

# The Joint Strike Fighter / F-35 Program

## A Canadian Technology Policy Perspective

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The Canadian F-35 procurement represents the largest peacetime acquisition of new aircraft for Canadian forces since the Korean War. Securing industrial benefits from military procurement is essential for advanced industrialized nations, and it has long been Canadian industrial policy to do so. For the CF-18 program, “offset” contracts were negotiated, valued at 2.7 billion Canadian dollars (CAD) or 110 percent of the worth of the initial contract.

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According to the US Department of Defense (DOD), Canadian participation in the Joint Strike Fighter (JSF) program offered the promise of leveraging an investment of US \$150 million into \$8–10 billion of incremental revenues for Canadian industry over the life of the program. However, procurement of the F-35 was a “no bid” sole-source contract that precluded any possibility of bargaining both for price and industrial benefits under the offset model.

Issues that resulted in the DOD structuring of the JSF program to preclude traditional offsets include recognition of the nonmarket nature of defense procurement in the context of acquisition reform and the changing nature of defense systems. Partners like the United Kingdom, Israel, and Norway adapted to this new “no offset” model in securing industrial benefits. As of 2012, Canada has considerable incremental opportunities to develop similar programs that will enhance industrial and regional benefits from the JSF program as long as the offset model is not considered the norm for twenty-first-century programs. We try to address the issue in terms of how a country that lived comfortably under the US North Atlantic Treaty Organization (NATO) umbrella since World War II with limited obligations can rebuild a drastically downsized defense capability after the end of the Cold War. Canadians have only a limited sense of awareness of the need for military capabilities for the Arctic and a very limited understanding of the importance of military power.

## Program History

Canada’s procurement of the JSF (F-35 Lighting II) is a controversial program in Canada, a country notable for controversial defense procurement programs. The acquisition began with Canada as a participant in the development. Beginning in 1997, Canada invested US \$10 million to participate in the concept demonstration phase, which resulted in the selection of Lockheed Martin as the winner in 2001. This was followed by an investment of US \$100 million plus an additional US \$50 million in federally funded Canadian technology programs.

Canada signed on to the JSF Production, Sustainment, and Follow-on Development Memorandum of Understanding (MOU) with an additional investment of US \$551 million to be spent between 2007 and 2051. In 2008 Canada announced its intention to acquire the JSF to replace the CF-18, with the government of Canada exercising its option under the MOU and committing roughly CAD 9 billion to acquire a fleet of 65 aircraft, weapons, support, spares, and operating costs in accordance with the Canada First Defense Strategy.

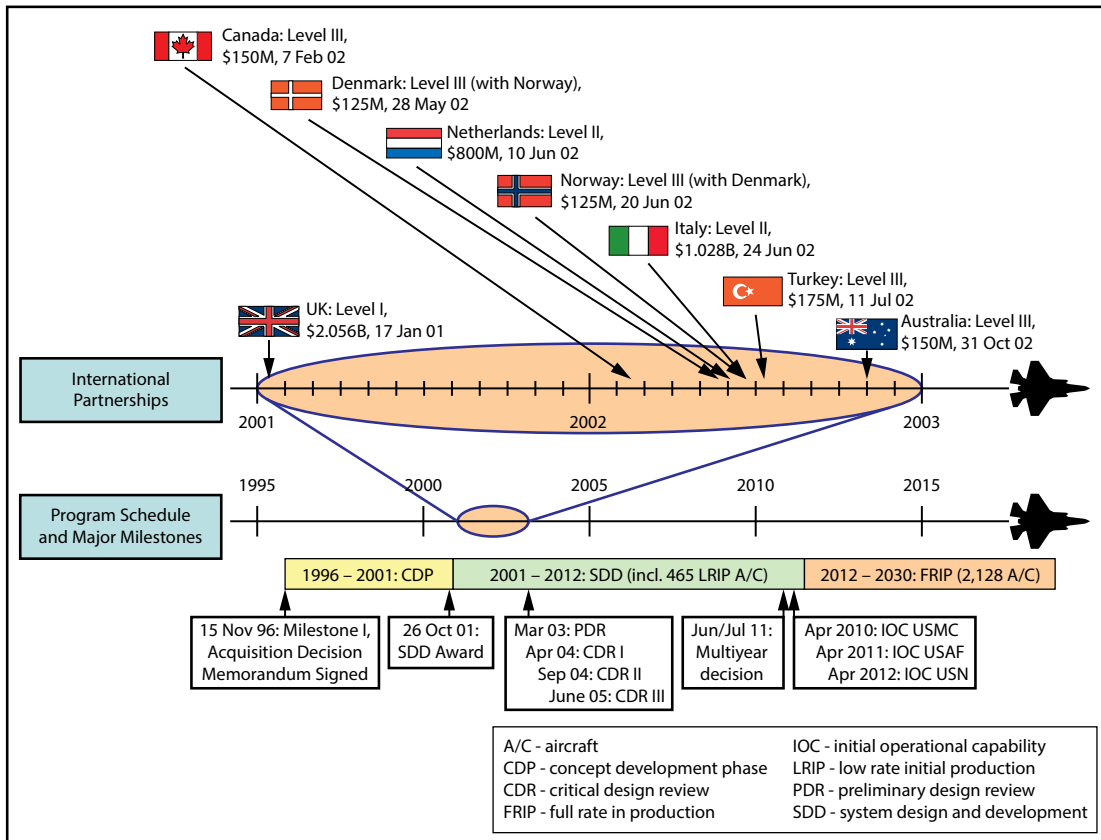
As of this writing, several embarrassing controversies have occurred, including an auditor general's *2012 Spring Report* that raised concerns about the no-bid/sole-source contract and many other issues, such as escalating costs. In light of these findings, the government of Stephen Harper established a Seven Point Plan that included creation of the National Fighter Procurement Secretariat, tasked with "ensur[ing] that the Royal Canadian Air Force acquires the fighter aircraft it needs to complete the missions asked of it by the Government, and that Parliament and the Canadian public have confidence in the open and transparent acquisition process that will be used to replace the CF-18 fleet."<sup>1</sup> As a part of this process, the secretariat issued new "terms of reference" in December 2012 for the evaluation of alternative aircraft to the F-35 and commissioned independent reviews of costs for the program.<sup>2</sup> Behind these concerns are the apparent lack of industrial benefits from what amounts to one of the largest Canadian defense procurements in decades as well as the decision makers' and general public's lack of understanding and perceived need for the increase in defense capability offered by the JSF. Significantly, there is little understanding of how peer nations like Norway, Israel, Singapore, and so forth, have been able to "plug in" to the JSF program to extract industrial benefits.<sup>3</sup>

The JSF program originated in the merger of two major programs: the Common Affordable Lightweight Fighter and the Joint Advanced Strike Technology, which emerged in 1993 to develop a replacement for the F-16, F/A-18, Harrier, and other programs. The ideas involved creating a common platform formerly served by three distinct plat-

forms: the F-16 as a multirole light fighter; the F-18 carrier-based, multirole fighter; and the Harrier as a short takeoff and vertical landing (STOVL) craft.<sup>4</sup> Other aircraft programs were consolidated into the JSF program around 1994.<sup>5</sup> The rationale for this consolidation of many aircraft types from the Navy and Air Force into one was the combining of the US defense industry after the end of the Cold War. The latter action resulted in the merger of many defense firms, virtually eliminating competitive forces from a market inherently not driven by market forces.<sup>6</sup> Three firms entered the competition for the JSF: Lockheed Martin, Boeing, and McDonnell Douglas. The latter's early elimination and the disbanding of its design team left the former two companies to field concept demonstration aircraft.<sup>7</sup> In 2001 came the decision to select the Lockheed Martin entry and proceed to the system development and demonstration phase with Lockheed Martin, Northrop Grumman, and BAE.<sup>8</sup>

