F-35 and the Future of Canadian Security

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EXECUTIVE SUMMARY

Canada's participation in the Joint Strike Fighter project has been fraught with much controversy and a lack of clarity. This study aims to assess how the F-35 meets Canadian defence requirements over the next few decades. It concludes:

- The global balance of power is currently shifting towards greater multipolarity, with a growing rivalry between a tier of rising new powers and established powers;
- Demographic, economic and political shifts in Western states may push the calculus of intervention towards aerial campaigns rather than ground invasions with large, manpower intensive armies;
- The international proliferation of highly effective air-to-air and ground-to-air systems pose a major threat to current generation fighters;
- Canada possesses several unique considerations involving northern defence, including long range capability, good reliability and an advanced sensor package.

The F-35 capabilities are an important response to these trends:

- The low observable features and avionics will enable the F-35 to operate in contested airspace denied to earlier generations of aircraft;
- Its avionics are essential to integrate into on-going networking trends and ensuring long-term affordability and viability;
- The F-35 should greatly enhance Canada's ability to perform its northern sovereignty operations, without risking pilot safety;
- Interoperability with the United States and other partners will vastly increase the effectiveness of Canada's F-35 fleet and maintain long-term affordability;
- The projected F-35 fleet size and aircraft serviceability are sufficient to maintain and even improve the capability of the Royal Canadian Air Force.

Several risks remain however, that must be acknowledged:

- Although the F-35 aircraft should meet the projected acquisition cost set out in the 2010 estimates, there is little flexibility left in the budget for further increases;
- The sequestration process set out in the United States Budget Control Act 2011 represents a major threat to the affordability of the F-35;
- The F-35's sustainment and logistical systems are in their infancy, and their development will be critical in determining operations and maintenance costs.

Based on these recommendations the government of Canada should:

- Remain engaged as a partner in the JSF program and continue to participate in its development;
- Closely observe and consider the fighter's progress in order to better inform its final decision to purchase the fighter after 2016;
- Ensure that the unique features of the F-35 operation are fully understood by all levels of government and implemented properly if purchased.

SOMMAIRE

La participation du Canada au projet d'avion d'attaque interarmées (JSF) s'est heurtée à de nombreuses controverses et d'un manque de clarté. Cette étude vise à évaluer la façon dont l'aéronef F-35 répond aux exigences canadiennes en matière de défense au cours des prochaines décennies. Il conclut:

- L'équilibre global du pouvoir se déplace actuellement vers une plus grande multipolarité, avec une rivalité croissante entre des pouvoirs nouveaux et des pouvoirs établis;
- Les changements démographiques, économiques et politiques dans les pays occidentaux pourrait pousser le calcul de l'intervention en faveur des campagnes aériennes plutôt que les invasions terrestres qui nécessitent d'équipement et de personnel considérable;
- La prolifération internationale des systèmes efficaces de air-air et sol-air constituent une menace majeure pour les chasseurs de la génération actuelle;
- Le Canada possède plusieurs considérations particulières concernant la défense de ces territoires du Nord, y compris la nécessité d'une bonne fiabilité, un rayon d'action à longue distance, et un ensemble de capteurs de pointe.

Les capacités du F-35 sont une réponse importante à ces tendances:

- La possession de capacités de furtivité et les avioniques permettra le F-35 a fonctionner dans l'espace aérien contesté, refusé aux générations précédentes de l'aéronef;
- Ces avioniques sont essentiels à l'intégration dans la direction des tendances actuelles de réseautage et d'assurer l'abordabilité et la viabilité à long terme;
- Le F-35 devrait améliorer considérablement la capacité du Canada d'exécuter ses opérations de souveraineté dans le Nord, sans risquer la sécurité des pilotes;
- L'interopérabilité avec les États-Unis et d'autres partenaires augmentera considérablement l'efficacité du flotte canadienne de F-35 et de maintenir l'abordabilité à long terme;
- La taille projetée du flotte de F-35 et du fonctionnement des aéronefs sont suffisants pour maintenir et même améliorer la capacité de l'Aviation royale canadienne.

Cependant il y a plusieurs risques qui restent et qui doit être reconnu:

- Bien que l'aéronef F-35 devrait faire face au coût d'acquisition projetée énoncées dans les estimations de 2010, il y a peu de souplesse laissée dans le budget pour des augmentations supplémentaires;
- Le processus de séquestration énoncées dans la Loi du contrôle budgétaire des Etats-Unis 2011 représente une menace majeure pour l'abordabilité du F-35;
- Les systèmes de soutien et de logistiques du F-35 sont encore à leurs débuts et leur développement sera cruciale dans la détermination des coûts d'exploitation et d'entretien.

