OFFICE OF THE PARLIAMENTARY BUDGET OFFICER

BUREAU DU DIRECTEUR PARLEMENTAIRE DU BUDGET

CANADA

An Estimate of the Fiscal Impact of Canada's Proposed Acquisition of the F-35 Lightning II Joint Strike Fighter

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Note to Reader:

The Parliament of Canada Act mandates the Parliamentary Budget Officer (PBO) to provide independent analysis to the Senate and House of Commons on the state of the nation's finances, the government's estimates, and trends in the national economy. Given the size and scope of the proposed expenditure, the request is consistent with the PBO's mandate to support Parliamentarians in providing independent analysis on the state of the nation's finances and scrutiny of the Estimates (i.e. Planned Expenditures).

The cost estimates and observations presented in this report represent a preliminary set of data for discussion and may change, as detailed financial and non-financial data are made available to the PBO by the Department of National Defence or by various agencies of the Government of the United States of America and other parties. The cost estimates and observations included reflect a point-in-time set of observations based on limited and high level data obtained from publicly available documents. These high-level cost estimates and observations are not to be viewed as conclusions in relation to the policy merits of the proposed military equipment acquisition.

PBO has contracted with an independent firm to provide specialized expertise in cost modelling and estimating. Decision Analysis Services (DAS) Limited of the UK employs a proprietary model that houses a database of military aircraft program costs going back thirty years. Where possible, the PBO has provided input factors to DAS and, as a result, the PBO has received output that informs the PBO's analysis. Notwithstanding this, responsibility for all of the costing outputs, analysis, and conclusions rests solely with the PBO.

The authors would like to thank the members of the independent peer review panel as well as a significant number of current and former public officials, who have chosen to maintain the anonymity of their current or former employers, for their comments and guidance. The authors would also like to thank Richard Aboulafia of Teal Group and Jeremiah Gertler of the Congressional Research Service for their advice and support throughout the development of the study. The advice and guidance of the members of the peer review panel imply no responsibility for the final product, which rests solely with the Parliamentary Budget Officer.

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Abbreviations

Abbreviation	Full Form
ALIS	Autonomic Logistic Information System
APB	Acquisition Program Baseline
ASTOVL	Advanced Short Take-off Vertical Landing
CAPE	Cost Assessment & Program Evaluation
CAW	Canadian Auto Workers
CDA	Concept Demonstration Aircraft
CER	Cost Estimating Relationships
CTOL	Conventional Take-off and Landing
DARPA	Defense Advanced Research Projects Agency
DAS	Decision Analysis Services Limited. of the U.K.
DND	Department of National Defence
DT&E	Developmental Testing and Evaluation
FACO	Final Assembly and Check Out
FMS	Foreign Military Sales
GE	General Electric
GAO	United States Government Accountability Office
IOC	Initial Operating Capability
IOT&E	Initial Operational Test and Evaluation
IRB	Industrial and Regional Benefits
ISP	Industrial Share Program
JASSM	Joint Air-to-Surface Stand-off Missile
JAST	Joint Advanced Strike Technology
JET	Joint Estimate Team
JSF	Joint Strike Fighter
LO	Low Observable
LRIP	Low Rate Initial Production
LRU	Line Replaceable Units
MDA	MacDonald Dettwiler
OEM	Original Equipment Manufacturer
PBL	Performance-Based Logistics
PBO	Parliamentary Budget Officer
PSFD	Production, Sustainment and Follow-On Development
RDT&E	Research, Development, Testing and Evaluation
SAR	Selected Acquisition Report
SDB	Small Diameter Bomb
SDD	System Development and Demonstration
SES	System Engineering Support
SOR	Statement of Requirements
STOVL	Short Take-off Vertical Landing
SWAT	STOVL Weight Attack Team
TBR	Technical Baseline Review

1

Executive Summary

On 16 July 2010, the Government announced its intention to acquire 65 F-35 Lightning II Joint Strike Fighter (JSF) aircraft for an estimated C$ 9 billion, with maintenance and support costs estimated at C$ 250–300 million per year.[1] These figures have been reported to result in a total ownership cost for the program of approximately C$ 16–18 billion.[2]

This PBO report is in response to a request from the Member of Parliament from Vancouver South[3] and the Member of Parliament from Beauséjour in relation to the Government's proposed acquisition.[4]

The request was in two parts. The first asked the PBO to identify the premium Canada might pay as a result of the decision to procure aircraft from one source (otherwise known as sole-sourcing) rather than run a competition among potential suppliers. The

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[1] Ross, D. (2010, October 19). Canada. Parliament. House of Commons. Standing Committee on National Defense. *Minutes of Proceedings*. 40th Parliament, 3rd session, meeting no. 14. Retrieved from National Defence and the Canadian Forces website: http://www.forces.gc.ca/site/news-nouvelles/news-nouvelles-eng.asp?cat=00&id=3619.

Department of National Defence and the Canadian Forces. (2011, March 3) *Response to Parliamentary Budget Office, Questions & Answers.*

[2] Blanchfield, M. (2010, July 16). Ottawa to spend $16-billion on fighter jets. *The Globe and Mail.* Retrieved from http://m.theglobeandmail.com/news/politics/ottawa-to-spend-16-billion-on-fighter-jets/article1642399/?service=mobile&template=shareEmail.

Canada to spend $9B on F-35 fighter jets. (2010, July 16). *CBC News.* Retrieved from http://www.cbc.ca/news/canada/story/2010/07/16/canada-jets.html.

[3] Dosanjh, U. (2010, July 21). Open letter to Parliamentary Budget Officer Kevin Page. Retrieved from Liberal Party of Canada website: http://www.liberal.ca/newsroom/open-letter-to-parliamentary-budget-officer-kevin-page/.

[4] LeBlanc, D. (2011, February 17) "Business of Supply". Canada. Parliament. House of Commons. *Edited Hansard 145*(3). 40th Parliament, 3rd session. Retrieved from Parliament of Canada website: http://www2.parl.gc.ca/HousePublications/Publication.aspx?Mode=1&Parl=40&Ses=3&DocId=4976561&Language=E#Int-3757421.

second was a request to provide an independent forecast of the acquisition and sustainment costs of the F-35.

As to the first question, some relevant data exists indicating that costs can be more than 20% higher for equipment acquired on a sole-source basis versus equipment acquired on a competitive basis.[5] Nevertheless this data is insufficient for the PBO to render a definitive opinion relating to the F-35. As to the second question, the PBO was of the view that a reasonable forecast of the acquisition and long-term sustainment cost could be calculated given the significant historical data available on fighter jet procurement.

Note:

This PBO report provides a high-level estimate of the financial impact of acquiring and supporting the F-35. The high-level cost estimates and observations presented are not to be viewed as conclusions in relation to the operational merits of the F-35.

Considerations for Parliamentarians

There are three important considerations in a military procurement.

First and foremost, the proposed acquisition must satisfy the Department of National Defence's (DND) Statement of Requirements (SOR).[6] The PBO has been provided with and has reviewed the relevant SOR. As it is written, the F-35 is the only strike/fighter jet that can meet the specifications contained in the SOR.[7]

Second, the acquisition and long-term sustainment costs of the procurement must be determined.

Third, large competitive military procurements typically require an industrial and regional benefits (IRB) plan whose value is equal to or greater than the value of the contract; these benefits will be both clearly defined and validated by Industry Canada.

In a typical competitive bid process, the requirements, acquisition, and long-term sustainment costs, and the IRBs are weighed together to select the winner. In the case of the F-35 proposal, no competition was held. The SOR has not been made publicly available, the capabilities of the aircraft remain uncertain given its current state of development, the IRBs remain unclear, and the acquisition and long-term sustainment costs have not been determined.

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[5] U.S. Library of Congress. Congressional Research Service (2010, March 22) *F-35 Alternate Engine Program: Background and Issues for Congress* by Jeremiah Gertler. Washington. (R41131).

[6] The Statement of requirements is a document prepared by the Military that articulates their expectations with respect to the specific procurement under consideration. These expectations describe both the mandatory and optional characteristics of the acquisition, relate this acquisition to the role and mission of the military, and support the numbers being requested.

Department of National Defence and the Canadian Forces. (2011, March 3) *Response to Parliamentary Budget Office, Questions & Answers*.

[7] Deschamps, A. (2010). Meet the F-35 Lightning II: Canada's Next Fighter. *Canadian Military Journal*, *11*(1), 49–52.

Canada has not signed any binding contract for acquisition, nor is it under any legal obligation—international or domestic—to go ahead with the purchase.[8] The significant investment made in the development phase is a sunk cost[9], so a decision not to proceed with the acquisition would not result in any incremental financial costs to the Canadian government.

Cost forecast

The PBO forecasted the acquisition and long-term sustainment costs using a 'top-down' model. This model estimates cost by reference to historical trends of previous fighter/strike aircraft and key cost drivers. The PBO engaged a specialist firm to undertake this modelling (see Note to Reader on page 2).

There has been an exponential increase in the cost to manufacture one kilogram of fighter jet over the last six decades. This cost has risen from under US$ 1,000/kg in 1950 to approximately US$ 10,000/kg today (both in 2009 dollars). This represents a real annual rate of increase of approximately 3.5%.[10]

During the same period, the average weight of jet fighter aircraft has increased by about 0.5% per year. Given this, the cost of fighter aircraft has increased 4% per year in real terms since 1950—doubling roughly every 18 years.

Relying on these historical trends and applicable cost drivers, the PBO was able to forecast a total ownership cost of approximately US$ 29.3 billion for the 65 aircraft over a 30-year period. This includes both acquisition and long-term sustainment costs and reflects a 75% confidence interval.[11]

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[8] Rodgers, B. (2008, September 3). *Government of Canada Invests in Nanotechnology Coatings for Joint Strike Fighter Program* (Press Release). Retrieved from Industry Canada Industrial Technologies Office website http://ito.ic.gc.ca/eic/site/ito-oti.nsf/eng/h_00618.html

'The Government of Canada's participation in the JSF program makes it eligible to benefit from preferential conditions and advantages reserved for JSF partners; however, this participation does not commit it to purchase the aircraft.'

Inside the Navy. (2010, July 7). Dutch Official Bemoans Impact of Potential Withdrawal from JSF Testing. *Inside Washington Publishers*, *23*(22).

'Canada is a program partner but its participation in the JSF initiative "does not commit the Department of National Defence to procuring the F35 aircraft," said Jocelyn Sweet, spokeswoman for Canada's defense department. "The recent delays and associated costs have no impact on Canada's commitment to, or participation in, the JSF program," added Sweet.'

[9] The term 'sunk cost' refers to those costs that have already been incurred and cannot be recovered.

[10] Pugh, P. G. (2007). *Source Book of Defence Equipment Costs*. Bedford, UK: P. G. Pugh.

[11] See Cost Analysis, below.

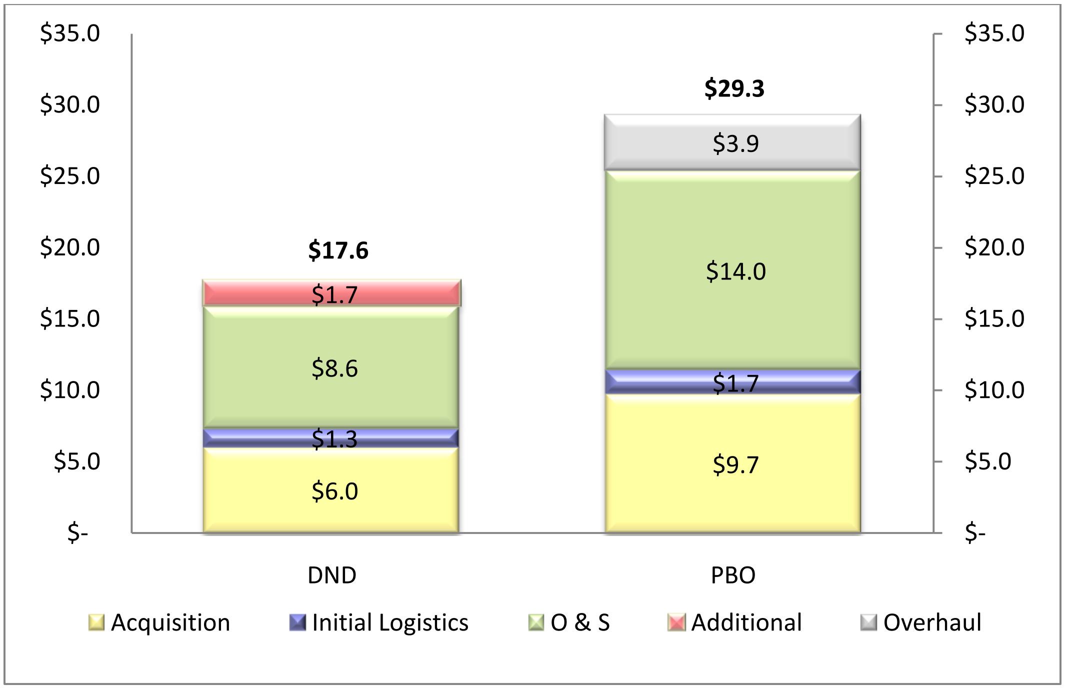
Total Ownership Cost US$ 29.3 billion	
Acquisition cost US$ 9.7 billion	**Ongoing sustainment cost** US$ 19.6 billion
Production cost US$ 9.7 billion	**Initial logistics set-up cost** US$ 1.7 billion
	Operating and support cost US$ 14.0 billion
	Overhaul and upgrade cost US$ 3.9 billion

Cost estimates from any source, including the PBO, should be seen in the context of the methodology employed, the available data, and the desired confidence interval. The PBO sought clarification from DND on the methodology employed, the data, and the desired confidence interval that form the basis of the government's costing figures. DND confirmed that such analysis has not yet been undertaken.[12]

[12] The House Standing Committee on Finance has made a request for detailed information on the F-35 costing including a number of related documents. See http://www2.parl.gc.ca/HousePublications/Publication.aspx?DocId=4792929&Language=E&Mode=1&Parl=40&Ses=3 and http://www2.parl.gc.ca/HousePublications/Publication.aspx?DocId=4683392&Language=E&Mode=1&Parl=40&Ses=3

Department of National Defence and the Canadian Forces. (2011, March 3) *Response to Parliamentary Budget Office, Questions & Answers*.

DND's and PBO's estimates of total cost for 65 F-35As (in US$ billions)[13]



There are risks associated with this estimate. There is a risk that costs may increase as a result of the distribution of the costs associated with research, development, testing, and evaluation (RDT&E), the threatened elimination of the alternate engine program, the possible elimination of the Short Take-off Vertical Landing (STOVL) variant, the possible integration of weapons systems, potential delays and reductions in US and international purchases, the unique cost of operating and support associated with a 5th generation strike/fighter jet, and the circumstances prevailing at the time of mid-life upgrades and overhauls.

Furthermore, the program has been subject to significant delays and cost overruns in the development and design phase. The JSF development phase is reported to be 5 years behind schedule and US$ 21 billion dollars over budget.[14] Should this translate into an increase in acquisition cost, overall production volume may be threatened.

The empirical strength offered by focusing on trends is counterbalanced by a key limitation: the analysis is historical. This means that it is possible that the F-35A constitutes an outlier, in that its cost might be significantly different relative to what the historical trend would suggest.

[13] DND Additional Costs include costs for project management, infrastructure, weapons, and a contingency. The PBO has not included these costs in its estimate. In addition, while the PBO operating and support cost is based on a 30-year program life, DND's operating and support cost is based on a 20-year program life. For purposes of comparability, PBO has increased the DND's forecast operating and support cost on a pro-rata basis to reflect a 30-year program life.

[14] U.S. Rep. Moran, James (2011, February 21) *Op-eds and columns keep funding the JSF Alternate Engine*. Press release.

2

F-35 background

The F-35 JSF is a multi-role fighter that covers three variants: the F-35A (the conventional take-off and landing variant), the F-35B (the Short Take-Off/Vertical Landing variant), and the F-35C (the aircraft carrier variant). The aim behind the project was to develop a common strike fighter platform upon which conventional and Advanced Short Take-off Vertical Landing (ASTOVL) versions could be based.[15]

The rationale behind commonality was volume; by mass producing the aircraft, per unit costs would be significantly decreased. Mass production would be achieved on a number of different fronts. First, as alluded to above, all three branches of the US Armed Forces would purchase aircraft derived from the same general design. Second, unlike the F-22, the F-35 would be a truly international fighter jet; purchases by international partners, such as Australia, Belgium, Denmark, Finland, Greece, Israel, Italy, Japan, the Netherlands, Norway, Singapore, South Korea, Spain, Turkey, and the United Kingdom, would drive down price by increasing volume. Third, the JSF program office would do away with the system of offsets that create the potential for market inefficiencies.

In March 1996, two teams—Lockheed Martin and Boeing—were selected to compete in the concept demonstration aircraft (CDA) phase. Under the CDA phase, both companies were to build prototype aircraft demonstrating the capabilities necessary for each of the variants mentioned above. Engine design, however, was to be handled separately. In order to encourage competition, both Pratt & Whitney and General Electric Company (GE) were to develop potential engines.

The history of the F-22 demonstrated that stealth—a central component of the F-35—necessitates three design specifications. First, the aircraft must be able to chart effectively a 'blue line' flight path to avoid hostile radar. Second, the aircraft's sensors have to be fused to make maximum use of passive and off-board sensors so as to minimize radar transmissions. Third, emission control must be managed to reduce detection. At the time of the F-22, achievement of these specifications required

[15] See Appendix I: Background, below.

supercomputer-level performance. This could only be achieved by sharing these tasks on a common integrated processor system. The same approach was adopted with respect to the F-35.

The F-35's design sought to reduce cost by adopting a number of groundbreaking and untested innovations. All electric supply systems, which are typically separate for functional and safety reasons, were integrated into one system. The hydraulic system was completely replaced by electrical power—eliminating high-pressure fluid lines and replacing them with cables.

Both Lockheed Martin and Boeing encountered technical difficulties in the CDA phase. Design problems encountered by Lockheed Martin required a substantial redesign of the aircraft's exterior. Nonetheless, it did complete the requirements of a short take-off, supersonic acceleration, and vertical landing satisfactorily. Boeing, on the other hand, was only able to demonstrate a vertical landing at sea level with substantial parts removed.