The idea called for building a common airframe with shared combat systems that would be customized to fulfill many roles for the purpose of gaining economies of scale and logistical simplicity with interchangeable and common stockpiles of parts (70–90 percent) among all participants of the program.<sup>9</sup> Allied nations were invited to formally participate in the program beginning in 2001, when the United Kingdom signed an MOU that built on that country's support of the concept phase nearly a decade earlier.<sup>10</sup> Other nations participated as follows: Canada joined the JSF program on 7 February 2002, committing \$150 million to become a level III partner. The United Kingdom is the only level I partner. The Netherlands and Italy are level II partners. Other level III partners include Australia, Norway, Turkey, and Denmark (fig. 1). Levels are primarily based on financial contributions, with between \$750 million to \$1 billion expected for a level II partner. However, Israel and Singapore, both with limited populations and relatively small defense budgets, became security cooperative partners with considerably smaller contributions in cash but significant contributions in expertise, technologies, and unique know-how. The original total US JSF program budget amounted to about US \$200 billion for 3,000 air-

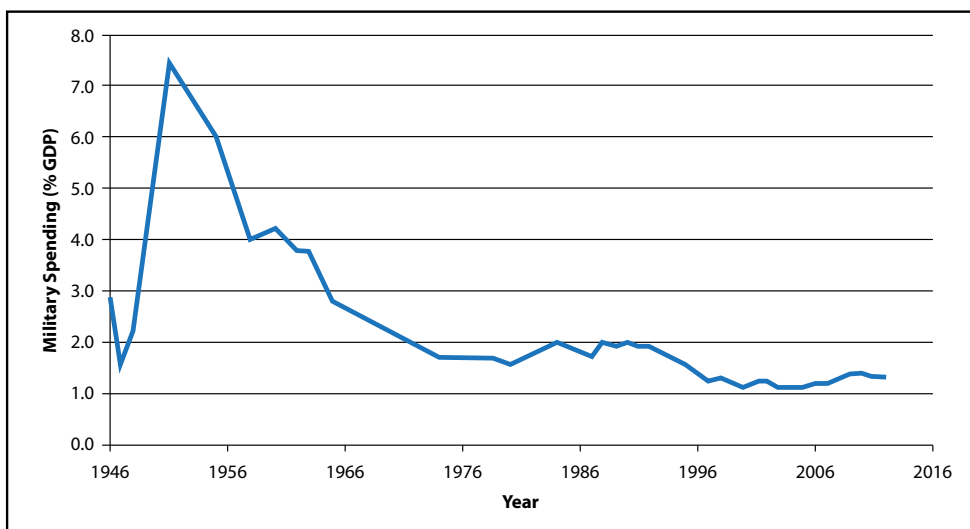
craft.<sup>11</sup> Increases, though, have caused project costs to balloon, some projections reaching over US \$1 trillion.<sup>12</sup>



**Figure 1. JSF timeline.** (From Office of the Deputy Under Secretary of Defense [Industrial Policy], *JSF International Industrial Participation: A Study of Country Approaches and Financial Impacts on Foreign Suppliers* [Washington, DC: Office of the Deputy Under Secretary of Defense (Industrial Policy), June 2003], 3, [http://www.ledevoir.com/documents/pdf/etude\\_internationale\\_defense\\_americaine.pdf](http://www.ledevoir.com/documents/pdf/etude_internationale_defense_americaine.pdf).)

## Controversy

Defense capital programs in Canada traditionally have been controversial for many reasons.<sup>13</sup> Historically, Canadian forces have found themselves underfunded relative to NATO expectations of 2 percent of gross domestic product (GDP). After the Cold War, defense spending was slashed in 1990 from just below 2 percent of GDP to 1 percent between 1998 and 2009 (fig. 2).<sup>14</sup> Canada made a major commitment after 9/11 that deployed its forces to Afghanistan under NATO that would have stressed the defense budget had expenditures remained at 1 percent of GDP. Consequently, by the end of the first decade of the twenty-first century, Canadian forces were severely underfunded. Estimates show that the Afghanistan conflict cost CAD 18 billion—a figure that may understate the cost to replace worn-out equipment from that conflict.<sup>15</sup> By 2008 politicians recognized the underfunding of Canadian forces and gradually increased the budget to its present level of about 1.5 percent of GDP.



**Figure 2. Canada's military spending.** (From *SIPRI Yearbook*, 2013, Stockholm International Peace Research Institute, accessed 7 February 2014, [http://www.sipri.org/research/armaments/milex/milex\\_database](http://www.sipri.org/research/armaments/milex/milex_database).)

The post-2008 fiscal climate worsened considerably with the federal budget in deficit from the stimulus program, and provinces like Ontario faced severe fiscal constraints. Because of the pressure, a program deemed essential—the replacement of military trucks—was recently cancelled days before the deadline for bidders.<sup>16</sup> Furthermore, the multibillion-dollar purchase of 28 CH-148 Cyclone helicopters is in jeopardy due to cost overruns and delays.<sup>17</sup>

Other countries such as the Netherlands are facing fiscal constraints. A general dissatisfaction with delays and cost increases that could scrap the program also exists.<sup>18</sup> Japan has decided to buy 42 F-35s while South Korea just vetoed what was thought to be a solid decision to buy F-15 Silent Eagles from Boeing. The South Korean government has concluded that a fifth-generation fighter is necessary to counter North Korea's arsenal, and it appears that the F-35 is the only contender for the \$7.2 billion contract.<sup>19</sup>

Canada's budget issue, like that of most other countries, is exacerbated by the politicization of defense procurement which, for example, resulted in the Liberal Party under Jean Chrétien threatening cancellation of the EH-101 "Cadillac" helicopter during the 1993 federal election campaign. The EH-101 was chosen as a successor to the then-30-year-old Sea King helicopter. Upon taking office, Prime Minister Chrétien cancelled the contract and paid the penalty of CAD 500 million for doing so to Augusta Westland.<sup>20</sup> Department of National Defense (DND) officials objected strenuously but without effect.<sup>21</sup> With this recent historical precedent and deep cuts in defense spending under Chrétien, the DND was precluded from becoming a major partner in the JSF program.<sup>22</sup> The DND, though, managed to contribute CAD 10 million in 1997 to become an informed partner.<sup>23</sup> This initial contribution was followed by the Chrétien Cabinet's approval of an MOU on 7 February 2002 that committed Canada to a total of US \$150 million, two-thirds from the DND and one-third from Industry Canada.<sup>24</sup> This decision set Canada down the path toward a no-bid contract for pur-



chasing the JSF. An actual signed contract for the JSF did not emerge until 2010. However, at this time Canada is indeed a level III partner.<sup>25</sup>

## Leveraging Industry Benefits

National defense and defense procurement are a core function of a modern state. Decision makers involved in this process commonly attempt to leverage these programs for benefits.<sup>26</sup> This policy is executed in Canada via Industry Canada's Industry and Regional Benefits Policy.<sup>27</sup> Traditionally, Canada utilized a benefits model based on the maximum use of domestic Canadian contractors for capital projects like vessels and so forth, which served both to stimulate industrial development and ensure that Canada was not held hostage to foreign suppliers for essential maintenance and repair over the life of the equipment. Yet, given the fact that the life-cycle maintenance of the CF-18 has already been very dependent on the United States, we can expect such dependence to increase with the JSF.

Moreover, modern military equipment is so complex that it is neither practical nor possible for Canadian industry to build many of the systems indigenously. This fact was reinforced by the historical precedent of the Avro Canada CF-105 Arrow project, cancelled on 20 February 1959. Since that time, Canada has had to rely on foreign suppliers for frontline fighter aircraft. The last major purchase took place in 1980 after pitting the F-16, F-18A/B, and F-14 against each other in the New Fighter Aircraft Competition—one that saw the F-16 eliminated due to a lack of engine redundancy as well as limited range and the F-14 eliminated because of cost. However, a combination of reasons, including technological change and policy changes under acquisition reform at the DOD in the 1990s, resulted in the United States not offering the offset or "coproduction" model for the JSF program. In lieu of traditional offsets, participants in the JSF program were offered the chance to competitively bid for contracts for the entire program. The following section discusses the benefits models.



### ***Coproduction / License Production Model***

The decision by the government of John Diefenbaker to exit from indigenously producing first-line fighter aircraft in 1959 was a watershed event in Canadian aviation history. From that day onwards, Canada had limited options for meeting the needs for fighter aircraft—namely, straight purchase, a model most often used by smaller or less developed nations; coproduction, used by many advanced industrialized nations like Japan and the United Kingdom; membership as a partner in a consortium such as the European Aeronautic Defence and Space Company; or a deal with a quasi-independent producer like Saab. As a NATO member, Canada does not have the option to purchase from sources outside alliance suppliers, such as Russian manufacturer Sukhoi, or to acquire equipment like the Chengdu J-20 from China, regardless of the “deal” offered.<sup>28</sup> Only one non-NATO option credibly exists, and that is a deal with Sweden that would have coproduced or jointly developed a new variant of the Saab JAS 39 Gripen.<sup>29</sup> The question is, how is Saab, with its comparatively low volumes and defense budget, able to keep the Gripen fighter viable in view of the historical rise in technological complexity and costs? It does so by in effect building a “kit plane” that heavily relies on components, systems, and subsystems manufactured by other nations.

