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CANADA'S FIGHTER CAPABILITY:

THE F-35 JSF IS THE RIGHT CHOICE TO REPLACE THE CF-18 HORNET

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ABSTRACT

The Harper Government's planned sole-source procurement of the advanced fifth-generation F-35 Lightning II fighter currently in development, to replace Canada's ageing CF-18 Hornets, has left it open to significant criticism from the opposition, media, subject matter experts and the interested public. More specifically, the belief is that a sole-source procurement of the F-35 would lead to higher procurement costs and expose Canada to the risk of buying an aircraft with capabilities driven by costly technologies that are not yet proven, and potentially not even needed. Yet, a detailed look at the facts surrounding Canada's participation in the Joint Strike Fighter (JSF) program, the RCAF's list of unclassified requirements, the future security environment, projected capabilities and costs, as well as an examination of the alternatives suggest otherwise. Canada remaining in the JSF partnership provides taxpayers with access to the best possible purchase price for the F-35 along with significant industrial opportunities. The technologies developed for this aircraft are all assessed as critical to Canadian aerospace operations both at home and abroad for the projected life of the aircraft in Canadian service. And finally, based on the current market and available contenders, the procurement of an existing, less capable design in lieu of the F-35 as Canada's replacement fighter for the next thirty years will not likely generate any procurement savings to the Canadian taxpayer, and would expose the RCAF's new fighter force to operational and sustainment risks in the longer term.

1. INTRODUCTION

> *While there has been a growing consensus that Canada needs a CF-18 replacement aircraft, there has been more vigorous debate with respect to the wisdom of the Government's selection of the F-35 as its candidate aircraft. Some of this debate has been balanced, but much has been based upon misconceptions and half-truths, and some commentators – including those who should know better – have willingly contributed to the confusion that exists about the F-35.*
>
> *- Lieutenant-General (Ret'd) Lloyd Campbell*[1]

The Next Generation Fighter Capability (NGFC) procurement program to replace the Royal Canadian Air Force's (RCAF's) aging CF-18 Hornet fighters has garnered significant media attention since Prime Minister Harper's Conservative government announced on 16 July 2010 that it would procure, without a competition, and at a cost of $9 billion, up to 65 Lockheed Martin F-35 Lightning II fighters.[2] The F-35, also known as the Joint Strike Fighter (JSF), is a recognized fifth generation fighter[3], one of only a few types currently flying today.[4] Other currently known fifth generation designs include the United States Air Force's (USAF's) F-22 Raptor, the only operational type of its

[1] Lloyd Campbell, "Replacing the Canadian Manned Fighter Capability," *Canadian Military Journal* 11 No. 3 (Summer 2011), 60.

[2] CBC News | Canada, "Canada to spend $9B on F-35 fighter jets," http://www.cbc.ca/news/canada/story/2010/07/16/canada-jets.html; Internet; accessed 04 May 2013.

[3] The definition of jet fighter "generations" has long been subject to debate. According to John A. Tirpak, broadly speaking, Generation 4 fighter designs incorporate pulse-doppler radar; high manoeuvrability and look-down, shoot-down missiles (e.g. F-15, CF-18, Mirage, MiG-29). Generation 4+ fighters include high agility; sensor fusion; reduced signatures (e.g. Eurofighter Typhoon, Su-30, advanced versions of F-16 and F/A-18, Rafale). Generation 4++ fighters include AESA radars, continued reduced signatures or "active" (waveform cancelling) stealth; some supercruise (e.g. Su-35, F-15 Silent Eagle). By comparison, Generation 5 fighters include all aspect stealth with internal weapons, extreme agility, full-sensor fusion, integrated avionics, some or full supercruise (e.g. F-22, F-35). See John A. Tirpak, "The Sixth Generation Fighter," *Air Force Magazine*, 92 no. 10 (October 2009): 40; http://www.airforcemag.com/MagazineArchive/Documents/2009/October%202009/1009fighter.pdf; Internet, accessed 30 December 2013.

[4] Jeremiah J. Gertler, *Tactical Aircraft Modernization: Issues for Congress*, CRS Report for Congress (Washington, D.C.: Congressional Research Service, 2009), 4; [archived document on-line]; available from www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA511404; Internet, accessed 04 May 2013.

kind,[5] along with the Russian Sukhoi T-50 (PAK-FA)[6] as well as the Chinese Chengdu J-20[7] and Shenyang J-31[8], the latter three being in early development phases.

As one of the largest military purchases in Canadian history,[9] the sole source procurement decision to buy the F-35 exposed the government to significant criticism from the opposition, the media, various subject matter experts and pundits alike. The Canadian NGFC procurement program came under intense scrutiny from these various groups and individuals, not just due to the sole-source procurement decision, but also because of the perceived risks associated with pursuing an aircraft still under development. Everything from cost and affordability, the lack of guaranteed industrial offsets, schedule delays, technical risk, classified operational requirements that were not releasable to the public, and even fundamental design issues (such as the F-35's single engine) were highlighted to bring into question whether the F-35 was in fact the right choice to be the RCAF's next fighter aircraft. Despite the fact that the Harper government fought and won an election and a majority government on 02 May 2011 partially on the platform of defending the F-35 procurement,[10] the continued heavy criticism, media exposure and a highly critical report from the Office of the Auditor General (OAG)[11]

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[5] *Ibid*., 4.

[6] RiaNovosti, "Russian T-50 Fighter Jet to Start State Flight Test in 2014," http://en.rian.ru /trend/_generation_fighter/; Internet; accessed 04 May 2013.

[7] Defense Update, "Chengdu J-20, China's Fifth Generation Fighter," http://www.defense-update.com/products/j/29122010_j-20.html; Internet; accessed 04 May 2013.

[8] The Aviationist, "China Unveils its brand new stealth fighter: the J-31 "Falcon Eagle". But it's a copy of the F-22 Raptor." http://theaviationist.com/2012/09/16/j-31/; Internet; accessed 04 May 2012.

[9] Petrolekas, George and David Perry. "CDA Institute Analysis of the KPMG Audit of the F-35 Costing Data." (Ottawa: Conference of Defence Associations Institute, 2012) [document on-line]; available from http://www.cdainstitute.ca/images/ cdai_analysis_f35_dec2012.pdf; Internet; accessed 14 September 2013.

[10] Conservative Party of Canada, "Here for Canada: Stephen Harper's Low-Tax Plan for Jobs and Economic Growth," http://media.conservative.ca/media/ConservativePlatform2011_EN.pdf; Internet; accessed 04 May 2013

[11] Office of the Auditor General, *Spring 2012 Report of the Auditor General to the House of Commons: Chapter 2 – Replacing Canada's Fighter Jets* (Ottawa: Public Works and Government Services

have led the government to reconsider the purchase. On 03 April 2012, the government stood up the National Fighter Procurement Secretariat (NFPS) within Public Works and Government Services Canada (PWGSC) to oversee a seven-point action plan and coordinate replacement activities for the CF-18 fleet.[12]

This paper will examine the NGFC procurement by comparing the F-35 to all other alternative solutions to replace the current Canadian fighter capability in accordance with current national defence requirements. Despite the negative publicity surrounding the JSF program, this paper will demonstrate that the F-35 is still the best option in the long term to replace Canada's current fleet of CF-18 Hornet fighters given existing military and political requirements.

This paper is divided into seven chapters, including the introductory and concluding chapters. The second chapter will describe Canada's geopolitical context. More specifically, it will highlight some of the foundations of Canadian defence and foreign policy, namely Dr. R.J. Sutherland's invariants of geography, economics and alliances.[13] The latest Government of Canada direction for the Canadian Armed Forces (CAF)[14], known as the *Canada First Defence Strategy* (CFDS)[15] will then be examined, along with Canada's obligations under the North American Aerospace Defence

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Canada, 2012); http://www.oag-bvg.gc.ca/internet/English/parl_oag_201204_02_e_36466.html; Internet; accessed 04 May 2012.

[12] Public Works and Government Services Canada, "Backgrounder: National Fighter Procurement Secretariat," http://www.tpsgc-pwgsc.gc.ca/app-acq/stamgp-lamsmp/docinfo-bckgrnd-eng.html; Internet; accessed 04 May 2012.

[13] See R.J. Sutherland, "Canada's Long-Term Strategic Situation," *International Journal* 17 no. 3 (Summer 1962): 199-223.

[14] This paper will use the term Canadian Armed Forces (CAF) to describe Canada's military services collectively. However, the term Canadian Forces (CF) is also used when quoting reference material written prior to 2013.

[15] Department of National Defence, *Canada First Defence Strategy* (Ottawa: Government of Canada, 2008) [archived document on-line]; available from http://www.forces.gc.ca/site/pri/first-premier/June18_0910_CFDS_english_low-res.pdf; Internet; accessed 05 May 2013.

Command (NORAD), and North Atlantic Treaty Organization (NATO) alliances. The aim of this chapter will be to provide a foundation for understanding why Canada needs to maintain its current fighter capability.

The third chapter will examine the CAF Force Development process, Canadian aerospace doctrine, and specifically fighter aircraft roles and missions. It will also examine the potential threat environment any replacement fighter could be exposed to from which overall future fighter capabilities are derived. The aim of this chapter is to identify core doctrinal requirements and threats which, when linked to strategic direction, drive the capabilities Canadian fighters must possess. This chapter therefore provides a framework from which the various options to maintain Canadian fighter capabilities can be reasonably assessed.

The fourth chapter will examine the F-35 as a candidate aircraft to replace the CF-18 Hornet. This chapter will provide an overview of the JSF Program and Canada's involvement to date. It will also examine the current status of the JSF program from the perspective of technology and capabilities, service life, sustainment requirements, and costs. This overview will provide a baseline for comparison of capabilities, limitations, risks and overall affordability with other potential future fighter capability solutions.

The fifth chapter will discuss non-JSF options to satisfy Canada's fighter capability requirement. Leading Generation 4.5 aircraft[16], including the Boeing F/A-18 E/F Super Hornet, Eurofighter Typhoon, Dassault Rafale, and Saab Gripen NG will be

[16] Generation 4+ and 4++ fighters are also referred to as Generation 4.5 fighters, which is the term this paper will use. The U.S. Congress considers the current upgraded models of U.S. fighter aircraft with some advanced capabilities and armaments such as the F/A-18E/F Super Hornet as Generation 4.5 fighters. See Gertler, *Tactical Aircraft Modernization: Issues for Congress*..., 5, 14.

examined in some detail. In addition, an Uninhabited (Combat) Air Vehicle[17] (UAV or UCAV)[18] solution will also be examined. All of these options will also be looked at from the perspective of technology and capabilities, risk areas and costs.

The sixth chapter will summarize and discuss the potential future fighter procurement options through a direct comparison of their capabilities, limitations, risks and costs and present the best CF-18 Hornet replacement choice resulting from this analysis.

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[17] The CAF use the non-gender specific *uninhabited* aerial vehicle vice *unmanned* aerial vehicle used by the U.S. DOD and elsewhere. UAVs are defined by DOD as powered, aerial vehicles that do not carry a human operator, use aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semiballistic vehicles, cruise missiles, and artillery projectiles are not considered UAVs by the DOD definition. See Harlan Geer and Christopher Bolkcom, *Unmanned Aerial Vehicles: Background and Issues for Congress*, CRS Report for Congress (Washington, D.C.: Congressional Research Service, 2005); 2; [archived document on-line]; available from http://digital.library.unt.edu/ark:/67531/metacrs8638/m1/1/high_res_d/RL31872_2005Nov21.pdf; Internet, accessed 30 December 2013.

[18] The term UCAVs as used in this paper refers to high performance uninhabited combat and strike aircraft, as opposed to UAVs with a lethal payload. UCAVs can perform all of the traditional missions a current manned multirole or specialty fighter can, including specifically, all required air-to-air missions.

2. FOUNDATIONS OF CANADIAN FOREIGN AND DEFENCE POLICY

> *To borrow a term from mathematics, there are certain invariants of Canadian Strategy. It is worth examining these rather carefully because they shed a great deal of light upon the foundations of Canada's national existence and her place in the world community. They determine, to some very considerable extent, the agenda of Canadian national policy – that is, those major questions with regard to which there is some genuine choice. And they also reveal important areas where there is no choice, however much we as Canadians might like to believe that there is.*
>
> *- Dr R.J. Sutherland*[19]

The fundamental national interest of any democratic government is to protect and promote the well-being of its citizens. Canada is no exception to this general rule and as much as any other country, its geopolitical situation, diplomatic history, economy and access to natural resources[20] generally drive the formulation of Canadian defence and foreign policy. Perhaps one of the most insightful papers documenting the foundations of Canadian policy was written by Dr R.J. Sutherland, entitled "Canada's Long-Term Strategic Situation," published in the 1962 summer edition of the *International Journal*.[21] Sutherland was a member, and later the director, of the Operational Research Group of Canada's Defence Research Board, and is widely regarded as "Canada's most influential strategist of the nuclear age."[22] Sutherland noted three key constants or 'invariants'[23] in respect to Canada's strategic situation in the world, which he identified as Canada's geography, her economic potential, and finally, her broad national interests which

[19] Sutherland, "Canada's Long-Term Strategic Situation"..., 201.

[20] Steven Kendall Holloway, "Defining the National Interest," in *Canadian Foreign Policy: Defining the National Interest*, 9-19 (Peterborough, ON: Broadview Press, 2006), 16.

[21] Sutherland, "Canada's Long-Term Strategic Situation"..., 199-223.

[22] Dwayne Lovegrove, "Sutherland in the 21st century: invariants in Canada's policy agenda since 9/11," *Canadian Military Journal* 10, no. 2 (Summer 2010): 13; [journal on-line]; available from http://www.journal.forces.gc.ca/vol10/no3/doc/04-lovegrove-eng.pdf; Internet; accessed 04 May 2013.

[23] Sutherland, "Canada's Long-Term Strategic Situation"…, 200-201.

invariably led to certain natural alliances and alignments.[24] Furthermore, he posited that these invariants didn't just help determine Canada's policy agenda, they also revealed the range of choices available to any Canadian government with respect to that agenda.[25]

Canada's Geography

Sutherland identified geography as the first and most important of the invariants affecting Canadian defence and foreign policy, noting that "Canada will [continue to] occupy the north half of the North American continent and the United States will occupy the south half."[26] While the vast size of the country makes it essentially impossible to conquer in the traditional sense, Canada's size and other geographical factors collectively also make policing, monitoring and defending Canadian territory (in terms of land, sea *and* air) extremely resource intensive, technically challenging and by extension, very expensive.

This fact has always been recognized by successive Canadian governments ever since Confederation. Sutherland noted that Canada's geographic situation has important strategic consequences, observing that the U.S. is bound to defend Canada from external aggression regardless of whether or not Canadians wish to be defended, a concept he termed the "involuntary American guarantee."[27] Sutherland further stated that if the U.S. is bound to defend Canada, "it is also true that Canada can never, consistent with her own interests, ignore the requirements of American security; because, in the final analysis, the

[24] *Ibid*., 202-208.
[25] *Ibid*.
[26] *Ibid*.
[27] *Ibid*., 202.

security of the United States is the security of Canada."[28] The first official public acknowledgement of this fact by both Canadian and American government representatives was during the Sudetenland Crisis just prior to the commencement of World War II. In an August 1938 speech delivered in Kingston Ontario, President Roosevelt stated:

> The Dominion of Canada is part of the British Empire. I give to you assurance that the people of the United States will not stand idly by if domination of Canadian soil is threatened by any other empire.[29]

In a speech from Woodbridge Ontario two days later, Prime Minister Mackenzie King responded to Roosevelt, acknowledging the imbalance between the two North American countries at the time:

> We, too, as a good friendly neighbour, have our responsibilities. One of them is to see that our country is made as immune from possible invasion as we can reasonably be expected to make it, and, that should the occasion ever arise, enemy forces should not be able to make their way, either by land, sea or air, to the United States across Canadian territory.[30]

These public declarations stimulated the negotiation of the 1940 Ogdensburg Agreement and the subsequent Hyde Park Agreement of 1941, which led to increased defence cooperation through the creation of the Permanent Joint Board on Defence (PJBD) and increased integration of Canada's and America's defence industries respectively.[31] Canada-U.S. defence integration has continued to this day. From Canada's perspective, the greatest example of this interdependent defence relationship is the NORAD Agreement. More than 94 percent of NORAD's personnel are American,

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[28] *Ibid*., 203.
[29] Tourism Kingston. "Franklin Delano Roosevelt's Historic Kingston Address." http://www.kingstoncanada.com/en/fdr.asp; Internet; accessed 08 May 2013.
[30] Sutherland, "Canada's Long-Term Strategic Situation"…, 202.
[31] See Paul Buteux, "Sutherland revisited: Canada's long-term strategic situation," *Canadian Defence Quarterly* (September 1994): 5.

and over 84 percent of NORAD's budget is paid for by the U.S., which clearly reflects the hierarchy within the alliance.[32] Lieutenant-Colonel Dwayne Lovegrove writes in a *Canadian Military Journal* article, that it is through access to the resources made available by agreements such as NORAD that Canada has been able to assert and successfully maintain control of its territory at reasonable cost.[33] Furthermore, partnership in NORAD specifically protects and enhances Canadian sovereignty, because the integrated command structure and bi-national nature of the treaty ensures a joint Canada-U.S. approval process.[34]

Canada's Economic Potential

Sutherland next identified the idea of Canada's economic potential as a relatively constant factor relevant to the development of Canadian policy. He noted that while Canada was not a superpower comparable to the U.S. or Russia, nor could it aspire to become one like China or India, Canada was unequivocally a member of the next tier or category of middle powers, such as Britain, France, Germany, Italy and Japan.[35]

It is a fact today that Canadians continue to enjoy one of the highest standards of living in the world. Furthermore, it is also clear that Canada's economy as it is currently

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[32] Patrick Lennox, "The Illusion of Independence," in *An Independent Foreign Policy for Canada? Challenges and Choices for the Future*, ed. Brian Bow and Patrick Lennox, 41-60 (Toronto ON: University of Toronto Press, 2008), 47.

[33] Canada's ability to maintain sovereignty comes at reasonable cost, because Canada can leverage off the size of the US military, allowing it to maintain a smaller military force structure to monitor and defend its territory than if it were a neutral country. See Lovegrove, "Sutherland in the 21st century"…, 14.

[34] Despite the gross disparity in defence resources between the two partners, Canada is able to maintain and enhance its sovereignty given that Canadian officers are permanently assigned to key positions within the command structure and by agreement, no actions to the benefit of either country can be taken without obtaining the approval of both governments (i.e. the U.S. president and Canadian prime minister). *Ibid.*

[35] Sutherland, "Canada's Long-Term Strategic Situation"…, 204.

structured, and by extension Canada's economic relationship with the U.S., continues to be the basis of its prosperity. Sutherland clearly identified the close integration of the Canadian and U.S. economies, which had the effect of making the two countries a single target system, with the caveat that Canada was the more vulnerable of the two partners to any attack on the integrated North American economic system.[36] The greater than $635 billion worth of trade that flows across the Canada-U.S. border each year represents approximately 73 percent of Canada's exports and 62 percent of its imports.[37] Canada's significant bilateral trade relationship with the U.S. has a clear impact on the formulation of economic and security/defence policy. A review of *Budget 2013* shows that while the overall focus of Canada's current Economic Action Plan is to weather the current international economic downturn, strengthening Canada's international engagement in the global economy through bilateral trade agreements, improving trade and tax policy, strengthening aerospace and defence sector industries, and improving border security with the U.S. also continue to be a priority.[38]

From a security perspective, the terrorist attacks of 11 September 2001 (9/11) initially had a significant effect on Canada's economy. In the immediate aftermath of 9/11, the U.S. put its border inspectors on level-one alert, effectively closing the Canada-U.S. border and severely affecting cross-border trade until new security initiatives were enacted.[39] Professor Frank Harvey posits that the primary motivation for counterterrorism

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[36] Sutherland, "Canada's Long-Term Strategic Situation"…, 204.

[37] Based on 2012 data. See Statistics Canada, "Imports, exports and trade balance of goods on a balance-of-payments basis, by country or country grouping," http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/gblec02a-eng.htm; Internet; accessed 14 September 2013.

[38] Department of Finance Canada, *The Budget in Brief 2013* (Ottawa: Public Works and Government Services Canada, 2013), 6, 7, 9, 19, 20; http://www.budget.gc.ca/2013/doc/bb/Brief-Bref-eng.pdf; Internet, accessed 11 May 2013.

[39] Patrick Lennox, "Defence Against Help: Canada and Transnational Security after 9/11," First Annual (2006) Graduate Symposium, Dalhousie University, (Halifax NS, 2006), 1.

policies and activities in Canada is to prevent the economic consequences of America's response to a future attack.[40] As Desmond Morton further emphasizes, "Americans may remember 9/11; we must remember 9/12, when American panic closed the U.S. border and shook our prosperity to its very core."[41]

Natural Alliances based on National Interests

Sutherland's third invariant was Canada's natural alliances based upon national interests. He identified that friendships between nations are based upon common interests but cautioned that no two nations have identical interests.[42] He further noted that Canada's strongest alignment was with the U.S., based primarily upon the dependent relationship Canada has with the U.S. in terms of both its economic and physical security and secondly, cultural affinity as joint participants in the North American culture.[43] He also identified Canada's natural alignment to Western Europe given shared history, language, religion and culture, which is clearly exemplified by Canada's participation in the NATO alliance. However, the pre-eminence of the Canada-U.S. defence relationship has some important implications for Canada's system of alliances in general.

Firstly, as a middle power, Canada was and still is today, in a subordinate relationship with the U.S. superpower. As noted by Professor Nils Ørvik, weaker states

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[40] Frank P. Harvey, "Canada's Addiction to American Security: The Illusion of Choice in the War on Terrorism," The American Review of Canadian Studies 35, No. 2 (Summer 2005), 272; http://web.ebscohost.com/ehost/pdfviewer/pdfviewer? vid=3&sid=851ec617-a089-4494-ac04-dadbf00cd2f3%40sessionmgr113&hid =21; Internet, accessed 05 May 2013.

[41] Desmond Morton, "Keynote Address to the Inter-University Seminar on Armed Forces and Society," Toronto, 1 October 2004, quoted by Derek H. Burney, "The Perennial Challenge: Managing Canada-US Relations," *Canada Among Nations 2005: Split Images*, Andrew F. Cooper and Dane Rowlands [Eds.] (Kingston: McGill-Queen's University Press, 2005), 73.

[42] Sutherland, "Canada's Long-Term Strategic Situation"…, 204.

[43] *Ibid.*, 205.

in a bilateral defence arrangement should exercise a "defence against help" strategy to maintain their sovereignty, by taking care of their own security in order to assuage the security concerns of their larger neighbour.[44] To ignore this principle risks marginalizing Canadian sovereignty in accordance with Sutherland's "involuntary American guarantee."

Secondly, as a middle power, Canadian foreign policy must seek the right balance between bilateralism with the U.S. and multilateralism on the international stage. Sutherland's continentalist[45] bent is evident in his position concerning Canada's traditional pursuit of multilateralism. For example, while he recognized Canada's enthusiastic support for the creation of NATO was heavily driven by a desire to offset excessive U.S. dominance,[46] he felt this was the wrong reason to embrace multilateral alliances and institutions. Multilateralism should rather be pursued to support Canada's global interests in two ways:

> Firstly, by being present at the table, we can serve as the spokesman for our own interests. If we are not present, our voice will not be heard. Secondly, to the extent that Canada plays a significant role in Western security, she can maintain real influence in Washington.[47]

Thus, by participating credibly in multilateral institutions and alliances of common interest to Canada and the U.S. such as NATO, Sutherland saw multilateralism as a way to enhance Canada's credibility with Washington. Canadian divergence from U.S. policy

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[44] Philippe Lagassé, "Nils Ørvik's defence against help." International Journal 65, no. 2 (Spring 2010): 465-467; http://proquest.umi.com/pqdlink?index=18&did=2089230881&SrchMode=3&sid=1&Fmt=6&VInst=PROD&VType=PQD&RQT=309&VName=PQD&TS=1326919083&clientId=36163&aid=1; Internet, accessed 11 May 2013.

[45] Continentalists recognize that Canada is engaged in a dependent relationship with the U.S. in terms of both its economic and physical security. Accordingly, any prioritization of defence responsibilities would rank domestic and continental (i.e. Canada-US) requirements higher than international ones. See Lennox, "The Illusion of Independence"…, 47.

[46] Sutherland, "Canada's Long-Term Strategic Situation"…, 207-208.

[47] *Ibid.*, 208.

and initiatives as exemplified by the heavily independent, multilateral and activist focus during the Chretien era from 1993-2003 generated hostility in Washington[48] and led to a decline in Canadian influence, not just with the U.S., but globally.[49]

The prescience of Sutherland's analysis is further exemplified by a review of the 1971, 1987 and 1994 Defence White Papers published well after Sutherland's 1962 treatise. Of note, although the details related to force structure, recapitalization requirements, training, and force commitment levels to various defence activities have varied, the various white papers all prioritized the roles for the CF as firstly the protection of Canadian sovereignty; secondly, the defence of North America, in cooperation with U.S. forces; and thirdly, contributing forces for operations worldwide.[50]

Thus, Canada's most important alignment undoubtedly continues to be with the U.S., and this fact poses a number of challenges to Canadian defence and foreign policy makers. Canada has a certain choice in respect to being treated as either a genuine partner or as a protectorate of its superpower neighbour. Furthermore, Canada's meaningful and astute participation in alliances and multilateral institutions is essential for the development of defence and foreign policy agendas which protect its sovereignty and other national interests.

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[48] The Chretien era was highlighted by a number of key disputes with the US, such as Canada's support for the creation of an International Criminal Court (ICC), Canada's strong backing of the Kyoto environmental accord, and public opposition to the 2003 invasion of Iraq, which was further exacerbated by numerous ill-advised public remarks made by several Chretien aides and Liberal party officials. See Andrew Richter, "From Trusted Ally to suspicious Neighbor: Canada-U.S. Relations in a Changing Global Environment," The American Review of Canadian Studies 35 no. 3 (Autumn 2005); 474-475, 486-487; http://web.ebscohost.com/ehost/pdfviewer/pdfviewer?sid=87f8624c-9dd8-4eb9-87c3-81baddddb392%40sessionmgr104&vid=2&hid=26; Internet, accessed 11May 2013.

[49] Allan Gotlieb, "Romanticism and Realism in Canada's Foreign Policy," Policy Options 26 no.2 (February 2005); 24; http://www.irpp.org/po/archive/feb05/gotlieb.pdf; internet, accessed 11 May 2013.

[50] See Department of National Defence, *1971 Defence White Paper* (Ottawa: Information Canada, 1971), 16; Department of National Defence, *Challenge and Commitment: A Defence Policy for Canada* (Ottawa: Supply and Services Canada, 1987), 49; and Department of National Defence, *1994 Defence White Paper* (Ottawa: Canada Communications Group, 1994), 27.

Canada's geopolitical situation, in terms of geography, economics and alliances is the foundation from which Canadian defence and foreign policy is crafted. Clearly, Canada's interdependent relationship with the U.S. reveals the true limits in terms of choices Canadian policymakers have if they are to be prudent in protecting Canada's national interests, especially in respect to sovereignty, security and prosperity. In the next section, CFDS will be reviewed to understand how, in broad terms, defence policy and guidance are translated into high level capability requirements, especially in regards to re-capitalization of aging military equipment.

Canada First Defence Strategy

Understanding the key geopolitical factors articulated by Sutherland, which affect Canadian policy development, helps to better contextualize current Canadian defence policy and any other formal guidance to the Department of National Defence (DND) and the CAF by the Government of Canada. Such formal direction articulates how Canada will meet current and future defence and security challenges. As noted above, written direction has been issued via White Papers (1964, 1971, 1987, 1994) and also in the Defence Policy Statement (DPS) 2005, but Defence Policy can also come in the form of a Speech from the Throne, a Ministerial Statement and/or Party Platforms.[51] White papers are most often published when governments change and some aspect of the new government's defence policy have changed from that which was previously published.

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[51] Department of National Defence, *Capability Based Planning in Force Development (CBP Handbook)* Version 5.2 (Ottawa, DND Canada, 2010), 6.

CFDS was formally released by the Harper government on 12 May 2008.[52] CFDS is more of a "vision" paper which describes the strategic environment, and outlines distinct CF missions, capability requirements, and resource needs to allow Canada to survive and operate in that environment. The development of CFDS followed a logical process as shown in Figure 1 below.

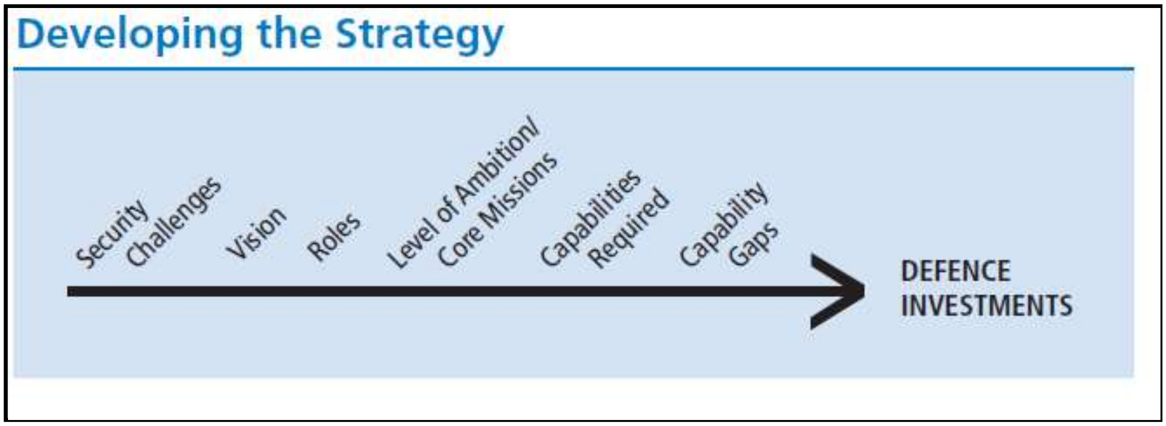

Figure 1 – Developing CFDS

Source: DND, Canada First Defence Strategy, 5.

In terms of the future security environment, CFDS identifies ethnic and border conflicts, fragile states, resurgent nationalism and global criminal networks as threats to international stability, along with the significant build-up of conventional forces in the Pacific region. In addition, the proliferation of advanced weapons and the potential emergence of new, nuclear-capable adversarial states headed by unpredictable regimes are also of concern.[53] Other influences on the projected operating environment of the CAF include domestic challenges associated with natural disasters, terrorist attacks, human and drug trafficking, foreign encroachments on Canada's natural resources,

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[52] Prime Minister of Canada, "PM Unveils Canada First Defence Strategy", http://www.pm.gc.ca/eng/media.asp?id=2095; Internet, accessed 11 May 2013.
[53] DND, *Canada First Defence Strategy…,* 6.

potential outbreaks of infectious disease, and increased access to the Arctic due to the warming environment.[54]

This analysis is the foundation upon which the Government has defined a "level of ambition" for the CAF. Given the government's desire is for the CAF to be able to effectively operate in this uncertain security environment, CFDS also provides "clear direction concerning their three roles – defending Canada, defending North America and contributing to international peace and security – as well as the types and numbers of missions it expects our military to fulfill."[55] The prioritization of these roles is logical and is consistent with the geopolitical invariants as documented by Sutherland, and unsurprisingly, is essentially identical to the priorities published in defence white papers since 1971 by both Liberal and Conservative governments. CFDS also clearly identifies six core mission priorities:

1. Conduct daily domestic and continental operations, including the Arctic and through NORAD;
2. Support major international events in Canada such as the 2010 Olympics;
3. Respond to a major terrorist attack;
4. Support civilian authorities during a crisis in Canada such as a natural disaster;
5. Lead and/or conduct a major international operation for an extended period; and
6. Deploy forces in response to crises elsewhere in the world for shorter periods.[56]

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[54] *Ibid.*

[55] *Ibid.*, 7.

[56] These core mission priorities have clearly evolved since the days of previously published white papers. For example, responding to a major terrorist attack has its foundations in 9/11. Also, the high priority of support to international events in Canada can be understood in the context of the upcoming 2010 Vancouver Olympics and international economic planning summits given the security concerns of a post-9/11 world. See DND, *Canada First Defence Strategy…*, 10.

Commensurate with these requirements is the recognition that significant capital investments to modernize the military will be required. CFDS identifies numerous equipment replacements which the government intends to pursue, including specifically, a replacement for Canada's fleet of CF-18 Hornets with a next generation fighter aircraft.[57] Additionally, the roles and missions as documented in CFDS explain in broad terms Canada's existing defence treaty obligations under both NORAD and NATO and identify interoperability, specifically with U.S. forces, as a key existing and future CAF requirement.[58] Interoperability is thus a key requirement for any Hornet replacement.

NORAD

NORAD is a United States and Canada bi-national command originally charged with the missions of aerospace warning and aerospace control for North America. The NORAD agreement was first signed on 12 May 1958, and was last updated and renewed in May 2006 when the maritime warning mission was added to its mandate and the Agreement renewed on a permanent basis.[59] Aerospace warning includes the detection, validation, and warning of attack against North America whether by aircraft, missiles, or space vehicles, while aerospace control includes ensuring air sovereignty and air defence

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[57]While CFDS does identify known recapitalization requirements for aging weapon systems such as RCAF fighters, Navy destroyers/frigates, and Army vehicles, it does not directly address new capability requirements for the future such as UAVs and cyber warfare. However CFDS does mandate DND to develop a multi-year Strategic Investment Plan to integrate all strategic funding requirements from across the department into a single coherent plan. This is to ensure that all future CAF requirements are properly integrated into the department's overall capital investment plan. *Ibid*., 12, 17, 19.