Sur la base de ces recommandations, le gouvernement du Canada devrait:

- Rester engagé en tant que partenaire dans le programme JSF et de continuer à participer à son développement;
- Observer de près et évaluer les progrès du chasseur afin de mieux informer sa décision finale d'acheter le chasseur après 2016;
- S'assurer que les caractéristiques uniques de l'opération des F-35 sont bien compris par tous les niveaux du gouvernement et mis en œuvre correctement si ils sont achetés.

Introduction

As Canada enters into the second decade of the 21st century, its strategic situation has become increasingly uncertain. While the bedrock of its security, the Canadian-American alliance, is on solid ground, the country's position in the world has shifted significantly. Much of the instability that has punctuated the Post-Cold War period remains, particularly within the Middle East and Central Asia. This, combined with the rise of the so-called BRIC states (Brazil, Russia, India and China) and others, has complicated Canada's relations in a number of regions. Nowhere is this clearer than in the Arctic, where the Russian Federation has asserted territorial claims encroaching on Canada's traditional sphere of influence.

In the face of these uncertainties, the Canadian Forces must also manage a large capital transition of its armed forces, during a period of global economic weakness and fiscal austerity. A number of its core capabilities purchased in the 1980s are reaching the end of their usable service life and require replacement (Huebert 2011, 229; McDonald 2003, 13). Furthermore, several newer systems were utilized at higher than anticipated rates in Afghanistan and require refurbishment or replacement. The shifting strategic situation has also brought with it the need for new capabilities, such as those for arctic security.

Consequently, the Government of Canada has launched several major capital programs that have a combined value of over $30 billion dollars over the next decade. This includes the Arctic Offshore Patrol Ship, the Fixed Wing Search and Rescue aircraft, and the Tactical Armored Personnel Vehicle program. Yet none of these projects have received the level of public scrutiny as the selection of the Lockheed Martin Joint Strike Fighter to replace the CF-18. The program's unique features and $9 billion dollar initial cost has led a number of commentators to question the actual suitability of the F-35 for the Canadian Forces.

This study will assess how the F-35 addresses Canada's defence requirements. The first section will examine the project's origins, including background information on low observable technologies. Section two will identify the strategic and operational features of the emerging threat environment. The remaining sections will discuss how the F-35 will addresses those challenges both domestically and abroad.

Lightweight Fighters and the "Stealth" Revolution

During the late 1950s and 1960s, the Soviet Union launched an extensive surface-to-air missile (SAM) development effort. While used to good effect during the Vietnam War, they emerged as a near decisive weapon during the 1973 Yom Kippur War. In that conflict they downed approximately 15% to 25% percent of the Israeli pre-war air force and mitigated their ability to influence ground operations (Nordeen 2010, 143). By the end of the 1970s, The Soviet Union fielded a variety of lethal systems that could challenge Western air dominance over Europe as they had over Israel. In response, the Lockheed Corporation undertook pioneering work that resulted in the development of the first true low-observable aircraft, the F-117 Nighthawk (Rich 2003, 17). The Nighthawk's unique shape greatly diminished its detection range by radars, but at a very high cost. The F-117 effectiveness was also magnified by the increasing use of precision-guided munitions. A single bomber equipped with laser-guided bombs could complete missions that previously required hundreds of aircraft. The ease at which they bypassed Iraq's vaunted Soviet-supplied air-defence network and destroyed key targets during the Gulf War convinced many in the Air Force of the value of low observable aircraft (Shultz, Pfaltzgraff 2002, 28).

In spite of the F-117's impressive performance, its revolutionary technology was adopted sparingly. Declining defence spending after the Cold War slowed the Pentagon's aircraft acquisition. Moreover, the complexity and cost of low-observable aircraft became painfully obvious during the Navy's A-12 program in the early 1990s. The program attempted to incorporate a number of revolutionary technologies, which resulted in major cost overruns, performance downgrades and eventual cancellation (Stevenson 2001). This colossal failure pushed the Navy to develop a low-risk derivative of the Hornet, the F/A-18E/F Super Hornet. Although initially criticized for mediocre performance, the Super Hornet became the USN's primary multi-role fighter. The USAF, without the cautionary experience of the A-12, pressed ahead with a revolutionary replacement of the F-15 Eagle. The Lockheed Martin F-22 Raptor incorporated high performance with stealth capabilities and advanced sensor systems. Mirroring the A-12, many of the fighter's technologies were immature and proved difficult to implement (Younossi et al. 2008). The F-22's high unit cost and other technical issues led to only 184 aircraft being produced, from the 750 originally projected in 1990.

