – Visual and Motion Systems* (London: The Royal Aeronautical Society, 1986), 127.

66. Laurence R. Young, "Visually Induced Motion in Flight Simulators," in *Advisory Group for Aerospace Research and Development (AGARD) Conference Proceedings* No. 249, (Brussels: AGARD,1978), 16-1.

67. The "leans" is probably the most common type of pilot spatial disorientation in flight. It is the result of a quick return to level flight with no reference to the natural horizon following a slow, gradual turn. The vestibular system is confused and senses that the pilot is not in straight and level flight, but rather in a banked turn in the opposite direction of the original turn.

68. Gellingham and Wolfe, 310.

69. Ibid.

70. H. Liebowitz and C. L. Shupert, "Two Modes of Visual Processing: Implications for Spatial Orientation," in *Peripheral Vision Horizon Display* (Edwards, California: NASA Conference Publication 2306, 14 November 1984), 42.

71. K. E. Money, "Theory Underlying The Peripheral Vision Horizon Device," in *Peripheral Vision Horizon Display* (Edwards, California: NASA Conference Publication 2306, 14 November 1984), 52.

72. Laurence R. Young, "Spatial Orientation," in *Principles and Practice of Aviation Psychology*, eds. Pamela S. Tsang and Michael A. Vidulich, (New York: CRC Press, 2003), 72.

started moving. As soon as you look outside you realize that your train is not moving and the illusion of motion disappears. This illusion of self-motion is a product of the ambient vision system and is referred to as "vection." The uses for vection are widely applicable to both the entertainment and simulation industries. Vection in flight simulation is central to the argument for reducing simulator platform motion requirements.[73]

Vection

The illusory effect of vection has been studied for almost a century.[74] Consequently, accepted truths and facts have been established. To successfully create the optical illusion, a wide field of view visual system is required to provide a coherent optical flow.[75] The technological ability to create large visual scenes with sufficient resolution to obtain the required coherent optical flow is something that has only recently become available to the simulator industry. In previous years, visual systems in flight simulators were not able to create the now almost industry standard 200-degree field of view or greater. Vection in early simulators was almost non-existent as visual systems consisted of small cathode ray tube (CRT) television screens that never engaged the ambient vision system.

There are governing factors affecting both the onset and strength of vection. The importance of a wide field of view in engaging the peripheral vision has already been discussed. To reinforce the importance of peripheral vision to vection, research has concluded that a visual stimulus within 50 degrees of centre has little to no effect.[76] In addition to the importance of a wide field of view, vection is affected by human focus points, onset delays, and visual field velocity.

The importance of focus points has been well documented in the creation of vection. In 1975, researchers determined that "background stimulation dominates over foreground stimulation."[77] Simply put, a stationary window frame or marks on a window itself do little to *inhibit* visually induced motion when the background picture is moving. However, recent studies have concluded that focus points in the foreground while the background moves may actually *enhance* visually induced motion. Dr. Bernhard Riecke and others concluded in a recent experiment that vection could be reliably and consistently reproduced in all test subjects.[78] Moreover, the experiment used stationary marks on viewing windows to enhance onset. These marks were unknown to the test subjects and the experiment concluded that "quick vection onset [could] indeed be reliably induced in a virtual reality simulator in a non-obtrusive way… under natural, relaxed viewing conditions."[79] A possible conclusion from this experiment is that vection in flight simulators might be enhanced by intentionally marking the windscreens with either unobtrusive dirt or bug stains.

Vection onset delay in virtual reality is a concern for flight simulation. It has been addressed in part by ongoing research as indicated in the previous paragraph. A continuing concern is that vection onset is highly variable among individuals. Studies continue to address this concern and the entertainment industry will surely be instrumental in onset-delay reduction studies. Onset delays can be mitigated by other sensory inputs such as limited onset motion cues. This is the fundamental concept behind the Mechtronix Full Flight Trainer discussed in Section 5.

73. Young, "Visually Induced Motion in Flight Simulators," 16-1.

74. For an excellent, in-depth explanation of vection see: L. J. Hettinger, "Illusory Self-Motion in Virtual Environments," in *Handbook of Virtual Environments*, ed. Kay M. Stanney, (Mahwah, NJ: Lawrence Erlbaum Associates, 2002), 471–92.

75. McCauley, 8.

76. Fred H. Previc, "Visual Orientation Mechanisms," in *Spatial Disorientation in Aviation*, ed. Paul Zarchan, (Reston,Virginia: American Institute of Aeronautics and Astronautics, 2004), 106.

77. Young, "Visually Induced Motion in Flight Simulators," 16-2.

78. Bernhard E. Riecke and others, "Enhancing the Virtually Induced Self-Motion Illusion under Natural Viewing Conditions," *Presence 2004: Conference Proceedings*, (London: University College London, September 2004), 125–132.

79. Ibid., 131.

Finally, vection is directly affected by the visual field velocity. The illusion of vection can only be maintained as long as the visual field can clearly replicate the sense of motion. If the image starts to blur or resolution is decreased, the illusion disappears.[80] Additionally, slowly moving or changing scenes tend to create the greatest sense of vection.[81] For this reason, airline and air mobility simulators are better suited to this type of simulation vice fast/fighter jet simulators.

The vestibular system

The human vision system is the dominant system for the processing of human motion and does not habituate to constant velocities. However, when visual cues are removed, motion perception begins to break down and our "orientation in Earth-fixed space suffers."[82] With the absence of vision cues, motion perception is derived from other motion sensing systems such as the vestibular system.

Understanding of the vestibular system has made great advancements since the days of the Ruggles Orientator. In 1917, the creators of the Orientator believed that the vestibular system could be trained to adjust to any possible postural orientation. Since then this has proven to be unequivocally false. The vestibular system is an important source of acceleration and orientation information, but it is also susceptible to a series of false cues. The vestibular system is the non-auditory portion of the inner ear. It provides a pilot with the sensations of both translational (along) and rotational (around) movements in the three axes. It consists of two components: the semi-circular canals and the otolith organs, which consist of both the utricle and saccule.

The semicircular canals

The semicircular canals are the sensors for rotational acceleration around the three axes. The three canals coincide with the orientation of the three axes and are filled with fluid known as endolymph. The walls of the tubes are filled with very sensitive hairs. As the head is rotated in any of the three directions, the fluid is displaced, which in turn displaces the hairs within the canals. These hairs then transmit the rotational displacement to the brain as motion.[83]

As the endolymph is displaced by rotation movement, it will eventually push up against and then be stopped by a membrane known as the cupula that prevents the fluid from entering the ampullae. Consequently, the semicircular canals are very accurate for brief head movements, but for sustained constant velocity motion their ability to sense motion decays to zero.[84] The semicircular canals are susceptible to the density and viscosity of the endolymph. Very gradual motion cannot be sensed. This is known as an effective threshold in human perception of rotation. There is no absolute threshold, as all individuals differ slightly. However, laboratory tests with fully attentive subjects have determined the rotational sensing threshold can be as low as 0.2 degrees per second squared ($^\circ/sec^2$) for yaw and only slightly higher values of $0.5^\circ/sec^2$ for pitch and roll.[85] Modern simulator motion platforms use these sensing thresholds to trick users by returning the platform to level without the occupants' knowledge.

80. Young, "Visually Induced Motion in Flight Simulators," 16-2.

81. Previc, 107.

82. Ibid., 95.

83. David C. Edwards, *Pilot: Mental and Physical Performance* (Ames: Iowa State University Press, 1990), 15.

84. Young, "Spatial Orientation," 75.

85. Ibid., 76.

Otolith organs

The otolith organs are used to sense linear accelerations in both the vertical and horizontal planes. Both the utricle and saccule are constructed the same way. The difference between the two is that the utricle senses acceleration in the horizontal plane while the saccule is responsible for the vertical plane.[86]

The otolithic membrane consists of dense calcium carbonate crystals known as otoconia resting on endolymph fluid. Consequently, the membrane is denser than the surrounding endolymph. Small hair cells extend from the underlying maculae and extend into the otolithic membrane. As a person leans forward, the effect of gravity pulls the otoconia forward. The motion is sensed by the small hair cells and, in this case, the signal is interpreted by the brain as either forward tilt or linear deceleration. The same concept applies to the saccule for processing vertical accelerations.

The organs are capable of determining postural vertical orientation to within two degrees. They are very sensitive to linear accelerations but are also susceptible to an effective perception threshold. For sustained horizontal accelerations, laboratory tests have indicated a sensitivity of 5–10 centimetres per second squared (cm/sec^2), while the vertical is less accurate at 20 cm/sec^2. Much like the semicircular canal perceptual threshold, motion platforms use these sensitivity thresholds in order to simulate unachieved motion. For example, by tilting simulators forward on a motion platform, the otolith organs can be tricked into signalling a linear deceleration when the visual inputs are removed or manipulated accordingly.[87]

Proprioceptive and aural systems: the reinforcing systems

The application of the visual and vestibular systems in the human processing of motion is intuitive to most people. The proprioceptive system is more subtle. The proprioceptive system comprises the total collection of inputs "from the pilot's joints and muscles, which provide information regarding the position of the limbs relative to the body."[88] Every muscle, joint, and tendon in the human body contains mechanoreceptors that provide spatial orientation information to the brain. Every movement of the head, shoulders, arms, legs, finger, and toes "stretches mechanoreceptors and inundates [the] brain with impulses that [are sorted] out into positional awareness."[89] Even while standing still, small tendons and muscles make positional corrections to maintain vertical posture.

The proprioceptive system involves the brain sending out instantaneous and subconscious signals to the body in order to achieve balance and movement. For a pilot this is critical information. The sense of motion is, therefore, reinforced by the proprioceptive system. The pressure on the rudder pedals and control stick is sensed by the limbs and confirms in the brain that the aircraft is actually in motion. The illusion of motion simulation is defeated or tainted if the aircraft controls do not react with the appropriate force. This is achieved in flight simulators through the use of control loading.[90]

Like the proprioceptive system, the auditory system also reinforces the sense of motion. On the ground, auditory cues play an important role in spatial orientation. A revolving sound source

86. Columbia University, "The Vestibular System," http://www.columbia.edu/itc/hs/medical/ neuralsci/2004/slides/32_LectureSlides.pdf (accessed July 9, 2012).

87. Alfred Lee, *Flight Simulation: Virtual Environments in Aviation* (Farnham, England: Ashgate Publishing Company, 2005), 41.

88. Ibid., 42.

89. David L. Phillips, "The Proprioceptive Nervous System," http://www.suite101.com/article.cfm/ chiropractic_health_care/102364; (accessed March 19, 2010, hyperlink no longer active).

90. Lee, 58–60.

can create a sense of vection in the form of rotational self-motion.[91] However, high ambient noise, especially in military aircraft, can negate auditory-induced vection. Nonetheless, pilots do extract reinforcing auditory orientation information. Aircraft make subtle sound changes in varying regimes of flight. Changing angles of attack affect sound patterns as the airflow is manipulated over the fuselage and wings. Engine noises increase during high workload manoeuvres. In fact, the CC177 engines make entirely different sounds during flap and slat extended assault approach landings as compared to straight and level flight.[92] All of these auditory cues combine to reinforce a sense of motion in the pilot.

Scientific research into the field of auditory vection has been surprisingly minimal. However, new research has been conducted by an ongoing European Union research project on Perceptually Oriented Ego-Motion Simulation (POEMS). In an overarching attempt to create an effective and convincing self-motion simulator, POEMS has concluded that auditory vection has certain limitations. First, auditory vection only occurs in 25–60 per cent of subjects. Second, although auditory vection can occur, auditory cues "alone are clearly insufficient to reliably induce a compelling self-motion sensation that could be used in applications."[93] However, POEMS has concluded that auditory cues can be used to reinforce visual vection and therefore improve overall immersion into a virtual environment.

How the systems combine for total motion sensing

The human sensing systems normally work together seamlessly and miscues in everyday life are rare for healthy individuals. However, the interaction between the visual, vestibular, proprioceptive, and auditory systems is often altered in the flying environment.[94] Spatial orientation combines the subconscious incorporation of vestibular and proprioceptive cues and the conscious analysis of visual and auditory cues. Each system has strengths and weakness that are either exploited or neglected in flight. When visual cues are removed from the equation, proprioceptive and vestibular cues try to compensate but are often subjected to their own limitations.

Vestibular perception thresholds allow for the misinterpretation or complete inability to identify subtle motions. Moreover, where the visual system receives constant updates, the vestibular system habituates to motion over time. An example of this is the cues identified by the pilot during a climbing manoeuvre to a new cruising altitude without visual references. When the climb is initiated, the vestibular otolith organs will indicate a linear acceleration. Over time the system will readjust to neutral as the otoliths adapt to the constant motion. When the aircraft is levelled off at cruising altitude, the pilot will sense that the aircraft has started a dive. If the pilot has visual reference to the horizon, the sense of diving will be overcome by the visual information provided to the brain.

Unresolved conflicting motion sensory information can result in motion sickness. In flight simulators where sensory limitations are exploited, the conflicting sensory inputs can result in a specific type of motion sickness referred to as simulator sickness. There are currently two accepted theories concerning the causes of simulator sickness: sensory conflict theory and postural instability theory, with the former being the most widely accepted.[95]

91. Gellingham and Wolfe, 330.

92. This is based on the author's experience flying C17 aircraft as an exchange pilot with the United States Air Force from 2005 to 2008.

93. Bernhard E. Riecke and others, "Influence of Auditory Cues on the Visually-Induced Self-Motion Illusion in Virtual Reality," *Presence 2005: Conference Proceedings*, (London: University College London, September 2005), 49.

94. Edwards, 16.

95. David M. Johnson, "Helicopter Simulator Sickess," *International Journal of Applied Aviation Studies* 7, no. 2 (Spring 2007): 184.

Sensory conflict theory suggests that motion sensing inputs are "provided in parallel to both a neural store of past sensory patterns of spatial movement and to a comparator unit."[96] This "comparator unit" analyses the currently sensed motion against a store of previously experienced motions. A mismatch between the two causes sickness. Postural instability theory suggests that simulator sickness is a result of a subject's inability to maintain postural control during unfamiliar motion environments.[97] Regardless, both theories suggest that simulator sickness can be overcome through exposure as either the subject's neural store of sensory patterns is adjusted or motion environments become familiar.

Regardless of the causal theories for simulator sickness, researchers agree upon four common factors. First, some people are more affected than others. Second, mental attitudes (i.e., expectations of being sick) significantly affect a subject's susceptibility. Third, a subject's control of the motion tends to reduce the effects on sickness. Finally, most people can adapt to simulator sickness through exposure.[98]

In 1989, the US Navy reported that simulator sickness "threatens the long term utility of ground-based flight trainers as integral components of military and civilian flight training."[99] Many have suggested that the lack of a motion platform causes the sensory mismatch between the vestibular system and the other sensing systems. Consequently, simulator sickness has been used in the argument in favour of motion platforms. The hypothesis that a high fidelity simulator motion platform would reduce simulator sickness occurrences was tested by National Aeronautical and Space Agency (NASA) researchers. Comparing subjects in both motion and non-motion test groups, it was determined that occurrences of simulator sickness were not significantly different. Based on the results of the experiment, guidelines to minimize simulator sickness were created; however, adding a motion base was not one of the recommendations.[100]

Summary

The human body has created a complicated and overlapping series of systems to process motion. For those not involved in the world of simulation, these systems are taken for granted and the interrelationship between them is not important. However, for flight simulators, a solid understanding of the interrelationship is critical for the recreation of flight in the virtual environment. Motion sensing is predominantly completed through a combination of the vestibular and visual systems, while the proprioceptive and auditory systems act in a reinforcing or confirming role.

No motion platform is able to create an exact replication of flight. Motion platforms use the known limitations of all the sensing systems to create the illusion of flight. The idea that a lack of a motion base causes simulator sickness due to a sensory mismatch was successfully debunked by NASA nearly 20 years ago. Having examined the way in which humans process motion and the interaction between the sensing systems, the following section will address how current Category D simulators use the Stewart-Gough platform to simulate six degrees-of-freedom motion and whether this level of motion is actually required.

96. Ibid.

97. Ibid.

98. Edwards, 17–18.

99. Lawrence M. Fisher, "Sickness in the Cockpit Simulator," *The New York Times*, February 20, 1989.

100. T. J. Sharkey and M. E. McCauley, *Does A Motion Base Prevent Simulator Sickness – AIAA Report 92-4134-CP* (Washington DC: American Institute of Aeronautics and Astronautics, 1992).

4. The motion requirement

Introduction

The history of aviation training has witnessed a marked increase in the use of simulators, especially over the last 20 years. Both the Federal Aviation Administration (FAA) and Transport Canada have implemented advanced qualification programs for pilot training. The dramatic technological advances in computer-based training and flight simulators have forced both regulatory agencies to allow "an air operator to develop innovative training and qualification programs that incorporate the most recent advances in training methods and techniques."[101] As simulators are much less expensive to operate than aircraft, commercial aviation has spearheaded a change to pilot training under advanced qualification programs to allow for ZFTT, which refers to training on an aircraft type rating course that is given entirely in a Level D flight simulator. This type of training is not available for all pilots and minimum experience levels are required prior to approval.[102] Most air operators would prefer to complete type training in simulators; however, the prohibitive associated acquisition costs of Level D simulators prevent this from becoming a reality for all but the large air carriers.

The most expensive portion of a Level D simulator is the platform motion base. Accordingly, a substantial amount of research has been conducted on how to improve motion cueing generators. However, this research has been misguided by the "unsubstantiated opinion that better training can be achieved by immersing pilots in higher *motion* [italics added] realism."[103] Even in 2010, it is not clear if the general preference of pilots for a full-motion simulator is the result of a psychological bias for motion. What can be agreed upon is that pilots do prefer motion. However, the method in which motion is achieved is irrelevant. Current motion research needs to focus not on the recreation of motion itself but rather on the recreation of the *perception* of motion, something that is very different than the use of an advanced motion platform. Although the bulk of research has been conducted in the field of commercial aviation, parallels can be drawn to fixed-wing military air mobility aircraft. When not operating in the tactical military realm such as low-level flight and airdrop, air mobility aircraft share many commonalities with civil air carriers while in transit and during strategic resupply.

In order to assess the requirement for motion, this section is divided into four parts. First, it will evaluate how motion is recreated using the industry standard Stewart-Gough platform and its existing limitations. Second, the significance of the different types of motion cues will be explained and their applicability to pilot actions and reactions with be evaluated. Next, this section will review the concept of skills transfer and the applicable studies to demonstrate that not all skills learned in flight simulators are necessarily completely transferable to aircraft handling. Lastly, the Volpe Center has conducted numerous studies and produced associated deductions concerning the effectiveness of motion in flight simulators. The Volpe Center serves as a US Department of Transportation sponsored vital research link between the transportation and technological communities.[104] Their studies form the backbone of contemporary research and will be examined in depth.

101. Transport Canada, *Development and Implementation of an Advanced Qualification Program* (Ottawa: Transport Canada, 2005), 19. Original hyperlink http://www.tc.gc.ca/civilaviation/commerce/aqp/menu.htm discontinued. Updated to modified document hyperlink http://www.tc.gc.ca/eng/civilaviation/standards/commerce-aqp-menu-1887.htm (accessed July 9, 2012).

102. Transport Canada, *Canadian Aviation Regulations (CARS) and Commercial Air Service Standards (CASS) – Part VII – Subpart 5 – Guidance Material* (Ottawa; Transport Canada, 2005), S745.124(8). Original hyperlink http://www.tc.gc.ca/civilaviation/commerce/manuals/guidance705/menu.htm discontinued. Updated to modified document hyperlink: http://www.tc.gc.ca/eng/civilaviation/standards/commerce-manuals-guidance705-menu-1789.htm (accessed July 9, 2012).

103. Judith Bürki-Cohen, Andrea L. Sparko, and Young Jin Jo, "Effects of Visual, Seat, and Platform Motion During Flight Simulator Air Transport Pilot Training and Evaluation," *Proceedings of the 15th International Symposium on Aviation Psychology* (Wright State University, Dayton, Ohio: 27–30 April 2009), 4.

104. Research and Innovative Technology Research, "Volpe National Transportation Systems Center," http://www.volpe.dot.gov/about/index.html (accessed July 9, 2012).

The Stewart-Gough motion platform

As described in Section 2, the Stewart-Gough motion platform was created based on research conducted in the early 1960s. Stewart concluded in 1966 that his design could "simulate true flight without any approximations within the amplitude limits set by the scale of the machine."[105] His design, combined with Gough's Universal Tyre Text Machine design, created the current Stewart-Gough motion platform.

Modern flight simulator cockpits are mounted on top of a platform articulated by six hydraulic or electrically powered legs. By manipulating the legs, the platform can be tilted in any direction. Pilot controls are linked to a computer system that interprets the inputs and manoeuvres the platform accordingly. In this manner, all six motions of roll, pitch, yaw, surge, heave, and sway are recreated. The controlling computer combines a mathematical aerodynamic model of the aircraft and "creates the appropriate physical effects such as stiffening the control column or adding bumps and vibration to simulate turbulence."[106] Leading simulator production company Thales claims that their simulators can achieve "total realism."[107] Unfortunately, this claim is misleading and inaccurate.

In order to achieve "total realism" a simulator platform would require sustained displacement over time. For example, a force of 0.1 G vertical acceleration at a frequency of 0.1 radian per second would require the motion platform to move vertically 322 feet (98 metres).[108] Obviously, space constraints preclude any simulator platform from achieving this kind of motion. Scientists have deduced two ways of reducing the amount of platform motion required. First is to only move the platform a percentage of the full motion. Second, is to move the platform at rates commensurate with human sensing perception thresholds, applying what are referred to as "washout filters."[109] Both of these approaches are combined in modern flight simulators.

The most important thing to keep in mind with regard to simulator motion platforms is that the simulator does not actually move in the same manner as an aircraft in motion. Flight simulators manipulate the way the gravity vector is exerted on its occupants in order to recreate a sense of vestibular motion. By manipulating perceptual cues to all the human sensing systems, a simulator can fool the human brain into believing it is experiencing an acceleration motion. If visual cues to reality are provided, the simulator occupant would correctly identify the motion as a tilt upward. However, if visual cues are absent or a visual system presents cues of straight and level, the motion will be interpreted as a linear acceleration.