The option to coproduce under license aircraft whose architecture was designed by another nation is “on the table” for all but the leading-edge aircraft (e.g., the F-35). For the right price, Canada could have asked for such an arrangement though it is generally acknowledged that coproduction of very small volumes of aircraft for a Canadian order would have added considerably to the cost without any obvious offsetting benefits over the long term. During the awarding of the CF-18 contract, coproduction was in fact offered and declined for these reasons.<sup>30</sup>

## *Offset Contracts*

Offset contracts are the primary means of securing industrial benefits. In essence, rather than Canada choosing a colicense to produce small numbers that will have no economies of scale, the idea is that Canadian contractors will be guaranteed a share of the work as subcontractors for the aircraft. When Canada turns to foreign suppliers for major military systems, it is routine for offset deals to be negotiated by Industry Canada as a normal part of any defense competition. The Maritime Helicopter Program reputedly obtained CAD 2 billion in offsets for a contract valued at CAD 1.8 billion.<sup>31</sup> For the CF-18 program, the offset contract proposal in fact exceeded the value of the deal by 10 percent, providing CAD 2.7 billion over 15 years—110 percent of the value of the contract that McDonnell Douglas received. Prime and major subcontractors like McDonnell Douglas, General Electric, and Hughes fanned out in Canada to identify qualified suppliers and provide them with contracts. The contracts stimulated development and enhanced Canadian industry although one should note that some of these deals would have happened without the offset contracts.<sup>32</sup> The offset model is widely used on many programs.<sup>33</sup>

How does a defense contractor address demands for offsets that are larger than the value of the deal? Most defense contracts are deals made for capital equipment that have a long lifetime, and during the life of the equipment, a steady stream of maintenance, support, upgrades, or replacements is required. The offset amount initially demanded may appear large, but the follow-on contracts are even larger when the customer is in a weak bargaining (or no-bargaining) position. Typically, the initial contract to purchase and support a major system represents \$1 against \$5 to \$10 of future noncompetitive or limited competition deals for items such as maintenance, support, upgrades, and so forth. (A one-to-five-and-beyond ratio might be possible if inflation is taken into account and issues such as fuel consumption are considered. However, such broad figures should be critically examined or put into context.)

Thus, manufacturers have an incentive to do whatever is necessary to win the deal and lock in a long-term customer in a monopolistic seller relationship for the future. Negotiating for a favorable offset deal from the perspective of the buying government is not necessarily an assurance that the entire package (over a program life that can span a half century or more) is a good deal, but it does offer the *appearance* of officials driving a hard bargain—an essential component to promotions in a merit-based bureaucracy of a modern nation in the Organization for Economic Cooperation and Development. When purchased systems either far exceed career lifetimes or key officials' duration at one post or politicians making decisions, it is not at all clear that such a system will deliver a good outcome for the nation on a life-cycle total-cost-of-ownership basis.<sup>34</sup> Despite these known shortcomings, the industrial offset model is tried, proven, and known to be viable as well as supported by bureaucratic momentum and routines in many nations. The question becomes why it was not offered as an option on the JSF program by the US government when the program was conceived in the 1990s.

### *The Current Situation*

Normally, American defense firms do not offer others the opportunity to participate early in a defense program, when most of the major decisions with respect to prime contractors and major performance parameters are made. Prior to the JSF, this collaborative approach was used primarily by Europeans who developed the Panavia Tornado, Eurofighter, Eurocopter Tiger, A400M, and so forth, with this model. By engaging allies and potential customers early in the design process and offering a "buy in," the model enabled partners to divide shares of the work from the program equitably. The American model differed in that the United States was, by far, the lead partner, expected to purchase more than 50 percent of the total units sold for the Air Force, Navy, and Marine Corps versions. Partners were not committed to purchase the aircraft; rather, they had to contribute development money, and then firms from partner countries could bid competitively on contracts.

However, in Canada's case, the DND could withdraw from the MOU if industrial benefits proved insufficient.<sup>35</sup> At that time, the F-35 was expected to have a “flyaway” cost of US \$37–47 million per unit (in retrospect, overly optimistic).<sup>36</sup> This figure compared favorably with that for the F/A-18E/F, which at initial operational capability in 2000, cost about US \$55 million a copy.<sup>37</sup> What did the politicians expect as benefits in 2001 upon agreeing to the MOU? Art Eggleton, Canada's minister of national defense, stated on 6 December 2001 that the JSF program “could result in some \$350 to \$450 million in contracts for Canadian companies and generate 3,500 to 5,000 person-years of employment. Over the life of the project, it is estimated that Canadian companies could potentially obtain between \$8 to \$10 billion worth of contracts resulting in 50,000 to 65,000 person-years of employment.”<sup>38</sup>

That would appear to be a very good return for a commitment of approximately \$150 million in research and development funds, a \$10 million “informed partner” fee, and unspecified amounts of use of Canadian facilities and limited staff support during the developmental process. This view was echoed by the DOD, which independently conducted a study for major participant countries published in June 2003, concluding that

JSF Canada estimates a potential for \$4.4 billion to 6.3 billion of revenues for Canadian industry over the life of the JSF program; our estimate is \$3.9 billion. . . . The sheer magnitude of the revenues combined with a relatively low level of SDD [system design and development] and TPC [Technology Partnerships Canada] investment is expected to translate into returns of approximately 4117%—a nominal payback of over \$41.00 per \$1.00 invested into the program. . . . This translates to an annual compounded rate of return of nearly 67%.<sup>39</sup>

This assessment is regarded as conservative compared to the figures cited by Defense Minister Eggleton although it counted only direct investment to the United States of US \$95 million rather than the total committed, including loans through Technology Partnerships Canada for Canadian industry.<sup>40</sup> The DOD stated its case succinctly (see the table below).

**Table. Potential impact of the JSF**

	Revenues	EBIT	EBIT Margin
	(\$US million current)		
	2012–26	2012–26	2012–26
CaseBank Technologies	\$266.8	\$66.7	25.0%
GasTOPS Ltd.	15.9	1.9	12.0%
Héroux-Devtek	255.2	16.4	6.4%
Magellan Aerospace	319.6	33.1	10.4%
Pratt & Whitney Canada	70.6	8.4	11.8%
Others	1,888.9	257.5	12.5%
<b>Total</b>	<b>\$2,817.0</b>	<b>\$384.0</b>	<b>12.6%</b>

Source: Adapted from Office of the Deputy Under Secretary of Defense (Industrial Policy), *JSF International Industrial Participation: A Study of Country Approaches and Financial Impacts on Foreign Suppliers* (Washington, DC: Office of the Deputy Under Secretary of Defense [Industrial Policy], June 2003), 50, [http://www.ledevoir.com/documents/pdf/etude\\_internationale\\_defense\\_americaine.pdf](http://www.ledevoir.com/documents/pdf/etude_internationale_defense_americaine.pdf).