[58] *Ibid*., 8, 9, 17.

[59] Prior to 2006, the NORAD agreement was renewed every five years. See North American Aerospace Defence Command, "U.S., Canada strengthen NORAD agreement," http://www.norad.mil/Newsroom/tabid/3170/Article/1240/us-canada-strengthen-norad-agreement.aspx; Internet, accessed 29 September 2013.

of the airspace of Canada and the United States.[60] Canada's contribution to NORAD includes radar and satellite coverage, naval assets (ships and submarines as required) as well as fighter and patrol aircraft. While radars, satellites, naval assets and maritime patrol aircraft are enablers for the aerospace and maritime warning missions, it is only fighter aircraft which can wholly execute the aerospace control mission. In fact, since the 9/11 attacks, a portion of the CF-18 fleet is continuously assigned to NORAD alert force duties on a daily basis under the auspices of Operation NOBLE EAGLE.[61] In today's RCAF force structure, it is only the CF-18 aircraft that intercept, escort, and if necessary, have the ability to shoot down unidentified aircraft penetrating the Canadian Air Defence Identification Zone (CADIZ), including Russian Long Range Aviation flights.[62] Clearly, NORAD is a key driver for the RCAF's requirement to operate fighter aircraft, due to the agreement's mandate for the defence of both Canadian and American airspace through the aerospace control mission, which only fighter aircraft can currently execute.[63]

NATO

NATO, also known as the North Atlantic Alliance, was created with the signing of the North Atlantic Treaty on 4 April 1949 in Washington and its fundamental role is to

[60] North American Aerospace Defence Command, "NORAD Fact Sheet," http://www.norad.mil/Newsroom/FactSheets/ArticleView/tabid/3991/Article/1056/north-american-aerospace-defense-command.aspx; Internet, accessed 29 September 2013.

[61] North American Aerospace Defence Command, "Canadian NORAD Region," http://www.norad.mil/AboutNORAD/CanadianNORADRegion.aspx; Internet, accessed 29 September 2013.

[62] Arguably an armed helicopter could carry out the aerospace control function in respect to light civil aviation aircraft. However modern fighters and their inherent capabilities are required to be able to intercept, escort and if necessary shoot down high flying airliners, civilian business jets, foreign long range patrol, reconnaissance, bomber and fighter aircraft, as well as high speed cruise missiles.

[63] While UAV capabilities are growing, the current evolutionary roadmap for UAV capabilities makes it clear that UAVs will not be able to execute the aerospace control mission for some time. See Chapter 5 for more details.

safeguard the freedom and security of its member countries by political and military means. Today, NATO is a political and military alliance of 26 countries in Europe and North America committed to the maintenance of democratic principles. As a military alliance, it is founded on the premise of collective defence, and the principle that an attack against one or several members would be considered as an attack against all.[64] NATO does not have independent military forces per se, other than those contributed by the member countries to military operations; however member nations contribute to a number of standing forces and recurring missions.[65] Therefore, when the North Atlantic Council decides to launch an operation, forces have to be made available by member countries through a force generation process.[66] Member countries, including Canada, normally declare generic force packages to NATO as part of the force generation process, with declared states of readiness. Canada is typically prepared to commit specific force elements, such as a naval vessel or task group, an army combat arms and/or combat support unit or battle group, or an aerospace expeditionary force, based on an assessment of capacity and mission needs.

Since the NATO force structure is founded on shared and compatible doctrine, training and equipment, contributing nations are expected to provide meaningful force elements to NATO, which can be collectively integrated into a larger capable multi-

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[64] North Atlantic Treaty Organization, *NATO Handbook 2006*(Brussels: NAT), 2006), 15-17; [archived document on-line]; available from http://www.nato.int/docu/handbook/2006/hb-en-2006.pdf; Internet, accessed 13 May 2013.

[65] NATO has four permanent standing groups: the two Standing NATO Maritime Groups (SNMGs) and another two Standing NATO Maritime Mine Countermeasure Groups (SNMCMGs). Canada contributes a frigate or destroyer to the SNMG 1 and/or 2 (formerly known as Standing Naval Forces Atlantic and Mediterranean, or STANAVFORLANT and STANAVFORMED). See NATO, "History of SNMG1," http://www.manw.nato.int/ page_snmg1_history.aspx; Internet, accessed 27 July 2014. Also, while Canada does not contribute any standing air forces to NATO, Canada has actively participated in Operation IGNITION, the rotational NATO air policing mission over Iceland since 2011. See also National Defence and the Canadian Armed Forces, "Operation IGNITION," http://www.forces.gc.ca/en/operations-abroad-past/op-ignition.page; Internet, accessed 27 July 2014.

[66] *Ibid*., 96.

national force structure tailored to the required mission. This concept has been a key driver of the CAF's overall force structure, which is primarily based upon the "balanced force" concept – the maintenance of certain key capabilities within each service, which is perceived to be in Canada's best interest. This allows for meaningful contributions of combat capability to any multi-lateral mission, and therefore provides the government with the most flexibility in terms of participation, and by extension, influence.[67] From the perspective of RCAF force development, it is therefore not surprising that the CFDS reaffirms the government's desire to replace the CF-18 with a fighter aircraft capable of providing Canada with an effective and modern air capability for not just domestic or continental use, but for international operations as well.[68]

Summary

Canadian foreign and defence policy is fundamentally tied to the realities of Canada's geopolitical environment. Canada's geography and the foundations of its economic strength have driven successive Canadian governments to form natural alliances with the U.S. and western democracies to protect Canada and Canadian interests in the most cost-effective manner possible. Clearly, the priorities the government of Canada intends to pursue in terms of developing or maintaining military capabilities as documented in CFDS reaffirms the geopolitical foundations from which Canadian defence policy has historically been built. CFDS also identifies Canada's continuing

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[67] Daniel Gosselin, "A 50-Year Tug-of-War of Concepts at the Crossroads: Unification and the Strong Service Idea," in *The Operational Art: Canadian Perspectives – Context and Concepts*, ed. Allan English and others, 129-200 (Kingston: Canadian Defence Academy Press, 2005), 161.

[68] DND, *Canada First Defence Strategy*…, 17.

need for a fighter aircraft, especially in the context of Canada's ongoing commitment to NORAD, but also for NATO, and potentially other multi-lateral/coalition commitments abroad.

3. FORCE DEVELOPMENT, AEROSPACE DOCTRINE AND THE THREAT

As I noted previously to this committee, manned fighters are essential to our ability to maintain control and sovereignty over our airspace, whether in Canada or during operations abroad. Neither unmanned aerial vehicles nor any other air platform can carry out this demanding and complex task, whether they are operating in air-to-air or air-to-ground roles. This is the same conclusion reached by many of Canada's allies.

- Lieutenant-General André Deschamps[69]

Force Development and Capability Based Planning

The force development process used by the CAF is now centred on capability based planning (CBP). CBP is a conceptual approach to the force development process, which identifies the effects that a future military force must be able to generate to meet national policy in the context of the Future Security Environment.[70] CBP is composed of three phases: 1) Analysis (foundational framework); 2) Assessment (testing); and 3) Integration (turning senior leader choices into plans), to support development of the preferred force structure. CBP output forms the basis of the required capability plan (the Force Capability Plan) and structure plan (the Multi-Year Establishment Plan).[71] Figure 2 below illustrates, in general terms, the CBP process currently in use.

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[69] Parliament of Canada, "Standing Committee on National Defence (SCOND) Meeting no. 30 Minutes 28 October 2010," http://www.parl.gc.ca/HousePublications/Publication.aspx?DocId=4738779&Language= E&Mode=1&Parl=41&Ses=2; Internet, accessed 27 July 2014.

[70] Chief of Force Development, *Director General Capability and Structure Integration (DGCSI) Operating Procedures Aide Memoire* (NDHQ Ottawa: 2012), B-1/11.

[71] *Ibid…,* B-1/11- B5/11.

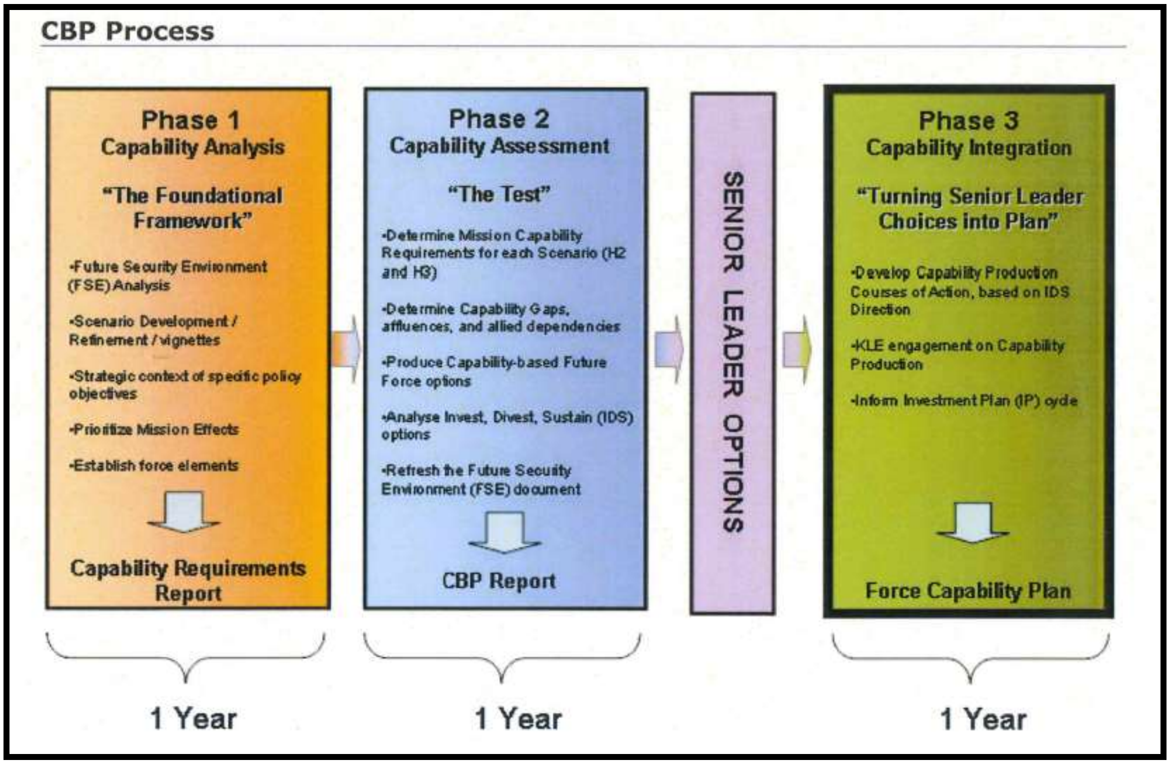

Figure 2 – Capability Based Planning Process

Source: DND, Chief of Force Development, Directorate of Capability Integration.

Within the CBP process, scenarios are key to the determination of capability priorities. Accordingly, it is necessary to link them to the types of operations that the Government of Canada might expect the CAF to be able to execute in the future. CFDS, discussed previously, identifies the government's level of ambition in this regard, and the six core missions it identifies therefore informs the Capability Analysis phase of CBP.

It is then possible, by applying the Operational Planning Process[72] to any scenario, to analyse and assess capabilities for the various force domains (e.g. aerospace, land, maritime) so as to determine the future requirement.

[72] The operational planning process is a methodology used by the CAF and other militaries to determine the best method of accomplishing assigned operational tasks and to plan possible future tasks. See Department of National Defence, B-GJ-005-500/FP-000, *The Canadian Forces Operational Planning Process* (Ottawa: DND Canada, 2008).

The Future Security Environment (FSE)

As previously noted, CFDS identifies the future security environment at a very high level. An understanding of the FSE is necessary for the CBP process to generate useful outputs. Since the planning scenarios are critical to generating viable outputs, they must present credible future operating environments and be compliant with policy if they are to be useful in CBP.

In order to inform the overall force development process, the CAF's Chief of Force Development issued *The Future Security Environment 2013-2040* for general reference in 2013.[73] It provides an analysis of current and emerging geopolitical, socio-economic, environmental, technological and military trends seen today, which affect the FSE. Other militaries have also published studies, notably the U.S., and the United Kingdom (U.K.), as well as NATO for guidance purposes to its member nations.[74] A review of these documents shows some general consensus on the key trends, although there may be slight differences in regards to expected timings. These trends, common to all of the analyses, include significant changes in globalization, migration, urbanization, climate, information exchange, and customization and miniaturization of new technologies which can be

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[73] Department of National Defence, *The Future Security Environment 2013-2040* (Ottawa: DND Canada, 2013).

[74] See Department of Defense, *The Joint Operating Environment 2010* (Suffolk: United States Joint Forces Command, February 2010); available from http://www.au.af.mil/au/awc/awcgate/jfcom/joe_2010.pdf; Internet, accessed 25 May 2013; United Kingdom, Ministry of Defence, *Global Strategic Trends Programme: Out to 2040,*4th ed. (London: Ministry of Defence Development, Concepts, and Doctrine Center, January 2010); available from https://www.gov.uk/government/publications/dcdc-global-strategic-trends-programme-global-strategic-trends-out-to-2040; Internet, accessed 25 May 2013; and North Atlantic Treaty Organization, *Future Security Environment 2025,* 1st ed. (Norfolk: NATO, 2007); available from http://www.bits.de/NRANEU/nato-strategy/ACTFutureSecurityEnvironmentFirstEdition.pdf; Internet, accessed 25 May 2013.

considered as dual-use.[75] Furthermore, CAF and western military assessments all identify the proliferation of advanced technologies, weapon systems (conventional and nuclear) and nuclear materials as a significant concern.[76] State and non-state actors will both seek to integrate conventional and irregular methods with advanced technologies.[77] Thus, the FSE of the post-Cold War period is more complex than previous eras and contains numerous potential threats, adversaries and actors with differing motivations that go well beyond the past competing Cold War ideologies of democracy versus communism.

Potential security challenges could develop almost anywhere in the world, from the Arctic to Asia. In regards to future military conflicts, the FSE assesses that the trend towards an increasing number of *intrastate* conflicts will continue as "globalization increases cultural conflict, penalises ineffective governance, and increases the ease with which irredentist groups can operate."[78] Also noted is that while the frequency of *interstate* conflicts will likely remain low in comparison to the last 100 years, wars will still occur and some will likely cause significant effects when they do, given increasing lethality and mass effect of weapon systems and the widening effects of globalization.[79] As a case in point, in the last twenty years Canada's armed forces have, on at least three occasions, confronted a conventional military adversary.[80] It can therefore be expected that within the next twenty years the CAF will likely be confronted at least once by the conventional

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[75] Dual use technologies can be used for both civilian and military purposes.

[76] DND, *The Future Security Environment…*, 14, 26, 48, 96-99, 101, 113,. See also NATO, *Future Security Environment 2025…*, 85, 92, 96, 108, 125, 126, 127, 128.

[77] This concept is known as hybrid warfare. DND, *The Future Security Environment…*, 93, 96, 100.

[78] *NATO, Future Security Environment* 2025…, 77.

[79] *Ibid.*

[80] The CAF fought against Iraqi forces in 1991, Serbian forces in 1999, and Libyan forces in 2011. Additionally, Canadian peacekeepers in the 1990s were exposed to the regular military forces from all of the successor states of the former Yugoslavia. Also of note, Canada fought in Afghanistan against irregular forces. While Canada did not deploy fighter aircraft to Afghanistan, other militaries did, and used them effectively to carry out a variety of missions during that conflict.

military power of a sovereign state either singly or through a regional conflict.[81] It is also likely that the CAF will be confronted by irregular forces while deployed during the same time period. Accordingly, events which could trigger future Government of Canada decisions to employ instruments of national power, especially military forces, are forecast to increase in frequency. DND's *FSE* concludes as follows:

> Even if only some of the trend projections described in this document eventually prove to be accurate, the FOE [future operating environment] will be challenging to operate in. Without question, the CAF must be able to operate across the length and breadth of Canadian territory, including its maritime and airspace approaches and it is likely that the GoC will continue to assign difficult expeditionary operations. Thus, flexible, adaptive, resilient, deployable forces able to operate with a high degree of situational awareness, with precision, and the ability to minimize collateral damage and casualties will be necessary.[82]

Given the projected FSE, a future RCAF fighter must be deployable, interoperable, survivable, lethal in air-to-air combat, able to carry out precision attacks, and highly capable in "non-kinetic"[83] roles such as intelligence, surveillance and reconnaissance (ISR).

The next step to understanding future fighter aircraft requirements given the assessed FSE is understanding the aerospace functions, roles and missions carried out by fighter aircraft. This begins by understanding air force doctrine.

RCAF Aerospace Doctrine

The RCAF's aerospace doctrine can be examined to identify typical functions, roles and missions carried out by fighter aircraft. The capstone document for RCAF

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[81] Dr. Andrew Godefroy (ed), *Projecting Power: Canada's Air Force 2035* (Trenton: Canadian Forces Aerospace Warfare Centre, 2009), 30.

[82] DND, *Future Security Environment…*, 128.

[83] Non-kinetic roles are those that do not require putting weapons on a target either directly or indirectly.

aerospace doctrine is B-GA-400-000/FP-000, *Canadian Forces Aerospace Doctrine*.[84] However, many of the corresponding operational and tactical level doctrine manuals to replace the rescinded "*Out of the Sun*" have yet to be published.[85] Accordingly, an appropriate contemporary guidance document which can be used in the interim is the *Aerospace Capabilities Framework* (ACF), which is the guide to the RCAF's development and transformation.[86]

The ACF includes an overview of the current functions, roles and missions of the RCAF.[87] The hierarchical aerospace functions, roles and missions specifically identified to fighter forces are identified in Table 1 below, which is an amalgamation of information from the ACF and LCol Murray's article in the Canadian Air Force Journal cited above.[88] It should be noted that the CF-18 Hornet has fulfilled all of these roles and missions in both peacetime (whether conducting domestic operations or on training exercises to maintain these capabilities), and in war, with the exception of dedicated Suppression of Enemy Air Defences (SEAD) and Electronic Attack (EA) missions.[89]

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[84] Department of National Defence, B-GA-400-000/FP-000*, Canadian Forces Aerospace Doctrine* (Ottawa, DND Canada, 2010).

[85] At the time of this writing, RCAF doctrine is in the middle of a significant transition to be more compatible with joint terminology. Accordingly, the hierarchy of strategic (fundamental concepts) to operational (functional capabilities) to tactical (force structure) level publications is incomplete. There is accordingly a gap in official documentation which properly links aerospace functions, roles and missions together. For an insightful discussion on the topic and a proposed way forward, see LCol Brian L Murray, "What air forces do," Canadian Air Force Journal 4 no. 4 (Fall 2011): 31-47; [Journal on-line]; available from http://airforceapp.forces.gc.ca/CFAWC/eLibrary/Journal/Vol4-2011/Iss4-Fall/AF_JOURNAL-Vol4-2011-Iss4-Fall_e.pdf#Page=1; Internet; accessed 29 September 2013.

[86] Department of National Defence, A-GA-007-000/AF-002 *The Aerospace Capabilities Framework* (Ottawa, DND Canada, 2003).

[87] *Ibid*., 7-13.

[88] More specifically, see *Ibid*., and Murray, "What air forces do"…, 33-45.

[89] SEAD and EA require specialized capabilities not currently maintained by the RCAF. These missions are usually carried out by aircraft specifically designed to carry them out, as are arguably, ISR missions. Although CF-18 aircraft have conducted ISR missions of limited scope given their sensors are optimized for aerial combat and air-to-surface targeting, the RCAF now have a highly capable ISR platform in the modernized CP140 Aurora. DND, *ACF*…, 35, 39, 69-70.

Table 1 – Aerospace Functions, Roles and Missions for Fighter Aircraft

Airpower Functions	Sub-Functions (Roles)	Typical Missions
Aerospace Control. A primary function of air forces. To possess this capability, an air force must be capable of conducting both surveillance and control.	**Offensive Counter-Air (OCA)**. Those operations conducted to limit, disrupt or destroy an adversary's aerospace power as close to its source as possible.	**Surface Attack (SA)**. To target the source of an adversary's aerospace capabilities, including warning and control facilities, and airbase and launch facilities.
		Suppression of Enemy Air Defences (SEAD). To target an adversary's aerospace defence systems.
		Sweep (SWP). To target adversary aircraft or targets of opportunity in an allocated area of operations.
	Defensive Counter-Air (DCA). Operations conducted to neutralize opposing forces that threaten friendly forces and/or installations.	**Combat Air Patrol (CAP)**. To defend friendly surface based forces against attack by opposing airborne forces.
		Escort (ESC). To defend airborne friendly forces against attack by opposing airborne forces.
		Air Intercept (AI). To intercept opposing aerospace forces conducted from alert facilities, airborne CAP, or diverted from other missions.
Aerospace Force Application. Also a primary function of an air force. It is the primary means of applying force against an enemy's centre of gravity to achieve desired strategic effects. This capability can also be used for coercive presence.	**Strategic Attack**. An air operation that target's an adversary's centre of gravity or vital targets leading to the centre of gravity.	**Strategic Attack (Strat Atk)**. Those missions conducted against vital target whose aim is to progressively destroy an adversary's capacity or will to wage war.
Contributing Functions. Those functions that contribute to the achievement of the objectives of other services.	**Indirect Counter-Land operations**. Those operations that aim to destroy, neutralize or delay an adversary's military potential before it cab be brought to bear effectiuvely against friendly forces.	**Battlefield Air Interdiction (BAI)**. Missions conducted against the enemy's lines of communication to destroy or disrupt the flow of supplies and/or reinforcements.
	Direct Counter-Land operations. Those air operations that aim to halt attacks, help create breakthroughs or cover and guard the flanks of friendly ground forces.	**Close Air Support (CAS)**. Those missions that use aerospace power to directly target an adversary's land forces on the battlefield.
	Indirect Counter-Sea operations. Air assets tasked into a geographically defined operating area to search for, identify, shadow and attack enemy surface vessels.	**Anti-Surface Warfare (ASuW)**. Those missions conducted against the enemy's sea lines of communication to destroy or disrupt naval operations in a defined operating area.
	Direct Counter-Sea oerations. Air assets performing directed missions to protect friendly naval forces.	**Tactical Air Support to Maritime Operations (TASMO)**. Those missions that use aerospace power to directly target enemy surface or air assets.
Enabling Functions. Those functions that span a wide range of operational activities necessary to conduct effective aerospace operations.	**Electronic Warfare (EW)**. Air assets performing directed missions to exploit the electronic spectrum to provide situational awareness and achieve offensive and defensive effects.	**Electronic Attack (EA)**. Missions conducted to disrupt, reduce or prevent the use of the electromagnetic spectrum by enemy forces.
	Intelligence, Surveillance and Reconnaissance (ISR). Air operations to detect, identify and monitor targets, and establish target damage objectives.	**Overwatch**. Missions which allow for a long-range view of the battlespace for the purpose of providing situational awareness for static or moving forces.
		Reconnaissance (Recon). Missions undertaken to obtain information about the activities and resouces of an opponent. They may be carried out for tactical or strategic objectives.
		Bomb Damage Assessment (BDA). Missions performed after attack to assess and disseminate weapons effects information.

It is clear that Canadians gain the most benefit from a fighter aircraft that is able to meet all three CFDS roles – defending Canada, defending North America and contributing to international peace and security. This is the capability baseline of the current CF-18 Hornet fleet until its currently forecasted retirement date in 2020,[90] and should arguably be the case for any fighter aircraft that is chosen to replace it. In fact, considering the projected FSE, the CAF and its equipment will need to be more useful across the entire spectrum of conflict – from peace support operations of a non-combat nature through high intensity state vs state conflict. From a fighter aircraft perspective, the ability to conduct ISR missions, which are non-kinetic in nature, and which leverage off the capabilities of multiple advanced sensors, would be an area of desired capability growth. Similarly, given digitization and advances in sensing technologies, the ability to conduct EA missions would be another area of needed capability growth.

The Concept of Threats

To further understand the capabilities a fighter aircraft must have in order to meet Canadian requirements, it is also necessary to understand what threats the aircraft could potentially be exposed to. Understanding the threat informs the operational capability (i.e. performance, effectiveness and lethality) and the survivability requirements the aircraft must meet in being able to execute any of the doctrinal aerospace functions, roles and missions expected of it.

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[90] According to the CF-18 Weapon System Management Office, it has been confirmed that the CF-18 retirement date can be pushed back five years from 2020 to 2025 for a reasonable cost due to lower than projected structural fatigue consumption if funding is made available to pay for some limited but required upgrades.

An examination of the FSE helps to develop an understanding of what potential threats will exist. Such assessments are typically carried out at the strategic level to identify trends which could lead to military use, and at the operational or tactical level to specifically identify exposure to threat systems in a given region.

Operational and Tactical Threats

In the aftermath of the 1991 Gulf War, a number of non-Western states, led by Russia and China, have been developing capabilities to challenge Western air dominance. China, specifically in recent years, is linking such capabilities together to form a comprehensive strategy known as "counter-intervention," which the U.S. now terms "anti-access/area denial" (A2/AD).[91] A2/AD systems are being exported by these regional powers to their client states world-wide, and their capabilities pose a direct challenge to the West's ability to carry out operations against some opponents.[92] These systems include advanced fighters (e.g. Su-27/30/35 FLANKER variants and the future PAK-FA and J-20/J-31 fifth generation fighters) as well as advanced mobile long range surface-to-air missile (SAM) systems (e.g. Russian based S-300 and S-400 variants). These systems pose a significant threat to current Western airpower given the current asset mix of Generation 4 and 4.5 fighters.[93] Modern Russian-based SAM systems, which

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[91] Office of the Secretary of Defense, *Annual Report to Congress: Military and Security Developments involving the People's Republic of China 2011* (Washington, D.C. 2011); 28; available from http://www.defense.gov/pubs/pdfs/2011_CMPR_Final.pdf; Internet, accessed 25 July, 2014.

[92] Richard Shimooka, *F-35 and the Future of Canadian Security*, SSWG Paper (Calgary: Canadian Defence and Foreign Affairs Institute, 2012), 7; [document on-line]; available from http://www.cdfai.org/PDF/F-35%20and%20the%20Future%20of%20Canadian%20Security.pdf; Internet; accessed 14 September 2013.

[93] Advanced Generation 4 and 4.5 fighters such as the Su-27/30/35 FLANKER variants as well as the newer fifth generation designs being pursued, have been or are being developed specifically to counter

are cheaper and easier to buy, operate and upgrade than fighters, have been even more widely exported to second and third world countries than advanced contemporary fighters, and navalized variants are also integrated in all major Russian Navy surface combatants.[94] Accordingly it is highly likely that Canadian aerospace forces will be exposed to these threat systems in the future whether deployed domestically or internationally.

Thus, any new fighter aircraft must be capable against a wide variety of contemporary and emerging threats. Table 2 below identifies, at a high level, the potential threat systems an RCAF fighter would be exposed to or have to defend against in the CFDS roles of Canadian/North American (i.e. Continental) defence, or contributing to international peace and security. Given the expected proliferation of all types of conventional weapons noted in the various FSE studies, the potential threat systems an RCAF fighter may be exposed to are as extensive as those expected to be associated with conventional warfare between rival states and/or groups of states. Table 2 is an amalgamation based on various sources, and illustrates this point.

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their contemporary opponents. Similarly, advanced mobile long range SAMs can reliably threaten support aircraft such as Airborne Warning and Control System (AWACS) and EW aircraft that have long been enablers of Western air superiority. Accordingly they are a significant threat to contemporary Western airpower given the current mix of Generation 4/4.5 aircraft types. *Ibid.*, 7-8.

[94] *Ibid*., 8.

Table 2 – Potential Threat Exposure Matrix for RCAF Fighters by CFDS Role

Potential Threat Exposure Matrix		
Threat Systems	**Continental**	**International**
Fighter Aircraft	x	x
Bomber Aircraft	x	x
Land Attack Cruise Missiles	x	x
Air-to-Air Missile (Beyond Visual Range)	x	x
Airborne Electronic Warfare/ Jammers	x	x
Airborne Warning and Control System (AWACS)	x	x
Ground-Based Surveillance and Tracking Radars		x
Ground Based Surface-to-Air Missile (SAM)		x
Ground-Based Anti-Aircraft Artillery (AAA)		x
Man-Portable Air-Defence Systems (MANPADS)	x	x
Naval Surface-to-Air Missile (SAM)	x	x
Naval Anti-Aircraft Artillery (AAA)	x	x
Naval Surveillance and Tracking Radars	x	x

A cursory examination of Table 2 shows the potential threats a Canadian fighter aircraft must be able to counter. It also demonstrates that there is not much difference between the required operational capability and survivability of a fighter executing a domestic or continental NORAD role compared to one executing an international peace and security role. The obvious difference is that a NORAD-only fighter would not be exposed to existing or future low- to high-end ground-based weapons or radars of a potential adversary. However, the addition of the maritime surveillance and control mission to NORAD now exposes any RCAF fighter to the naval equivalents of those threat systems,[95] unless the Canadian Government were to deliberately choose not to expose RCAF fighters to such threats in waters of Canadian interest by abrogating that sovereign responsibility and transferring it to U.S. forces.

[95] Naval and land-based surface-to-air missiles, anti-aircraft artillery, as well as surveillance and fire-control radars are usually similar in terms of tactical performance.

Additionally, upgrades are available for many existing weapon systems, such as digitization for radars and seeker upgrades for missiles, which significantly enhance the inherent capabilities of older analog threat systems, for a fraction of the cost of procuring a new top-end weapon system.[96] This makes highly capable SAM systems available to a large number of nations, including poor ones, thereby increasing the likelihood that an RCAF fighter will be exposed to them if deployed. Finally, technology is not stagnant, and it is expected that future combat aircraft and air defence systems will 1) have improved performance; 2) leverage low observable technologies in the electromagnetic spectrum; 3) incorporate active electronically scanned array (AESA) radars[97] and use passive detection systems as complementary sensors; 4) utilize data fusion from multiple sensor sources including integrated EW systems; and 5) use secure and low-probability of intercept (LPI) data sharing systems.

General Requirements of a Replacement Fighter Aircraft

The measure of a weapon system's capability is ultimately relative, that is, it is measured relative to the potential threat systems of the evolving battlespace. While the current capabilities of the CF-18 Hornet are sufficient until its projected retirement date, this 'capability baseline' is relative and will erode through the 2020s as technologies and the military capabilities of other nations and non-state actors improve. Maintaining the

[96] Air Power Australia, "Legacy Air Defence Systems Upgrades," http://www.ausairpower.net/ APA-Legacy-SAM-Upgrades.html; Internet, accessed 26 May 2013.

[97] AESA radars have a number of advantages over their predecessors. These include increased reliability due to fewer moving parts, and with digitally controlled electronic beam-shaping and frequency agility, AESA radars exhibit improved power management, detection and anti-jamming performance, and have a low probability of intercept (LPI) against threat detectors. An excellent summary may be found at Air Power Australia, "Active Electronically Steered Arrays – A Maturing Technology," http://www.ausairpower.net/ aesa-intro.html; Internet, accessed 26 May 2013.

relative levels of present capability will clearly demand a more capable replacement fighter than the current CF-18 Hornet, especially if it is expected to operate in Canadian service for at least two to three decades after its procurement.

The ability to counter contemporary and projected future threats given recent and expected technological improvements has led to a general list of mandatory capabilities for Canada's Next Generation Fighter. As identified in the RCAF's *Aerospace Capabilities Framework*, Canada's Next Generation Fighter must:

- be highly manoeuvrable, capable of achieving supersonic speed and have significant range, endurance and acceleration capabilities;
- have onboard sensors capable of monitoring large volumes of airspace at long distances and the detection, identification, discrimination, designation, tracking and full-spectrum day, night and adverse weather engagement of multiple airborne targets;
- have an integrated situation awareness display capable of portraying air-to-air and air-to-surface targets and threats and communicating this information to other aircraft and surface-based forces;
- have long range jam resistant and secure communication and information systems, interoperable with other aerospace control elements;
- be capable of employing visual and beyond visual range (BVR) short and long range air-to-air weapons capable of autonomous guidance to airborne targets during the day, at night and in adverse weather conditions, complete with requisite stores carriage, management, release and fire control systems;
- be capable of employing precision and near-precision guided air-to-surface weapons capable of destroying targets on the ground during the day, at night and in adverse weather conditions;
- have accurate navigation and positioning systems;
- be fitted with laser, radar and missile approach warning systems;
- have stealth characteristics and adequate self-protection capabilities such as chaff, flares and electronic jamming; and

- have an Air-to-Air Refuelling capability.[98]

The former Chief of the Air Staff, Lieutenant-General André Deschamps, also identified, from his perspective, a qualitative list of mandatory capabilities for any CF-18 replacement fighter to the Standing Committee on National Defence. His list included:

- Range: The aircraft must have the range to be capable of deploying in NORAD and NATO alert configuration, in accordance with instrument flying rules without air-to-air refuelling support, whether the aircraft is flying non-stop from a main operating base to a deployed operating base or from a main operating base to a forward operating location with one stop enroute if required.

- Endurance: The aircraft must have the endurance to be capable of operating from a main operating base, a deployed operating base or a forward operating location in accordance with instrument flying rules and maintain a combat air patrol in accordance with Canadian Forces, NORAD and NATO requirements.

- Speed: Our next fighter must have the speed to be capable of successfully conducting an intercept of airbreathing threats – that is to say, non-ballistic threats such as fighters or bombers – to Canadian airspace or to airspace assigned to the Canadian Forces in accordance with NORAD and NATO standards.

- Air-to-Air Refuelling: The fighter must be capable of receiving fuel in-flight to extend its range and endurance.

- Deployability: Our next fighter must be capable of deploying to and operating from forward operating locations domestically and worldwide in a full range of geographic, environmental, climatic and threat conditions.