Both competitors submitted formal bid proposals for the systems development and demonstration (SDD) phase. Lockheed Martin was declared the winner on 26 October 2001. However, the company faced the challenge of developing the three variants under a tight schedule. The effect of these design challenges began to materialize a couple of years later. In late 2003, it was discovered that the STOVL variant was massively overweight and could not meet its vertical landing key performance parameter without significant redesign.

At this point, the program came under its first review by the STOVL Weight Attack team. The actions of the team in reducing the weight delayed the program by approximately two years and pushed back the first flight to mid 2008. The emphasis on reducing weight resulted in increased structural complexity, a reduction in the maximum load of the aircraft, and the adoption of different design specifications for the F-35A. The design changes increased complexity and compromised commonality—one of the cornerstones of the common platform.

The next stage of international cooperation in development was driven by the production, sustainment, and follow-on development (PSDF) memorandum of understanding. Although the memorandum did not contain firm purchase numbers for international partners, partner nations did provide their intended purchase numbers, and a method for distributing development costs was established.

Up until now, no contract for full-scale production had been signed by the Pentagon or international purchasers. In fact, for the US Armed Forces, the signing of a future contract would have been legally impermissible: the Pentagon cannot enter into defence contracts before the fiscal year in which the money for the project is appropriated.[16] Furthermore, under US law, defence material cannot be exported at a lower price than that paid by the US government itself.

[16] See Appendix I: Background, below. The only exception to this is where Congress gives special approval for the Department of Defense to enter into multi-year procurement contracts where the contracts meet certain conditions favourable to the government.

None of this, however, would stop international partners from signing contracts for production. However, a push by Lockheed Martin to secure international contracts was ultimately unsuccessful.

3

Delays

The JSF program has been fraught with problems and delays. In 2004, three years after the start of the development phase, the program was re-baselined due to airframe weight problems, causing a Nunn-McCurdy breach.[17] In 2007, the program was re-baselined,[18] and, in 2010, further delays and cost overruns resulted in another Nunn-McCurdy breach and a complete program restructuring, resulting in an extension of the development phase.[19] In January of 2011, a further restructuring was announced.[20]

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[17] U.S. Government Accountability Office. (2005, March). *Defense Acquisitions: Assessments of Selected Major Weapons Programs* (Publication No. GAO-05-301). Retrieved from GAO Reports Main Page via GPO Access database: http://www.gao.gov/new.items/d05301.pdf

A Nunn-McCurdy breach is said to occur when a program's estimated unit-procurement costs exceed 15% of what was planned at the outset. When this occurs, the program must be 'recertified', which means that, within 60 days, the Pentagon must confirm that the program is essential and that costs are both reasonable and being effectively controlled by management. In addition, the Pentagon must provide Congress with the costs of an alternative solution to the program.

Sack, K., & Miller, A. (2005, July 16). THE NATION: North Carolina Crash Is Second in a Month for Marine Harrier Jet; The pilot ejects safely. The plane has long been plagued by mechanical and maintenance woes. *Los Angeles Times*, A-12.

[18] Trimble, S. (2007, April 1). US DoD overrules government auditors' calls to delay F-35 orders. *Jane's Defence Industry.*

[19] Harrington, C. (2010, February 19). F-35 likely to face a Nunn-McCurdy breach, says USAF chief. *Jane's Defence Weekly.*

Harrington, C. (2010, June 3). Pentagon keeps faith with F-35 programme despite soaring costs. *Jane's Defence Weekly*.

Wagstaff, K. (2010, November 25). US awards JSF contract modification. *Jane's Defence Weekly.*

Jennings, G. (2010, November 22). Pentagon subjects JSF programme to further scrutiny. *Jane's Defence Weekly*.

U.S. Government Accountability Office. (2010, March). *Joint Strike Fighter: Additional Costs and Delay Risk Not Meeting Warfighter Requirements on Time* (Publication No. GAO-10-382). Retrieved from GAO Reports Main Page via GPO Access database: http://www.gao.gov/new.items/d10382.pdf

[20] Harrington Lee, C. (2011, January 7). US puts F-35 STOVL variant on two-year probation. *Jane's Defence Weekly.*

F-35 development is now five years behind the schedule set at the outset of the program, and total SDD overruns are projected to exceed US$ 21 billion—60 per cent above the original goal. The relevant milestone for Canadian purposes is the point at which the A variant attains Initial Operational Capability (IOC). The Department of National Defense (DND) requires the achievement of IOC in order to de-commission the current fleet of CF-18s. In addition, significant cost overruns for development may have an impact on the availability of funding for production. While it is true that the US government is substantially paying for the SDD phase, overruns in this phase can lead to a reduction in the number of planes acquired, potentially resulting in a significant increase in the cost per plane.[21]

	2007 Re -baselining	**2010 Restructure (Feb 2010)**	**2011 Restructure (Jan 2011)**
Program Inception	1996, November		
SDD Start	2001, October		
Design Review	2007, June		
Low-Rate Decision	2007, June		
DT&E Complete	2012, October	2015, March	2016, October
IOT&E Complete	2013, October	2016, January	
SDD Complete	2013, October	2016, April	
Full-Rate Decision	2014, October	2016, April	
IOC - F-35B	2012, March		Program on Probation
IOC- F-35A	2013, March	2016, June	Likely to slip
IOC - F-35C	2015, March	2016, June	

Harrington Lee, C. (2011, January 21). F-35 progress review highlights programme issues. *Jane's Defence Weekly.*

Harrington Lee, C. (2011, January 27). Lockheed Martin responds to DoD F-35 report. *Jane's Defence Weekly.*

U.S. Government Accountability Office. (2010, March). *Joint Strike Fighter: Additional Costs and Delay Risk Not Meeting Warfighter Requirements on Time* (Publication No. GAO-10-382). Retrieved from GAO Reports Main Page via GPO Access database: http://www.gao.gov/new.items/d10382.pdf

[21] U.S. Government Accountability Office. (2010, March). *Defense Acquisitions: Assessments of Selected Weapons Programs* (Publication No. GAO-10-388SP). Retrieved from GAO Reports Main Page via GPO Access database: http://www.gao.gov/new.items/d10388sp.pdf

U.S. Government Accountability Office. (2010, March). *Joint Strike Fighter: Additional Costs and Delay Risk Not Meeting Warfighter Requirements on Time* (Publication No. GAO-10-382). Retrieved from GAO Reports Main Page via GPO Access database: http://www.gao.gov/new.items/d10382.pdf

4

Industrial and regional benefits

'Industrial and regional benefits' (IRBs) refers to those benefits accruing to Canadian industry as a result of Canada's participation in a military procurement program. As a matter of course, international defence contractors agree to make investments in Canadian industry as a condition of receiving a procurement contract.[22] These benefits may lie in an expanded supplier base, capital investment, technology transfer, and joint ventures, to name a few.[23] Such benefits, then, notionally 'offset' the costs of the military procurement. Although benefit is often defined in dollar terms, such amounts are not definitive of the extent of industrial and regional benefit.[24]

At its heart, any military procurement is driven by the operational requirements of the Department of National Defence.[25] However, procurement is also a function of both the equipment's price and the benefit that will accrue to Canadian industry by virtue of the procurement. It is, therefore, correct to say that the decision to go ahead with a military procurement should include serious consideration of both these elements. If, as is argued by some defence officials, the industrial and regional benefits that would accrue to Canadian companies are significant, the case might be more easily made that Canada go through with the planned purchase.[26] The difficulty in this analysis lies in accurately

[22] Industry Canada. (2011). *How does the Industrial and Regional Benefits (IRB) policy work?* Retrieved from http://www.ic.gc.ca/eic/site/ad-ad.nsf/eng/ad03661.html

[23] Industry Canada. (2011). *Info Kit for SMEs: Who can benefit from IRBs?* Retrieved from http://www.ic.gc.ca/eic/site/ad-ad.nsf/eng/ad03857.html

[24] See Appendix III: Industrial Share Participation Risk and Opportunities Assessment.

[25] The Statement of requirements is a document prepared by the Military that articulates their expectations with respect to the specific procurement under consideration. These expectations describe both the mandatory and optional characteristics of the acquisition, relate this acquisition to the role and mission of the military, and support the numbers being requested.

[26] Note that statements by defence officials around the world seem to suggest that both considerations are important: O'Dwyer, G. (2008, October 20). Focus Put on F-35 Cost in Norway Contest. *Defense News*.

This is reflected in past practice and also the position of Unions: Pugliese, D. (2010, December 6). Canadian Companies Press for JSF Workshare. *Defense News*, 6.

forecasting the benefit that will accrue to Canadian industry. This is so for a number of reasons. First, under the JSF industrial share program (ISP), Canadian industry is not guaranteed any benefits. Second, the quantification of benefits is a function of a number of different factors—not just dollar values of contracts awarded.

Conventional offsets

When procurement is conducted by way of a competition, Industry Canada's IRB policy[27] requires a minimum one-for-one benefit. This means that any successful bidder must provide industrial benefits to Canada equal to or greater than the value of the contract won. This dollar value is a minimum, and the Industrial and Regional Benefits Directorate at Industry Canada very carefully scrutinizes the industrial benefits to which the dollar value equates. These benefits might be characterized as direct or indirect. 'Direct benefits' refers to those benefits specifically associated with the piece of equipment being procured. 'Indirect benefits' refers to all other ancillary benefits that the contractor may provide that are unrelated to the production of the military equipment itself.

In aid of this process and through the normal course of events, bidders submit an IRB proposal. This proposal outlines the bidder's proposed business activities in Canada and its specific plans for engaging with Canadian companies should its bid be accepted.

Any plans that are submitted are then reviewed and vetted by Industry Canada. The benefits claimed in the proposal are judged by reference to their 'Canadian content value'—broadly speaking, the degree to which Canadian labour and Canadian goods and services will be engaged.[28] Canadian content will be determined by reference to the wages, salaries, and benefits paid to Canadian workers, parts and materials (of Canadian origin) for plant equipment, transportation costs within Canada, facility costs in Canada, engineering and professional services in Canada, travel expenses on Canadian carriers, and profits earned in Canada that are reasonably attributable to the IRB work.[29] If satisfied by the benefits and their content, Industry Canada then approves the bidder's IRB proposal, and, then, broadly speaking, the purchase is free to go ahead.

Industrial Share Participation

There are no publicly available and directly applicable official documents detailing the way in which the JSF ISP is to operate. However, certain criteria can be deduced.

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[27] Industry Canada. (2011). *Backgrounder—Canada's Industrial and Regional Benefits Policy: IRB Requirements.* Retrieved from http://.ww.ic.gc.ca/eic/site/ic1.nsf/eng/05240.html

[28] 'Canadian content value' is described as '… that portion of the selling price of a product or service associated with the work actually performed in Canada.' Industry Canada. (2011). *Info Kit for SMEs*. Retrieved from http://www.ic.gc.ca/eic/site/ad-ad.nsf/eng/ad03857.html

[29] Industry Canada. (2011). *Info Kit for SMEs.* Retrieved from http://www.ic.gc.ca/eic/site/ad-ad.nsf/eng/ad03857.html

In theory, the JSF ISP will operate differently than conventional offsets. One of the prime objectives of the JSF program is to produce the most affordable 5th generation fighter jet possible.[30] Early on, conventional offsets were identified as economically inefficient. Given this, the program office was of the view that it would be more efficient to select contractors on the basis of 'competitive best value' rather than national affiliation. However, the bidding process would be limited to the companies of participant nations. As long as the contractors of a participant nation satisfy Lockheed Martin's quality, price, and performance specifications, they would be entitled to bid on production contracts for the entire program.[31] This constitutes a departure from the conventional approach.[32] Whereas under the conventional approach, the contractor's ability to select a subcontractor might be limited to the Canadian market, industrial share participation under the JSF ISP program allows the contractor to select its subcontractors from companies located in any participant nation. In theory, this would increase the number of firms competing for any given subcontract, thereby improving quality and reducing cost.

Canada's decision to procure the F-35A would entitle Canadian companies to bid on JSF-related contracts. In this way, Canadian companies would not be guaranteed work but, rather, access to the bidding process. Industry Canada estimates the value of this work to be C$ 12 billion. Given Industry Canada's requirement under a competitive bid process is one-to-one and the PBO's forcasted cost of approximately US$ 29.3 billion, Parliamentarians might seek further clarification to explain the difference.[33]

Analysis

There are four related but distinct risks posed by the JSF ISP program.

The first relates to a lack of clarity. There are no clear policy documents outlining the specifics of how the program will function in practice. Given this uncertainty, it is hard to say precisely how Canadian industry might benefit from having access to bid on contracts. In addition, there has been a shift from 'best value' to 'strategic best value'.[34]

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[30] Office of the Deputy Under Secretary of Defense. (2003, June). *International Industrial Participation: A Study of Country Approaches and Financial Impacts on Foreign Suppliers* (Industrial Policy).10–12. Retrieved from http://www.f-16.net/f-16_forum_download-id-11283.html: 'The cornerstone of the JSF program is affordability—reducing the development cost, production cost, and cost of ownership.'

[31] Opall-Rome, B., & Pugliese, D. (2010, December 20). Israeli Clarification Calms Canada's Ire on Offsets'. *DefenseNews*, 7.

[32] This approach has aroused much anxiety in partner countries: Barrie, D. (2006, March 27). The Mouse That Roared: Oslo offers final opportunity for Washington to identify adequate JSF work before determining fate of its involvement. *Aviation Week & Space Technology*, 164(13), 35.

[33] Industry Canada. (2010, October 27). *Ministers Clement and Lebel Celebrate Aerospace Successes and Highlight Government Commitment to Canadian Industry*. Ottawa. Retrieved from http://www.ic.gc.ca/eic/site/ic1.nsf/eng/05997.html

[34] Barrie, D. (2006, March 27) The Mouse That Roared: Oslo offers final opportunity for Washington to identify adequate JSF work before determining fate of its involvement. *Aviation Week & Space Technology*, 164(13), 35.

The latter seems to signal some sort of preferential allocation of work. How such an approach would operate is beyond the scope of this paper.

The second risk relates to the pressure that will likely be brought to bear on the program itself. Given the direct industrial offsets that were accorded under F-16 procurements and, indeed, many European fast jet programs,[35] it is almost inevitable that countries will seek guaranteed industrial benefits for their domestic industries;[36] both past and recent developments illustrate this.[37] The JSF program office has publicly

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[35] Janssen Lok, J. (2000, February 1). New-age F-16 spans the fighter generations. *Jane's Defence Weekly*, *33*(2).

Grevatt, J. (2010, July 16). South Korea and Indonesia join forces for 'F-16-like' aircraft. *Jane's Defence Industry*.

Janssen Lok, J. (1993, May 22). 80% Offsets for F-16 MLU Nations. *Jane's Defence Weekly*, 19(21), 15.

Harrington, C. (2010, June 14). Thirty years and counting: F-16 fighter battles on against younger competitors. *International Defence Review*.

Massy-Beresford, H. (2007, March 20). Norway faces delay to fighter procurement. *Flight International.* Retrieved from http://www.flightglobal.com/articles/2007/03/20/212642/norway-faces-delay-to-fighter-procurement.html

[36] Warwick, G. (2006, June 27). JSF special: Going global. *Flightglobal*. Retrieved from http://www.flightglobal.com/articles/2006/06/27/207394/jsf-special-going-global.html

[37] Barrie, D. (2006, March 27). The Mouse That Roared: Oslo offers final opportunity for Washington to identify adequate JSF work before determining fate of its involvement. *Aviation Week & Space Technology,* 164(13), 35. '[T]here are those in Oslo and Washington who are sceptical the U.S. company is in a position to actually provide what the Norwegian Labor government needs to stay in the program. "I think it's nearly impossible that Lockheed Martin will be able to come up with an acceptable package," says one U.S. industry source.'

Kington, T. (2010, February 1). Italy Threatens to Halt JSF Plant Work. *DefenseNews.* Retrieved from http://www.defensenews.com/story.php?i=4478916

Kington, T. (2010, November1). Italy's JSF Assembly Line Takes Shape. *DefenseNews*. ' "Through the Italian MoD procurement office, we have created a relationship with Lockheed Martin and were able to meet with Lockheed Martin supplier firms," he [Carlo Festucci, the head of Italy's defense and aerospace manufacturers' associated] said. "We accept that work is given out on best value principles, but Lockheed Martin has recognized that we need the conditions in which we can promote ourselves effectively." '

Kington, T., & Ege Bekdil, B. (2006, March 20). Italy, Turkey Win JSF Work. *DefenseNews*. 'The U.S.-led multinational consortium that builds the future F-35 Joint Strike Fighter (JSF) has offered $3.5 billion worth of commitments to Turkish industry and a possible $7.2 billion in production work to Italy, company and government officials said.'

Opall-Rome, B. (2008, November 17). Skittish Israel Pares F-35I Extras - Lockheed CEO: More Workshare A Possibility. *DefenseNews*. '[T]he CEO of F-35 Joint Strike Fighter (JSF) prime contractor Lockheed Martin dangled the possibility of more workshare for Israeli firms if the government places its orders promptly.'

Opall-Rome, B., & Pugliese, D. (2010, December 20). Israeli Clarification Calms Canada's Ire on Offsets. *DefenseNews,*.

Pugliese, D. (2010, December 27). Aerospace union says guarantees are needed of $16 billion worth of work before Canada buys the F-35 Joint Strike Fighter. *Ottawa Citizen.* Retrieved from http://communities.canada.com/ottawacitizen/print.aspx?postid=463474.

Pugliese, D. (2010, December 6). Canadian Companies Press for JSF Workshare. *DefenseNews*.

Trimble, S. (2009, December 1–7). Israel pushes for bigger role in F-35 programme. *Flight International*. 'Israeli officials will continue to push for a larger role in the Lockheed martin F-35 Joint Strike Fighter programme, after winning a key victory on weapons integration.' 19.

stated that workshare is to be a function of procurement.[38] However, it is not immediately clear how such guarantees of workshare commensurate with procurement are possible given the 'best value sourcing model'.[39] This model envisages the selection of contractors and subcontractors on the basis of the value they provide relative to cost. If this is correct, it seems antithetical to the basis of the program to say that a participant nation is entitled to a particular workshare.