As the 1990s progressed, both the USN and the USAF faced a looming procurement crisis surrounding its lightweight tactical fighter aircraft. The first generation of F-16s and F/A-18s were reaching 20 years of service and would require replacement within a decade. They were originally devised as lightweight fighters that could successfully combat superior numbers of cheap and manoeuvrable Soviet aircraft. It resulted in a generation of manoeuvrable aircraft equipped with less capable avionics, but could be bought in greater quantities (Stevenson 1993, 107). The F-16A and F/A-18A were also adapted into tactical strike aircraft and performed remarkably well in these roles, becoming the core of the US military's air power.[1] The Marine Corps faced a similar prospect with the AV-8 Harrier, a short takeoff and vertical landing (STOVL) multi-role aircraft. In 1994 the Department of Defense combined the services' separate requirements into a single program, known as the Joint Strike Fighter (JSF). Lockheed Martin would eventually win the tender for this program in October 2001, resulting in the F-35 Lightning II.

The Emerging Strategic and Operational Environment

The development of the JSF reflected the accumulated experiences of American and NATO militaries during the 1990s, best represented by Operation Allied Force over Kosovo in 1999. The NATO-led intervention was intended to coerce Serbia to halt its brutal occupation of its breakaway province. The Serbian operation was not based on a pressing security threat, but on moral considerations concerning ethnic cleansing. Consequently, there was a hesitance among Western public opinion towards actually deploying land forces (Everts 2002, 173). Serbia adopted an asymmetric strategy that avoided direct confrontation with Western air forces in order to husband its limited air defence capabilities. Their systems were only utilized when reasonably assured of a successful interception. Serbia anticipated that by drawing out the campaign and inflicting a constant stream of casualties, they could sap public opinion among coalition countries. This included a media campaign that highlighted the loss of an F-117 and an F-16 to air defences and civilian casualties from air strikes. Although Serbia was ultimately unsuccessful, others might seek to emulate its strategy on account of the great disparity in military capabilities between the West and most countries.

This approach is not unfamiliar in the post-WWII era. A number of combatants have attempted attrition-based strategies in the face of overwhelming inferiority. The most prominent case was the Vietnam War, where the North Vietnamese Air Force faced technical and numerical dominance by the United States and subsequently adopted such a strategy. They adopted similar asymmetric tactics in order to attrit American capabilities. Launchers were frequently relocated among a number of prepared sites or in areas known to be off limits for bombing, and targeting radars were only utilized at the last possible moment to minimize the possibility of suppression (Thompson 2000, 105). Consequently, the US military was unable to eliminate the SAM threat for the entire war and could only minimize its efficacy.

The wars in Afghanistan and Iraq after the September 11th attacks marked a major break from the predominant strategy of the 1990s. Airpower shifted in focus from the sole military instrument in a conflict to a complementary one in support of ground troops. Nevertheless, operations had some significant consequences for the future. One of the key aspects was the greater network integration among the constituent parts of American military power, including air-power. This included the proliferation of reconnaissance capabilities, which Benjamin Lambeth (2005) described as near revolutionary:

1 For the purposes of this article, strike refers to all conventional ground to air attacks, rather than the Canadian convention of referring to nuclear weapons employment.

> Throughout Enduring Freedom, persistent [intelligence, surveillance and reconnaissance assets] and precision attack gave CENTCOM the ability to deny the enemy a sanctuary both day and night. Such network-centric operations are now the cutting edge of an ongoing paradigm shift in American combat style that may be of greater potential than was the introduction of the tank at the beginning of the 20th century.

The practical results of this shift have altered how commanders and pilots perceive and control the battlefield (Alberts, Garstka and Stein 1999). Planning cycles that were once measured in days now occur in minutes, as the ability of American forces to locate, identify, track and prosecute targets has increased dramatically. Aircraft over Afghanistan are often re-tasked to strike at newly identified targets of opportunity. This is not simply due to the increase of deployed sensor platforms, but also the inclusion of new analysis tools that better organize sensor data (Drew 2010). Sensor proliferation and networking has also assisted in avoiding negative outcomes, like friendly fire or civilians casualties. The development of versatile precision-guided munitions, like the GPS-guided GBU-38 JDAM, further leveraged these benefits. They are highly reliable and accurate, which means fewer aircraft are required to ensure a successful strike with a lower risk of collateral damage

Without the benefit of these systems, earlier strike aircraft were limited in their flexibility and responsiveness. Aircraft were tasked with specific missions before each flight and could not easily deviate from them. The F-117 stealth bomber epitomized this approach. Apart from its bomb-aiming instrumentation, the Nighthawk possessed rudimentary sensor and networking systems. Each sortie, therefore, had a fixed flight plan to maximize the efficacy of its radar dampening design, thus making it inflexible to new threats or opportunities (Rich 1993, 95). Serbian air defences took advantage of this vulnerability by identifying the ingress paths of the F-117 and relocating their missile launchers accordingly (Sweetman 2008). After several attempts they successfully downed one of the aircraft on March 27, 1999.