- Intelligence, surveillance and reconnaissance (ISR): The fighter must be capable of providing non-traditional intelligence, surveillance and reconnaissance data, before, during and following the deployment of weapons. This capability will assist targeting, intelligence and command entities in a variety of decision-making processes.

- Weapons: The aircraft must precisely deliver a range of air-to-air and air-to-surface weapons in all weather conditions, day and night, and in permissive and non-permissive environments to provide a spectrum of tailored weapons effects.

[98] DND, *Aerospace Capabilities Framework…*, 69.

- Survivability: The aircraft must be capable of defending itself by employing a range of self-defence technologies and minimizing the risk of detection, engagement and damage in predicted threat environments.

- Growth Potential: The aircraft must be capable of continuous upgrade to its level of interoperability, survivability and operational capabilities for the duration of its lifetime.

- Fleet Size: The fleet must be large enough to conduct assigned missions and roles while simultaneously maintaining combat-ready force generation capability (that is, training new crews and maintenance of aircraft).

- Certification: The aircraft must be capable of certification and sustainment in accordance with Canadian standards.

- Delivery: The delivery times must give us the capability of achieving an initial operating capability of the new aircraft coordinated with the CF-18 Hornet's end of lifetime. In other words, the new fighter must begin delivery in 2016 to allow overlap with the Hornet's projected retirement in 2020 and thus avoid a gap in our defence capabilities by ensuring that such needs as trained crews are ready to go.[99]

From these broad requirements and in-depth study, a detailed statement of operational requirements (SOR) was built for the NGFC acquisition program.[100] SORs are drafted by project staff and describe the required capability characteristics of the project deliverable. As a living document, SORs are created and updated when requesting approval authority to move a capital project from the Options Analysis phase to Project Definition, and then Implementation.[101] Building a detailed SOR from these basic mandatory requirements and choosing a platform which satisfies them ensures that the fighter aircraft chosen to replace the CF-18 can meet the government's direction and level of ambition as outlined in CFDS, and satisfies forecasted mission requirements in

[99] The list was provided by LGen Deschamps to the Standing Committee on National Defence on 28 Oct 2010. Contrary to the quoted information, as noted earlier, deliveries could be pushed back to 2020-2026 at reasonable cost due to lower than projected CF-18 structural fatigue consumption. Original text from Parliament of Canada, "Standing Committee on National Defence Meeting no. 30...."

[100] DND, *Aerospace Capabilities Framework…*, 69.

[101] CFD, *DGCSI Operating Procedures Aide Memoire…,* J-5/13, J9/13 - J10/13.

the aerospace domain *throughout its projected operational life* in the increasingly complex and challenging FSE.

Summary

To summarize, CBP analysis reconfirms Canada's need for a replacement fighter aircraft. To maintain existing national capabilities will require an aircraft that can at least carry out all of the roles and missions of the current CF-18 Hornet fleet, from aerospace control, to aerospace force application, to enabling aerospace functions, in accordance with RCAF aerospace doctrine. The FSE suggests that events which could trigger CAF involvement will be increasing in frequency and the ability to operate across the full spectrum of operations for all CAF force elements is essential. Furthermore, any suggestion that a NORAD-only fighter would require less capability than a fighter which can reliably participate in international operations world-wide is not borne out by the facts unless there is a deliberate decision to not expose future Canadian fighters to the maritime control role. Both the domestic/continental and international battlespaces are evolving and set to expose any Canadian fighter to a significant and similar array of threat systems and associated capabilities. Finally, given that technology continues to evolve, and with it the future projected battlespace in which Canadian fighters must be able to operate, maintaining the RCAF's current relative capability in the aerospace domain demands the acquisition of a fighter aircraft that is significantly more capable than the current CF-18 Hornet.

4. THE JOINT STRIKE FIGHTER PROGRAM AND CANADA

In no other area of warfare is the importance of technology as critical as in the air. Those flying and fighting with yesterday's technology are at more than a disadvantage: they are out of the game entirely. We have seen this in every recent engagement since the end of the Cold War. In both Operation Desert Storm over Kuwait and Iraq, as well as in Operation Allied Force over Serbia and Kosovo, opposing air forces made desultory attempts to defend their own air space before conceding the inevitable and hiding their aircraft as best as possible.

- Paul T. Mitchell[102]

The JSF Program – A General Overview

Although Canada has been involved with the U.S. led JSF Program since 1997,[103] the program itself is somewhat older, having evolved from a number of earlier U.S. military programs. The JSF Program's antecedent was the Joint Advanced Strike Technology (JAST) Program. In the summer of 1993, the U.S. Department of Defense (DOD) conducted a "Bottom-Up Review" and concluded that the pursuit of both the U.S. Navy's (USN's) Advanced Attack Fighter (AF/X) and the U.S. Air Force's (USAF's) Multi-Role Fighter (MRF) programs together at the same time was unaffordable.[104] In lieu, the JAST program was created to develop and mature technologies, develop requirements and demonstrate concepts for affordable next-generation joint strike warfare.[105] Also during this time, the U.S. Defense Advanced Research Projects Agency (DARPA) was leading a technology program to collaboratively develop an Advanced

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[102] Paul T. Mitchell, "Lightning in a Bottle: The F-35 and the bankruptcy of modern warfare," *Canadian Foreign Policy Journal* 17 no. 3, (3rd Issue 2011): 193; http://www.tandfonline.com/doi/pdf/10.1080/11926422.2011.648749; Internet, accessed 09 April 2013.

[103] The Auditor General's report cites that Canada signed the Concept Demonstration Phase partnership memorandum in December 1997, while some U.S. sources cite January 1998 as the commencement of Canadian partnership in the JSF program (see Table 3 below). OAG, *Spring 2012* Report…,1.

[104] Craig E. Steidle, "The Joint Strike Fighter Program," *Johns Hopkins APL Technical Digest* 18 no.1 (1997), 6; http://techdigest.jhuapl.edu/TD/td1801/steidle.pdf; Internet, accessed 06 November 2013.

[105] Navy Matters, "Lockheed Martin Lightning II Joint Strike Fighter," http://navy-matters.beedall.com/jsf.htm; Internet, accessed 08 Nov 2013.

Short Take-off and Vertical Landing (ASTOVL) aircraft for the U.S. Marine Corps (USMC) and U.K. Royal Navy.[106]

However, as the JAST Program progressed, it became apparent that this effort would be funding one or more concept demonstrator aircraft around 1996 to meet its goals, which was estimated to be around the same time as DARPA's ASTOVL Program planned to enter its Full-Scale Demonstration effort. Furthermore, the work under ASTOVL, as an advanced technology concept development program for a future joint-service strike fighter, appeared to fall within the bounds of DOD's JAST program.[107] Fiscal Year 1995 budget legislation passed by the U.S. Congress in November 1994 directed both programs to be merged,[108] and the program was renamed the Joint Strike Fighter Program when JAST entered its Concept Demonstration Phase (CDP) in late 1995.[109] The following Service needs were presented to the JSF Program at its initiation:

- USN – A first day of the war, survivable strike fighter to complement the F/A-18E/F Super Hornet until its retirement;
- USAF – A multi-role aircraft (primarily air-to-ground) to replace the F-16 and A-10 and to complement the F-22;
- USMC – An ASTOVL aircraft to replace the AV-8B Harrier and F/A-18 A-D Hornet; and
- U.K. Royal Navy – An ASTOVL aircraft to replace the Sea Harrier.[110]

The rationale which drove a common design family to meet these competing requirements was volume; mass production of the aircraft would create significant economies of scale and allow per unit costs to be significantly decreased if significant

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[106] *Ibid.*
[107] *Ibid.*
[108] F-35 Lightning II Program. "Joint Strike Fighter Program History." http://www.jsf.mil/history/index.htm; Internet, accessed 08 November 2013.
[109] *Ibid.*
[110] Steidle, "The JSF Program"…,7.

commonality could be achieved.[111] The JAST/JSF Concept Definition and Design Research (CDDR) phase was completed in 1996, with separate CDDR contracts having been awarded to Boeing Defense and Space Group, Lockheed Fort Worth Co., McDonnell Douglas Aerospace, and Northrop Grumman Corporation in December 1994. CDDR ended with the November 1996 down-select contract awards to the Boeing Company and Lockheed Martin Corporation for CDP. A final conclusion of CDDR also confirmed that a high level of airframe commonality was possible for a family of aircraft from a single production line. Furthermore, with 100% commonality in displays, avionics, ejection seats, software, test equipment, depot repair, commonality values were calculated to exceed 70% and result in projected savings of 30-31% in unit costs, and 28-32% savings in life-cycle sustainment costs for the U.S. DOD.[112]

Given this fact, and considering the numerous different aircraft types the JSF was now being designed to replace, the U.S. DOD briefed the JSF Program to a number of countries, which it considered to be potential customers. Between 1997 and 1999, eight countries, in addition to the U.K., joined the JSF Concept Demonstration Phase (CDP), including Canada.[113] Table 3 below identifies international JSF CDP participation, levels of financial contribution and partnership status.

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[111] Parliamentary Budget Office, *An Estimate of the Fiscal Impact of Canada's Proposed Acquisition of the F-35 Lightling II Joint Strike Fighter* (Ottawa: Public Works and Government Services Canada, 2011): 11; www.parl.gc.ca/pbo-dpb/ documents/F-35_Cost_Estimate_EN.pdf; Internet, accessed 04 May 2013.

[112] Steidle, "The JSF Program"…,16, 17.

[113] John Birkler *et al*, *Assessing Competitive Strategies for the Joint Strike Fighter: Opportunities and Options* (Santa Monica, CA: RAND Corporation, 2001), 15-18; [archived document on-line]; available from http://www.rand.org/pubs/monograph_reports/MR1362.html; Internet, accessed 08 Nov 2013.

Table 3 – International Participation in the JSF CDP

Country	Status	Agreement	Foreign contributions	U.S. contributions	Date joined
United Kingdom	Full Partner	MoU	$200M	—	Dec 95
Netherlands	Associate Partner	MoA	$10M	$10M	Apr 97
Norway	Associate Partner	MoU	$10M	$10M	Apr 97
Denmark	Associate Partner	MoU	$10M	$10M	Sept 97
Canada	Informed Partner	MoU	$10M	$50M	Jan 98
Italy	Informed Partner	MoA	$10M	—	Dec 98
Singapore	Major Participant	LOA	$3.6M	—	Mar 99
Turkey	Major Participant	LOA	$6.2M	—	Jun 99
Israel	Major Participant	LOA	$0.75M	—	Sep 99

Source: John Birkler *et al*, *Assessing Competitive Strategies…*, Table 2.1, 18.

For the CDP Phase, four levels of international participation were created, with decreasing levels of influence:

- Full Collaborative Partner (active participation in the process of developing JSF requirements documents);
- Associate Partner (ability to Influence requirements development for the CTOL JSF variant as long as they and the U.S. perceived the results to be mutually beneficial);
- Informed Partner (participates in design refinements, but no authority to influence requirements); and
- Foreign Military Sales (FMS) Major Participant (involvement in the generic JSF project, which provides extensive unclassified and non-proprietary information about JSF requirements and designs, and allows participation in a variety of different CDP activities).[114]

[114] *Ibid.*, 16-17.

CDP resulted in a fierce competition between Lockheed Martin and Boeing. Over a four year period, prototypes of these two competing companies' designs were built, flight tested and reviewed in an intense fly-off competition.[115] When Canada joined the CDP as an Informed Partner, it was offered the opportunity to participate directly in the competition evaluation between Lockheed Martin and Boeing. While Canada declined this offer, having confidence in the U.S. competitive process, Canada did assign DND personnel to the international JSF Program Office to keep the Government of Canada informed of program developments, and had full access to the competition results.[116] CDP ended in late 2001 with Lockheed Martin's prototype X-35 winning the competition. As a result, Lockheed Martin was awarded a contract for the next phase of the program, known as System Development and Demonstration (SDD).

The aim of SDD, as its name implies, is the continued development and maturation of the F-35 design. It involves significant testing of the entire aircraft weapon system, and includes manufacturing processes.[117] Figure 3 below shows the current three F-35 variants, which are evolutions of Lockheed Martin's winning design from the CDP phase.

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[115] F-35 Lightning II program, "Introduction," http://www.jsf.mil/f35/index.htm; Internet, accessed 14 November 2013.

[116] Ken Pennie (LGen ret'd), "Strategy and the F-35." *Frontline Defence* Issue 3 2011 (May-June 2011): 36-39; http://frontline-canada.com/downloads/11_DEF3_F35_ KenPennie.pdf; Internet, accessed 04 May 2013.

[117] F-35 Lightning II program, "Introduction"….

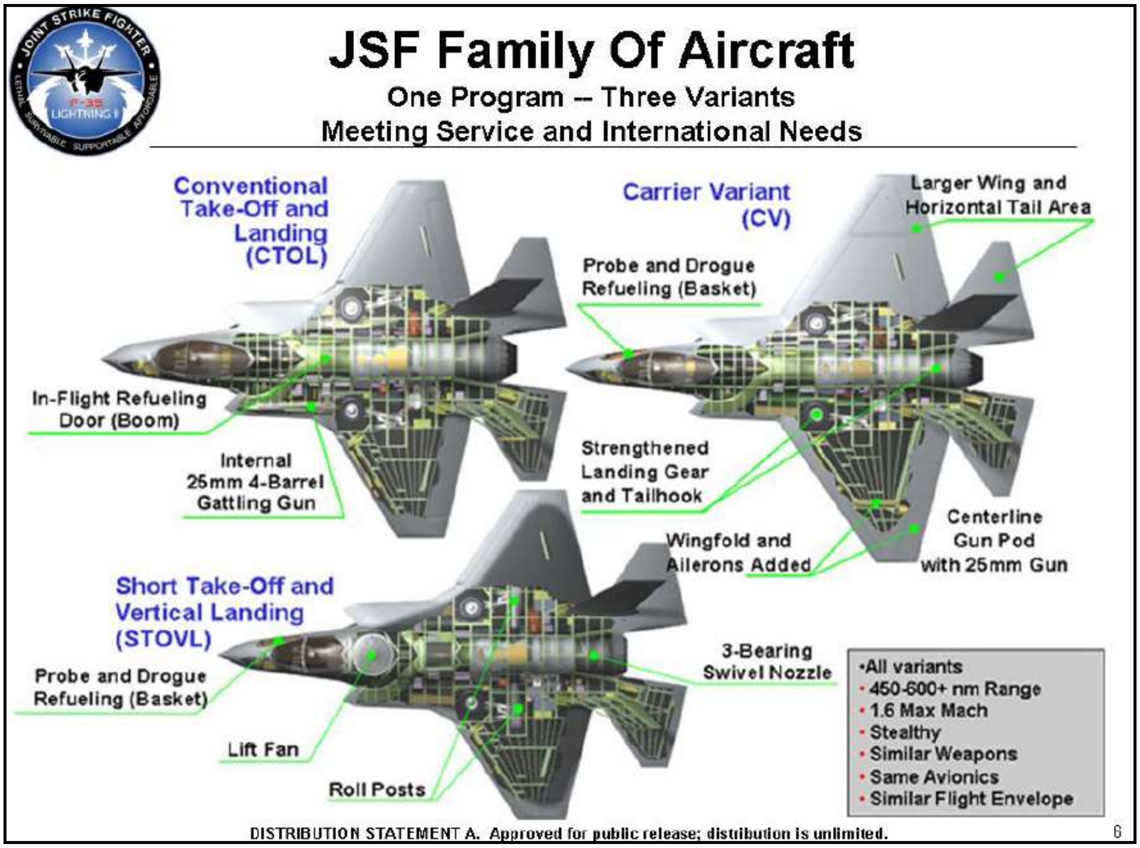

Figure 3 – The Three F-35 JSF Variants

Source: F-35 JSF F-35 Lightning II Program, *F-35 Lightning II Program Brief…*, 6.

A tiered participation framework was also set up for SDD, which began in November 2001 and is currently set to continue to 2019.[118] This new framework has enabled countries to participate in a flexible manner, with influence on the program based upon money contributed. To date, there are eight international partners in the JSF Program; the U.K. is the only Level I partner, Italy and the Netherlands are Level II partners, and Australia, Denmark, Norway, Turkey and Canada are Level III partners.[119]

[118] Government Accountability Office, GAO 13-309 *F-35 Joint Strike Fighter: Current Outlook Is Improved, but Long-Term Affordability is a Major Concern*, (Washington, D.C., 2013), 32; available from http://www.gao.gov/products/GAO-13-309; Internet, accessed 14 September 2013.

[119] The CDP phase partnership levels were renamed and restructured in the SDD phase. Jeremiah J. Gertler, *F-35 Joint Strike Fighter (JSF) Program: Background and Issues for Congress*, CRS Report for

Additionally, DOD also offers Foreign Military Sales (FMS)-level of participation in the F-35 program for countries unable to commit to partnership in the program's SDD phase; for example, Israel and Singapore both expressed their intent to buy JSFs early in the SDD phase, and are known as "Security Cooperative Participants,"[120] with Japan and South Korea following suit in 2011, and 2013 respectively.[121]

The final phase of the JSF Program, which significantly overlaps the SDD phase, is known as Production, Sustainment and Follow-on Development (PSFD). It was put into effect by the PSFD MOU in 2007 to define production schedules, and identify sustainment and upgrade requirements for the operational lifespan of the JSF worldwide, for 42 years, out to 2051.[122] Currently, JSF is in Low Rate Initial Production (LRIP); it is envisioned that once developmental and operational flight testing are completed and the JSF design frozen at the end of SDD in 2019, full rate production will commence to generate significant per-unit cost savings.

To summarize, the JAST/JSF Program was created to address the high cost of tactical aviation, the need to deploy fewer types of aircraft in order to reduce acquisition

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Congress (Washington, D.C.: Congressional Research Service, 2009), 10-12; [archived document on-line]; available from www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA511315; Internet, accessed 04 May 2013.

[120] *Ibid*., 10.

[121] See F-35 Lightning II, "JASDF's Next Generation Fighter," https://www.f35.com/global/participation/japan; Internet, accessed 27 July 2014 and Ju-Min Park, and Joyce Lee, "South Korea to buy 40 Lockheed F-35s, further 20 jets still open," *Reuters*, 22 November 2013; http://www.reuters.com/article/2013/11/22/us-korea-fighters-idUSBRE9AL09520131122; Internet, accessed 27 July 2014.

[122] Canada signed this MOU in December 2006. Memorandum of Understanding among the Department of Defence of Australia and the Minister of National Defence of Canada and the Ministry of Defence of Denmark and the Ministry of Defence of the Republic of Italy and the State Secretary of Defence of the Kingdom of the Netherlands and the Ministry of Defence of the Kingdom of Norway and the Undersecretariat for Defense Industries on behalf of the Ministry of National Defense of the Republic of Turkey and the Secretary of State for Defence of the United Kingdom of Great Britain and Northern Ireland and the Secretary of Defense on behalf of the Department of Defense of the United States of America Concerning the Production, Sustainment, and Follow-on Development of the Joint Strike Fighter (Short Title – JSF PSFD MOU). http://www.jsf.mil/downloads/documents/JSF_PSFD_MOU_-_07_Feb_07.pdf; Internet, accessed 08 November 2013.

and operating costs, and counter projections of future threat scenarios and enemy capabilities. The program has progressed from a foundational CDDR analysis phase, to CDP which flight tested competing prototype aircraft, to overlapping SDD and PSFD phases, whereby flight testing, development, LRIP and sustainment efforts are concurrently ongoing.

JSF Operational Requirements

As previously noted, one of the key goals of the JAST/JSF Program was to create a family of next generation tactical combat aircraft, which could counter projected future threat scenarios and capabilities. To meet this goal, the JAST/JSF Program followed a rigorous and detailed requirements determination process, which saw the iterative development of multiple Joint Initial Requirements Documents (JIRDs) between 1995 and 1999, and culminated in the creation of a draft and then final Joint Operational Requirements Document (JORD) in 1999 and 2000 respectively.[123] Of note, given the affordability goals of the JAST/JSF Program, the acquisition reform concept of Cost As an Independent Variable (CAIV) was aggressively applied, which raises cost goals to the same level as performance goals and other system requirements.[124] This meant that cost-benefit analyses had to be conducted and trade-off decisions made where necessary. Figure 4 below identifies how an iterative cost and operational performance trade (COPT) analysis for each planned iteration of the JIRD eventually led to the creation of the JORD. Assessment factors were clearly identified for each iteration cycle, which

[123] Birkler *et al*, *Assessing Competitive Strategies*…, 13.
[124] *Ibid*.

included affordability, as well as required weapon system features and performance characteristics as identified by military service representatives. The JIRD iteration cycle was also designed to develop the aircraft weapon system in a structured manner.[125] As a final step, a Joint Requirements Oversight Council (JROC) was set up to manage and approve all JSF Program requirements and any subsequent changes to them.[126]

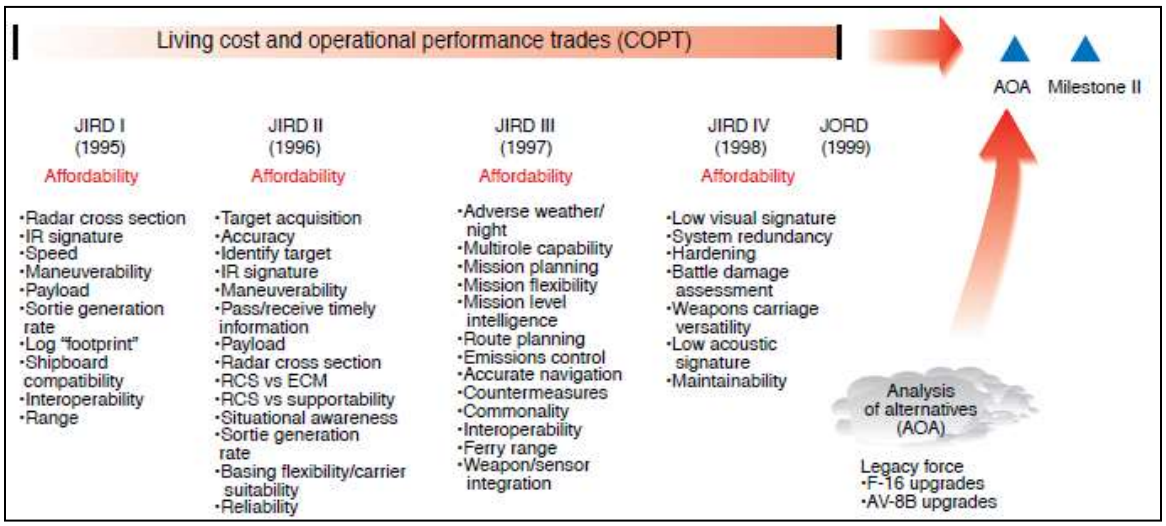

Figure 4 – JSF JORD Roadmap identifying key COPT assessment factors

Source: Steadle, The JSF Program…, 10.

Key characteristics and requirements for the JSF weapon system which were analysed using COPT methodology became key performance parameters (KPP) and were incorporated into the JORD. Table 4 below provides a listing of some of the KPPs for the JSF, which are critical factors driving the design of the weapon system. These important

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[125] For example, JIRD-I was focused on qualities and characteristics that would drive the design of the aircraft's outer mold line; similarly, JIRD-II centred on key avionics trade-off analyses such as target acquisition, weapon system delivery and accuracy, supportability versus radar cross section, and supportability versus diagnostics. See Steidle, "The JSF Program"…, 8-11.

[126] *Ibid*., 8.

characteristics, which were analysed during the iterative JIRD development process, stimulated and drove the research and development of advanced technological solutions to meet service requirements.

Table 4 – JSF KPPs

Source of KPP	KPP	F-35A Air Force CTOL version	F-35B Marine Corps STOVL version	F-35C Navy carrier-suitable version
Joint	Radio frequency signature	Very low observable	Very low observable	Very low observable
	Combat radius	590 nm Air Force mission profile	450 nm Marine Corps mission profile	600 nm Navy mission profile
	Sortie generation	3 surge / 2 sustained	4 surge / 3 sustained	3 surge / 2 sustained
	Logistics footprint	< 8 C-17 equivalent loads (24 PAA)	< 8 C-17 equivalent loads (20 PAA)	< 46,000 cubic feet, 243 short tons
	Mission reliability	93%	95%	95%
	Interoperability	Meet 100% of critical, top-level information exchange requirements; secure voice and data		
Marine Corps	STOVL mission performance – short-takeoff distance	n/a	550 feet	n/a
	STOVL mission performance – vertical lift bring-back	n/a	2 x 1K JDAM, 2 x AIM-120, with reserve fuel	n/a
Navy	Maximum approach speed	n/a	n/a	145 knots

Source: F-35 program office, October 11, 2007.

Notes: PAA is primary authorized aircraft (per squadron); vertical lift bring back is the amount of weapons with which plane can safely land.

Source: Gertler, *F-35 JSF Program…*, Table B-1, 123.

JSF Technologies

As an advanced next-generation fighter, it is not surprising that the JSF design incorporates new and novel technologies. During CDDR, a significant analysis effort was conducted on the future strike warfare environment, the impact of stealth, and the domains of logistics and sustainment as a force multiplier. Each area generated future weapon system requirements and the development of new technologies to meet KPPs. Appendix 1 provides further details of the advanced technologies and systems that have been developed for the F-35 JSF from the analyses of these three requirements areas.

However, it is the synergistic linkage of the various F-35 systems which provides revolutionary new capabilities. For example, fully automated sensor fusion of on- and off-board sensor data and sensor tasking provides superior situational awareness and reduces workload, allowing the pilot to proactively manage the F-35's signature by adjusting its flight path in response to pop-up threats. This is a capability that the previous generation of stealth aircraft (i.e. the F-117 and B-2) did not have, limiting their operational flexibility.[127]

Since Very Low Observable (VLO) aircraft will reduce the range and effectiveness of an adversary's sensors to a greater extent than non-VLO types, it also increases the effectiveness of friendly (on-board and off-board) electronic countermeasures. Moreover, the F-35's advanced radar can be used to electronically attack enemy air defences, reducing the requirement for supporting specialized EW/SEAD aircraft. The JSF's advanced networking capabilities, which are not available in contemporary Generation 4 and 4.5 fighters,[128] allows for the automated tasking of off-board sensors and complementary sharing of the resulting data to create a common operational picture, and similarly decreases the need for specialized Airborne Warning and Control System (AWACS) support aircraft. Thus, the integration of these various

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[127] For example, the F-117 flew pre-planned flight paths based on known threats. One was downed during the 1999 bombing of Serbia after Serbian forces relocated some of their SAM sites. See Shimooka, *F-35 and the Future of Canadian Security*…, 6, 8.

[128] *Ibid.*, 6.

advanced capabilities gives the F-35 an unprecedented level of operational and tactical flexibility which is simply not available in current Generation 4 and 4.5 fighters. The F-35's VLO signature coupled with fully automated sensor fusion therefore provides needed capability in the future battlespace beyond "day one" of a future air campaign scenario,[129] and is essential to maintaining *relative* capability in the future evolving battlespace beyond the next decade.

To sum up, there are significant technological improvements being incorporated into the JSF weapon system design. These improvements resulted from detailed analyses of operational requirements in a number of key functional domains early in the program. However it is the synergistic linking of numerous advanced systems together through sensor fusion, integrated into a smart and reliable VLO aircraft that can leverage off the information domain, which is producing a revolutionary leap in fighter aircraft capabilities. This leap is creating a significant paradigm shift in air combat tactics, operations and sustainment activities, and is expected to enable the F-35 to retain its operational effectiveness for several decades.

JSF Program Risk Areas

Weapon system procurement programs must manage five areas of risk: technical, schedule, cost, operational and sustainment. A program as ambitious as the JSF is no

[129] Many JSF critics assert that stealth is not required after the proverbial "first day of the war," when all air defence systems are degraded or destroyed after initial attacks by cruise missiles and stealthy aircraft. This is a narrow view of VLO benefits, and does not take into account the improved performance and lethality of advanced weapon systems or other capabilities such as "shoot and scoot" tactics used by mobile SAMs to improve their survivability. For a detailed discussion of the benefits that stealth brings to the modern battlespace, see Rebecca Grant, *The Radar Game: Understanding Stealth and Aircraft Survivability* (Arlington: Mitchell Institute Press, 2010); 34-55; http://sobchak.files.wordpress.com/2010/10/radargame.pdf; Internet, accessed 25 July 2014.

exception. This section will identify major areas of risk for the JSF Program. Costs associated with the Canadian NGFC Program will be discussed in a separate section.

Although the JSF program is introducing revolutionary military aerospace capabilities, the F-35 is not yet a mature and frozen design, and there have been numerous delays and cost overruns during SDD in order to overcome technical challenges. The U.S. Government Accountability Office (GAO) has issued numerous reports on the JSF program identifying technical, cost and schedule issues associated with the program. Their 2013 report states:

> While a program as complex and technically challenging as the F-35 would be expected to have setbacks, we have reported that the magnitude and persistence of the program's cost and schedule problems can be largely traced to (1) a highly concurrent acquisition strategy that significantly overlapped development, testing, and manufacturing activities; and (2) decisions at key junctures made without adequate product knowledge.[130]

Since the commencement of SDD in 2001, the program was rebaselined in 2004 to address weight and performance problems, and in 2007 because of cost growth and schedule slippage.[131] In March 2010, DOD declared that the program had breached Nunn-McCurdy statute cost thresholds, and, after a number of positive restructuring initiatives, the program was rebaselined yet again by the DOD in March 2012.[132] Some of the remaining areas of technical risk include: 1) the Helmet Mounted Display System (HMDS); 2) the limited capability of the Autonomic Logistics Information System (ALIS) as currently fielded; 3) carrier variant arresting hook redesign; and 4) bulkhead and rib cracking, which have resulted in some structural redesigns. The GAO report notes that considerable progress was made in 2012 to resolve these issues and overall risk has

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[130] GAO 13-309 *F-35 Joint Strike Fighter*…, 1.
[131] *Ibid*., 3.
[132] *Ibid*., 3-4.

decreased in these areas.[133] The other identified area of significant technical risk is the area of software block development, which is essential to achieving full sensor fusion, weapons and fire control, maintenance diagnostics, and propulsion management capabilities.[134] The GAO's 2012 JSF report identifies the magnitude of the JSF software development effort:

> The lines of code necessary for the JSF's capabilities have now grown to over 24 million—9.5 million on-board the aircraft. (By comparison, JSF has about 3 times more on-board software lines of code than the F-22A Raptor and 6 times more than the F/A-18 E/F Super Hornet). This has added work and increased the overall complexity of the effort… JSF software growth is not much different than other recent defense acquisitions, which have experienced from 30 to 100 percent growth in software code over time.[135]

Positive risk management efforts have been undertaken by both Lockheed Martin and the JSF Program Office and software correction trends are positive, which has led to increased confidence in the upcoming Block 2B fleet release required to declare USMC Initial Operational Capability (IOC) with the F-35B variant. Nevertheless, software development remains one of program's highest risks given its complexity and potential to impact the scope and schedule of the flight test program.[136]

The other area of significant concern with the JSF program is cost growth. The JSF program structure was designed with significant concurrency (i.e. overlap) between development, testing and production efforts. This has increased schedule and cost risk; testing drives engineering and design changes, which then drives changes to production.

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[133] The GAO report details the issues and mitigations for these technical areas of concern as of December 2012. *Ibid.*, 10-11.

[134] *Ibid.*, 11.

[135] Government Accountability Office, GAO 12-437 *Joint Strike Fighter: DOD Actions Needed to Further Enhance Restructuring and Address Affordability Risks*, (Washington, D.C., 2012), 18; available from http://www.gao.gov/products/GAO-12-437; Internet, accessed 14 September 2013.

[136] Software capabilities are developed, tested and delivered in three major blocks and an initial and final increment for each block. Block 2B is required for USMC IOC and delivers about 78% of sensor fusion capabilities, however Block 3.0, which provides full sensor fusion and additional weapons capabilities, is required for USAF and US Navy IOC. GAO 13-309, *Joint Strike Fighter*…, 11-15.

Concurrency is resulting in retrofit work to fix deficiencies discovered in testing to LRIP aircraft already delivered, also adding costs to the program, however a cost sharing agreement has been reached by DOD with Lockheed Martin to limit the cost to the U.S. taxpayer.[137] Additionally, estimated total program costs have grown 70% from $233 billion in 2001 to $395.7 billion in 2012, and the average procurement cost per aircraft has grown from $69 million to $137 million.[138] Given the increase in projected procurement costs, the U.S. Office of the Secretary of Defense's (OSD's) Cost Assessment and Program Evaluation (CAPE) office completed a sensitivity analysis of procurement quantities on unit costs, which showed costs to be much less sensitive to production quantities than previously expected.[139] A final affordability concern was also highlighted by the CAPE, in regards to long term operating and sustainment (O&S) costs for the JSF fleet, which were calculated to exceed $1 trillion, based on an estimated 30 year service life.[140] However, the result of the estimate depends upon the assumptions made, and recent press articles dispute some of the methodology used in the CAPE assessment. For example, senior USMC leaders noted that the assessment assumed the F-35B would be flown at full throttle in STOVL mode 80% of the time, and many costs

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[137] The JSF Program Office forecasts $900 Million in rework costs for 58 aircraft delivered to the U.S. services, and a further $827 Million until the design is frozen and full rate production begins. Cost sharing for concurrency issues through the LRIP 5 contract is 50/50 between DOD and Lockheed Martin, and 55/45 for non-concurrency cost increases until the contract ceiling is reached, after which the contractor assumes full responsibility for additional costs. *Ibid*., 19-20.

[138] It must be noted that the Average Procurement Costs quoted include the aircraft, ancillary equipment, technical data, support and training equipment, and initial sparing. Furthermore, it is also the average cost for all three variants which will be paid by U.S. taxpayers. Canadian procurement costs will be different and are discussed in detail in a separate section. See Table 1, *Ibid*., 5.