It seems more plausible, and consistent with the sentiments expressed by officials, that participant nations will demand, at the very least, one-for-one offsets—that is, one dollar of contract value to domestic companies for every dollar spent on procurement. The imposition of such a requirement is not reconcilable with the underlying objective of the program itself unless Lockheed Martin allows the companies of participant states exclusive access to other F-35-unrelated contracts or 'indirect benefits'.[40] The extent of such benefits and, indeed, the degree to which it would benefit Canadian industry is beyond the scope of this paper. In the absence of any document outlining the specifics of such a proposal, the PBO is not qualified to venture an opinion on the efficacy of the program in offsetting any price that might be paid for the purchase.

The third risk posed by the ISP program relates to the volume of the JSF acquisition. As is mentioned by the US Under Secretary of Defense (Industrial Policy), the Program's '… sheer size and global reach is critically important to the worldwide defense industrial base.'[41] Volume will undoubtedly impact the degree to which Canadian industry benefits. Any potential benefit gained by Canadian subcontractors will be correspondingly diminished by any reduction in orders or increased by any increases in orders.

The fourth risk relates to the position that the Canadian industry finds itself in with regards to its ability to compete effectively for contracts and subcontracts under the program. Again, although it is likely that Canadian industry is well placed to compete for defence subcontracts, such a pronouncement is beyond the scope of this paper.

Wall, R. (2009, November 30). Time After Time: Australia buys into JSF, with a sense of caution. *Aviation Week & Space Technology,* 171(20), 33. 'The government also signals that its 2012 decision will be influence by the industrial benefits Lockheed Martin can provide to Australian companies.'

[38] Opall-Rome, B., & and Pugliese, D. (2010, December 20). Israeli Clarification Calms Canada's Ire on Offsets. *DefenseNews*, 7.

[39] This 'best value sourcing model' is originally found in Office of the Deputy Under Secretary of Defense. (2003, June). *International Industrial Participation: A Study of Country Approaches and Financial Impacts on Foreign Suppliers* (Industrial Policy). 10. Retrieved from http://www.f-16.net/f-16_forum_download-id-11283.html

[40] In fact, this prospect has been alluded to: O'Dwyer, G. (2009, November 16). Norwegian Companies Hope for $3.5B in F-35 Work' *DefenseNews*: ' "We will consider business opportunities offered by the F-35 program itself, as well as what Lockheed Martin may offer in the margins of, or in addition to, this program," Norwegian Economics Minister Trong Giske said.'

[41] Office of the Deputy Under Secretary of Defense. (2003, June) *International Industrial Participation: A Study of Country Approaches and Financial Impacts on Foreign Suppliers* (Industrial Policy). 13. Retrieved from http://www.f-16.net/f-16_forum_download-id-11283.html

5

Cost analysis

The total ownership cost of a piece of military equipment is composed of:

1. acquisition cost
2. ongoing sustainment costs

Acquisition cost is the price a country pays to obtain the military equipment.

Ongoing sustainment costs are those incurred after purchase of the military equipment. They continue over the course of the equipment's operational life.

These two categories can be further broken down.

Acquisition cost typically consists of the cost involved in the equipment's:

- production (fixed and marginal)
- research, development, testing, and evaluation (RDT&E)
- modification and improvements at the time of purchase

Ongoing sustainment costs typically consist of the costs involved in the equipment's:

- initial logistics set-up
- operating and support (O&S)
- overhaul and upgrade
- disposal
- infrastructure
- linked indirect costs

The forecast contained in this report excludes the following costs:

> Research, Development, Testing and Evaluation (RDT&E) costs have not been included. There are two reasons for this. First, the RDT&E amounts pledged under various MoUs are properly viewed as sunk costs and should, therefore, not be considered in deciding whether or not to purchase. Second, Canada and

other consortium partners have been exempt from a RDT&E levy that would, in the normal course of events, be applied under the Foreign Military Sales (FMS) program. That said, Canada is only a Level III Partner.[42] Should RDT&E costs increase significantly, it may become more difficult to pass on those costs to non-consortium members while still maintaining the volume of purchases necessary to keep down the average unit acquisition cost. The impact this may have on the price Canada pays is difficult to forecast. DND includes RDT&E costs within the forecasted acquisition cost of the F-35A, suggesting that such costs may indeed be passed on.[43]

Note:

Although the program officially started at the end of 1996, RDT&E expenditure started in 1994. The latest estimate for development at fiscal year 2009 is US$ 49.3 billion.[1] With the development activity still running, an estimate of a further US$ 5 billion expenditure has been assumed.[2] This would bring the total development cost up to approximately US$ 55 billion.

[1] U.S. Government Accountability Office. (2010, March). *Joint Strike Fighter: Additional Costs and Delay Risk Not Meeting Warfighter Requirements on Time* (Publication No. GAO-10-382). Retrieved from GAO Reports Main Page via GPO Access database: http://www.gao.gov/new.items/d10382.pdf

[2] Speculated by the think tank Centre of Defense Information (CDI).

Modification and improvements have not been included. Although Canada will likely require some modification to the F-35A[44] to ensure it is capable of operating in Canadian conditions, such changes are unlikely to result in material cost increases.[45]

Disposal has not been included for three reasons. First, it depends on the number of planes in service in thirty years' time. Second, it is likely that there will be significant recycling of parts during disposal. Third, given the disposal date, the materiality of relative cost in 2009 dollars is reduced.

Infrastructure costs have not been included. It is unlikely Canada will be building new bases; rather, current bases will likely be modified for the F-35A. Past experience suggests the costs associated with the modifications necessary to

[42] The development of the F-35 JSF has been supported by level I, II, and III partners. The level of partnership corresponds to development contributions. The UK is the only level I partner, having contributed the lionshare of international investment. Italy and the Netherlands are level II partners. Australia, Canada, Denmark, Norway, and Turkey are level III partners.

[43] Department of National Defence and the Canadian Forces. (2011, March 3) *Response to Parliamentary Budget Office, Questions & Answers*. In response to the PBO's question as to the constituent elements of DND's acquisition cost of US$ 9 billion, DND responded that it was to include research, development, testing and evaluation.

[44] Three variants of the F-35 are being produced (see Background, above). Canada intends to purchase the Conventional Take-off and Landing (CTOL) variant, also known as the 'A' variant.

[45] See Appendix II: Modifications, below.

accommodate new aircraft can be significant.[46] Given the fact that Canada has not operated an aircraft that requires low observability restoration, retrofitting Canadian bases could be costly. That said, in the absence of further information on the current state of Canadian bases and details of the specific modifications necessary, forecasting these costs is difficult.

Linked indirect costs have not been included. Such costs include any general and administrative costs associated with the acquisition.

The PBO has arrived at a conservative, high-level estimate on the total ownership cost of the proposed acquisition of 65 F-35As.

It did so by adopting a 'top down' approach to forecasting costs. This approach focuses on historical trends of previous strike/fighter aircraft to forecast acquisition and ongoing sustainment costs.

Research and consultation confirmed that the trend in the acquisition cost growth of strike/fighter aircraft is exponential. A plot of the acquisition cost per kilogram of previous fighter/strike aircraft against the dates for the first deliveries clearly exhibits this upward trend. This remains true even after deflating cost using applicable indices.[47]

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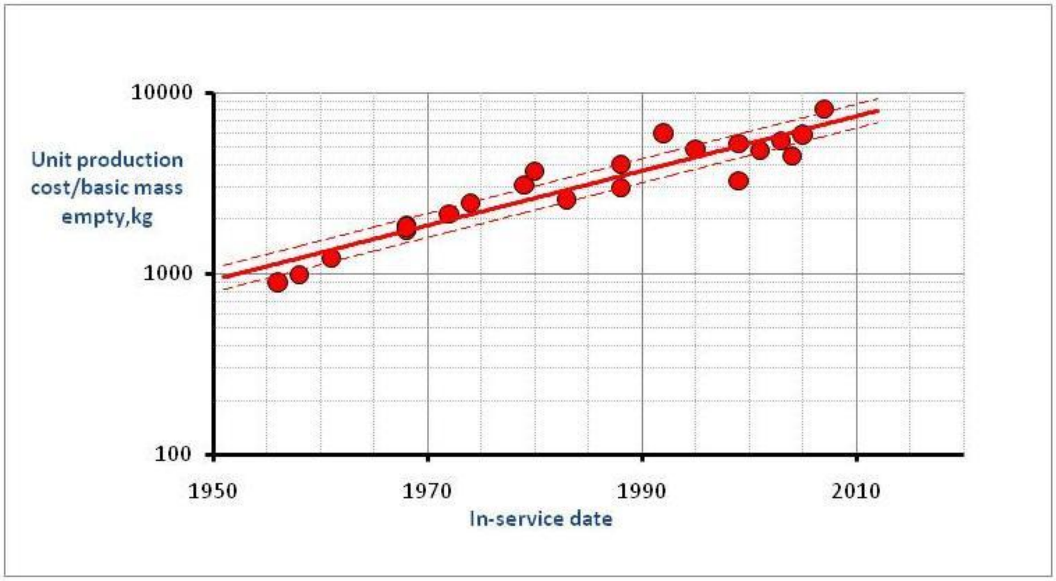
[46] Standing Committee on Public Works, Australia. (2008, August 18). *Australian Super Hornet Facilities Project, RAAF Base Amberley, QLD* [Press release]. Retrieved from http://www.aph.gov.au/house/committee/pwc/superhornetamberley/media/media02.pdf

Parliamentary Standing Committee on Public Works, Australia. (2008, October). *Australian Super Hornet Facilities Project: RAAF Base, Amberley*. Retrieved from http://www.aph.gov.au/house/committee/pwc/superhornetamberley/report/fullreport.pdf

Department of Defence, Australia. (2010, November 19). *Defence Annual Report 2009–10,* Appendix 5, 323. Retrieved from http://www.defence.gov.au/Budget/09-10/dar/dar_0910_v1_s4.pdf#nameddest=a5

[47] U.S. Office of the Undersecretary of Defence (Comptroller). (2010, March). *National Defense Budget Estimates for FY 2011*. 45. Retrieved from http://comptroller.defense.gov/defbudget/fy2011/FY11_Green_Book.pdf. Table 5-4 provides the DOD deflators using the Procurement and RDT&E columns to identify the rate of change between 2000 and 2009.

Historical trends in cost for strike/fighter aircraft[48]



The size of strike/fighter aircraft is found to increase at about 0.5% per annum. The cost per kilogram shows significant real growth at about 3.5% per annum. Given this, the cost of fighter aircraft has increased by approximately 4% per year in real terms since 1950—doubling roughly every 18 years.

This period covers several generations of strike/fighter aircraft and includes a number of significant changes in manufacturing technology.

Historical data also provided the basis upon which to estimate the ongoing sustainment costs: initial logistics set-up, O&S, and overhaul and upgrade. By looking at these costs relative to acquisition cost in prior programs, it was possible to extrapolate what these costs might be based on the likely acquisition cost for the F-35A.

The empirical strength offered by focusing on trends is counterbalanced by a key limitation: the analysis is historical. This means that it is possible that the F-35A constitutes an outlier, in that its cost might be significantly different relative to what the historical trend would suggest.

General assumptions

The PBO's modelling is based on the following general assumptions:

1. US DOD deflators are used to bring all costs to a common 2009 economic base date.[49]

[48] Historical data for strike/fighter aircraft exhibit a well-defined pattern of exponential increase in specific production cost. Such a plot for combat aircraft is illustrated in Pugh, P. G. (2007). *Source Book of Defence Equipment Costs*. Bedford, UK: P. G. Pugh, 46.

[49] U.S. Office of the Undersecretary of Defence (Comptroller). (2010, March). *National Defense Budget Estimates for FY 2011*. 45. Retrieved from http://comptroller.defense.gov/defbudget/fy2011/FY11_Green_Book.pdf. Table 5-4 provides the DOD

2. There will be no exchange rate variation over the delivery horizon.

Acquisition cost

The PBO's forecast for Canada's average unit acquisition cost is based on the following assumptions:

1. No RDT&E recovery levy will be applied to the acquisition cost.
2. The total production run for the F-35A will be 2,478.
3. Canada's F-35As will be delivered according to the following schedule: 1, 3, 9, 13, 13, 13, 13 aircraft each year over 7 years beginning in 2016.[50]
4. Canada will make payments at the time of delivery.
5. The aircraft basic mass empty is 13,318 kg.[51]
6. The rate of production learner is 9.1%.[52]
7. The time at which Canada takes delivery in 2016, 330 F-35As will have been delivered.[53]

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deflators using the Procurement and RDT&E columns to identify the rate of change between 2000 and 2009.

[50] Department of National Defence and the Canadian Forces. (2011, March 3) *Response to Parliamentary Budget Office, Questions & Answers*.

[51] F-35 Communications Team. (2011, January). *F-35 Lightning II Program Update and Fast Facts*. Retrieved from http://f-35.ca/wp-content/uploads/2011/01/F-35-Fast-Facts-Jan-10-2011.pdf

[52] The exact percentage arrived at is .091324 and is based on the SAR Average Unit Production Cost and the Low-rate Initial Production (LRIP) batch 2 cost for 17 aircraft and LRIP batch 3 cost for 31 aircraft.

[53] For the delivery schedule, see Appendix IV: Delivery schedule, below.

These figures are based on the Production, Sustainment, and Follow-on Development MoU amended by developments and changes in planned procurement. The changes are as follows:

Australia has modified its delivery schedule. It now plans to take delivery of 2 F-35As in 2014, 4 in 2015, 8 in 2016, 15 in 2017, 15 in 2018, 15 in 2019, 13 in 2020, 15 in 2022, and 13 in 2023: The Cost of Defence: ASPI Defence Budget Brief 2010-2011. (2010, May 27). The Australian Strategic Policy Institute, 201–2. Retrieved from http://www.aspi.org.au/publications/publication_details.aspx?ContentID=254&pubtype=3

The US purchases of the F-35A have been changed. The US F-35A purchase is now planned as follows: 19 in 2012, 24 in 2013, 40 in 2014, 50 in 2015, 70 in 2016. See: U.S. Undersecretary of Defense (Acquisition, Technology and Logistics). (2011, January 6). *JSF Fact Sheet.* (Issued at U.S. Secretary of Defense Gates's announcement on 2001, January 6).

In addition, purchase of the F-35A by other countries is in question:

The Netherlands purchase is in question: MacKenzie, C. (2010, May 21) Dutch Vote to Cancel Order for F-35 JSF. *Aviation Week*. Retrieved from http://www.aviationweek.com/aw/blogs/defense/index.jsp?plckController=Blog&plckBlogPage=BlogViewPost&newspaperUserId=27ec4a53-dcc8-42d0-bd3a-01329aef79a7&plckPostId=Blog%3A27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post%3A126f6b53-45ed-4603-b333-56e5e9a80e20&plckScript=blogScript&plckElementId=blogDest

8. The time at which Canada takes its last delivery in 2022, 1,367 F-35As will have been delivered.

As mentioned above, for the purposes of this report, acquisition cost consists of the fixed and marginal costs of production. The estimated program average unit acquisition cost for the F-35A was modelled using a Cost Estimating Relationships (CER) model.[54] The program average unit acquisition cost for the F-35A over the course of the entire program has been modelled on a total production run of 2,478 of the F-35A. This number is based on official Program Office figures detailing the anticipated purchases for the three branches of the US Armed Forces and all International Partners.[55]

The mass used in the model is the Basic Mass Empty of the aircraft at 13,318 kg. This value has been taken from official program documentation.[56] The results of the analysis give a forecast program average unit acquisition cost for the F-35A over the entire program of US$ 128.8 million. The following plot shows the distribution of the estimate around the mean.

Denmark has delayed its decision to purchase and is investigating alternatives: Denmark F-35 Fighter Jet Decision Postponed. (2009, April 29) *defencetalk.com*. Retrieved from: http://www.defencetalk.com/denmark-f-35-fighter-jet-decision-18247/

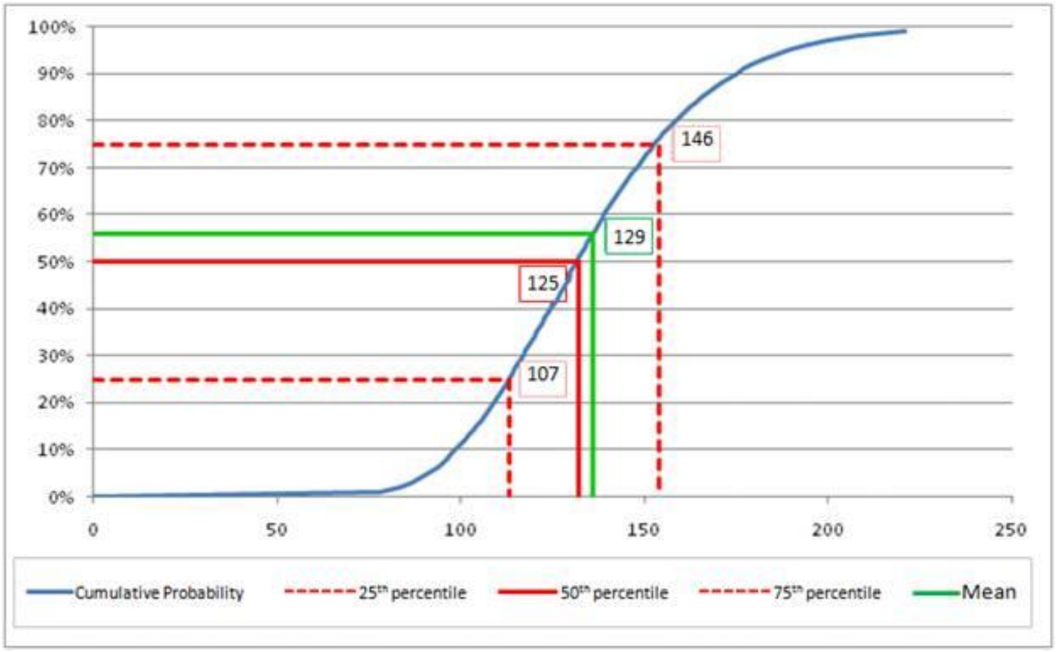
[54] The CER is derived by statistical analysis of the final costs of past fighter aircraft programs. The model employs a combined design and performance-based approach in which information concerning performance requirements and technical characteristics of the proposed design solution are used as inputs to generate costing figures. The input data supplied to the model is in a format such that the values for the cost drivers are accompanied by a measure of its estimating uncertainty. The forecast is based on information available in the public domain and contains a set of explicit program input assumptions that have been thoroughly explored.