The above scenario can be used to explain the force and motion sensations experienced by the pilot during a take-off conducted in a typical full-motion simulator. As the simulated aircraft "accelerates" down the runway, the motion platform tilts backward at a rate above the otolith organs' perception threshold. As the initial acceleration wears off after brake release, the simulator starts to tilt forward at a rate below the otolith organs' perception threshold. At all times, the simulator's visual system maintains a level picture. As the aircraft attains take-off speed, the pilot applies back pressure to the stick and the aircraft starts a "climb." The simulator platform again rotates backward at a rate greater than the perception threshold. As the aircraft attains a steady climb, the platform again tilts forward to a level attitude at a rate below perception thresholds. Finally, as the aircraft

105. D. Stewart, "A Platform with Six Degrees of Freedom," *Proceedings of the Institute of Mechanical Engineers* 180, no. 15 (1965–1966): 386.

106. Thales, "A Layman's Guide to Full Flight Simulators," http://www.thalesgroup.com/News_and_events/ 2009-01-27_UK_FOC_Aero_Laymans_Guide_FFS/ (accessed July 9, 2012).

107. Thales, "Civil Aviation Training Capabilities," *Thales Pamphlet* 5A-26-0220078 www.thalesgroup.com (accessed July 9, 2012).

108. Kaiser and Schroeder, 456.

109. Ibid.

reaches "cruise" altitude, the sense of levelling off is simulated by rotating the platform forward above perception levels and then slowly rotating back to level at a rate below perception levels. The interpretation of these motions is solidified by a visual representation that confirms the illusion.[110]

The rate at which motion is attenuated is the work of algorithmic washout filters. There has been extensive research conducted to maximize these washout filters in order to achieve realistic motion. However, as the motion is not true motion, there exist significant limitations. Most flight simulators subject their occupants to miscues along with the primary motion cues they are trying to simulate. Consider a standard bank right turn. In the aircraft, the plane is smoothly rolled to and maintained at specific angle. As the turn stabilizes at a constant bank angle, the vestibular system habituates to the motion. To recreate this motion in a simulator, the platform is initially rolled right and then slowly rolled left back to neutral. The return to level is meant to be below perception thresholds.[111] However, because not all humans share the same vestibular threshold perception levels, the left roll or motion miscue is often felt.

In 1997, a study was conducted to evaluate how a simulator replicates the initial rolling, yawing, and pitching motions associated with an outboard engine failure of a multi-engine aircraft after take-off. A comparison between the simulator and aircraft motions produced the following results: classic platform washout algorithms reproduced only 15 per cent of the actual roll rate, 19 per cent of the yaw rate, and 50 per cent of the pitch rate.[112] The motions associated with an aircraft malfunction such as an engine failure are critical for pilot reaction. In a simulator that cannot produce a completely true representation of such cues, the requirement for motion changes. The new question becomes: what motion cues are most important to pilots?

Types of motion cues

The goal of flying is to maintain an aircraft on an assigned flight path. This is conducted by processing and assessing different types of motion cues. Motion cues were identified and classified as "manoeuvre" and "disturbance" by Paul W. Caro in 1979.[113] Consequently, researchers have determined that the control tasks associated with flying can be broken down into two general types: manoeuvre task and disturbance task management.[114]

Manoeuvre management is conducted through the completion of manoeuvre tasks which are sometimes referred to as tracking tasks. Manoeuvre tasks are "where the discrepancy between the target and current flight path is controlled" by the pilot.[115] These tasks are the domain of the visual system which uses visual rate feedback.[116] In visual flight conditions, the pilot will rely on visual scene detail to provide feedback for controlling the aircraft. Completing an approach to a landing field, formation flying, and low-level flying all require the pilot to maintain control through a visual comparison between the desired and actual flight paths. In instrument flight conditions, the pilot completes manoeuvre tasks by visually comparing his instrumentation to his desired and actual

110. David Allerton, *Principles of Flight Simulation* (Reston, VA: American Institute of Aeronautics and Astronautics, 2009).

111. Kaiser and Schroeder, 457.

112. Alfred Lee, *Flight Simulation: Virtual Environment in Aviation* (Surrey, England: Ashgate Publishing Company, 2005), 48.

113 . Paul W. Caro, "The Relationship Between Flight Simulator Motion and Training Requirements," *Human Factors* 21, no. 4 (August 1979): 493–501.

114. Shane A. Bowen, Brian P. Oakley, and John S. Barnett, *Effects of Motion on Skill Acquisition in Future Simulators: Study Report 2006–07* (Arlington, VA: US Army Research Institute for Behavioral and Social Science, 2006), 6.

115. Air Line Pilots Association, *ALPA White Paper: The Need for Motion in Flight Simulation* (Washington DC: ALPA International, September 2007), 3.

116. Rudd Hosman, Sunjoo Advani, and Nils Haeck, *Integrated Design of Flight Simulator Motion Cueing Systems*, (London: Royal Aeronautical Society Conference on Flight Simulation, May 2002), 6.

flight paths. Maintaining the localizer needle centred on a primary flight display (PFD) during an instrument landing system (ILS) approach is a good example. Regardless of the type of flying, the pilot must often learn to ignore vestibular inputs in order to avoid spatial disorientation during manoeuvre tasks.[117]

Unlike manoeuvre management tasks, disturbance management tasks use vestibular feedback.[118] Disturbance tasks are not the result of pilot control input but rather external forces, such as turbulence or engine malfunctions, that are exerted on an aircraft. Disturbance cues are not expected by the pilot and, therefore, play a significantly different role in overall aircraft control tasks. They serve as alerting cues to an unknown or unexpected situation. Although a major weakness of the vestibular system is that it habituates to motion over time, its greatest strength is that initial accelerations and motions are instantaneously identified. Often, disturbance cues may be the primary indication of a system malfunction such as an engine failure. The Air Line Pilots Association (ALPA) in the United States has used the importance of disturbance task management as its central argument in favour of simulator motion. Their White Paper concluded that "motion is required because pilots operate in an arena of motion and the vestibular system provides them with the most powerful and rapidly sensed cue for self-motion control."[119] The problem with ALPA's conclusion is that it assumes that skills learned in a full-motion simulator are fully transferable to the aircraft.

Skills transfer from simulator to aircraft

The value and effectiveness of a flight simulator needs to be evaluated against its ability to transfer learned skills to the flight environment.[120] At the end of the day, the only thing that matters is a pilot's proficiency in the actual aircraft. For this reason, a significant amount of research has been invested in skill transfer studies. Stanley Roscoe concluded in 1991 that motion could be turned off in full-motion simulators without being noticed by the pilots and that no loss in training transfer occurred.[121] Consequently, he questioned the cost-effectiveness of expensive motion platforms.

Three types of transfer of training (ToT) exist: positive, neutral, and negative. Positive transfer occurs when an individual correctly applies "knowledge, skills, and/or attitudes learned to a different setting."[122] This is the goal of any training system or aid. However, if there is no transfer whatsoever then ToT would be assessed as neutral. Finally, negative transfer occurs when existing knowledge and/or skills "impede proper performance in a different task and/or environment."[123] For the purposes of this study, the skills to which we are referring are skills that result from the presence of a motion platform, which means the reactions and skills learned in response to the vestibular cues used to identify disturbance cues.

The main concern with conducting ToT studies in aviation is that they are difficult, expensive, and potentially dangerous.[124] To conduct ToT studies, two or more subject groups are required. In the training system this normally reaches a level of risk to the training outcome of pilots that is unacceptable to the training institution. It can interrupt the training flow and schedule. A pure ToT

117. Lee, 49.

118. Ibid.

119. Air Line Pilots Association, 6.

120. Richard S. Jensen, *Aviation Psychology* (Brookfield: Gower Technical, 1989), 117.

121. Stanley N. Roscoe, "Simulator Qualification: Just as Phony as it Can Be," *The International Journal of Aviation Psychology* 1, no. 4 (Winter 1991): 336.

122. Beth Blickensderfer, Dahai Liu, and Angelica Hernandez, *Simulation Based Training: Applying Lessons Learned in Aviation to Surface Transportation Modes* (Dayton Beach: Emery Riddle Aeronautical University, 30 June 2005), 25.

123. Ibid.

124. McCauley, 10.

experiment in the aviation field would ideally consist of two groups, one trained in a full-motion simulator and the other trained in a no-motion simulator. The success of the training would then be evaluated in a real aircraft. Understandably, the level of risk associated with either the loss of life or equipment, as well as the operating costs associated with the aircraft, normally preclude these types of experiments from being conducted. Nonetheless, a few pure ToT experiments have been conducted, most notably by Robert Jacobs and Stanley Roscoe at the Universtiy of Illinois in 1975.[125]

Jacobs and Roscoe completed their ToT experiment using a non-visual Link Trainer for training and a Piper Cherokee Arrow airplane as the test platform. There were 27 subjects divided into three groups, with an additional dedicated test control group. The first group was trained in the simulator without motion, the second group with normal motion, and the third group with random negative motion. The test control group received no simulator training at all. Jacobs concluded that the group trained with normal motion performed better in the simulator than the other two simulator groups. However, when all three groups transferred to the aircraft there was no marked improvement over the performance of the test control group. This led to the conclusion that simulator motion aids students in flying the simulator, but the skills did not transfer to the aircraft.[126]

Although the results of Jacobs and Roscoe's experiment are interesting, they were limited by the level of technology available at the time. The simulator industry has made great advances in motion generating technology. It is conceivable that today's more advanced simulators with improved motion fidelity could produce better training transfer.

The majority of ToT studies now employ test methodology referred to as "quasi-transfer." In this type of testing, a full-motion simulator is used as a stand-in for the actual aircraft. This allows for one test group to be trained in a no-motion simulator while the other group is trained in a full-motion simulator. Evaluation of both groups is then conducted in the full-motion simulator, and the performance of the no-motion group is assessed to see if they performed better or worse than the full-motion-trained group. This type of testing has some significant advantages over pure ToT experiments. Using the motion simulator as a test bed vice the actual aircraft allows the researchers to control extraneous factors such as aircraft performance, weather, lighting, and time of day.[127] The effectiveness of the quasi-transfer experiment methodology was validated by Henry Taylor, Gavan Lintern, and Jefferson Koonce in 2001.[128]

The Volpe Center has been at the forefront of the majority of quasi-transfer experiments. Between 2000 and 2005 researchers at Volpe completed three significant quasi-transfer experiments. All three experiments focused on the effect of motion on pilot reactions to disturbance motion cues by simulating engine failures after take-off in multi-engine aircraft. All three experiments concluded that there were no "operationally relevant effects of motion."[129]

Volpe Center studies

The purpose of the Volpe Center studies in the field of aviation quasi-transfer experiments has been to assist an FAA initiative "towards promoting affordable flight simulators for US commuter

125. Robert S. Jacobs and Stanley N. Roscoe, "Simulator Cockpit Motion and the Transfer of Initial Flight Training," *Human Factors and Ergonomics Society Annual Meeting Proceedings* 19, no. 2 (Spring 1975): 218–226.

126. Ibid.

127. Henry L. Taylor, Gavan Lintern, and Jefferson M. Koonce, "Quasi-Transfer as a Predictor of Transfer From Simulator to Airplane," *The Journal of General Psychology* 120, no. 3 (Fall 2001): 258.

128. Ibid.

129. Judith Bürki-Cohen and others, "Effects of Visual, Seat, and Platform Motion During Flight Simulator Air Transport Pilot Training and Evaluation," in *Proceedings of the 15th International Symposium on Aviation Psychology* (Dayton, OH: Wright State University, 27–30 April 2009), 2.

airline training."[130] Aside from assisting the FAA, their studies are beneficial to all simulator users, manufacturers, and procurers, including the military. Their three significant quasi-transfer experiments were completed in a building-block approach. The first experiment utilized a Level C simulator as the test platform, simulating a 30-passenger twin-engine turboprop aircraft. Unfortunately, this study was limited by the quality of the simulator. They concluded that the simulator utilized may have "failed to provide lateral acceleration cueing representative for the test manoeuvres."[131] Accordingly, the next test conducted in 2003 addressed this concern by utilizing the Level D NASA Ames flight simulator attenuated to augment lateral motions that were found lacking in the 2000 experiment. This test also concluded that motion appeared to have no beneficial effect on recurrent training.[132]

The third Volpe study conducted in 2005 was the culmination of the two previous experiments. Where the previous studies evaluated qualified pilots on the type of aircraft being simulated, this experiment was designed to examine the "effect of simulator platform motion on initial training of airline pilots that have never flown the simulated aircraft."[133] Consequently, 49 newly hired pilots were evaluated in a Level D Boeing 717–200 simulator after having completed requisite ground school. The experiment focused on pilot reaction to an engine failure after take-off and the subsequent engine out precision instrument approach.

Pilot reaction to engine failures after take-off was logical test criteria for the Volpe quasi-transfer experiments. When an engine fails immediately following take-off, the aircraft will instantly present disturbance cues in the form of roll, pitch, and yaw. These motions are accentuated by the remaining engines being at full power. The manoeuvre is a particularly time-sensitive one due to the aircraft's proximity to the ground. Pilot reactions need to be correct and prompt. In order to remain in controlled flight, the pilot must maintain aircraft airspeed greater than the minimum control speed in the air (Velocity – Minimum Control Air [VMCA]), which is the minimum airspeed at which an aircraft can maintain controlled flight with one engine inoperative. Although the speed differs by configuration and aircraft type, the definition and parameters remain the same. The CC177 Performance Data Flight Manual, similar to all aircraft manuals, stipulates that initial pilot reaction requires the immediate use of the rudder to counter the yawing motion and up to five degrees angle of bank away from the inoperative engine to counter the rolling motion.[134]

The third Volpe Center experiment followed the same methodology as the previous experiments. One group of pilots was trained with no motion while the other group was trained with full motion. After the training, both groups were evaluated in the full-motion Level D simulator. The results with respect to pilot reaction to an engine failure after take-off were conclusive.

In training, the motion-trained group sensed the yawing disturbance cue associated with the engine failure faster than the no-motion group. The motion group was approximately 0.5 seconds faster in applying the appropriate pressure to the required rudder pedal. This faster reaction is significant for all the reasons that engine failures after take-off are critical manoeuvres. The most interesting fact is that the difference in reaction time was not transferred to the test platform. Despite

130. Judith Bürki-Cohen and others, "Simulator Fidelity—The Effect of Platform Motion," in *Proceedings of the International Conference Flight Simulation — The Next Decade* (London: Royal Aeronautical Society, 10–12 May 2000), 1.

131. Ibid., 7.

132. Judith Bürki-Cohen and others, "Simulator Fidelity Requirements for Airline Pilot Training and Evaluation Continued: An Update on Motion Requirements Research," *Proceedings of the 12th International Symposium on Aviation Psychology* (Dayton, OH: Wright State University, April 2003), 7.

133. Judith Bürki-Cohen and Tiauw H. Go, *The Effect of Simulator Motion Cues on Initial Training of Airline Pilots* (Reston, VA: American Institute of Aeronautics and Astronautics, 2005), 1.

134. United States Air Force, *C-17 Flight Manual Performance Data – Change 1* (Wright Patterson Air Force Base: Department of Defense, 2007), 3–6.

having trained without motion, the no-motion group reacted just as quickly as the motion-trained group when the sequence was repeated with motion disturbance cues present.[135]

The experiment proved two significant facts. First, motion disturbance cues *do* provide an alerting function to pilots. Even when forewarned of the impending engine failure, pilots without motion cues were unable to react as quickly as those with motion cues. Second, and perhaps most noteworthy, the no-motion pilots' delay in reaction did *not* transfer. In other words, the no-motion pilots "did not have to be trained with motion to recognize the cues signalling an engine failure on takeoff."[136] When transferred to full motion, the recognition of an engine failure was intuitive and natural for all the tested pilots. Consequently, the real question is, what does motion contribute to training? The apparent answer is disconcerting to most pilots: nothing.

Summary

Due to recent advances in the understanding of the purpose of motion in flight simulation, questions have been raised about the requirement for motion. Technology has permitted full-motion simulators to replicate motion; however, the replicated motion is not, and has never been, 100 per cent true to actual aircraft motion. A rudimentary understanding of the relationship between the human motion sensing systems permits technology to trick the human brain by manipulating how the force of gravity is exerted on simulator occupants. Nonetheless, these tricks are not perfect. The subtle motions used to reset a Stewart-Gough platform are often sensed by the occupants, creating sensory miscues.

Modern simulators are required to recreate two types of motion: manoeuvre and disturbance. While manoeuvre motions are detected by the visual system, disturbance cues are sensed by the vestibular system. These disturbance motions are instantaneously processed by the vestibular system and serve an alerting function to abnormal flight conditions for the pilot. For this reason, many propose that motion is required. However, the scientific evidence indicates that some skills learned in the simulator are not transferred to the actual aircraft. While cognitive skills such as procedure training, decision making, and crew resource management are transferred to the aircraft, handling skills are not. Study results support this finding, as pilot reactions to an engine failure after take-off were handled equally well by both motion-trained and non-motion-trained pilots.

It appears that the only function for motion in flight simulators is to provide disturbance motion cues. If so, then the new question in the motion debate is what kind of motion is required to provide motion cues? Does the simulator need to have 60 inches of motion travel or can small motions produce the same result? What is the future of the full-motion simulator? This topic will be discussed in the next section.

5. The future of full-motion flight simulation

Introduction

The heated and often contested motion requirement debate in aviation simulators often neglects the true goal of flight simulation. From its inception, flight simulation has been designed to train better pilots. The intention is to provide a safe and controlled environment where pilots can hone their skills. The problem with the motion debate is that it concerns itself with only one small aspect

135. Bürki-Cohen and Go, 7.

136. Ibid., 11.

of the overall world of flight simulation. The constant desire to create realistic mimicking of the real-world environment has caused many to forget that a simulator is "just a tool for training."[137]

What does full motion do to enhance the overall goal of pilot training? Previous sections have described how platform motion is not a true replication of aircraft motion. Moreover, due to limitations on displacement and subsequent acceleration forces, platform motion can create perceptual miscues as the motion base is manipulated at rates and frequencies assumed to be below human perception thresholds.

It is currently accepted that motion perceived by pilots can be divided into manoeuvre motion cues and disturbance motion cues. Motion does little to assist with manoeuvre tasks as this is predominantly completed by the visual system as the pilot maintains an aircraft in controlled flight along a designated flight path. There is a place for physical motion in the completion of disturbance tasks, as disturbance motion cues have been shown to serve as an alerting function for pilots as aircraft flight is disrupted by external forces. However, recent research indicates that disturbance cue reactions may not transfer to the aircraft. Apparently, pilots do not need to feel a simulator motion-kick in order to realize that an aircraft will react the same way in response to disrupting forces, such as engines failures after take-off. In other words, an intelligent individual does not need to be hit in the head with a baseball bat to realize that it hurts.

Motion is only a small part of simulation

So where does motion fit into the overall framework of flight simulation? It is by far the most expensive component of a Level D simulator. These simulators are typically large machines requiring separate and type-specific infrastructure as well as a high degree of technical expertise and maintenance support.[138] Are the large financial expenditures cost effective? Unfortunately, they are not. As early as 1975, Edward Huff and David Nagel proposed a simple model of the ideal flight simulation. The model is still applicable today. The ideal simulation involves multiple, interrelated factors that directly contribute to pilot performance and consequent training. What is interesting to note is that motion generation, as highlighted, is only one portion of this ideal simulation.

If motion only has limited applicability to pilot training in terms of disturbance motion cues, and if quasi-skill transfer experiments demonstrate little operational relevance for motion, why does industry persist to push for Level D simulators? The answer to this question is complex. Essentially, although motion has not been proven to enhance skill transfer, it certainly has not been proven to *impede* transfer. The onus remains on the scientific community to prove that a lack of motion will not adversely affect pilot training. As with anything else in life, any change to the status quo is very difficult. Moreover, the status quo of the motion requirement is endorsed by most pilots, not for scientific reasons but rather perceptual ones. The Air Line Pilots Association is adamantly against even opening discussions on reducing the motion requirement. ALPA's official position is:

> If the purpose of pilot training is to develop and evaluate the required skills, knowledge and performance necessary to pilot an aircraft, then it is essential to recreate the actual flight environment as closely as possible. Other senses (i.e., visual, aural, tactile) are important, but complementary…. ALPA policy is that the "highest level flight simulators shall be used to the maximum extent possible" [emphasis in original document].[139]

137. Eduardo Salas, Clint A. Bowers, and Lori Rhodenizer, "It is not how much you have but how you use it: toward a rational use of simulation to support aviation training," *The International Journal of Aviation Psychology* 8, no. 3 (Fall 1998): 200.

138. Berhard E. Riecke and others, *Towards Lean and Elegant Self-Motion Simulation in Virtual Reality* (Bonn, Germany: IEEE Virtual Reality, 2005), 131.

139. Air Line Pilots Association, 6.

The idea that the other senses are complementary goes against the science behind how humans process motion, as described in Section 3. The dominant spatial orientation system is the visual system, followed by the vestibular system, not vice versa. The mindset of organizations such as ALPA will have to change over time. Fortunately, regulatory agencies such as the FAA, Transport Canada, and the JAA in Europe are exploring alternatives to full-motion simulators. The most promising advance has been the recent JAA certification of a no-motion full-flight trainer (FFT-X) produced by the Montréal-based Canadian company Mechtronix. In a relatively dramatic turn, the JAA has granted the FFT-X "training, testing, and checking credits equivalent to the ones usually granted to a Level B Full Flight Simulator (FFS)."[140] By allowing the FFT-X to conduct training that previously required a Level B motion simulator, the JAA implicitly acknowledged that full-motion platforms are not always required and that other technologies can achieve the same results.