[139] Currently the U.S. services plan to buy 2,443 aircraft, and partner countries an additional 697 aircraft. The CAPE analysis estimated that if the U.S. services cut their procurement numbers to 1500 aircraft (a 38% cut to U.S. numbers and a 30% cut to the total number of deliveries), unit prices would increase by 9%. Furthermore, if the U.S. bought 1,500 and the international partners 0 (a roughly 50% overall production cut), unit costs would increase 19%. *Ibid*., 25.

[140] The GAO and CAPE estimate notes that this value is expected to be 60% higher than the aircraft types the JSF will replace. *Ibid*., 26.

were extrapolated from the older AV-8B Harrier the F-35B is designed to replace;[141] also of concern are "unfair projections of inflation."[142] In fact, the JSF Program Office has revised the CAPE O&S costs down to $857 billion.[143] A final cost concern driven by schedule slippage is how the various U.S. and international military services are being forced to bridge the gap between the JSF and the aircraft they are slated to replace. This has in some cases forced additional aircraft procurements (such as the F/A-18E/Fs for the USN) and additional costs to extend the useful lives of legacy aircraft.[144]

While there have been significant problems with the development and fielding of the F-35 JSF to date and there are still some significant up-front risks associated with its concurrency structure, the GAO report does note that the program is stabilizing since the March 2012 restructure and key indicators are trending positively.

Canadian Involvement in the JSF Program

As previously noted, Canada has been involved with the JSF program since 1997, when it signed a memorandum for participation in the JSF Program CDP, and contributed $15.2 million ($10.6 million U.S.).[145] As per Table 2, Canada committed $10

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[141] In addition to some incorrect assumptions, the USMC also estimated that once the three fleets the F-35B is designed to replace are completely retired (the AV-8B, F/A-18 and EA-6B), it is expected to save the Service $520 million per year. See Colin Clark, "Marines Put F-35B Flight Costs 17 Percent Lower than OSD," *Breaking Defense*, 21 August 2013; http://breakingdefense.com/2013/08/marines-put-f-35b-flight-costs-17-percent-lower-than-osd/; Internet, accessed 16 November 2013.

[142] Aaron Mehta and Marcus Weisgerber, "Kendall: F-35 Sustainment Costs Likely to Drop," *Defense News*, 04 September 2013, http://www.defensenews.com/article/20130904/DEFREG02/309040014/; Internet, accessed 16 November 2013.

[143] *Ibid*.

[144] GAO 13-309, *Joint Strike Fighter*…, 25, 26-27.

[145] Department of National Defence, *Next Generation Fighter Capability Annual Update, August 2013* (Ottawa: DND Canada, 2013), 11; http://www.forces.gc.ca/assets/FORCES_Internet/docs/en/about-reports-pubs/ngfc-annual-update-2013.pdf; Internet, accessed 08 November 2013.

million to this phase of the program, and the U.S. contributed another $50 million to the Canadian partnership contribution. This was, by far, the best cost-share ratio for any nation participating in CDP. Canada's participation in CDP ensured that Canada had knowledge of the program's requirements and how they evolved, access to the technologies being developed, and an understanding of how to best involve Canadian industry.[146]

Canada continued its participation in the program's SDD phase, and directly contributed $139.4 million ($94.4 million U.S.) to the program and a further $77.9 million ($50 million U.S.) to Canadian aerospace industries through Industry Canada's Strategic Aerospace and Defence Initiative (SADI), formerly Technology Partnership Canada.[147] This participation continued Canada's exposure to the aircraft, test data, technologies, new management and engineering approaches, and also increased opportunities for Canadian industrial participation in the program.[148]

In December 2006, Canada signed on to the PSFD MOU as a partner. While the MOU provides a framework that allows the partners to cooperate in the production, sustainment and follow-on development (i.e. upgrades) of the F-35, it does not commit Canada to actually purchase the aircraft.[149] However should Canada continue its participation in the program, the benefits would include continuing opportunities for

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[146] George Macdonald (LGen ret'd), "Canada's Partnership in the Joint Strike Fighter Program," *On Track* 16 no. 2 (Summer 2011): 17; http://cda-cdai.ca/cdai/uploads/cdai/ontrack16-2.pdf; Internet, accessed 09 April 2013.

[147] SADI investments are repayable by industry to Canada. DND, *NGFC Annual Update August 2013*…, 11.

[148] *Ibid*.

[149] However, the implication is that industrial benefits would not continue if Canada did not eventually procure the aircraft. Although this may appear intuitively obvious, this fact was not clearly communicated by DND to senior minsters when the decision to sign the PFSD MOU was being solicited. OAG, *Spring 2012 Report…,*19.

Canadian industry, involvement and influence in future upgrade decisions, reduced acquisition costs, and savings in sustainment costs resulting from the collective purchase and management of spares required to support the projected global F-35 fleet.[150] The current ceiling for Canada's participation in this phase is $551.6 million U.S., of which Canada has contributed $167.5 million ($162.5 million U.S.) as of 30 April 2013.[151]

In summary, Canada has participated since 1997 in the largest defence acquisition program in the history of the U.S., which has provided unprecedented access to key weapon system requirements, technologies, testing and performance data. Also, Canada is now in a partnership arrangement with the three U.S. and seven other allied military services, which provides a measure of influence on the JSF's design, and mitigation activities for sustainment, production, upgrades and contracting issues. The cost of Canada's participation to date has been $322.1 million ($267.7 million U.S.) directly to the program along with $77.9 million ($50 million U.S.) to Canadian aerospace companies through SADI.[152] However, Canadian industry has benefitted handsomely from Canadian participation in JSF and is now well-positioned to exploit future contracting opportunities. Canadian companies have so far secured $488 million U.S. in design, development, production and sustainment contracts directly as a result of Canada's participation in the JSF Program.[153] Industry Canada also reports up to $9.264 billion U.S. more in currently identified potential opportunities for the duration of the

[150] DND, *NGFC Annual Update August 2013…*, 11.

[151] A country's maximum contribution in PSFD may only be increased through an amendment to the MOU. *Ibid*.

[152] *Ibid*., 12.

[153] Industry Canada, *Canadian Industrial participation in the F-35 Joint Strike Fighter Program, Spring 2013* (Ottawa: Industry Canada, 2013): 5, 8; http://www.ic.gc.ca/eic/site/ad-ad.nsf/vwapj/Spring_IP_Report_to_Parliament_v12_Final_eng.pdf/$file/Spring_IP_Report_to_Parliament_v12_Final_eng.pdf; Internet, accessed 08 November 2013.

JSF's life cycle,[154] which will likely increase as the required global sustainment program matures. This amount adequately offsets the $9 billion (Canadian) estimated total purchase costs of the F-35 as forecasted by DND,[155] and is expected to exceed traditional Industrial and Regional Benefits (IRBs).[156]

F-35 Costs from a Canadian Acquisition Perspective

There is significant amount of misunderstanding about JSF costs, especially as related to the RCAF acquisition effort. In order to fully understand acquisition costs, it is necessary to understand four types of costs associated with procurement:[157] recurring flyaway cost, procurement cost, acquisition cost, and total ownership cost.

The basic unit of cost analysis is known as Unit Recurring Flyaway (URF) cost, and includes program management, hardware, airframe, vehicle and mission systems, propulsion and engineering change orders.[158] Average Production Unit Cost (APUC) includes all the items covered by URF costs plus expenditures for ancillary mission equipment (e.g. pylons, specialized aircrew life-support equipment), and initial spares as well as technical data, publications and support/test equipment.[159] Program Acquisition Unit Cost (PAUC) includes all APUC costs as well as costs for facility construction

[154] *Ibid*., 5-6.

[155] Table 2 of the NGFC Annual update summarizes DND's total estimated life cycle costs. DND, *NGFC Annual Update August 2013*…, 27.

[156] IRB Policy ensures that companies that have won Government of Canada defence and security contracts place business activity in the Canadian economy equal to 100 percent of the contract value. See Industry Canada, "Industrial and Regional Benefits," http://www.ic.gc.ca/eic/site/042.nsf/eng/home; Internet, accessed 30 December 2013.

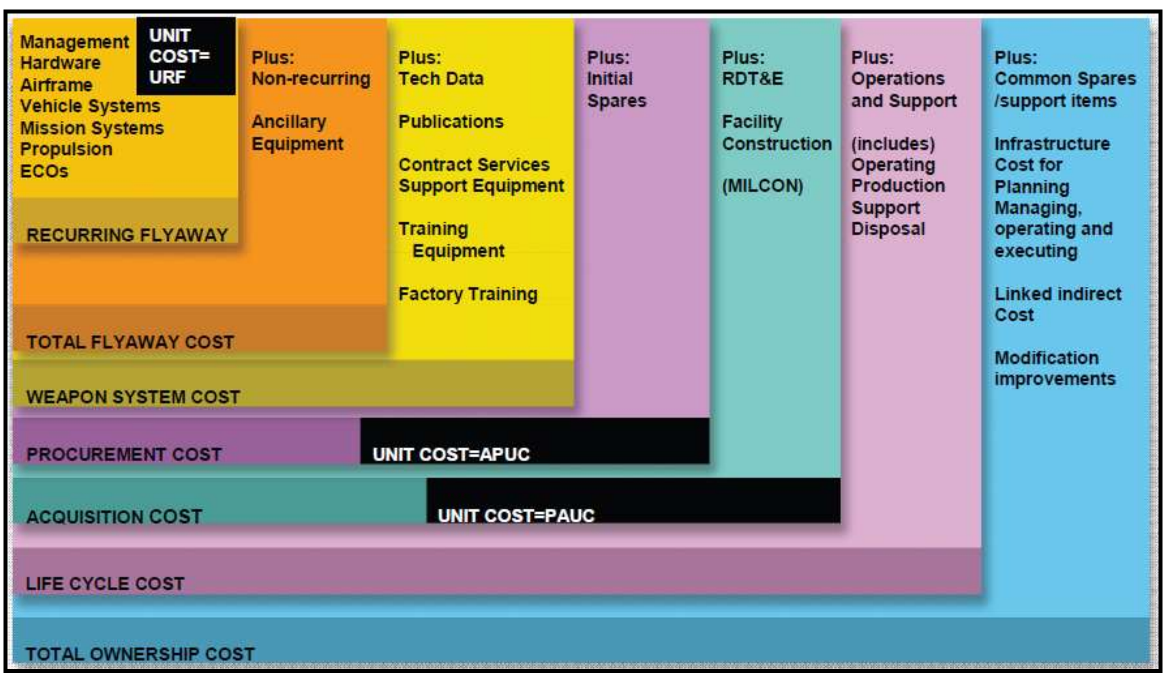
[157] Procurement is a specific sub-process of acquisition.

[158] URF cost, as its name implies, includes costs for an aircraft to be flyable, including the costs of the engine and the mission systems. It therefore represents the basic cost to procure one unit. See David Perry, "Canada's Joint Strike Fighter Purchase: Parsing the Numbers," *On Track* 16 no. 2 (Summer 2011): 19; http://www.cdainstitute.ca/images/ontrack16n2.pdf; Internet, accessed 07 December 2013.

[159] DND, *NGFC Annual Update, August 2013*…, 9, 16.

(infrastructure), and for research, development, test and evaluation.[160] When Canadian authorities use the term "unit cost", they are usually referring to URF cost, whereas U.S. authorities are usually referring to either APUC or PAUC; this is an important distinction, since the PAUC for a single aircraft could be almost twice the amount of its URF cost.[161] Finally, total ownership costs also include, in addition to all relevant procurement costs, all expenditures related to life cycle support, including operation and support costs, disposal activities, upgrades, all spare parts procurements and indirect costs such as weapon system management activities over the service life of the aircraft. Table 5 below identifies the various cost categorizations associated with weapon system procurement, and their detailed composition.

Table 5 – Aircraft Cost Composition and Definitions



Source: Perry, Canada's Joint Strike Fighter Purchase: Parsing the Numbers…, 18.

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[160] *Ibid*.
[161] *Ibid*.

With a proper understanding of the various cost definitions used by different agencies, it is now possible to understand why there is a divergence between Canadian and U.S. cost figures for the JSF. Furthermore, the GAO's most recent PAUC of $161 million and APUC of $137M *is the estimated average cost to the U.S. taxpayer for all three JSF variants*.[162] The RCAF was planning to procure the F-35A Conventional Take-Off and Landing (CTOL) variant of the JSF, the model to be produced in the largest numbers with the lowest projected URF cost. Table 6 below identifies all life cycle costs for the Canadian JSF Program.

The NGFC Life Cycle Cost (LCC) assessment documents an acquisition budget of $8.99 billion dollars for the procurement of 65 F-35A Lightning II fighters. This amount includes all acquisition costs including identified URF costs of $6.187 billion,[163] concurrency updates, alternate manufacturing sources and ancillary equipment buys of $352 million, sustainment set-up costs of $1.068 billion, initial sparing, ammunition, infrastructure upgrades, initial cadre training, project management and miscellaneous costs of $1.041 billion, and $342 million of identified contingency funds.[164] The total Canadian F-35 program cost of approximately $45.7 billion often referenced in the press represents the total cost of buying, operating, sustaining, replacing expected losses (i.e. attrition buys), and disposing of the F-35 fleet over its service life, not just the acquisition costs for the 65 aircraft the RCAF wishes to buy.[165]

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[162] See Table 1, GAO 13-309 *F-35 Joint Strike Fighter*…, 5.

[163] This equates to a calculated Canadian URF cost of ~$95 million, which is above the DND calculated figure of $88.5 million using a weighted 2017-2023 buy profile. For costs and risks including DND's sensitivity analysis, see DND, *NGFC Annual Update August 2013*…, 32-35.

[164] The $8.99 billion DND procurement cost produces a Canadian F-35A APUC of $138.3 million.

[165] This difference is analogous to highlighting the total cost of owning a car (which includes gas, insurance, maintenance and buying spare/replacement parts for the entire duration of its useful life) as opposed to its purchase price. When DND releases cost information associated with a weapon system procurement, it is typically budgeted or total forecasted acquisition costs which are provided to the public.

Table 6 – Full Canadian Program Cost Estimate for the F-35 JSF (2013)

LCC Phases	Cost Element		Estimate $Million CAD (BY)	
Development	Production, Sustainment, Follow-on Development MOU		499	
	Project Management Office		28	
	Contingency		79	
Development Total				606
Acquisition	Unit Recurring Flyaway Cost	F-35A Airframe	3,208	
		Vehicle Systems	764	
		Mission Systems	1,261	
		Propulsion System	846	
		Engineering Change Orders	108	
	URF Total			6,187
	Concurrency Modifications			24
	Diminishing Manufacturing Sources			70
	Ancillary Equipment			258
	Sustainment Set-Up	Training Devices	372	
		Support Equipment	428	
		Autonomic Logistics	72	
		Labour	196	
		Depot Stand-Up	0	
	Sustainment Set-Up Total			1,068
	Initial Spares			236
	Reprogramming Lab			219
	Infrastructure			244
	Ammunition			59
	Initial Training			116
	Project Management Office			123
	Other			44
	Contingency (Note 1)			342
Acquisition Total				8,990
Sustainment	Unit Level Consumption			4,818
	Depot Maintenance			773
	Contractor Support			2,115
	Sustaining and Other Support	Sustaining Support	3,164	
		Other Support	689	
	Total Sustaining Support			3,853
	Contingency			3,496
Sustainment Total				15,055
Operating	Personnel	Direct Personnel	5,809	
		Support Personnel	4,789	
	Total Personnel			10,598
	Operating	Aviation Fuel	4,330	
		Unit Level Consumption	1,704	
		Base Support Cost	3,225	
	Total Operating			9,259
Total Operating				19,857
Disposal	Disposal		129	
	Contingency		39	
Disposal Total				168
Full Program Life-Cycle Cost Estimate				44,676
Attrition Replacement (Note 2)				1,015
				45,691

Note 1: The full amount of acquisition contingency suggested by the Life-Cycle Cost Framework would be approximately $1,550 million (Table 4). If the full available contingency was required, the shortfall could be met by buying fewer aircraft.

Note 2. It is estimated that seven to eleven aircraft could be lost over the program life-cycle and the cost to replace these lost aircraft could be in the order of $1 billion. This cost is not included in the Life-Cycle Cost estimate. Sustainment and Operating estimates assume a constant number of 65 aircraft.

Source: DND, *NGFC Annual Update, August 2013*…, 27, Table 2.

The updated cost assessment by DND for the NGFC project from which Table 6 and other JSF cost data has been referenced, was built in response to the critical 2012 OAG Report. That report had concluded that full life cycle costs were not presented and were likely underestimated by DND, and therefore recommended that DND "should refine its estimates for complete costs related to the full life cycle of the F-35 capability" and to "regularly provide the actual complete costs incurred throughout the full life cycle of the F-35 capability."[166] However further context is required to dispel the negative implications produced by the OAG report. While DND originally developed life cycle costs out to 20 years, vice developing full expected life cycle costs from project initiation to F-35 disposal as per Treasury Board guidelines, the use of 20 years was based on several factors:

- 20 years has been a standard practice and norm for reporting to Treasury Board for all major DND projects and the NGFC program was not unique in this regard;
- The DND investment plan covers a 20-year period;
- At the time, the 20-year period aligned well with anticipated sustainment contracting authorities to be sought from Treasury Board; and
- The reliability of cost data after 20 years is suspect with the only variances in the longer term often attributable to inflation and foreign exchange.[167]

Additionally, the OAG report also highlights inconsistent 20-year cost estimates produced by DND. More specifically, for decision-making purposes, DND used a $25.12 billion estimate generated in 2010, whereas in responding to the 2011 Parliamentary

[166] OAG, *Spring 2012 Report*... 26-30, 35.
[167] Department of National Defence, *Next Generation Fighter Capability Annual Update, December 2012* (Ottawa: DND Canada, 2012), 42; http://www.forces.gc.ca/assets/FORCES_Internet/docs/en/about-reports-pubs/ngfc-annual-update-2013.pdf; Internet, accessed 08 November 2013.

Budget Office (PBO) report, DND used $14.7 billion.[168] However, once again, context is important. The PBO report was written in response to a request from two Canadian Members of Parliament (MPs) in relation to the Government's proposed acquisition of the F-35; more specifically, the PBO was requested to 1) identify the premium Canada might pay from a sole-sourcing decision; and 2) provide an independent forecast of the acquisition and sustainment costs of the F-35.[169] Accordingly, DND's response to the PBO did not include contingency ($860 million), operating costs ($4.83 billion) or national defence personnel costs ($4.74 billion), in their response. The acquisition and sustainment costs identified ($9 billion and $5.7 billion respectively) were almost identical to the decision-making 20-year estimates produced by DND in 2010 ($8.98 billion and $5.71 billion respectively).[170] As a final point, if the total cost generated by the new KPMG cost model as documented in the *2012 NGFC Annual Update* is applied to a 20-year time period vice the total estimated 42-year program life cycle, the original DND estimates from 2010 compare well to the new model output ($25.12 billion vice $25.83 billion respectively).[171]

To summarize, there are differences in F-35 cost figures depending upon the agency providing the information and the context in which it is produced. U.S. cost figures for the JSF must be put into context and cannot be directly used to assess Canadian JSF program costs for comparison purposes. The various JSF program cost values released by Canadian government departments and quoted by the press also have different meanings depending upon how they were calculated. What is clear is that total

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[168] OAG, *Spring 2012 Report…* 27-28.

[169] PBO, *An Estimate of the Fiscal Impact of Canada's Proposed Acquisition…,* 6-7.

[170] OAG, *Spring 2012 Report…* 27.

[171] Note that disposal costs are not included in in the 20 year estimates. DND, *NGFC Annual Update, December 2012…*, 41-46.

Canadian *acquisition* costs have consistently been estimated to be about $9 billion, and the best current estimate for the F-35's *total* Canadian life cycle cost is approximately $45.7 billion for 30 years of service if forecasted attrition buys are included.

JSF Program and Canada - Summary

The F-35 JSF evolved from the amalgamation of previous U.S. service requirements for next generation replacement fighter aircraft. The program has expanded to include eight international partner countries including Canada as well as four other non-partner nations, which collectively intend to procure more than 3,100 aircraft at this time. The JSF design has been driven by an optimized balance between service requirements and cost. These service requirements have driven technological improvements in the areas of sensor fusion, affordable stealth, and autonomous logistics. Collectively these advances provide revolutionary next generation fighter aircraft capability improvements as integrated in the F-35. However, the aircraft is still not a mature design, and not all areas of technical risk have been fully mitigated. Furthermore, the program management principle of concurrency has led to developmental cost increases and schedule delays, and full-rate production is not scheduled to begin before 2019. Nevertheless, the program now appears to be stabilizing and key project management indicators are now trending favourably to mitigate remaining technical, cost and schedule risk.

Canada has been involved with all phases of the JSF Program since 1997. This has provided numerous benefits including unprecedented access to requirements, technologies, testing and performance data on the one hand, and industrial benefits on the other. Canadian companies have so far secured $488 million in contracts directly as a result of Canada’s JSF participation, which has cost the Canadian taxpayer $322 million as of 2013. These companies are well positioned to exploit future contracting opportunities, which have been currently assessed at more than $9 billion and will likely increase as the global sustainment program grows. Finally, the identified acquisition cost for the purchase of 65 F-35s has been consistently pegged at $9 billion, and DND currently estimates the total costs to the Canadian taxpayer for the F-35 to be $45.7 billion over 30 years.

5. OTHER POTENTIAL CF-18 REPLACEMENT OPTIONS

> *During the [CF-18 replacement] evaluation process, it was determined that only five manufacturers in the western world produced fighter planes: Boeing (which acquired McDonnell Douglas and produced the F-18), Lockheed Martin (JSF), Saab (Gripen), Dassault (Mirage and Rafale) and British Aerospace-EADS (Eurofighter).*
>
> *- Lieutenant-General (Ret'd) Ken Pennie*[172]

If the F-35 JSF is not the right solution to replace the CF-18 Hornet as Canada's next fighter aircraft as many critics contend, the next question which must be answered is: what are the other viable options? Given the general listing of requirements identified in Chapter 3 of this paper, it is possible that one or more of the currently available advanced western-built[173] fighter aircraft on the market, none of which are fifth generation models, may still be able to meet RCAF needs for an ostensibly lower cost, better industrial benefits and at less overall risk to Canada. As noted previously, maintaining the *relative* levels of present capability given the evolving FSE will therefore demand a higher performing replacement fighter than the current CF-18 Hornet. The CF-18 is commonly considered a fourth generation fighter; clearly, any replacement fighter should be at least a Generation 4.5 design, especially if it is expected to remain in Canadian service for 20 to 30 years. The accepted western-built Generation 4.5 contenders are the Boeing F/A-18E/F Super Hornet; British Aerospace-EADS Eurofighter Typhoon; Dassault Rafale, and Saab JAS-39 Gripen E/F (also known as the

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[172] Pennie, *Strategy and the F-35…, 37*.

[173] While there are some excellent non-Western fighter designs on the market today, the ability to certify and sustain them to Canadian airworthiness standards is highly problematic (hence LGen Deschamps' identification of the Certification requirement to the SCOND). For example, many airworthiness standards are fundamentally different or non-existent outside the West. In many cases, the required documentation, or information from which a finding of compliance would normally be made is simply not available such that equivalency of design, certification and continuing airworthiness standards cannot be proven. The author is currently the Type Certificate Holder for the CF-18 Hornet and as such is responsible for the continuing airworthiness of Canada's CF-18 Hornet fleet.

Gripen NG for Next Generation). Aside from the currently available Generation 4.5 aircraft, another CF-18 replacement option cited by JSF critics is the possible acquisition of a UAV/UCAV system. These alternatives to the JSF will be summarized below, with a more detailed assessment of technologies and risks for each candidate provided at Appendix 2.

Boeing F/A-18E/F Super Hornet

The F/A-18E/F Super Hornet is the second major upgrade to the F/A-18 aircraft program.[174] While both F/A-18A-D and F/A-18E/F fighters are considered to be Hornet family fighters, the Super Hornet is in fact an entirely new aircraft designed to replace the earlier A-D models. The Super Hornet has less than 40% commonality with previous F/A-18A-D versions,[175] and is 25% larger than the "classic" Hornet. It has new, larger and more powerful engines, greater range due to increased internal and external fuel capacity, a larger wing with two more hard points for pylon carriage of additional weapons, improved tactical sensors, an improved EW system and improved cockpit technologies.[176] A future variant, known as the Advanced Super Hornet (ASH) is

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[174] F/A-18C/D aircraft replaced the initial A/B models of the Hornet, and similarly, the F/A-18E/F variants have been designed to replace the older F/A-18C/Ds and upgraded F/A-18A/Bs.

[175] Defense Industry Daily, "Super Hornet Fighter Family MYP-III: 2010-2014 Contracts," http://www.defenseindustrydaily.com/Super-Hornet-Fighter-Family-MYP-III-2010-2013-Contracts-06392/; Internet, accessed 30 December 2013.

[176] Australian National Audit Office, *Management of Australia's Air Combat Capability – F/A-18 Hornet and Super Hornet Fleet Upgrades and Sustainment* (Canberra: DMO Australia, 2012); 112; http://www.anao.gov.au/~/media/Files/Audit%20Reports/2012%202013/Audit%20Report%205/201213%20Audit%20Report%20No%205%20OCRed.pdf; Internet, accessed 20 January 2014.

currently under development by Boeing and Northrop-Grumman, a key supplier, at their own cost. [177]

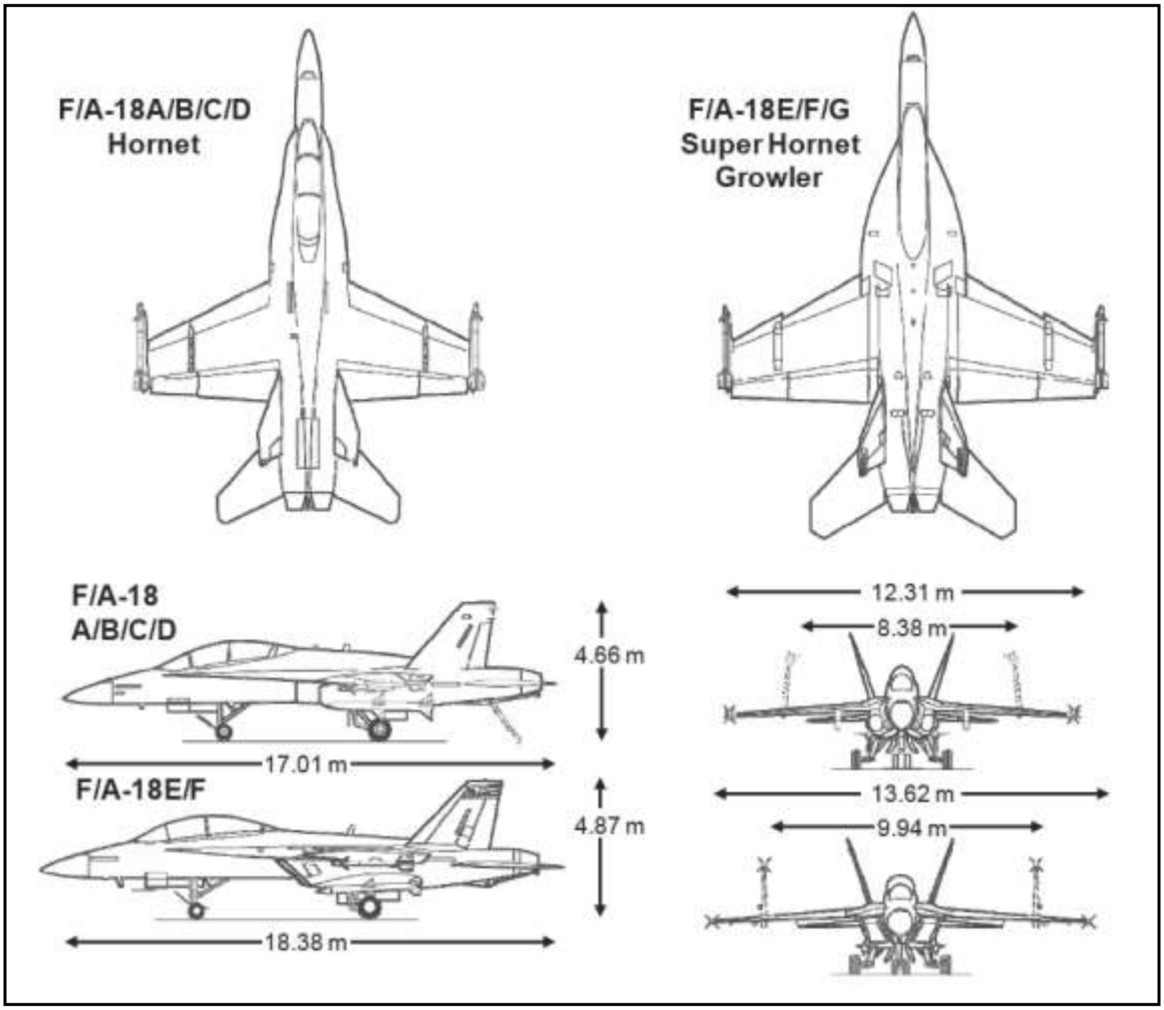

Figure 5 – Comparison of Classic F/A-18A-D Hornet with F/A-18E/F Super Hornet

Source: ANAO, "Management of Australia's Air Combat Capability…, 113.

[177] Fox Business News, "Boeing aims to keep building F/A-18 jets through 2020," http://www.foxbusiness.com/technology/2013/05/09/boeing-aims-to-keep-building-fa-18-jets-through-2020/; Internet, accessed 04 January 2014.

Eurofighter Typhoon

The Eurofighter Typhoon evolved out of a 1979 U.K Royal Air Force (RAF) requirement known as Air Staff Target 403 to replace their Harrier and Jaguar fighters.[178] Common requirements with other nations eventually led to the European Fighter Aircraft (EFA) program in 1982, when the U.K., along with France, West Germany, Italy and Spain agreed to develop a common air superiority fighter for the 21st century.[179] France eventually pulled out to develop their own design.[180] The remaining partners eventually negotiated acceptable work shares between them and set up a production consortium for the aircraft (Eurofighter GMBH) and engines (Eurojet Turbo GMBH), rebaselining the effort in 1992, which then evolved into the Eurofighter 2000 program.[181] First entering service in 2003, the highly manoeuvrable twin-engine Eurofighter, also dubbed Typhoon for the international export market, is optimized for the air defence mission, but also maintains an evolving air-to-ground strike capability.[182]

[178] Target Lock, "Eurofighter Typhoon: Origins," http://www.targetlock.org.uk/typhoon/index.html; Internet, accessed 01 February 2014.

[179] Aerospaceweb.org, "Eurofighter Typhoon Multi-Role Fighter," http://www.aerospaceweb.org/aircraft/fighter/typhoon/; Internet, accessed 01 Febuary 2014.

[180] The French design became the Dassault Rafale. See Target Lock, *Eurofighter Typhoon: Origins*.

[181] The program was rebaselined to retain Germany's partnership. After German reunification, in a desire to cut costs, the new German government wanted to defer their deliveries until 2002, and remove some equipment the Luftwaffe considered unnecessary, which resulted in 30% cost reduction. *Ibid*

[182] Aerospaceweb.org, *Eurofighter Typhoon Multi-Role Fighter*....

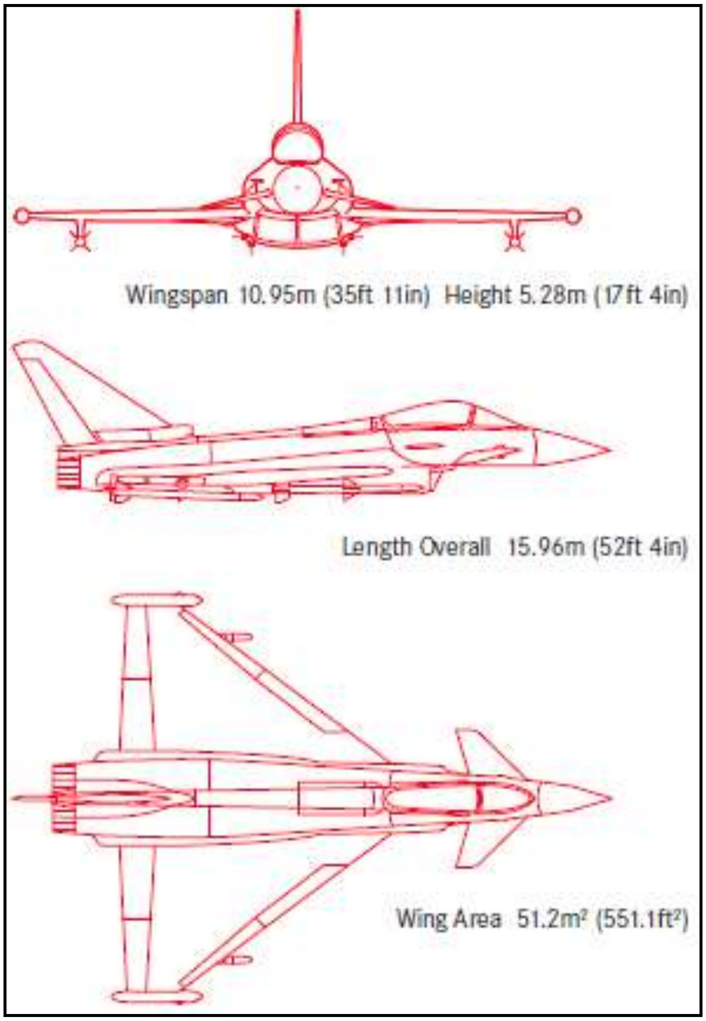

Figure 6 – Eurofighter General Characteristics

Source: Eurofighter Jagdflugzeug GmbH, *Eurofighter Technical Guide*…, 9.