[55] US purchases of 1,763 and overseas purchases of 715.

[56] F-35 Communications Team. (2011, January). *F-35 Lightning II Program Update and Fast Facts*. Retrieved from http://f-35.ca/wp-content/uploads/2011/01/F-35-Fast-Facts-Jan-10-2011.pdf

Distribution of uncertainty around the PBO estimate

The 50th percentile represents the historical average against all strike/fighter jets represented in the model. The 25th percentile and 75th percentile are the confidence limits around this historical average. The mean represents the estimate produced by the model on the basis of the input data. In this case the input values represent higher than historical data average. So, this is saying the F-35 input variables are above the historical average for strike/fighter jets.



The Government intends to procure 65 F-35As. This report assumes that Canada intends to take delivery of 1, 3, 9, 13, 13, 13, 13 aircraft each year over 7 years beginning in calendar year 2016.[57] According to the Program Office's forecasts, by the time Canadian deliveries begin, a maximum of 330 aircraft will have been manufactured and delivered; by the time Canada takes the last delivery, a maximum of 1,367 F-35As will have been manufactured and delivered to US and international purchasers. The midpoint of these values is 848.[58]

To calculate the potential average unit cost at the 848th aircraft, it was necessary to establish the rate at which the price alters relative to quantity changes (otherwise known as the learning curve rate).[59] This was achieved by identifying known cost points

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[57] Department of National Defence and the Canadian Forces. (2011, March 3) *Response to Parliamentary Budget Office, Questions & Answers*.

[58] This figure is arrived at simply by averaging the 330 and 1,367.

[59] The principles of learning curves were first developed by T. P. Wright and published in the 1936 *Journal of the Aeronautical Sciences.*

For further background see Ostwald, P. F. (1991) *Engineering Cost Estimating*, Houston.

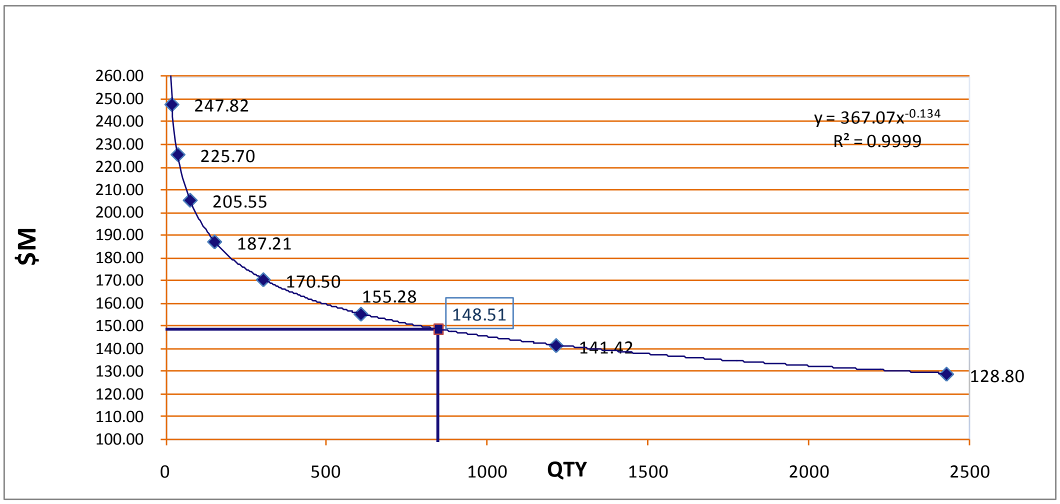
Goldberg M. S. and Touw, A. E. T. (2003) Institute for Operations Research and the Management Sciences, MD: Hanover.

and using those to extrapolate and establish a mathematical curve which best represents the rate of change.[60]

The learning curve reflects a diminishing per unit acquisition cost as production progresses; early purchasers pay a relatively higher price when compared to those who purchase at a later date. This is because purchasing at a later date allows the purchaser to benefit from the advantages gained through, among other things, improved manufacturing, increased scale, and other technology enhancements. Conversely, early purchasers tend to bear a disproportionate premium relative to later purchasers.

Using the learning curve model and the program average unit acquisition cost for 2,478 aircraft of US$ 128.8 million, Canada's average unit acquisition cost for 848 units moving up the learning curve returns a value of US$ 148.5 million.[61] On the basis of the delivery schedule provided, brining these values to FY 2009 results in Canada's acquisition cost being US$ 9.7 billion.

Learning curve



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[60] The known cost points that were used were derived from various LRIP contracts and SARs: SAR average unit production cost for 2,478 aircraft = US$ 86.2 million, LRIP 2 average cost for 17 aircraft = US$ 154 million + US$ 15 million Engine cost = US$ 169 million, LRIP 3 average cost for 31 aircraft = US$ 148 million + US$ 15 million engine cost = US$ 163 million. The LRIP figures were sourced from the US Department of Defense, which excluded engines cost. PBO has estimated the cost of an engine at US$ 15 million each. Using these 3 points, the following graph has been generated. As was discovered when using the US$ 86.2 million SAR estimate as the total average per unit cost, this method produces reasonably accurate output.

[61] The learning curve has been calculated on a platforms level basis using the average unit cost for the total quantity of platforms and the LRIP2 & LRIP 3. This calculated percentage represents the rate at which labour hours and material cost reduce as further production platforms are completed.

Ongoing sustainment costs

As mentioned above, for the purposes of this report, ongoing sustainment costs consist of the costs associated with the equipment's:

- initial logistics set-up
- operating and support (O&S)
- overhaul and upgrade

The estimates reached below constitute a combination of costs taken from the US DOD Selected Acquisition Reports (SARs)[62] and estimates generated using historical data and developed cost models.

Initial logistics set-up

The PBO's forecast for the cost of initial logistics set-up is assumed to be 18% of the Canada's average unit acquisition cost with expenditure spread between years 2016 to 2022.[63] This is US$ 1.7 billion.[64]

Initial logistics set-up covers three different components.

First, it extends to the initial procurement of all required spares to support the aircraft and ensure the maintenance of operational capability. Such spares extend from those required for preventative maintenance to capital spares (such as major parts, engines, under-carriages, etc) to be used for corrective maintenance. Stores in all operational bases will need to be adequately stocked and available for transport where necessary.

Second, facilities will need to be assembled for diagnostic testing. These facilities will carry out diagnostic testing and commissioning post-repair. Such preflight testing is a crucial component of aircraft's general operation.

Third, staff must be adequately trained to carry out testing and maintenance of the aircraft, its parts, and major Line Replaceable Units (LRU) at 1st, 2nd, and 3rd line.[65] Such training is necessary to ensure timely and effective deployment of aircraft.

[62] Selected Acquisition Reports (SARs) summarize the latest estimates of cost, schedule, and performance status for a military acquisition program. These reports are prepared annually in conjunction with the President's budget. Subsequent quarterly exception reports are required only for those programs experiencing unit cost increases of at least 15 percent or schedule delays of at least six months. Quarterly SARs are also submitted for initial reports, final reports, and for programs that are rebaselined at major milestone decisions.

Selected Acquisition Reports, 10 U.S.C. §2432

[63] Komarek, J. (2001, October 24–5). *Life Cycle Cost Simulation in Defence Planning.* RTO SAS Symposium on 'Cost Structure and Life Cycle Cost (LCC) for Military Systems' in Paris France (RTO-MP-096). Retrieved from DTIC Online: http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA418689#page=101

[64] (US$ 148.51 x 65) x 0.18 = US$ 1.73 billion

[65] This would include engines, and major engine parts, all electronic black boxes, avionic black boxes, under carriage left & right, wheels and brakes, radar, cockpit displays, rudder and flap actuators, weapon pylons.

Operating and support

The PBO's forecast for the cost of O&S is based on the following assumptions:

1. All 65 F-35As will be in active fleet for 30 years from their date of delivery.
2. There will be no aircraft replacement due to attrition.
3. The O&S cost per aircraft is based on program average unit acquisition cost, basic mass empty, platform complexity, and 240 flying hours per aircraft per year.[66]
4. Additional capital spares are accounted for within the O&S costs.
5. There will be no cost of disposal.

O&S constitutes one of the major cost components of ongoing sustainment. It includes all costs associated with keeping the aircraft in an operational state of readiness.

Some relevant data exists indicating that average O&S costs for fighter/strike jets range from approximately 3–5% per annum. This data forms the basis for the development of CERs associated with particular inputs. These inputs include basic mass empty, delivery time, and flying hours per year. The model returns percentage values for O&S costs that are a function of the fighter/strike jet's inputs and acquisition cost. Although the data that is publicly available is not sufficient to form the basis of a model of the same nature as that used to forecast acquisition cost,[67] to the extent that data is available, the percentages returned by this model are believed to be reasonable.

Using as inputs an acquisition cost of US$ 128.8 million, the F-35's basic mass empty of 13,318 kg, and the F-35As 5th generation capability, the model returns an O&S cost of 6.4%. Given the program average unit acquisition cost of US$ 128.8 million, this returns an O&S cost of US$ 8.24 million per year per aircraft. Relying on Canada's planned delivery schedule, the total cost of O&S for 65 F-35As in FY 2009 is approximately is US$ 14 billion.

There is a degree of uncertainty in the estimates that the model returns. The introduction of new designs and technologies represents a considerable risk. Despite all the reliability calculations and analysis using the prototype aircraft and historical data, the true levels of reliability will be known only once the operational aircraft have been flown for a number of years. It is often during these initial years that issues are identified that might cause reliability to fall below the specified levels, thus requiring additional design engineering function. This is further complicated by the fact that there are no 5th generation fighter/strike aircraft that have been in service for any length of time. In the case of the F-35 JSF program, this uncertainty is heightened for a number of reasons. By way of example, the F-35 contains an unprecedented number of on-board

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More generally, this includes all those parts that come under particular stress and are more likely to break or fail and require replacement.

[66] This number is consistent with the NATO average, Canada's current flying profile for the CF-18s, and has been confirmed as an appropriate figure by officials from the Department of National Defence.

[67] If nations were to purchase the very same capability every time it would be significantly easier to accurately predict O&S cost. But, the very nature of defence capability is one of continual evolution and an increasing demand for innovative technology.

lines of software code. Furthermore, the degree to which thermoplastics and advanced metals are used in all F-35 variants' fuselage poses a significant risk with respect to costs. Such materials may be difficult to repair and possibly demand a one-for-one replacement. This may prove to be expensive if the production processes were such that disassembly is difficult or unworkable, thus demanding specialized facilities.

Aircraft overhaul and upgrade

The PBO's overhaul and upgrade cost is based on the following assumptions:

1. The F-35A will be subject to two overhaul and upgrades (the first conducted 10 years after delivery and the second conducted 20 years after delivery).
2. Apart from enabling access to the engine and avionics, no changes will be made to the external airframe to maintain stealth integrity.
3. Any changes to the engine and avionics will be minor.
4. The aircraft will go through a comprehensive test and certification prior to going back into service.

Previous generations of strike/fighter aircraft have been progressively upgraded throughout their operational lives. The DOD has not published anything on its proposed strategy for upgrading the F-35, but it is understood that any upgrades could largely be limited to software. If the changes were to involve the airframe, engine, or avionics, this could potentially impact the unit production cost of the F-35 depending on where the change occurred in the production run.

This could be further complicated by the prevailing commercial terms and conditions which could limit or prevent the ability for the removal and replacement of any items that might be considered commercially or militarily sensitive. Such changes might be seen as the province of the DOD, US government, and/or aircraft manufacturer. It could turn out that, to a certain extent, it is only possible for upgrades and overhauls to be carried out by Lockheed Martin at its Fort Worth facility.

Despite this complication, it is possible to provide a rough view of the possible cost associated with any upgrade.

The aircraft might be broken down into three areas that might be upgraded:

- airframe
- engine
- avionics

Based on the assumptions above, a rough order of magnitude cost for a single overhaul and upgrade activity has been estimated at US$ 30.38 million +/- US$ 5 million per aircraft.[68] These costs will be incurred consistent with the current delivery schedule;

[68] By way of background, BAE SYSTEMS successfully ungraded 142 Tornado aircraft from GR1 to GR4 at a cost of £ 943 million in FY 2003. This represents £ 6.64 million per aircraft or US$ 12.8 million at FY2009. An estimated Unit Production Cost for the Tornado aircraft is £ 56 million. The upgrade represents 12% of the unit cost (£ 6.6/£ 56 = 11.7%).

exactly 10 years after being delivered, each F-35A will be overhauled and upgraded. In constant FY 2009, this results in a total cost of US$ 3.95 billion.

Total cost

Total ownership cost consists of acquisition and ongoing sustainment costs (initial logistics set-up, O&S, and upgrades or overhauls).

The PBO arrived at US$ 148.5 million for Canada's average unit acquisition cost at the point in the production cycle at which Canada is scheduled to take delivery.[69] This average unit cost summed over the delivery time frame of 2016–22 for results in an acquisition cost of roughly US$ 9.7 billion (in 2009 dollars). As regards ongoing sustainment, the PBO estimates a total cost of US$ 1.7 billion for initial logistics and US$ 14.0 billion for O&S over a 30 year lifespan for the fleet (both in 2009 dollars).[70] This former figure is calculated as a percentage of Canada's average unit acquisition cost, and the latter figure is calculated as a percentage of the program average unit acquisition cost. In addition, PBO estimates that a US$ 30.38 million per plane will be required for a single overhaul and upgrade. This totals US$ 3.9 billion. Given all this, the total ownership cost, expressed in FY 2009 dollars, for the purchase of 65 aircraft is estimated at approximately US$ 29.3 billion or US$ 450 million per plane.

<table>
<tr><td colspan="2">Total Ownership Cost
US$ 29.3 billion</td></tr>
<tr><td>Acquisition cost
US$ 9.7 billion</td><td>Ongoing sustainment cost
US$ 19.6 billion</td></tr>
<tr><td rowspan="3">Production cost
US$ 9.7 billion</td><td>Initial logistics set-up cost
US$ 1.7 billion</td></tr>
<tr><td>Operating and support cost
US$ 14.0 billion</td></tr>
<tr><td>Overhaul and upgrade cost
US$ 3.9 billion</td></tr>
</table>

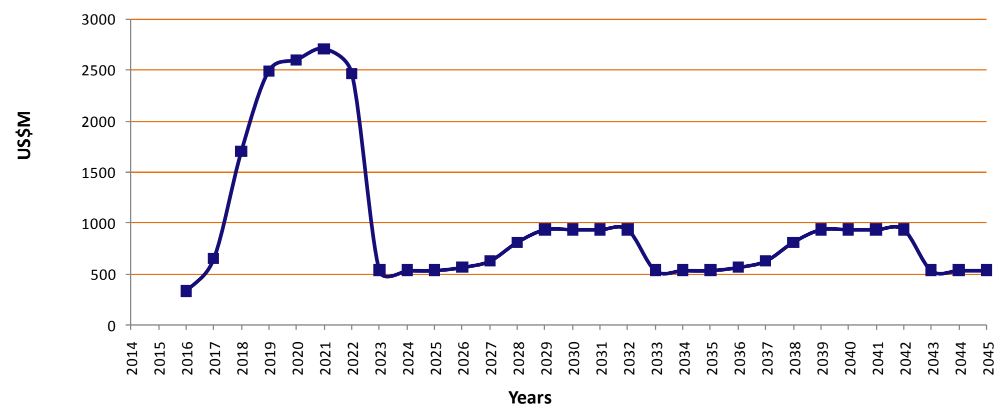
The Harrier was upgraded from GR7/7A to GR9 at a cost of £ 500 million for 60 aircraft = £ 8.3 million per aircraft at FY 2003, or US$ 16 million at FY2009. An estimated Unit Production Cost for the Harrier aircraft is £ 41 million. The upgrade represents 20% of the unit cost (£ 8.3/£ 41 = 20%).

[69] This estimate is provided at a 75% confidence level (meaning that there is a 75% chance that the estimate is correct).

[70] A percentage of 6.4% of acquisition cost per year was derived by running the model given the specific input parameters of the F-35A. This percentage is derived from the model and based on historical trends.

The sustainment costs appear to be within the rough order of magnitude as cited by a number of researchers: Choi, J. (2009) *O&S Cost Growth*, Centre for Naval Analysis, Alexandria VA.

Cost over 30-years in-service



A distribution of these costs over the lifetime of the aircraft yields the above cost horizon.

6

Conclusions

The F-35 was developed to serve the operational needs of the US Navy, Marines, and Airforce. The objective was to develop and produce a stealthy multi-role strike/fighter. That said, development was to be driven not only by performance objectives but also by treating cost as an independent variable. A reasonable average unit acquisition cost was to be achieved by obtaining economies of scale; three common variants of the F-35 were to be mass-produced not only for the three branches of the armed forces but for international partners, as well.

The demand for stealth and commonality necessitated significant technological innovations that have not yet been field tested. In addition, the development program has been subject to weight overruns, significant delays, and increasing costs. No contracts for final production have yet been signed, and, as such, the purchase numbers of both international partners and US armed forces remains to be confirmed. Canada has not signed any binding contract for acquisition. Despite significant investment in the development phase of the aircraft, a decision not to proceed with the acquisition would not result in any incremental financial costs to the Canadian government.

There are three important considerations in a military procurement.

First and foremost, the proposed acquisition must satisfy the DND's Statement of Requirements. The PBO has been provided with and has reviewed the relevant Statement of Requirements. The F-35 is the only strike/fighter jet that can meet the specifications contained in this document as written. Second, the acquisition and long-term sustainment costs of the procurement must be determined. Third, large competitive military procurements typically require an industrial and regional benefits plan whose value is equal to or greater than the value of the contract; these benefits will be both clearly defined and validated by Industry Canada.

In the end, the requirements, the acquisition and long-term sustainment costs, and the industrial and regional benefits are weighed together to select the winner. In the case of the F-35, no competition was held. The Statement of Requirements has not been widely distributed, the capabilities of the aircraft remain uncertain given its current state of development, the industrial and regional benefits remain unclear, and the acquisition and long-term sustainment costs have not been determined.