EBIT - earnings before interest and taxes

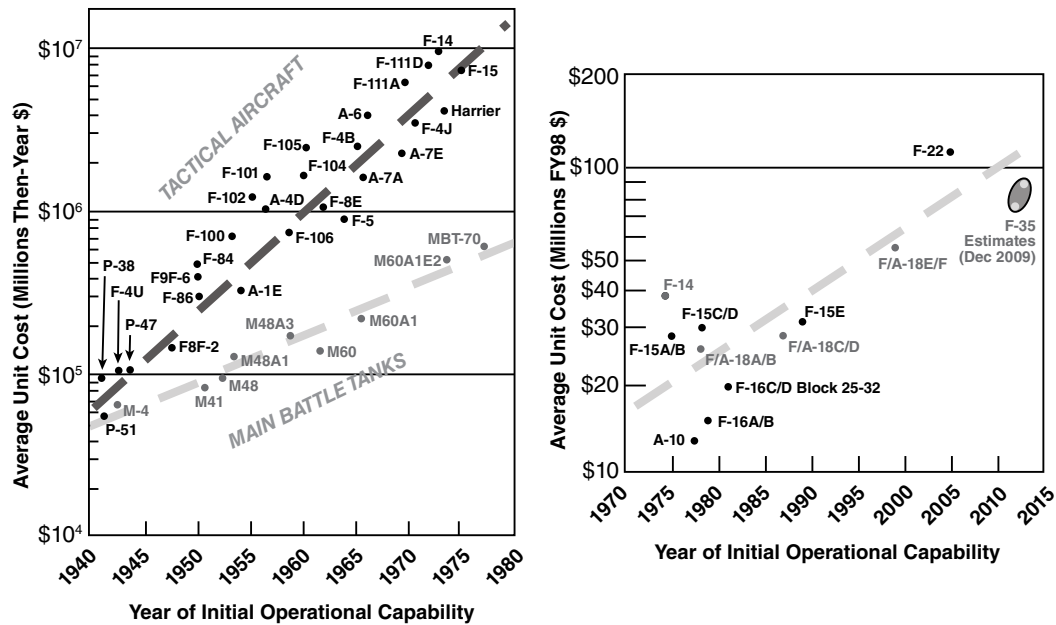
This estimation of benefits is troubling for many reasons. The government of Canada effectively wrote a check ranging from \$100 million to \$160 million for the program. Although there is no dispute that the return on gross revenues will be large, that may not be a good perspective for understanding gains. A more plausible method might involve summing up the EBIT for the program (\$110 million [2002–11] plus \$384 million [2012–26] equals \$494 million over the life of the program in incremental EBIT earnings by Canadian firms). That may reflect favorably on a taxpayer-funded investment that is three to five times the initial investment, but such a calculation is fraught with risks and pitfalls.

### *Cost and Schedule Slippages and Allied Partners*

Growth of program cost is the norm in military programs. It comes from the tendency of defense procurement to focus on the “best” without regard to costs, simultaneously requiring relatively small quantities compared with many mass-produced civilian products. At the

same time, considerations of logistics and the security of the supply chain sharply raise the cost of many components.<sup>41</sup>

The program-cost growth for the JSF program, however, is both predictable and entirely foreseeable based on the history of military aircraft programs. The cost of fighter aircraft has steadily risen since World War II as aircraft became more capable. A retroactive look at expenses by Norman Augustine shows cost growth from initial estimate to initial operational capability (fig. 3).<sup>42</sup> Parsing this data, one notes that the early versions (e.g., F-15A/B, F-14, F-22) tend to lie above the trend line. Programs that are extensions or elaborations of existing programs have the best chance of staying at or below this line. The Parliamentary Budget Office came to substantially the same conclusion using trend lines in the historical cost growth of strike fighters and based on the weight of the airframe.<sup>43</sup> Regardless of the methodologies chosen, it is clear that the life-cycle cost of ownership of the F-35s will be substantially higher than the projection by Canadian DND officials.



**Figure 3. Average unit costs.** (From Barry D. Watts and Todd Harrison, *Sustaining Critical Sectors of the U.S. Defense Industrial Base* [Washington, DC: Center for Strategic and Budgetary Assessments, 2011], 20.)

The above discussion suggests that cost and schedule slippages in the JSF program are quite normal and lie within the realm of reason and historical experience. The problem, accordingly, arises not so much from the cost/schedule slippage itself but from the desire by Canadian DND officials to paint the most optimistic picture of costs for their political masters without regard for readily obtainable data of past program experience. Although other partners have grumbled about rising costs in the aftermath of the 2008 economic crash, the vociferousness of the complaints in Canada is notable for the degree to which it has contributed to political discord there. That is a function of the political establishment, Industry Canada, and—more recently—the auditor general expressing considerable dismay at how the DND was talked into the program, apparently in violation of the industrial and regional benefits normally expected by the government of Canada and politicians.



The question then becomes one of whether a viable alternative to the F-35 did in fact exist. There is a viable stopgap that any modern fighter could fill—one that would be good for about 10–20 years. The Australians think they have a gap, and they bought F-18s to plug it. As for costs, they are irrelevant in terms of a stopgap airplane since it will be obsolete before reaching its designed life span.

### *Decision-Making Power*

From the inception of the JSF program, the lion's share of the decision-making power and authority rested with the DoD. No matter how optimistic the projections, the largest single buyer was obviously the DOD to fill requirements for the Air Force, Navy, and Marine Corps. Their needs dictated the architecture of the craft, and their priorities drove the needs of the program far above those of the industrial partners. The only major exception was the United Kingdom, which leveraged its expertise and capabilities in vertical and/or short takeoff and landing acquired through the Harrier program to a privileged place both as a supplier and major customer for the STOVL version F-35B. Even then, the United Kingdom experienced considerable difficulty securing commitments from the United States with respect to accessing the software code. This is a critical issue for the program in many ways, including the matter of leveraging industrial benefits. With the United States as the dominant partner, participants—let alone customers—have scant opportunity to make material changes in the package.

One must also note that the “prime” contractor for the F-35, Lockheed Martin, is a 30 percent stakeholder in the program, with other key companies providing the rest of the capability—notably with regard to the combat systems. The latter represent the element of greatest value in the aircraft and will be updated over time because the platform is software upgradeable. A substantial number of elements of the aircraft are being produced by a global supply chain; currently, upwards of 20 percent of the entire supply chain is foreign.<sup>44</sup>

## Joint Strike Fighter Systems

### *Software*

Defense equipment has fundamentally changed from the 1970s and 80s. Most defense systems' added value is no longer in the hardware but overwhelmingly in the software. Given the growing complexity of software, cost and schedule overruns escalated and, with them, the cost not only to develop but also to maintain the software during the life of the system. A common rule of thumb holds that maintenance of the software will require about 40 percent of the cost to develop it, assuming the addition of no major new capabilities.<sup>45</sup> Furthermore, although estimating the added value of software versus hardware in the JSF program lies beyond the scope of this article, a plausible guess is that it cannot be lower than the F/A-18 at over 50 percent software and likely is in the 80–90 percent range or higher, depending on the value of the reused code modules from previous programs and the cost of writing DO-178x-certified code.<sup>46</sup> Once the United States made the policy decision that it would not share the source code (not even at the modules level) with the largest partner and biggest contributor to the program (the United Kingdom), it became clear that such a policy effectively locks out partners from all but a very small amount of the added value in the entire program, no matter how many industrial benefits the DOD may claim for the partners. The question then becomes, how can one leverage benefits from such a model imposed by the DOD?

Britain initially sought to have source-code access to the JSF software as befitting the sole level I partner of the program. The United States, however, refused the request. Ultimately, Britain applied considerable pressure up to and including a threat to pull out of the JSF program and obtained an agreement in 2006. According to President G. W. Bush and Prime Minister Tony Blair, "Both governments agree that the UK will have the ability to successfully operate, upgrade, employ and maintain the Joint Strike Fighter such that the UK retains opera-

tional sovereignty over the aircraft.”<sup>47</sup> The specifics and details remain classified, but it is believed that the United States in fact did not transfer the source code but gave the United Kingdom priority and assurance that its needs would be met by timely American-engineered upgrades.<sup>48</sup> Why is control of the software so important?

Technologically, functionality has steadily migrated from hardware to software ever since creation of the first vacuum tube electronic device. Added value has steadily moved away from making physical things to designing software that made the devices more useful. During World War II, a major Allied innovation was the invention of the proximity fuse, a miniaturized radar transceiver that triggered the explosion of an artillery shell near a target, enabling the use of airbursts of shrapnel against difficult-to-hit targets such as aircraft. This progress continued the use of hard-wired electronics until the recognition that in the 1973 Arab-Israeli war, such electronics enabled the jamming of Israeli systems and led to the development of reprogrammable radar and electronics. The F/A-18 was the first aircraft of its kind to be equipped with a programmable radar having a one-kilobyte hard drive on board. This radar allowed dynamic reconfiguration of the F/A-18 in flight, switching from air-to-air combat mode to ground-attack mode, making the aircraft the world’s first truly multirole fighter. It was also the first major defense program in which the cost of developing the software exceeded the development budget for the hardware. Since that time, on every major program, software costs have exceeded those for hardware.