Multi-role fighters like the F-16 and F/A-18 have undergone significant avionics upgrades to better integrate them into the developing battlefield networks. This allowed them to play an invaluable role over Iraq and Afghanistan, providing critical close air support for coalition troops on the ground. However, the upgrades have been accomplished piecemeal and are limited in capability. Pilots remain largely responsible for sorting through sensor data to determine a course of action. Given the fighters' age and design, it is difficult and costly to upgrade these fighters with such capabilities.

The network revolution also witnessed the burgeoning use of Unmanned Aerial Vehicles (UAVs) in operations. These systems often provided vital and timely intelligence data that enabled effective precision strikes. They also possess several advantages over manned systems, including persistence over a target area and affordability. Medium Altitude UAVs like the MQ-9 Predator can loiter over a target area for over eight hours, compared with two hours for a manned fighter. Unfortunately the conflicts also made the limitations of these systems extremely evident. UAVs experienced relatively high accident and loss rates, at least twice to three times that of conventional aircraft (USAF 2009). The high attrition and maintenance needs have meant that predicted cost savings have not been realized. Furthermore, until a number of contributing technologies are significantly improved in sensors and situational awareness, the utility and flexibility of armed UAVs will be limited. None of the systems projected to enter service in the next 20 years will be able to undertake air superiority or a full range of air to ground missions (Schogol 2012). Consequently the USAF only plans to increase its UAV inventory by 200 units in the next ten years, compared to over 500 F-35s during that same period (OSD 2012).

Since 2006, the Kosovo air campaign model has re-emerged as a viable military response to some international crises. The so-called Vietnam syndrome towards deploying large forces to meet foreign policy crises seems to have remerged after the difficult experiences in Iraq and Afghanistan. Western populations in the future may not be so willing to put large numbers of troops at risk without an existential threat. This may force a return to airpower as a surrogate for a conventional military intervention. Two examples are the American unmanned aerial vehicle campaign in the Federally Administered Tribal Areas of Pakistan and the 2011 intervention over Libya. In both cases, the West refused to deploy a ground military presence and utilized airpower as the primary means to achieve its objectives. Libya also illustrated another growing trend in Western operations: devolving responsibility to regional security frameworks. Although the United States initially led the military operation against the Qaddafi regime, it largely withdrew from frontline combat by the end of the first month. Subsequently, its NATO allies and other EU states provided the vast majority of the operational sorties. The possibility of coalitions of the willing where the United States plays a secondary role may become more prevalent as it executes its so-called strategic "pivot," or reorientation, towards Asia. European states may become increasingly responsible for military operations within its security sphere. This was one of the primary rationales behind the creation of the European Security and Defense Policy in 1998 and successive efforts to enhance interoperability among member states (Rutten 2001).

In addition to shifts in public opinion and the threat environment, demographic and economic developments may encourage the greater use of airpower in the future. With the "graying" of Western states' populations, greater fiscal austerity and changing budget priorities, policymakers may shift their considerations on interventions (Haas 2007, vol. 32). Entitlement spending related to both active duty and retired personnel will take up an increasing proportion of the defence budget, making the maintenance of a large, manpower-intensive army unsustainable over the long term. Already the US Army has faced a disproportionate level of cutbacks compared to the other services, with 20% of its brigade combat teams to be eliminated (Brannen, 2012). Airpower can offer an attractive alternative to deploying and sustaining a large invasion force in a foreign country, which may be politically or financially unfeasible within a certain context.