Insofar as industrial and regional benefits are concerned, there are four distinct risks associated with the F-35 JSF Industrial Share Participation (ISP) program. First, the ultimate benefit to Canadian industry is neither certain nor validated by Industry Canada. Second, there is significant risk associated with ISP operating according to theory. Third, any diminution in volume will impact the market available to Canadian companies. Fourth, the advantage Canadian industry might enjoy in bidding for contracts under ISP is not clear, nor is the benefit that this would offer in terms of investment, job creation, technology transfer, etc.

Cost

The PBO has estimated the total program cost—including acquisition and ongoing sustainment—to be US$ 29.3 billion. Divided over 65 aircraft, this results in a cost of approximately US$ 450 million per aircraft in FY 2009 dollars.

There is continuing speculation as to the final average acquisition cost per aircraft. It would appear that Lockheed Martin remains confident that the average cost will come down. However, it is not immediately obvious, given the available evidence, how the cost can be reduced to estimates predicted by Lockheed Martin over 10 years ago. Not only do such figures not resemble the PBO's costs estimates, but they are considerably lower than the forecasts issued by the DOD organizations, such as the CAPE and the GAO. The Selected Acquisition Report (SAR) published by the DOD shows an average unit production cost of US$ 91 million per aircraft. Being of the view that the program was in even worse shape, NAVAIR's analysts under Vice Admiral David Venlet predict an average unit cost of US$ 128 million.[71] Unless there is compelling evidence to the contrary, it is difficult to see prices reducing to their original estimated level.

Uncertainties

There are a number of factors driving uncertainty around costs. Most pose a risk of increased cost relative to the forecast provided here. Some pose a risk of reduced costs. For others, it is difficult to say what their effect may be.

Based on the above independent cost estimates using historical cost data for strike/fighter aircraft, experience would suggest that the average unit cost provided could be subject to an increase due to:

- increases in and the distribution of RDT&E costs;
- the threatened elimination of an alternate engine program;
- the potential elimination of the STOVL variant;

[71] Trimble, S. (2010, March 11). Lockheed's F-35 faces second restructuring this year. *Flight International*. Retrieved from http://www.flightglobal.com/articles/2010/11/03/349254/lockheeds-f-35-faces-second-restructuring-this-year.html: 'NAVAIR's analysts under Venlet (Vice Adm David Venlet) decided the program was in even worse shape, predicting average costs will rise to over US$ 128 million per aircraft'; furthermore, it is not entirely clear whether this includes the engine cost, which is predicted to be in the realm of US$ 15–20 million.

- the potential integration of weapons systems;
- potential reductions in US and international purchases;
- the unique cost of operating and support associated with a 5th generation strike/fighter jet; and
- the circumstances prevailing at the time of mid-life upgrades and overhauls.

Research, Development, Testing and Evaluation (RDT&E)

RDT&E poses a significant risk and may increase the cost Canada pays.

The RDT&E phase is yet to be completed, and with low rate production started, there remains significant risk of costs increases. Between 2001 and 2009, there have been growth figures of 40% for RDT&E and 54% for production.[72] It is yet unclear how these costs will be distributed among purchasers.

It has been assumed that the price paid by the Canadian Government for the 65 F-35A aircraft will not include any levy or RDT&E recovery. That said, if RDT&E expenditures increase, it is unclear who will bear such costs.

Engine

The proposed elimination by the US Congress of the engine competition poses a risk of cost increase. If the alternative engine program is cancelled, Canada will have no choice but to purchase the engine from Pratt & Whitney. The cost and quality implications of this are hard to predict.

Cancellation

There has been considerable discussion surrounding the possible cancellation of the STOVL variant, particularly the F-35B variant.

Secretary of Defense Gates has put the F-35B on probation and has threatened to cancel it if improvement is not seen.[73] Whether cancellation would increase or decrease cost is a matter for debate. Cancelling the F-35B may significantly reduce cost by eliminating an expensive and complicated variant that has driven a significant amount of technically challenging modifications. However, elimination of this variant would lead to a reduction in overall volume, possibly increasing the per unit price. As such, commenting on the implications of such a development would be speculative at best.

Weapons systems

The integration of weapons on the F-35 will be an issue that any potential user will need to address carefully. Statements in the public domain indicate that the F-35 will employ a variety of US and allied weapons. Weapons to be cleared for internal carriage include: JDAM (joint direct attack munition), CBU-105 WCMD (wind-corrected munitions

[72] See Delays, above.

[73] Secretary of Defense Gates, R. (2011, January 6). *Statement on Department Budget and Efficiencies*. The Pentagon, Washington DC. Retrieved from http://www.defense.gov/speeches/speech.aspx?speechid=1527

'F-35B STOVL "on probation"–Gates' (2011, January 7) *Australian Aviation.* Retrieved from http://australianaviation.com.au/2011/01/f-35b-stovl-%E2%80%9Con-probation%E2%80%9D-%E2%80%93-gates/

dispenser) for the sensor-fused weapon, JSOW (joint stand-off weapon), Paveway IV guided bombs, small diameter bomb (SDB), AIM-120C AMRAAM air-to-air missile, and Brimstone anti-armour missile; for external carriage: JASSM (joint air-to-surface stand-off missile), AIM-9X Sidewinder, AIM-132 ASRAAM, and Storm Shadow cruise missile. However, the integration of nation-specific weapons not cleared by Lockheed Martin and the DOD may lead to additional cost that will be borne by Canada. Recent comments in the press on the proposed purchase of F-35s by the Israeli air force serve to highlight this issue.[74]

Volume

As mentioned above, mass production was intended to reduce per unit price.[75]

If, however, procurement numbers do not materialize—whether due to reduced international or American interest—the implications for acquisition cost could be considerable.[76] This downward pressure on numbers has been reflected in recent delays and reductions in planned acquisitions by the US and international partners. Costs are driven by a number of factors, such as investment in infrastructure, facilities, tooling, and test equipment allowing the automation of activities from part manufacture to system integration and test. While production investment may well be committed without reference to planned quantity, an absence of economies of scale, the likes of which were anticipated by the JSF program office, will likely result in increases in the average unit acquisition cost. The average unit acquisition cost might be driven even higher should the numbers fall below price breaks agreed upon by individual subcontractors. Given Canada's and other nations' reductions in intended procurement thus far, further reductions may lead to increases in the per unit acquisition cost that Canada pays.

Operating and support

The cost associated with operating and support for a 5th generation strike/fighter jet constitutes a significantly unknown quantity. The O&S costs for fast jets are difficult to estimate, as they are driven by a number of interrelated elements. This is further complicated by the lack of historical precedents covering 5th generation aircraft. The percentage used for the forecast in this report is based on basic mass empty, max takeoff weight, and estimated number of flying hours per year.

Overhauls and upgrades

Overhauls and upgrades will be expensive and may be dependent on the availability of Lockheed Martin workforce and facilities. As discussed above, expertise, tools, specialist fixtures, test equipment, and sensitive information may require Canada to rely solely on Lockheed Martin for upgrades and overhauls. As with elimination of the alternative engine program, this creates the potential for significant cost increases.

[74] Israeli Plans to Buy F-35s Moving Forward. (2010, October 17). *Defense Industry Daily.* Retrieved from http://www.defenseindustrydaily.com/israel-plans-to-buy-over-100-f35s-02381/

[75] See Background, above.

[76] See Cost Analysis (Learning Curve), above.

Technological innovation

The design demands on the F-35 led to the adoption of a number of new technologies that have not been field tested.[77] For example, all electrical systems—including emergency systems—were integrated into one. Such innovation may lead to unexpected consequences.

[77] See Appendix I: Background, below.

7

Annex I: Background

The F-35 program originated from the fusion of three parallel fighter development efforts in the early to mid-1990s. These were a US-UK project to define a replacement for the BAE Harrier short take-off—a vertical landing (STOVL) fighter, a US Navy program to develop a stealth attack aircraft, and the USAF's plans for an aircraft to replace the F-16.

The US-UK Advanced STOVL (ASTOVL) project started in 1986 but, by the early 1990s, had made little progress for three main reasons. First, the least complex and risky technical solutions turned out to have serious operational failings. Second, there was no near-term funding in sight for the program, because the UK budget was dominated by the Eurofighter Typhoon and the Navy had no plans to invest in an all-new fighter for the Marines. Third, some US companies—primarily Lockheed Martin—were trying to interest the US services in a stealthy design. Stealth or 'low observable' technology was classified and could not be shared with the British.

In early 1991, US Defense Secretary Dick Cheney cancelled development of the General Dynamics/McDonnell Douglas A-12, a carrier-based, stealthy, heavy attack aircraft. By 1992, the Navy had launched the F/A-18E/F Super Hornet program for a multi-role strike fighter. This left the Navy's need for a stealth attack aircraft unfilled. In 1992, the Navy started a program known as 'Attack Experimental' to meet that requirement.[78]

The USAF, by 1991–2, had started studies of a multi-role fighter to replace the F-16. This move was influenced by several factors: the perceived success of the F-117 stealth attack aircraft in the first Gulf War, the need for a lower-cost complement to the F-22A stealth fighter (the subject of a full-scale development contract awarded in August 1991), and the advent of precision-guided weapons.

The fusion of these programs followed a complex and rapid series of events.

[78] Boeing. (2011). *Defence, Space and Security*. Retreived from http://www.boeing.com/defense-space/military/fa18ef/fa18efmilestones.htm

In 1991–2, ASTOVL advocates persuaded the Defense Advanced Research Projects Agency (DARPA) to support an ASTOVL demonstration program. The key to this was the invention of new ASTOVL concepts using remotely driven lift fans to assist vertical flight, along with a conceptual innovation: different variants of the aircraft could be built. By removing the lift fan, it would be possible to build a conventional version of the ASTOVL aircraft with increased fuel capacity and range.

This was the first vision of an ASTOVL-based 'universal fighter', and the DARPA project was named the Common Affordable Lightweight Fighter. At this point, DARPA's plan was to fund the testing of large-scale, powered models of two ASTOVL concepts.

In early 1993, the Clinton administration took office. The new deputy defense secretary, Dr William Perry, was determined to make weapons more affordable and to consolidate the defense industry. He quickly directed that the Attack Experimental and Multi-Role Fighter programs be consolidated into a new effort called Joint Advanced Strike Technology (JAST). A program office was established under the leadership of Gen George Muellner, whose many assignments had included command of the USAF's classified flight test centre at Groom Lake in Nevada.

In April 1992, before his appointment to head JAST, Muellner had visited the Lockheed Skunk Works at Palmdale and was briefed on the Common Affordable Lightweight Fighter program and its potential to create a tri-service fighter.[79] By the end of the year, it was clear that the JAST office would absorb the Common Affordable Lightweight Fighter program. By the end of 1994, what was clearly recognizable as today's JSF program was being publicly briefed.

At this point, a number of important strategic and technical decisions were taken by Perry and his senior aides, including Dr Paul Kaminski (who had assisted Perry in launching the first stealth programs in the late 1970s). These decisions adopted—as a primary goal of the program—the obtaining of economies of scale and the treatment of cost as an independent variable; the program was to be aimed at reducing cost as much as possible by mass producing three variants of the fighter. By focusing on commonality to develop a fighter that would service all three branches of the US armed forces, high production rates could be achieved and, thereby, costs could be reduced. All three versions were to have a largely common outer mold line and components. The only major difference would be the way in which they landed and took off.

Mass production would be enhanced by servicing not only the three arms of the US armed forces but international partners, as well. Unlike in the previous ASTOVL program, the market would be expanded to cover operators of the F-16 and F/A-18, dominating the world market and expanding potential production to several thousand aircraft.

This focus on mass production was to be attended by another key principle: cost as an independent variable. The customer (in this case, the Pentagon and international partners) would establish a fixed cost for the aircraft, and other key performance parameters would be traded against each other within that cost boundary. In previous

[79] More detail on the evolution of the Lockheed Martin design can be found in: Bevilaqua, P. M. (2009, November). Genesis of the F-35 Joint Strike Fighter. *Journal of Aircraft, 46*(6). doi: 10.2514/1.42903

programs, cost targets had been set, but they were flexible: cost could be increased in order to meet other requirements. The four-year demonstration program would support a parallel process in which the final requirements would be established.

The new aircraft was to reflect key lessons derived from the 1991 Gulf War. Stealth was seen as immensely valuable in the first day of the war; however, after the first day's operations, the Iraqi integrated air defense system never recovered, and Pentagon planners believed that stealth would be less vital as any campaign continued. In addition, operations revealed the high value of precision guided munitions. The Joint Direct Attack Munition[80] program, the first full-production GPS guided bomb, was well under way by 1995. This meant that a combat aircraft could be lethal even with a relatively small weapon load. All this led to a 'day-one stealth' concept, where the aircraft would carry a restricted internal load at the start of the campaign but then switch to non-stealthy operations with a larger load of external weapons afterward in order to deal with bigger target sets. This transformation in approach called for a versatile design.

The goal of tri-service commonality limited the weight and dimensions of the aircraft. The three arms of the armed forces settled on a single-engine design.[81] This decision imposed a ceiling on the total weight of the aircraft. The size of the deck, elevators, and hangars of the US LHA-class ships used by the Marines and the desire to avoid wing folding limited the dimensions of the aircraft.

Size and cost constraints would put restrictions on performance requirements. As the largest customer, the USAF had a strong influence on the basic operational requirement, which was expressed early on as '70 per cent strike and 30 per cent fighter'. In USAF service, the F-15 and, later, the F-22 are the primary air combat fighters, with F-16s in a fighter-bomber role. The strike mission emphasized ground targets, called for the ability to carry bombs (bulkier and heavier than air-to-air missiles), and required a built-in infrared/laser targeting system. Fighter missions stressed speed and acceleration, radar size and power, and agility.

The USAF's thinking was strongly affected by Gulf War experience. The result was a specification that resembled an F-117—a stealthy aircraft designed to carry two 2,000-pound precision-guided bombs—but that eliminated the F-117's limitations.

- The F-117 could not survive in daylight. The new fighter would be able to do so with a combination of situational awareness and air-to-air missiles for self-defense.
- The F-117 was limited to clear air conditions and fixed targets. The new fighter would have a much better electro-optical targeting system and a radar.

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[80] The JDAM was the first full-production GPS-guided bomb and promised to be much less expensive than earlier laser-guided bombs, making unguided bombs almost redundant.

[81] Two engines are normally considered to enhance safety. However, this is not the case for a STOVL aircraft, since it has not been possible to design a two-engine STOVL jet that will fly in powered-lift mode with one engine failed. Consequently, a two-engine STOVL is less safe, because the probability of failure is doubled.

- The F-117 was a one-mission aircraft. The new fighter would, at least, have F-16-level agility and would be able to carry external weapons.

The program had been renamed Joint Strike Fighter (JSF) by the time the request for proposals for the concept demonstration aircraft (CDA) phase was issued in March 1996. Two teams would be selected to carry out the CDA phase. Each would build two prototype aircraft, which, between them, would demonstrate the STOVL, conventional, and carrier-based designs. They would also conduct ground tests to demonstrate stealth and other attributes of their designs.

In parallel, a number of generic technology demonstrations were brought under the JSF umbrella with data to be available to both teams. These included subsystems and avionics technology efforts.

Engine development was to be handled separately. The timing of the CDA and the size of engine required had the effect of compelling the competitors to use prototype engines based on the Pratt & Whitney F119, used in the F-22, because it was the only fighter engine large enough that was in production. However, with fresh memories of the 'great engine war' of the 1980s, both Congress and the customers wanted to create a level playing field for competition. The solution defined by early 1996 was to create competition in production rather than development. Pratt & Whitney would develop the CDA engine and an engine for the production aircraft. A GE team, on a later schedule, would build an alternate production engine to be procured competitively for each lot of production aircraft.

Also under CDA, the airframe teams would refine their final designs, known as Preferred Weapon Systems Concepts. This process would be linked to an iterative process of refining requirements based on the results of large-scale combat simulations, flight tests, and other technology programs and involving all the operators. The result would be a series of Joint Interim Requirements Documents culminating in a Joint Operational Requirements Document. The plan was that the final Joint Operational Requirements document would define a balance among the key performance parameters that could be achieved at the desired cost.

Some Pentagon leaders hoped that the four US fighter design houses would form two teams to compete for JSF, eliminating a downselect and keeping all in the game, but this did not happen, and three bids were received. In November 1996, Lockheed Martin and Boeing were selected for the CDA program. Lockheed Martin's aircraft was to be designated X-35, and the Boeing design became the X-32[82]. The move was a shock to McDonnell Douglas. The announcement was received on the heels of an internal review that had showed the company was in an unrecoverable position in commercial aircraft manufacturing and, ultimately, triggered its acquisition by Boeing. Lockheed Martin, meanwhile, added McDonnell Douglas's teammates Northrop Grumman, BAE Systems, and Rolls-Royce to its own team.

In the CDA program, Lockheed Martin and the customer adopted several key technical features that were handed down to the production aircraft.

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[82] The X-32 designation had originally been allocated to the DARPA CALF program, which had envisaged flying only one STOVL design. The X-33 and X-34 designations had been assigned to NASA programs by the time of the JSF CDA downselect.

The avionics system was to be designed on the same principle as the F-22. In the conceptual stages of the F-22 program in the mid-1980s, it was realized that three related real-time tasks were essential to the success of a stealth fighter.

- 'Blue line' flight path—the guiding of the aircraft on a path that minimizes its exposure to radar—was essential to stealth. A 'blue line' flight path is determined by the location and performance of hostile radars and the varying susceptibility of the aircraft to detection from different aspect angles. In other words, the aircraft threads a path between radar sites while making precisely timed turns to avoid exposing the peak side-on radar signature to the threat. The F-117 used a pre-programmed flight path, but this left it vulnerable to 'pop-up' threats in an unexpected location.
- Sensor fusion—the integration of signals from multiple different sensors into a single set of target data—was seen as essential. Before the 1980s, the different sensors on a fighter—its radar, friend-or-foe identification equipment, radar warning receiver, etc—were functionally separate and 'integrated' in the pilot's brain. This system would not work for the F-22, because it was essential to make maximum use of passive and offboard sensors so as to minimize radar transmissions.
- Emission control—the management of the radar and other transmitting devices to avoid detection—was a function of sensor fusion.

By the standards of the day, these tasks required supercomputer-level performance. The only way to provide this level of performance on a fighter was to share the tasks on a common integrated processor system[83]—a single, high-performance, centralized mainframe computer with (for the day) close-to-supercomputer performance. In the mid-1990s, the same approach was selected for the JSF. The sensors were regarded as 'apertures' or 'peripherals' feeding the common integrated processor.