The non-motion alternative

An emerging alternative to six degrees-of-freedom of motion flight simulators are fixed-base flight simulators with a dynamic pilot seat providing initial disturbance cues via heave onset cues. It was exactly this type of alternative that the Avions de Transport Regional (ATR) Training Centre in Toulouse, France, used to convince the JAA to grant aircraft type rating without the use of motion. This training facility is the world's largest manufacturer of regional turboprop aircraft and houses its own pilot training centre in order to support its airline customers.[141] Regional European airlines regularly send their pilots to Toulouse to complete both ab initio training and recurrent training. The ATR training centre recently partnered with Mechtronix to provide cost-effective pilot training through the use of a "FFT 'brain-motion' simulator program."[142]

Mechtronix's FFT-X is actually an FFS without the motion.[143] It employs all of the human motion processing systems to create a virtual *immersive* environment for pilot training. To engage the visual system, it employs a 200 degree by 40 degree field of view collimated visual system comparable to those used in a Level D simulator. The vestibular system is engaged by an electrically driven dynamic seat used to provide the motion-cueing effects of acceleration, deceleration, and turbulence. The proprioceptive system is engaged by a high-fidelity aerodynamic and flight control force model. Additionally, the cockpits are exact replicas of the aircraft they are simulating, providing tactile feel of the panel and switches. Finally, the auditory system is engaged through the use of high-end sound simulation, including a subwoofer mounted on the structure to provide constant aircraft vibration and engine noise.[144] In accordance with Huff and Nagel's model of ideal simulation, Mechtronix has focused on the immersive nature of flight simulation where the pilot's brain extrapolates information and sensory inputs from multiple feedback loops.

In the fall of 2006, the French National Aviation Authority under the JAA successfully completed the type rating of six pilots using the Mechtronix FFT-X non-motion simulator. This was a groundbreaking and world-first occurrence. Observing during the training were researchers from the Volpe Center. Having completed quasi-transfer studies in full-motion simulators, they were eager to observe and assist with the proof of concept of a non-motion simulator used for aircraft type qualification. They released a report of their findings in 2007. The pilots who successfully completed

140. Judith Bürki-Cohen, Andrea L. Sparko, and Tiauw H. Go, *Training Value of a Fixed-Base Flight Simulator with a Dynamic Seat* (Hilton Head, South Carolina: AIAA Modeling and Simulation Technologies Conference, 20–23 August 2007), 10.

141. ATR, "Company Profile," www.atraircraft.com (accessed July 9, 2012).

142. Jeff Apter, "ATR Mulls Option for Larger Turboprop," *Aviation International News Online* (14 July 2008), http://ainonline.com/aviation-news/farnborough-air-show/2008-07-12/atr-mulls-options-larger-turboprop (accessed July 9, 2012).

143. Email Major Jason Stark and Xavier Lalonde, Sales Coordinator Mechtronix, 28 January 2010.

144. Mechtronix, *There Is Nothing General About The Way We Approach Aviation* (Montreal: Mechtronix Headquarters, 2009), 15.

the aircraft type qualification consisted of two experienced and four non-experienced pilots. The two experienced pilots held multi-pilot type rating licenses. They held a total of 14,000 and 11,000 hours for flight experience, respectively. The four non-experienced pilots held single-pilot licenses and had no airline experience. Their flying experience ranged from 6,000 hours to 563 hours.[145]

The Volpe researchers found that the pilots' performance in the actual aircraft after transition was rated by flight line instructors as the same as a typical pilot trained in an FFS. Moreover, while completing certain flight sequences in the simulator, such as engine-out instrument approaches and abnormal landing configurations, the trainees performed "moderately better" and "much better" than a typically full-motion-trained pilot, respectively.[146] Only the trainees themselves were asked to rate the acceptability of the FFT-X both prior to and following experience in the actual aircraft.

Prior to flying the actual aircraft, trainees rated the FFT-X as only needing "minor improvements" or better for 77 per cent of the manoeuvres trained. This assessment was based on their impression of how the actual aircraft would feel and react to pilot input. However, following their experience in the actual aircraft, trainees rated the FFT-X as only "slightly different from the airplane."[147] There were, however, some differences in trainee opinions on the lack of motion. Two trainees stated that the FFT-X motion was "very different than the airplane." Nevertheless, these rating were offset by other individual ratings that stated that the FFT-X motion was "same as the airplane."[148] This indicates that motion perception is extremely subjective, and it could be interpreted that the difference in opinions would have been present in a transition from an FFS to the actual aircraft.

The goal of flight simulation in the realm of aircraft type training is whether there are issues, concerns, or difficulties in the transition to the actual aircraft. All six pilot trainees were unanimous in their evaluation that they experienced no problems in transition. This was echoed by the flight line instructors, who noted that all six pilots were well equipped and trained for the actual aircraft and that there did not "appear to be a difference between FFS and FFT training."[149]

At the end of the training, the National Aviation Authority decision maker found that there were no training problems associated with the lack of motion in the FFT-X. Moreover, the National Aviation Authority official emphasized that the focus of flight simulation "should be on effective stimulation of the pilot, rather than emphasizing rote simulation of the aircraft."[150] This progressive attitude is slowly starting to change the aviation industry. It is this type of forward thinking that is required of the Canadian Air Force.

Summary

Regulatory agencies, especially the JAA, are looking to the future and exploring alternative technologies to provide the same level of training as an FFS. The impetus for the quest for non-motion effective simulators is born out of a desire by the airline industry to reduce costs—both in terms of initial acquisition and maintenance. The military, although not a profit-based organization, shares these same desires. The problem for the military is that we are not taking the lead on exploring these new technologies.

145. Bürki-Cohen, Sparko, and Go, 9.
146. Ibid., 14.
147. Ibid., 16.
148. Ibid.
149. Ibid., 17.
150. Ibid.

The role of simulators is to train pilots to operate in the complex aviation environment. The goal of simulators is to provide much more than simple motion cues. The quest for realistic motion is a phantom dream that industry and the military have been chasing at the expense of achieving realistic immersion. The cost associated with large full-motion base platforms is not justified when one considers Huff and Nagel's model of ideal simulation. Motion is such a small portion of simulation, yet it seems to consume such a large part of the thought process. Creating an *immersive* environment is much more important than creating a *mobile* one.

For the military, the majority of Canadian Forces pilots are post-operational training unit and wings qualified. This is a mass market that could significantly benefit from a high-quality, immersive, non-motion simulator such as the FFT-X. Senior Air Force leadership needs to look to the future and re-evaluate the allocation of resources. The Air Force trains some of the best pilots in the world. Now we need to look at how to maintain that high level of proficiency in a cost-effective, logical, and continuing way.

6. Conclusion

The original question posed in this analysis was whether simulator platform motion was required in aviation flight simulators. Throughout the course of the discussion, the question was refined to what types of motion were required in flight simulators? It is now evident that the most accurate question should be: what type of simulator training requires motion? The nuance in the question change is subtle yet significant.

This analysis was logically organized to address the motion debate from a critical point of view. Section 2 established the baseline of terminology and nomenclature in order to enter the debate arena with a common understanding. The evolution of flight simulation from the time of the Wright Brothers to the use of the Desdemona simulator in the Netherlands indicates how the virtual-reality world constantly evolves as science and technology are improved. Section 3 provided an in-depth explanation of how humans process motion. A solid understanding of the human motion perception systems and their interaction are instrumental in understanding how motion can be a mental perception vice a physical movement. Inputs from the visual, proprioceptive, and auditory systems can effectively compensate for a lack of vestibular motion cues, especially with respect to manoeuvre motion cues. Section 4 differentiated between manoeuvre and disturbance motion cues. Although physical motion is required for disturbance cues, the latest research in transfer of training studies indicates that skills acquisition associated with disturbance motion cues do not appear to transfer to the aircraft. Transfer of training research reinforces the fact that simulators are better suited for training higher cognitive skills. Lastly, after demonstrating that motion is not necessarily required for continuation pilot training, Section 5 presented a non-motion alternative to the current industry Level D flight simulator.

Motion *is* required in certain types of simulator training. There is a specific niche for full-motion flight simulators, even extremely advanced ones like Desdemona. The testing of pre-production and established aircraft fleets requires full motion. Aviation research requires full motion in order to continue quasi-transfer studies into the field of transfer of training. However, *the continuation training of qualified pilots does* ***not***. Research indicates that pilot performance in aircraft is actually a factor of their inherent flying skills, plus "what they have learned from the visual system about attitudes and perspectives."[151] The goal of flight simulation in continuation pilot training should

151. David Learmount, "Civil simulators special: Going through the motions – are motion systems for simulators on their way out?" *Flight International* (27 April 2009), http://www.flightglobal.com/articles/2009/04/27/325612/civil-simulators-special-going-through-the-motions-are-motion-systems-for-simulators-on-their-way-ou.html (accessed July 9, 2012).

be to immerse the pilot in a virtual aviation environment. With that as the goal, it is apparent that motion only plays a minimal role.

The purpose of traditional platform motion is to engage the vestibular motion system. However, as Section 4 illustrated, vestibular motion is only useful for the recognition of disturbance motion cues. The primary human motion sensing system remains the visual system. With the vestibular system understood as serving an alerting function to aircraft disturbance, research needs to focus more on how much physical motion is actually required. The use of a dynamic seat may suffice. Already industry is slowly retreating from full motion by permitting Level D simulators to reduce the amount of motion travel from 60 inches (150 centimetres [cm]) to 35 inches (89 cm).[152] The large Stewart-Gough motion platforms have served their purpose; however, industry needs to look forward at new technological solutions to create the illusion of aircraft motion in flight.

The battle surrounding the motion requirement for flight simulators involves many players. The airline industry is always looking for less expensive means of completing flight training. Regulatory agencies want to ensure that training remains relevant, effective, and controlled. Simulator manufacturers want to maintain profit margins. Finally, unions and associations such as ALPA do not want to make any changes to the status quo and invoke fears of catastrophic pilot failures.

Following the February 12, 2009 fatal crash of a regional airline in Buffalo, NY, the National Transport Safety Bureau (NTSB) made a call for expanded simulator training in order to equip pilots with the requisite skills to recognize and recover from loss of control scenarios. Accordingly, ALPA immediately issued a statement that there is "no excuse not to" use enhanced motion flight simulators to provide pilots with the hands-on training on how to recover from aerodynamic stalls and other extreme scenarios.[153] However, FAA officials have a more balanced and responsible approach. The FAA position is that it would rather focus pilot training to avoid loss of control scenarios in the first place.[154] The goal of effective pilot training should not be to qualify pilots to recover from extreme attitudes or situations but rather to avoid those situations all together.

The military is in a unique position to once again take the lead in the development of flight simulation technologies, much like during the Second World War. Unlike the civilian industry, the military is not subject to same rules and regulations imposed by Transport Canada, the Federal Aviation Authority, or the Joint Aviation Authority. The military, although cost conscious, is not a profit-based organization and the effective training of pilots will always remain paramount in the view of the Chief of the Air Staff. Once trained to operational status in the air mobility community, Canadian military pilots can complete better continuation training at lower cost by using less expensive flight simulators to create a virtual flight environment. The goal is to develop the cognitive pilot skills such as decision making and crew resource management. Less expensive simulators would allow for the purchase of greater numbers, thus permitting greater access to training for pilots. However, this better training at lower financial cost is associated with a higher level of risk.

The purpose of this paper has not been to address the effects of motion in flight simulators for initial pilot training. Moreover, there will always be certain military skills and flight profiles that no current level of flight simulation can simulate. Even the successful type rating of pilots at the ATR Training Centre using non-motion simulators, as described in Section 5, did not deal with teaching initial "stick-and-rudder" skills. The subject pilots were already fully licensed and experienced

152. Ibid.

153. Alan Levin, "Simulators Target Crash Scenarios," *USA Today*, 9 March 2010.

154. Ibid.

aviators. However, what the ATR Training Centre and the JAA did demonstrate is that full motion is not always required.

The most intense training a military pilot receives after initial flight training is the aircraft type-specific training conducted at the OTUs. This type of training requires pilots to fly the actual aircraft, and ZFTT will never be achievable. However, continuation or recurrent training on a yearly basis is normally focused on emergency procedures, crew resource management, and mission management. In the air mobility community, this type of training is very similar to the airline philosophy of line orientated flight training. According to the FAA, line orientated flight training is designed to give "crewmembers the opportunity to practice line operations (i.e., manoeuvres, operating skills, systems operations, and the operator's procedures) with a full crew in a realistic environment."[155] Because all military mobility pilots have this yearly requirement, the associated training bill is very high. For example, the only CC130 Hercules simulator in Canada is located at 8 Wing Trenton, Ontario. Therefore, to conduct continuation simulator training, crews from Nova Scotia and Manitoba are required to fly to Trenton. Similarly, CC177 Globemaster and CC150 Polaris crews are required to leave the country to use simulators not currently owned by Canada.[156]

There will always be a requirement to have full-motion simulators at the OTUs. Military pilots who attend initial training courses at these units are very inexperienced, often with just over 200 hours of total flight experience. The systems used to simulate motion may not need to be large and expensive Stewart-Gough platforms. Technology is advancing quickly and, eventually, physical motion will be able to be replaced with ego-motion.[157] However, we may not necessarily be there yet. Where there is immediate room to advance is in the area of continuation training.

Non-motion flight simulators, like the FFT-X, that employ sensory cues to all human perception systems should have a niche in continuation training. They are substantially less expensive. Multiple units could be purchased and placed at all the applicable bases so that pilots have increased accessibility. This would involve less travel time to simulator locations, less expenditures for travel and accommodations for crews, as well as less impact to the operational environment. Typically, one continuation training simulator session at a third location involves two days of travel for one day of training. The operational tempo in air mobility shows no signs of diminishing and alternative means of training will be required sooner rather than later. Changing the status quo of how we operate and employ simulator training, and the platforms we use to achieve it, will require future leaders to have the courage to look forward and not backward.

Civilian associations such as ALPA have no desire or inclination to challenge the pilot training status quo. Their position is that the large, expensive, full-motion simulators will always be the best tool for pilot training. The Air Force needs to have greater vision. How the illusion of aircraft motion is recreated is irrelevant to a pilot. The mechanics behind motion processing, the functions of the visual and vestibular systems, and the illusion of vection are all things that do not matter to a pilot. The true litmus test of an effective flight simulator is whether the pilot feels immersed in the simulation. Is there pilot buy-in to the overall virtual environment?

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155. Federal Aviation Authority, *Line Operation Simulations, Advisory Circular 120-35C* (Washington, DC: US Department of Transportation, 2004), v.

156. Telecon Major Jason Stark and Lieutenant-Colonel Col Dave Murphy, Wing Operations Officer, 8 Wing Trenton, 13 April 2010.

157. Ego-motion is motion perceived yet not physically experienced. The human ego is the part of the human personality that is responsible for defensive, perceptive, cognitive-intellectual, and executive functions. For more information on ego refer to Ruth Snowden, *Teach Yourself Freud* (New York: McGraw Hill, 2006).

Continuing studies by Volpe Center in the United States and the POEMS program in the European Union will be instrumental in breaking down the preconceived notions about the significance of physical motion. Until these notions are successfully debunked, organizations such as the military will default to positions forwarded by civilian organizations such as ALPA. Consequently, this requires the scientific community to continue pursuing alternative means of simulation. Scientists need to provide policy makers with sufficient support to "make the proper evidence based decisions on military flight simulation."[158]

This author has no doubt that years from now we will look back at the current Level D, six degrees-of-freedom, fully articulated flight simulator with its associated infrastructure and wonder at the folly of our ways. Much like we currently look back at the massive computers of the 1960s, we will look back at the Level D simulator as an overpriced and inefficient flight simulation platform. Science is currently well aware of the fact that the effects of motion can be simulated and compensated for by the overlapping human processing systems. It now requires technology to determine the optimum way to correlate this information in a cost-effective simulator. The area for the greatest amount of progress is in post-wings pilot continuation training.

Consider the questions posed at the start of this concluding section: Is simulator platform motion required in aviation flight simulators? The answer: not always. What type of motion is required in flight simulators? The answer: disturbance motion. Finally, what type of flight simulator training requires motion? The answer: certainly ***not*** pilot continuation training.

158. Bernd de Graaf and others, "MSC: Vehicle Validation of Military Flight Simulation," http://ftp.rta.nato.int/Public/PubFullText/RTO/MP/RTO-MP-HFM-136/MP-HFM-136-16.pdf (accessed July 9, 2012).

Abbreviations

AACMO	Army Air Corps Mail Operations
ALPA	Air Line Pilots Association
ATR	Avions de Transport Regional
cm	centimetre
FAA	Federal Aviation Administration
FFS	full flight simulator
FFT-X	no-motion full-flight trainer
FSTD	flight simulation training device
G	One "G" is the equivalent of the force of gravity exerted on a static, immobile object.
JAA	Joint Aviation Authority
Level A FFS	Four degrees-of-freedom of motion, basic visual system. See Transport Canada TP 9685 http://www.tc.gc.ca/eng/civilaviation/publications/tp9685-chapter2menu-1050.htm (accessed July 9, 2012).
Level B FFS	Four degrees-of-freedom of motion, visual system is capable of reproducing depth perception and sink rates. See Transport Canada TP 9685.
Level C FFS	Six degrees-of-freedom of motion, visual system capable of reproducing better than Level B along with night and dusk scenes. See Transport Canada TP 9685.
Level D FFS	Six-degrees-of-freedom of motion, visual system capable of producing better than Level C along sufficient scene detail to recognize terrain, airports and major landmarks. Simulator needs to be able to recreate full daylight lighting and scene detail. See Transport Canada TP 9685.
NASA	National Aeronautical and Space Agency
POEMS	Perceptually Oriented Ego-Motion Simulation is a European Union sponsored research program into non-motion virtual reality simulators.
TC	Transport Canada
ToT	transfer of training
US	United States
Volpe Center	The John A. Volpe National Transportation Systems Center in Cambridge, Massachusetts, is an internationally recognized center of transportation and logistics expertise sanctioned by the US Department of Transportation.
ZFTT	zero flight time training

Chapter 5 – Canada's Air Force Kinetic Capability for the 21st Century: What Is Needed?

Major Paul J. Doyle

Abstract

The *Canada First* Defence Strategy (*CFDS*) has outlined the future roles that the Canadian Forces may be called upon to deliver. In general terms, the Canadian Forces need to be capable of defending Canada and Canadian interests abroad in the pursuit of Canadian government policies. The *CFDS* indicates the Government of Canada's intention to replace CF188s, the only aircraft currently in the Canadian Air Force's inventory capable of land attack, with modern fighter aircraft. This signals that the Government of Canada understands the role that the Canadian Air Force can play in the support of deployed operations that require kinetic air power.

The intent of this paper is to step through the development of modern counter-land theory and its application for the Canadian Air Force of the 21st century. To accomplish this, the integration of kinetic air power to support ground operations will be examined from the perspective of the formulation of modern doctrine and how this doctrine is evolving with tangible trends to reflect the present use of air power in deployed operations. For the Canadian Air Force, there exists a unique opportunity to capitalize on the evolution of kinetic air support to ground operations through the procurement of new aircraft to provide kinetic effects. The kinetic capability of the Canadian Air Force needs to be examined with a view of deploying a balanced force of fixed-wing, rotary-wing and unmanned vehicles capable of delivering accurate firepower in both pre-planned and reactive counter-land missions. This force structure will provide the greatest impact to joint fires from the Canadian Air Force.

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1. Introduction

With the publication of the *Canada First* Defence Strategy, the Government of Canada has indicated its intent for the Canadian Forces to play a crucial role in the defence of Canadian interests at home and abroad. This strategy outlines six mission types that the Canadian Forces will be able to execute whether in North America or abroad. These missions are:

a. Conduct daily domestic and continental operations, including in the Arctic and through North American Aerospace Defence Command (NORAD).

b. Support a major international event in Canada.

c. Respond to a major terrorist attack.

d. Support civilian authorities during a crisis in Canada, such as a natural disaster.

e. Lead and/or conduct a major international operation for an extended period.

f. Deploy forces in response to crises elsewhere in the world for shorter periods.[1]

The success of the Canadian Forces to succeed in the fulfillment of these missions hinges on the ability of the Army, Navy and Air Force to complement each other's capabilities to maximize the efficacy of the contribution of the Canadian Forces to the achievement of Canadian policy objectives.

Canada's Air Force has a crucial role to play to provide capabilities that can only be provided using the flexible power projection that defines air power. Canadian aerospace doctrine defines the Canadian Air Force as a "… vital national security institution, an instrument of national policy and an element of national power."[2] The effects that the Canadian Air Force can provide range from firepower on a battlefield to surveillance of Canada's coastal waters to transport of resources, both people and equipment, for domestic and international operations. For non-kinetic effects, the Air Force needs to be equipped and trained to enable supported units to arrive on time with the correct force composition to carry out their missions. For kinetic effects, the Air Force can play an active role with proper doctrine and equipment to attain mission success.[3]

The willingness of the Canadian government to use the Canadian Forces to defend Canadian interests abroad in the 21st century was signalled with the deployment of the Canadian Navy on Operation APOLLO to the north Arabian Sea in October 2001. The North Atlantic Treaty Organization's (NATO) invocation of Article 5 of the Washington Treaty in response to the terrorist attacks on the United States in September 2001 provided the alliance framework for this deployment.[4] Canada's contribution to what became known as the global war on terrorism (GWOT) followed with the deployment of a battle group to Kandahar, Afghanistan, built around the 3rd

1. Department of National Defence, *Canada First* Defence Strategy (Ottawa, ON: Department of National Defence, n.d.), http://www.forces.gc.ca/site/pri/first-premier/index-eng.asp (accessed June 28, 2012).

2. Department of National Defence, B-GA-400-000/FP-000, *Canadian Forces Aerospace Doctrine* (Ottawa, ON: Department of National Defence, 2007), ii.

3. Kinetic effects are those delivered from explosive weapons. For example, the kinetic effect of a bomb exploding may be the destruction of a building. Non-kinetic effects are those effects that can be accomplished without the use of a weapon. For example, a non-kinetic effect to clear a building may be done with loudspeakers warning of an attack.

4. NATO Parliamentary Assembly, "Press release, Members of Parliament from NATO countries Declare Solidarity with United States, Support for Article 5 Collective-Defence Declaration," NATO Parliamentary Assembly, http://www.nato-pa.int/archivedpub/press/p010914a.asp (accessed June 28, 2012).