Dassault Rafale

The Dassault Rafale, like the Eurofighter, also evolved from the EFA program, which began in 1982. In 1985, the French, wanting a lighter multirole aircraft suitable for carrier use, and wanting to retain design authority for the program, chose to pursue their own development effort.[183] Rafale was designed from the start to be a multirole platform (Dassault identifies the aircraft as "onmirole"), equally capable of performing many required roles, including air defence/air superiority, reconnaissance, close air support, precision strike, anti-ship attack, nuclear strike and buddy refuelling.[184]

Constructeur	Dassault Aviation
Longueur	15,27 m
Envergure	10,21 m
Hauteur	5,34 m
Masse à vide	10'220 kg
Masse maximale au décollage sans charges externes	14'900 kg
Masse maximale au décollage	24'500 kg
Capacité des réservoirs de carburant, internes/externes	4'680 kg/6'720 kg
Constructeur des réacteurs	Snecma
Nombre et types de réacteurs	2x M88-2
Poussée maximale par réacteur, sans/avec post-combustion	50 kN/75 kN
Canon	30 mm GIAT 30M791
Charges externes 14 points d'emport externes pour - missiles air-air - réservoirs supplémentaires de carburant - nacelle de reconnaissance aérienne et d'illumination de cibles - armes air-sol	jusqu'à 9'500 kg

Performances avec équipements pour le service de police aérienne:	
Distance minimale de décollage sans/avec post-combustion	820 m/590 m
Distance minimale d'atterrissage	490 m
Vitesse ascensionnelle maximale	> 250 m/s
Vitesse maximale à basse altitude	1'350 km/h
Nombre maximal de Mach	Mach 1.8
Facteurs de charge	de –3,2 à +9 g
Plafond pratique	15'240 m MSL

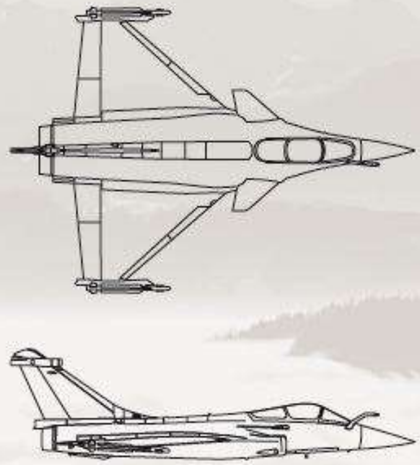

Figure 7 – Dassault Rafale Technical Characteristics

Source: Rafale International Switzerland, *Rafale Technical Fiche*…, 8.

[183] Defense Industry Daily, "France's Rafale Fighters: Looking for Love…," http://www.defenseindustrydaily.com/Frances-Rafale-Fighters-Au-Courant-in-Time-05991/; Internet, accessed 16 February 2014.

[184] Dassault Aviation. "Rafale – Omnirole by design." http://www.dassault-aviation.com/en/defense/rafale/omnirole-by-design/; Internet, accessed 15 February 2014.

Saab JAS-39E/F Gripen NG

The Saab JAS-39 Gripen is a single-engine, lightweight multirole fighter which was designed to replace the Swedish Air Force's Saab Draken and Viggen fighters.[185] The Gripen A (single seat) and -B (twin seat) models were designed specifically for the Swedish Air Force, however the design was refined and improved as the C/D[186] export variant with improved performance thanks to an uprated engine, integration of NATO compatible weapons, an improved cockpit and in-flight refuelling capability.[187] The Gripen E/F[188] is the latest evolution of the Gripen fighter, with some significant upgrade features from the previous Gripen C/D design including yet better performance thanks to a new engine, more internal fuel capacity, two additional fuselage weapon pylons, and upgraded avionics including new computers, an IRST and an AESA radar.[189]

Gripen NG is still a developmental effort and not yet in service with any nation's forces, however the Swedish government have committed to purchasing 60 Gripen Es which are due for delivery starting in 2018 and the design has also won fighter replacement competitions in Switzerland[190] and most recently, in Brazil.[191]

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[185] Aerospaceweb.org, "Saab JAS 39 Gripen Multi-Role Fighter," http://www.aerospaceweb.org/aircraft/fighter/gripen/; Internet, accessed 06 April 2014.

[186] Gripen C is the single seat variant and Gripen D is the twin seat variant.

[187] Aerospaceweb.org, *Saab JAS 39 Gripen Multi-Role Fighter*….

[188] Similarly, Gripen E is the single seat and Gripen F is the twin seat variant of the NG design.

[189] The Gripen A/B/C/D is powered by a Volvo variant of the General Electric F404 engine, which powers the F/A-18 A/B/C/D Hornet. Similarly, the Gripen NG is powered by a variant of the General Electric F414 engine, which powers the F/A-18E/F/G Super Hornet and Growler. Saab Group, "Gripen E – A High Tech Fighter," http://www.saabgroup.com/en/Air/Gripen-Fighter-System/Gripen-and-Switzerland/Gripen-E/The-Fighter/; Internet, accessed 06 April 2014.

[190] Defense Industry Daily, " Switzerland Replacing Old F-5 Fighters with New Gripen-E," http://www.defenseindustrydaily.com/switzerland-replacing-its-f-5s-04624/; Internet, accessed 06 April 2014.

[191] Defense Industry Daily, "F-X2: Brazil Picks Saab's JAS-39 Gripen NG over Rafale, Super Hornet," http://www.defenseindustrydaily.com/brazil-embarking-upon-f-x2-fighter-program-04179/; Internet, accessed 22 March 2014.

Figure 8 – Gripen NG Technical Characteristics

Source: JSF Nieuws, *Gripen Demonstrator Program*…, 5.

UAV/UCAV Solutions

The development and use of Uninhabited Aerial Systems (UASs) in the military sphere has grown significantly in recent years. UASs can aid forces directly or indirectly in combat, by providing information to friendly forces, but also perform strike missions against pre-planned, or high-value targets in some cases. However, there are still some significant challenges associated with UASs. Current systems are, in general, remotely piloted by a ground controller. Future concepts focus on increased autonomy, with less controller influence on mission conduct because providing situational awareness to an operator far removed from the air vehicle requires the use of significant signal bandwidth to transfer the required information,[192] especially during the course of a complex combat

[192] Michael Franklin, *Unmanned Combat Air Vehicles: Opportunities for the Guided Weapons Industry?* (London: Royal United Services Institute, 2008), 1,2; [archived document on-line]; available

engagement. Clearly, the use of large numbers of UCAVs operating simultaneously together cannot be realized with the present remote piloting framework. Accordingly, such significant technological challenges must still be overcome before UASs can conduct all doctrinal aerospace roles and missions and fully replace manned aircraft. Rather, it is expected that, for the foreseeable future, UASs will be used to complement the capabilities of manned aircraft, including, specifically those related to the complex environment of air combat in contested airspace.[193]

The USAF roadmap for UAS development identifies a fighter aircraft recapitalization plan which includes the use of medium sized UCAVs. These systems will be the successors to the current MQ-1 Predator and MQ-9 Reaper armed ISR UAVs, which will eventually be able to carry out a full range of doctrinal aerospace roles and missions, including counter-air ones.[194] Figure 9 below identifies the USAF's notional planning timelines associated with various classes of UASs. Of interest for aerospace control requirements is the evolution of the medium sized family of UASs, boxed in red.

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from: http://www.rusi.org/downloads/assets/Unmanned_Combat_Air_Vehicles.pdf; Internet, accessed 04 May 2014.

[193] For example, by 2032, the U.S. Navy's F/A-18E/F pre-Block II Super Hornet replacement may be a mix of manned, optionally manned or unmanned platforms, which will work with F-35C and F/A-18E/F Block II+ fighter aircraft within a system of systems. See DoN, *Naval Aviation Vision January 2012*..., 19, 31-32.

[194] Department of the Air Force, *United States Air Force Unmanned Aircraft Systems Flight Plan 2009-2047* (Washington, D.C. 2009) 34, 38-39; http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA505168; Internet, accessed 04 May 2014.

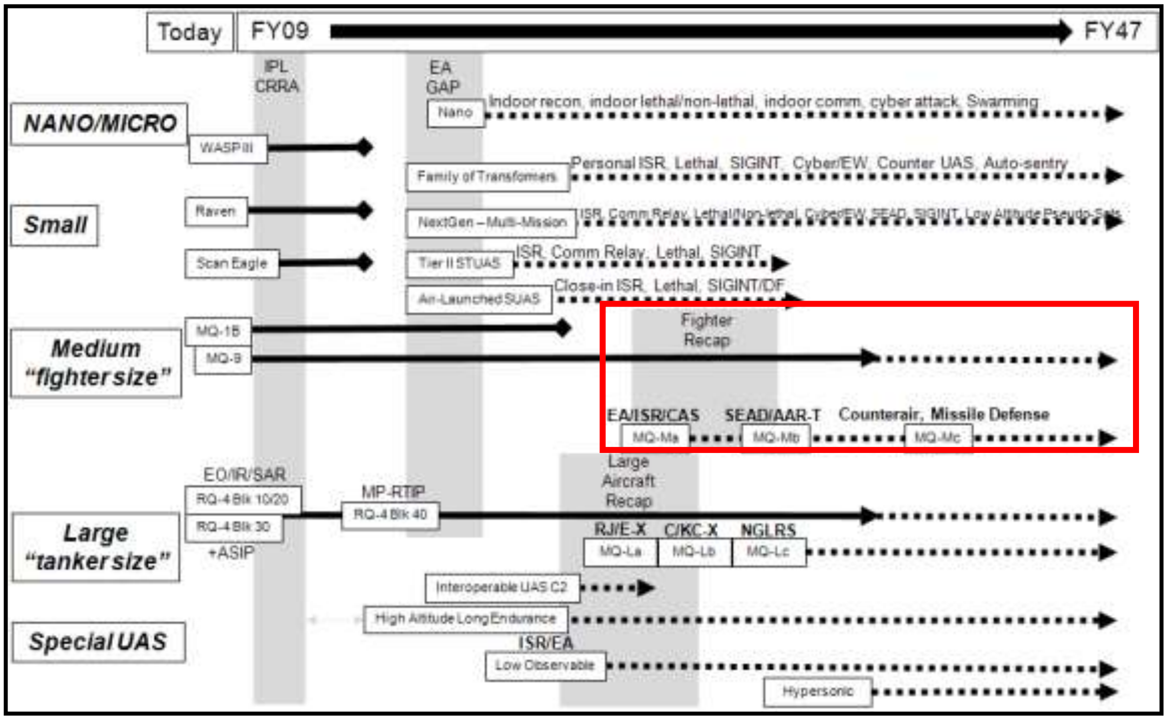

Figure 9 – Potential sets of platform capabilities for UAS

Source: DOAF, *United States Air Force Unmanned Aircraft Systems Flight Plan…, 34.*

According to the USAF, their planned medium sized UAS class will go through three phases of evolution, known as MQ-Ma, MQ-Mb, and culminating in MQ-Mc, each building upon the previous system until the full spectrum of capabilities required by combatant commanders world-wide is attained, sometime between 2025 and 2047.[195] Figure 10 below shows the medium class evolution in more detail.

[195] DOAF, *United States Air Force Unmanned Aircraft Systems Flight Plan*…, 38-39.

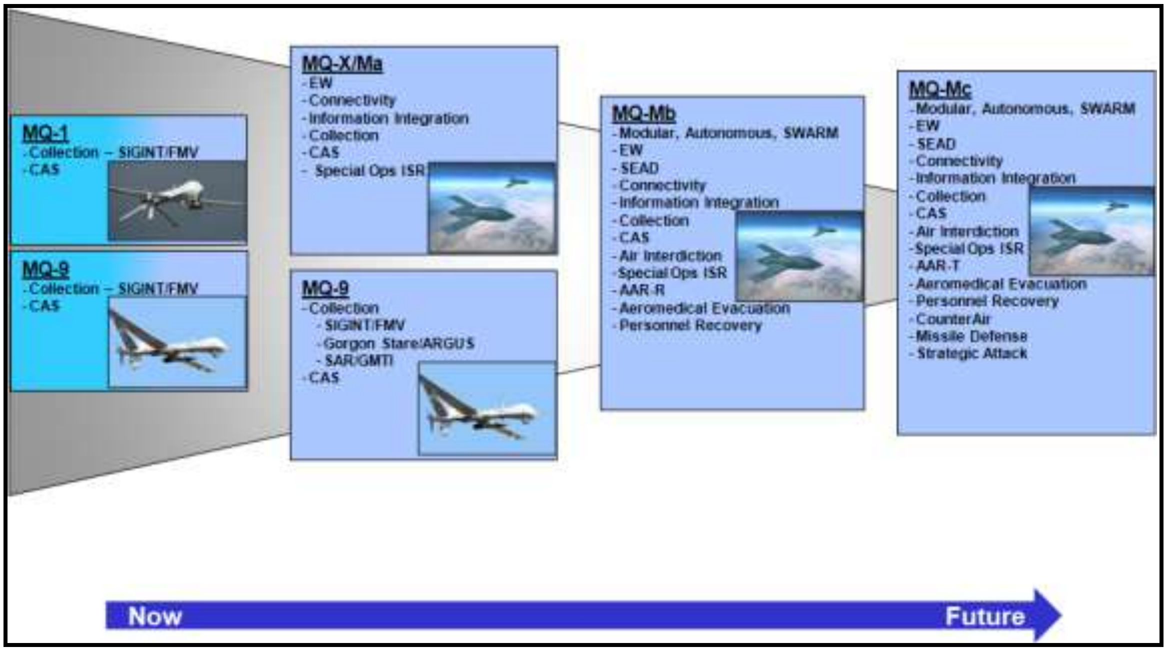

Figure 10 – Medium Class UAS Evolution

Source: DOAF, *United States Air Force Unmanned Aircraft Systems Flight Plan*…, 38.

The USAF planning map for UAS capabilities sees the concepts swarm and loyal wingman technologies as the next evolutionary step in the aerospace environment enabled by increased automation.[196] Automation will evolve from fully automated take-off and landing to include in-transit flight as well as automated ground-taxi.[197] The first level of loyal wingman will be incorporated into the MQ-Ma requirement to increase the mission effectiveness of manned platforms, with increased capabilities as automation

[196] Swarming consists of a group of partially autonomous UASs operating in support of allied manned and unmanned weapon systems while being monitored by a single operator, all linked together through an ad hoc wireless network. Loyal wingman technology refers to the concept of a UAS complementing a manned aircraft to execute a required mission by augmenting its sensors, control and weapons capabilities. See DOAF, *United States Air Force Unmanned Aircraft Systems Flight Plan*…, 34.

[197] *Ibid*., 39.

increases. In the long term, the SAF expects swarm technology to be incorporated into the MQ-Mb and -Mc requirements.[198]

As can be seen, while the various UASs fielded today provide key capabilities in the modern battlespace and show much future promise, they are not yet technologically mature to be considered as a viable replacement for the CF-18 Hornet. Additionally, the high accident and maintenance needs of UAVs have not generated predicted cost savings.[199] Based on this, and the RCAF's own experience with the CF-18 Hornet procurement, a mixed fleet solution to pair a UAS with a cheaper manned fighter is also not feasible, from a cost and personnel resource perspective.[200]

Analysis Summary of Non-JSF Contenders

Table 7 below comparatively summarizes the technologies, risks and total estimated Canadian acquisition costs[201] associated with each of the non-JSF contenders,

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[198] *Ibid*.

[199] Shimooka, *F-35 and the Future of Canadian Security*…, 6.

[200] The multi-role CF-18 Hornet was chosen to replace the CF-104 Starfighter, the CF-5 Freedom Fighter and the CF-101 Voodoo aircraft during the New Fighter Aircraft (NFA) program. An analysis commissioned by the RCAF during the NFA program showed that it would be cheaper to buy the most expensive fighter aircraft option than to buy an equal number of the two cheapest fighters, split between two fleets, in any reasonable combination. The result of this study was noted by Member of Parliament Laurie Hawn, a former RCAF fighter pilot, during a SCOND meeting to discuss the CF-18 replacement effort. See Parliament of Canada, *Standing Committee on National Defence Meeting no. 38 Minutes*….

[201] A detailed cost assessment for each non-JSF candidate aircraft is not possible with the available information. However, it is likely that the non-aircraft specific acquisition costs will be similar in magnitude for all of the contenders, but not specifically identical by category (e.g. initial sparing, simulators, training, ancillary equipment, required infrastructure upgrades, etc). Therefore, a high level interpretation of the publicly available cost information was used to determine whether or not the overall program acquisition costs for each option would be higher than the current JSF acquisition budget of $9 billion. URF equivalent cost information was available for all candidate aircraft except the Super Hornet. Therefore, if the URF cost multiplied by 65 aircraft was greater than the identified contingency funding for the current JSF program, it was assumed that overall acquisition costs would be greater than $9 billion. In the case of the Super Hornet, Australian acquisition costs were prorated to 65 aircraft to determine a reasonable Canadian total acquisition cost. This was considered reasonable given that 1) many of the non-aircraft costs are indirectly dependent on fleet size (training, ancillary equipment, initial sparing) and 2) the

based on the available open-source information documented in Appendix 2. Since UCAVs cannot currently meet RCAF requirements, they have been excluded from further assessment.

Table 7 – Summary of non-JSF Contenders

Parameter/Aircraft	F/A-18E/F	ASH	Eurofighter	Rafale	Gripen E/F (2019+)
Technologies					
- Primary Sensors	AESA radar, IRST (external), TGP (ATFILR)	AESA radar, IRST, TGP (ATFLIR)	AESA radar 2019, PIRATE, TGP (LITENING III)	AESA radar, OSF, TGP (DAMOCLES, PDL-NG 2018)	AESA radar, Skyward-G, TGP (LITENING III)
- Self-protection suite	ALQ-214 IDECMS	ALQ-214 IDECMS	DASS	SPECTRA	EWS-39 NG
- Level of Sensor Fusion (SF)	SA display, HOTAS, JHMCS, not fully automated	SA display, HOTAS, JHMCS, not fully automated	SA display, VTAS, HMSS, not fully automated	SA display, no HMD,VTAS, not fully automated	SA display, partial SF, HMD, VTAS, not fully automated
- Level of Stealth	LO	RO	RO	RO	RO
Risks					
- Technical	Low (Canadianization)	Low-Medium (still under development)	Medium (AESA integration, Canadianization)	Medium (HMD integration, Canadianization)	Low-Medium (still under development, Canadianization)
- Schedule	Medium (production line closes 2016-18)	Low-Medium (still under development)	Medium (production line closes 2017, integration testing)	Medium (integration testing)	Low-Medium (still under development, integration testing)
- Sustainment	Medium 2035+ (current fleets retire)	Unknown - no orders yet	Medium 2040+ (current fleets retire)	Medium 2040+ (current fleets retire)	Low - Medium (small fleet size, European supply source)
- Operational	Medium 2035+ (high threat counter-air A2/AD)	Medium 2035+ (high threat counter-air A2/AD)	Medium 2035+ (high threat counter-air A2/AD)	Medium 2035+ (high threat counter-air A2/AD)	Medium 2035+ (high threat counter-air A2/AD)
Estimated Canadian Acquisition Cost (JSF URFC ~$89M, APUC ~ $138.3M)	around $9 billion Estimated APUC: ~ $135M	> $9 billion Developmental; Estimated APUC: >$135M	> $9 billion Estimated URFC: >$135M	> $9 billion Estimated URFC: >$170M	> $9 billion Estimated URFC: >$110M

Summary

The fourth generation CF-18 Hornet needs to be replaced by a more modern fighter aircraft to maintain the relative superiority the RCAF fighter force enjoys today

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overall similarities between the RAAF and RCAF legacy Hornet fleets in terms of usage, organization and doctrine.

given the projected FSE and the evolution of the future battlespace. An analysis of the currently available western Generation 4.5 fighter designs shows that all of the available options have one or more technical, schedule, sustainment and/or operational risks to contend with, and in most cases, are not necessarily cheaper to procure for the RCAF than the current JSF plan.

6. ANALYSIS SUMMARY

> *In response to the government's announcement of the purchase of 65 F-35 Joint Strike Fighters (JSF), the parliamentary opposition, critics within the attentive public, and the media concentrated almost exclusively upon the process leading to the decision, and the costs of the program. In so doing, they criticized the decision to eschew an open competition in favour of a directed buy, argued that viable cost-effective alternatives existed to the F-35, and suggested that National Defence had significantly under-estimated procurement and lifecycle costs. Only a small number of voices on the margin questioned the requirement for an advanced, multirole fighter. These primarily argued that there was no military air threat to Canada that necessitated an advanced fifth generation multi-role stealth fighter… and this environment only required a platform capable of performing an air sovereignty/policing role. Cheaper and less capable fighters, such as the Swedish Gripen, would suffice to meet Canada's national requirements*.
>
> *- James Fergusson*[202]

There are a number of very capable modern fighter designs flying today, which could be considered to replace the RCAF's CF-18 Hornet fleet. However, as noted previously, there are varying combinations of capabilities, risks and differing costs associated with each potential acquisition option. An assessment of each competing fighter against the RCAF's publicly declared key capabilities listed in Chapter 3 will be used to directly compare and contrast the strengths and weaknesses associated with each aircraft, and thereby determine the best acquisition solution for the RCAF. Table 8 below is a side-by-side comparison of each fighter aircraft analysed, with each aircraft broken down into two time periods (2015-2035 and 2035 to 2050+) and assessed against the Chapter 3 key mandatory capabilities along with cost.

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[202] James Fergusson, "The right debate: airpower, the future of war, Canadian strategic interests, and the JSF decision," *Canadian Foreign Policy Journal* 17 no. 3, (3rd Issue 2011): 204; http://www.tandfonline.com/doi/pdf/10.1080/11926422.2011.638195; Internet, accessed 09 April 2013.

Table 8 – Comparison of CF-18 Hornet Replacement Options

Mandatory Capabilities	Aircraft & Time Period									
	F-35A JSF		F/A-18 E/F Super Hornet		Eurofighter Typhoon		Dassault Rafale		Saab Gripen E/F	
	2015-2035	2035-2050+	2015-2035	2035-2050+	2015-2035	2035-2050+	2015-2035	2035-2050+	2015-2035	2035-2050+
1. Range. Alert configuration deployable from MOB to DOB or FOL with only 1 stop enroute	with internal fuel	with internal fuel	with EFT or CFT	with EFT or CFT	with EFT or CFT	with EFT or CFT	with EFT or CFT	with EFT or CFT	with EFT	with EFT
2. Endurance. All weather operating requirements for CAP as per RCAF NORAD & NATO.	with internal fuel	with internal fuel	with EFT or CFT	with EFT or CFT	with EFT or CFT	with EFT or CFT	with EFT or CFT	with EFT or CFT	with EFT	with EFT
3. Speed. Speed to successfully intercept airbreathing threats as per NORAD & NATO standards (i.e. must be supersonic capable).	> M 1.0 (air-to-air)	> M 1.0 (air-to-air)	> M 1.0 (air-to-air) supercruise	> M 1.0 (air-to-air) supercruise	> M 1.0 (air-to-air) supercruise	> M 1.0 (air-to-air) supercruise	> M 1.0 (air-to-air) supercruise	> M 1.0 (air-to-air) supercruise	> M 1.0 (air-to-air) supercruise	> M 1.0 (air-to-air) supercruise
4. Air-to-Air Refuelling. In-flight refuelling capability required.*	boom system	boom system	probe & drogue	probe & drogue	probe & drogue	probe & drogue	probe & drogue	probe & drogue	probe & drogue	probe & drogue
5. Overall Deployability. Can operate domestically or worldwide in a full-range of geographic, environmental, climatic and threat conditions.										
5a. Geographic/Environmental/Climatic limitations										
5b. Threat environment limitations	high threat counter-air A2/AD	high threat counter-air A2/AD	high threat counter-air A2/AD	high threat counter-air A2/AD	high threat counter-air A2/AD	high threat counter-air A2/AD	high threat counter-air A2/AD	high threat counter-air A2/AD	high threat counter-air A2/AD	high threat counter-air A2/AD
6. ISR. Capable of providing ELINT and non-traditional ISR data with multiple advanced sensors					No AESA until 2018				after E/F is operational	
7. Sensor fusion. Includes an integrated situational awareness (SA) display for air and surface threats, and securely communicating with other aircraft and surface-based forces.	Fully automated sensor tasking for SA	Fully automated sensor tasking for SA	Advanced Cockpit being developed	Advanced Super Hornet (ASH) solution			Ho Helmet Mounted Display in F3R standard		Limited EW Suite integration with other sensors	Assumes EW Suite integration with other sensors
8. Weapons. Precision delivery of long and short range air-to-air and air-to-surface weapons in all weather conditions, and permissive or non-permissive environments.			ASH with EWP	ASH with stand-off weapons	Limited Air-to-ground until ~2020	Stand-off weapons required	RCAF weapons integration or new buys required	Stand-off weapons required	Some integration may be required	Stand-off weapons required
9. Survivability. Must have advanced integrated self-defence technologies to minimize risk of detection, engagement and damage										
9a. Upgradable Advanced intgegrated self-protection suite				No upgrades after 2035?		No upgrades after 2040?		No upgrades after 2040?		
9b. Low observability category (LO, RO, VLO)	VLO	VLO	LO	RO (ASH)	RO	RO	RO	RO	RO	RO
10. Delivery. 2015-2035: Identify best delivery time. 2035-2050: Identify long term production limitations	2020-2026 to limit technical risk and reduce cost	production to 2037	2016-2022 may be too early for Canadian buy	production to 2016 without Canadian buy	2016-2022 may be too early for Canadian buy	production to ~2016 without Canadian buy	2020-2026 to limit technical risk	production to ~2023 without Canadian buy	2020-2026 to limit technical risk and reduce cost	production to 2020+ without Canadian buy
11. Overall In-Service Support. Must be supportable for the duration of its operational life cycle.										
11a. Growth Potential. Must be capable of continuously upgradable for interoperability, survivability and operational capabilities	continuous upgrades to ~2050		Spiral development	worldwide fleet to be retired ~ 2035	Known upgrade path	No upgrades after 2040?	Known upgrade path	No upgrades after 2040?	Defined and scheduled upgrade path	
11b. Sustainment. Must have access to OEM engineering, spares, repair and overhaul capabilities.				Sustainment risk beyond 2035	European/ consortium supply chain	Sustainment risk beyond 2040	European supply chain	Sustainment risk beyond 2040	European supply chain, small fleet size	European supply chain, small fleet size
12. Fleet Size. Must be large enough to conduct assigned missions and roles, while taking into account attrition.		Can delay attrition buy decision		requires up front attrition buy		requires up-front attrition buy		requires up-front attrition buy		may require attrition buy prior to mid-life point
13. Certification. Must be capable of certification and sustainment to Canadian DND airworthiness standards.										
14. Estimated Canadian Acquisition Cost. Estimated acquisition cost same or less than 2013 JSF procurement plan for 65 aircraft using URFC = $89M?	Yes if Canada remains a partner nation and does not procure JSFs via FMS. Estimated acquisition cost $9B.		Yes. However, not likely if an ASH is procured.		No. Estimated procurement costs at least $46M more per aircraft		No. Estimated URF costs may be at least $81M more per aircraft.		No. Estimated URF cost may be at least $21M more per aircraft.	
Overall Assessment. Summary of Concerns	**Technical risk:** short term concurrency issues to planned IOC (2019) **Acquisition Cost:** >$9B if bought via FMS		**Technical risk:** short term ASH **Operational Risk:** high threat counter-air A2/AD 2035+ **Sustainment Risk:** 2035+		**Technical risk:** full Air-to-ground & AESA capability **Schedule risk:** early buy **Operational Risk:** high threat counter-air A2/AD 2035+ **Sustainment Risk:** 2040+ **Acquisition Cost:** > $9B		**Technical risk:** weapons integration, HMD **Operational Risk:** high threat counter-air A2/AD 2035+ **Sustainment Risk:** 2040+ **Acquisition Cost:** > $9B		**Technical risk:** short term development **Operational Risk:** high threat counter-air A2/AD 2035+ **Acquisition Cost:** > $9B	

* Changeover to a USAF boom system for air-to-air refuelling will require new aerial tankers for the RCAF.
However they will also be able to refuel RCAF C-17s, which currently rely on USAF tankers if / when required.

Assessment Results

A review of the data contained in Table 8 above shows that all the potential CF-18 replacement fighters under consideration have a number of issues or deficiencies. Table 8 is colour coded based upon risk. Any mandatory capability that is achieved is colour coded as green. A slight risk area is colour coded darker green, and an increased risk area is colour coded yellow. These mandatory capabilities are an outgrowth of 1) existing CF-18 capabilities (e.g. air-to-air refuelling, worldwide deployability, aeronautical performance); 2) expected life cycle requirements (budget, certification, in-service support, delivery dates); and 3) an assessment of the future battlespace through CBP (e.g. fleet size, ISR, sensor fusion, weapons, survivability). The results for each aircraft are briefly summarized below.

JSF

The strongest contender is the F-35A, however as detailed in Chapter 4, due to ongoing technical risk associated with identified concurrency issues (software, structure, and HMDS) and the slippage of the full-rate production schedule to 2019, it would be prudent to delay the desired buy profile by three years from 2017-2023 to 2020-2026. This would decrease the risk of the RCAF procuring an LRIP standard aircraft subject to modification, and would also result in reduced URF costs due to forecasted full-rate production efficiencies.[203] Furthermore, given the projected long-term benefits to

[203] Because the acquisition cost of the aircraft varies from one delivery date to another, a country's buy profile is a crucial factor in the costing of the aircraft or the fleet. Also, once the aircraft is in

Canadian industry of continued access to JSF sustainment contracts along with the discounted costs (compared to an FMS procurement) and royalties afforded partner nations, it also makes sense for Canada not to withdraw from the PSFD MOU and to continue the JSF acquisition through the current JSF MOU framework.

F/A-18E/F

The Super Hornet provides increased capability over the RCAF's legacy Hornet. However, as noted in Chapter 5 and detailed in Appendix 2, there are a number of issues associated with this platform. The current Super Hornet production run has ended, with the last F/A-18E/Fs switched to EA-18G Growlers for the USN.[204] Absent any additional buys, the Super Hornet/Growler production line will end in 2016, which will require an acquisition decision before then with Canadian deliveries set no later than 2016-2022. These timelines are tight, unless some special arrangement could be made with Boeing or the production line is otherwise extended. Furthermore, the preferred long-term solution would be to procure the ASH, however there are currently no buyers for the aircraft, it is not projected to be available before 2020, and unit prices would be higher than a straight Super Hornet procurement. Without future customers, the forecasted production end date would most certainly necessitate an up-front attrition buy to minimize long term operational risk, thereby increasing the required acquisition budget. Additionally, the aircraft is already operationally limited, and would continue to degrade in operational

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full-rate production, Lockheed-Martin has forecasted a production learning effect. Increased production rates associated with full-rate production and a stable design are expected to decrease URF costs. For example, a one-year delay could save $160M. See DND, *NGFC Annual Update August 2013…,* 32-33, 34-35.

[204] Defense Industry Daily, *Super Hornet Fighter Family MYP-III: 2010-2014 Contracts*….

capability and relevance over the course of the next thirty years of potential RCAF service. Longer term, the aircraft will be limited to employing long-range stand-off weapons in a high threat counter-air A2/AD environment. Finally, from a sustainment perspective, the USN and RAAF both plan to retire their Super Hornets and Growlers by the mid-2030s, which adds sustainment risk to an RCAF fleet in the longer term.

Eurofighter

The Eurofighter provides some increased capability over the RCAF's legacy Hornet. However, as noted in Chapter 5 and detailed in Appendix 2, there are also a number of issues associated with this aircraft. The current production standard Tranche 3A does not have an AESA radar, which would need to be included in an RCAF variant. Moreover, the current aircraft is still limited in its air-to-ground capability and further software and hardware integration is required to rectify these two issues.[205] Also from an operational perspective, the Eurofighter will be limited to employing long-range stand-off weapons in the longer term, much like the Super Hornet. In terms of acquisition timelines, the Tranche 3B production run has been delayed indefinitely and there is no confirmation of additional Eurofighter orders, with the result that production will cease in 2016. This would necessitate an RCAF acquisition decision before then with Canadian deliveries set no later than 2016-2022, with an AESA radar retrofit in the future. Barring some special arrangement with the Eurofighter consortium, or the production line being

[205] The Eurofighter's lack of a mature air-to-ground capability was highlighted during the Swiss evaluation for their F-5 replacement. The Part II evaluation assessed Tranche 3 P1E standard Eurofighters for 2015 delivery, and provided an assessed rating of low to good for strike missions. See SAF, *SAF/OT&E Evaluation Report NFA Evaluation (RFP2) 2009…*, VI-9/10.

somehow otherwise extended, these timelines are almost unachievable, since Eurofighter would require more up-front engineering study to determine and finalize a Canadianized design than a Super Hornet buy would. In terms of price, the Eurofighter would be a more expensive buy than a JSF procurement as a partner nation, and any Canadianization would further increase costs. Also, like the Super Hornet, the pending closure of the production line would also require an up-front attrition buy, further increasing the required acquisition budget. Sustainment risk would also be higher with European consortium-based supply sources and longer term, the aircraft is expected to be retired from service around 2040, which brings into question the issue of viable and cost effective in-service support beyond that point.