The importance of software in increasing the capabilities and lethality of military systems is now central. For instance, software lines of code (SLOC) for all F/A-18 variants are as follows: A/B model was 943,000 (943K), C/D (2,130K), Night Attack (3,054K), C/D XN-8 (6,629K), C/D SMUG/RUG (14,268K), and E/F (17,101K).<sup>49</sup> As “smartness” of weapons increased, productivity improved. During the first Gulf War, although the tonnage of “smart” bombs was relatively small, they demonstrated to the world that a few precision targeted bombs

could accomplish what formerly required large fleets of bomber aircraft carrying “dumb” bombs. This brings up the issue of productivity or lethality of the JSF versus that of the alternatives.

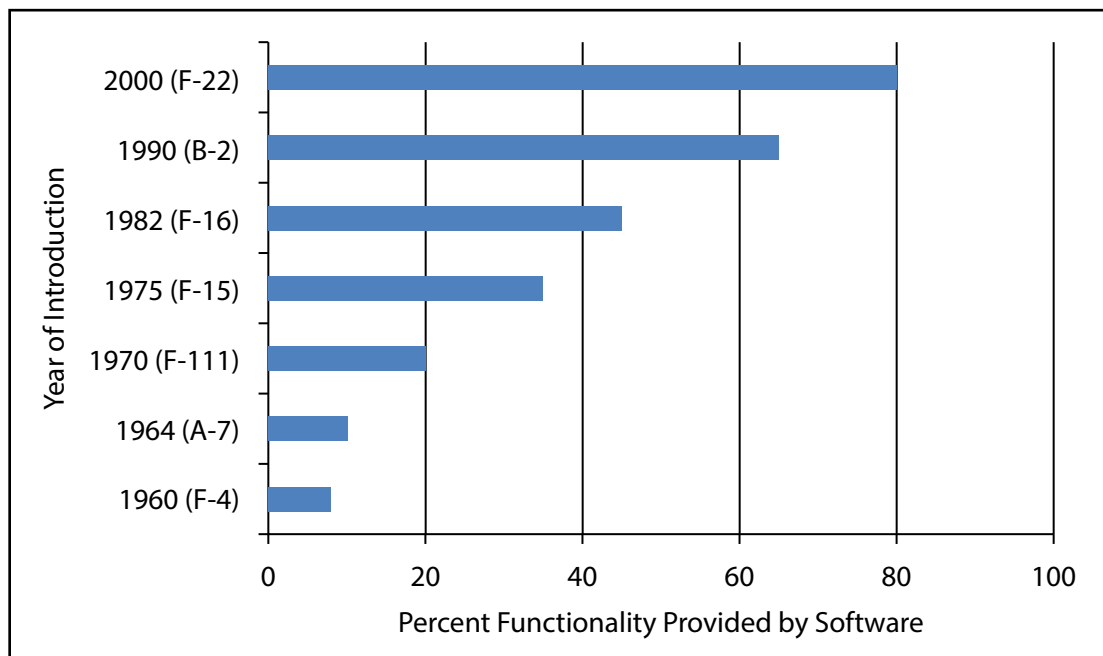
As the largest contributor, the United Kingdom solved the problem by leveraging a technology that it historically controlled into STOVL technology, ensuring that not only the manufacturing of the physical parts but also the software developed for that portion of the JSF stayed in the United Kingdom. Norway, on the other hand, lobbied the United States successfully for a commitment to integrate the Norwegian-made Joint Strike Missile (JSM) into the F-35, which will likely have many customers—including the US Navy. Norway estimated that the JSM will probably result in \$3.3 billion to \$4.2 billion in revenues.<sup>50</sup> In a similar fashion, Israel, one of America’s closest allies, got a commitment from the United States for “plug and play” compatibility for a range of Israeli-made electronic warfare and other systems.<sup>51</sup>

All of these models did not require the United States to compromise on its insistence on sole control of the F-35 source code. At present, it remains unknown whether Canada, as a part of the Canadian JSF program, has crafted or is crafting a complementary program to develop and field a JSF-compatible product that fits with particular Canadian needs and that potentially has an export market to all JSF customers, including the DOD. Given the size and scope of Canada’s commitment to the JSF program and that country’s long-standing status as a reliable ally, it is within the realm of possibility to ask the United States for at least a deal comparable to Norway’s and Israel’s.<sup>52</sup>

### *Lethality and Productivity: Automated Warfare*

One of the least understood aspects of the JSF program concerns the reason why this aircraft is so different from its predecessors. Side-by-side comparisons that utilize published specifications cited by aviation enthusiasts reveal an aircraft inferior in many respects to the best Russian craft being exported. Indeed, Australian Airpower, an independent air defense think tank staffed by former Royal Australian Air

Force pilots, published many studies that showed the F-35's technical inferiority.<sup>53</sup> When experienced veteran pilots of close US allies are so negative, it raises the question of why the benefits of the JSF program were not effectively communicated. From the first day of flight, aircraft have become gradually more automated, and as automation enhanced function, crew workloads gradually declined, resulting in smaller crews doing more. Figure 4 illustrates the trend of increasing automation in the cockpit.



**Figure 4. Growth in software functionality of military aircraft software.**

(Adapted from Daniel L. Dvorak, ed., *NASA Study on Flight Software Complexity* [Washington, DC: NASA Office of Chief Engineer, 2009], 30, [http://www.nasa.gov/pdf/418878main\\_FSWC\\_Final\\_Report.pdf](http://www.nasa.gov/pdf/418878main_FSWC_Final_Report.pdf))

The size of cockpit crews has steadily declined even as the platforms became more capable. The CF-18s were primarily single-seat A models, but the B models were built with a second seat for the weapons systems officer, in line with the now-retired F-14 of the same vintage

that required a crew of two. With automation and considerable attention to reducing pilot workload, modern aircraft have made two seats unnecessary, just as improvements in reliability have made two engines unnecessary.<sup>54</sup> Both of these developments are the direct product of improved software—the former from cockpit automation and the latter from the monitoring of engines and preemptive maintenance to reduce the chances of in-flight failure. Critics have observed that the F-35 is a single-engine craft unable to “supercruise” like the apparently more advanced F-22.<sup>55</sup>

With the increase in software functionality have come improvements in platform reliability, the active management of a system’s performance, the tracking and logging of data, and, finally, the use of the data itself.<sup>56</sup> In other words, all data from every program participant is pooled together. This enables the building of a large database that, in turn, permits identifying and proactively addressing issues before the actual point of failure (see the system for engine health management, below).<sup>57</sup> Because of these changes, the reliability of a single-engine craft can approach and, in fact, exceed the reliability of twin-engine craft that have less sophisticated onboard management systems, such as the F/A-18A/B currently in the Canadian inventory.<sup>58</sup>

Additional features on the F-35 that set it entirely apart from any previous aircraft except the F-22 include a limited amount of stealthiness, passive conformal sensors, and a helmet display that greatly reduces the pilot’s workload.<sup>59</sup> The F-35’s stealthiness against radar is designed to reduce its signature, primarily at the X band but not the L band or other VHF band radars. Infrared signature is produced by designing the airframe to limit hot spots and blending hot exhaust gases to reduce the signature. However, no matter what one does to reduce the signature, emerging technologies—including networked sensor technologies based on optics—can render the issue moot.<sup>60</sup> A major improvement initiated in the F-22 and publicly disclosed in the F-35 is the use of conformal passive sensors and difficult-to-detect distributed aperture radar.<sup>61</sup> However, these improvements are still single-platform

enhancements. Signature reduction is an evolving challenge with emerging sensor technologies that make older generations of stealth technology obsolete.

### *Automation to Network-Centric Warfare*

Communications have always been central to warfare. From the earliest days of fighting, combatants were trained to use and follow what ultimately evolved into an elaborate system of commands and controls. The key to the increased lethality of modern weapons platforms is the move toward network-centric as opposed to platform-centric approaches of the past. As part of acquisition reforms in the 1990s, individual platform-specific systems were gradually phased out and replaced with platforms interoperable with architecture designed to share data. Beginning in the 1990s, the idea of data fusion, whereby data from platforms could be electronically accessed by other platforms, became an aspiration for all defense systems.<sup>62</sup> This contrasts historical models whose sensor data (e.g., from the Airborne Warning and Control System platform) must be interpreted; only then can a controller manually vector an aircraft to the threat.<sup>63</sup> The F-35 is the first major platform that can not only access sensor data but also seamlessly operate a fleet of remotely piloted assets in its vicinity. SLOCs illustrate the complexity of network-centric software in the F-35 and its expansion through generations of aircraft.