Battalion, Princess Patricia's Canada Light Infantry.[5] The deployment of forces in the global war on terrorism has continued throughout the first decade of the 21st century, with the heavy engagement of the Canadian Forces in operations throughout southwest Asia by its Army, Navy and Air Force. What has been missing from these operations has been the delivery of kinetic effects from the Canadian Air Force to support operations by Canadians fighting the insurgency in Afghanistan. Canadian kinetic air power was absent from Afghanistan until the deployment of CH146 Griffons to Kandahar in 2008; they were armed only with machine guns mounted as door guns, which limit the effects that these aircraft can deliver.[6]

The question that begs to be asked is what other kinetic effects can the Canadian Air Force deliver in the 21st century in the pursuit of the policy objectives of the *Canada First* Defence Strategy? The Canadian Air Force is equipped with the CF188 Hornet that has completed avionics and equipment upgrades that make it a versatile, fourth generation fighter aircraft that is able to project offensive and defensive air power across wide distances quickly. The CP140 Aurora and CH148 Cyclone are weapons platforms that will enable the Canadian Air Force to assist the Canadian Navy in executing maritime missions around the world. The CU170 Heron is an indication of the intent of the Canadian Air Force to expand the unmanned aerial vehicle (UAV) capabilities with a potential to include weapon delivery. The provision of additional firepower for CH146s deployed to Afghanistan highlights the requirement to provide armed escort helicopters for the CH147 Chinooks that are operating in the Afghanistan theatre of operations.[7]

The Canadian Air Force needs to determine the force structure it requires for the 21st century in order to best provide kinetic effects on the present and future battlespaces. In particular, the Air Force needs to be prepared to deliver kinetic effects to support land operations in order to maximize the contribution the Air Force makes to the defence of Canadian interests abroad. This paper will show the relevance of aerial firepower for the 21st century for land operations. To accomplish this, this paper will first discuss the changing nature of conflict in the 21st century and what this means for the Canadian Air Force. The next topic of discussion will be the evolution of the kinetic capability of the Canadian Air Force in a modern context using the history of operations from the last two decades of the 20th century into the 21st century. The penultimate topic will be to discuss the current trends in Western militaries for the development and use of aircraft, whether manned or not, as Air Forces look to the future. The sixth section will follow the framework of the previous sections to provide a perspective for the Canadian Air Force for the 21st century and how it will be able to best provide a contribution to kinetic effects to defend Canadian interests at home and abroad.

2. Development of air-ground doctrine

The end of the cold war brought a period of uncertainty for planners in Western militaries. The overwhelming success of the coalition forces in Operation DESERT STORM was viewed as a vindication of the development of the United States (US) fighting doctrine of AirLand Battle as a means to fight the Warsaw Pact in central Europe. This doctrine, a development of the US Army's previous doctrine of Active Defense, was a synchronization of the combined effects of land and air firepower in order to defeat an adversary that was not only in contact with friendly forces but also on the follow-on forces that had not yet entered the fight. AirLand Battle depended on the ability

5. "The Canadian Forces' Contribution to the International Campaign Against Terrorism," http://www.forces.gc.ca/site/mobil/news-nouvelles-eng.asp#/site/mobil/news-nouvelles-eng.asp?id=403 (accessed November 27, 2012).

6. Lieutenant-Colonel Tom Kupecz, "Escort for Canada's *Chinook* Helicopter," *Canadian Military Journal* 8, no. 3 (Autumn 2007): 94, http://www.journal.forces.gc.ca/vo8/no3/kupecz-eng.asp (accessed June 28, 2012).

7. Ibid., 93.

of forces from NATO to engage and defeat a numerically superior enemy through the combination of speed and agility of joint forces enabled by technology to strike at key points along and behind the front line.[8]

In the context of the Canadian Air Force, the evolution of the fighting doctrine of the United States Air Force (USAF) and Army is important because of the influence that these forces have on the fighting doctrine of NATO. The size of the US military gives it a large influence over NATO doctrine, not through malicious intent but through the importance of US forces and their firepower to the NATO alliance. The Canadian Air Force has and will continue to evolve based on its doctrine. For delivering land kinetic effects specifically, the AirLand Battle and the United States Air Force air-ground doctrine has remained a key influence in the provision of counter-land missions in the Canadian Air Force.[9]

The US Army emerged from the Vietnam War as a battered force that institutionally required self-examination to draw lessons on how it would fight. The US Army also examined the 1973 Yom Kippur War to glean lessons for how to fight while outnumbered.[10] The paradigm that the US military had been using, large conventional forces manned by conscripts from a draft, was modelled on the Second World War industrial way of fighting war. The end of the draft at the conclusion of the Vietnam War ended the belief that follow-on forces, trained after the start of war, could contribute to the success of the US military to win wars.[11] The imperative for forces in place, able to carry the burden of fighting, became evident as the US Army moved on from Vietnam and looked at the role that it would have in any NATO confrontation with the Warsaw Pact in central Europe.

Exiting Vietnam, the foreign and defence policies of the US "… implied that the US national defense posture should reemphasize the primacy of the defense of Western Europe over US involvement in other parts of the globe."[12] The US Army's Training and Doctrine Command (TRADOC), therefore, needed to develop a fighting doctrine that would allow the US Army to lead the way in the development of tactics to enable NATO to push back a Soviet assault across West Germany. TRADOC examined the Yom Kippur War to place the developing tactics of Active Defense, and then AirLand Battle, in the context of an outnumbered but more technologically advanced NATO conventional military dominating on the battlefield.[13]

As the US Army was developing its fighting doctrine of AirLand Battle, USAF was going through the machinations of its own doctrinal development. When USAF became a separate service in 1947, the strategic bomber in the nuclear role reigned supreme. Strategic Air Command (SAC) had the most influence on the development of tactics and equipment of USAF throughout the 1950s and 1960s.[14] It was not until the Vietnam War that tactical air power became more prominent and started to edge into the limelight with Strategic Air Command. This tactical air power, in the form of fighter aircraft of varying sizes and sophistication, bore the brunt of the fight in the air, with fighters from USAF, the United States Navy (USN) and the United States Marine Corps (USMC)

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8. John Andreas Olsen, *John Warden and the Renaissance of American Air Power* (Washington, DC: Potomac Books, 2007), 103.

9. Counter-land missions are defined as air and space operations against enemy land force capabilities to create effects that achieve joint force commander objectives. United States Air Force, Air Force Doctrine Document (AFDD) 2-1.3, *Counterland Operations* (Washington, DC: United States Air Force, 2006), viii.

10. Saul Bronfeld, "Fighting Outnumbered: The Impact of the Yom Kippur War on the U.S. Army Part 1," *The Journal of Military History* 71, no. 2 (Apr 2007): 469.

11. Ibid., 473.

12. Ibid., 469.

13. Ibid., 473–74.

14. Olsen, *John Warden*, 102–3.

carrying the fight to the enemy or flying support missions for friendly troops in contact with the enemy.[15]

As a result of the experiences in Vietnam, Tactical Air Command (TAC) started to develop doctrine in concert with TRADOC that contributed to the air piece of the integration of kinetic power in a fight along the doctrinal lines of AirLand Battle.[16] The development of tactics to allow fighters to either operate close to the forward line of own troops (FLOT) or in-depth behind the forward echelons of enemy troops allowed TAC to drive the development and procurement of new fighter aircraft such as F-16 Fighting Falcon for USAF and F-18 Hornet for the USN and USMC. With the increase in influence of TAC into any future fight, especially against the Warsaw Pact in central Europe, what has become known as the "Fighter Mafia" grew in power and influence in USAF.[17]

Not all within the Fighter Mafia were content with the status that TAC had adopted of closely aligning the fighting doctrine of fighters to being closely tied to supporting the Army as per AirLand Battle. Some within USAF started to argue that air power could make more of a contribution to fighting in a high-intensity conventional conflict than direct support of the ground forces. The chief proponent of the idea of using air power as a deciding factor in a conventional fight was John Warden, a USAF colonel and fighter pilot. His book, *The Air Campaign* written in 1989, laid the framework for "… design[ing] a coherent and unified air campaign. By doing so he hoped to provoke and reopen the debate on the true potential of conventional air power."[18] Warden felt that the AirLand Battle doctrine would relegate the USAF to a supporting tactical role to the US Army without allowing air planners to identify and attack operational targets that would better serve the goals of an operational air campaign.[19]

On the surface, Warden's argument for the separation of an air campaign from ground operations would appear to dismiss the role of air support for ground operations. This is not the case, and Warden points to the flexibility that close air support (CAS) can provide a ground commander. In Warden's view, CAS should be used as an operational reserve to either blunt an enemy attack or to break through enemy lines.[20] Warden's promotion of the operational art of using air power in a campaign came to fruition when Saddam Hussein invaded Kuwait in 1990. The air campaign that Warden helped to design for Operation DESERT STORM in January 1991 epitomized the effectiveness of Western air power in a campaign designed to gain air superiority over an adversary and then methodically attack identified centres of gravity in order to decrease the fighting effectiveness of an adversary.[21]

The overwhelming success of the allied coalition fighting the large conventional forces of the Iraqi military in 1991 was an indication of the maturity of the fighting doctrines of Western armies and air forces. The famous "left hook" of the ground forces through eastern Iraq, rather than a frontal assault through Kuwait, has been lauded as the ultimate example of the fighting prowess of

15. Wayne Thompson, "Operations Over North Vietnam," in *A History of Air Warfare*, ed. John Andreas Olsen (Washington, DC: Potomac Books, 2010), 119.

16. Olsen, *John Warden*, 104–5.

17. Colonel John Jogerst, "Air Power Trends 2010: The Future is Closer than You Think," *Air & Space Power Journal* 23, no. 2 (Summer 2009): 101–2.

18. Olsen, *John Warden*, 64.

19. Ibid., 65.

20. Ibid., 72–73.

21. John Andreas Olsen, "Operation Desert Storm, 1991," in *A History of Air Warfare* ed. John Andreas Olsen (Washington, DC: Potomac Books, 2010), 182.

modern Western militaries. The effectiveness of the air campaign in attacking strategic leadership, infrastructure and fielded force targets showed the lethality of fighter aircraft equipped with modern air-to-air and air-to-ground weapons.[22]

Changing face of battle

This conventional fighting might did not stagnate in 1991. NATO's Operation ALLIED FORCE air campaign against Serbia in 1999 reinforced the image of the lethality of air power. The invasion of Afghanistan in 2001 and Iraq in 2003 did little to dispel the conclusion that the conventional fighting power of the US, and by extension Western militaries as a whole, could not be matched by any other state competitors. The experience of the Taliban and then the Iraqi regime showed potential adversaries that engaging in conventional fighting would not be an effective way to either resist or defeat Western militaries.[23]

This conclusion, reached by state and non-state actors alike, provides an indication on the future of fighting in the 21st century. The likelihood of major state-on-state conventional conflict is not great as the 21st century progresses.[24] More likely conflict scenarios involve low-intensity conflicts that blend differing means of fighting to attain an objective. An excellent description of how wars will be fought in the 21st century is "hybrid war." The proponents of this school

> … believed that irregular challenges represented one end of a single continuum with more dramatic and costly catastrophic challenges occupying the opposite extreme. [B]oth the combination of mounting irregular and catastrophic challenges … indicate that active challenges would often blend into complex hybrids. … Clear throughout, however, was the idea that all consequential actors—state and nonstate—were moving away from traditional military rivalry as the principal forum for competition with the United States.[25]

An excellent example of this is the 2006 conflict in southern Lebanon between the Israeli Defence Force (IDF) and Hezbollah, a non-state actor whose indirect attacks on Israel led Israel to attack its forces. Israel was not successful in destroying Hezbollah because of the challenges presented by its opponent. Hezbollah did engage in conventional, force-on-force fighting, but it also fought the IDF using guerrilla tactics. Direct conventional tactics and indirect guerrilla tactics of Hezbollah presented the IDF with the hybrid threat that will be the face of battle for the 21st century.[26]

The fighting method chosen by Hezbollah in its confrontation with the IDF is not unique to non-state actors. In the book *Unrestricted Warfare*, the two authors (Qiao Liang and Wang Xiangsui, both colonels in the People's Liberation Army of China) acknowledge that a dominant conventional adversary cannot be defeated using direct attacks. Their book reveals how nations like China, faced with an American military so technically advanced, can overcome this advantage and defeat the enemy.[27] Qiao and Wang provide suggestions for how warfare will be fought in the 21st century in suggesting total war. Their theory is that total war (combining military attacks with those on economic, social and political targets) is an excellent example of how a lesser military force can

22. Ibid., 196–98.

23. Nathan Freier, *Strategic Competition and Resistance in the 21st Century: Irregular, Catastrophic, Traditional and Hybrid Challenges in Context* (Carlisle: Strategic Studies Institute, 2007), 15, http://www.strategicstudiesinstitute.army.mil/Pubs/display.cfm?pubid=782 (accessed June 28, 2012).

24. Lieutenant-Colonel Bruce Floersheim, "Forging the Future of American Security with a Total Force Strategy," *Orbis* 53, no. 3 (Summer 2009): 474.

25. Freier, *Strategic Competition and Resistance*, 6.

26. Ralph Peters, "Lessons from Lebanon: The New Model Terrorist Army," *Armed Forces Journal International* 144, no. 3 (October 2006): 39.

27. Qiao Liang and Wang Xiangsui, *Unrestricted Warfare* (Panama City, Panama: Pan American Publishing Company, 2002), ix.

leverage the vulnerabilities of a larger military force to confront an adversary on more equal terms. This theoretical blueprint outlined by Qiao and Wang serves as a guidepost on how to provide "… meaningful resistance to [a] dominant military power."[28]

For Western military forces to confront the challenges of hybrid warfare, they will need to adapt their ground force structure to include flexible conventional forces that are highly mobile and adaptable to different fighting situations. They will need to be able to close with and engage a hybrid threat "… whose cover and concealment make them impossible to destroy at standoff ranges."[29] These same forces will need to be able to contribute to security in a counter-insurgency (COIN) campaign that does not require as robust a force structure. Victory in counter-insurgency for a military rests with providing security to the development efforts to render insurgents irrelevant and without support.[30] While not definitive, the solutions to the force structure demands for Western militaries are easier to define for ground forces than they are for air forces. It is widely acknowledged that the fighting forces of the future will be smaller, mobile forces that will operate more independently from each other than in previous constructs. These forces, often not in contact with flanking units, will require the support of air power in order to accomplish their missions. The role of air power in a hybrid conflict will often be the "… indirect application of airpower [sic]—that is, the use of aviation resources for reconnaissance, transportation, psychological operations, and communications—that proves most useful."[31] To this must be added the movement of armies

> … to become more strategically deployable and agile on the battlefield, [thereby] reducing the weight of ground-based fires available to maneuver units. Although not yet fully detailed, the number of independent artillery brigades will shrink. … Moreover, operations are expected to center increasingly on independent brigades, which will operate without or with less corps fire support. These factors, combined with a newfound [confidence] in the accuracy and responsiveness of air-delivered fires, will result in increased requests for CAS and air interdiction.[32]

The renewed emphasis on joint operations is clear because of the complementary nature that environments have with each other. It is this fluid nature of conflict that will require joint forces that can operate together to best meet the objectives of a campaign.[33]

The future for air power in the 21st century is not to act as the sole decisive force because "… aerospace forces as a single force element are limited in solving the totality of … military problems."[34] Air power will retain the ability to project power through speed, range, precision and versatility across the spectrum of conflict and operations throughout the world.[35] The central tenets for how air power will contribute to the militaries of the Western nations were described by USAF General T. Michael Moseley as being:

28. Freier, *Strategic Competition and Resistance*, 37.

29. Stephen Biddle and Jeffrey A. Friedman, *The 2006 Lebanon Campaign and the Future of Warfare: Implications for Army and Defense Policy* (Carlisle: Strategic Studies Institute, 2008), 80–81, http://www.strategicstudiesinstitute.army.mil/Pubs/display.cfm?pubid=882 (accessed June 28, 2012).

30. Kenneth C. Coons and Glenn M. Harned, "Irregular Warfare is Warfare," *Joint Force Quarterly* 52 (1st Quarter 2009): 99.

31. James Corum and Wray Johnson, *Airpower in Small Wars: Fighting Insurgents and Terrorists* (Lawrence, KS: University Press of Kansas, 2003), 8.

32. Bruce Pirnie and others, *Beyond Close Air Support: Forging a New Air-Ground Partnership* (Santa Monica, CA: RAND, 2005), 167–68.

33. Joint Chiefs of Staff, Joint Publication 3-0, *Joint Operations* (Washington, DC: Joint Chiefs of Staff, 2008), xii–xiii.

34. Gene Myers, "Projecting Power," *Armed Forces Journal* 146, no. 1 (July/August 2009): 20.

35. Ibid.

a. Global vigilance: persistent worldwide capability to keep an unblinking eye on any entity;

b. Global reach: ability to move, supply or position assets with unrivalled velocity and precision; and

c. Global power: ability to hold at risk, or strike, any target, anywhere in the world and project decisive, precise effects.[36]

The ability of Western air forces to provide forces able to deliver on these tenets is central to the relevancy of air power in the 21st century. This is relevant to the Canadian Air Force in the context of kinetic land support because of the timing of the renewed interest in air power to support ground operations with the tenets described above. The Canadian Air Force needs to closely examine how to structure itself for future conflicts because "… as Canada makes plans to replace its F-18 [sic] fleet, it is looking at a mix of manned and unmanned platforms. … Canada is also looking at its future UAV needs, and this could include—indeed, is likely to include—a platform with a ground strike capability."[37]

Global vigilance can be provided by either air-breathing or space-based platforms. The former can be armed with weapons to aid in giving flexibility to both ground and air commanders alike. The MQ-9 Reaper is an excellent example of an aircraft that can provide persistent intelligence, surveillance and reconnaissance (ISR) support to an operation that also provides a kinetic capability with bombs or missiles. Global reach alludes to the "… range and speed essential to 21st century military operations."[38] This will allow high-demand, low-density assets such as fighter aircraft to range across a whole area of operations (AO) without being tied to one geographic area. The final tenet, global power, is central to the understanding of the future of air power. This speaks to the capability of air forces to deliver weapons against air and ground targets alike. The ability to project power will be hinged on the ability to either blunt enemy attacks or break through enemy lines as envisioned by Warden. Gene Myers has summed up the future of air power in the 21st century thus:

> Since history clearly teaches us that we really don't know where and to what degree we will be involved next, flexibility and versatility are the keys to military readiness—the most important and validated of aerospace power characteristics.[39]

It is, therefore, interesting to examine the future of air power in the context of the Canadian Air Force. This is especially timely with the announced reduction that Canada will play in the fight against the counter-insurgency in Afghanistan: a mission that has been a defining moment in the history of the Canadian Forces. The lack of air force kinetic power in that theatre until 2008 should give pause to the commanders of the Canadian Air Force to reflect about how, if at all, Canadian aircraft should be equipped with offensive weapons.

Influence on the Canadian Air Force

Canadian foreign and defence policies will continue to be driven by the country's relationship with the United States. However, Ottawa will not be beholden to Washington in the formulation of policies that will decide the future employment of the Canadian Forces. This is made very clear in the

36. T. Michael Moseley, "America's Air Force: The Nation's Guardian," *Joint Force Quarterly* 49 (2nd Quarter 2008): 11.

37. Elinor Sloan, "The Role of Aerospace Power 2018 and Beyond," in *The International System, Canada, Armed Forces and Aerospace Power: 2018 and Beyond*, Silver Dart Canadian Aerospace Studies, vol. V, ed. James G. Fergusson (Winnipeg, MB: University of Manitoba, Centre for Defence and Security Studies, 2009), 148.

38. Gene Myers, "Projecting Power," 21.

39. Ibid., 40.

Canada First Defence Strategy as described in the introduction.[40] Also, as Alexander Moens has noted:

> [t]he growth in NATO's role and mandate will be an important part of Canadian foreign policy as it allows Canada to combine working interests inside an alliance and within Canadian-American interests. The investments in military equipment started in 2006 to support Canada's robust role in Afghanistan give it a strong foundation to be in the vanguard of alliance operations.[41]

As in other countries around the world, Canada is engaged in debate about how defence and foreign policies will be set in the 21st century. It is acknowledged that Canada will not take unilateral military action but will operate in cooperation with other countries to meet policy goals and objectives. These coalitions may not necessarily be restricted to NATO or the United Nations (UN), but they will be established depending on the geopolitical situation at the time. The Canadian Forces needs to remain capable of conducting a range of missions to reflect the reality of its present and future missions. Therefore, because the future is uncertain, the Canadian military needs to retain the capacity for the full spectrum of potential operations in which the Canadian military could conceivably engage.[42]

Returning to the *CFDS*, the Canadian Air Force can play a role in providing firepower for all of the envisioned combat roles outlined in the document. The fighter force will continue to play a pivotal role in Canada's contribution to NORAD. Armed aircraft ensuring the sovereignty of Canada, whether in the Arctic or further south in Canada, will continue for the foreseeable future. Kinetic air power will also provide unique capabilities in the support of international operations abroad for either extended or short periods of time. This kinetic support is not limited to fighter aircraft but may also include armed UAVs and armed helicopters that are able to provide firepower in support of a mission.

The ability of the Canadian Air Force to provide relevant kinetic air power will depend on decisions that take place over the next decade as aircraft, such as the Griffon and Hornet, come up for replacement. The replacements for these airframes will be complemented with other aircraft that will allow the Canadian Air Force to provide flexible, wide-ranging and precise firepower to an operation. The chaotic nature of conflict in the 21st century will require Canada to stay engaged internationally for the protection of its sovereignty and the promotion of its interests abroad. A kinetic capability on the part of the Canadian Air Force will, therefore, be paramount for the effective conduct of operations by the CF when engaged in operations such as those recently experienced in Afghanistan.

3. The modern fighting history of the Canadian Air Force

After the Second World War, it would take 46 years for the Canadian Air Force to take to the skies in battle over the Persian Gulf during Operation DESERT STORM.[43] It would take another eight years before Canadian fighters once again conducted offensive air strikes as part of Operation ALLIED FORCE, the 1999 NATO air campaign against Serbia in retaliation for Serb

40. *Canada First* Defence Strategy.