Rafale

The Rafale also provides some increased capability over the RCAF's legacy Hornet. As noted in Chapter 5 and detailed in Appendix 2, there are a number of issues associated with this aircraft as well. The current F3R production standard does not have an HMD, which would need to be included in an RCAF variant. Also, from a weapons perspective, the RCAF will either have to invest in procuring French weapons, or embark upon a time-consuming weapons clearance and certification effort for existing weapons and pods. Beyond 2035, it is expected that the Rafale will also become operationally limited to employing long-range stand-off weapons in a high threat counter-air A2/AD environment. In terms of acquisition timelines, the Rafale production run is expected to cease around 2023 with the Indian procurement. This would enable an RCAF acquisition timeline to meet a desired delivery profile from 2020-2026, which would likely allow for the time required to complete engineering studies to determine and finalize a Canadianized design. However, procuring a Canadian variant is problematic for an aircraft already significantly more expensive than a partner procured JSF, as is the need to procure attrition aircraft up front due to the 2023 production end date. Costs to the Canadian taxpayer would further increase because of the need to either buy or integrate the required weapons. Sustainment risk for the RCAF would also be higher with the Rafale given the small current fleet size and European supply sourcing for a smaller RCAF fleet. Like the Eurofighter, the Rafale is expected to be retired from French service around 2040, which adds risk if Canada were to continue fling the aircraft beyond that point.

Gripen NG

The Gripen NG is forecast to provide some increased capability over the RCAF's legacy Hornet, however as noted in Chapter 5 and detailed in Appendix 2, the Swiss OT&E evaluation assessed the Gripen NG to be the least capable contender they were assessing overall. As noted in Chapter 5, a Gripen NG acquisition is not without issues as well. The current aircraft is still not in production. Although the Gripen NG demo program is currently still on schedule, the production configuration hardware designs for some of the avionics systems are still not finalized. The MS21 standard will not initially have its EW suite fused with the other aircraft sensors, which is not desirable from an RCAF perspective. Some weapons integration work would be required for RCAF weapons and pods, but less than that for a Rafale option. Beyond 2035, Gripen NG, like other Generation 4.5 aircraft, is expected to become operationally limited to employing long-range stand-off weapons in a high threat counter-air A2/AD environment. In terms of acquisition timelines, the initial production line will start delivering aircraft for the Swedish and Brazilian orders starting in 2019. This would enable an RCAF acquisition timeline to meet a desired delivery profile from 2020-2026, which would likely allow for the time required to complete engineering studies to determine and finalize a Canadianized design. However, Canadianization would further increase unit costs, which are already forecast to be higher than a partner procured JSF. Also, given the uncertain nature of the Gripen NG production run beyond the two currently confirmed customers, it would also be prudent to buy attrition aircraft with the initial buy. Although lower sustainment costs are a big advantage for this aircraft, sustainment risk for the RCAF would be higher for the Gripen given the small current fleet size and European supply sourcing for a smaller RCAF fleet. However, as the newer design not yet in production, a projected service life of 30 years from first production delivery would ensure the aircraft is flown and supported by Saab until 2048.

Assessment Recommendation

A review of the assessment parameters suggests that there are some inherent risks associated with all of the CF-18 replacement contenders. JSF and Gripen E/F both exhibit up-front technical risk as aircraft under development and not yet in full-rate production with a frozen design. F/A-18E/F, Eurofighter and Rafale, as mature designs flying today will exhibit some up-front technical and cost risks associated with development of a Canadianized design, however there is also an increased level of sustainment risk in the longer term should the RCAF procure these platforms. Finally, there is also an increased level of operational risk for all of the contenders beyond 2035, however this risk area will be higher for the Generation 4.5 designs than for JSF in high threat areas defined by advanced counter-air A2/AD technologies.

Additionally, despite the reporting today and the general assumption that existing Generation 4.5 designs would be a less expensive acquisition option for Canada, the available open source information suggests that this is not the case if Canadian JSF URF costs as a partner nation fall within the bounds of the sensitivity analysis conducted by the NGFC Program Office for buy profiles, production learning efficiencies and total aircraft buys. In fact, purchasing a non-JSF NGFC solution would essentially be "buying less for more."

Accordingly, the best solution to replace the CF-18 Hornet in terms of required capability, cost and mitigation of overall risk to the RCAF is for Canada to retain its membership within the framework of the JSF PSFD MOU and procure the JSF, but to delay the planned buy profile by three years to the period between 2020 and 2026.

7. CONCLUSION

In general, it would seem a poor wager to bet against the long term success of the F-35. Across all the world's air forces, over 6000 air frames will need to be replaced in the coming years, ensuring a large market for this aircraft; indeed, air industry analyst Richard Aboulafia has long referred to the F-35 as more an industrial policy than a fighter programme. In the US alone, airframes acquired in the late 1970s and onwards, such as the USAF's A-10, F-16, and F-15 will all need to be replaced. Both the US Navy's and Marine Corps F-18s and the Marines' Harrier jump jets also fall into this category.

- Paul T. Mitchell[206]

The Harper government's announcement that it would purchase, without competition, up to 65 F-35 Lightning II fighters to replace the CF-18 Hornet at a cost of $9 billion left it open to significant criticism. That criticism was based on both the government's rejection of an open competition to replace the CF-18, as well as the choice of the platform itself – a technologically advanced aircraft still in development might be too technologically risky and perhaps, in the end, more of a fighter aircraft than Canada truly needed.

The fundamental requirement for Canada to operate a fighter aircraft is the need to assert sovereignty. Fighters alone can execute aerospace control functions; therefore, fighters alone can properly protect Canadian airspace. An RCAF fighter capability is also driven by Canada's military obligations to NORAD and NATO. Beyond our alliance obligations, fighters are also a discretionary capability, which can be deployed by the government as a viable military capability to participate meaningfully in a wide range of multilateral peace support operations around the world.

Canadian defence procurement is driven by a force development process centred on CBP. Critical to CBP is an understanding of the future security environment.

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[206] Paul T. Mitchell, *Lightning in a Bottle*…, 193.

Canadian and allied assessments suggest the proliferation of advanced technologies and weapon systems (conventional and nuclear) will be a significant concern in the future. Furthermore, inter- and intra-state conflicts could erupt anywhere in the world, and there is a strong possibility that Canadian military forces could be confronted at least once in the next thirty years by the conventional military power of a sovereign state either singly or through a regional conflict. It is in the context of such an environment that a future Canadian fighter aircraft must be able to operate. Thus, a replacement fighter should be able to carry out all of the doctrinal missions the current CF-18 Hornet is capable of against future threat systems, and arguably, with a similar relative level of capability as the CF-18 vis-à-vis the legacy threats it was designed, and modernized, to defeat.

Amongst the current contenders to replace the CF-18, the JSF is the only available fifth generation design. The controversial and technologically complex JSF program has been soundly criticized for rising costs, and a highly concurrent development, testing, manufacturing and acquisition strategy, which has resulted in significant schedule slippage whenever technical issues are not resolved as quickly as envisaged. Although risk mitigation efforts are trending positively, there still remains up-front technical and cost risk associated with a potential JSF procurement. Accordingly, Canada would do well to delay procurement if this aircraft is chosen to replace the Hornet until full-rate production begins, currently forecasted for 2019. Canada has been involved with the JSF Program since 1997, which has ensured that the RCAF has had access to and influence on the program's requirements, access to the technologies being developed, and industrial involvement beyond the government investments made. Continuing involvement in the JSF program is beneficial to both the RCAF and Canadian industry given the large projected fleet size of 3100 aircraft and the potential for over $9 billion in long-term sustainment contracts throughout the JSF's life cycle.

Potential Generation 4.5 contenders to replace the Hornet are the Super Hornet (including the Advanced Super Hornet offshoot), Eurofighter, Rafale, and the Gripen NG, which are all Western built. Yet none of these JSF alternatives would be a risk-free solution to the RCAF or the Canadian taxpayer. All of them are projected to suffer from increased operational risk in high threat environments beyond 2035 as counter-air technologies evolve. Furthermore, projected acquisition costs are likely higher than JSF, due to the inefficiencies associated with smaller production runs and unique Canadianization requirements, with the possible exception of the Super Hornet (but not necessarily the Advanced Super Hornet). Furthermore, Super Hornet and Eurofighter production lines are forecasted to close by 2017 and 2016 respectively, and they may not be available for purchase if a Canadian acquisition decision is delayed. Additionally, these other contenders, with the exception of Gripen, are mature designs, and sustainment risk for the RCAF will increase significantly if and when user nations begin retiring their aircraft before Canada does.

In conclusion, this paper has examined the NGFC procurement by comparing the F-35 to all other alternative solutions to replace the current Canadian fighter capability. The best option for Canada, based on currently available information, is a delayed acquisition of the JSF. This solution would best mitigate known risks and provide the RCAF with the best overall capabilities in the longer term, at a comparable or better price than the alternative solutions currently available. In the political context, the F-35 gives the government the greatest flexibility and utility for the longest operational lifetime, for the best or comparable costs when measured against the other available fighter options for procurement.

APPENDIX 1 – SUMMARY OF JSF TECHNOLOGIES

As previously noted, the new technologies developed for, and their integration into, the JSF platform is the result of detailed assessments conducted during CDDR of the future strike warfare environment, the impact of stealth or Very Low Observable (VLO) technology on the future battlespace, and the domains of logistics and sustainment as a force multiplier. Below is a summary of the assessment results and the technological advances that were generated.

The Future Strike Warfare Environment and Sensor Fusion

The future strike warfare environment was analysed through a modelling effort known as the Virtual Strike Warfare Environment (VSWE).[207] The study indicated that weapons delivery against most targets by the JSF would require the use of on-board sensors, as is currently the case. However, it was also concluded that the ability to fuse off-board sensors and weapons would increase the target set the JSF could strike. Furthermore, the studies also showed that off-board information could be used and fused with on-board data to regulate a pilot's situational awareness and yield "measurable improvements" in the pilot's ability to prosecute a target in a survivable manner.[208] This

[207] *Ibid*., 11-12.
[208] *Ibid*.

led to the creation of sensor fusion requirements, and the further concept of mutually supportive and interactive on-board and off-board sensor architecture.[209]

Sensor Fusion – General. Advanced fusion carries out three functions for the pilot: 1) it assembles a single integrated operating picture from all sensors; 2) it automatically tasks the various sensors to fill in missing data in a complementary fashion; and 3) it shares the information with all other members of the network to build a Common Operational Picture (COP).[210] A key advantage of this capability is that in order to significantly degrade the situational awareness that an integrated COP provides to every pilot, the enemy force will need to defeat not just one sensor on one aircraft, but multiple sensors on multiple aircraft; because F-35 sensors are fused, the pilot in one aircraft can link (and task) the sensor suite of another F-35.[211] The F-35 was designed and built with a communications architecture that enables interactivity between all combat systems to create a "combat system enterprise" managed by the aircraft's computer, and linked by a high-speed fibre-optic data bus.[212] The data bus connects the Communications, Navigation and Identification (CNI) system to the aircraft's core combat systems, specifically the Active Electronically Scanned Array (AESA) radar, the Distribute Aperture System (DAS), Electro-Optical Targeting System (EOTS), and the Electronic Warfare (EW) system.[213] In addition, the cockpit, helmet and fusion engine were designed to synergistically interact in order to reduce pilot workload while

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[209] Second Line of Defense, "Shaping the F-35 Combat System Enterprise," http://www.sldinfo.com/ shaping-the-f-35-combat-system-enterprise/; Internet, accessed 14 November 2013.

[210] Second Line of Defense, "The F-35 and Advanced Sensor Fusion," http://www.sldinfo.com/ whitepapers/the-f-35-and-advanced-sensor-fusion/; Internet, accessed 14 November 2013.

[211] *Ibid*.

[212] Robbin F. Laird and Edward T. Timperlake, "The F-35 and the Future of Power Projection," *Joint Forces Quarterly* 66 no. 3 (3rd Quarter 2012): 88.

[213] *Ibid*.

enhancing situational awareness.[214] Each of these systems will be discussed briefly in turn. Figure 11 below is a diagram of the F-35 Advanced Fusion Avionics Suite. An important factor to consider is that although each system by itself is an advancement in technology, the aircraft as a weapon system was designed to fuse all the systems together automatically in a synergistic fashion to create a significant capability improvement in situational awareness.

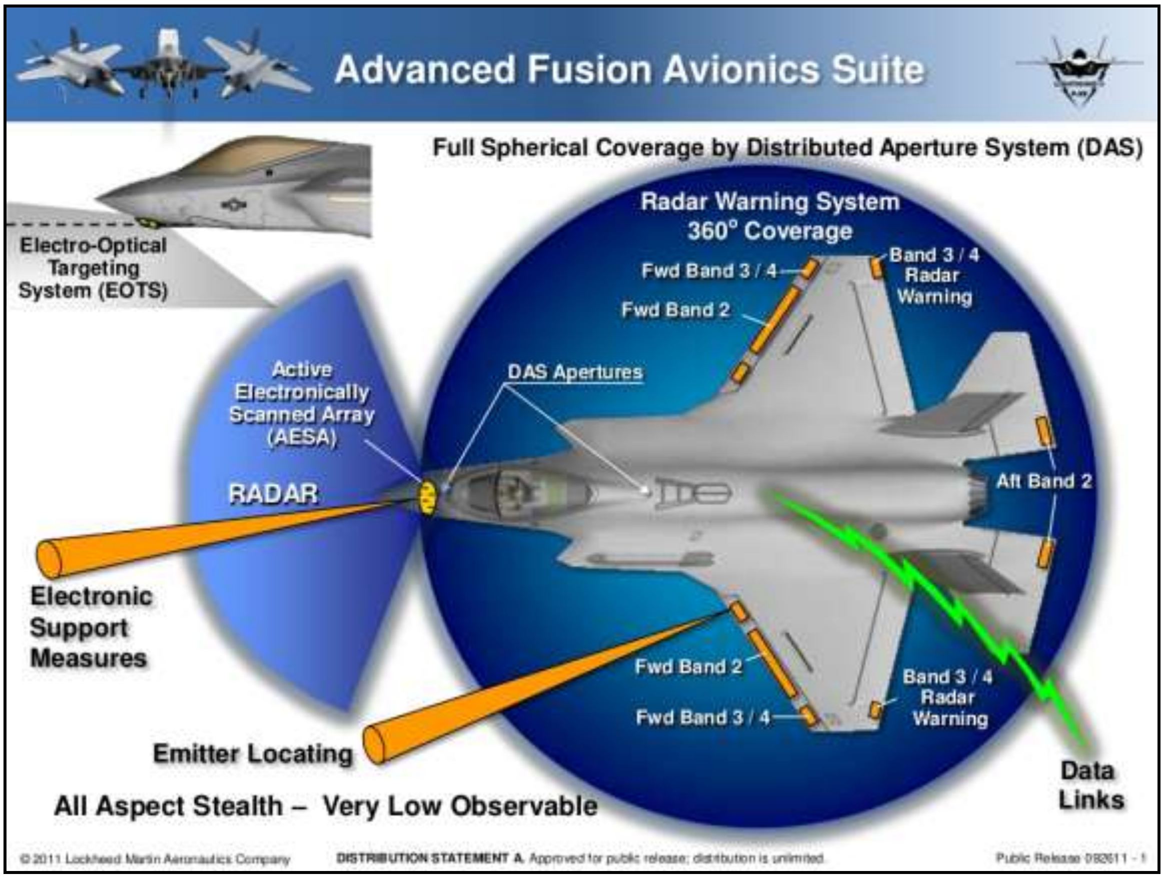

Figure 11 – F-35 Advanced Fusion Avionics Suite

Source: Second Line of Defense, *The F-35 Combat Systems Fusion Engine*.

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[214] Second Line of Defense, "Shaping a Manageable Workload for the Pilot." http://www.sldinfo.com/whitepapers/shaping-a-manageable-workload-for-the-pilot/; Internet, accessed 14 November 2013.

CNI. This revolutionary system is essentially a radio frequency (RF)-based software-defined radio (SDR), which instantiates radio waveforms for Tactical Air Navigation (TACAN), Instrumented Landing System (ILS), voice and datalink functions.[215] The CNI system therefore builds the radio in software once the computers initialize and run their programs. A significant advantage of SDRs is that upgrades to waveforms and datalink requirements are done through software, rather than hardware upgrades, a significant paradigm shift.[216] A key component of the CNI system, which can manage 27 different waveforms, is the Multifunction Advanced Data Link (MADL) waveform, which is a high-data-rate, directional (i.e. Low Probability of Intercept) communications link designed for JSF networking.[217]

AN/APG-81 AESA Radar. AESA radars are the successors to the previous generation of Mechanically Scanned Array (MSA) Radars. The AN/APG-81 integrated into the F-35 provides long-range, multiple simultaneous air-to-air and air-to-ground targeting, as well as a synthetic aperture radar (SAR) terrain-mapping capability.[218] Also a first for a fighter, there is a colour weather radar capability.[219] Finally, the AN/APG-81 radar interacts directly with the EW system symbiotically to draw on advanced jamming resources; in addition to traditional radar functions, it can also act as an EW aperture, providing electronic protection, electronic support and electronic attack functions.[220]

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[215] Second Line of Defense, "The F-35 Combat Systems Fusion Engine," http://www.sldinfo.com/whitepapers/the-f-35-combat-systems-fusion-engine/; Internet, accessed 14 November 2013.

[216] *Ibid*.

[217] Aaron Mehta, "New Data Link Enables Stealthy Comms," *Defense News*, 14 July 2013, http://www.defensenews.com/article/20130714/DEFFEAT01/307140011/; Internet, accessed 15 November 2013.

[218] Defense Media Network, "F-35 Lightning II Joint Strike Fighter," [magazine On-line]; available from http://www.nxtbook.com/faircount/F-35LightningII/JSFII/; Internet, accessed 15 November 2013.

[219] Second Line of Defense, *The F-35 and Advanced Sensor Fusion*....

[220] Second Line of Defense, *Shaping the F-35 Combat System Enterprise*….

AN/AAQ-37 DAS. This unique and revolutionary system is comprised of six high resolution infrared (IR) electro-optic sensors to provide spherical 360 degree coverage around the aircraft. It provides *automated* missile detection and tracking, launch point detection, situational awareness infrared Search and Track (IRST) and cueing, weapons support and day/night navigation, even in a highly dynamic environment such as a multiple aircraft dogfight.[221] It is also designed to interface with the pilot's helmet, allowing the pilot to see clearly in any direction, including "through" the aircraft.[222]

EOTS. The F-35 EOTS is the world's first and only sensor that combines forward-looking infrared (FLIR) and IRST functionality. It is a multifunction system for precision air-to-air and air-to-surface tracking, packaged in a low-drag and stealthy chin fairing under the aircraft's nose. It provides the F-35 pilot with access to high-resolution imagery, automatic tracking, IRST, laser designation and rangefinding, and laser spot tracking at extended ranges.[223]

AN/ASQ-239 EW System. This is a multiple band passive radar system which provides basic radar warning, and multispectral countermeasures for self-defence against threat missiles, situational awareness and high-sensitivity electronic surveillance and reconnaissance. Sensors are placed at ten locations to provide 360 degree coverage including: on the wings' leading edges (6), trailing edges (2), and on the horizontal

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[221] Northrop Grumman, "AN/AAQ-37 Distributed Aperture System (DAS) for the F-35," http://www.northropgrumman.com/capabilities/anaaq37f35/pages/default.aspx; Internet, accessed 14 November 2013.

[222] Second Line of Defense, "An Overview of the F-35 Cockpit," http://www.sldinfo.com/whitepapers/an-overview-of-the-f-35-cockpit-what-5th-generation-aircraft-are-all-about/; Internet, accessed 14 November 2013.

[223] Lockheed Martin. "F-35 Lightning II EOTS." http://www.lockheedmartin.ca/content/dam/lockheed/data/mfc/pc/f-35-lightning-ii-electro-optical-targeting-system-etos/mfc-f-35-eots-pc.pdf ; Internet, accessed 15 November 2013.

stabilizer's trailing edges (2).[224] Also, as previously noted, this system is linked to both the radar and DAS to create an EW system for the aircraft with significantly greater overall functionality and capability.

Pilot-Vehicle Interface (PVI). There are a number of key elements which make up the F-35 cockpit. The first is a 20" x 8" multifunction panoramic cockpit display, designed to provide a useful view of the battlespace and air vehicle management parameters. It provides functional flexibility to allow the pilot to change window sizes, display locations, and contents where the outputs of the sensor fusion engine can be displayed. Fusion takes the information from all available on-board and off-board sensors, and displays it as an easy to understand operating picture.[225] Furthermore, the one-gigabyte per second data interfaces enable the display to project six full-motion images simultaneously.[226] Another key feature of the cockpit is the multiple ways to interface with systems management functions. For example, the display system can be manipulated through touch-screen or cursor-hooking functions vice push-button architecture; furthermore, voice recognition commands are also a feature of the F-35 cockpit.[227] The other key component of the PVI is the Helmet Mounted Display System (HMDS). The helmet is designed to be an extension of the panoramic cockpit display, and replaces the traditional Heads Up Display (HUD) present in current fighter aircraft. This functional leap allows important information and symbology to be viewed by the

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[224] Asia pacific Defence Reporter, "Electronic Warfare: Australia's Mixed Record," http://www.asiapacificdefencereporter.com/articles/19/Electronic-Warfare-Australias-mixed-record ; Internet, accessed 15 November 2013.

[225] Second Line of Defense, *An Overview of the F-35 Cockpit*….

[226] F-35 Lightning II Program. "Technology" http://www.jsf.mil/f35/f35_technology.htm; Internet, accessed 08 November 2013.

[227] Second Line of Defense. "Flying with the Common Operational Picture." http://www.sldinfo.com/ whitepapers/flying-with-the-common-operational-picture-cop/; Internet, accessed 14 November 2013.

pilot no matter where he is looking, vice only through the forward windscreen, as per current HUDs. In addition, the pilot can also select imagery from the DAS to be projected, giving the pilot full situational awareness in all directions, day or night.[228] Ultimately, the JSF PVI was designed to create manageable pilot workload in a data heavy environment, and it leverages off the automated sensor fusion architecture thereby returning the pilot to the role of an air tactician in the modern battlespace.

Stealth

The other hallmark attribute of the F-35 JSF is a high degree of stealth, or Very Low Observable (VLO) capability. Initial survivability studies were conducted on various combinations of RF and IR signature levels and self-protection suites; VLO attributes were clearly identified as a significant contributor to survivability, and thus a critical requirement which influences campaign-, mission-, and engagement-level outcomes.[229] Accordingly, VLO characteristics have been designed into the aircraft from the outset. Firstly, the aircraft adheres to fundamental shaping principles of an RF-stealthy design.[230] Secondly, all sensors, required fuel and baseline weapons and quantities are moved inside the aircraft.[231] Thirdly, the selection of stealthy radar absorbent materials (RAM), which are baked into the aircraft composite skin at

[228] Second Line of Defense, *An Overview of the F-35 Cockpit*….

[229] Steidle, "The JSF Program"…,10.

[230] For example, the leading and trailing edges of the wings and tails have identical sweep angles, a concept known as planform alignment. The fuselage and canopy have sloping sides. The vertical tails are canted. See Global Security.org, "F-35 Design," http://www.globalsecurity.org/ military/systems/ aircraft/f-35-design.htm; Internet, accessed 13 Nov 2013.

[231] Second Line of Defense, "The F-35: Creating a 21st Century Fighter," http://www.sldinfo.com/ whitepapers/the-f-35-creating-a-21st-century-fighter/; Internet, accessed 14 November 2013.

manufacture,[232] were assessed for performance, service life degradation and repairability and balanced against affordability,[233] as per COPT methodology. Fourthly, the engine itself uses a reduced signature nozzle,[234] and integration of the airframe and powerplant masks the line of sight to the engine compressor using a diverterless intake.[235] According to unclassified November 2005 reports, the F-35 has a lower radar cross section (RCS) than the F-117 and is comparable to the B-2, which was half that of the older F-117; its RCS was said to be equal to a metal golf ball, about 0.0015m^2, about 5 to 10 times greater than the minimal RCS of the F-22, which is said to be marble sized, or 0.0001-0.0002 m^2.[236] Another source corroborates these unclassified values using the RCS measure of decibels per square meter (dBsm)[237] attenuation:

> The F-22 had a -40dBsm all-aspect reduction requirement [i.e., a requirement to reduce the radar reflectivity of the F-22 when viewed from all angles by 40 decibels per square meter], while the F-35 came in at -30dBsm with some gaps in coverage.[238]

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[232] Flight Global, "U.S Air Force praises early performance of Lockheed Martin F-35," http://www.flightglobal.com/news/articles/us-air-force-praises-early-performance-of-lockheed-martin-f-35-378578/; Internet, accessed 13 November 2013.

[233] *Ibid*.

[234] *Ibid*.

[235] A diverterless supersonic inlet (DSI) is a type of jet engine air intake used by high performance aircraft to control air flow into their engines. It consists of a "bump" and a forward-swept inlet cowl, which work together to divert boundary layer airflow away from the aircraft's engine while compressing the air to slow it down from supersonic speed. The DSI can be used to replace conventional methods of controlling supersonic and boundary layer airflow for speeds of up to Mach 2, such as the intake ramp and inlet cone, which are more complex, heavy and expensive. See Eric Hehs, "JSF Diverterless Supersonic Inlet," *Code One magazine*. [Journal on-line]; available from http://www.codeonemagazine.com/article.html?item_id=58; Internet, accessed 14 Nov 2013.

[236]While the F-35 design is not as stealthy as the F-22, improvements to RAM performance contribute significantly to the F-35's VLO signature. The F-35 RAM is thicker, more durable, less expensive and manufactured to tighter tolerances than F-22 RAM. Tighter tolerances means less radar signal can penetrate openings and reflect back to its source. Additionally, the newer RAM developed for the F-35 is also more effective against lower frequency radars. Some forms of RAM are also reported to have electrical plates or layers within the layers of carbon composites. Despite this, forecasted maintenance should cost about a tenth that of the F-22 or B-2. By comparison, the RCS of a MiG-29 is about 5m2. See course material available from: Naval Postgraduate School, "Radar Cross-Section Reduction (Chapter 7)," http://faculty.nps.edu/jenn/EC4630/RCSredux.pdf; Internet, accessed 10 November 2013.

[237] For a chart comparing the relationship between RCS in m^2 and dBsm, see Grant, *The Radar Game*…, 35.

[238] David A. Fulghum and Bradley Perrett, "Experts Doubt Chinese Stealth Fighter Timeline," *Aerospace Daily & Defense Report*, November 13, 2009: 1-2.

In addition to being designed to VLO RF requirements, the F-35 JSF is also designed to have a reduced IR signature. The JSF design incorporates reducing design features and treatments in the aft fuselage area and the engine nozzle employs specially designed shaping, ceramic shielding and other coatings to effectively decrease IR emissions.[239] Additionally, Pratt & Whitney, the manufacturer of the F135 engine for the JSF, has worked collaboratively with the U.S. Air Force Research Laboratory to test and mature adaptive third stream bypass flow techniques in order to increase performance and decrease jet engine thermal signatures.[240]

Autonomous Logistics

Another result of CDDR study efforts was that a decreased logistics footprint coupled with enhanced sortie generation rates were also a significant force multiplier.[241] A review of Table 3 above shows KPPs specifying logistic footprint for a deployed unit in numbers of equivalent C-17 transport aircraft loads, and required surge and sustain sortie generation rates for each JSF variant, which are better than current legacy weapon system benchmarks. Also tied to these KPPs is the concept of overall logistics sustainment. Sustainment requirements were also assessed using the COPT methodology to derive a

[239] Lockheed Martin, "Request for Binding Information Response to the Royal Norwegian Ministry of Defence, Program 7600 Future Combat Aircraft, Executive Summary Part 1," http://www.regjeringen.no/upload/FD/ Temadokumenter/JSF_RBI-svar.pdf; Internet, accessed 13 Nov 2013.

[240] Modern military turbofan engines have two airstreams – one that passes through the core of the engine, and another that bypasses the core. Testing has shown that development of a third stream of airflow will allow for improved fuel efficiency and cooler heat sinks which improve thermal management of the air system and reduce heat signature. See Pratt & Whitney, "Pratt & Whitney Advancing Sixth Generation Military Engine Technology," http://www.pw.utc.com/press/story/20130925-1100; Internet, accessed 13 Nov 2013.

[241] Steidle, "The JSF Program"...,8-9.

new paradigm known as the Autonomic Logistics Support Concept, which defines the support infrastructure required to generate initial surge and sustained combat sortie rates. To minimize this sustainment footprint, autonomic logistics (AL) leverages off information technology (IT) to enable proactive support.[242] The AL concept is based on five key concepts:

- Smart and Reliable Aircraft – An aircraft with reliability, maintainability and prognostic and health management (PHM) inherent in the design, which enables the entire AL concept;
- Technology Enabled and Supported Maintainer – Trained maintenance personnel, with information, instructions, tools, parts and materials;
- Integrated Training Environment – Enables the development of mission-qualified pilots and maintainers, regardless of location;
- Intelligent Information Infrastructure – An Information Technology (IT) framework that captures, analyses and identifies system characteristics and interfaces with legacy support systems to provide F-35 information for every user world-wide; and
- Performance-Based Best Value Sustainment – a business approach that equally weighs risk, schedule, cost and technical aspects to provide a cost effective, affordable support system that reduces total ownership costs over the weapon system life cycle.[243]

The AL concept drove the requirement to develop a comprehensive embedded PHM system for the aircraft. The JSF PHM system is revolutionary, and includes the following capabilities to support logistics and maintenance requirements:

- Testability/Built In Test (BIT) capabilities;
- Pertinent data acquisition at sensor, component, and subsystem level;
- Enhanced diagnostics beyond legacy testability/BIT capabilities;

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[242] *Ibid*., 9.
[243] F-35 Lightning II Program. "Autonomous Logistics" http://www.jsf.mil/program/prog_org_autolog.htm; Internet, accessed 08 November 2013.

- Prognostics, including material condition assessment and prediction of remaining useful life and time to failure of components by modelling fault progression; and

- Health Management, including the capabilities to maximize system effectiveness in the presence of system anomalies, provide decision support to optimally plan or defer maintenance, and manage component life.[244]

While the aircraft's PHM system will enable more effective and efficient sustainment capability, it is also a force multiplier in an operational context. According to a Lockheed Martin press release, a pending radar system failure during flight was simulated during PHM testing. Historically, this type of failure would have generated a mission abort. Instead, the PHM software predicted time remaining before radar shutdown, and presented mission options to the pilot of the disabled aircraft in order of lethality. This allowed the pilot to select the preferred option, shut down his radar, trade places with his wingman, receive information from his wingman's radar, deploy weapons, destroy the target and complete the mission.[245]

The JSF's PHM system is the key enabler of the AL framework, but the complementary enabler is the supporting IT backbone, known as the Autonomic Logistics Information System (ALIS). It serves as the secure information infrastructure for the F-35, integrating operations, maintenance, PHM, supply chain, customer support, training and technical data using web-enabled applications on a distributed network.[246] The JSF PHM System and ALIS are an integrated system; the aircraft's PHM System

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[244] E.R. Brown *et al*, "Prognostics and Health Management: A Data-Driven Approach to Supporting the F-35 Lightning II," 2007 IEEE Aerospace Conference Digest, Big Sky Montana; 3; http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4161628; Internet, accesed 13 November 2013.

[245] PR Newswire. "Mission Completion Assured with Lockheed Martin JSF Prognostic Information Systems; Data Shuttling Enhances Survivability and Lethality, Lowers Repair Costs." http://www.prnewswire.com/news-releases/mission-completion-assured-with-lockheed-martin-jsf-prognostic-information-systems-data-shuttling-enhances-survivability-and-lethality-lowers-repair-costs-73436652.html ; Internet, accessed 15 November 2013.

[246] Lockheed Martin. "ALIS." http://www.lockheedmartin.ca/us/products/f35/f35-sustainment/alis.html; Internet, accessed 10 November 2013.

will automatically detect faults and isolate them using various on-board sensors for key subsystems and components, perform higher level analysis, and transmit the results to ALIS prior to landing via an RF downlink so as to enable the prepositioning of parts and qualified maintenance technicians in order to minimize maintenance downtime and increase efficiency.[247]

[247] Having detailed knowledge of future maintenance requirements for all aircraft flying a mission prior to landing enables the planning optimization of maintenance resources, thereby increasing efficiency. *Ibid*.

APPENDIX 2 – TECHNOLOGY AND RISK SUMMARY FOR NON-JSF CANDIDATES

Weapon system procurement programs must assess and develop mitigation strategies for four areas of risk besides cost: technical, schedule, sustainment and operational. These additional areas of risk all have the potential to impact the weapon system's ability to meet the operational requirements throughout the planned service life for which it was procured. For example, in the case of the CF-18 replacement effort, technical risk speaks to the risk associated with the ability of the RCAF to purchase a fighter which meets its technical requirements; technical risk usually also affects cost, the development schedule and operational capability, if a solution to an identified technical deficiency is not found. Schedule risk has the potential to impact delivery timelines and required in-service dates. If mitigation efforts are unsuccessful, the result will be a gap in operational capability. Sustainment risk, if not mitigated, also creates operational risk. More specifically, a sustainment risk affects the ability of the RCAF to properly support and operate the weapon system in sufficient numbers for the required time period, which could lead to a gap in operational capability. Finally, operational risk directly speaks to the ability of the weapon system to meet defined operational requirements throughout its service life. Operational risk, therefore, takes into account the FSE, the projected future battlespace and the existing and projected operational capabilities of the fighter in question until its planned retirement.

This appendix provides a summary of the technologies inherent in each potential non-JSF candidate, planned upgrades, an identification of technical, schedule, operational, sustainment risks, and a best assessment of potential costs using available open-source information.