Two other technical innovations were aimed at reducing maintenance costs. First, most of the hydraulic system was to be replaced by electrical power, eliminating multiple high-pressure fluid lines from the aircraft and replacing them with cables. Second, a 270 VDC electrical system was to be installed—a considerably higher voltage relative to other fighters. This was necessitated by the force required to drive the moving aerodynamic control surfaces (stabilizer, rudders, and ailerons[84]) of a 9-g, 25-ton fighter aircraft.

In addition to these innovations, the JSF integrated all electric supply systems into one by way of Joint Integrated Subsystems Technology—an innovation derived from a USAF demonstration program. Fighter aircraft require an environmental control system to cool the cockpit and avionics, auxiliary power to start the engine and operate systems on the ground, and emergency power to keep the aircraft flying after a loss of main

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[83] Raytheon Company. (2011). *F3A-22 Common Integrated Processor*. Retrieved from http://www.raytheon.com/capabilities/products/f22_cip/

[84] Hinged control surfaces attached to the rear fuselage, vertical fins, or trailing edge of the wing of a fixed-wing aircraft.

engine power. The Joint Integrated Subsystems Technology combined these systems into a single set of machinery.

Neither team had a trouble-free CDA program. The schedule was tight, and, unlike in the case of the demonstration program that preceded the F-22 program, the customer requested the contractors not spend any more than their contracted funds. Overall, however, the outcome favoured Lockheed Martin.

Lockheed Martin experienced problems manufacturing its prototype aircraft, but, first, Boeing ran into insuperable difficulties with its thermoplastic-matrix composite structure and, in 1998–9, was forced to redesign its production aircraft design with four tail surfaces (to improve its carrier-landing performance) and a revised inlet.

The differences continued into the crucial STOVL testing. Although Lockheed Martin and Pratt & Whitney struggled with mechanical failures in the shaft-driven lift fan system, it was installed in one of the X-35 prototypes and, at Edwards AFB in July 2001, performed the so-called 'Mission X' test: a single mission comprised of a short take-off, supersonic acceleration, and vertical landing.

Boeing's X-32 did not perform as well. The STOVL prototype was ferried to the Navy's flight test centre at Patuxent River, Maryland—at sea level rather than at 2,300 feet elevation—but still did not demonstrate a vertical landing except with its landing gear doors and articulated inlet lips removed.

Following the conclusion of the CDA program, both competitors submitted formal proposals for the system development and demonstration (SDD) program. However, there was no formal review of the outcome of CDA to determine whether it had shown that the JSF goals were achievable or whether alternative approaches to fighter replacement would be cost effective. For example, it was assumed that a largely common design, rather than a design that emphasized commonality at a component or subsystem level, would be the least expensive solution.

The timing of the program combined with the result of the 2000 presidential election meant that the source selection had to be made by a new leadership team at the Pentagon. The timing of the source selection process—from the submission of final bids to the final decision date—also extended over the 9/11 attacks.

A transition from CDA to SDD also meant an end to cost as an independent variable—at least, in practice. The development contract would be cost-plus-incentive-fee, and the acquisition and operating costs would be targets and would not be binding. Only goals for system performance would be fixed.

The SDD program was the largest in history, extending over 126 months and including 20-plus flight and ground test articles and, as usual in large government programs, was conducted on a 'blind' basis with neither side being aware of details of the other's bid. The pressure on the competing teams to produce overwhelmingly superior bids was even greater than usual in view of the size of the planned program and the absence of any other large combat aircraft requirement in the foreseeable future.

Full-scale military development contracts awarded in the US after such competitive bidding have historically not performed in terms of cost and schedule, even when fully funded. The most recent of such aircraft programs in 2001 (the B-2, F-22, A-12, and

RAH-66 Comanche) had followed that pattern. It would, therefore, have been surprising if the JSF had been completed according to the estimated cost and on schedule.

On 26 October 2001, Lockheed Martin was announced the winner of the JSF contest and was immediately awarded a contract to perform the SDD program. Due to a verbal misunderstanding in the press conference where the announcement took place, the new fighter was allocated the out-of-sequence designation F-35.[85]

The schedule was demanding, and there were other complicating factors to the program. The first of these was the sequencing of the three variants—the USAF's runway-based F-35A, the STOVL F-35B for the Marines and the UK, and the carrier-based F-35C. With the Boeing F/A-18E/F Super Hornet just entering service, the Navy's requirement was least urgent, and the schedule placed the F-35C last. However, the Marine Corps leadership was set against any use of the Super Hornet, and its legacy force of 'classic' Hornets and AV-8B Harriers was shrinking due to age and attrition. As a result, the most complex version of the JSF was due to be operational first.

Under Lockheed Martin's bid, the program would be centred on its Fort Worth plant, which produced the F-16 fighter and components of the F-22. The Skunk Works in Palmdale, California had invented the shaft-driven lift fan concept, led the capture of both the CDA and SDD contracts, and led the design of the production aircraft. In the SDD program, the Skunk Works in Palmdale was relegated to the specialized design of 'low observable (LO) systems'—the special materials and structures directly associated with stealth.

At the inception of the JSF program, Fort Worth had only recently been acquired by Lockheed (before the merger with Martin-Marietta), and very few, if any, Fort Worth personnel moved to Palmdale to support CDA. Similarly, not many Palmdale personnel moved to Fort Worth to take part in SDD.

The first major setback in the JSF program occurred in late 2003 with the discovery that the STOVL version of the aircraft was massively overweight and would not be able to meet its vertical landing key performance parameter without redesign. The F-35A version was also overweight, but by a smaller amount that was not critical, and the F-35C was, as yet, early in its design stages. Palliative measures were deemed inadequate, and the program was halted in April 2004 to allow the problem to be fixed by the so-called STOVL Weight Attack Team (SWAT).[86] The objective of the SWAT was to reduce the weight of the JSF.

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[85] The program office maintains that the designation was a deliberate choice. See F-35 Lightning II Program Office. (n.d). *Frequently Asked Questions*. Retrieved from http://www.jsf.mil/contact/con_faqs.htm. An independent expert, Andreas Parsch, has the full story, available at: Parsch, A. (2006). *Non-Standard DOD Aircraft Designations*. Retrieved from http://www.designation-systems.net/usmilav/nonstandard-mds.html#_MDS_F35

[86] Pappalardo, J. (2006, November 11). Weight Watchers: How a team of engineers and a crash diet saved the Joint Strike Fighter. *Smithsonian Air & Space Magazine*. Retrieved from http://www.airspacemag.com/military-aviation/weight_watchers.html

SWAT resulted in a two-year delay in the first flight of what was now called the 'weight-optimized' aircraft. The AA-1,[87] a pre-SWAT design, would be completed, but the first redesigned aircraft was not ready to fly until mid-2008. That said, the initial operational capability date for the F-35B slipped by only one year, increasing pressure on the flight test.

While the redesign process reduced weight, it had less desirable side effects. Generally, it resulted in increased structural complexity, such as dual nose landing gear doors and a larger number of wing spars. It also led to reduced commonality: in order to save weight, the maximum maneuvering load on the STOVL F-35B was reduced to 7 g, and major structural components were made differently than for the F-35A. For example, bulkheads were changed from titanium to aluminum, and the horizontal tails were made smaller. Other components, such as control actuators, became less common across the variants.

As the F-35C version proceeded through its design review process, it, too, was found to need a larger wing than expected (about a 10 per cent increase in gross area) to meet carrier landing standards. Its weight also grew; an indication of the diminished commonality between the F-35A and F-35C is that the carrier jet's airframe (minus the identical engine) is almost 25 per cent heavier than that of the USAF aircraft.

The AA-1 prototype made its first flight in December 2006, and the 'weight-optimized' BF-1 rolled out at the end of 2007, flying in June 2008 in accordance with the post-SWAT schedule. Privately, executives were complaining of a 'constipated' supply chain, and deliveries slipped increasingly behind schedule.[88] Across the program, suppliers were struggling with the design and manufacture of parts that might be different for all three models and that were constantly changing over time as the design was refined.

Meanwhile, specific warnings that the project might be delayed began to emerge. In a March 2007 report, the US Government Accountability Office cited a February 2006 assessment by an operational test team that identified 'several … issues [that] if not adequately addressed, are likely to pose a substantial or severe operational impact to the JSF's mission capabilities.' These included a 'success-oriented' software development and testing schedule and a compressed developmental flight test schedule.[89]

As early as mid-2007, program leaders were saying that the key to completing flight tests on time would be to reach a point where all 12 production-design aircraft were performing 12 valid test sorties each per month. They predicted that such a rate would be attained by early 2009. In fact, it had not been reached by the end of 2010.[90]

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[87] Individual JSF aircraft carry sequential numbers prefaced with AF, BF, or CF according to variant. The AA-1 designator indicated that the first aircraft to fly was not a definitive F-35A design.

[88] Defensetech. (2011). JSF Hoping for a Brighter New Year. *Av Week Extra*. Retrieved from http://defensetech.org/2007/12/13/jsf-hoping-for-a-brighter-new-year/

[89] Sullivan, M. J. (Ed.). (2007, March). *Joint Strike Fighter: Progress Made and Challenges Remain* (Report to Congressional Committees GAO-07-360), 21. Retrieved from U.S. Government Accountability Office website www.gao.gov/new.items/d07360.pdf

[90] Warwick, G. (2011, January 4). F-35 Begins Year With Test Objectives Unmet. *Aviation Week*. Retrieved from

The next step in the international partnership program for the JSF was the agreement of the Production, Sustainment and Follow-On Development (PSFD) memorandum of understanding, finalized in February 2007 with all eight international partners and preceding the July 2007 award of the first Low Rate Initial Production (LRIP) contract for two F-35As.[91]

Under the PSFD, the partners did not contract to buy F-35s. However, they did agree on how to buy them if they took that decision and on rules for international industry participation. An appendix included planned delivery schedules for the US and international partners.

Neither the PSFD nor its subsequent revisions represent any kind of contractual commitment to acquire the aircraft. This would actually be quite difficult under US law, which specifically indicates that defence material cannot be exported at a lower price than is available to the US government.[92] Furthermore, the US government cannot sign defense contracts before the fiscal year in which the money is appropriated,[93] with limited exceptions for multi-year purchases. Although the JSF production program is a multi-year purchase, it cannot be signed until operational testing is completed.[94] Up to late 2010, accordingly, the only export contracts signed for the JSF are included in batches already ordered by the US government.[95]

Many non-US governments, however, can enter into binding contracts covering multiple future years. Recognizing this difficulty as early as mid-2007, Lockheed Martin and the JPO attempted to define and conclude an agreement in which the international partners would sign up for a joint purchase of F-35s spread over several years.[96] The price would be an average of early- and later-year prices, since the planned buy encompassed the ramp-up to full-rate production and included more expensive LRIP aircraft. However, Lockheed Martin claimed that the deal would also allow economies of scale (such as early, bulk contracts with suppliers) that would be passed on to the customers.

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http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/awst/2011/01/03/AW_01_03_2011_p22-279507.xml

[91] United States Secretary of Defense. (2007, February 7). *JSF PSFD Memorandum of Understanding* (among United States Department of Defense and Multiple "Participants"). Retrieved from http://www.jsf.mil/downloads/documents/JSF_PSFD_MOU_-_07_Feb_07.pdf

[92] Procurement for cash sales, 22 U.S.C. § 2762 (2010). Retrieved from http://www.law.cornell.edu/uscode/22/usc_sec_22_00002762----000-.html

[93] U.S. constitutional law prevents Congress from binding future congresses.

[94] Operational test and evaluation of defense acquisition programs , 10, U.S.C . § 2399 (2010). Retrieved from http://www.law.cornell.edu/uscode/search/display.html?terms=Operational%20Test%20and%20Evaluation&url=/uscode/html/uscode10/usc_sec_10_00002399----000-.html

[95] The exception is Israel, but since those aircraft are US-funded the law applies differently.

[96] Sweetman, B. (2007, June 21). JSF: Buy Now and Save. Message posted to Le Bourget on Aviation Week. Retrieved from http://www.aviationweek.com/aw/blogs/lebourget/index.jsp?plckController=Blog&plckBlogPage=BlogViewPost&newspaperUserId=703fd128-d069-40de-813b-a73b428e169b&plckPostId=Blog%3a703fd128-d069-40de-813b-a73b428e169bPost%3a4fb4ec09-d53f-4ea2-bd4f-ef3ec5b982d6&plckScript=blogScript&plckElementId=blogDest

Lockheed Martin and the JPO also made the very firm point that once such an agreement was signed, there would be penalties for withdrawal.[97] Any partner pulling out would be liable for the extra costs incurred by the other partners in the team.[98] Some provisions of US law would also have had to be waived to make the deal possible, because laws covering defense exports specifically require that foreign customer prices are set on the same basis as US purchases.[99] By late 2009, however, no movement had been made towards concluding a consortium buy, and the Australian government concluded that it was dead.[100]

So far, therefore, the only JSFs under contract to foreign governments comprise a handful of aircraft for the UK and Netherlands, which are intended to take part in the initial operational test and evaluation (IOT&E) phase.

Since early 2008, delays to the JSF program have been well documented. A one-year delay in the completion of development testing was agreed upon at a JSF Executive Steering Board meeting in early 2008.[101] A September 2008 briefing by then program office director Maj Gen Charles Davis predicted that all but one of the SDD flight test aircraft would have flown by the end of 2009.[102] In fact, three of them (CF-2, CF-3, and AF-4) had not flown by the end of 2010.

Following the one-year delay in the program announced in May 2008, a revised schedule was adopted, which envisaged the completion of developmental testing and evaluation (DT&E) in mid-2013 and operational testing a year later. Initial operational capability dates, however, were held as before: the US Marine Corps at the end of the first quarter of 2012, the USAF one year later, and the Navy two years after that, in early 2015.

The USMC would declare initial operating capability (IOC) after the completion of DT&E of Block 1 software. The USAF would start operations with Block 2. Production plans

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[97] Procurement for cash sales, 22 U.S.C. § 2762 (2010). Retrieved from http://www.law.cornell.edu/uscode/22/usc_sec_22_00002762----000-.html

[98] Sweetman, B. (2008, August 1). JSF Office Makes Buyers an Offer They Cannot Refuse. *Aviation Week*. Retrieved from http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=dti&id=news/DTIJSF.xml&headline=JSF%20Office%20Makes%20Buyers%20an%20Offer%20They%20Cannot%20Refuse

[99] Procurement for cash sales, 22 U.S.C. § 2762 (2010). Retrieved from http://www.law.cornell.edu/uscode/22/usc_sec_22_00002762----000-.html

[100] Sweetman, B. (2009, October 5). JSF Multi-Year Buy - Dead or Just Resting? *Aviation week*. Retrieved from http://www.aviationweek.com/aw/blogs/defense/index.jsp?plckController=Blog&plckScript=blogScript&plckElementId=blogDest&plckBlogPage=BlogViewPost&plckPostId=Blog%3A27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post%3A5fb4f326-cfc0-4910-82eb-30cf7134155c

[101] Janssen Lok, J. (2008, May 12). Dutch Say JSF SDD Phase May Be Extended. *Aviation Week, Aerospace Daily & Defense Report*. Retrieved from http://www.aviationweek.com/aw/generic/story.jsp?id=news/JSF051208.xml&headline=Dutch%20Say%20JSF%20SDD%20Phase%20May%20Be%20Extended&channel=defense

[102] Davis, C.R. (2008, September 30). *Joint Strike Fighter: Lethal, Survivable, Supportable, Affordable. Economic Development Council Presentation*. [PowerPoint slides]. Retrieved from http://www.florida-edc.org/Roundtable/MGen%20Davis%20F-35%20Sept08.pdf

were left largely unchanged by the 2008 delay, except for the addition of an eighth low-rate initial production (LRIP) lot.

Under US law, the Pentagon's Cost Assessment & Program Evaluation (CAPE) office audits, evaluates, and forecasts costs associated with major defence acquisition programs.[103] In the summer of 2008, the Office of the Secretary of Defense commissioned a JSF-specific Joint Estimate Team (JET) to assess the Program Office's plans to complete development. The JET concluded that the JPO was underestimating the time needed to complete testing of Block 3 software by more than two years and the cost by some US$ 5 billion. However, the JET report did not result in major changes to the program. In its response to a March 2009 report by the Government Accountability Office[104], which drew heavily on the JET report, the Department of Defense described the program as 'well managed, with the proper amount of oversight, and well positioned to succeed.'

In August 2009, Defense Secretary Gates visited Lockheed Martin's Fort Worth plant and told reporters: 'My impression is that most of the high-risk elements associated with this developmental program are largely behind us.' According to a Reuters report, 'Gates said company officials expressed confidence that development problems either had been, or were being addressed through better manufacturing and supply chain improvements.'[105]

However, it was also clear that many of the milestones set in 2008 were being missed, including the delivery of development aircraft to government flight test locations (Edwards AFB and Patuxent River NAS) and the start of powered-lift testing with the F-35B version (that is, test flights with the lift-fan operational). In September 2009, at a media briefing at the Air Force Association's annual meeting in Washington DC, Deputy Program Office Director Brig Gen CD Moore presented a new schedule for the following year.[106] The key goals were as follows:

- The remaining SDD aircraft were all to be delivered by late summer 2010. By September 2010, all 12 aircraft would be performing an average of 12 sorties per month. (A rate of 1700+ sorties per year would complete the DT&E program, then planned at just over 5,000 sorties, by the mid-2013 goal date.)

[103] Reed, J. (2010, March 11). DoD: F-35 costs rise at least 50 percent. *Navy Times*. Retrieved from http://www.navytimes.com/news/2010/03/defense_jsf_breach_031110w/

[104] United States Government Accountability Office. (2009, March). *Joint Strike Fighte: Accelerating Procurement before Completing Development Increases the Government's Financial Risk*. (GAO-09-303). Retreived from http://www.gao.gov/new.items/d09303.pdf

[105] Stoddard, E. (2009, August 31). Gates backs Lockheed F-35; cost and schedule key. *Reuters*. Retrieved from http://www.reuters.com/article/2009/08/31/us-lockheed-gates-idUSTRE57U48X20090831

[106] Warwick, G. (2009, September 14). F-35 Progress – 'Flying Will Support Training IOCs'. Message posted to Ares, A Defense Technology Blog on Aviation Week.com http://www.aviationweek.com/aw/blogs/defense/index.jsp?plckController=Blog&plckBlogPage=BlogViewPost&newspaperUserId=27ec4a53-dcc8-42d0-bd3a-01329aef79a7&plckPostId=Blog%3a27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post%3a211f70d5-d607-43a7-bd32-6559aeb111da&plckScript=blogScript&plckElementId=blogDest

- The first two LRIP aircraft would also be delivered to Eglin AFB, the training location, by the summer of 2010, starting the process that would provide the Marine Corps with operational crews by its planned 2012 IOC date.