41. Alexander Moens, "Canadian Domestic and Foreign Policy Determinants in 2018," in *The International System, Canada, Armed Forces and Aerospace Power:2018 and Beyond*, Silver Dart Canadian Aerospace Studies, vol. V, ed. James G. Fergusson (Winnipeg, MB: University of Manitoba, Centre for Defence and Security Studies, 2009), 123.

42. Department of National Defence, "Broadsword or Rapier? The Canadian Forces' Involvement in 21st Century Coalition Operations" (Kingston, ON: Canadian Forces Leadership Institute, April 2008), 31.

43. Canadian fighter pilots did fly USAF Sabres in Korea, but they did not fight as part of a formed Canadian unit in conflict. Brereton Greenhous and Hugh Halliday, *Canada's Air Forces 1914–1999* (Montreal, QC: Art Global, 1999), 130.

atrocities in the province of Kosovo.[44] The Canadian Air Force has not sent aircraft offensively into battle since then, despite the heavy engagement of the Canadian Army in Afghanistan and the Canadian Navy in the Persian and Arabian Gulfs in the global war on terrorism. Canadian aircraft, such as the CC130 Hercules, have operated in theatres where they came under attack, but no CF188s, the only aircraft in the Canadian Air Force inventory capable of offensive kinetic operations against land targets, have been committed to action since 1999. The answer to why no Canadian fighter aircraft have been engaged in operations alongside the Canadian Army is not easily answered but can be placed in context by examining the development of kinetic capabilities, for either air-to-air or air-to-ground missions, for the Canadian Air Force since 1945.

When the Korean War started in 1950, Canada elected to participate in the collective United Nations effort to fight in South Korea and force the withdrawal of North Korean forces from South Korea.[45] The Canadian contribution to the war was limited from the perspective of aircraft: Canadian ground and naval forces were heavily engaged throughout the conflict, but participation from the Royal Canadian Air Force (RCAF) was limited to 426 Transport Squadron.[46] At that time, the RCAF was transitioning its fighter aircraft from propeller aircraft such as the P-51 Mustang to jet aircraft such as the DH-100 Vampire.[47] However, the RCAF was not able to contribute to the air war because of the limitations of non-jet aircraft.

In the Korean War, the air war was fought by aircraft of emerging technology coupled with proven airframes from the Second World War. The RCAF no longer had the robust bomber fleet of 6 Bomber Group lore, as those aircraft had become obsolete with the advent of jet-powered fighter aircraft. The USAF's B-29 Superfortress was used extensively in the conflict for air-ground attack, but these aircraft were countered by Soviet-built MiG-15s. It was recognized that the RCAF's DH-100s were no match for the air threat, and subsequently, no RCAF fighters were deployed to Korea. The RCAF was transitioning to the F-86 Sabre, a capable fighter able to match or outperform the MiG-15, but the focus of RCAF Sabres was not Korea but Europe. "Canadian Sabres were directed to home defence or to meet NATO commitments …" at a time that the Korean War had stabilized, and no escalation in participation in Korea was required of the RCAF.[48]

It was this focus on defence of North America and meeting NATO commitments that were the defining tenets of the RCAF's offensive and defensive capability, a trend that continues to the present day. Acquisition of fighter aircraft after the introduction of the F-86 Sabre was focused on the requirements for NORAD and NATO missions. For the former, the fighters required were interceptors capable of all-weather intercept of Soviet transcontinental bomber aircraft. This requirement was met by the acquisition of aircraft such as the CF100 Canuck and the CF101 Voodoo, which were the cornerstone aircraft of Canada's NORAD force during the cold war.[49] Both the Canuck and the Voodoo lacked an air-to-ground capability and, therefore, did not contribute to the provision of a ground support capability to the Canadian Army. The aircraft acquired to fulfill the requirements of NATO roles were also limited in scale of support that Canadian fighters could provide the Army.[50]

44. Michael W. Manulak, "Canada and the Kosovo Crisis: A 'Golden Moment' in Canadian Foreign Policy?" *International Journal* 64, no. 2 (Spring 2009): 566–67.

45. Elizabeth Ridell-Dixon, "Canada at the United Nations 1945–1989," *International Journal* 62, no. 1 (Winter 2006/2007): 148.

46. Department of National Defence, *On Windswept Heights* (Ottawa, ON: Department of National Defence, 2009), 36.

47. Greenhous and Halliday, *Canada's Air Forces,* 130.

48. Ibid.

49. Ibid., 150–51.

50. John Gellner, "Canada in NATO and NORAD," *Air University Review* XVIII, no. 3 (March–April 1967): 24–25.

The first Canadian air-to-ground fighter for NATO missions was the CF104 Starfighter. This aircraft was originally acquired as a high-speed strike and reconnaissance fighter to equip RCAF squadrons in central Europe. Designed by Kelly Johnson and his staff at Lockheed Martin's Skunk Works, the Starfighter was intended to be a high-altitude, supersonic interceptor but was used in Europe in attack roles. The strike role flown by the Starfighter, by definition, did not lend itself very well to close cooperation with ground forces. The nuclear weapons that Starfighters would have delivered were targeted far beyond the front line; targets for Canadian pilots were deep within East Germany and Czechoslovakia. When the Canadian government moved the Canadian Forces away from nuclear roles, the Starfighter's mission was changed to conventional attack but still focused on air interdiction rather than missions to directly support the Canadian Army.[51]

The RCAF had acquired fighters that were not suited to employment in support of land operations, and upon unification, the Canadian Air Force inherited these aircraft. Not necessarily by design but more by political manipulation, the next fighter that the Canadian Air Force acquired could be used for CAS. Paul Hellyer, the Minister of National Defence from 1963 to 1967, forced upon the Canadian Forces the CF116 Freedom Fighter. The focus of the leadership of the Canadian Air Force was on retaining a multirole capability, and the consensus among the Air Force brass was that the McDonnell Douglas F-4C should be acquired to fill NATO and NORAD requirements.[52] However, Hellyer's championing of the CF116 was not based on mission requirements but was rooted in politics and economics. The aircraft were to be built under license in Canada, thereby providing jobs, and were not as expensive to purchase because they were solely ground attack aircraft. In fact, when the CF116 was introduced into service, the Canadian military had to find a role for the aircraft because it was deemed to be not suitable for use in central Europe. The role that Canada assumed for reinforcement of Norway in the event of conflict was a good fit because the assessment of Soviet air defence and fighter capability in that area of operations was deemed acceptable for employment of CF116s.[53]

Therefore, the first serious foray of Canadian fighters into missions supporting ground operations came not by design on the part of the Air Force but more by default with the acquisition of the CF116. The aircraft were operated by squadrons that were part of 10 Tactical Air Group (10 TAG) that were part of Mobile Force Command (MFC).[54] Created after the unification of the Canadian Forces in 1964, Mobile Force Command was the command of the Canadian Army. While the CF116 did suffer from range and payload limitations, the provision of support to ground operations marked a high point in joint capabilities between the Canadian Army and Canadian fighter aircraft. Fighter pilots were qualified as forward air controllers (FACs), complementing the other Air Force FACs who flew CH136 Kiowa with other 10 TAG squadrons.[55] The inclusion of Air Force FACs, specifically fighter pilots, provided visibility to the Army of the contribution that coordinated air power could bring to land operations.

Fighter pilots maintaining positions and qualifications as FACs continued in the modern era when the CF104, CF101s and CF116s were replaced with the CF188 Hornet starting in 1982. The Hornet was envisioned as a multirole fighter that would be able to conduct both air-to-air and air-to-ground missions for both NORAD and NATO missions. The Hornet has been successful in both

51. Anthony Stachiw and Andrew Tatersall, *Canadair CF104 Starfighter* (St. Catherines, ON: Vanwell Publishing, 2007), 24.

52. Ray Stouffer, "Cold War Air Power Choices for the RCAF: Paul Hellyer and the Selection of the CF-5 *Freedom Fighter*," *Canadian Military Journal* 7, no. 3 (Autumn 2006): 63, http://www.journal.forces.gc.ca/vo7/no3/stouffer-eng.asp (accessed June 28, 2012).

53. Ibid., 69.

54. Greenhous and Halliday, *Canada's Air Forces*, 142.

55. Ibid.

roles and has received substantial avionics upgrades with the Incremental Modernization Project (IMP), which has provided the Canadian Air Force with a fighter that is on par with similar fighters in terms of communications, sensors and weapons.[56]

The Canadian Air Force has an extremely capable fighter aircraft in the CF188 that is able to excel in both air and ground attack missions, but these aircraft have not been deployed to Afghanistan in support of the Canadian Army in Kandahar province. Superficially, the answers to the question of why this is the case are that having Hornets in theatre would be an escalation in the Canadian mission and that it would also be cost prohibitive. While these do factor into why Hornets were not deployed to Kandahar airfield, the answer to the question lies more in the cultures of the Canadian Air Force and Army over the last 20 years since the end of the cold war.

When Hornets took to the skies in Operations DESERT STORM and ALLIED FORCE, the missions that were flown were seen as a validation of the air power theories of John Warden in the design of an air campaign using fighters to strike at critical nodes of an adversary's power. The missions that Canadian pilots flew in Kuwait and Iraq were sweep and escort air-to-air missions; they also conducted air interdiction missions, dropping unguided bombs on Iraqi positions after the start of the ground offensive.[57] When Hornets again took to the air in combat in ALLIED FORCE, the bulk of the missions flown were air interdiction (AI) or defensive counter-air (DCA) missions. The missions that were tasked as CAS in Kosovo were not doctrinally pure CAS because, due to the fact that no NATO ground forces were committed to conflict in Kosovo, these missions were not flown to integrate offensive air strikes into the ground scheme of manoeuvre. The experiences gained from DESERT STORM and ALLIED FORCE were taken as validation of the emphasis that was placed on the training that Canadian fighter pilots received in DCA and AI missions.[58]

Both before and after Operation ALLIED FORCE, the fighter force witnessed a decrease in the number of trained effective fighter pilots and technicians. The modernization of the airframe was also announced, but it was decided, for both engineering and financial reasons, that only 80 Hornets would be upgraded and the remaining aircraft would be retired.[59] The next event that took place that changed the dynamic of training and employment of the fighter force was the terrorist attacks in the United States on 11 September 2001. These attacks led to an increase in the number of CF188s on alert duties at the same time that the fleet was starting to undertake its modernization.[60] The increase of NORAD duties in 2001 and 2002 severely restricted the number of aircraft that were available for expeditionary operations. When the Canadian Army became heavily engaged in operations in Afghanistan in 2003, the Hornet fleet was poised to provide a contribution to the provision of air fires in support of Canadian operations, but Hornets were not deployed. The NORAD tasking level had decreased, which freed up airframes for deployment, but Hornets were not deployed for combat operations because of the culture that had developed within the fighter force with respect to CAS.

Prior to the deployment of Canadian units to Afghanistan, the Canadian Army and the fighter force had grown apart since the days of fighters belonging to 10 TAG. The stand-up of

56. Department of National Defence, "CF-18 Modernization: Acceptance of First Phase I Modernized Aircraft," BG-03.031, May 14, 2003, http://www.forces.gc.ca/site/news-nouvelles/news-nouvelles-eng.asp?id=1074 (accessed June 28, 2012).

57. Greenhous and Halliday, *Canada's Air Forces*, 154–55.

58. Department of National Defence, B-GA-432-000/FP-002, *Fighter Pilot Training Directive* (Winnipeg, MB: Department of National Defence, 2002).

59. The decision to update 80 aircraft was based on money available for the project and the fact the earliest lots of CF188s received could not be upgraded under the ECP-583 programme because of physical airframe limitations, i.e., different bulkheads.

60. Joseph Jockel, *Canada in NORAD, 1957–2007: A History* (Kingston, ON: McGill-Queen's University Press, Queen's Centre for International Relations and Defence Management Program, 2007), 167.

1 Canadian Air Division, along with the dissolution of the air groups in 1997, was the first step in the disengagement of the fighter force from the Canadian Army. This disengagement had started with the retirement of the CF116 from operational squadrons in 1988, and it accelerated throughout the 1990s. Canadian fighter pilots were deployed as FACs in support of Canadian units in Bosnia-Herzegovina, but this marked the high water point of Canadian fighter pilot engagement with the Canadian Army. After these deployments, the number of fighter pilots qualified as FACs steadily decreased. The end of the brigade-level Exercise RENDEZVOUS in 1997 also limited the large event training exercises for CF188s with Army brigades. After ALLIED FORCE, the fighter force continued to concentrate on AI missions as its specialty for air-to-ground missions. Conversely, due to the disengagement of the fighter force from providing FACs, Army officers were unaware of the firepower effects that fighters are able to provide a ground commander.[61]

The unintended consequences of these incidents led to the tragic events in September 2006 where a USAF A-10 mistakenly fired on Canadian troops, killing one soldier and wounding over 30 in a single strafing pass.[62] There were many individual occurrences that led to this tragic event, from obscured visibility to fatigue, but one key contribution was the lack of a tactical air control party (TACP) with the Canadians at the brigade or battle group level. In Bosnia, there had been TACPs, populated by fighter pilots, attached to the Canadian units. These pilots were trained as FACs, and their expertise on CAS, from the perspective of the pilot, was leveraged in order to maximize the CAS support to the ground commander. However, by 2006 the Canadian Forces was not following doctrine, and TACPs had not been formed or deployed into the theatre of operations.[63] Unfortunately, it took this accident to bring this deficiency to light in the subsequent investigations.

The doctrinal role of a TACP is to advise ground commanders on the best use of aircraft, maintain command and control of air assets and, as required, provide terminal attack guidance for attacks to support ground operations.[64] FACs, also referred to as joint terminal attack controllers (JTACs), belong to the commander of the TACP and work at the unit level in order to provide a local commander with the level of precise control required in order to safeguard friendly forces and limit collateral damage, while carrying out attacks on adversaries. The absence of TACP and FAC qualified fighter pilots was recognized as a deficiency within the Canadian Air Force and Army. The Commander of 1 Canadian Air Division and the Commander of Land Force Doctrine and Training Systems (LFDTS) jointly re-energized the tactical units of the Air Force and Army to better align the efforts of the fighter force and Army to better integrate the units deployed to Afghanistan.[65]

Another follow-on effect to the experience gained by the Canadian Army from operations in Afghanistan was the requirement for realistic training in Canada prior to the deployment of forces to the theatre of operations. CF188s, from both 3 Wing Bagotville and 4 Wing Cold Lake, have provided critical support to Army training at all levels, from basic FAC training to battle group validation exercises at the Combat Manoeuvre Training Centre at Canadian Forces Base Wainwright.[66] While the support that these fighters have provided battle groups has been key to the

61. During the author's time as a pilot on an operational fighter squadron, there were no large scale training events with the Canadian Army until the start of the MAPLE GUARDIAN series of exercises in Wainwright, the planning of which started in 2005–2006.

62. Department of National Defence, *Board of Inquiry Minutes of Proceeding Topic of Inquiry: A-10A Friendly Fire Incident 4 September 2006, Panjwayi District, Afghanistan* (Ottawa, ON: Department of National Defence, 2006), 4, http://www.forces.gc.ca/site/focus/opmedusa/A10_BOI_Report_e.pdf (accessed June 28, 2012).

63. Ibid., 5.

64. United States, Joint Chiefs of Staff, Joint Publication (JP) 3-09.3, *Joint Tactics, Techniques, and Procedures for Close Air Support (CAS)* (Washington, DC: Joint Chiefs of Staff, 2003), GL-18.

65. LFDTS and 1 Cdn Air Division have been actively engaged in the revamping of CAS training within the Army and fighter force. In 2009, a joint standards cell for CAS training was established at LFDTS HQ in Kingston with a CF188 pilot on the staff.

66. Scott Taylor, "Ex Maple Guardian," *Esprit de Corps, Canadian Military Then and Now* 15, no. 5 (June 2008): 9.

realistic training of Canadian soldiers prior to their deployment to Afghanistan, the fighter force is not any closer to having aircraft deployed to the same theatre.

To summarize, when the Canadian Forces deployed to Afghanistan, CF188s (to provide support for the Canadian battle group) were not included in the force package that was deployed. During the cold war, the Canadian fighter force had been organized to fly in either NORAD or NATO missions that did not involve CAS missions. The only close operational contact between Canadian fighters and Mobile Command was through 10 TAG and the limited number of CF116s that were in service. When these were retired from service, the Canadian fighter force accelerated a disengagement from operations with the Canadian Army that culminated in the operations that took place during Operation ALLIED FORCE. The DCA and AI missions that CF188s flew into Kosovo and Serbia during this conflict were seen as validation of the emphasis that had been placed in the fighter force on equipping for and training to mission types that followed the strategic principles of Colonel Warden's rebirth of strategic air power in his *The Air Campaign: Planning for Combat*. This book provided the blueprint for the air campaign of the 1991 Persian Gulf War. The experience of the Air Force's fighters since the end of the Second World War in training and operations were air centric. This emphasis did not fit into the joint capabilities that were required for CF188s to fit into the deployment and battle plans of the joint task force that deployed to Afghanistan. An additional impediment to the integration of Air Force and Army kinetic operations in Canada was the increased NORAD tasking level in the immediate aftermath of 11 September 2001 limiting the number of aircraft available for deployment.

The fact that CF188s have not been deployed to Afghanistan to support Canadian soldiers engaged in fighting has been a missed opportunity to cement the bond between the fighter force and the Canadian Army. Fighter pilots have been trained and deployed as FACs working in TACPs and have provided critical support to ground commanders in Kandahar. Also, the inclusion of CF188s in the training of soldiers in Canada prior to deployment has also helped close the tactical gulf that exists between the fighter force and the combat arms. The end of the CF188 Incremental Modernization Programme, with increased interoperability systems and weapons, was a key milestone for the fighter force in its ability to conduct CAS missions with the latest technology and weapons available. The completion of these upgrades has to ensure the maximum lethality and effectiveness of the Hornet as a weapons platform for missions that fit into the ground scheme of manoeuvre. Time will tell if the fighter force will be deployed in the future to provide the flexible kinetic effects that are the hallmark of air power, in air-to-air missions or air-to-ground missions that not only are AI missions but also will include CAS missions. A future deployment is contingent on the ability of the fighter force to demonstrate its proficiency and on the Canadian Forces including Air Force kinetic power in future joint task forces. As will be shown in a subsequent section, these kinetic effects should not be confined to fighters but may also include some form of unmanned combat air vehicle (UCAV) as a weapons platform of the not-so-distant future.

4. Air power trends

The Canadian Air Force is not unique in how its air power has developed since the end of the Second World War. The onus that has been placed on the development of fighter capability to defend airspace and attack strategic targets is reflected throughout the air forces of NATO. The largest Western air force, that of the United States, has promoted with vigour the platforms that best allow conduct of operations as those exemplified in Operations DESERT STORM and ALLIED FORCE. The missions in these operations, of which Canadian fighter pilots ably participated, were flown with massed formations of fighters, bombers and support aircraft penetrating into the airspace of the adversary to strike at targets that were determined to be key to the enemy's ability to fight. However, the conflict trends of the past decade are leaning away from high-intensity conflicts such as Operation DESERT STORM and are showing the hybrid nature of contemporary conflict that is fought in a non-linear battlespace in which air power can provide critical support to land forces.

Independent of the type of conflict, whether against the Taliban of Afghanistan or the Iraqi military, tangible trends have emerged that will dictate the effects that air power will have in the future and what roles aircraft will play in the conflicts of the future. The importance of control of the air has been reinforced as a trend that will continue with the move towards increasingly stealthy aircraft such as the F-22, billed as the world's first air dominance fighter. Second, the technology trends that indicate that aircraft are capable of delivering increasingly precise weapons are a stark contrast to the kinetic effects that aircraft could deliver prior to the invention of global-positioning-system (GPS) guided munitions. Third, the reliance that commanders have on intelligence, surveillance and reconnaissance has grown with the move towards increasing networked forces. Persistent ISR in the form of long-endurance UAVs started to have an impact over Kosovo and has developed to the point that UAVs are now integral to any deployed force. The final trend that is worthy of examination is how armed helicopters, such as AH-64 Apaches, fit into the equation of mobile attack capability throughout an area of operation for commanders in the future and how these aircraft can sustain substantial damage when not employed properly. The trend for the use of armed helicopters shows that they may be too vulnerable to ground fire when involved in higher intensity fighting.

As mentioned earlier, the Canadian Air Force has embarked on a process of renewed commitment to the role that air power can provide to the concept of joint fires in operations with the Canadian Army in order to have a visible impact on the battlefield. Joint fires is the "… employment of forces from two or more components in coordinated action to produce desired effects in support of a common objective."[67] The motivation for this renewed energy is the realization of how vital to joint fires that air power has become. The ability to precisely strike targets with a compressed kill chain, the process from requesting an attack to delivering weapons on the target, has made the flexible response of air power a key component to the successful conduct of operations. In order to help chart the future for kinetic air power for the Canadian Air Force, the trends that have emerged over the last decade of air power operations will be discussed in turn, starting with Kosovo through to the operations that are currently taking place in Afghanistan and the role of air power in the US-led invasion of Iraq in 2003. These air power trends will give an indication of how Canadian air power can develop and what platforms will be required of the Canadian Air Force to best contribute to joint fires to maximize the impact of air power in the conduct of Canadian operations, as outlined in the *Canada First* Defence Strategy.

Air in the latest conflicts

Operation ALLIED FORCE, NATO's air campaign in Serbia, is an interesting case study in that it is the only recent conflict that was fought solely with aircraft and no ground troops. ALLIED FORCE started on 24 March 1999 to

> … force [Serbian President Slobodan] Milosevic back to the negotiating table so that NATO could find a way short of independence to protect Kosovo's ethnic Albanian population from Serb violence and political domination. This bombing campaign, it was emphatically stated, was not a war, and none of the NATO leaders had any intention of waging one.[68]

67. Joint Chiefs of Staff, Joint Publication 3-0, *Joint Operations*, III-17–III-18.

68. Ivo H. Daadler and Michael E. O'Hanlon, *Winning Ugly: NATO's War to Save Kosovo* (Washington: Brookings Institution Press, 2000), 2.