Tactical Threats and Responses

Realistically, any future employment of airpower will likely face a number of challenges. Since 1990, The Russian Federation, China and several other states have developed a number of capabilities to challenge Western air dominance. The comprehensive nature of Beijing's systems is commonly referred to as part of an "anti-access/area-denial" strategy. It seeks to restrict or deny access to "land, sea and air spaces along China's periphery, including the western Pacific" (OSD 2011). Although a direct conflict with any one of these nations is exceedingly unlikely, these systems are being exported to their client states around the world. They pose a challenge to the West's ability to undertake operations against some opponents. Modern fourth generation aircraft like the Su-27 Flanker family (including the Su-30 and 35) have become increasingly prevalent among countries not aligned with the West, including Venezuela, Iran and Syria. The Flanker was designed in the 1980s as a heavy air superiority fighter and has been continually updated since. Furthermore, both China and the Russian Federation have also launched their own "fifth generation" programs, the J-20 and Pak-FA, respectively. These new capabilities pose a lethal threat to 4th Generation fighters like the CF-18.

The F-35 is considered to be an important response to the threat these aircraft pose. While it does not possess the speed, manoeuvrability and range of the F-22, the JSF should nonetheless be a lethal air-to-air fighter. The F-35's aerodynamic performance is roughly equal to that of an F-16 or an F/A-18 carrying an equivalent air superiority loadout (Majumar 2011). All three aircraft excel in the transonic flight envelope, or speeds between 0.5 to 1.2 Mach, where the majority of air-to-air engagements occur. However, unlike the Falcon and the Hornet the F-35's low-observable design and advanced avionics offer it superior situational awareness and decision-making abilities. An F-35 should "see" an adversary with its sensors and data-sharing capabilities well before it is itself detected and determine where and how an engagement will occur.

The development and proliferation of next generation Russian SAMs, such as the S-300 and S-400 families, has become a particular concern for the operational capability of existing generations of fighter aircraft. It is one of the few areas where national investment has remained high (IISS 2012, 190). SAMs are comparatively cheaper to field than aircraft and require less training and infrastructure to operate. These strategic air defence systems are highly mobile and are noted for their long range and lethality (Gunzinger 2010, 22). They are well adapted to shoot and scoot tactics that would be central to any asymmetric strategy. Their long-range kill capability also presents a serious challenge for support aircraft that have long facilitated Western air superiority, such as early warning AWACS and non-stealthy jamming aircraft. In addition, SAMs are easily upgraded throughout their service life, retaining their lethality for decades. Modern Russian SAMs have been widely exported across the second and third world, including Algeria, Belarus, China, North Korea, Syria, Venezuela and Vietnam (IISS 2012). They are also integrated in all major Russian Navy surface combatants, which regularly operate in northern waters. Considering their proliferation, there is a significant probability that Western forces may face the threat these systems pose in the future.

The F-35's low observable technology diminishes the effectiveness of these systems, but they should not be considered a panacea; the Russian Federation and others have invested considerable resources into improving their detection systems against low observable technologies. Thus F-35s are unlikely to operate virtually unchallenged by integrated air defence networks like the F-117 did during the Gulf War. Instead, an aircraft equipped with low observable technologies will reduce the range and efficacy of the adversaries' detection systems compared with unequipped counterparts. This reduces the constraints on their operations, while increasing the efficacy of friendly electronic countermeasures. No other major Western tactical fighter, save for the F-22, possesses the same level of signature reduction. For example, the F/A-18E Super Hornet only possesses a few low observable features, limiting its survivability against modern air-defence networks (Mitchell 2010, 34). Similarly the Eurofighter's low observable features are only viable in a narrow forward aspect without carrying stores, thus severely limiting its operational utility.

Furthermore, the F-35's survivability is not completely dependent on its low-observable features. Rather it is one of several systems intended to work together to allow it to operate in a non-permissive environment. According to the *Center for Strategic and Budgetary Assessments,* the F-35's sensors and avionics enhance the fighter's survivability in several ways:

> The sensor suite "gives the F-35 an ability to adjust its flight path in real time in response to pop-up threats, something neither the F-117 nor the B-2 have been able to do."
>
> The F-35's AESA radar can be used to electronically attack enemy air defences either through jamming or digital radio frequency memory.
>
> The networking capabilities enable F-35s and F-22s to operate in teams that can conduct effective suppression of air defence operations (Watts 2011, 25).

All of these systems operate together to manage the F-35's signature profile in a synergistic fashion. It creates unprecedented flexibility, offering a pilot multiple courses of action to different tactical situations that are not available in other fighters. This should enable the F-35 to retain its operational effectiveness for several decades.