The Pentagon's new Under Secretary of Defense for Acquisition, Technology & Logistics, Dr Ashton Carter, had meanwhile reconvened the JET and launched a parallel assessment of the propulsion program and, by November 2009, was publicly mentioning misgivings about the feasibility of test plans.[107] At the same time, it was increasingly being reported that the program would report a 'critical' breach of Nunn-McCurdy cost-escalation limits in early 2010.[108]

On February 2, 2010, while introducing the FY2011 defense budget, Secretary Gates announced the firing of JPO Director Maj Gen David Heinz due to 'a troubling performance record' in the program. [109]

In early March 2010, the JSF program's significant cost increases required the DOD to notify Congress that the project had breached the US Nunn McCurdy statute.[110] This meant that the program had witnessed an increase of greater than fifteen percent relative to the original acquisition program baseline (APB) established for the JSF program in 2001.[111] Carter and other DoD officials briefed Congress on their initial findings. Carter announced that the DT&E schedule would be extended another 13 months.[112] It was also announced that both USAF and USN IOC dates would be slipped into 2016 following the completion of Block 3 DT&E and initial operational test and evaluation (IOT&E) and that the CAPE office was predicting an increase in unit

[107] Butler, A. (2009, November 24). More JSF Test Planes' Software Work Needed. *Aviation Week, Aerospace Daily and Defense Report*. Retrieved from http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/F35112409.xml

[108] Sweetman, B. (2010, March 15). Ides of March. *Aviation Week*. Retrieved from http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/dti/2010/02/01/DT_02_01_2010_p32-199424.xml Under Nunn-McCurdy, introduced by Senator Sam Nunn and Congressman Dave McCurdy in the United States 1982 Defense Authorization Act and made permanent in 1983. If a program's estimated unit-procurement costs exceed 15% of what was planned at the outset (or "rebaselined" before 2005), the program must be recertified. This means the Pentagon must confirm that it is essential, costs are reasonable, and management is in control of costs. The Pentagon also has to provide Congress with the costs of an alternative solution to the requirement—all within 60 days of notification.

[109] Whitlock, C. (2010, February 2). Defense secretary Gates fires general in charge of Joint Strike Fighter program. *Washington Post*. Retrieved from http://www.washingtonpost.com/wp-dyn/content/article/2010/02/01/AR2010020103712.html

[110] Clark, C. (2010, March 2). Few JSF Changes After Nunn-McCurdy. *DoD Buzz: Online Defense and Acquisition Journal.* Retrieved from http://www.dodbuzz.com/2010/03/02/few-jsf-changes-after-nunn-mccurdy/

[111] *Cost Assessment and Program Evaluation: Hearing before the United States Senate Committee on Armed Services.* (Sec. 513 of P.L. 110-81) 110 Cong. 4 (2010) (testimony of Christine Fox). Retreived from http://armed-services.senate.gov/statemnt/2010/03%20March/Fox%2003-11-10.pdf

[112] *F-35 Joint Strike Fighter (JSF) program: Acquisition, Technology and Logistics, Submitted Statement to the United States Senate Committee on Armed Services.* (Sec. 513 of P.L. 110-81) 110 Cong. (2010) (statement of Dr. Ashton B. Carter). Retreived from http://armed-services.senate.gov/statemnt/2010/03%20March/Carter%2003-11-10.pdf

acquisition costs of almost 90 per cent.[113] Later, it was announced that increased development costs would be covered by deferring acquisition of 122 aircraft from the low-rate initial production (LRIP) lots.

Heinz's successor, US Navy Vice Admiral David Venlet—previously the leader of Naval Air Systems Command—was confirmed by Congress in May 2010. Venlet replaced key people at the JPO,[114] imposed a virtual blackout on communications and public appearances by JPO personnel,[115] and initiated a Technical Baseline Review (TBR) of the development and flight-test program.

A further development surfaced in October when the British government announced the results of its Strategic Defence and Security Review. It included a decision to abandon the F-35B STOVL version of the JSF in favour of the catapult/arrest F-35C, combined with a delay in service entry and an unspecified cut in the number of JSFs to be acquired for a joint Royal Navy/Air Force unit.

By late 2010, it was being widely reported that the TBR would lead to further major changes in the program.[116] These changes were announced by Gates on 6 January 2011[117] with further details emerging in the subsequent weeks.[118] The actions included:

- Extending development testing to October 2016. The new program will include 7,800 flights, restoring the 2,000 test sorties that the JSF Program Office cut in 2007.
- Placing the F-35B 'on probation' because of concerns that actions required to make the aircraft reliable and operationally suitable will cause unacceptable weight and cost increases.

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[113] *Cost Assessment and Program Evaluation: Hearing before the United States Senate Committee on Armed Services.* (Sec. 513 of P.L. 110-81) 110 Cong. 4 (2010) (testimony of Christine Fox). Retreived from http://armed-services.senate.gov/statemnt/2010/03%20March/Fox%2003-11-10.pdf

[114] Sweetman, B. (2010, October 4). Leadership Changes On JSF + End-FY Update. Message posted to Ares, A Defense Technology Blog. Retrieved from http://www.aviationweek.com/aw/blogs/defense/index.jsp?plckController=Blog&plckScript=blogScript&plckElementId=blogDest&plckBlogPage=BlogViewPost&plckPostId=Blog:27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post:834b014a-d395-4174-a358-f1eb286a617a

[115] Trimble, S. (2010, September 13). Have you seen this man? Message posted to The Dew Line on Flightglobal.com/blogs Retreived from http://www.flightglobal.com/blogs/the-dewline/2010/09/have-you-seen-this-man.html

[116] Capaccio, T. (2010, November 1). Pentagon May See Higher F-35 Costs, Delays Up to Three Years. *Bloomberg*. Retreived from http://www.bloomberg.com/news/2010-11-01/pentagon-said-to-see-higher-f-35-costs-delays-up-to-three-years.html

[117] Gates, R.M. (2011, January 6). *Statement on Department Budget and Efficiencies*. Speech presented at The Pentagon, Washington D.C. Retreived from http://www.defense.gov/speeches/speech.aspx?speechid=1527

[118] Warwick, G., & Butler, A. (2011, February 7). F-35 Replan Adds Time, Resources For Testing. Aviation Week. Retrieved from http://www.aviationweek.com/aw/generic/story.jsp?topicName=Check6&id=news/awst/2011/02/07/AW_02_07_2011_p25-287076.xml&headline=F-35%20Replan%20Adds%20Time,%20Resources%20For%20Testing&channel=&from=topicalreports

- Cutting F-35B production to the minimum possible number through 2013. Production of the A and C variants is also to be slowed down, in order to fund partly a further US$ 4.6 billion increase in development costs, removing another 124 aircraft from LRIP.

Overall, F-35 development is now five years behind the schedule set at the outset of the program, and total SDD overruns are projected to exceed US$ 21 billion, or 60 per cent above the original goal.

8

Appendix II: Modifications

To meet Canada's mission requirements, there are only two minor changes that AIRCOM may or may not wish to make to the F-35. The first modification would be installing a drag chute. This would be useful for reducing landing speeds and landing distances—a capability that would be needed in northern airfields, which tend to be smaller, rougher, and icier. While most fighter jets (including the F-35) have arrestor hooks, these arrestor hook systems can be difficult to maintain and deploy.

Lockheed Martin has stated that the cost of installing a chute would be minimal, particularly if Norway (which has requested a drag chute as an option) or other F-35A customers shared in any development expense. The company has also said that the chute can be fitted in a "benign" location on the aircraft, with no compromise to the aircraft's low-observable characteristics. In the past, the RCAF had no trouble adapting a drag chute to its Lockheed F-104s, which were not baselined with drag chutes.

The second modification would be a probe-and-drogue refueling system. For all types of combat operations, but especially coalition warfighting and intercept, the ability to refuel in mid air would be useful. The F-35B and C use a retractable probe-and-drogue refueling system (which is Canada's current capability), but the F-35A uses a boom system with a refueling boom socket behind the cockpit. Booms provide a more rapid fuel offload capability but are more expensive systems.

There are no major technical or costs challenges to installing the F-35B/C's probe-and-drogue on the F-35A. Total impact on the F-35's price tag would be well under 1% of program cost, and if other partners wanted to share the development cost of this effort, the cost impact on Canada would be even less. However, there are two important possible reasons why the probe-and-drogue might not be necessary:

1. Canada might convert its air-to-air refueling system. AIRCOM is increasingly reliant on its Boeing C-17s for long-range lift, and it would be advantageous to have a national capability that can refuel this asset. The recent basing disruption with the United Arab Emirates, requiring AIRCOM to divert its C-17s to Italy, highlighted this requirement. If AIRCOM purchased Boeing KC-767s or Airbus KC-30s with a boom system, they would also be useful for F-35A boom refueling. A new tanker acquisition is a strong possibility in any event. The

current AIRCOM Airbus A310 tankers (CC-150 Polaris in AIRCOM service) are converted Ward Air/Air Canada passenger jets built in the 1980s.

2. Many F-16 users were offered or requested installation of a probe-and-drogue refueling system but found they had no actual need for it. Of the current 25 F-16 users, only about seven have a boom refueling capability, and no F-16s have been fitted with a probe-and-drogue. However, it is noteworthy that the F-16 continues to be offered with one and has been baselined as part of Lockheed Martin's India Air Force bid. It remains a relatively simple modification.

Of course, Canada would also be able to solve both of these problems by converting its F-35A order to an F-35C order. In addition to having a probe-and-drogue refueling system, the C has a larger wing with a slower landing speed, which would be ideal for smaller and rougher air bases in the north. However, there would be a loss of range and payload with the C, as well as a higher price tag, so staying with the F-35A and considering either or both modifications would be a much simpler and less expensive solution.

9

Appendix III: Industrial Share Participation Risk and Opportunities Assessment

Offsets have long been a key feature of the global military aircraft export market. The US Government Department of Commerce defines offsets as:

> The practice by which the award of contracts by foreign governments or companies is exchanged for commitments to provide industrial compensation. In defence trade, offsets include mandatory co-production, licenced production, subcontractor production, technology transfer, and foreign investment. … Offsets may be direct, indirect, or a combination of both. Direct offsets refer to compensation, such as co-production or subcontracting, directly related to the system being exported. Indirect offsets apply to compensation unrelated to the exported item, such as foreign investment or purchases of goods or services.[119]

Direct offsets are also known as Industrial and regional Benefits (IRBs) and can be broken down into two categories:

1. *Traditional direct offsets*: equipment and services that directly pertain to the actual systems purchased by the offset recipient country.
2. *General direct offsets*: equipment and services that directly pertain to the systems purchased by the offset recipient country, but which can be used in copies of these systems that go to a wide variety of actual users.

Two possible examples of *traditional direct offsets* include F/A-18 nose barrels built by Canadair for use in AIRCOM CF-18s, and CF-5s assembled in Canada for AIRCOM. An example of *general direct offsets* could be F/A-18 nose barrels built by Canadair for use in F/A-18s for the export market.

[119] U.S. Department of Commerce. (2011). *Impact of Offsets in Defense Trade: An Annual Report to Congress*. Retrieved from http://www.bis.doc.gov/defenceindustrialbaseprograms/osies/offsets/default.htm

Indirect offsets refer to all other ancillary benefits that the contractor may provide that are unrelated to the production of the military equipment itself. Indirect offsets may include entirely different business activities carried out by the prime contractor, consultative business revenues (engineering or professional services), food and hospitality, hotel occupancy, and follow-on tourism interests that may not have existed in the region if prime contractors or major subcontractors, such as Boeing or General Electric, had not been awarded contracts.

The price of jobs, technology, sovereignty, and other offset goals

With all offsets, a key consideration is frequently overlooked: generally, it is inevitable that offsets will be paid for by the customer nations. This is inevitable given the fact that costs associated with offsets are substantial, and defence companies are unwilling to sell planes with significantly lower profit margins than those paid by their home country market.

The costs associated with specific direct offsets can be particularly heavy. They often involve replicating factories and manufacturing facilities. Such an exercise is expensive. Also, in the aircraft industry, or in any heavy manufacturing industry, volume is extremely important. Anything that dilutes volume disrupts economies of scale and entails cost implications for the entire program.

Shareholders exert significant pressure on defence companies to maintain profit margins. As such, the costs of direct offsets cannot easily be passed on to the companies themselves; rather, the costs of direct offsets are largely covered by taxpayers in the customer country. This conclusion is consistent with the absence of evidence that export orders involving offsets provide any lower level of profit than domestic orders.

Japan provides an extreme example of specific direct offsets in practice. The Japanese constitution prohibits the export of locally-built defence equipment, so offset components that are exported on systems leaving the country are not possible. Yet, for national security reasons, Japan demands something close to industrial sovereignty for its combat aircraft, with all major systems built in-country. This means a high level of specific direct offsets throughout the supply chain.

Japan's most recent fighter acquisition was the F-2, effectively a re-engineered Lockheed Martin F-16C. While a typical F-16C sells for US$ 30–40 million depending on the options, recurring cost of the F-2 topped US$ 100 million. This excludes about US$ 4 billion in development costs, amortized over a total production run of just under 100 aircraft.

For more accurate cost comparisons, Japan's F-15 buy was the last major aircraft purchase that did not involve a major re-design. Mitsubishi's F-15 production line, with its network of Japanese suppliers, was merely a low-volume mirror image of the US production network. The last purchase, in FY 1996, showed a unit cost of US$ 116.8 million, according to the Japanese defence budget. The FY 1995 unit cost was US$ 115.3 million. By contrast, the final USAF F-15 buy, in FY 1996–7 and FY 1997–8, had a unit cost of US$ 55 million. The USAF planes were F-15E models, which are also more capable than the Japanese F-15DJ models.

The Japanese case study, due to its emphasis on vertical replication of the supply chain, constitutes an extreme example. However, due to the proprietary nature of most fighter export contracts, it is impossible to 'cost out' the added burden of direct offsets.

History shows that Canadian offset programs have been closer to specific direct offsets but with some general direct offsets, too. The CF-104 and CF-5 were built in Canada under traditional direct offset contracts but with some additional general offset work for export. Starting in 1959, Canadair manufactured 200 F-104s for the RCAF under licence from Lockheed. However, in addition, Canadair was given a contract to manufacture wings, tail assemblies, and rear fuselage sections for 66 Lockheed-built F-104Gs destined for the West German Luftwaffe.

With the CF-5, Canadair began building 115 aircraft for Canadian forces in 1965. Orenda was also selected to build the General Electric J85 engine in-country. An additional 105 NF-5s for the Netherlands were also assembled by Canadair, as were 16 CF-5s to replace inventory units sold to Venezuela.

The CF-18 was something of a departure from these two examples. The planes were not assembled in Canada. Instead, Canadair was contracted to build 50% of all nose barrels required for USN F/A-18s. Other Canadian and Canada-based companies, particularly Magellan, Edo Canada, and Messier-Dowty Canada, received component contracts which generated export revenues.

In short, traditional specific direct offsets are basically domestic consumption. They are largely paid for locally and used by a local consumer. Both the general direct offset approach and the F-35 approach create export demand for a nation's products. Export customers pay for and use the components that are manufactured.

Moving beyond national demand

Lockheed Martin's goal with the F-35 Industrial Share Program (ISP) is to remove completely traditional direct offsets as a possibility. Instead of using traditional direct offsets, it aims to move towards sourcing purely on the basis of competitive best value. As discussed below, there is evidence to suggest that the company has not completely succeeded in this objective. Nonetheless, this approach points to an acknowledgement of offsets as expensive replication and a commitment to move away from them. In direct contradiction to traditional direct offsets, Lockheed Martin's approach involves placing subcontracts in customer countries for aircraft parts that are ultimately destined for a third party.

Military aircraft manufacturers are no different from other manufacturers of complex products, such as ships, rockets, or electricity generation plants. They need to source components from a wide variety of suppliers to spread risk and costs throughout a large supply chain. They also seek to avoid vertical integration, making sure that all components are sourced from specialists who bring best-in-breed capabilities to all key product requirements. In an ideal world, a manufacturer maintains this approach to outsourcing, while simultaneously using 'strategic sourcing' to help open new markets to the final product. This is the goal for the F-35 ISP. The intention is that everyone work together, with no duplication of effort, to create a world-class product with a strong presence on the market.

Any effort to pursue opportunities mutually in global export markets needs to be undertaken as part of a customer/vendor relationship. Allowing direct offset recipients to sell their wares in export markets invariably produces competitive tensions between the finished product manufacturer and the offset recipient.

Canada's experience with the F-5 provides the best example of this tension. After producing CF-5s for Canada and the Netherlands, Canadair sold two CF-5s, on top of an additional 16 Canadian Forces planes, to Venezuela. Northrop then sued the Canadian Government. If the F-5 offset program had been configured along the lines of the F-35 ISP program, Canadian industry would have benefited (in a smaller way) from a much greater number of aircraft sales and without the legal problems associated with building and exporting finished aircraft.

So far, anecdotal evidence suggests that Canadian content of the F-35, in dollar terms, will be higher relative to other partner nations' content. This reflects the advantage enjoyed by Canadian high tech manufacturers rather than labour-intensive component assemblers. For example, Héroux-Devtek will likely be producing wingbox parts, wing carry-through bulkheads, wing structural components, and landing gear door lock assemblies. Magellan Aerospace will likely provide wing tie bars for leading edge flap installation and aft engine thrust mounts.

All of this work involves sophisticated manufacturing of advanced alloys and composite materials. This kind of work tends to have relatively high entry barriers and is easily transferrable to work on civil aerospace projects. Canada can also be expected to enjoy a strong competitive advantage in working on avionics, software, diagnostics systems, and training and simulation systems. All of these areas are high value added, with considerable opportunities for technology advancement and commercial market crossover. That said, these manufacturing sectors are not particularly labour intensive.