F/A-18 E/F Super Hornet Summary

F/A-18E/F Technology

The F/A-18E/F is the end product of the U.S. Navy's Hornet 2000 program, which began in the early 1980s as one of a number of design solutions to develop a new supersonic fighter/attack aircraft.[248] Although development of the F/A-18E/F followed the acquisition reform concept of CAIV like the JSF program did, the difference was the use of mostly off-the-shelf technologies to keep costs down. In addition, the very demanding performance and capability requirements associated with the USAF's newest fighter, the F-22 Raptor, such as supercruise,[249] full stealth capability, thrust vectoring, fully integrated avionics and an AESA radar were not pursued.[250] The F/A-18E/F program is best characterized as a spiral development program, which has followed, since its inception, the acquisition philosophy of Pre-planned Product Improvement (P3I). For example, while no AESA radar or FLIR systems were specified as a requirement for the initial variant, they were included in the approved engineering specification as planned upgrades for future variants.[251] Boeing began building improved capability Block II

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[248] Obaid Younoss, David E Stem, Mark A. Lorell and Frances M. Lussier, *Lessons Learned from the F/A-22 and F/A-18E/F Development Programs* (Santa Monica, CA: RAND Corporation, 2005), 21-22; available from http://www.rand.org/content/ dam/rand/pubs/monographs/2005/RAND_MG276.pdf; Internet, accessed 03 January 2014.

[249] Supercruise is the ability to fly at supersonic speeds without the use of afterburners.

[250] Younoss, *Lessons Learned from the F/A-22 and F/A-18E/F Development Programs*…, 23.

[251] *Ibid*.

Super Hornets (manufacturing Lot 26+) in 2003, with a re-designed forward fuselage and some key upgrades to critical avionics systems, including the multi-mode AN/APG-79 AESA radar, AN/ALQ-214 Integrated Defensive Electronic Counter-Measures (IDECM) System with ALE-50/55 towed decoys, and also upgraded the cockpit by integrating an Advanced Crew Station (ACS) with Advanced Mission Computers and Displays (AMC&D) and the Joint Helmet Mounted Cueing System (JHMCS).[252] In addition, the AN/ASQ-228 Advanced Targeting FLIR (ATFLIR) has been integrated on the platform,[253] although carrying it takes up the left fuselage missile station, as per earlier Hornet variants.

Today, the F/A-18E/F is considered to be one of the most advanced and capable multirole fighters currently operated by any of the U.S. services other than the USAF's fifth generation F-22 Raptor. Twenty-four (24) F/A-18F two-seat variants are also operational with the Royal Australian Air Force (RAAF) both as a replacement for their retired F-111 strike aircraft, and to bridge a potential fighter capability gap while awaiting JSF deliveries as their legacy F/A-18A/B aircraft are slowly retired at the end of their safe structural lives.[254] In addition, six RAAF Super Hornets are wired for conversion to the EA-18G 'Growler' EW variant.[255] Boeing continues to develop upgrades for the F/A-18E/F design to meet the USN's Super Hornet 'Flight Plan' (planned upgrade) requirements. These upgrades will include the addition of an IRST system, advanced sensor integration, and other hardware and software upgrades to enable

[252] These P3I upgrades have provided significantly more capability to the original Block I Super Hornet variant. See Defense Industry Daily, *Super Hornet Fighter Family MYP-III: 2010-2014 Contracts*….

[253] Avionics Today, "Upgrading the Hornet," http://www.aviationtoday.com/av/issue/feature/Upgrading-the-Hornet_79535.html; Internet, accessed 03 January 2014.

[254] ANAO, *Management of Australia's Air Combat Capability*…, 111, 117.

[255] The designation EA signifies Electronic Attack, rather than F/A for Fighter/Attack. The E/A-18G Growler specializes in electronic warfare missions. *Ibid*., 114.

network-centric operations to enhance situational awareness and data transfer thereby ensuring required operational capability until at least 2032.[256] Given USN requirements for continuing upgrades and the aircraft's perceived deficiencies in the area of stealth versus the F-35 internationally, as previously noted, Boeing and Northrop-Grumman have built a prototype Advanced Super Hornet (ASH) at their own cost to demonstrate an advanced signature reduction design with a lower radar signature, which first flew in August 2013.[257] To further complement the advanced signature reduction techniques used, the upgraded ASH variant as a start integrates a conformal fuel tank (CFT) and a stealthy Enclosed Weapons Pod (EWP), both of which reduce radar cross section when compared to carrying fuel tanks and weapons externally on fuselage and/or wing hard points; of note, the ASH demo with these concept prototypes has demonstrated a radar signature reduction of 50% to the baseline Super Hornet design.[258] According to Boeing, the ASH is also being offered with options tailorable to the customer, including an enhanced engine, next generation cockpit, and an internal IRST.[259] While the concept is promising, these developments and enhancements are still at the prototype stage, and at the time of writing, the USN does not intend to procure the ASH.[260] However, the USN is

[256] Department of the Navy, *Naval Aviation Vision, January 2012* (Washington, D.C., 2012); 31-32; http://www.public.navy.mil/airfor/nae/Vision%20Book/Naval_Aviation_Vision.pdf; Internet, accessed 04 January 2014.

[257] Boeing Defense Space and Security, "Backgrounder – F/A-18E/F Super Hornet," http://www.boeing.com/assets/pdf/defense-space/military/fa18ef/docs/bkgd_advanced_super_hornet_0813.pdf; Internet, accessed 04 January 2014.

[258] However, the weight of additional fuel and the carriage of a stealthy weapons pylon will still decrease overall aerodynamic performance. *Ibid*.

[259] The Block II Super Hornets used by the USN will integrate an IRST capability using a modified 480 gallon fuel tank carried on the centreline station. While this approach to a capability improvement precludes the need to redesign the internal configuration of the aircraft thereby decreasing upgrade costs, carriage of a centreline pod will result in a performance and stealth penalty. *Ibid*.

[260] Vic Johnson, "Advanced Super Hornet Unveiled," *Frontline Defence* 2013 no. 6 (November-December 2013): 29.

currently committed to at least investigating the integration of CFTs on their Block II+ aircraft.[261]

F/A-18E/F Risks

Technical Risks. The current baseline F/A-18E/F is a mature platform, integrated with excellent state-of-the-art technologies, which continues to evolve according to a USN defined P3I (spiral) upgrade concept in partnership with Boeing. However, the same cannot be said for the ASH variant. In both cases, a Canadian procurement would require a certain level of engineering study to determine if and how any Canadian unique requirements are to be incorporated (e.g. weapons, aircrew equipment, unique Arctic requirements, NORAD-specific requirements). While these technical risks are low considering the successful adaptation of the F/A-18A/B Hornet to Canadian use, the overall technical risk would be greater for an ASH if and until functional flight testing of all proposed enhancements is successfully completed.

Schedule Risks. According to Boeing, the Hornet/Growler production run will end in late 2016 unless the status quo changes. Currently Boeing is producing four aircraft per month. Given the lack of additional orders, Boeing now intends to cut production to three or even two aircraft per month to extend the production timelines by 1-2 years and

[261] CFTs have been successfully integrated on some other U.S. aircraft types, notably the F-15 and later F-16 variants. Accordingly, it is considered a low risk integration option in terms of potential RCS and range benefits versus kinematic performance penalties. See Flight Global, "US Navy may add conformal fuel tanks to F/A-18E/F Super Hornet fleet," http://www.flightglobal.com/news/articles/us-navy-may-add-conformal-fuel-tanks-to-fa-18ef-super-hornet-383701/; Internet, accessed 04 January 2014.

retain critical skilled jobs.[262] Furthermore, the current schedule for projected availability of ASH upgrades is 2020; accordingly Boeing is proposing an initial Canadian F/A-18E/F procurement with an upgrade to the ASH configuration after 2020.[263]

Sustainment Risk. Currently the USN plans to fly their F/A-18E/F and EA-18G aircraft into the 2030s; by 2025, their oldest Super Hornets are forecast to be at their structural safe life limit and the USN will begin to progressively retire the Super Hornet fleet and replace it with a new weapon system.[264] The RAAF initially planned to retire their Super Hornets by 2025,[265] however, with the recent purchase of twelve (12) dedicated EA-18G Growler EW variants of the Super Hornet, the current government has officially decided to defer any retirement decision until around 2030.[266] With no additional partner countries flying the Super Hornet at this time, sustainment will become significantly more challenging to any prospective buyer once the number of operational aircraft are significantly decreased from the current planned total of 563 aircraft.[267] Finally, since the production run is expected to end before the end of this decade, it would preclude the future purchase of additional aircraft to make up for attrition losses should they be required.

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[262] Christopher P. Cavas, "End In Sight For The Hornet Line – Or Is It?" *Defense News*, 15 February 2014, http://www.defensenews.com/article/20140215/ DEFREG02/302150023/End-Sight-Hornet-Line-; Internet, accessed 10 May 2014.

[263] Johnson, *Advanced Super Hornet Unveiled*…, 28.

[264] The U.S. Navy's projected F/A-18E/F replacement could be a mix of manned, optionally manned or unmanned systems. The EA-18G replacement is currently forecasted to be a manned aircraft. DoN, *Naval Aviation Vision January 2012*..., 19, 31-32.

[265] ANAO, *Management of Australia's Air Combat Capability*…, 133.

[266] The Australian government will eventually decide whether to retain their Super Hornet and Growler fleets or retire them to buy a fourth F-35 squadron. See Minister of Defence for Australia. "Joint Media Release – 2013 Defence White Paper: Air Combat Capability." http://www.minister.defence.gov.au/2013/05/03/prime-minister-and-minister-for-defence-joint-media-release-2013-defence-white-paper-air-combat-capability/; Internet, accessed 04 January 2014.

[267] Defense Tech, "Navy Weighs Possible Upgrade to Advanced Super Hornet," http://defensetech.org/2013/11/04/navy-weighs-possible-upgrade-to-advanced-super-hornet/; Internet, accessed 04 January 2014.

Operational Risk. The Super Hornet is currently assessed by the U.S. DOD's Director of Operational Test and Evaluation (DOT&E) as operationally effective and suitable for most threat environments, but also notes that the platform is not operationally effective in certain threat environments, the details of which are classified.[268] It further notes some deficiencies with the APG-79 AESA radar in terms of reliability, performance and EW capability.[269] In terms of aerodynamic performance, the larger and heavier Super Hornet already has slower acceleration than the legacy F/A-18A-D models it has replaced.[270] Although it remains excellent in slow-speed dogfights, competing newer Generation 4.5 designs such as the Russian Su-30MKI/A/M, Su-35 and MiG-35 or the European Typhoon, Rafale and Gripen, which are equipped with thrust vectoring and/or canards, already possess superior kinematic performance to the Super Hornet today.[271] Furthermore, the current advantages the Super Hornet enjoys with respect to sophisticated avionics are already beginning to erode, as rival foreign designs (including the latest operational Russian and Chinese models) also field AESA radars, helmet mounted cueing systems, IRSTs and advanced EW suites.[272] New fifth generation VLO, super-manoeuvrable designs such as the PAK-FA and Chinese J-20 will further marginalize the Super Hornet during its operational lifetime and push it towards a more limited role. Finally, the lack of flexibility in regards to the late purchase of spare attrition aircraft increases the risk that the fleet size will eventually become too small to meet all required operational commitments, unless extra aircraft are procured up front.

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[268] Clearly, some high threat A2/AD contested airspace scenarios would be challenging for the current Super Hornet. Office of the Secretary of Defense, *Director, Operational Test and Evaluation FY 2012 Annual Report* (Washington, D.C. 2012); 154; http://www.dote.osd.mil/pub/reports/FY2012/pdf/other/2012DOTEAnnualReport.pdf; Internet, accessed 03 January 2014.

[269] *Ibid*.

[270] See Defense Industry Daily, *Super Hornet Fighter Family MYP-III: 2010-2014 Contracts*.

[271] *Ibid*.

[272] *Ibid*.

Accordingly, the purchase of a Super Hornet variant as an NGFC solution would result in the RCAF operating an aircraft that will be marginalized in the post-2035 FSE due to emerging threat capabilities and technologies. Therefore, acquisition of a Super Hornet variant means the RCAF will not have the aerospace forces required (in terms of capability and potentially numbers) to meet all existing defence policy roles much sooner than currently envisioned.

F/A-18E/F Cost

Given the F/A-18E/F evolved as a low-risk and low cost option for a new supersonic attack aircraft, the Super Hornet is considered a very affordable Generation 4.5 fighter design.[273] While Boeing itself touts Super Hornet URF cost figures for its own marketing purposes, the costs associated with the RAAF's Super Hornet buy are also publicly available from U.S. government sources and provide an excellent metric on which to base a foreign military procurement of the F/A-18E/F. According to Australian government sources, the RAAF budget for the procurement of their 24 F/A-18Fs was Australian (Aus) $3,274.775 million excluding weapons[274], while U.S. government sources identify a Foreign Military Sales (FMS) contract value for procurement at U.S. $2.474 billion,[275] with an additional $214.4 million for the procurement of 56 F414

[273] Department of Defense, *Selected Acquisition Report (SAR) F/A-18E/F, 31 December 2011* (Washington, D.C. 2011); 4; http://www.dod.mil/pubs/foi/logistics_material_readiness/acq_bud_fin/SARs/DEC%202011%20SAR/F%20A-18E%20F%20-%20SAR%20-%2031%20DEC%202011.pdf; Internet, accessed 04 January 2014.

[274] The RAAF procurement included pre-installed wiring for conversion of 12 of the 24 aircraft to the EA-18G Growler EW variant ($35 million) and long lead item purchases of $19 million for Growler conversion kits. See ANAO, *Management of Australia's Air Combat Capability*…, 114-117.

[275] DOD, *Selected Acquisition Report (SAR) F/A-18E/F, 31 December 2011*…, 20.

engines.[276] Based on Australian program costs, an APUC for RAAF F/A-18Fs is approximately Aus $134.2 million.[277] This approximately equals U.S. $112.6 million using the average annual exchange rate for 2007,[278] which equates very well using the available U.S. figures.[279] A prorated cost for 65 aircraft would equal approximately U.S. $7.319 billion in 2007 year dollars, which amounts to Canadian $8.751 billion in 2014 year dollars.[280]

The F/A-18E/F is also considered by some to be the most cost-effective tactical aircraft in the U.S. services to operate per flight hour,[281] however this metric is not directly transferrable to the Canadian context.[282] A more appropriate source for comparison is once again the RAAF, who have a similar operating and maintenance doctrine to the RCAF.[283] Based on a USAF study of its F-16 fleet in-service costs, an IHS Jane's study on Cost Per Flying Hour (CPFH) for modern tactical fighters estimates that

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[276] Defense Industry Daily, "Australia's 2nd Fighter Fleet: Super Hornets and Growlers," http://www.defenseindustrydaily.com/australia-to-buy-24-super-hornets-as-interim-gapfiller-to-jsf-02898/; Internet, accessed 30 December 2013.

[277] Like a Canadian weapon system procurement, the Australian budget included costs not just for the purchase of the aircraft, engines and operational flight program software, but also the costs of initial sparing, technical manuals/engineering change orders, project management fees, simulators, infrastructure upgrades, initial training for aircrew and technicians, and ancillary equipment. In Australian dollars: $3,274.775 = 19-35 = $3,220.775 / 24 = $134,199. These calculations specifically do not include the procurement of follow-on weapons worth Aus $ 273.666 million.

[278] The average annual Australian to U.S. dollar exchange rate was 0.838909. See Reserve Bank of Australia, "Exchange Rate Data, 2007-2009," http://www.rba.gov.au/statistics/hist-exchange-rates/2007-2009.xls; Internet, accessed 12 January 2014.

[279] In millions of U.S. dollars: $2,474+214.4 = 2688.4 / 24 = $112 million.

[280] $112.6m x 65 = $7.319b. Canadian calculated value uses Bank of Canada exchange rates for 2007 (1.074748) and inflation factors 2007-2014 (1.11252). Relevant Statistics can be accessed at Bank of Canada, "Monthly and annual average exchange rates," http://www.bankofcanada.ca/rates/exchange/exchange-rates-in-pdf/; and "Inflation Calculator," http://www.bankofcanada.ca/rates/related/inflation-calculator/; Internet, accessed 11 January 2014.

[281] Boeing Defense Space and Security, *Backgrounder – F/A-18E/F Super Hornet*.

[282] Sustainment costs depend on the in-service support architecture in place, the maintenance philosophy employed, and the air technician organizational construct. For example, the RCAF and RAAF use four primary air technician trades (aviation, avionics, structures and armament), while the U.S. Navy uses more, due to increased technician specialization. This directly affects the number of technicians required to support an aircraft per flying hour.

[283] The maintenance culture and spares usage patterns of the RAAF are very similar to the RCAF's when comparing legacy F/A-18 Hornet data. Sustainment costs are primarily driven by flying hour usage, structure of the approved maintenance program and the overall reliability of the weapon system.

its value is composed of approximately: 1) 10-15% consumable spares; 2) 20-25% fuel; and 3) 60-70% depot repair and systems maintenance.[284] This study estimates that F/A-18E/F costs are U.S. $24,400 per flying hour using RAAF data, compared to $21,000 per flying hour estimated for the JSF (also calculated using RAAF methodology); by comparison, U.S. figures for these aircraft are respectively, $11,000 and $31,000 (estimated).[285] While the RAAF F/A-18E/F costs are significantly higher than the USN's calculated costs, the report also states that this is at least partly attributable to the relatively small size of the RAAF fleet and the relative immaturity of the supply chain, when compared to the USN.[286]

Eurofighter Typhoon

Eurofighter Technology

The Eurofighter has been operational since 2003, however as is common with most modern combat aircraft designs, was developed with growth potential and the capability for important upgrades. Eurofighter is being produced in Tranches or financial divisions, subdivided into blocks, or capability baselines of hardware, software and structural changes.[287] A total of 112 Tranche 3A jets started production in 2013 and the

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[284] Jane's data obtained from StratPost, "Gripen's operational cost lower than all Western fighters," http://www.stratpost.com/gripen-operational-cost-lowest-of-all-western-fighters-janes; Internet. Accessed 08 February 2014.

[285] *Ibid.*

[286] Clearly there are 'sunk' costs associated with supporting any aircraft fleet. The larger the fleet, the more hours it can fly annually to the limits of its resource constraints, and thus the more efficient the supply chain can become on a CPFH basis. *Ibid.*

[287] Each Tranche is a separate contract between the four partner nations and the production consortium for an agreed number of aircraft. This arrangement provides the flexibility to change the

production run is expected to continue until 2016.[288] These jets represent the newest standard and the most upgraded capability, including the structure, power and cooling requirements required to integrate an AESA radar (which the aircraft currently lacks) along with the upgraded structure required to mount conformal fuel tanks.[289] The Eurofighter design currently incorporates the multi-mode ECR-90 CAPTOR Radar, purportedly the best performing MSA radar in its class.[290] Although the Eurofighter is currently being marketed for future customers as AESA capable, the integration effort has been plagued by numerous delays, with initial integration of the Captor-E AESA radar now set no earlier than 2015/2016; in fact, a full AESA radar capability is now planned for integration over two planned successive retrofits in 2017 and 2019, if the latest schedule does not slip further.[291] Eurofighter also carries an internally integrated IRST sensor known as PIRATE (**P**assive **IR** **A**irborne **T**racking **E**quipment), which provides passive air-to-air and air-to-ground detection along with long-range visual

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number of aircraft ordered (at a penalty cost), and/or specification changes (i.e. features to be added or deleted) as required. See Fast Air Photography, "Eurofighter Typhoon Guide," http://www.fast-air.co.uk/typhoon-block-tranche-summary/; Internet, accessed 01 February 2014.

[288] *Ibid*.

[289] Conformal fuel tanks are a critical upgrade because they replace the fuel capacity of the three external fuel tanks currently carried for certain combat loadouts. For example, the Storm Shadow strike missile will only be cleared on the two 'wet' wing pylons used for 1000 liter fuel tank carriage. Similarly, the centreline pylon is the currently certified station for the Lightning (or other) targeting pod. Without conformal fuel tanks, carriage of some weapons and especially targeting pods required for modern precision strike will require trade-offs between range and payload, decreasing flexibility for some operational scenarios. Furthermore, CFTs also have a less damaging effect on performance and RCS than external fuel tanks. See UK Armed Forces Commentary, "Typhoon's Present and Future," http://ukarmedforcescommentary.blogspot.ca/2012/08/typhoons-present-and-future.html; Internet, accessed 01 February 2014.

[290] While very capable, mechanically scanned arrays are not low probability of intercept radars and are not as jam resistant as their AESA cousins. Captor radar information from Eurofighter Jagdflugzeug GmbH, *Eurofighter Technical Guide*, (Hallbergmoos: Eurofighter Jagdflugzeug GmbH, 2013) 7,15; http://www.eurofighter.com/; Internet, accessed 01 February 2014.

[291] AESA radar integration for Eurofighter is progressing along two different evolutionary paths. Captor-E is the solution being offered by Euroradar to meet customer requirements for an integrated AESA capability. The UK Ministry of Defence has separately pursued an AESA technology demonstration program known as 'Bright Adder' as a Plan B should Captor-E implementation not be found acceptable to meet RAF requirements. See UK Armed Forces Commentary, *Typhoon's Present and Future*.

identification capabilities.[292] The Eurofighter also boasts a sophisticated and automated Defensive Aids Sub-System (DASS), which integrates front and rear hemisphere laser detectors and missile approach warning (MAW) sensors, chaff/flare dispensers, jammers, radar warning receivers and a towed decoy system.[293] To enable an air-to-ground strike capability with laser guided weapons, a LITENING III Targeting Pod (TGP) capability has been incorporated on some Eurofighters although the pods are currently integrated for carriage only on the centreline weapons station in accordance with Change Proposal CP-193; future upgrades show LITENING pods carried on a new dedicated forward left fuselage (chin) station, similar to how F-16s now mount their targeting pods.[294] The *Eurofighter Technical Guide* also states: "Future generations of targeting and tracking sensors will be readily integrated into Eurofighter Typhoon through the evolving avionics and weapon system architecture."[295] The aircraft is also equipped with the current NATO compatible Multifunctional Information Distribution System (MIDS) Link-16 secure data-link system.[296] The Eurofighter also has an advanced cockpit which includes voice command integration with a traditional throttle and stick interface known as VTAS (Voice + Throttle and Stick), linked with five major displays (three heads down displays, a HUD and the Helmet Mounted Symbology System or HMSS), which are integrated to provide sensor fused data, decreasing pilot workload.[297] Although the Eurofighter was not designed as a stealth fighter, it was designed with reduced observability (RO) features

[292] Eurofighter Jagdflugzeug GmbH, *Eurofighter Technical Guide…,* 33.
[293] *Ibid*.
[294] Fast Air Photography, *Eurofighter Typhoon Guide*….
[295] Of note, should the RCAF choose to purchase Eurofighter, it would require the integration of their existing AN/AAQ-33 SNIPER Targeting Pods on the Eurofighter, or the procurement of new Targeting Pods already integrated on the Eurofighter, such as LITENING III. See Eurofighter Jagdflugzeug GmbH, *Eurofighter Technical Guide…,* 35.
[296] Eurofighter Jagdflugzeug GmbH, *Eurofighter Technical Guide…,* 34.
[297] Eurofighter Jagdflugzeug GmbH, *Eurofighter Technical Guide…,* 7, 27, 36.

to optimize it for BVR combat; according to published RAF material, Eurofighter exceeds frontal aspect RCS specifications, and comments from BAE suggest the radar return is around four times less than a Tornado, or around 1m^2.[298] Furthermore, its ability to supercruise at certain altitudes in some configurations reduces its IR detection range.[299] However, the benefits of limited RCS reduction are marginal with external stores being carried and unless an LPI radar is carried such as the AESA Captor-E, any radar emissions will betray the fighter to an opponent with a radar warning receiver well beyond radar detection range. Of course, Eurofighters today have an option to operate with their radars turned off in a hostile environment and rely on their PIRATE IRST until an AESA radar is properly integrated into the aircraft.

Eurofighter Risks

Technical Risks. The current baseline Eurofighter (Tranche 3A) is a mature design, with a known upgrade path already defined and agreed to by the partner nations. A critical upgrade, which has not yet been successfully integrated into the aircraft, is a fully capable AESA radar. Additional upgrades, which are highly desirable from an RCAF perspective, would be an upgraded ultra-violet (UV) spectrum all-aspect MAW capability[300] for increased survivability and the integration of a new chin targeting pod station. A Canadian procurement would also require a certain level of engineering study

[298] RO features include intake sloping and shaping to mask engine compressor blades, semi-recessed air-to-air missile stations, optimized wing hardpoint placement and design, radome construction, the use of RAM coatings for wing leading edges, intake interior and edges, rudder and strakes. See Eurofighter Typhoon, "Structure," http://typhoon.starstreak.net/Eurofighter/structure.html; Internet, accessed 02 February 2014.

[299] Eurofighter Jagdflugzeug GmbH, *Eurofighter Technical Guide…,* 5, 13.

[300] See Eurofighter Typhoon, "Defences," http://typhoon.starstreak.net/Eurofighter/defences.html; Internet, accessed 02 February 2014.

to determine if and how any Canadian unique requirements are to be incorporated (e.g. weapons, targeting pods, aircrew equipment, unique Arctic requirements, any NORAD-specific requirements). Since the current upgrade path is contractually agreed to by the partner nations, Canada would need to accept the current upgrade program, or develop and fund required capabilities alone. All of the expected Canadian upgrades would preclude a Eurofighter purchase from being a simple "turn-key" Military-Off-The-Shelf (MOTS) procurement.

Schedule Risks. The Eurofighter Consortium has been successful at selling Eurofighters beyond the partner nations, winning competitions in Austria, Oman and Saudi Arabia. However, given the recent competition losses to rival fighter designs, Airbus CEO Tom Enders is not very optimistic about securing additional future Eurofighter orders, which would necessitate closure of the production line in 2017.[301] Furthermore, as noted above, the current projected schedule for a full AESA capability is not before 2019 (assuming no schedule slippage), although an initial capability is expected between 2015 and 2016. Accordingly, the procurement decision for a Canadianized AESA-equipped Eurofighter variant would ideally need to be made prior to 2017 to minimize risk.

Sustainment Risk. Although their future plans may yet change, currently the U.K. expects to fly their 58 Tranche 1 Eurofighters only until 2019, and retire their remaining 107 Tranche 2 and 3A aircraft by 2030, leaving it with a JSF-only air combat capability

[301] Defense Industry Daily, "Eurofighter's Future: Tranche 3, and Beyond," https://www.defenseindustrydaily.com/eurofighters-eur-9b-miltinational-tranche-3a-contract-05674/#News&Views; Internet, accessed 02 February 2014.

beyond that point.[302] Absent any future orders for Eurofighters, the retirement of 160 out of 571 aircraft world-wide will likely drive sustainment costs up beyond 2030, as will any subsequent retirements by any of the current user nations. The Eurofighter was designed with a 25 year inspection free service life or 6000 hours of flight, based on the certified safe structural life of the airframe, whichever comes first.[303] The Eurofighter consortium's current plans envision a product life cycle approaching 50 years from start of development until retirement, which includes a 30 year in-service phase for the user nations, to at least 2040.[304] Also in regards to sustainment concerns, the 2011 U.K National Audit Office report on the Typhoon program identified significant problems with spares availability under the collaborative support contracts in place, which was also a contributing factor in the RAF's recent failure to achieve flying hour targets.[305] Given a longer trans-Atlantic supply chain, this data point is concerning for the RCAF, which is already experiencing logistics support problems with another European consortium developed and supported aircraft fleet, the EH-101 Cormorant helicopter, such that nine decommissioned VH-71 U.S. presidential VIP variants were purchased in 2009 from the

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[302] National Audit Office, *Management of the Typhoon Project* (London: The Stationary Office, 2012); 6,15,21,22; http://www.nao.org.uk/report/management-of-the-typhoon-project/; Internet, accessed 01 February 2014.

[303] Optimized usage for the Eurofighter without any service life extension would be 240 hours per year per aircraft. However, based on Canada's experience with the CF-18, safe structural life could be extended with sufficient engineering data and a tailored structural repair program, and service life for aging aircraft subsystems can also be extended with adequate monitoring and repairs. Robert Dilger, Holger Hickethier, and Michael D. Greenhalgh, "Eurofighter: A Safe Life Aircraft in the Age of Damage Tolerance," First International Conference on Damage Tolerance on Aircraft Structures; available from http://dtas2007.fyper.com/userfiles/file/Paper%2009_Dilger.pdf; Internet, accessed 02 February 2014.

[304] Last deliveries are currently planned for 2017. Thirty years of service would obligate the Eurofighter consortium to provide in-service support until at least 2047. See Peter Hüber, "Eurofighter - Typhoon Entwicklungsprogramm," http://www.dglr.de/fileadmin/inhalte/dglr/fb/l6/l62/2011-05-10_workshop/03-Huber_Vortrag_EF_Entwicklungsprogramm_10Mai11.pdf; Internet, accessed 02 February 2014.

[305] The current contracted support arrangements complicated and cumbersome, with late deliveries of spares and poor turn-around times for repairable equipment being prevalent. Support arrangements are being improved with 11 existing contracts being reduced to three. *Ibid*., 17, 18, 19.

USMC for spare parts at a cost of $160 million.[306] Finally, since the production run is expected to end before the end of this decade, it would preclude the future purchase of additional aircraft to make up for attrition losses should they be required.

Operational Risk. By all accounts, a fully capable Tranche 3 Eurofighter is an excellent platform, which will remain competitive against all current Generation 4 to 4.5 adversaries during its projected life cycle. However, the Eurofighter will not enjoy the same level of *relative* capability against new fifth generation VLO designs with AESA radars and advanced missiles such as the PAK-FA and Chinese J-20 once they are fielded. Therefore, given its lack of all-aspect VLO characteristics, and without a fully mature air-to-ground capability, Eurofighter currently is not, nor will it be, operationally effective conducting certain missions in certain threat environments during its operational lifetime. Finally, the lack of flexibility in regards to the late purchase of spare attrition aircraft increases the risk that the fleet size will eventually become too small to meet all required operational commitments, unless extra aircraft are procured up front. Accordingly, the purchase of a Eurofighter variant as the NGFC solution would result in the RCAF operating an aircraft that will be marginalized in the post-2035 FSE due to emerging threat capabilities and technologies. Therefore, acquiring the Eurofighter means the RCAF will not have the aerospace forces required (in terms of capability and potentially numbers) to meet all existing defence policy role sooner than currently planned.

[306] CTV News, "Mackay asks for review of used U.S. choppers for search and rescue fleet," http://www.ctvnews.ca/canada/mackay-asks-for-review-of-used-u-s-choppers-for-search-and-rescue-fleet-1.1268391; Internet, accessed 02 February 2014.

Eurofighter Costs

Numerous public cost figures are available for the Eurofighter, however it is difficult to project the total cost of a Canadian procurement given that none of the buys to date are for an AESA configured variant of interest to Canada. The best available recent procurement figures available are from 2009 for the Eurofighter consortium's €9 billion contract for the delivery of 112 Tranche 3A jets and 241 engines to the four partner nations.[307] This data produces a reasonable but incomplete estimate for a production (i.e. URF) cost of €80.357 million, which equates to approximately Canadian $135 million in 2014 year dollars.[308] To this cost must be added additional sparing and training, which were not required by the partner nations, as this was not an initial procurement contract. Furthermore, the cost is for the baseline Tranche 3A aircraft configuration, and does not include the additional costs for AESA radars, conformal fuel tanks, upgraded DASS, weapons and additional air-to-ground capabilities or any Canadianization requirements. Accordingly, the procurement of the Eurofighter for the RCAF would be *more expensive* than the existing procurement plan for the JSF.

From the perspective of operating and sustainment costs, IHS Jane's analysis estimates Eurofighter sustainment costs at U.S. $18,000 per flying hour.[309] Sustainment costs, already higher than necessary due to some cumbersome collaborative sparing

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[307] Eurofighter Typhoon, "9 billion euro contract for 112 Eurofighter Typhoons signed," http://www.eurofighter.com/news-and-events/2009/07/9-billion-euro-contract-for-112-eurofighter-typhoons-signed; Internet, accessed 02 February 2014.

[308] The Canadian calculated value uses Bank of Canada exchange rates for 31 July 2009 (1.5406) and inflation factors 2009-2014 (1.0905). Relevant Statistics can be accessed at Bank of Canada, "Monthly and annual average exchange rates," http://www.bankofcanada.ca/rates/exchange/exchange-rates-in-pdf/; and "Inflation Calculator," http://www.bankofcanada.ca/rates/related/inflation-calculator/; Internet, accessed 02 February 2014.

[309] StratPost, *Gripen's operational cost lower than all Western fighters*….

arrangements,[310] are likely to increase once the worldwide fleet size shrinks as partner nations retire their fleets.

Dassault Rafale

Rafale Technology

The Rafale entered operational service in 2004 with the Marine Nationale (French Navy), and 2006 with the l'Armée de l'Air (French Air Force).[311] There are three developed variants currently in production or available for export: the Rafale-B (dual-seat) and -C (single seat) versions for land-based operations, and the navalized single seat Rafale-M.[312] These types are also grouped into Tranches based on software and hardware capability. The current in-service standard is Tranche 3 known as F3, whilst the latest production standard since 2013 is Tranche 4 known as F3R, to be fully qualified by 2018.[313] All Rafale aircraft delivered since September 2013 are equipped with the upgraded RBE2-AA AESA radar.[314] In addition, the Rafale also mounts the OSF (Optronique Secteur Frontale) IRST, which provides passive long-range detection, identification, high-resolution angular tracking and laser range-finding for air, sea and ground targets.[315] The DAMOCLES Targeting Pod is also integrated on the aircraft as is

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[310] See National Audit Office, *Management of the Typhoon Project…*, 7, 8.
[311] Defence Industry Daily, *France's Rafale Fighters….*
[312] *Ibid*.
[313] *Ibid*.
[314] *Ibid*.
[315] Dassault Aviation, "Rafale – A wide range of smart and discrete sensors," http://www.dassault-aviation.com/en/defense/rafale/omnirole-by-design/; Internet, accessed 15 February 2014.

the AREOS reconnaissance pod.[316] Since DAMOCLES is already outclassed by some contemporary targeting pods, the F3R standard will also integrate the new PDL-NG surveillance and targeting pod on the aircraft by 2018.[317] The Rafale also has a tailored automated self-protection suite known as SPECTRA (Système de Protection et d'Évitement des Conduites de Tir du Rafale*)*, which includes radar detectors, laser warning receivers, IR MAW sensors, chaff and flare dispensers, and radar jammers. This highly integrated system enables SPECTRA to provide electronic intelligence (ELINT) capabilities, and purportedly, stealthy jamming modes built around the concept of active cancellation technology to reduce the aircraft's RCS.[318] The aircraft is also equipped with a secure data-link system, and Dassault offers a NATO standard Link-16 version for nations cleared to use it.[319] The Rafale also has an advanced VTAS cockpit,[320] linked with four major displays (a head level display, two colour touch screens and a wide field of regard HUD), which are integrated to provide data fused from all critical sensors, including the IR seekers from MICA missiles, if so equipped, to decrease pilot workload.[321] Notably absent from the F3R standard is a Helmet Mounted Display available with most other 4.5 Generation aircraft.[322] Although Rafale was not designed as a stealth fighter, it was designed with RO features. More specifically, RAM is used

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[316] *Ibid*.