Complexity in software expanded sharply between the relatively new F-22 program (1.9 million SLOCs) to more than 9.5 million SLOCs in the F-35 for the aircraft portion of the code. Additional code not on board the F-35 totals over 24 million SLOCs.<sup>64</sup> The 2012 Government Accountability Office review notes that

the lines of code necessary for the JSF's capabilities have now grown to over 24 million—9.5 million on board the aircraft. By comparison, JSF has about 3 times more on-board software lines of code than the F-22A Raptor and 6 times more than the F/A-18 E/F Super Hornet. This has added work and increased the overall complexity of the effort. The software on-board the aircraft and needed for operations has grown 37 percent since



the critical design review in 2005. . . . JSF software growth is not much different than other recent defense acquisitions which have experienced from 30 to 100 percent growth in software code over time. However, the sheer number of lines of code for the JSF makes the growth a notable cost and schedule challenge.<sup>65</sup>

### *Lethality Multiplication*

What caused this drastic increase in software complexity with the F-35? The maturation of first-generation remotely piloted platforms and the US Air Force's change of heart toward remotely piloted versus manned represent the major change from 1990s when the program was conceived for the twenty-first century. The growing legitimacy of remotely piloted assets in the US Air Force resulted in substantial increases in requirements for software for the F-35, no longer viewed as a conventional fighter aircraft. This revised concept addressed many concerns about the F-35, including its relatively undistinguished performance in conventional air-to-air combat roles, noted by independent studies.<sup>66</sup>

Appraisals of F-35 lethality fail to recognize that as a stand-alone platform, it is as vulnerable as they claim. But the US Air Force has moved far beyond deploying the F-35 in the conventional role of a strike fighter. A new generation of remotely piloted aircraft (RPA) has architecture from the ground up to operate semiautonomously without the need for a ground controller to “fly” them; the present generation of RPAs, such as the Predator MQ-1, is being tested and “mated” to the F-35 as a strike package.<sup>67</sup> These new swarms will both address these concerns and give the F-35 a capability that effectively multiplies its lethality—though the exact degree of multiplication has yet to be proven in combat. Fusion of the combat system is more important than RPAs, which are very vulnerable assets. The ability to deliver data throughout the fleet with these common combat systems, for electronic warfare and cyber war, is crucial as well.

Given this major increase in capability, one question that needs to be raised is whether the original DND statement of requirements that

specified 65 aircraft remains relevant when the F-35 is used as presently designed in conjunction with semiautonomous, remotely piloted assets. Another major question has to do with why Canadian forces have lagged in adopting and developing remotely piloted technologies.<sup>68</sup>

## Conclusion

The dominant industrial and regional benefits offset model was historically a good one for much of the twentieth century. It remains an excellent mechanism to secure economic benefits and technology transfer from a prime or major subcontractor to Canadian industry and to ensure some degree of control by Canada over security of supply for logistical purposes in the event of war. However, as the proportion of software grew in terms of total value, the most critical element became not the making of the physical product but access to the system software. The DOD has made it amply clear that such access will not be granted in a meaningful fashion, even to the closest allies. Under such circumstances, even if Canada hypothetically were able to secure the production contract for the entire JSF program (US and foreign combined), the benefits would (a) remain well below 50 percent of the total value of the program and (b) not materially improve Canada's position of dependence on the United States to provide the software. No JSF can fly without the software, and it is not within the capabilities of anyone other than a consortium of the European Union to develop an alternative software suite independent of the United States.

As the largest and closest ally of the United States in the JSF program, the United Kingdom in effect secured the majority of the manufacturing and some of the software work specific to the F-35(B) STOVL version. Even then, the deal left it dependent upon America for most software modules. Both Israel and Norway, relatively small players, leveraged "plug compatibility" for major additions to the F-35. Norway will implement the Joint Direct Missile Program, and Israel will implement its own equipment and weapons into the JSF.<sup>69</sup>

The Canadian armed forces and Industry Canada could have used the Norwegian, Israeli, Singaporean, and UK programs as templates to produce the architecture for a set of complementary products and services that would meet unique Canadian needs and potentially have a large export market by securing from the United States the assurance of plug compatibility on the F-35 platform. As of the date of this publication, the opportunity to leverage the Canadian JSF procurement into a set of complementary programs with substantial industrial and regional benefits—while addressing pressing Canadian priorities such as Arctic sovereignty / resource and environmental management—is still open. ✪

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## Notes

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3. “Chapter 2, Replacing Canada’s Fighter Jets,” in *Report of the Auditor General of Canada to the House of Commons* (Ottawa: Office of the Auditor General of Canada, Spring 2012), [http://www.oag-bvg.gc.ca/internet/docs/parl\\_oag\\_201204\\_02\\_e.pdf](http://www.oag-bvg.gc.ca/internet/docs/parl_oag_201204_02_e.pdf); and “Canada’s Next Generation Fighter Capability: The Joint Strike Fighter F-35 Lightning II,” Government of Canada, 16 July 2010, <http://news.gc.ca/web/article-eng.do?m=/index&nid=548059>.
4. “Program Overview,” F-35 Lightning II Program, accessed 15 January 2014, <http://www.jsf.mil/program/>. The article’s focus is primarily on the issue of leveraging industrial benefits from the program, given the way it is structured by the DOD.
5. “Pre JAST: History,” F-35 Lightning II Program, accessed 15 January 2014, [http://www.jsf.mil/history/his\\_prejast.htm#ASTOVL](http://www.jsf.mil/history/his_prejast.htm#ASTOVL).
6. See Jacques S. Gansler, *Democracy’s Arsenal: Creating a Twenty-First-Century Defense Industry* (Cambridge, MA: MIT Press, 2011).
7. “JSF: History,” F-35 Lightning II Program, accessed 15 January 2014, [http://www.jsf.mil/history/his\\_jsf.htm](http://www.jsf.mil/history/his_jsf.htm).
8. Ibid.
9. “Program Overview.” This is believed to apply to the commonality of hardware parts, not software.

10. "International Participation: Program," F-35 Lightning II Program, accessed 15 January 2014, [http://www.jsf.mil/program/prog\\_intl.htm](http://www.jsf.mil/program/prog_intl.htm).

11. Leslie Wayne, "One Fighter, 11 Nations and Building Problems," *New York Times*, 22 July 2004, <http://www.nytimes.com/2004/07/22/business/one-fighter-11-nations-and-building-problems.html>.

12. This is a conservative estimate. A more aggressive one by the DOD's Cost Assessment and Program Evaluation Office put the cost at US \$1.45 trillion over the life of the program. See Andrea Shalal-Esa, "JSF Lifetime Cost Hits \$1.45T: Reuters," *Aviation Week Intelligence Network*, 29 March 2012.

13. See the special issue on the Canadian F-35 program in the *Canadian Foreign Policy Journal*, Special Issue 13, no. 3 (September 2007); and an overview in Srdjan Vucetic, "Canada and the F-35: What's at Stake?," *Canadian Foreign Policy Journal* 17, no. 3 (September 2011): 196–203. Perspectives generally supportive of the program include James Fergusson, "The Right Debate: Airpower, the Future of War, Canadian Strategic Interests, and the JSF Decision," *Canadian Foreign Policy Journal* 17, no. 3 (September 2011): 204–16; and Paul T. Mitchell, "Lightning in a Bottle: The F-35 and the Bankruptcy of Modern Warfare," *Canadian Foreign Policy Journal* 17, no. 3 (September 2011): 193–95. For opposition to the program, see Michael Byers and Stewart Webb, "Canada's F-35 Purchase Is a Costly Mistake," *Canadian Foreign Policy Journal* 17, no. 3 (September 2011): 217–27; and Anton Bezglasnyy and Douglas Alan Ross, "Strategically Superfluous, Unacceptably Overpriced: The Case against Canada's F-35A Lightning II Acquisition," *Canadian Foreign Policy Journal* 17, no. 3 (September 2011): 239–50.