Whether or not Canada could do more to secure a greater presence in the F-35 program (by, for example, taking a harder line in commercial negotiations) is beyond the scope of this report. If the program works as theorized, it might offer significant commercial opportunities. Lockheed Martin has one powerful draw for its ISP approach to offsets. If Lockheed Martin is able to resist the temptation to offer direct offsets and the volume that it claims materializes, the market the F-35 would provide may be relatively large. Such a development may make the F-35 unique both as a plane and as an industrial opportunity.

The industrial opportunity the program would provide lies in its volume. When looking at the appeal of general direct offsets over traditional specific offsets, a key factor is how many planes will be built. For example, receiving a 3% share of a 4,000 aircraft production run (under the F-35 ISP) is much more appealing than receiving a 50% share of a 70 aircraft production program (under a traditional direct offset arrangement), especially since that traditional direct offset share would add significant costs to the price paid for the aircraft and be borne by the customer. That said, a 3% share of a 300 aircraft production run would mean very little. Therefore, much revolves around the commercial outlook and the volume numbers associated with the program.

History provides some good examples. Canadian industry's involvement in the F/A-18 program yielded long-term dividends, because the F/A-18 itself had many years of production life ahead of it. In fact, when the F/A-18 reached its current and final evolutionary stage, the F/A-18E/F, Canadian industry had a competitive edge in bidding for contracts due to its familiarity with the program. Magellan Aerospace, which started building bulkheads for centre barrel retrofits on the F/A-18C/D, won the contract to build titanium bulkheads, spindles, engine mounts, formers, and F414 engine components on the F/A-18E/F. Without this long-term success for the F/A-18, the approach taken with CF-18 offsets would look much less successful in hindsight.

The problem with the export approach

The downside risk lies in the demands that currently are and will be placed on the ISP. Cracks have already become visible. Although, from a purely macroeconomic standpoint, the draw of these export orders under a general direct offset approach would be sufficient to satisfy Canada's export requirements, it may not be sufficient in others. As has been witnessed in numerous media reports, international partners—the companies of which may not offer best value in the production of components of the F-35—have begun to demand traditional offsets as a condition of purchase.[120] The

[120] Barrie, D. (2006, March 27). The Mouse That Roared: Oslo offers final opportunity for Washington to identify adequate JSF work before determining fate of its involvement. *Aviation Week & Space Technology*, 35. "[T]here are those in Oslo and Washington who are skeptical the U.S. company is in a position to actually provide what the Norwegian Labor government needs to stay in the program. 'I think it's nearly impossible that Lockheed Martin will be able to come up with an acceptable package,' says one U.S. industry source."

Kington, T. (2010, February 1). Italy Threatens to Halt JSF Plant Work. *DefenseNews.* Retrieved from http://www.defensenews.com/story.php?i=4478916

Kington, T. (2010, November 1). Italy's JSF Assembly Line Takes Shape. *DefenseNews.* " 'Through the Italian MoD procurement office, we have created a relationship with Lockheed Martin and were able to meet with Lockheed Martin supplier firms,' he [Carlo Festucci, the head of Italy's defense and aerospace manufacturers' association] said. 'We accept that work is given out on best value principles, but Lockheed Martin has recognized that we need the conditions in which we can promote ourselves effectively.' "

Kington, T., & Ege Bekdil, B. (2006, March 20). Italy, Turkey Win JSF Work. *DefenseNews*, 6. "The U.S.-led multinational consortium that builds the future F-35 Joint Strike Fighter (JSF) has offered $3.5 billion worth of commitments to Turkish industry and a possible $7.2 billion in production work to Italy, company and government officials said."

Opall-Rome, B., (2008, November 17). Skittish Israel Pares F-35I Extras - Lockheed CEO: More Workshare A Possibility. *DefenseNews.* "[T]he CEO of F-35 Joint Strike Fighter (JSF) prime contractor Lockheed Martin dangled the possibility of more workshare for Israeli firms if the government places its orders promptly."

Opall-Rome, B., & Pugliese, D. (2010, December 20). Israeli Clarification Calms Canada's Ire on Offsets. *DefenseNews.*

Pugliese, D. (2010, December 27). Aerospace union says guarantees are needed of $16 billion worth of work before Canada buys the F-35 Joint Strike Fighter. *Ottawa Citizen.* Retrieved from http://communities.canada.com/ottawacitizen/print.aspx?postid=463474.

Pugliese, D. (2010, December 6). Canadian Companies Press for JSF Workshare. *DefenseNews*, 6.

Trimble, S. (2009, December 1-7). Israel pushes for bigger role in F-35 programme. *Flight International,* 19. "Israeli officials will continue to push for a larger role in the Lockheed martin F-35 Joint Strike Fighter programme, after winning a key victory on weapons integration."

Wall, R., (2009, November 30). Time After Time: Australia buys into JSF, with a sense of caution. *Aviation Week & Space Technology.* "The government also signals that its 2012 decision will be influence by the industrial benefits Lockheed Martin can provide to Australian companies."

granting of such strategic sourcing arrangements would be antithetical to the ISP itself and risks compromising its systematic integrity.

Further risk lies in the nature of the work itself. As mentioned above, the majority of the work that would be awarded to Canadian companies is not labour intensive. Such work may not satisfy the interests of trade unions and their membership. Unions typically seek traditional specific direct offsets, which provide greater breadth of jobs and more secure contracts (largely because the money would come from the taxpayer rather than a defence contractor seeking best value for money).

In its November 2010 presentation to the House of Commons defence committee, Canada's aerospace union, the Canadian Auto Workers (CAW), made it clear that it represented 'Boeing of Canada, Bombardier, Bristol Aerospace, Cascade Aerospace, IMP Group, MacDonald Dettwiler (MDA), Northstar Aerospace and Pratt & Whitney Canada.' Some of these companies would certainly do well with the F-35 ISP, but some would not. By contrast, contracts and jobs from a traditional specific direct offset program could be spread out more evenly and in a more labour intensive way. It would cost the Canadian government more to secure these jobs, and they might not last as long as the kind of jobs provided by the F-35 ISP, but these traditional offset jobs would satisfy the greatest number of labour constituencies. These traditional offset jobs would generally be more labour intensive than the kind of high-tech manufacturing jobs provided by the ISP, but that too would be appealing to labour constituencies.

This problem—a clash between sound macroeconomics and a preference for more jobs—is being observed in other F-35 partner countries. Norway trade union confederation acting president Roar Flathen, when asked about Norway's industrial role in the F-35 program, proclaimed, 'No offset, no plane'.[121]

As mentioned above, Lockheed Martin has not been completely successful in its efforts to move towards a competitive best value approach to the F-35 ISP. This is because Lockheed Martin has needed to deal with union and government demands for some level of offset guarantees. As a result, the company is now doing outreach work necessary to make certain national defence industries more competitive. This process does not benefit Canada, where the broader aerospace industry is relatively healthy by global standards. But it shows that Lockheed Martin has needed to move to a greater level of guaranteed work rather than maintaining a strictly best-value approach on ISP. As alluded to above, such activities place significant stress on the integrity of the ISP, given they undermine its fundamental policy rationale of best value. They also threaten the share of work that Canadian companies—already well placed to take advantage of such opportunities—would be likely to win.

As certain countries clamour for additional F-35 work, one problem Lockheed Martin faces is that the program offers little by way of locally-based aircraft support and maintenance work. Historically, this has been a highly sought form of offset work. For example, Canada's CF-18 System Engineering Support (SES) contract, awarded to Canadair/CAE in December 1986, was preceded by a fierce competition for a program

[121] Janssen Lok, J. (2006, March 3-8). Norwegian unions press for JSF offset. *Jane's Defence Weekly*, 19.

employing over 500 workers.[122] Maintenance and upgrade work tends to be relatively labour intensive.

F-35 support will be based on a global sustainment enterprise. The plan uses a performance-based logistics (PBL) model with a single global supply chain. This means that instead of contracting for specific parts or services, customers will sign up for a level of performance at a fixed price, with the F-35 contractor team responsible for providing this performance. The F-35's autonomic logistic information system (ALIS) will collect data on F-35 parts requirements. At first, spares will be warehoused locally, but just-in-time delivery from original equipment manufacturer (OEM) suppliers will come with later releases to support PBL. All of this means greater centralization and less of an aircraft support role for in-country contractors.

The F-35 is designed to be compatible with a PBL model. For example, many of the systems, particularly the engine, use a modular approach to design. As they require maintenance, these modules are removed and replaced. The old modules are shipped back to the OEMs for refurbishment, and replacement modules are immediately inserted.

The problem with counting

In addition to the difficulties outlined above, the quantification of offsets is a fraught issue. Offsets are typically quantified in dollar terms;[123] however, it is not immediately clear that the dollar terms presented equate to an objective assessment of the benefit obtained by Canadian industry. This is so for two distinct but related reasons. First, there is no established method for the calculation of the dollar amounts associated with offsets. Second, dollar amounts themselves are merely indicative, not conclusive, of industrial and regional benefits.

Turning to the first reason, an example illustrates the point best.

Canadian contractors win $ 100 million worth of contracts. In example (A), all subcontracts are performed by the prime contractor in house within Canada. In example (B), the prime contractor subcontracts out $ 90 million to non-Canadian companies. Although it might be said that in each of these two scenarios the industrial benefit Canada has received is $ 100 million, this does not reflect an analogous benefit to Canadian industry; Canadian industry has enjoyed a significantly greater benefit in example (A) than it has in example (B).

If the examples are differentiated by counting all subcontracts, a more misleading picture is presented. If the Canadian contractors subcontracted out $ 90 million to Canadian companies, and those subcontractors then contracted out $ 80 million, again, to Canadian companies, and the subsubcontractors then contracted out $ 70 million to Canadian companies, and so forth until a $ 10 million subsubsubsubsubsubcontractor completed the final contract, the total value to Canadian industry would be $ 550 million. This multiplier effect leads to a skewed image of the true benefit. It seems odd

[122] Pickler, R., & Milberry, L. (1995). *Canadair: The First 50 Years*. Toronto, ON: CANAV Books.

[123] Clement, T. (2011, February 17). Industry minister responds to F-35 purchase criticisms (Letter to the Editor). *Ottawa East EMC*. Retrieved from http://www.emcottawaeast.ca/20110217/news/Industry+minister+responds+to+F-35+purchase+criticisms

that an increase in the number of subcontracting steps could somehow increase the industrial and regional benefit. For example, would we not be just as happy with this subcontracting situation as we would be if the prime contractor completed all the work itself in house within Canada?

Turning to the second reason, quantifying industrial and regional benefits in dollar terms is not only problematic from the perspective of accounting but also from the perspective of substance. Dollars mean nothing concrete. They might be said to be merely indicative of industrial and regional benefit. We typically see industrial and regional benefit being articulated in terms of jobs created, industries stimulated, technologies developed, or capacity created. Although dollar figures might indicate the existence of these benefits, they say nothing definitive about whether benefits are actually obtained in practice.

The FACO option

As mentioned above, Lockheed Martin has not been completely successful in its efforts to move away from traditional direct offsets with the F-35 program. For countries and unions that feel more comfortable with traditional offsets, Lockheed Martin has devised a solution—but it is an expensive solution, deliberately priced as a discrete option to highlight the costs associated with traditional direct offsets. It involves setting up a Final Assembly and Check Out (FACO) line in a customer country. Original F-35 program plans called for all F-35 final assembly to take place in Texas, but a separate FACO is now available as a *de facto* option.

So far, only Italy has signed for a FACO. This FACO will be equipped with duplicates of the airframe mate tools, assembly stations, and test facilities found in Fort Worth. In short, it has all the expensive characteristics associated with the duplication inherent in traditional direct offsets.

According to Lockheed Martin and other sources, Italy's FACO will cost US$ 900 million to be established. The complete details of Italy's FACO contract, if ever made public, will also provide insight into the question of who actually pays for offsets. By most accounts, Italy is responsible for the entire cost of this facility and has reportedly budgeted US$ 900 million for its share of the work. One academic paper puts Italy's share at US$ 775 million,[124] but this study is 18 months old and reflects an earlier cost estimate for the FACO.

A national FACO is clearly appealing from an industry standpoint. Yet, by highlighting the costs associated with this option, Lockheed Martin has effectively strengthened the hand of policy makers who do not want jobs at a price. For example, UK industry demanded a FACO for the country's F-35 acquisition, but the UK government vetoed the concept on costs grounds. As Japan and South Korea move towards F-35 acquisitions, both will likely find a FACO the only way to preserve any level of national military aircraft self-sufficiency. They also might need a FACO to maintain their longstanding government policies of support for their national aerospace industries.

[124] Gasparini, G., Marrone, A., & Nones, M. (2009, July). Europe and the F-35 Joint Strike Fighter (JSF) Program. (Alegi, G., & Miranda, V., Trans.). *IAI Quaderni,* (31), 9.

From Canada's standpoint, a FACO would be a very different creation than Italy's FACO, and the business case would be difficult to make. The Italian FACO is meant to build a much larger number of aircraft. Italy plans to procure 131 F-35s. The Italian line will also be responsible for producing aircraft for the Netherlands, which plans to buy 85 F-35s. Italy may also bid to produce aircraft for additional European customers. Effectively, Italy would like to serve the role played by the Netherlands' Fokker in the F-16 European Participating Group program. In addition to F-16s for the Netherlands, Fokker built F-16s for Denmark and Norway.

While a Canadian FACO could try to compete for other countries' F-35 orders, it would not have any European Union home market advantage. Elsewhere, even if it could negotiate an export agreement with Lockheed Martin, the Texas-based line would have an enormous cost advantage due to volume.

The Italian FACO is also intended to be a regional aircraft support facility. As noted above, F-35 maintenance and refurbishment work will be considerably reduced from the level of previous fighters. However, there will be a need for a regional stockpile of rotable items. Also, a jointly-owned stock of spare parts might be an attractive idea, particularly if European countries are concerned about US arms import/export regulations and the time associated with dealing with these regulations.

Thus, Italy's FACO could play a role supporting hundreds of European-owned F-35s. A Canadian FACO, by contrast, would be geographically constrained to support F-35s based in North America. Since US planes would get parts directly from the OEMs, that would leave a Canadian FACO to support the spares needs for just 65 Canadian jets.

Given this, it is unlikely that a FACO would quell the demands in Canada for jobs as opposed to work.

Industrial participation risks conclusion

In theory, it might be said that the F-35 ISP program would be good for Canada as a whole. In contrast with traditional offsets, the program would impose no major burden on taxpayers. Products and components built for the ISP would largely be for export, with a favourable balance of trade impact. The high technology work received would likely provide R&D benefits for Canadian industry.

In practice, however, the F-35 ISP is unlikely to work for a few reasons. First, there is a risk that it will satisfy neither the demands for jobs in Canada nor the demands for breadth of company involvement. One way to satisfy traditional offset-demanding constituencies, particularly unions, would be a FACO. However, as mentioned above, the establishment of a FACO in Canada is unlikely for two reasons: the cost would be borne entirely by the Canadian taxpayer, and its utility, given Canada's close proximity to Forth Worth, would be questionable. Construction of a FACO would generate offset-related upward cost pressures on Canada's F-35 buy. If Canada wanted guaranteed up-front benefits and wanted to pay for a FACO, the price tag would likely be similar to the US$ 900 million budgeted for Italy's line. That would add about 10% to the cost of Canada's F-35 acquisition program. Assuming acquisition of 65 aircraft, that works out to US$ 13.9 million per plane. Given the unlikelihood of construction of a FACO, it is likely that labour interests will place increasing pressure on Canada to secure traditional offsets. Second, demands placed by international partners may prove critical. A number of countries that do not enjoy a developed capacity or competitive advantage in the production of components for the F-35 have spurred on two developments: Lockheed Martin has begun to engage in outreach to assist in developing these industries and, also, to provide strategic sourcing contracts that look very similar to traditional offsets. These two moves threaten the potential benefit to be enjoyed by Canadian industry in two ways. The former means that Canadian companies that already enjoy a competitive advantage in a particular area may be unseated. The latter threatens the very foundation of the ISP program itself by engaging in a practice antithetical to it.

Appendix IV: Delivery schedule

	Year																						
Participant	**Total**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28–38**
Australia	100								2	4	8	15	15	15	13		15	13					
Canada	65										**1**	**3**	**9**	**13**	**13**	**13**	**13**						
Denmark	48								8	8	8	8	8	8									
Italy	131						4	12	12	12	13	13	13	12	10	10	10	10					
Netherlands	85			1	1		2	4	9	10	10	10	10	10	10	8							
Norway	48								8	12	12	12	4										
Turkey	100							6	6	12	12	12	12	12	8	8	8	4					
UK	138			2	1			7		9	11	3	6	14	10	2	4	14	14	14	14	13	
United States	1763	1	7	10	12	15	19	24	40	50	70	90	100	110	120	130	130	130	130	130	100	80	265
TOTAL	2478	1	7	13	14	15	25	53	85	117	145	166	177	194	184	171	180	171	144	144	114	93	265
TOTAL CUMULATIF		1	8	21	35	50	75	128	213	330	475	641	818	1012	1196	1367	1547	1718	1862	2006	2120	2216	2478

Midpoint of Canada's purchase	**848**

The above delivery schedule is based on the figures contained in the Production, Sustainment, and Follow-on Development Memorandum of Understanding (PSFD MoU). The schedule contained in Annex A of that document details the delivery schedule on the basis of estimates provided by the Participants current to 11 November 2009. As outlined above, this schedule has been amended where conclusive data provides for a new delivery schedule.[125] Information released by the Undersecretary of Defense (Acquisition, Technology and Logistics) outlines a reduced US delivery schedule for the F-35A;[126] US deliveries of the F-35A will now occur according to the following schedule: 19 in 2012, 24 in 2013, 40 in 2014, 50 in 2015, and 70 in 2016. Prior to this, the PSFD MoU envisioned the delivery of 52 F-35s in 2011. Given this new production schedule, the PBO has smoothed deliveries, maintaining the final delivery number for US F-35As.

[125] For further details of changes, see footnote 53.

[126] U.S. Undersecretary of Defense (Acquisition, Technology and Logistics). (2011, January 6). *JSF Fact Sheet.* (Issued at U.S. Secretary of Defense Gates's announcement).