The trends that emerged from Kosovo for joint fires are limited because of one simple fact; there were no joint fires in ALLIED FORCE due to the absence of a land campaign. Air power, in any shape or form, did not need to integrate into a ground scheme of manoeuvre, and therefore, the complex coordination of joint fires was not exercised at any point during the bombing campaign. In Kosovo, "… NATO's air war had two main thrusts: a strategic campaign against the Serb heartland and a tactical campaign against Serb forces doing the killing and the forced expulsions in Kosovo."[69] The strategic campaign was conducted along the same lines as those of Operation DESERT STORM: the seizing of air superiority and then the systematic attack of targets in keeping with John Warden's theories that were used in 1991 in Iraq. The dominance of NATO over the Serbian Air Force allowed for the conduct of the operation on the terms that NATO decided in its planning cycle. NATO had an "overwhelming superiority in air combat capability, air combat aircraft, sensors and battle management systems, and the strike capabilities needed for air base suppression."[70] The ability to wrest control of the air over Serbia and Kosovo was a reinforcement of the belief in the necessity to have air superiority, or better still air dominance, as a precursor to attacks on ground targets. The Serbian integrated air defence system (IADS) was not destroyed, but it was suppressed to the point that only two allied manned aircraft were shot down without loss of life, with an additional four Predator UAVs shot down. Serbian IADS was suppressed using dedicated electronic warfare aircraft such as EA-6B Prowler and F-16CJ equipped with jamming capability and armed with AGM-88 high-speed anti-radiation missile (HARM) designed to attack radar-equipped air defence systems.[71]

In Operation ENDURING FREEDOM in Afghanistan, allied aircraft were not faced with an IADS of any description. There were no systematic impediments from the Taliban to deny the use of airspace to aircraft other than through small arms and man-portable air defence systems like shoulder launched surface-to-air guided missiles (SAMs). The free rein of not having to contend with enemy fighters or radar systems had allowed commanders the flexibility to concentrate air power when and where they chose.[72] Missions flown to integrate aircraft into joint fires can be time consuming when these attacks are to be made close to friendly positions to ensure that the proper targets are hit while minimizing the probability of friendly casualties. ENDURING FREEDOM has shown the value in being able to dominate the airspace in a theatre of operations to maximize the impact that air power can bring to a fight.

During Operation IRAQI FREEDOM, coalition aircraft again ruled the skies over Iraq, but this was a carry-over from the results of Operation DESERT STORM. In 1991, Iraq fought back with fighters and surface-to-air missiles against the coalition aircraft and cruise missiles that were attacking targets in Kuwait and Iraq as part of the operation to expel Iraq from Kuwait. Following the conflict, two areas were established as no-fly zones for the Iraqi Air Force. These zones were patrolled by a continuous presence of American and British fighters operating from bases close to Iraq in order to enforce the UN sanctions against Iraq. Iraqi air defence units were attacked if they threatened allied aircraft. The December 1998 Operation DESERT FOX, in addition to targets linked to the Iraqi weapons of mass destruction programme, also struck Iraqi air defence units to further degrade the ability of the Iraqi military to mount a defence against allied aircraft. In the lead-up to the invasion of Iraq in March 2003, American forces started to attack Iraq in July 2002. Under a secret plan called SOUTHERN FOCUS, the commander of the Allied Air Component, USAF Lieutenant General T. Michael Moseley "expanded the list of targets [that could be struck.]

69. Ibid., 4–5.

70. Anthony H. Cordesman, *The Lessons and Non-lessons of the Air and Missile Campaign in Kosovo* (Westport: Praeger, 2001), 258.

71. Daniel Haulman, *U.S. Unmanned Aerial Vehicles in Combat, 1991–2003* (Maxwell AFB, AL: Air Force Historical Research Branch, 2003), 8.

72. Eric Theisen, *Ground-Aided Precision Strike: Heavy Bomber Activity in Operation Enduring Freedom* (Maxwell AFB, AL: Air War College, 2003), 2.

[This was done] as a way of compensating for the possibility that the air commanders might have little time to set the stage for a ground assault."[73] By the end of SOUTHERN FOCUS, the Americans "… dropped 606 bombs on 391 targets …" that included attacks on the Iraqi Air Defence Command at H-3 airfield in Western Iraq.[74] Unlike Operation DESERT STORM, the invasion of Iraq in 2003 was not preceded by weeks of punishing air attacks throughout the country. IRAQI FREEDOM'S air campaign struck targets that had been identified to best support the ground commanders and not destroy the infrastructure of the country that would be vital to the new Iraqi government after the removal of Saddam Hussein from power.[75] These attacks were possible because of the dominance that the coalition had in the skies over Iraq.

Operations over Kosovo, Afghanistan and Iraq show the importance of air superiority as a minimum and air supremacy as a goal for future operations. Air superiority is defined by NATO as the "degree of dominance in the air battle of one force over another which permits the conduct of operations by the former … at a given time and place without prohibitive interference by the opposing force."[76] Air supremacy is different in that the "… dominance of one force is not restricted to a given place and time but is complete in that the opposing force is incapable of effective interference."[77] The USAF F-22 is an example of an aircraft that is designed to dominate the airspace in any theatre. It is the first fifth generation fighter that is designed to operate with impunity against advanced enemy fighters operating within a modern IADS with the most advanced SAMs. The F-35 Lightning II, also known as the Joint Strike Fighter, in development as the next generation strike aircraft to replace the current fourth generation aircraft, such as the CF188, also follows along the theme of designing an aircraft that exploits technology to decrease the threat posed by an adversary's IADS.[78] The trend of dominating the air above a battlespace is a theme reinforced during the operations that have taken place to date in the 21st century.

Towards the best weapon

The weapons used during Operation ALLIED FORCE showed the quickening pace in the trend towards the increased use of precision-guided weapons and precise weapons in modern operations. Precision-guided weapons guide on laser energy reflected off a target from either a ground or air designator to hit a target. These weapons require a clear line of sight to the target during critical parts of the trajectory of the weapon to successfully guide to the target. Precise weapons use information from GPS satellites to determine the weapon's location with respect to the calculated position of the target in order to strike a selected aim point and do not require further human action to guide to the target. During Operation DESERT STORM less than 10 per cent of the weapons employed were precision-guided weapons.[79] During Operation ALLIED FORCE, this percentage had increased to approximately 33 per cent and included the employment of GPS-guided bombs, such as joint direct attack munition (JDAM), and cruise missiles on a large scale from a variety of aircraft, from fighters to strategic bombers such as B-2 Spirits that flew missions direct from their base in Missouri.[80] This percentage grew even more during Operation IRAQI FREEDOM to

73. Michael R. Gordon and Bernard E. Trainor, *Cobra II: The Inside Story of the Invasion and Occupation of Iraq* (New York: Pantheon Books, 2006), 69.

74. Ibid.

75. Ibid., 209.

76. North Atlantic Treaty Organization NATO Standardization Agency, AAP-6 (2009), *NATO Glossary of Terms and Definitions* (Brussels: NATO Standardization Agency, 2009), 2-A-11.

77. Ibid.

78. Bill Sweetman, *Ultimate Fighter: Lockheed Martin F-35 Joint Strike Fighter* (St. Paul, MN: MBI Publishers, 2004), 52.

79. Anthony H. Cordesman, *The Iraq War: Strategy, Tactics and Military Lessons* (Westport: Praeger, 2003), 279.

80. Cordesman, *Air and Missile Campaign in Kosovo*, 97.

having the overwhelming majority, almost 70 per cent, of the weapons dropped being either laser- or GPS-guided munitions.[81] Combined laser- and GPS-guided weapons are now in the Canadian Air Force arsenal. They can be dropped using either of the two guidance systems that is best suited for the attack required and the environmental conditions of the day. Current non-linear battlespace, such as typified in Operations ENDURING FREEDOM and IRAQI FREEDOM, demand joint fires of unprecedented precision that can only be accomplished through the employment of guided munitions to avoid friendly casualties or unwanted collateral damage to property. The upward trend in the requirement for guided weapons for integration into joint fires will not decrease in the 21st century. In fact, air forces may get to the point that the only unguided weapons used will be direct fire weapons such as the 20 mm Vulcan Cannons that equip fighters such as the CF188.

Deadly persistence

The trend in better integrating air power into joint fires has not come from new and advanced manned aircraft but in the guise of increasingly sophisticated and capable UAVs. The technological development has reached the point that these aircraft have become vital to the air and land commanders' views of the battlespace. UAVs have developed from the surveillance drones first used in large numbers in DESERT STORM at the tactical level, like the Pioneer, to the strategic assets, such as the Global Hawk. Their endurance is measured in tens of hours, and they are capable of flying at altitudes once the realm of reconnaissance aircraft such as the SR-71 and U-2. The RQ-1 Predators that were used in ALLIED FORCE provided commanders with a real-time view of events in Kosovo with images sent back to the combined air operations centre in Italy that directed the air campaign.[82] The Predators were used to identify targets and start what became the time-sensitive-targeting (TST) process to identify targets, obtain permission to strike and then attack something that was first identified by the UAV. There were shortfalls in the equipment, such as the inability to provide commensurated waypoint information of a target of sufficient fidelity to allow for attack by GPS-guided bombs, but technology has advanced to minimize these shortfalls in order to maximize the utility of these assets.

Modern UAVs, like MQ-9 Reapers, provide commanders with persistent ISR coverage that has also grown to include an added bonus for the ground commander. Upgraded MQ-1 Predators have been armed with AGM-114 Hellfire missiles while the MQ-9 Reaper, a larger version of the Predator, is armed with a combination of both Hellfire missiles and guided 500-pound (225-kilogram) bombs. These armed UAVs were first used in the initial stages of the global war on terrorism to great effect. An AGM-114 fired from a Predator struck a truck in Yemen and killed a high-ranking al-Qaeda commander in 2002.[83] This was the first documented case of a UAV being used to strike a target successfully, but these missions have become commonplace in Iraq and Afghanistan since that time. In addition to being able to provide deadly persistence to the joint fire equation, UAVs are able to move above the battlespace without giving away their position. Loitering at altitude above an area of operations, UAVs can capitalize on both their low visual and noise signatures to remain undetected to those on the ground.[84]

81. Cordesman, *Iraq War*, 279–80.

82. Haulman, *U.S. Unmanned Aerial Vehicles,* 4–5.

83. Carl Doyon, "Replacing the CF-18 Hornet: Unmanned Combat Aerial Vehicle or Joint Strike Fighter?" *Canadian Military Journal* 6, no. 1 (Spring 2005): 35, http://www.journal.forces.gc.ca/vo6/no1/technolo-eng.asp (accessed June 28, 2012).

84. Luther S. Turner, Jason T. Adair, and Louis Hamel, "Optimizing Deadly Persistence in Kandahar: Armed UAV Integration in the Joint Tactical Fight," *Colloquium* 2, no. 2 (June 2009): 7.

UAVs "… are coming of age in an era of data networking and they are taking full advantage of this technology."[85] In fact, the move to more network-based command and control systems has highlighted the benefits of including UAVs in the ISR design of a campaign: "… net-centric operations enable … UAVs and networked munitions to conduct missions more effectively and increase the effectiveness of manned and space platforms."[86] An example of how the capabilities of UAVs can be optimized to help manned aircraft target enemy units that may deny their full and free use of airspace is that during Operation IRAQI FREEDOM Global Hawks were "… used in 55% of the TST missions against enemy air defence equipment."[87] An indication of the trends in the development of UAVs, the USAF believes that:

> [w]eaponized unmanned systems can, in certain circumstances, provide lower-cost, lower-risk alternatives to manned missions. Operating in strike packages with manned aircraft or other unmanned aircraft, armed … UAVs can carry out destruction or suppression of enemy air defense missions by using a combination of kinetic and non-kinetic weapons.[88]

Of the major trends in the development of air power contributing to joint fires, the development and employment of armed UAVs is by far the most significant trend witnessed to date.

The Canadian Air Force has recognized this trend but has not yet introduced to service an armed UAV along the lines of the MQ-1 or MQ-9. The CU161 Sperwer has been replaced in Afghanistan with the CU170 Heron UAV operated by the Canadian Air Force. The Heron provides a more persistent ISR capability than that offered by the Sperwer and can remain on station for 24 hours to provide support to ground commanders. The limited capabilities that the Sperwer provided, in terms of ISR functionality and persistence, gave rise to the requirement for the Canadian Air Force to field a UAV that better supported the requirements of ground commanders. A major improvement in the ISR functionality that the Heron provides that the Sperwer did not is the remotely-operated, video-enhanced receiver (ROVER) system.[89] A unit on the ground equipped with a ROVER system is able to receive images transmitted from whatever system is transmitting the images. This capability allows FACs to specifically highlight targets for attack using the images provided from above. Ground commanders can also use this system to help provide situational awareness of what is happening in an area beyond their observation due to distance or terrain.[90] The Canadian Air Force is well placed to make a significant advance in the persistent support that it can provide to joint fires through the exploitation of the capabilities that are now being shown possible with modern UAVs.

The final trend for discussion is the development of armed helicopters for the inclusion in the joint fires equation and when these aircraft are best employed. The "… standard for the middle and great powers within the Western alliance" is to include these versatile aircraft in the combat fleets of their militaries, whether as part of their Army or Air Force.[91] As such, ground commanders have come to rely on the flexibility that these platforms play in the delivery of timely fire support to the ground scheme of manoeuvre. This is especially true in the US Army; it has fielded dedicated attack helicopters since the Vietnam War and now uses the AH-64 Apache as its main attack platform.

85. United States, United States Air Force, *The U.S. Air Force Remotely Piloted and Unmanned Aerial Vehicle Strategic Vision* (Washington, DC: United States Air Force, 2005), 7.

86. Ibid.

87. Ibid., 2.

88. Ibid., 9–10.

89. Details of the sensing capability of the CU170 Heron are discussed at http://www.casr.ca/101-af-cu170-heron-uav.htm (accessed June 28, 2012).

90. Ibid.

91. Thierry Gongora and Slawomir Wesolkowski, *What Does a Balanced Tactical Helicopter Force Look Like?* (Ottawa, ON: Department of National Defence, 2008), 9.

The impetus for the development of these aircraft is that the ground commander can exercise direct control over a platform that is organic to its organizational structure. This is an understandable conclusion that, while it may be a source of friction between air and ground commanders, is almost irrelevant. As will be discussed in the next section, what is most important for the role of air power in the provision of support for joint fires is not what platform provides kinetic support in conflict but what type of kinetic support is provided. In essence, this is an "… effects-based approach that starts with the desired outcome … and then determines the resources needed to achieve them."[92]

The missing piece – armed helicopters

In operations in Afghanistan and Iraq, armed helicopters have done yeoman service in the provision of joint fires. However, some shortcomings of these aircraft have been noted that suggest that armed helicopters, while they do have an extremely important role to play in kinetic operations, cannot operate with impunity on the battlefield and, at times, are not the best platform to provide the required support to ground operations. Experience has shown that helicopters are susceptible to ground fire due to the low altitudes and slower speeds that they operate at when flying either CAS or close combat attack (CCA).[93] This is not to suggest that armed helicopters have no place on the battlefield but is a recognition of the fact that commanders need to weigh risks and benefits when deciding which platform will provide joint fires when it is required.

Operation ANACONDA, conducted in the Shahi Kot valley in eastern Afghanistan 2–16 March 2002, is a now classic example of the emerging face of battle that is fought on non-linear battlefields that require the full integration of joint fires. This operation to clear the Shahi Kot valley of remaining al-Qaeda and Taliban forces was at the end of the opening stage of operations in Afghanistan.[94] Over the two weeks of the battle (involving troops from eight countries, including Afghanistan), "… bombers, fighters, helicopters and AC-130 gunships delivered CAS into the postage-stamp size battle area measuring about 8 [nautical mile] x 8 [nautical mile] [14.8 kilometers by 14.8 kilometers]." As an indication of the role that CAS played, in the first 72 hours alone of the operation, over 750 bombs were dropped into this small area.[95] All of the AH-64s that took part in the opening phase of the operation, "… took damage. By the end of the day, four had returned to the forward arming and refuelling point (FARP), while three remained in action despite battle damage."[96] The CAS support to the fight in the valley was so intense that, over the span of the operation, an average of 235 bombs per day were dropped in addition to strafing from fighters and fire support from attack helicopters and AC-130 Spectres.[97] This gives testimony to the vital role that air power played in this fight. The troops that were engaged in the fight did not have organic artillery support and depended on CAS to provide them with the firepower that they required to win firefights and defeat their adversaries.

The next section will discuss how doctrinally the tasking of air power in joint fires did not work as efficiently as could have because of a lack of focus on the effects that were required rather than on what platforms were providing the support. The Air Force was not involved in the planning of support for the operation until only five days prior to the planned start date for the battle.

92. Lieutenant-Colonel J. P. Hunerwadel, "The Effects-Based Approach to Operations," *Air & Space Power Journal* (Spring 2006): 57, http://www.airpower.au.af.mil/airchronicles/apj/apj06/spr06/hunerwadel.html (accessed June 28, 2012).

93. CAS and CCA are the same mission, but the US Army uses the CCA description so that it does not infringe on the Key West Agreement that outlined the roles and missions that the USAF and US Army would fulfill.

94. United States, United States Air Force, *Operation Anaconda: An Air Power Perspective*, 3.

95. Ibid.,7.

96. Ibid., 66.

97. Ibid., 101.

This meant that "[n]either the land nor air component did all they needed to do to put a theatre air control system in place to handle close air support requests."[98] Therefore, the airborne assets that were to make "… up for the lack of ground-based combined arms elements" defaulted to the organic air support of the AH-64 that the US Army could task as the lead nation in the planning.[99] The intensity of small arms fire and rocket-propelled grenades (RPGs) decreased the employment of the Apaches due to the damage that they received, and the controllers directing the CAS had to rely on joint fires from fighters, bombers and AC-130s to provide them with the support they required without exposing the crews to unmanageable risk. In Operation ANACONDA, it was not that armed helicopters could not provide the joint fires required but more an example of fixed-wing platforms being available that were able to provide the same support without the same risk, this meant that the helicopters were not used as much.[100]

In another example of how exposed helicopters can be to ground fire is the now infamous attack on the Iraqi Medina Division on 24 March 2003 by AH-64s of the 11th Aviation Regiment. On their attack, "… the helicopters encountered heavy small arms and light anti-aircraft fire before they closed on the Iraqi armour, and had to retreat back to base after doing minimal damage."[101] The changes that the US Army instituted after that failed attack was not to the equipment but in the employment, ensuring the best effect that armed helicopters could provide. Apaches were used in attacks behind the front line, in so-called deep attacks, but they were most successful and provided the best effects to the ground commanders when they were used as armed scouts to either secure a flank or provide mobile firepower in the ground scheme of manoeuvre.[102] The failed attack of 24 March 2003 shows the damage that an alerted enemy can do to a helicopter raid when the "… objective of their attack [becomes] clearly predictable … ."[103] Therefore, the trend in the use of armed helicopters is not to discount their utility but to ensure that these critical platforms are used in missions that require their unique capabilities.

In essence, all of these trends discussed are continuations of the evolution of air power and what it brings to a fight. Air power needs to be responsive to the requirements of a conflict to be "… capable of delivering scalable destructive power with a variety of kill mechanisms where ground forces need them and when they need them—all the while surviving the possible battlefield threats."[104] By surviving the threat to provide weapons on targets, air power will be able to "… employ weapons close to or far from … troops, day or night and in poor weather."[105] In the next section we will see how doctrine and employment of air power is evolving from the lessons learned during the last conflicts of the Western powers. The attainment of air supremacy has remained as a cornerstone for the conduct of operations on land, sea and air. The capabilities that precision and precise weapons bring to joint fires denote a marked difference in the effectiveness of air power in kinetic operations. This realization is recognized in the doctrinal changes to joint fires that have decreased the safety distance to friendly troops that FACs can use when calling for joint fires when laser-guided bombs (LGBs) or GPS-guided weapons are employed. The persistent ISR (that UAVs of differing types have) has become as important to operations as maintaining air supremacy. Without ISR feeding information into the intelligence and targeting cycle, air power would not be as effective as it is now.

98. Ibid., 6.

99. Lieutenant-Colonel Collin T. Ireton, "Shifting the Air Force's Support Ideology to Exploit Combined Arms in the Close Fight," *Air & Space Power Journal* (Winter 2008): 87.

100. Ibid.

101. Cordesman, *Iraq War*, 318.

102. Ibid., 320–21.

103. Ibid., 321.

104. Ireton, "Shifting the Air Force's Support Ideology," 88.

105. Ibid.

Finally, when tasked and employed properly, armed helicopters can provide incredible support to ground commanders. The freedom of manoeuvre and firepower that these aircraft bring to a battlefield cannot be equaled because of how closely they can be integrated into the ground commander's plans. The future of air power in the joint fires equation is bright, and subsequent sections will demonstrate how the Canadian Air Force will be able to provide the effects that are required by the Canadian Army to allow it to operate with the support provided by air power through joint fires.

5. Improving the joint fight

In the previous section, the latest trends that have emerged in the use of air power were discussed in order to set the foundation to discuss how these trends will contribute to the future of air power and its ability to provide kinetic effects on the battlefield of tomorrow. This issue is important to discuss because it is from this assessment of the future of air power's effects on the battlefield that the future of Canada's Air Force can be examined. This discussion is especially timely for the Canadian Air Force with the examination of the future of UAVs in the Air Force, the coming replacement of the CF188, the deployment of CH146s to Afghanistan, and the primacy of the defence of Canada in the *Canada First* Defence Strategy. In order to place all of these factors in context for Canada, it is first important to discuss the cumulative effects of the current trends in the evolution of kinetic air power and its ability to make a contribution in areas of operations.