[317] Defence Industry Daily, *France's Rafale Fighters*….

[318] Active cancellation is supposed to work by sampling and analyzing incoming radar and feeding it back to the hostile emitter 180 degrees out of phase to cancel the returning echo. Defence Aviation, "Thales SPECTRA, the tactical advantage for Indian Air Force pilots," http://www.defenceaviation.com/2012/02/thales-spectra-the-tactical-advantage-for-indian-air-force-pilots.html; Internet, accessed 15 February 2014.

[319] Dassault Aviation, *Rafale – A wide range of smart and discrete sensors*….

[320] Rafale International. *Fox Three* No. 3, http://www.dassault-aviation.com/wp-content/blogs.dir/2/files/2013/04/Fox_Three_nr_3.pdf; Internet, accessed 15 February 2014.

[321] Dassault Aviation, "Rafale – The sheer power of multisensor data fusion," http://www.dassault-aviation.com/en/defense/rafale/the-sheer-power-of-multisensor-data-fusion/; Internet, accessed 15 February 2014.

[322] Defence Industry Daily, *France's Rafale Fighters*….

strategically throughout the airframe, sawtooth edges are designed into the foreplanes, flaperons, and some access panels, the engines are hidden using shaped intakes to mask compressor blades, a specialized Hot Spot treatement is used to decrease IR signature, and the Snecma M88 engines have been designed with a decreased thermal signature. [323]

Rafale Risks

Technical Risks. The current baseline Rafale is a mature design, with a known upgrade path and a planned mid-life upgrade after 2020. However, as previously mentioned, a critical upgrade not yet successfully integrated into the aircraft is a helmet mounted display, and it is not currently planned into the F3R standard. As with the Eurofighter option, a Canadian procurement would also require a certain level of engineering study to determine the feasibility and cost for any Canadian unique requirements (aircrew equipment, unique Arctic requirements, NORAD-specific requirements). For example, Canadian pilots from the Directorate of Air Requirements (DAR) noted that the Rafale's cockpit was somewhat smaller than the Eurofighter's, Super Hornet's and JSF's, to the point that a pilot in full contemporary Arctic weather flying gear would be impacted in his/her ability to fight and fly the jet.[324] One of the largest concerns with the Rafale is with respect to weapons and targeting pod integration. While the French weapons suite available for use on the Rafale is impressive and highly capable, the only two options for providing a Canadian combat capability with this aircraft are to either procure French weapons and targeting pods in quantities sufficient to

[323] Rafale International. *Fox Three* No. 4, http://www.dassault-aviation.com/wp-content/blogs.dir/2/files/2013/04/Fox_Three_nr_4.pdf; Internet, accessed 15 February 2014.
[324] Discussion between the author and DAR 5 (Fighter Requirements) pilots 07 April 2014.

meet Canadian operational requirements, or integrate and certify the current suite of preferred Canadian air weapons and the state-of-the-art AN/AAQ-33 Sniper targeting pod, which are American designed and procured.[325] A full clearance and integration effort for existing Canadian weapons and other stores such as airborne instrumentation system (AIS) pods is technically risky, costly and time consuming.[326] Furthermore, integration of the Meteor BVR Air-to-Air missile, a leading contender to succeed the AMRAAM and MICA medium range air-to-air missiles for most western combat aircraft, will not be ready before 2018, well behind Rafale's competition (excepting JSF), and will be the only fighter with a 1-way (vice 2-way) data-link, decreasing overall capability.[327] The expected Canadian upgrades, and especially weapons integration efforts, should they be pursued, would preclude a Rafale purchase from being a simple "turn-key" Military-Off-The-Shelf (MOTS) procurement.

Schedule Risks. Dassault has until now been unsuccessful at selling Rafales internationally. Although Rafale has won the large Indian Medium Multi-Role Combat Aircraft (MMRCA) competition (126 aircraft with options for up to 64 more), a contract has yet to be signed, with a number of contractual provisions still under contention,

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[325] Canadian air weapons include the AIM-9 Sidewinder and AIM-120 AMRAAM variants currently in use or planned for future procurement, along with Canadian laser and GPS guided bombs, including GBU-10/12/16/24 and GBU-31/38 JDAM variants. Of note, the RCAF is retiring its current stock of AGM-65 Maverick air-to-surface missiles.

[326] As an example, carriage, safe separation, ballistics, and end-to-end tests are required to clear a weapon, and in the case of guided weapons and targeting pods which interface with the aircraft, software integration is also required. In some cases, required weapons or pods may adversely impact aircraft flight performance when carried, or the achievement of full performance capability may be deemed too costly. As a case in point, the author was involved in the CF-18 PGM integration effort for the AN/AAS-38 NITEHAWK targeting pod, GBU-12 and -24 laser guided bombs and AGM-65 Maverick missiles, which took four years from start to initial operational capability, and achievable aircraft performance for certain desired weapons configurations were deemed to be operationally unacceptable.

[327] Defense Industry Daily, *France's Rafale Fighters….*

including overall work shares and responsibilities.[328] As a result, Dassault has sustained the production line at minimum capacity (11 per year) for domestic orders, increasing unit costs.[329] While this rate will increase thanks to the India win, it appears that once the first 18 aircraft are delivered, the remaining aircraft would be manufactured under licence by Hindustan Aircraft Limited under a tentative 70/30 work share agreement with Dassault.[330] Nevertheless, the extra Indian orders are expected to extend the Rafale's production line beyond 2021, which was the expected closure date without export orders.[331] Clearly, development efforts (engineering studies and finalized designs) for a Canadianized variant would ideally need to be completed before then.

Sustainment Risk. Currently, the French Air Force and Navy expect to continue operating their Rafales until at least 2040.[332] Analysis of structural testing has shown a projected safe economic life of 7,000 flying hours and 5,300 landings, which would be able to meet RCAF requirements.[333] The main drawback of the Rafale is its relatively small worldwide fleet size. Currently, the French services have a total order of 225 aircraft,[334] with aircraft deliveries continuing until 2021. The Indian requirement will add 126 additional aircraft (and possibly 64 more) to the worldwide mix, but with no other firm orders, fleet size would be limited to between 351 and 415 aircraft. In terms of sustainment, a relatively small fleet size and an overseas supply source increases

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[328] Defense Industry Daily, "India's M-MRCA Fighter Competition: "Thank you, HAL"," http://www.defenseindustrydaily.com/mirage-2000s-withdrawn-as-indias-mrca-fighter-competition-changes-01989/; Internet, accessed 15 March 2014.

[329] Defense Industry Daily, *France's Rafale Fighters*….

[330] Defense Industry Daily, *India's M-MRCA Fighter Competition*….

[331] Defense Industry Daily, *France's Rafale Fighters*….

[332] Dassault Aviation, *Rafale – Omnirole by design*.

[333] This equates to 35 years if aircraft are flown 200 hours per year, which is similar to CF-18 usage rates in recent years, and expected improvements in simulation for fighter pilot training could reduce currently required usage rates.

[334] Defense Industry Daily, *France's Rafale Fighters*….

sustainment risk from the perspective of parts availability for a relatively small RCAF fleet. Finally, since the production run is expected to end in 2021, well before the mid-life point of a Canadian fleet, it would preclude the late purchase of additional aircraft to make up for attrition losses should they be required.

Operational Risk. Rafale is a highly capable Generation 4.5 fighter, with proven combat experience in Afghanistan, Libya and now Mali.[335] It is expected that the aircraft will remain competitive versus all other Generation 4 and 4.5 adversaries during its life cycle in terms of performance and capability. However, like the Eurofighter, the Rafale, will not enjoy the same level of *relative* capability against new fifth generation VLO designs with AESA radars and advanced missiles such as the PAK-FA and Chinese J-20 once they are fielded. Given its lack of all-aspect VLO characteristics, Rafale will not be operationally effective conducting certain missions in certain threat environments during its operational lifetime. Additionally, the lack of flexibility in regards to the late purchase of spare attrition aircraft increases the risk that Canada's fleet size will eventually become too small to meet all required operational commitments, unless extra aircraft are procured up front. Accordingly, the purchase of a Rafale variant as the NGFC solution would result in the RCAF operating an aircraft that will be marginalized in the post-2035 FSE due to emerging threat capabilities and technologies. Acquisition of the Rafale means the RCAF will not have the aerospace forces required (in terms of capability and potentially numbers) to meet all existing defence policy roles sooner than currently envisioned.

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[335] Dassault Aviation, "Rafale – Combat proven," http://www.dassault-aviation.com/en/defense/rafale/combat-proven/; Internet, accessed 15 March 2014.

Rafale Costs

Some open source cost figures are available for the Rafale, however it is difficult to project the total cost of a Canadian procurement given the additional variables associated with weapons (either integration of current weapons or procurement of new French ones) and other unique RCAF requirements. The French government's 2010 annual report on the conduct of armament programmes documented the many costs associated with the Rafale fighter program, including overall program cost (€ 40.69 billion), actual procurement cost (PAUC equivalent - €142.3 million), and actual production line (i.e. roughly URF) costs (€101.1 million) for 286 aircraft forecasted as of 2009.[336] Since the French domestic order has since been cut to 225 aircraft and the production line retarded, all unit costs are actually higher today than the 2009 source data noted in the report. Using a best case production cost of €101.1 million would yield a URF cost of approximately Canadian $169.85 million in 2014 year dollars,[337] unless the French government (and Dassault) were willing to sell the aircraft at a loss. To this cost must be added additional sparing and training, and the additional costs for Canadian unique requirements and weapons (either integration or new purchases). Accordingly, the procurement of the Rafale for the RCAF would also be *more expensive* than the existing procurement plan for the JSF, based on open source information available today.

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[336] Cour des Comptes, *Rapport public annuel 2010 – La conduite des programmes d'armement*. (Paris, France: Cour des Comptes, 2010). 50, 68; http://www.ccomptes.fr/content/download/1341/13203/version/1/file/1_conduite -des-programmes-armement.pdf; Internet, accessed 15 February 2014.

[337] The Canadian calculated value uses Bank of Canada exchange rates for 31 July 2009 (1.5406) and inflation factors 2009-2014 (1.0905). Relevant Statistics can be accessed at Bank of Canada, "Monthly and annual average exchange rates," http://www.bankofcanada.ca/rates/exchange/exchange-rates-in-pdf/; and "Inflation Calculator," http://www.bankofcanada.ca/rates/related/inflation-calculator/; Internet, accessed 02 February 2014.

From the perspective of operating and sustainment costs, IHS Jane's analysis estimates Rafale sustainment costs at U.S. $16,500 per flying hour,[338] which is lower than the calculated Eurofighter costs using U.K. data and the Super Hornet using RAAF data. However, sustainment costs could also increase after 2040 if the French and/or Indian services retire their fleets prior to a Canadian one.

Saab Gripen E/F

Gripen E/F Technology

Gripen NG is the only Generation 4.5 CF-18 replacement contender to the JSF, which is not yet operational. However, the Gripen NG demo has been flying since 2008,[339] and as noted, the NG program is on track for initial deliveries to the Swedish Air Force in 2018. The Gripen E/F is equipped with a Selex ES-05 AESA radar, with a rotating swashplate to increase angle of coverage.[340] The Gripen E/F will also carry a Selex Skyward G IRST above the nose, for passive sensing of air and ground targets.[341] A number of Reconnaissance pods are currently being integrated, as is the Litening III Targeting Pod.[342] The aircraft is also to be equipped with an upgraded EWS-39 NG EW

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[338] StratPost, *Gripen's operational cost lower than all Western fighters….*

[339] Saab Group. "Saab's Maiden Flight with Gripen Demo." http://www.saabgroup.com/en/about-saab/newsroom/press-releases--news/2008---5/saabs-maiden-flight-with-gripen-demo/; Internet, accessed 06 April 2014.

[340] The radar array sits on a swashplate tilted to 30 degrees, allowing increased angular coverage up to 100 degrees by rotating the plate on its longitudinal axis. See Saab Group, "Gripen E – AESA Radar," http://www.saabgroup.com/en/Air/Gripen-Fighter-System/Gripen-and-Switzerland/Gripen-E/AESA-radar/; Internet, accessed 06 April 2014.

[341] Saab Group, "Gripen E – Other Sensors," http://www.saabgroup.com/en/Air/Gripen-Fighter-System/Gripen-and-Switzerland/Gripen-E/Other-sensors/; Internet, accessed 06 April 2014.

[342] *Ibid*.

system with significantly more capabilities compared to the Gripen A-D variants currently flying, including ELINT and electronic attack;[343] the new system will include digitally integrated radar warning receivers, an enhanced self-protection jammer, chaff/flare dispensers, towed decoys, laser warning sensors, UV spectrum MAW sensors (upgradeable to dual-IR band sensors if/when available and affordable), and interface for carriage of an external jamming pod, if desired.[344] Gripen-E, like its predecessors, also comes with one or two secure tactical data-links (a Saab proprietary data-link as well as a Link-16 NATO standard version).[345] The Gripen E/F also has a fully digital cockpit, with a traditional Hands On Throttle And Stick (HOTAS) interface linked to five displays (three heads down multifunction colour displays, a wide area HUD and a helmet mounted display - HMD), which are integrated to provide partial sensor-fused data, decreasing pilot workload.[346] The Gripen demo program is also investigating direct voice input and 3D-audio to enhance and improve the human-machine interface.[347]

Gripen E/F Risks

Technical Risks. The current baseline Gripen C/D is a mature design, however the Gripen E/F is still under development. The Gripen NG demo program, which began

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[343] The proposed Gripen NG EW suite is not yet fully mature, but the architecture has been defined and designed. See JSF Nieuws, "Gripen Demonstrator Programme," http://jsfnieuws.nl/wp-content/JSF15_ERIC_GRIPEN_DEMOROLLOUT2008.pdf; Internet, accessed 06 April 2014.

[344] *Ibid*.

[345] Saab Group, "Gripen E – Communication," http://www.saabgroup.com/en/Air/Gripen-Fighter-System/Gripen-and-Switzerland/Gripen-E/Communication/; Internet, accessed 06 April 2014.

[346] It remains to be seen whether the EW suite information will be fully integrated with other sensors such as the radar and IRST. Saab Group, "The Gripen Mission," http://www.saabgroup.com/Global/Documents%20and%20Images/Air/Gripen/Gripen%20product%20sheet/The_Gripen_Mission.pdf; Internet, accessed 06 April 2014.

[347] JSF Nieuws, *Gripen Demonstrator Programme*…, 4.

in 2008, is scheduled to continue through 2018, and will use four demo aircraft to trial Gripen E's design, systems, sensors and weapons.[348] However, Gripen E/F requires development of over 70% of the aircraft systems from the Gripen C/D baseline.[349] According to Saab, demo testing is currently on schedule, with the first flight of a functioning IRST just completed.[350] A Canadian procurement would require a certain level of engineering study to determine if and how Canadian unique requirements are to be incorporated (e.g. weapons, targeting pod, aircrew equipment and NORAD-specific requirements).[351] As noted previously, a stores clearance program can be technically risky, costly and time consuming. The expected Canadian upgrades, and stores clearance efforts, should they be pursued, would preclude a Gripen E/F purchase from being a simple "turn-key" Military-Off-The-Shelf (MOTS) procurement.

Schedule Risk. As previously noted, now that Saab has won fighter replacement competitions in Switzerland and most recently, in Brazil with the Gripen E/F, the Swedish government has committed to procuring Gripen E/Fs for its own Air Force, with deliveries slated to commence in 2018. With some up-front technical risk associated with its developmental nature, and potential delays for any Canadianization efforts, it would make sense to delay procurement of a Gripen E/F for the RCAF beyond 2018 with

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[348] Aircraft 39-7 is the original Gripen NG demo aircraft to validate overall design and the AESA radar integration. Aircraft 39-8 will be used to validate airframe and general systems, 39-9 will validate tactical systems and functionality, and 39-10 will be the production airframe. See Saab Group, "Gripen E – Delivery," http://www.saabgroup.com/en/Air/Gripen-Fighter-System/Gripen-and-Switzerland/Gripen-E/Delivery/; Internet, accessed 06 April 2014.

[349] Titus Plattner, "Le Gripen, un avion où tout reste à faire," *Le Matin Suisse*, 12 May 2012, http://www.lematin.ch/suisse/suisse-veut-98-retouches-gripen-7/story/25116550; Internet, accessed 06 April 2014.

[350] Saab Group, "Saab successfully completes flight test with IRST for Gripen E," http://www.saabgroup.com/en/About-Saab/Newsroom/Press-releases--News/2014---4/Saab-successfully-completes-flight-test-with-IRST-for-Gripen-E/; Internet, accessed 06 April 2014.

[351] A stores clearance program can take some time to clear all required weapons from the Gripen NG to tactically acceptable speeds. Furthermore, it would also be desirable to integrate the RCAF's current AN/AAQ-33 Sniper targeting pod vice procuring Litening III pods.

deliveries expected around 2020 (or later). In fact, Saab is proposing a Gripen C/D lease option for both Switzerland[352] and Brazil[353] until E/Fs are ready for delivery.

Sustainment Risk. Currently, the Swedish Air Force intends to procure 60 Gripen E for delivery in 2018, and will make the aircraft the backbone of its air force "for the next 30 years," circa 2048.[354] Like the Rafale, the projected Gripen E/F fleet size is currently quite small. In addition to the Swedish government buy, the Brazilian buy is currently confirmed at 36 aircraft (although a potential total could be anywhere from 60 – 104),[355] for a total of 96 aircraft. Furthermore, the projected Swiss buy of 22 aircraft, which would grow the world-wide fleet to 118 confirmed aircraft, has been cancelled in the aftermath of a referendum loss.[356] Saab projects the worldwide Gripen E/F fleet to grow to about 300 aircraft,[357] the smallest projected fleet size of the Generation 4.5 contenders. This imposes sustainment and its related cost risk for a Canadian Gripen fleet, more so if other Gripen E/F users retire their aircraft before the Swedish Air Force does.

Operational Risk. The overall projected multi-role capabilities of the Gripen E/F are excellent. Additionally, Saab has developed and continues to refine a continuous upgrade program for the Gripen.[358] Accordingly, it is expected to remain competitive against all current Generation 4 to 4.5 adversaries during its projected life cycle. However, like its other Generation 4.5 competitors lacking all-aspect VLO

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[352] Saab Group, *Gripen E – Delivery*….

[353] Defense Industry Daily, *F-X2: Brazil Picks Saab's JAS-39 Gripen NG*….

[354] Saab Group, *Gripen E – Delivery*….

[355] Defense Industry Daily, *F-X2: Brazil Picks Saab's JAS-39 Gripen NG*….

[356] Defense Industry Daily, "Switzerland Replacing Old F-5 Fighters with New Gripen-E," http://www.defenseindustrydaily.com/switzerland-replacing-its-f-5s-04624/; Internet, accessed 06 April 2014.

[357] Saab Group, *Gripen E Users*….

[358] Saab Group, "Gripen – Solid Base," http://www.saabgroup.com/en/Air/Gripen-Fighter-System/Gripen-and-Switzerland/The-Gripen-Solution/Solid-base/; Internet, accessed 06 April 2014.

characteristics, Gripen E/F will not enjoy the same level of *relative* capability against new fifth generation VLO designs with AESA radars and advanced missiles such as the PAK-FA and Chinese J-20 once they are fielded. In comparison to its peers, Gripen is considered a lightweight fighter,[359] and in a leaked comprehensive operational test and evaluation (OT&E) assessment conducted by the Swiss Air Force in 2009 for air policing, DCA, escort, reconnaissance and strike missions, it came in last overall against the Rafale and Eurofighter, and was assessed as never reaching "Meet Minimum Expected Capabilities" in all types of missions.[360] Based upon information available, Gripen E/F appears to be the least capable Generation 4.5 contender; as such, it will not be operationally effective conducting certain missions in certain threat environments during its operational lifetime. In fact, Saab representatives proposed the procurement of a mixed fleet of Gripens and JSFs to Canadian parliamentarians for a variety of reasons, acknowledging that JSF was better suited to high threat strike missions during a meeting of the Standing Committee on National Defence (SCOND).[361] As a final point, there is still a measure of uncertainty as to how long Gripen E/F production lines will remain open; in order to minimize operational risk due to attrition, extra aircraft would need to

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[359] A light weight fighter will typically experience a greater performance degradation carrying weapons than a heavier counterpart of similar clean performance. Defense Industry Daily, "The JAS-39 Gripen: Sweden's 4+ Generation Wild Card," https://www.defenseindustrydaily.com/the-jas39-gripen-swedens-4th-generation-wild-card-02401/; Internet, accessed 06 April 2014.

[360] The leaked Swiss evaluation was conducted in two parts, the first being based on 2008 flight tests and the second assessing the delivery configuration of the candidate aircraft in 2015 (for which Saab offered the Gripen MS21 or E/F variant). Although Gripen obtained the highest delta effectiveness score (i.e. the change in assessed scores from the flight tested Gripen C/D to the delivery standard Gripen E/F), it was still assessed as not being able to compete with the other two candidate aircraft. See Swiss Air Force, *SAF/OT&E Evaluation Report NFA Evaluation (RFP2) 2009,* available from http://www.letemps.ch/r/Le_Temps/Quotidien/2012/02/13/ Suisse/Textes/gripen.pdf; Internet, accessed 04 April 2014.

[361] Saab executives acknowledged Canada's heavy involvement in the development of JSF, and suggested a mixed fleet solution as a possibility, when taking into account political, cost and operational factors. See Parliament of Canada, "Standing Committee on National Defence Meeting no. 38 Minutes 07 December 2010," http://www.parl.gc.ca/HousePublications/ Publication.aspx?DocId=4865088&Language=E&Mode=1&Parl=40&Ses=3; Internet, accessed 06 April 2014.

be procured up front to ensure an adequate fleet size throughout a Canadian fleet's operational life. Therefore, the purchase of a Canadianized Gripen as the NGFC solution would result in the RCAF operating an aircraft that will be marginalized in the post-2035 FSE due to emerging threat capabilities and technologies. Acquisition of the Gripen means the RCAF will not likely have the aerospace forces required (in terms of capability and potentially numbers) to meet all existing defence policy roles sooner than was planned.

Gripen E/F Costs

Some publicly available cost figures are now available for the Gripen E/F, which suggest the procurement cost will be somewhat higher than the C/D variants currently flying. For example, the Swiss procurement contract value for 22 aircraft was publicly stated as Swiss Franc (SFR) 3.126 billion or U.S. $ 3.43 billion as of April 2012.[362] This produces a PAUC of $158.7 million in 2014 Canadian dollars.[363] The more recent Brazilian F-X2 contract was publicly identified as costing U.S. $6 billion for 36 aircraft of which $1.5 billion was for maintenance.[364] This produces a PAUC of $135 million in 2014 Canadian dollars.[365] An additional cost point from the Swedish *Ny Teknik* (New

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362 Defense Industry Daily, *Switzerland Replacing Old F-5 Fighters*….

363 The Canadian calculated value uses Bank of Canada exchange rates for April 2012 (0.99263) and inflation factors 2012-2014 (1.02547). Relevant Statistics can be accessed at Bank of Canada, "Monthly and annual average exchange rates," http://www.bankofcanada.ca/rates/exchange/exchange-rates-in-pdf/; and "Inflation Calculator," http://www.bankofcanada.ca/rates/related/inflation-calculator/; Internet, accessed 02 February 2014.

364 Defense Industry Daily, *F-X2: Brazil Picks Saab's JAS-39 Gripen NG*….

365 The Canadian calculated value uses Bank of Canada exchange rates for April 2012 (1.063915) and inflation factors 2013-2014 (1.01546). Relevant Statistics can be accessed at Bank of Canada, "Monthly and annual average exchange rates," http://www.bankofcanada.ca/rates/exchange/exchange-

Technology) magazine identifies the Gripen E unit price (i.e. URF) for the Swiss Air Force as fixed at SFR 100 million per plane, which is purportedly lower than the cost of the aircraft for the Swedish government, identified as between SFR 115 – 130 million, depending upon configuration.[366] The best case Swiss unit price equivalent would be a URF cost of $110.1 million in 2014 Canadian dollars.[367] These numbers are undoubtedly high because of the inefficient production scales associated with small fleet sizes, which is also a problem facing the other Generation 4.5 contenders when compared to JSF. Adding Canadianization requirements to the Gripen NG and paying for any required weapons integration efforts would further increase costs, suggesting that procurement cost for the Gripen NG would likely be higher than the current JSF procurement plan, based on currently available information.

Saab designed the Gripen to be cost effective to operate and support from the outset, and they are quick to reference the IHS Jane's analysis on their website to confirm their success at meeting this goal.[368] The IHS Jane's study indicates that in terms of fuel used, servicing, maintenance and personnel overhead, the Gripen is the least expensive aircraft to operate and support among modern Western fighters, estimated at only U.S. $4,700 per flying hour, using the same calculation methodology as its competitors.[369] This figure, comparatively speaking, is significantly lower than F/A-18E/F, Eurofighter,

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rates-in-pdf/; and "Inflation Calculator," http://www.bankofcanada.ca/rates/related/inflation-calculator/; Internet, accessed 02 February 2014.

[366] Original article in Swedish. See Monica Kleja, "Svensk Gripen E påstås dyrare än schweizisk," *Ny Teknik*, 11 Dec 2012; [magazine online]; available from http://www.nyteknik.se/nyheter/fordon_motor/flygplan/article3601869.ece; Internet, accessed 06 April 2014

[367] The Canadian calculated value uses Bank of Canada exchange rates for December 2012 (1.0735) and inflation factors 2012-2014 (1.02547). Relevant Statistics can be accessed at Bank of Canada, "Monthly and annual average exchange rates," http://www.bankofcanada.ca/rates/exchange/exchange-rates-in-pdf/; and "Inflation Calculator," http://www.bankofcanada.ca/rates/related/inflation-calculator/; Internet, accessed 02 February 2014.

[368] See Saab Group. "Gripen – The Multirole Fighter." http://www.saabgroup.com/en/Air/Gripen-Fighter-System/gripen-fighter/; Internet, accessed 06 April 2014.

[369] StratPost, *Gripen's operational cost lower than all Western fighters….*

Rafale, or JSF, although it is for the Gripen A-D variants. It is expected that Gripen E/F, with a larger engine and more complex systems, will cost somewhat more to operate and support than its earlier cousin, however Gripen E/F should still be less expensive to operate and support than its Generation 4.5 or 5 competitors.

APPENDIX 3 – LIST OF ACRONYMS

A2/AD	Anti-Access and Area Denial
AAA	anti-aircraft artillery
ACF	Aerospace Capabilities Framework (Canada)
ACS	Advanced Crew Station (F/A-18E/F)
AESA	Active Electronically Scanned Array
AI	Air Intercept
AIS	airborne instrumentation system
AL	Autonomous Logistics (JSF)
ALIS	Autonomic Logistics Information System (JSF)
AMC&D	Advanced Mission Computers and Displays (F/A-18E/F)
ANAO	Australian National Audit Office
APUC	Average Production Unit Cost
ASH	Advanced Super Hornet
ASTOVL	Advanced Short Take-off and Vertical Landing
ASuW	Anti-Surface Warfare
ATFLIR	Advanced Targeting Forward Looking Infrared
Aus	Australian
AWACS	Airborne Warning and Control System
BAI	Battlefield Air Interdiction
BIT	built-in test
BVR	beyond visual range
CADIZ	Canadian Air Defence Identification Zone
CAF	Canadian Armed Forces
CAIV	Cost As an Independent Variable
Can	Canadian
CAP	Combat Air Patrol
CAPE	Cost Assessment and Program Evaluation

CAS	Close Air Support
CBP	Capability Based Planning
CDDR	Concept Definition and Design Research (JSF)
CDP	Concept Demonstration Phase (JSF)
CF	Canadian Forces
CFD	Chief of Force Development (Canada)
CFDS	Canada First Defence Strategy
CFT	conformal fuel tank
CNI	Communications Navigation and Identification (JSF)
COP	Common Operational Picture (JSF)
COPT	cost and operational performance trade
CPFH	cost per flying hour
DAR	Directorate of Air Requirements (Canada)
DARPA	Defense Advanced Research Projects Agency (U.S.)
DAS	Distribute Aperture System (JSF)
DASS	Defensive Aids Sub-System (Eurofighter)
dBsm	decibels per square meter
DCA	Defensive Counter Air
DND	Department of National Defence
DOAF	Department of the Air Force (U.S.)
DOD	Department of Defense (U.S.)
DON	Department of the Navy (U.S.)
DOT&E	Director of Operational Test and Evaluation (U.S.)
EA	Electronic Attack
EFT	external fuel tank
ELINT	electronic intelligence
EOTS	Electro-Optical Targeting System (JSF)
ESC	Escort
EW	Electronic Warfare
EWP	Enclosed Weapons Pod
FLIR	forward looking infrared

FMS	Foreign Military Sales
FOE	Future Operating Environment
FSE	Future Security Environment
GAO	Government Accountability Office (U.S.)
HMD	helmet mounted display
HMDS	Helmet Mounted Display System (JSF)
HMSS	Helmet Mounted Symbology System (Eurofighter)
HOTAS	Hands on Throttle and Stick
HUD	Heads Up Display
IDECM	Integrated Defensive Electronic Counter-Measures (F/A-18E/F)
ILS	Instrumented Landing System
IOC	Initial Operational Capability
IR	infrared
IRST	infrared search and track
ISR	Intelligence Surveillance and Reconnaissance
IT	information technology
JAST	Joint Advanced Strike Technology
JHMCS	Joint Helmet Mounted Cueing System (F/A-18E/F)
JIRD	Joint Initial Requirements Document (JSF)
JORD	Joint Operational Requirements Documents (JSF)
JROC	Joint Requirements Oversight Council (JSF)
JSF	Joint Strike Fighter
KPP	key performance parameter
LCC	life cycle cost
LO	Low Observable
LPI	Low Probability of Intercept
LRIP	Low Rate Initial Production
MANPADS	Man Portable Air Defence System
MAW	missile approach warning
MIDS	Multifunctional Information Distribution System
MMRCA	Medium Multi-Role Combat Aircraft (India)

MOTS	Military-Off-The-Shelf
MOU	memorandum of understanding
MP	Member of Parliament (Canada)
MRF	Multi-Role Fighter (U.S.)
MSA	Mechanically Scanned Array
NATO	North Atlantic Treaty Organization
NFA	New Fighter Aircraft (Canada)
NFPS	New Fighter Procurement Secretariat (Canada)
NGFC	Next Generation Fighter Capability (Canada)
NORAD	North American Aerospace Defence Command
O&S	operating and sustainment
OAG	Office of the Auditor General (Canada)
OCA	Offensive Counter Air
OPP	Operational Planning Process
OSD	Office of the Secretary of Defense (U.S.)
OSF	Optronique Secteur Frontale (Rafale)
P3I	Pre-Planned Product Improvement
PAUC	Program Acquisition Unit Cost
PBO	Parliamentary Budget Office/Officer (Canada)
PHM	Prognostic and Health Management (JSF)
PIRATE	Passive IR Airborne Tracking Equipment (Eurofighter)
PJBD	Permanent Joint Board on Defence
PSFD	Production, Sustainment and Follow-on Development (JSF)
PVI	Pilot Vehicle Interface
PWGSC	Public Works and Government Services Canada
RAAF	Royal Australian Air Force
RAM	radar absorbent material
RCAF	Royal Canadian Air Force
RCS	radar cross section
RF	radio frequency
RO	Reduced Observable

SA	situational awareness
SA	Surface Attack
SADI	Strategic Aerospace and Defence Initiative (Canada)
SAM	Surface to Air Missile
SAR	Selected Acquisition Report (U.S.)
SAR	synthetic aperture radar
SCOND	Standing Committee on National Defence (Canada)
SDD	System Development and Demonstration (JSF)
SDR	software-defined radio
SEAD	Suppression of Enemy Air Defences
SFR	Swiss Franc
SOR	Statement of Operational Requirements
SPECTRA	Système de Protection et d'Évitement des Conduites de Tir du Rafale
STOVL	Short Take-off and Vertical Landing
SWP	Sweep
TACAN	Tactical Air Navigation
TASMO	Tactical Air Support to Maritime Operations
TGP	targeting pod
U.K.	United Kingdom
UAS	uninhabited or unmaned aerial system
UAV	uninhabited or unmanned aerial vehicle
UCAV	uninhabited combat aerial vehicle
URF	Unit Recurring Flyaway
URFC	Unit Recurring Flyaway Cost
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
UV	ultraviolet
VLO	Very Low Observable
VSWE	Virtual Strike Warfare Environment
VTAS	Voice + Throttle and Stick

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