14. "Mark Collins—Canada's Declining Defence Budget as Percentage of GDP," *3Ds Blog*, Canadian Defence and Foreign Affairs Institute, accessed 11 November 2013, <http://www.cdfai.org/the3dsblog/?p=1197>.

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18. "Dutch Plans to Buy F-35 Fighter Jets in Doubt," Reuters, 5 July 2012, <http://it.reuters.com/article/idUKBRE8640X620120705>.

19. Jung Sung-Ki, "F-35 Back in S. Korea Fighter Contest," *Defense News*, 28 September 2013, <http://www.defensenews.com/article/20130928DEFREG/309280008/F-35-Back-S-Korea-Fighter-Contest>.

20. "Requiem for the Sea King," *CBC News*, February 2006, <http://www.cbc.ca/news2/background/cdmilitary/seaking.html>.

21. Except for the Arrow, a developmental versus acquisition program, Canada did not cancel a major defense capital acquisition program in recent history before the EH-101 deal.

22. Note that smaller countries contributed sums disproportionate to the size of their economies.

23. Michel Rossignol, *The Joint Strike Fighter Project* (Ottawa: Library of Parliament, Parliamentary Research Branch, 15 July 2002, rev. 19 February 2003), 3, <http://publications.gc.ca/collections/Collection-R/LoPBdP/PRB-e/PRB0207-e.pdf>.

24. Ibid. Note that the figures are different by source. Office of the Deputy Under Secretary of Defense (Industrial Policy), *JSF International Industrial Participation: A Study of Country Approaches and Financial Impacts on Foreign Suppliers* (Washington, DC: Office of the Deputy Under Secretary of Defense [Industrial Policy], June 2003), 3, [http://www.ledevoir.com/documents/pdf/etude\\_internationale\\_defense\\_americaine.pdf](http://www.ledevoir.com/documents/pdf/etude_internationale_defense_americaine.pdf).

25. David Ljunggren, "Canada to Buy 65 F-35 Jet Fighters in C\$9 Bln Deal," Reuters, 16 July 2010, <http://www.reuters.com/article/2010/07/16/canada-fighters-idUSN1611146620100716>. See also "F-35 Joint Strike Fighter (JSF) Lightning II," GlobalSecurity.org, accessed 15 January 2014, <http://www.globalsecurity.org/military/systems/aircraft/f-35-int.htm>.

26. Corruption in military procurement is legendary. A well-known fable about a businessman who paid many bribes to obtain an order for tents from the tsar in Russia was asked for a final, very large bribe for the approval. He complained that he would not be able to deliver the goods and was reputedly told by the courtier, "Why deliver the tents?"

27. Industry Canada is a federal department that oversees industrial development policy for the benefit of Canadians. The Industrial and Regional Benefits Policy goes further in that it requires companies that secure military contracts with Canada to spend 100 percent of the contract value in Canada. See "What Is the IRB Policy?," Industry Canada, 11 October 2013, [http://www.ic.gc.ca/eic/site/042.nsf/eng/h\\_00016.html](http://www.ic.gc.ca/eic/site/042.nsf/eng/h_00016.html).

28. Integration of equipment from suppliers within a single nation (e.g., the United States) is a nontrivial issue. Such integration between existing Canadian inventories and newer equipment from different NATO suppliers is a sizable issue due to the different architectures and the difficulties working with legacy equipment. Furthermore, had a nontraditional supplier like Sukhoi been used, there would likely be no support from the United States for integrating it into a usable system with existing equipment. Considerable nonrecurring engineering costs will be necessary to make it work even at a minimal level.

29. Sweden, Saab's home nation, is unusual in having a close security relationship with NATO but is not a member. See "NATO's Relations with Sweden," North Atlantic Treaty Organization, accessed 15 January 2014, [http://www.nato.int/cps/en/natolive/topics\\_52535.htm](http://www.nato.int/cps/en/natolive/topics_52535.htm).

30. Office of Management and Budget, "F/A-18 Aircraft Sales to Canada, Australia, and Spain: A Case Study of Offsets," *DISAM [Defense Institute of Security Assistance Management] Journal* 13, no. 1, (Fall 1990): 32–46.

31. "Maritime Helicopter Project (MHP)," Industry Canada, 6 February 2012, <http://www.ic.gc.ca/eic/site/043.nsf/eng/00004.html>. See also Canada Department of National Defence, "Canada—Maritime Helicopter Project: Status—Streitkräfte der Welt World's Armed Forces," GlobalDefence.net, accessed 7 February 2014, <http://www.globaldefence.net/defence-news/21510-canada-maritime-helicopter-project-status.html>.

32. Office of Management and Budget, "F/A-18 Aircraft Sales to Canada, Australia, and Spain: A Case Study of Offsets," *DISAM Journal* 13, no. 1 (Fall 1990): 36, [http://www.disam.dsca.mil/pubs/Vol%2013\\_1/OMB.pdf](http://www.disam.dsca.mil/pubs/Vol%2013_1/OMB.pdf).

33. For a list of recent procurements under industrial and regional benefits, see “List of Procurements and their IRB Managers,” Industry Canada, 11 October 2013, [http://www.ic.gc.ca/eic/site/042.nsf/eng/h\\_00017.html](http://www.ic.gc.ca/eic/site/042.nsf/eng/h_00017.html).

34. Life-cycle cost of ownership is not traditionally used in many procurement decisions. Credible estimates have to deal with considerable uncertainties, including the possibility that equipment lasts either not as long (often due to obsolescence) or much longer than originally intended.

35. Rossignol, *Joint Strike Fighter Project*, 4.

36. Ibid.

37. Barry D. Watts and Todd Harrison, *Sustaining Critical Sectors of the U.S. Defense Industrial Base* (Washington, DC: Center for Strategic and Budgetary Assessments, 2011), 20.

38. Rossignol, *Joint Strike Fighter Project*, 3.

39. Office of the Deputy Under Secretary of Defense (Industrial Policy), *JSF International Industrial Participation*, 50–51. Please note that the dollar estimates are nominal dollars and that the rate-of-return estimates are nominal as well.

40. Ibid. The minor differences in calculation do not alter the main finding. That is, the Technology Partnerships Canada funds were variously quoted as being \$50 million to \$75 million in the above study.

41. For example, digital electronic components can rapidly become obsolete, often on an 18-month product life cycle based on Moore’s law. After as little as a decade, the device may no longer be available if the supplier has shut down production of the line and the line could not be reopened without considerable sunk cost. The default solution calls for the Pentagon to stockpile parts expected to be required during the life of the system. However, it is not anticipated that most allies or customers of the system would have their independent stockpiles but would rely on the Pentagon for supply as needed.

42. See the classic “Augustine’s Laws” about the history of cost and schedule in defense procurement. Augustine offers an example of an arms maker given a contract for rifles for the American revolutionary war—one that was delayed and over budget. Norman R. Augustine, *Augustine’s Laws / Norman R. Augustine*, rev. and expanded ed. (New York: Viking, 1986). Initial operational capability is a standard program milestone whereby a system meets a minimum criterion.

43. See Tolga R. Yalkin and Peter Weltman, *An Estimate of the Fiscal Impact of Canada’s Proposed Acquisition of the F-35 Lightning II Joint Strike Fighter* (Ottawa: Office of the Parliamentary Budget Officer, 10 March 2011), 36, [http://publications.gc.ca/collections/collection\\_2011/dpb-pbo/YN5-31-2011-eng.pdf](http://publications.gc.ca/collections/collection_2011/dpb-pbo/YN5-31-2011-eng.pdf).

44. Jeremiah Gertler, *F-35 Joint Strike Fighter (JSF) Program: Background and Issues for Congress*, CRS Report for Congress RL30563 (Washington, DC: Congressional Research Service, 26 April 2011), 17.

45. The historical cost estimates of sustainment costs based on the CF-18A/B may not be applicable given the differences in the software suite. The JSF may have a cost structure resembling a major software system like SAP or Oracle, wherein maintenance costs can well exceed the cost of the initial purchase.

46. DO-178x is the standard for aerospace-grade software code. See “DO-178B Industry Group for Engineers,” accessed 15 January 2014, <http://www.do178site.com/>.