The easiest way to summarize how the role of air power in joint fires is viewed is, at the most basic level, simply being the increased cooperation and integration with land forces. This emerged in embryonic form during Operation DESERT STORM but was not fully identifiable until the recent Operations ENDURING FREEDOM and IRAQI FREEDOM. In Operation DESERT STORM, the designers of the air campaign reluctantly moved away from the strategic campaign along Warden's model of not holding air power as subordinate to land power but capable of striking at the heart of an adversary's military and society to carry the fight.[106] The missions that were flown by air power to support land forces in their ground offensive, from CAS missions from A-10s and Marine aircraft to CCA missions by AH-64s, were not viewed as important as the attacks independent of the ground scheme of manoeuvre.[107] This isolation of air power from the land forces was not limited to the 1990s but continued with Operation ALLIED FORCE and permeated its way through the Canadian fighter force, as discussed in an earlier section. Operation ENDURING FREEDOM placed this paradigm of independent air forces attacking targets beyond the front lines on its head and forced leaders with the Western air forces to seriously study the role of air power in joint fires. Operation IRAQI FREEDOM, and the continuation of operations in Iraq and Afghanistan into 2010, served to reinforce the realization that air power is required as a cornerstone in joint fires. In order to remain relevant, air power needs to integrate into joint fires as an equal partner with land forces in contemporary and future battlespaces. The advocates of air power employed along lines of operations separate from ground forces are becoming fewer as the lessons of Operations ENDURING FREEDOM and IRAQI FREEDOM become fully assessed and included in doctrine.

USAF counter-land doctrine

The USAF is aggressive in its development of doctrine for the employment of air power in contemporary operations. The USAF views air power, combined with space enablers, as a form of

106. Olsen, "Operation Desert Storm," 182.

107. Ibid., 195–96.

"aerial maneuver that seeks to shatter an enemy's fighting ability through focused attacks against key enemy military targets."[108] The latest version of the USAF *Counterland Operations* doctrine was published in 2006 after the inclusion of the lessons gleaned from Afghanistan and Iraq. What is interesting to note is how some vestiges of parochial service interests remain in the counter-land doctrine of the USAF with regards to the division of the mission sets between AI and CAS. The friction between these missions is not rooted in a denial of the requirement for these missions but is more centred on the debate on who the coordinating authority is for missions in a battlespace. Both CAS and AI can be used in aerial manoeuvre to attack an enemy, but these missions, whether flown as pre-planned or reactive, can change in nature depending on the effect that they are designed to meet. This friction harkens back to the ongoing debate of whether air power is aerial artillery for the ground commander or whether air power, in AI missions, is best employed against targets that are identified as key to the enemy following the Warden school of thought.

The USAF defines CAS as "air action by fixed- and rotary-winged aircraft against hostile targets that are in close proximity to friendly forces and which require detailed integration of each air mission with the fire and movement of those forces."[109] There is no debate that CAS needs to be highly controlled in order to mitigate the risk of hitting the wrong target and attacking friendly troops rather than the adversary.[110] Coordination for CAS is done in the planning stages using TACPs at all levels of command and with FACs as the final authority for the release of weapons. Doctrinally, the definition of CAS is well understood, as are the benefits that CAS offers a joint force commander. Air power provides "… speed, range and maneuverability [sic] to allow CAS assets to attack targets that other supporting arms may not be able to engage effectively."[111] Therefore, air power provides a ground commander with vital firepower support to "… halt attacks, help create breakthroughs, destroy targets of opportunity, cover retreats and guard flanks."[112]

AI is the other half of the defined *Counterland Operations* doctrine. AI is designed to "… attack the enemy's ability to fight by targeting tactical and operational forces and infrastructure … . AI is conducted at such distance from friendly forces that detailed integration of each air missions with the fire and movement of friendly forces is not required."[113] For the air power purists, AI is the ultimate mission for kinetic effects following the air power theories of Warden, Mitchell and Trenchard. AI is viewed as operations to "… divert, disrupt, delay or destroy the enemy's military potential before it can be brought to bear effectively against friendly forces … ."[114] It is recognized that AI is a powerful mission set that can have a profound impact in the conduct of a campaign. The development of persistent ISR to find targets of opportunity, such as the use of Global Hawks in Operation IRAQI FREEDOM to find Iraqi air defence systems, and the integration of more precise weapons has made AI a high-demand mission because of the effects it can deliver. The friction in AI comes, therefore, in how the target sets are determined for AI and to what ends they are attacked. AI missions can be used to follow an air campaign that complements the ground objectives or they can be flown in support of the ground campaign, in what are called shaping operations.[115]

108. USAF, AFDD 2-1.3, *Counterland Operations*, 2.

109. Ibid., 6.

110. Ibid., 7.

111. Ibid., 6.

112. Ibid.

113. Ibid., 5.

114. Ibid.

115. Charles Kirkpatrick, *Joint Fires as They Were Meant to Be: V Corps and the 4th Air Support Operations Group During Operation Iraqi Freedom* (Arlington, VA: The Institute of Land Warfare, 2004), 2–3.

Optimizing CAS

The debate over the control of AI and CAS missions is rooted in the defined demarcations between these two mission sets. When describing these two missions, the distinguishing definition relates to the interaction between aircraft and friendly troops. Many different procedural methods are used in warfighting to deconflict friendly troops to avoid fratricide, and air power is not separate from this procedural requirement.[116] As is often the case in air control measures, a procedural line is often established to allow for the safe, effective conduct of operations. The line that generally marks the difference between AI and CAS missions is the fire support coordination line (FSCL). Usually, any missions inside of the FSCL to the position of friendly troops are CAS missions that must be controlled by a FAC. Missions flown beyond the FSCL are generally AI missions that do not require the coordination with friendly troops, unless friendly troops are operating beyond the FSCL such as special forces.[117] It can be seen that the crux of the friction between CAS and AI is not the requirements and definitions of these missions but the placement of the FSCL. The FSCL used to be defined using specific geographic features that were easily identifiable from both the air and ground. The integration of GPS navigation into air and land forces has rendered this method moot. With precise navigation, the FSCL can be set using points of longitude and latitude. The FSCL can, therefore, be defined at a line that marks the range of the organic tube-artillery that a ground commander controls.[118] This is important to define because beyond the range of tube-artillery, a ground commander will not be able to attack targets and, therefore, will not be firing indirect weapons into the same airspace in which friendly aircraft are operating.

The ideal of an FSCL set and defined in advance of friendly troops works well in linear operation battlespaces:

> Linear operations are normally conducted against a deeply arrayed, echeloned enemy force or when the threat to LOCs [line of communications] reduces friendly force freedom of action. In these circumstances, linear operations allow commanders to concentrate and integrate combat power more easily.[119]

The examples given for linear operations are the two World Wars, the Korean War, Operation DESERT STORM and the initial stages of Operation IRAQI FREEDOM. These actions were all major force-on-force high-intensity operations that had definable boundaries between friendly and enemy forces. However, Operation ENDURING FREEDOM did not involve the classic high-intensity operations; the lines between friendly and enemy forces, along with non-combatants, were blurred.

This blurring of the lines is defined as nonlinear operations. In nonlinear operations:

> … forces orient on objectives without geographic reference to adjacent forces. Nonlinear operations typically focus on multiple decisive points and are characterized by noncontiguous operations. Nonlinear operations emphasize simultaneous operations along multiple lines of operations from selected bases.[120]

116. US, Joint Chiefs of Staff, JP 3-09.3, *Joint Tactics, Techniques, and Procedures for CAS,* I-4.

117. USAF, AFDD 2-1.3, *Counterland Operations*, 71.

118. Ibid., 70.

119. Ibid., 65–66.

120. Ibid., 66.

In nonlinear operations, without proper control of joint fires, the potential for fratricide is greatly increased because of the lack of easily identifiable friendly positions. Even before the fall of Baghdad, Operation IRAQI FREEDOM was showing a trend towards nonlinear operations. Operation ENDURING FREEDOM is the epitome of nonlinear operations; the Canadian battle group in Kandahar province continues to operate from many different forward operating bases (FOBs) from which they conduct the fight against the insurgency.[121] Air power, therefore, needs to be responsive to this way of fighting to ensure that it contributes most efficiently and effectively. These nonlinear operations fit the model of hybrid warfare discussed earlier as the face of conflict in the future.

The FSCL is still a valid concept for use in nonlinear operations. However, this line needs to be placed "… where the preponderance of effects on the battlefield shifts from the ground component to the air component. In this way, the FSCL placement maximizes the overall effectiveness of the joint force …. History has shown that placing the FSCL too deep is detrimental to overall joint force effectiveness and may even provide the enemy sanctuary from effective air attack."[122] The purpose of doctrine is to provide forces with a departure point from which it can develop tactics, techniques and procedures (TTP) that best allow weapons to be brought to bear on the enemy. For that reason, doctrine should not be an impediment to carrying the fight to the enemy but should complement it.

While the ideal of the FSCL is sound, it needs to be adapted to the modern dynamic of mobile warfare on a scale not managed before on a battlefield. Using the term FSCL comes with a cultural context that is different depending on which perspective is used—a land or air point of view. A clean break from this parochial view of the FSCL is required, and it can leverage work already done by other environments. The USMC uses the term battlefield coordination line (BCL) as the delineation between AI and CAS missions. The BCL is set to the maximum range of organic artillery and can, therefore, be easily adopted by air forces and land forces alike.[123] The doctrinal debate is important to resolve because it serves as a measure of how best to use air effects to provide kinetic support to land forces. In hybrid warfare, the mixture of high and low intensity warfare requires soldiers to carry the fight to the enemy and stabilize a theatre of operations; it cannot be done with air power alone but as a complement to the lines of operations on the ground.

When examining the direct support that air power can provide a ground commander, the support provided by CAS far outweighs the support afforded by AI. The doctrinal definition of these missions clearly shows this, as does the practical application of CAS on the modern battlefield. This is especially true with the kinetic effects that air power brings to the contemporary fight. It has been "… the success of air power in providing day, night, adverse-weather precision support for ground forces [that] has convinced the [US] Army leadership that it can make its forces more deployable and agile by reducing its own artillery support and relying more heavily on air power."[124] CAS has evolved quickly since the end of the cold war because of the different context in which aircraft would be integrated into joint fires on the battlefield. The lessons from Operations ENDURING FREEDOM and IRAQI FREEDOM solidified the maturity of air power in counter-land CAS missions. This maturity has benefited from new precise weapons, GPS navigation and improved ISR that provides commanders with a better appreciation of the fighting on the ground.

121. The various Canadian battle groups that have operated in Kandahar Province have placed different emphasis on FOBs and patrol bases, but operations by Canadians in Kandahar Province have used FOBs as forward staging bases for fighting the insurgency.

122. USAF, AFDD 2-1.3, *Counterland Operations,* 69.

123. Ibid., 71.

124. Pirnie and others, *Beyond Close Air Support,* 3.

Lessons learned in the employment of CAS have led to the development and use of the concept that CAS can be applied using three varying levels of control from the FAC. The first, Level 1 CAS, is the most restrictive and Level 3 CAS is the least restrictive. The objective is "… to offer the lowest level supported commander … the latitude to determine which type of terminal attack control best accomplishes the mission."[125] Before the maturity of counter-land doctrine and the realization of the increased utility of CAS, there was only one method of delivering CAS effects using FACs that was akin to the contemporary Level 1 CAS.

As mentioned, Level 1 CAS is the most restrictive form of CAS and is used when friendly troops are in close contact with the enemy. In fact, GBU-12 LGBs can be used as close as 200 metres in combat without having to make the additional caveat of "danger close" for the engagement. Declaring "danger close" means that a ground commander is accepting the increased risk of friendly casualties from the explosion of weapons close to the friendly positions. In fact, accepting the risk of 10 per cent friendly casualties, a FAC can control attacks into 75 metres with a GBU-12 LGB, as an example of the faith that ground commanders have in the precision of CAS using guided weapons.[126] FACs use "… Type 1 control when the risk assessment requires them to visually acquire the attacking aircraft and target under attack."[127] Type 1 CAS is the most time consuming because it requires the FAC to pass the target coordinates to the attacking aircraft and then ensure verbally that the aircrew identify, either visually or using targeting systems such as forward looking infra-red (FLIR) pods, both the friendly and target locations. Type 1 CAS is used when the target is closest to friendly troops so the FAC needs to "… ensure the attack will not affect friendlies by visual acquisition and analysis of attack geometry / nose position to determine weapon impact point." Before the "… recent technological advances in aircraft capabilities, weapons systems and munitions …" this method of CAS was the only means available to FACs to attack targets with aircraft.[128]

To cut down on the time to deliver weapons, other methods of controlling CAS assets have been developed. The impetus for developing other CAS TTPs was not solely to reduce the time delay of Type 1 CAS in the kill chain. The employment of UAVs in CAS has made it more difficult for FACs to visually acquire the attacking aircraft because of its small size and quietness; these two attributes are advantageous for attacking forces because the enemy is not aware of an impending attack. Following from Type 1 control, "… Type 2 control [is] used when the [FAC] desires control of individual attacks but assess[es] that either visual acquisition of the attacking aircraft or target at the weapons release is not possible … ."[129] This form of CAS takes advantage of recent technology using "… digital or data link systems capable of displaying aircraft track, sensor point of interest [to] significantly enhance situational awareness that better enable the [FAC] to authorize weapons release … ."[130] This form of control, which has also become associated with systems CAS, is especially interesting because a FAC does not need to be physically with the troops to control the terminal attack. Using data link systems such as ROVER, properly equipped receivers on the ground are able to view streaming video transmitted from an aircraft's targeting pod to ensure that the proper target has been identified. This method of attack can be very efficient and provides very quick attacks on threats to friendly forces.

125. US, Joint Chiefs of Staff, JP 3-09.3, *Joint Tactics, Techniques, and Procedures for CAS*, V-14.

126. Ibid., D-2.

127. Ibid., V-14.

128. Ibid., V-16.

129. Ibid., V-15.

130. Ibid.

The final method for controlling CAS aircraft is Type 3 control. This method of control "… may be used when the tactical risk assessment indicates that CAS attacks impose low risk of fratricide. When commanders authorize Type 3 control, [FACs] grant a 'blanket' weapons release clearance to an aircraft or flight attacking a target … ."[131] While Type 3 control is the least restrictive, it is also the least used because, while the FAC maintains the authority to abort attacks, the FAC does not have as close control over individual attacks by aircraft as they do in the other two control methods.

Kill boxes and keypads—air to ground of the future

CAS control has, therefore, evolved to take advantage of modern technology such as guided weapons, UAVs and ROVER. While these control types have improved the TTPs for counter-land missions directly supporting ground troops, procedural steps have also improved despite the friction generated by defining the placement of the FSCL. The two most important improvements have come from the development of kill boxes and keypad CAS. Kill boxes are a development of Type 3 CAS, with keypad CAS serving as a subset of kill boxes that allow FACs to control aircraft over a greater area of the battlespace. Both of these procedural methods require high situational awareness of the location of friendly forces throughout an area of operation. These new procedures "… focus on effects by implementing design elements specifically put in place to enhance the prioritization and synchronization of joint fires and maneuver to achieve the objectives of the JFC [joint force commander] across the entire theatre."[132] These procedural methods allow for the systematic division of an area of operations without becoming restricted by the location of the FSCL in nonlinear operations.

Kill box and keypad establishment is possible with the precise navigation that GPS affords modern aircraft. Areas of operations can be divided into 30-nautical-mile by 30-nautical-mile (55.6-kilometres by 55.6-kilometres) kill boxes based on the area reference system, which is an "… operational-level administrative measure used to coordinate geographical areas rapidly for battlespace deconfliction and synchronization."[133] The standardized battlespace area reference system is the global area reference system (GARS). GARS uses a "… grid system with a simple, universal identifier recognizable by each component and their associated command and control and attack assets. Three numbers followed by two letters describe a unique 30-minute by 30-minute (55.6-kilometres by 55.6-kilometres) area. … GARS is highly useful in facilitating rapid attacks on TSTs and for expediting deconfliction of friendly force locations … ."[134] A kill box uses these GARS but adds a third dimension in altitude to delineate an area reference for joint fires. When established, "… the primary purpose [of kill boxes] is to allow air assets to conduct interdiction against surface targets without further coordination with the establishing commander and without terminal control."[135] Kill boxes can be further broken down to 10-nautical-mile by 10-nautical-mile (18.5-kilometres by 18.5-kilometres) keypads that provide ground commanders more flexibility in employing aircraft in joint fires. For example, one quadrant of a kill box can be closed to air attack due to the presence of friendly troops, but another quadrant can remain open for air attack that does not require terminal control from a FAC. The flexibility afforded by these procedures capitalizes on the flexibility of air power to rapidly move above a battlespace and deliver air effects in a campaign:

131. Ibid.

132. Jody Jacobs and others, *Enhancing Fires and Maneuver Capability Through Greater Air-Ground Joint Interdependence* (Santa Monica, CA: RAND, 2009), xiii.

133. USAF, AFDD 2-1.3, *Counterland Operations*, 72.

134. Ibid., 73.

135. Ibid., 74.

> A combination of kill box and traditional FSCMs [fire support coordination measures] is possible, such as when a single large advance is made from a classic linear battlefield (such as operations during [Operation IRAQI FREEDOM] OIF). Here the standard FSCL could be used for the slower moving ground forces, and localized JFLCC [joint force land component commander] kill box system could be created in front of, or behind, a rapid advance. This allows for more efficient air attack on non-engaged enemy land forces … especially during non-linear operations.[136]

Kill Boxes can be fully exploited only with the cooperation of both land and air commanders to defeat an enemy's force, whether massed or in small parties, no matter what the nature of the conflict.

The effectiveness of these new coordination procedures hinges on the placement of the dividing line between AI and CAS. A ground commander will want to maximize the size of their AO and make it large enough to employ all of the organic assets under their control. In Operation IRAQI FREEDOM, the JFLCC set the AO for V Corps to "… allow [the] component commander to employ their organic, assigned and supporting systems to the limits of their capabilities."[137] This meant that the ground commander used air power for corps shaping under close control because the FSCL was set at times 100 kilometres beyond friendly troops. While kill boxes were established, they were not often opened because the deep placement of the FSCL did not allow for the flexible use of air power to attrit the adversary's force before coming into contact with friendly troops. In fact, manoeuvres by the US Army on the battlefield on the move to Baghdad did flush out formed units of the Iraqi Army. Kill boxes were opened, and air power was able to attrit enemy forces to the point of rendering them combat ineffective such as the Iraqi 10th Armoured Brigade on 2 April 2003.[138]

From the perspective of the air commander, AI is the best method to attack an adversary beyond the range of ground joint fires. However, the fact that air commanders do not want to "… integrate [themselves too] deeply with ground operations likely reflects a culture wary of jeopardizing its independence—and of relinquishing its newly realized capacity to be decisive in theatre-level counter-land operations."[139] From the view of an air commander, the only way that air power will be able to truly exploit the range and speed of aircraft above a battlespace will be through the use of AI missions to exploit the "… operational opportunities created by enemy forces uncovering themselves in reaction to ground maneuver."[140]

It is this last theme, the engagement of enemy forces reacting to the movement of friendly troops, which is the key to the increased cooperation between joint commanders in the pursuit of victory on the battlefield. Doctrine needs to evolve to become truly joint and exploit the unique capabilities that different services bring with them. At times, a ground commander may be supported by air power providing joint fires in CAS; conversely, an air commander may be a supported commander with friendly ground forces manoeuvring to flush out adversary forces, thereby exposing them to air attack.[141] Friendly troops, such as special forces operating behind enemy lines, can identify targets for attack by aircraft flying AI missions. This real-time update of targets is not CAS because friendly troops are not in contact with the enemy but remain covert; this tactic has been called ground-assisted precision strike and was used with great success in the early stages of

136. Ibid., 77.

137. Jacobs and others, *Enhancing Fires and Maneuver Capability*, 12.

138. Kirkpatrick, *Joint Fires as They Were Meant to Be*, 15.

139. Jacobs and others, *Enhancing Fires and Maneuver Capability*, 16.

140. Ibid.

141. Pirnie and others, *Beyond Close Air Support,* 84–86.

Operation ENDURING FREEDOM. In fact, bomber aircraft such as B-52s and B-1s, which had hitherto been considered strategic bombers, were able to fly these tactical missions with excellent results from their superb on-station time and large payload.[142]

Towards new doctrine for Canada

Doctrine needs to evolve to embrace the opportunities to capitalize on the firepower that air power brings to the joint fires contribution to the attainment of victory on the battlefield, whether it is a high-intensity conflict or a hybrid war insurgency. The dividing line between CAS and AI needs to be set as a compromise between the wishes of a ground commander to shape the battlefield for land operations and the desire of an air commander to allow for the attack of enemy forces without the procedural constraints of CAS. The FSCL can be replaced in entirety with kill boxes and keypads to allow for the exploitation of modern situational awareness and navigational tools:

> In many applications, kill boxes and their subdivisions are a more efficient way to delineate battle space than traditional lines, especially during fast-paced, fluid operations like those envisioned under current programs to transform military forces.[143]

It is not a huge leap of faith to see that the way ahead is to view air support to a ground commander beyond the paradigm of CAS under the restrictions of operating inside a defined FSCL. To this end, air power can be viewed as a complement to ground power as either a supporting or supported partner in joint fires.

There presently exists a golden opportunity for Canadian doctrine to rapidly evolve and establish the framework from which the Canadian Air Force and Army can embark on a new relationship that outlines the modern symbiotic relationship between modern air and ground power. *Canadian Forces Aerospace Doctrine* does not address any issues below the strategic level and, therefore, only gives an overview of the employment of air power in either a supporting or supported role. The closest that Canadian doctrine comes to defining the interaction of air and ground power on the battlefield is in the Canadian Army's *Firepower Doctrine* from 1999 that holds the FSCL, defined by the ground commander, as the demarcation between mission sets for levels of air support.[144] This striking absence of Canadian Forces doctrine, from which TTP will stem, can be corrected with the inclusion of the advancing concepts of how air power can best contribute to joint fires. This air piece into the joint-fires puzzle is not through setting defined lines on the ground, such as FSCLs or BCLs, but in the flexible adoption of kill boxes and keypads.

Embracing this new method of conducting counter-land operations will be a force multiplier for a JFC. The basic concept is very simple; an established grid based on GARS is either defined as a manoeuvre or close-combat box. The former is an area that "… contain[s] no friendly ground forces and would allow air to operate without terminal control, but all strikes would be integrated with the planned ground scheme of maneuver."[145] The later boxes would contain friendly troops, and any contribution by aircraft to the joint fires would need to be controlled by a FAC.[146] This method of dividing an AO into grids maximizes the advantages of network-enabled operations as a command and control tool. The increased situational awareness from network-enabled operations will allow

142. Theisen, *Ground-Aided Precision Strike*, 11.

143. Pirnie and others, *Beyond Close Air Support,* 82.

144. Canada, Department of National Defence, B-GL-300-007/FP-001, *Firepower* (Ottawa, ON: Department of National Defence, 1999), 44.