The F-35's avionics also represents a major advance in on-going network integration efforts. The key system is the *Multifunction Advanced Data Link* (MADL), which can create a low probability of intercept battlefield network between similarly equipped aircraft. MADL allows the F-35 to share its on-board tactical information and target data with other aircraft, creating a small, decentralized network in the air. The fighter will not simply be a "consumer" of data, as it possesses a highly advanced set of sensors and processing capabilities. The Northrop Grumman AN/APG-81 radar is among the most advanced currently available, and can detect track and identify air and ground targets at extremely long ranges. In addition, *Electro-Optical Targeting System* and the *Distributed Aperture System* (DAS) provides passive optical and infra-red capabilities in all weather conditions, and is able to identify a human-sized object over 50 km away (BBC 2010). The DAS also assists a pilot's situational awareness by displaying a 360-degree panoramic view in the helmet visor, allowing for an unimpeded view outside. Enabling all of these functions is the F-35's computer core. It can process large volumes of information from onboard and off-board sensors to provide pilots enhanced awareness (Laird 2011b). Furthermore the computers are viewed as essential for future growth, as they will allow the partners to integrate new technologies and functions into the aircraft throughout its lifecycle.

Most competing systems do not possess the same range of sensor and networked capability. The Dassault Rafale's RBE-2/SPECTRA suite approaches the F-35's functionality, but its older communication backbone and lack of a helmet-mounted display (HMD) are significant limitations (Swiss Air Force, 2009, 1). Similarly the F/A-18E/F possesses an advanced radar, HMD and advanced computing capabilities, but is without the advantages of the MADL or DAS system. Furthermore, most fighter aircraft are at least a decade into their operational lifecycles, and are unlikely to see many more costly upgrades to their avionics systems.

Unfortunately these capabilities do come at a high cost and significant risk. Between 2001 and 2010 the project witnessed a 50% program cost increase over its 2001 baseline and a delay in introduction by eight years. The problems could be attributed to several factors, including unrealistic cost and schedule estimates and unexpected technological difficulties (Blickstein et al. 2011, 58). Despite these problems, the Pentagon only made very modest cuts to the program. Instead it delayed purchasing early pre-production aircraft and used some of the cost savings to cover the development program overruns. This was part of a larger restructuring that saw the project milestones pushed back in order to give more realistic development timelines (Van Buren and Venlet 2011, 4). While the program has generally met its milestones since then, moderate risk remains with ensuring all programming is completed by 2016 (Kendall, Van Buren and Venlet 2012, 10).

The delays have forced the US military and partner nations' air forces to extend the life of their current tactical aircraft assets beyond their original timelines. Several governments' made their purchases based on fairly fixed budget assumptions and were forced to delay their purchases until the aircraft's per-unit price declined to an affordable level. Canada, for example, pushed the bulk of their purchases to after 2019. These cost increases have also forced other states to curtail their total expected purchases. This trend has been most apparent among European customers implementing severe austerity measures, such as the United Kingdom, the Netherlands and Italy. Further price increases will likely cause additional cuts to orders, both in Canada and among other partners.

Further cost increases and risk still remains however, because of the Budget Control Act 2011 (BCA). It outlines a series of automatic budget cuts (sequestration), which were triggered due to the failure of the bipartisan super committee to reach a debt reduction deal. BCA 2011 will automatically cut 15% from every defence program in the 2013 Financial Year, which could cause significant delays in delivery and increase per-unit costs of the F-35 program (Brookings 2012). Furthermore, the DoD's previous strategy of delaying preproduction aircraft to cover cost overruns is unavailable under current law. The JSF's R&D and pre-production programs exist as separate budget lines, which prevents the Pentagon from shifting funds under the sequester language. Moreover, the JSF Program Office already implemented this policy as part of its 2010 restructuring, and it is questionable whether a second such cut will produce the required savings. However, it should be noted that there is a significant likelihood that aspects of the BCA 2012 will be altered due to the inflexible and indiscriminate nature of the sequestration process. A number of senior military and political officials have indicated their desire to protect the Pentagon's and the F-35's budget by finding cost savings elsewhere (Scicchitano and Kessler 2012; Panetta 2012).

The F-35 and Canadian Defence Policy

The Government of Canada's decision to acquire the F-35 rested on two pillars. While understated, expeditionary operations reflected the primary rationale for the F-35's procurement. Since 1990, Canada has participated in four major coalition air operations: 1991 Gulf War; 1996~1999 Operation Deliberate Guard, and 1999 Operation Allied Force in Kosovo; and 2011 Unified Protector over Libya. These operations often retain significant public support, as compared with more direct forms of military intervention (Martin and Fortmann 2001, 50; Ipsos 2011). The 2005 Defence Policy Statement written under a Liberal government specifically called upon the Canadian Forces to prepare for another Kosovo-like intervention, as well as maintain a high degree of interoperability with its allies (Government of Canada 2005, 28).

The subsequent Conservative government reaffirmed these requirements in their Canada First Defence Strategy (Government of Canada 2008, 17). The direction given by the document, along with Canada's obligations to NATO and NORAD, and an assessment of the future international environment, provided the foundation for the development of the project's requirements (Anonymous 2012b). An analysis of the aircraft available found that the JSF was the only option that met those criteria and could operate successfully in this future threat environment (Office of the Auditor General 2012, 22). If the question is framed as what type of violence or political effects can a capability provide (Fergusson 2012, 206), then it can be said that the F-35 offers policymakers the greatest flexibility and utility of all the possible options for the longest operational lifetime.

The second rationale for the JSF's purchase is to defend "the sovereignty of Canadian airspace", as stated in the Canada First Defence Strategy and as part of Canada's NORAD commitment. Subsequent statements by the Conservative government have affirmed this view, frequently pointing to defending Canada's northern approaches as a key mission for the new fighter (Duggan 2010). The JSF's ability to fulfil this role has become a point of contention. Among the most criticized aspect is the fact that the F-35 is a single engine plane, which some claim to be less reliable than a twin-engine fighter like the CF-18 (Byers, Webb 2010, 221). The expressed fear is that a single engine fighter is more vulnerable to engine failure, which may force a pilot to bail out over harsh arctic landscape.

Yet evidence suggests a far more mixed picture. Single engine fighters tend to require less engine maintenance, are more fuel efficient and cheaper to maintain. In comparison, the redundancy of twin engines possesses several major advantages from an operational standpoint. Historically, twin engines tend to suffer one-fourth the catastrophic engine mishaps as the single engine aircraft (Air Force Safety Centre, 2011). This has important operational consequences as well. Due to the perceived vulnerability of their systems, pilots with a single engine will often abort a mission upon receiving an abnormal system warning (Anonymous 2011). Twin-engine pilots often feel that greater reliability offers greater leeway in such a situation, allowing them to fly with a degraded system.

However, advances in technology and maintenance routines have dramatically improved modern engine reliability (McDermott 2011). This is apparent when comparing the service history of the Pratt and Whitney F100-229 engine, which was designed in the 1990s and shares a number of features with the F-35's F135. According to United States Air Force Safety data (2011), no F100-229-equipped F-16C Block 52 (with a single engine) has suffered an engine-related failure with over 250,000 flight hours of operations, compared with four failures in over 900,000 hours for F-15Es (with twin engines). Although the F-16C Block 52 has flown significantly fewer hours than the F-15E, its mishap rate offers a good indication of the F135's potential reliability. A Canadian fleet of 65 F-35s would accumulate approximately 520,000 flight hours over a lifetime of 8,000 hours per aircraft, or just over double that of the F-16's service history. Based on these figures, the JSFs may potentially have a similar number of engine failures as the CF-18 over its life. The F-35's active diagnostics system should also provide warnings significantly earlier than previous engines, adding to pilot safety. These figures require some qualification however. They do not include foreign object damage and bird strikes, which can lead to the loss of an aircraft during take-offs and landings. It is difficult to estimate their potential effect on the F-35, as the F135 engine is significantly more robust than the F100-229 or any other military engine currently in service and will provide improved resistance to catastrophic engine failure (Anonymous 2012a).

Canadian concerns over reliability are by no means unique. The USN insists on stringent reliability standards for their aircraft because of their demanding operational environment.[2] Carrier-based aircraft are often exposed to harsh sea conditions and violent catapult launches and arrested landings. The Air Force F-35A will benefit from the Navy's standards due to the high level of commonality between their versions (Department of Defense 2011, 3). Furthermore, it should also be noted that Norway and the United States have successfully operated F-16s in a similar arctic environment for over 20 years and plan to replace their fleets with F-35As.

2 The F-35 must pass the US Navy and Marine Standards enclosed in Section 19 in addition the USAF standards in *MIL-HDBK-516B, Airworthiness Certification Criteria.* Department of Defense Available URL: http://www.theiplgroup.com/MIL-HNBK-516B.pdf.

Another key requirement for operating in the north is adequate range. CF-18s are often deployed to a forward operational base within Canada when required, such as Inuvik and Iqaluit in the north when Russian aircraft encroach on Canadian borders. The furthest distance it would be expected to travel is approximately 1055 nautical miles from Cold Lake to Inuvik, while a typical intercept might be 500 nautical miles from base with 25 to 30 minutes to escort the target (Anonymous 2012b). For this mission, CF-18s require three external tanks (16,000 lbs of fuel) and carry at least two AIM-9 Sidewinders, resulting in a rough combat radius of 650 nautical miles. The JSF normally carries all its fuel and ordinance internally as a low-observable aircraft, which is more efficient than most other aircraft. According to US Government estimates, the F-35A's combat radius is 590 nautical miles with a nominal combat load (with 18,250 lbs of fuel), which would be sufficient for most intercepts (Department of Defense 2011a, 10). However, this estimate is based on a less efficient high-med-high altitude flight profile while carrying 4000lbs of air-to-ground ordinance. The F-35's radius will easily exceed that of the CF-18 and the F/A-18E with this weight removed (Department of Defense 2011, 9), but not that of the Rafale or the Eurofighter (Rafale International 2000, 4). Finally, the F-35's sensor capabilities can be used for search and rescue functions to a much greater effect than current CF-18s. The F-35's electro-optical sensor system will also be particularly effective for locating aircraft and ships intruding into Canadian territory.

Unfortunately, the continuing program difficulties will come with consequences for Canada. The F-35's per-unit costs should be about 10% higher than anticipated based on recent Government Accountability Office (GOA) reporting and lot contract prices, consuming the government's expected contingency for cost increases (GAO 2012, 13). Moreover the RCAF will face a near term challenge at meeting all foreign and domestic contingencies between 2019 and 2022. Squadron personnel will be undergoing conversion training to the JSF at that time, straining the military's ability to generate sufficient support to deploy a contingent abroad. However, there should be sufficient airframes and support to maintain the Canadian domestic commitment to NORAD. Since 2000, the RCAF has implemented an aggressive life extension program on its CF-18s, which should enable it to husband the fleet's remaining flight hours even past 2022.

Once in service, the number of aircraft should be sufficient to maintain, and even expand, Canada's ability to conduct air operations. At any one time 12 to 24 out of 85 operational CF-18s are undergoing long-term maintenance and unavailable for deployment (Anonymous 2012b). The F-35's conditions based maintenance approach and modular design should significantly reduce the time aircraft spend in maintenance. Based on advances in the practices of the civil aviation industry over the past two decades, onboard diagnostics will identify parts nearing failure, which will then be replaced utilizing spares from a global supply pool. Consequently, the RCAF does not anticipate the F-35 will require any depot level maintenance over its initial 8000-hour lifecycle (Anonymous 2012b) and should maintain a mission reliability rate of 98% over that time (DoD 2011, 14). The F-35 also utilizes a composite low-observable skin, which is significantly more durable than earlier radar absorbent coatings utilized on the F-22 and B-2 programs (Butler 2010).

There are challenges to the desired maintenance approach, however. Key features of the JSF's maintenance system are still in infant stages of development and may not operate as planned (Ahern et al. 2011, 17). A partial failure in this system will require ground personnel to spend more time maintaining the fighter and consume spare parts at a greater rate than previously planned. If the sustainment system operates as planned, squadrons will likely require larger upfront stocks of certain spares than had traditionally been provided to previous aircraft types. The F-35's logistical process is designed for quick replacement of defective parts to maintain the airframe's high mission availability. Failure to provide sufficient spares will force the RCAF to spend more of the budget on unscheduled shipments to and from deployed locations, which will impact the aircraft's readiness and increase its cost per flying hour (Anonymous 2012a).

Conclusion

On the whole, there is little doubt that the F-35 likely represents the future of Western tactical air forces for the next 40 years, or longer. This study finds that the F-35 is best suited to meet the future range of foreign and domestic challenges facing Canada. If the government and the public desire to maintain the current level of operational capability in terms of a technological parity or advantage against an increasingly sophisticated adversary, the F-35 is clearly the correct choice amongst the options available. A number of common concerns surrounding its performance, particularly concerning range, reliability and total numbers, somewhat diminish once examined critically.

Nevertheless, a number of important challenges remain, which could negatively affect the operational suitability or affordability of the aircraft. Several key features of the program, such as advanced avionics and logistics function, remain in the early stages of development. There are also risks concerning the implementation of these systems in practice. Logistical, maintenance and training practices all require a critical examination in order to obtain optimum performance. Yet, it is important not to overstate the challenges involved. The program's early failures have led to heavy scrutiny in the US and abroad. The result has been a better-managed program that has experienced fewer delays and cost increases over the past two years. Nevertheless, Canada should monitor the full spectrum of risks carefully as the aircraft matures during the development process. This will prove invaluable when the government makes a final commitment to purchase after 2016.

As is often the case, any investment for the future will involve risk. In terms of a replacement for the CF-18, procurement and sustainment of the F-35 through the JSF Program represents the appropriate balance of risk and long-term benefit at this point in time.

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