47. "UK Offered 'Operational Sovereignty' over Lockheed Martin F-35 Joint Strike Fighter, Diffusing Technology Transfer Row," *Flightglobal*, 31 May 2006, <http://www.flightglobal.com/news/articles/uk-offered-39operational-sovereignty39-over-lockheed-martin-f-35-joint-strike-fighter-206979/>.

48. Colin Clark, "US Guards JSF Crown Jewels," *DoD Buzz*, 24 November 2009, <http://www.dodbuzz.com/2009/11/24/us-guards-jsf-software-crown-jewels/>.

49. Mike Philips, "Toward Efficient and Effective Software Sustainment," *SEI Blog*, 27 February 2012, <http://blog.sei.cmu.edu/post.cfm/toward-efficient-and-effective-software-sustainment>.

50. Robert Wall, "Norway's JSF Deal Bolsters JSM Missile," *Aviation Week*, 25 June 2012, [http://www.aviationweek.com/Article.aspx?id=/article-xml/AW\\_06\\_25\\_2012\\_p32-469614.xml](http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_06_25_2012_p32-469614.xml).

51. "Israeli Plans to Buy F-35s Moving Forward," *Defense Industry Daily*, 25 April 2012, <http://www.defenseindustrydaily.com/israel-plans-to-buy-over-100-f35s-02381/>.

52. New weapons that will work with the F-35 are more like applications derived from common software code (i.e., like apps that work with Android). It should be possible, therefore, for foreign missile manufacturers to make plug-compatible weapons, and for the first time they will be able to access a global market. One criticism of US missile manufacturers is that they are disadvantaged by the global common fleet, which creates a different playing field. US firms do not like the globalism of the aircraft delivered through a software-upgradeable platform whereby the partners can create caucuses to shape evolution and then leverage the global market. Lockheed Martin's role is simply to incorporate the applications into stable software code.

53. Wing Cdr Chris Mills, RAAF, Retired, "How? The Deadly Question for the F-35 Joint Strike Fighter," *Air Power Australia*, 5 July 2010, <http://www.ausairpower.net/APA-NO-TAM-05072010-1.html>; and "RAAF vs F-35 Lightning II Joint Strike Fighter," *Air Power Australia*, accessed 16 January 2014, <http://www.ausairpower.net/jsf.html>.

54. There is no readily available public data on the reliability of small-diameter (military) jet engines, but that on the reliability of civilian engines can be tracked and is roughly comparable. Boeing now offers 330 minutes of extended operations on the 777. See Geoffrey Thomas, "FAA Extends 777 ETOPS Approval to 330-Min," *Air Transport World*, 13 December 2011, <http://atwonline.com/aircraft-amp-engines/faa-extends-777-etops-approval-330-min>.

55. *Supercruise* refers to the ability to fly at supersonic speeds with a useful payload without the use of afterburners. Dr. Carlo Kop is a strong critic who unsuccessfully advocated the purchase of the F-22 for the Royal Australian Air Force. See Carlo Kopp, "Just How Good Is the F-22 Raptor? Carlo Kopp interviews F-22 Chief Test Pilot, Paul Metz," *Air Power International* 4, no. 3 (September 1998), <http://www.ausairpower.net/API-Metz-Interview.html>.

56. Lars Seumenicht, "New Developments for Military Jet Engines" (presentation at the Seventh Israeli Symposium on Jet Engines, Technion-Israel Institute of Technology, Haifa, Israel, 6 November 2008, Rolls-Royce Deutschland, Germany), <http://jet-engine-lab.technion.ac.il/7AIJESpresent/1.-LARS.pdf>.

57. This same concept is now widely used for commercial aircraft and increasingly in modern autos as well as many other systems, even individual machine tools. In effect, the original equipment manufacturer pretty much knows what the customer is doing with their equipment, nearly in real time.



58. The debate over one versus two engines in Canada is rather quaint. It is mostly conducted by those who are not aware of the technical advances in software-based engine management and its contribution to reliability and the avoidance of catastrophic failures that will almost certainly result in the loss of hull in a single-engine craft.

59. A passive conformal sensor is a radar receiver that is blended into the airframe/wing/body (conformal) and only receives (does not send out) signals, making it difficult to detect. It lets something else (RPA-borne radar transmitter or a ship-based radar) light the target, but the reception and processing of the signal occurs on board the JSF, allowing it to see but not be the source of the light. Older fighters must rely on their onboard radar to guide them to the target and shoot once they are vectored to the general vicinity by a platform like the Airborne Warning and Control System or shipboard radar like Aegis.

60. The US Air Force has more experience operating stealth fighters and bombers than any other service. The step back from stealthiness occurs for many reasons but is primarily driven by the ease with which stealth can be defeated by a technologically sophisticated adversary. See the Rand presentation by John Stillion and Scott Perdue, "Air Combat Past, Present and Future," Project Air Force briefing, Rand Corporation, August 2008, <http://www.scribd.com/doc/7774389/Rand-StudyFuture-fo-Air-Combat>.

61. See "AN/APG-81 AESA Radar," Northrop Grumman, accessed 15 January 2014, <http://www.northropgrumman.com/Capabilities/ANAPG81AESARadar/Pages/default.aspx>; and Wing Cdr Chris Mills, "F-35 Joint Strike Fighter vs Russia's New Airborne Counter-Stealth Radars," Air Power Australia, 14 September 2009, <http://www.ausairpower.net/APA-NOTAM-140909-1.html>.

62. See D. L. Hall, "An Introduction to Multisensor Data Fusion," *Proceedings of the IEEE* 85, no. 1 (January 1997): 6–23.

63. The issue of communications systems complexity is central to a modern command and control system. During the 1990s, a major air force purchased aircraft from three different sources and ended with a nightmare when the only way to pass commands and communications between them called for going through ground controllers to relay the messages! This matter of compatibility and communications upgrades is one of the major issues addressed in the CF-18 incremental modernization program. See Allan Ng, "The CF18 Incremental Modernization Program—in Detail," *Canadian American Strategic Review*, December 2003, <http://www.casr.ca/id-cf18-3-1.htm>.

64. House, "Joint Strike Fighter: Restructuring Added Resources and Reduced Risk, but Concurrency Is Still a Major Concern," *Statement of Michael J. Sullivan, Director, Acquisition and Sourcing Management, Testimony before the Subcommittee on Tactical Air and Land Forces, Committee on Armed Services, House of Representatives, 112th Cong., 2nd sess.* (Washington, DC: Government Accountability Office, 20 March 2012), 11, <http://www.gao.gov/assets/590/589454.pdf>.

65. *Ibid.*

66. For example, see the 2008 Rand study by Stillion and Perdue, "Air Combat Past, Present and Future," which generated intense controversy and resulted in Rand issuing the following "clarification": Andrew Hoehn, "Statement Regarding Media Coverage of F-35 Joint Strike Fighter," Rand Corporation, 25 September 2008, <http://www.rand.org/news/press/2008/09/25.html>. This did not stop the Australians from extending the study to show the F-35's vulnerability: "Australian Committee Hearing Reveals Details of F-35 Performance

in Wargame," Defense-Aerospace, 6 March 2012, [http://www.defense-aerospace.com/article-view/verbatim/133273/f\\_35-fares-worse-in-rand-wargame.html](http://www.defense-aerospace.com/article-view/verbatim/133273/f_35-fares-worse-in-rand-wargame.html).

67. Predator MQ-1s are remotely piloted but for practical purposes, remotely manned. Remote operators "fly" them via a satellite link and control everything they do—hence the need for large amounts of satellite bandwidth whenever they are deployed. See Peter B. de Selding, "Troop Drawdown Won't Crimp Bandwidth Demand, Officials Say," *SpaceNews*, 2 December 2011, <http://www.spacenews.com/article/troop-drawdown-wont-crimp-bandwidth-demand-officials-say>.

68. Canadians' interest in RPAs dates from the early 2000s. They were flying SAGEM CU-161 Sperwer tactical RPAs in Afghanistan from 2003 onwards. See "Canada Crafting High-End UAV Requirements," *Defense Industry Daily*, 19 December 2005, <http://www.defenseindustrydaily.com/canada-crafting-highend-uav-requirements-01640/>.

69. "Israeli Plans to Buy F-35s Moving Forward," *Defense Industry Daily*, 25 April 2013, <http://www.defenseindustrydaily.com/israel-plans-to-buy-over-100-f35s-02381/>.



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