145. Pirnie and others, *Beyond Close Air Support,* 83.

146. Ibid.

air and ground commanders to share information on the status of their operations to allow for the synchronization of their efforts towards the common goal of success on the field of conflict.

Another mission set that has matured to the point of inclusion in doctrine is the concept of GARS. This mission, as already mentioned, was used with great success in Operation ENDURING FREEDOM. Small units of special forces were deployed into the theatre before the arrival of larger conventional forces. The task of the special forces was to identify targets for air attack; the attacking aircraft did not have the particulars of their targets before launching on the mission and received the coordinates of the targets once identified by special forces. GARS is a simple tactic to employ because standardized attack profiles can be flown against whatever target is identified. The crucial coordination function of target area deconfliction from friendly troops can be accomplished by covert special forces that are sent into the target area by a ground commander for the express purpose of identifying targets according to identified lines of operation in an overall campaign plan. GARS is an excellent way to integrate AI missions into the campaign plan of a JFC without giving up the flexibility of this type of mission.[147]

While AI can be flown into open kill boxes with predetermined targets, GARS shows that these same missions can be flown supported by ground troops against targets of opportunity. These can be attacked by aircraft flying in kill boxes with a list of priority target types. These missions are akin to the armed reconnaissance role that was used with success in the Second World War by the Western Allies in Europe after the Normandy invasion.[148] The danger in these missions is twofold for a JFC. First, the onus for target identification will be on the aircrew to identify valid targets according to the international laws of armed conflict. This is not always easily accomplished, as was witnessed in the cases of civilians being incorrectly identified as Serbian military during some attacks in Operation ALLIED FORCE. Second, these missions will need to be synchronized with the overall objectives of the JFC. Aircrew cannot randomly attack targets but need to hit targets that will contribute to the attrition of the combat power of an adversary before they come into contact with friendly forces. Therefore, a potential modification of the armed reconnaissance role will be to use high endurance UAVs to identify targets for attack once they have been vetted through command and control to ensure target validity, meeting both legal and operational standards for attack.

The above doctrinal changes are well suited to linear operations in high intensity conflicts where air supremacy has been attained. The unimpeded movement of aircraft in counter-land operations needs control of the air to allow for the efficient attack of targets; this is especially true for CAS because aircraft will fly in fairly fixed areas as they prosecute attacks controlled by FACs. However, these counter-land operations and the recommended doctrinal changes do not fit well with nonlinear operations. This is true for AI missions when looking at a hybrid war scenario that has transitioned to stability operations. The initial stages of a hybrid war may allow for AI missions in open kill boxes. However, the more likely use of air power will be in Type 2 CAS using rules of engagement that allow for the attack of vetted targets that are not necessarily attacking friendly troops. For example, streaming video imagery can be used to identify targets that have been vetted for attack. CAS procedures are used to control the attacks to ensure that valid targets are hit; attacking invalid targets in stability operations can translate tactical action into strategic consequences that undermine the mission. The same grid system can be used in linear and nonlinear operations. The only difference in these operations will be to what extent kill boxes are open for AI attack and how many will be closed, thereby requiring terminal control of air power in joint fires.[149]

147. Theisen, *Ground-Aided Precision Strike*, iii.

148. Antony Beevor, *D-Day: The Battle for Normandy* (New York, NY: Viking Books, 2009), 361.

149. Jacobs and others, *Enhancing Fires and Maneuver Capability*, 41–43.

It would be naive to believe that updating Canadian doctrine to replace the FSCL with a GARS-based kill box system for counter-land operations will have a profound impact on American doctrine. The doctrine of the United States needs to be considered because of the influence that the US military has on global operations based on the size of their forces. The US will be the first amongst equals in any coalition operation in the future, and their modus operandi will set the tone for how an operation will be managed and fought. However, Canadian doctrine and TTPs can lean forward to adapt to emerging technologies. With properly equipped and trained forces that are supported by TTPs rooted in emerging doctrine, Canadian expeditionary forces can seamlessly integrate into coalition operations. The opposite is not true because without the proper networked equipment, forces cannot be integrated into the command and control structures of the future. These systems are not unique to expeditionary operations but will also be applied for domestic operations; thereby meeting the requirements of the *Canada First* Defence Strategy.

The Canadian military is at a crossroads when examining the doctrine of counter-land operations. There is no argument that air power has a key role to play in the provision of joint fires to a JFC in the conduct of an operation. The Canadian Air Force has an opportunity to lead the way in assessing how air power can be used in the Canadian Forces to deliver kinetic land effects in operations in the future. This assessment can translate to doctrine that will provide guidance for the acquisition of equipment in the future. This paper has already identified how decisions will need to be made in the near future on how the Canadian Air Force will replace equipment that is nearing the end of its service life. There is an opportunity to acquire equipment that provides the firepower and ISR requirements of joint fires in the future as the lessons from operations of the last decade are included in the doctrine of tomorrow. The next section will, therefore, discuss how this opportunity can be translated into equipment that will best place the Canadian Air Force to deliver air effects in counter-land operations.

6. What now for Canada?

In examining the questions of how the Canadian Air Forces of the future can best accomplish counter-land missions, it is important to focus on the capabilities that are required and not on the specific platforms that would fit these missions. This is important to do because some aircraft are equally able to perform different missions with the same amount of capability. For example, the multirole CF188 is able to excel in both AI and CAS missions, but the current breed of armed UAVs are not capable of conducting AI missions in addition to CAS. The Canadian Air Force is not unique in considering how to structure its force composition as it embarks on a new round of equipment procurement. All of the major Western air forces are absorbing the lessons of Operations ALLIED FORCE, ENDURING FREEDOM and IRAQI FREEDOM to best determine the optimum future force composition to deliver the proper air power effects, at the correct time on the correct target. Fitting future air power into the joint fires equation will ensure that counter-land missions are timely and relevant when they are flown. Timely in that these effects are provided to friendly troops when required, and relevant in that targets struck, especially in the context of AI missions, aid in the synchronized attack of enemy targets.

When examining the Canadian Air Force for the 21st century, it is important to frame the conversation using the *CFDS* as the cornerstone for the evolving structure of the Canadian Air Force. To this end, it will become evident how aircraft that operate domestically in support of the first mission of *CFDS*, the conduct of daily domestic operations and continental operations, will also have the capability to excel at missions that execute the 5th and 6th missions types of *CFDS*, to partake in an international deployment for either a prolonged or short deployment. In the three generic platform types that have been discussed earlier, there is a place in the 21st century Canadian Air Force for a force that includes fighter aircraft, armed UAVs and armed helicopters. A fighter replacement for the CF188 will be capable of providing counter-land kinetic effects across the potential spectrum of operations in the near and far future. An armed UAV is ideally suited to provide persistent ISR in domestic operations but, more importantly in the context of expeditionary operations, is able to provide these same effects coupled with weapons to provide kinetic effects, if required. A gap in the counter-land capabilities of the contemporary Canadian Air Force is a helicopter that is able to sense and shoot.

Breaking down the counter-land mission sets, it becomes clear that only a manned fighter is currently able to fulfil the requirements necessary to fly AI missions in high intensity operations.[150] Undoubtedly, in the future there will be autonomous aircraft that are able to cope with the complex scenarios that are inherent in AI missions. The complexity in AI missions stems from the integration of aircraft working together to provide both support to and protection of aircraft that are striking AI targets. An AI scenario will almost always include pre- and post-attack air-to-air refuelling. Flexible target area deconfliction is required in response to adversary IADS activity. No current open source literature alludes to an unmanned system that could be purchased by the Canadian Air Force in the next half decade.[151] This timeline is important because of the expected retirement of the CF188 starting in 2017. In order to introduce into service the replacement for the CF188, a contract would need to be finalized over the next few years. Therefore, it follows that the replacement for the CF188 will be another manned, multirole fighter that is capable of flying not only NORAD missions but also in deployed, expeditionary operations in either high or low intensity operations.[152]

Both the USAF and Royal Air Force have placed growing emphasis on the provision of UAVs in support of ground operations in Iraq and Afghanistan. In 2006, the USAF released its UAV strategic vision for the next 25 years that calls for the expansion of the UAV fleet to provide increased ISR support to global operations.[153] From the perspective of counter-land operations, it is clear that the USAF has embraced the unique effects that UAVs such as MQ-9 Reapers can provide commanders. The Canadian Air Force has lagged in the fielding of an armed UAV capability. The CU170 Heron that has replaced the CU161 Sperwar is, by far, a more capable ISR platform, but it still lacks the ability to deliver kinetic effects in addition to persistent ISR support to commanders at all levels.

The persistent ISR capability of the CU170 needs to be bolstered by a platform that provides the same level of ISR with the added benefit of precise weapons to provide Type 2 CAS support for deployed forces. The added capability of a platform with more endurance than a manned fighter that is able to deliver either an LGB or GPS guided weapon under the terminal attack control of a FAC is a requirement that the Canadian Air Force should enthusiastically pursue.

The rationale for this is simply because of the cost of these platforms. The MQ-9, the most widespread of the armed UAVs, has a unit cost of $10 million USD. The next generation of manned fighter for the Canadian Air Force will cost upwards of $50 million USD for the F-18 E/F Super Hornet to $80 million USD for the F-35 Lightning II. The Canadian government has indicated in the *Canada First* Defence Strategy that it is planning to purchase 65 next generation fighter

150. Thierry Gongora, *Future Combat Air Operations System: Initial Assessment of Roles and Options* (Ottawa, ON: Department of National Defence, Operational Research Division, 2003), 36.

151. Doyon, "Replacing the CF-18 Hornet?" 35.

152. Ibid., 39–40.

153. USAF, *U.S. Air Force Remotely Piloted Aircraft*, 22–27.

aircraft to replace the CF188.[154] Shying away from the classified war plans of NORAD and Canadian commitments to NATO, a fleet of 65 aircraft does not leave the Canadian Air Force with many aircraft that can be deployed on a major international operation at the same time that the threat levels in Canada require more aircraft dedicated to NORAD missions. This scenario, with an increase in aircraft on NORAD alert, is not unprecedented, as it happened in the aftermath of the terrorist attacks of 11 September 2001.[155] In order to retain an assured deployment capability for expeditionary operations by fighter aircraft, the Canadian Air Force will require more than 65 aircraft to replace the CF188; regardless of the capability of the airframe, it comes down to the number of aircraft committed to NORAD that will dictate the number of internationally deployable aircraft.

The desire to have more manned fighters to fly in international operations also needs to be weighed against the likelihood of platforms being deployed on kinetic expeditionary operations. The governments of Prime Ministers Jean Chrétien, Paul Martin and Stephen Harper have all sent the Canadian Forces into harm's way, but the emerging face of war is not one of high intensity conflict. To draw conclusions about the nature of conflict for the foreseeable future based on the recent conflicts of the major Western powers is fraught with danger; the maxim of preparing to fight the last war comes to mind. But the reality facing the Canadian Air Force is that there is only so much money available for the department as a whole for capital projects such as the next generation fighter aircraft. While the Canadian governments of the 21st century to date have all committed forces to the global war on terrorism, the likelihood that Canadian aircraft will be sent into a conflict that will require them to fly complex AI missions into foreign lands with a robust IADS, as was done in Serbia, is not great. The more likely scenario that Canadian troops will face in the future will be more stability operations in failed or failing states such as in Afghanistan. The CAS support that troops in these theatres of operations will require can be met by armed UAVs that also provide the persistent ISR that is vital to ground commanders.

This is not to say that manned fighters will not be sent into a theatre of operations to fly CAS missions. An interesting scenario would involve manned fighters being guided to their targets based on ISR intelligence gained from a UAV. United States Air Force UAVs can use their laser designators to guide LGBs to their targets; the fighter releases the weapons, and the UAV guides the weapon to the target.[156] The multirole fighter that replaces the CF188 will have the capability to fly AI and CAS missions, but the greater return on investment for the Canadian Air Force to provide CAS support to deployed operations will come from an armed UAV to supplement the CU170 Herons that are providing critical support to the Canadian battle group in Afghanistan. The only option that will remain for the Canadian Air Force to conduct an offensive air campaign into opposed airspace will come from the fighter force, with either CF188s or their replacement.

The remaining capability that needs to be met by the Canadian Air Force of the future is the fielding of an armed helicopter that is able to sense and engage targets. Experience from Afghanistan and Iraq has shown that helicopters are vulnerable to ground fire, as witnessed in the damage sustained by AH-64s in the early stages of Operation ANACONDA and the failed deep strike attack in Iraq on 24 March 2003. Armed helicopters have a unique niche to fill on the contemporary and future battlespaces of escort and screening missions. The Canadian Air Force has recently signed an order for CH147D and CH147F Chinooks. These large helicopters have been and will continue to be used to transport troops and supplies in an AO to decrease the reliance on combat logistics

154. *Canada First* Defence Strategy.

155. Jockel, *Canada in NORAD*, 167.

156. For more on the discussion of the role of armed UAVs in the future, see David Hume, *Integration of Weaponized Unmanned Aircraft into the Air-to-Ground System* (Maxwell AFB, AL: Air University Press, 2007).

patrols (CLPs). A decrease in the number of CLPs required will decrease the exposure of friendly troops to improvised explosive devices (IEDs) that have become among the weapons of choice of insurgents in hybrid warfare. Therefore, when Canadian troops deploy in the future, the force structure will invariably include a CH147 component. It has been recognized that CH147s flying in the AO require an escort because of the identification of CH147s as high pay-off targets for insurgents.[157] The CH146s that are currently deployed to Afghanistan are flying escort and light utility missions as well as the platform allows, but the Griffons are limited in speed to react to threats and in the amount of firepower that they can bring to bear on a target.

A replacement for the CH146 is again dependent on funding like the replacement for the CF188. The Canadian Air Force still has a utility requirement that a Griffon replacement will need to fill, but this replacement should also include an attack capability. An attack helicopter to fly escort missions for CH147s does not require a dedicated airframe such as the AH-1Z or AH-64 but requires a platform armed with guided weapons able to deliver the capability to cruise at a speed in excess of the CH147 with an additional utility capability. This may not be possible with the current specialized airframes that are in production by major Western helicopter companies, but the requirement remains for a replacement for the Griffon to be capable of escorting CH147s in operations.

Escort missions on their own do not constitute a counter-land mission according to accepted doctrine. However, this is an air-to-ground kinetic capability that the Canadian Air Force should strive to attain. Another derivative of this mission is the screening of ground manoeuvre that an armed helicopter can do to great effect. The screening missions that AH-64s flew in the advance to Baghdad are testament to the flexibility of armed helicopters when they are able to operate in concert with ground operations.[158] Their long endurance and ability to rapidly rearm helicopters from forward locations make the AH-64s capable force multipliers for joint fires. A balanced force structure for a future helicopter force should include a platform that is able to provide firepower support in response to friendly troops under attack or in response to ground fire on CH147s that are moving troops and supplies within a future AO.[159]

The deployment of Canadian troops in the global war on terrorism has provided a new focus on counter-land missions within the Canadian Air Force. The experience from 1999's Operation ALLIED FORCE in Serbia showed the value of a fighter force that is able to successfully conduct AI missions into opposed airspace. The collective Western experience from Operations ENDURING FREEDOM and IRAQI FREEDOM have provided signposts for the future of counter-land operations in future conflicts that span from high intensity conflicts to counter-insurgency missions, sometimes within the same AO. The replacement for the CF188 will be capable of flying opposed and unopposed AI and CAS missions concurrently. The requirement to provide persistent ISR capability that can be provided by an armed UAV to supplement manned fighters has also been identified. In any future AO, the Canadian Air Force will be counted on to provide helicopter lift which will require escort that can be best provided by an armed helicopter that can sense and engage targets with guided weapons. For the warfighters in the Canadian Air Force, the future is bright because of the requirement to provide precision air power in joint fires to either provide support to or be supported by ground forces. A force structure, including numbers and specific airframe types, has yet to be determined. What is without debate is that the Canadian Air Force of the future must be equipped to provide the precise joint fires that operations over the last decade have shown are essential.

157. Kupecz, "Escort for Canada's *Chinook* Helicopter," 91–92.

158. Gordon and Trainor, *Cobra II*, 352.

159. Kupecz, "Escort for Canada's *Chinook* Helicopter," 95.

7. Conclusion

The evolution of Canadian kinetic air power has been disjointed since the end of the Second World War because of the few occasions that Canadian aircraft have been deployed overseas in conflict to attack an adversary. CF188s flew in 1991's Operation DESERT STORM and 1999's Operation ALLIED FORCE in both DCA and AI roles. These two deployments are the only occasions in the 65 years since the end of the Second World War that Canadian aircraft have employed weapons offensively against targets. CH146s have been deployed to Bosnia and, recently, Afghanistan armed with self-defence weapons, but they have not been employed to offensively strike targets in support of land operations. However, the Canadian Air Force of the future is on the cusp of being able to replace retiring equipment with platforms that are ideally suited to provide precision kinetic support to counter-land operations.

The *Canada First* Defence Strategy has identified the Canadian government's intention to be active internationally to protect Canadian sovereignty and interests both at home and abroad. Specifically, the commitment to conduct major international operations for an extended time or to react to specific world events with shorter operational deployments highlights the requirement for the Canadian Air Force to arm itself with equipment and doctrine that exploits the technological advances in air power to provide an air contribution to joint fires. This ability to fly counter-land missions in either a supporting or supported role is a departure from the hitherto traditional role of the branches of the Canadian Air Force equipped with aircraft capable of flying counter-land operations.

After the Second World War, the main effort of the Canadian fighter force was put towards providing an AI or strike capability in Europe flying in support of NATO. The aircraft that were employed in central Europe were not well suited to providing synchronized support to land operations because of their manoeuvrability, range or armament. This changed with the introduction of the CF188 Hornet and the gradual inclusion of CAS as a capability that the fighter force delivered.

All of this was happening against the backdrop of a culture within Western air forces that asserted its collective independence from land forces. This assertion of independence was born of the belief that air power in its own right held the keys to success in modern conflict through the ability to strike at the core of an adversary's fighting capability. The bombing campaign that served as the opening stages of Operation DESERT STORM and NATO's air campaign against Serbia in Operation ALLIED FORCE highlighted the technological advances that had occurred in guided weapons that allowed for the more efficient striking of identified targets crucial to an adversary's war effort, spanning from command and control nodes to transportation infrastructure that facilitated the supply of fielded forces. Culturally, the Canadian fighter force grew apart from the Canadian Army after the success of these two operations; Canadian participation in AI missions in these two conflicts were seen as validation of the promotion of the emphasis of AI over CAS as Canada's counter-land capability.

This culture of Air Force kinetic operations separate from the synchronization of missions to support joint fires has been a contributing factor to the lack of CF188 deployment to Afghanistan in support of Canada's contribution to the global war on terrorism. This fact has led to a reassessment of the relevance of Canadian Air Force support to counter-land operations. However, the experience of the Canadian Army in Afghanistan has shown the relevance of air power in joint fires when combined with the overall lessons learned from Operations ENDURING FREEDOM and IRAQI FREEDOM. Additionally, the trend to persistent air power capable of providing precise kinetic support to joint fires gives more credence for the call for Canada's Air Force to evolve doctrinally with new equipment that is able to provide timely kinetic air power in future deployments by Canadian troops.

The Canadian Air Force has an opportunity to capitalize on the lessons and trends from the conflicts of the last 10 years to diversify the number of deployable platforms available to provide counter-land support to deployed operations. These same deployable platforms, such as an armed UAV and the manned fighter replacement for the CF188, can also fly in operations in North America to defend Canadian sovereignty. A multirole helicopter that is able to provide a transport capability while having the modular ability to include a sense-and-shoot capacity is sorely needed in the future Canadian Air Force to balance the helicopter fleet that is deployable for global operations. The evolution of counter-land doctrine to embrace the advances in modern technology in the Canadian Air Force is required to set the framework from which the requirements for these modern, multirole aircraft can be acquired and deployed in support of future Canadian expeditionary operations.

The intent of this paper has been to discuss the evolution of the ability of the Canadian Air Force to provide kinetic support to land operations. This capability is rapidly evolving to embrace the technological advances witnessed since the end of the cold war. Future weapons systems need to be purchased to maximize the capability of the Canadian Air Force to provide timely and accurate kinetic support to joint fires. The future of kinetic air power in the Canadian Air Force cannot merely be viewed as providing aerial firepower to land operations. Modern conflict requires the synchronized operations of all environments in order to collectively succeed on the battlefield. The Canadian Air Force is on the cusp of capitalizing on the shared realization of the power of synchronized efforts in counter-land operations to best prepare the force structure for the challenges and demands of future battlespaces. The kinetic capability of the Canadian Air Force needs to be examined with a view of deploying a balanced force of fixed-wing, rotary-wing and unmanned vehicles capable of delivering accurate firepower in both pre-planned and reactive counter-land missions. This force structure will provide the greatest impact to joint fires from the Canadian Air Force.

Abbreviations

10 TAG	10 Tactical Air Group
AFDD	Air Force Doctrine Document
AI	air interdiction
AO	area of operations
BCL	battlefield coordination line
CAS	close air support
CCA	close combat attack
CFDS	*Canada First* Defence Strategy
CLP	combat logistics patrol
DCA	defensive counter-air

FAC	forward air controller
FOB	forward operating base
FSCL	fire support coordination line
GARS	global area reference system
GPS	global positioning system
GWOT	global war on terrorism
IADS	integrated air defence system
IDF	Israeli Defence Force
ISR	intelligence, surveillance and reconnaissance
JFC	joint force commander
JFLCC	joint force land component commander
JP	Joint Publication
LFDTS	Land Force Doctrine and Training Systems
LGB	laser-guided bomb
NATO	North Atlantic Treaty Organization
NORAD	North American Aerospace Defence Command
RCAF	Royal Canadian Air Force
ROVER	remotely-operated, video-enhanced receiver
SAM	surface-to-air guided missile
TAC	tactical air command
TACP	tactical air control party
TTP	tactics, techniques and procedures
TRADOC	Training and Doctrine Command
TST	time-sensitive targeting
UAV	unmanned aerial vehicle
UN	United Nations
US	United States
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy