Lexington Institute

POWERING JSF

ONE ENGINE IS ENOUGH

FINDINGS IN BRIEF

The F-35 Joint Strike Fighter is being developed to meet the future needs of three U.S. military services and eight foreign allies for an agile, affordable multi-role aircraft. It is expected to be the biggest military aircraft program in the world during the first half of the present century, and will play a key role in sustaining U.S. dominance of global aerospace markets. Each F-35 will be powered by a single high-performance turbofan engine designed to deliver exceptional thrust and reliability at relatively low cost. Following direction from Congress, the Department of Defense plans to buy the engines from two different sources, competing purchases annually to assure the best price and performance. It does not plan to buy the aircraft or any other on-board component from competing sources.

Competition is a powerful driver of progress in free markets, disciplining the price and performance of products. However, military procurement is not a free and open market, because there is only one customer -- the government -- and a handful of potential suppliers for any given product. That means all the costs of sustaining two engine suppliers must be paid by that one customer, from design to development to production to in-service maintenance. The government must pay for duplicate engineering teams, production tooling, assembly sites, parts inventories and repair centers. Each of these areas of required investment will function less efficiently if there are two engine designs rather than one because workloads will be smaller, and excess capacity must be carried that can absorb additional work that might be won in future competitions. Studies conducted by government agencies and outside experts have found that price discipline resulting from competition will not cover the additional costs required to sustain two engine suppliers, so there will be no net financial benefit to the government.

Competition also will not enhance the safety and other performance features of Joint Strike Fighter engines, because the cost and complexity of operating two different engine designs will make it harder rather than easier to introduce improvements. In order to meet design requirements the competing engines must be functionally interchangeable, so performance features such as thrust cannot be upgraded in one design unless equivalent improvements are made in the other. Not only will the higher cost of modifying two designs deter improvements, but in some cases it may not be feasible to make parallel improvements to both engines, forcing users to forego the enhancement entirely. Moreover, the second or “alternate” engine for the F-35 will debut on a single-engine fighter, unlike the primary engine which was matured on the twin-engine F-22 fighter; past experience indicates this will result in the alternate engine being less safe than the primary engine, with adverse consequences for aircraft and pilot alike.

Using two different engine designs on the Joint Strike Fighter will be detrimental to American industry. Splitting the manufacture and sustainment of engines between two teams means that each company participating in the program will get less work than they would have if all the engines had been purchased from a single source. When workloads shrink, the potential for economies of scale are reduced. Fixed costs must be spread over a smaller business base and there are fewer opportunities to extract price reductions from vendors on big orders. Thus industry becomes less efficient. In addition, the decision to fund a redundant “alternate” engine is an industrial subsidy to the dominant military-engine supplier, weakening its main competitor despite the fact that competitor's product was deemed to be superior in past comparisons. None of these consequences is likely to help U.S. industry in its struggle to remain competitive in global markets.

This report was written by Dr. Loren Thompson of the Lexington Institute staff as part of the Institute's continuing effort to analyze military technology requirements and acquisition practices.

POWERING JSF: ONE ENGINE IS ENOUGH

The United States and eight foreign partners are developing a multi-mission military aircraft called the Joint Strike Fighter that is expected to be the biggest weapons program in the world during the early decades of the present century. Officially designated the F-35 Lightning II, the Joint Strike Fighter will replace several types of aircraft currently in service with the U.S. Air Force, Navy and Marine Corps. Replacement is necessary because the existing fleet of cold-war planes is growing too old and antiquated to cope with emerging threats. Allies such as Italy and the United Kingdom that face a similar problem with aging air fleets are contributing a sizable portion of the development budget so that they too can acquire the F-35, pushing the program's production goal to over 3,000 aircraft.

The F-35 will be a technological marvel, featuring a stealthy airframe equipped with agile sensors and weapons that is powered by the most efficient fighter engine ever built. Its performance will so greatly exceed the capabilities of likely adversaries that it is expected to preserve U.S. global air dominance until at least 2040, and may remain in service for many decades thereafter. It will also help U.S. workers to preserve their dominance of the global aerospace market during the same period. However, the plan to build this much-needed aircraft hinges on keeping it affordable, both during production and during its service life. If the cost of buying or operating the F-35 grows too great, participants will begin withdrawing — setting off a chain reaction of further cost increases as economies of scale are lost.

This report is about an aspect of the Joint Strike Fighter program that contributes to cost growth: the plan to develop two competing engines from different suppliers. Many members of Congress believe that competition among engine-makers is vital if the government is to obtain the best price and performance from the F-35 propulsion system. The Congress has therefore insisted on funding an "alternate engine" designated the F136 in addition to the F135 engine included in the winning design for the aircraft. It has not sought to sustain competition for other elements of the design such as the airframe or radar. Although competition is a core feature of markets that usually contributes to efficiency, the report argues that in the case of the Joint Strike Fighter engine it will produce the opposite result:

- Competition will waste money rather than saving it.
- Competition will undermine safety rather than bolstering it.
- Competition will discourage improved performance rather than encouraging it.
- Competition will harm American industry rather than helping it.

Each of these findings is explained in the report using simple, common-sense reasoning. But before setting forth the case against the alternate engine, it is first necessary to explain the importance of the Joint Strike Fighter, the role of the engine in the aircraft's design, and the peculiar dynamics of the defense market that undercut the value of competition.

THE ROLE OF THE JOINT STRIKE FIGHTER

The F-35 Joint Strike Fighter was conceived in the early 1990s as an affordable replacement for cold war aircraft such as the Air Force's F-16 Falcon and the Navy's F/A-18 Hornet. Tactical aircraft such as the Falcon and Hornet have four primary missions: to secure control of contested air space by defeating enemy defenses; to destroy fixed and moving surface targets; to provide "close air support" to friendly ground forces; and to conduct reconnaissance missions. Successful execution of each mission requires that aircraft meet a range of specific performance requirements, and those requirements have grown more demanding as new threats emerge, technology evolves, and the goals of national strategy change. For example, it is much harder to survive in hostile air space today than it was a generation ago, because many countries have deployed agile, integrated air defenses. And it is much harder to attack hostile ground forces because adversaries have become more fleeting and elusive.

By the 1990s, it was clear that the existing generation of fighters would not be able to perform effectively against some future enemies. Not only were they wearing out, but they failed to incorporate features such as radar-evading stealth and digital data links necessary for victory in modern warfare. The Joint Strike Fighter was conceived to address this looming shortfall in capabilities by developing a replacement fighter that would be:

- Three times more effective than legacy aircraft in suppressing enemy air defenses.
- Four times more effective than legacy aircraft in defeating enemy fighters.
- Eight times more effective than legacy aircraft in attacking enemy ground targets.

However, these basic performance goals were just the beginning of what was expected from the Joint Strike Fighter. It was supposed to be so versatile that it could meet the diverse air power needs of three domestic military services and overseas allies for many decades to come. It was supposed to exploit new information technologies so skillfully that its pilot would possess unprecedented situational awareness. It was supposed to be so reliable and maintainable that it would require less logistical support than cold war fighters despite its technological sophistication. And it was supposed to achieve all of these gains without costing much more than the aging fighters it would replace.

The plan devised to reconcile the program's demanding performance requirements with affordability was to buy a very large number of aircraft in three versions with 80% commonality of parts and components across all three versions. Past experience had proven that it was not feasible to design one aircraft variant that could meet the diverse mission needs of domestic users and overseas allies. The plane would either be too expensive to buy in sufficient quantities or too poor at performing some missions to satisfy requirements. So the solution was to buy a family of planes, but planes that were closely related — sharing the same basic airframe, electronics and propulsion system. Planners recognized from the start that commonality and economies of scale were essential to the success of the program.

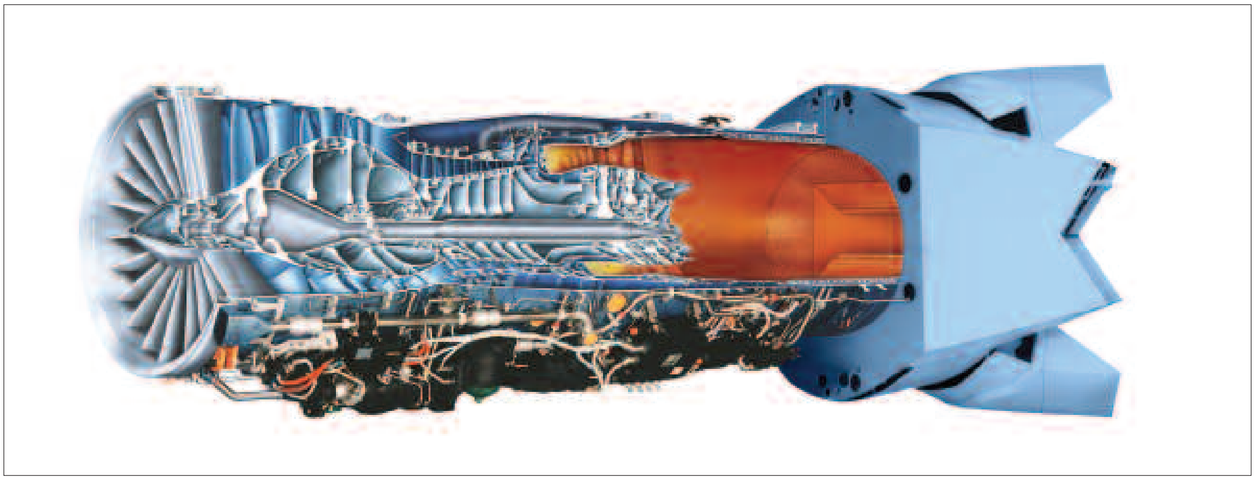
Following award of the Joint Strike Fighter development contract to a team led by Lockheed Martin on October 26, 2001, the new plane was officially designated the F-35 Lightning II (after Lockheed's P-38 Lightning of World War Two fame). A separate version is being built for each participating U.S. service:

- The F-35A will be a conventional-takeoff/landing variant that begins replacing Air Force F-16s and A-10 Thunderbolt attack planes in 2011; over two-thirds of the planes in the domestic fleet — 1,763 of 2,443 Joint Strike Fighters — will be the "A" variant, and it is also the version most allies are expected to buy.

- The F-35B will be a short-takeoff/vertical-landing variant that begins replacing Marine Corps F/A-18s and AV-8B Harriers in 2012; the "B" variant will feature a powerful lifting fan at mid-fuselage and vectored thrust at the rear nozzle to land in forward locations where there are no airstrips.

- The F-35C will be an aircraft-carrier variant that begins replacing Navy F/A-18s in 2012; it will have broader wings and bigger control surfaces to provide slow-speed carrier landing capability, and a reinforced structure to withstand the stresses of carrier operations.

The 680 F-35s bought for the Navy and Marine Corps will be the first fully stealthy airframes operated by those services. The 1,763 F-35s destined for the Air Force will operate in tandem with the equally stealthy F-22A Raptor, from which many features of the F-35 were derived. All three versions will incorporate an "active electronically-scanned array" radar that is able to perform multiple offensive and defensive missions simultaneously, including electronic attack of enemy networks. Additional sensors will be distributed throughout the airframe and the planes will be equipped with data links to remote sensors, so that collections from both on-board and off-board sources can be fused into a coherent operating picture for the pilot. The plan of countries such as Australia, Canada, Italy and Israel to buy the F-35 assures that many of America's most important allies will be able to mesh their future air operations with those of the domestic military services as the United States fields a new generation of fighters. The affordability of a plane hosting so many advanced features also helps the United States to maintain its dominance of the global market for military aircraft.



Turbofan engines use a fan to boost the intake of air into a combustion chamber, where the compressed air is mixed with fuel and ignited to generate energy that is extracted by turbines in the form of thrust.

THE F-35 PROPULSION SYSTEM

Each F-35 Joint Strike Fighter will be powered by a single jet engine that is the most advanced fighter turbofan in the world. Turbofans are a type of gas turbine engine that uses a fan at the front of the engine to increase the amount of air flowing through it. Like all gas turbine systems, turbofans compress air and then ignite fuel in that air to drive turbines that extract energy from the burning mix in the form of thrust. Following Newton's third law of motion that "for every action there is an equal and opposite reaction," the amount of energy exiting the back of the engine is proportional to the thrust pushing it forward. In turbofans, that energy is increased by using a large fan to boost the intake of air.

The first engine that will be used on all three variants of the F-35 is the Pratt & Whitney F135, an evolved version of the F119 engine employed on the Air Force's twin-engine F-22 Raptor fighter. Pratt & Whitney is the propulsion business of the United Technologies Corporation that was selected in 1996 as engine supplier by both teams competing to build the Joint Strike Fighter (a third team eliminated in the early rounds of competition initially chose a different engine and then switched to the Pratt & Whitney model). Congress directed development of a second, "alternate" engine in 1998 so that there would be competing suppliers of the propulsion system. The latter engine, designated F136, is being built by a team of General Electric and Rolls-Royce, and it is required to be operationally interchangeable with the Pratt & Whitney F135. Rolls-Royce also builds the lift fan that provides vertical takeoff/landing capability to the Marine variant of the plane. The propulsion system of the Marine variant is more complex than those on the Air Force and Navy variants, but it uses the same engine — the F135 or F136 — as its primary powerplant.

Because it was funded later than the Pratt & Whitney engine, the General Electric/Rolls-Royce engine will not be used in the early production lots of the Joint Strike Fighter. Current plans call for Pratt & Whitney to receive sole-source awards each year until 2010, when the first award will be made for the alternate engine. In 2012, the two teams will begin competing for annual engine contracts on a "best value" basis, meaning that awards will be based not just on price but also other factors such as safety and maintainability. In addition to building new engines, the two teams will also be responsible for performing "off-wing" maintenance of fielded engines. Most of the parts in jet engines must eventually be replaced due to wear — in some cases several times before the engine is retired — and it is common for engine-makers to generate more profits from post-production support than they do from building new engines.

The F135 and F136 have been designed to offer major cost and performance gains over previous generations of fighter engines. The two most critical performance parameters are thrust and reliability, since thrust is essential to other facets of aircraft performance and failure of the propulsion system in a single-engine plane is likely to be catastrophic. But that is just the beginning. The F135 engine that will power the initial production versions of the Joint Strike Fighter offers these additional features:

- 35% lower costs across the lifetime of the engine.
- 40% fewer parts to repair or maintain in the final design.
- 50% less infrastructure required to support the fielded engine.
- 50% less airlift required to support the engine in overseas deployments.
- 90% less time to detect and diagnose problems affecting engine performance.

Since the F135 was designed from the start to be more maintainable than previous fighter turbofans, it is expected to require only half as many visits to repair centers. Frequently replaced parts can be removed using six common hand tools, and the engine has built-in systems to monitor performance and predict problems before they occur. The F136 will offer similar features in a package that is physically and functionally indistinguishable to pilots from the F135. No other tactical aircraft engines in the world offer equivalent performance and sustainability at such an affordable price.

However, the Department of Defense in recent years has questioned the need to develop two different engines for the Joint Strike Fighter, arguing that the benefits of competition are not sufficient to justify the cost of sustaining two suppliers. Congressional proponents of the alternate engine (the General Electric/Rolls-Royce F136) contend that past experience proves competition will pay for itself while encouraging gains in performance and safety. In order to assess which side in this dispute is likely to be right, it is necessary to examine how competition typically plays out in military contracting.

THE LOGIC AND LIMITATIONS OF COMPETITION

Since 1998, Congress has directed the Department of Defense to fund development of two different engines for the F-35 from rival suppliers so that purchases of production engines could be competed. Based on past experience with buying engines for Air Force fighters, proponents of competition believe that having two suppliers from which to choose will reduce the price of new engines and the cost of maintaining those engines once they are fielded. Competition is also said to promote greater engine reliability, faster introduction of performance enhancements and a healthier domestic industrial base. Such benefits are consistent with the results seen from competition in a wide range of commercial markets, so it is not surprising that there is a strong political constituency for competition in powering the Joint Strike Fighter.

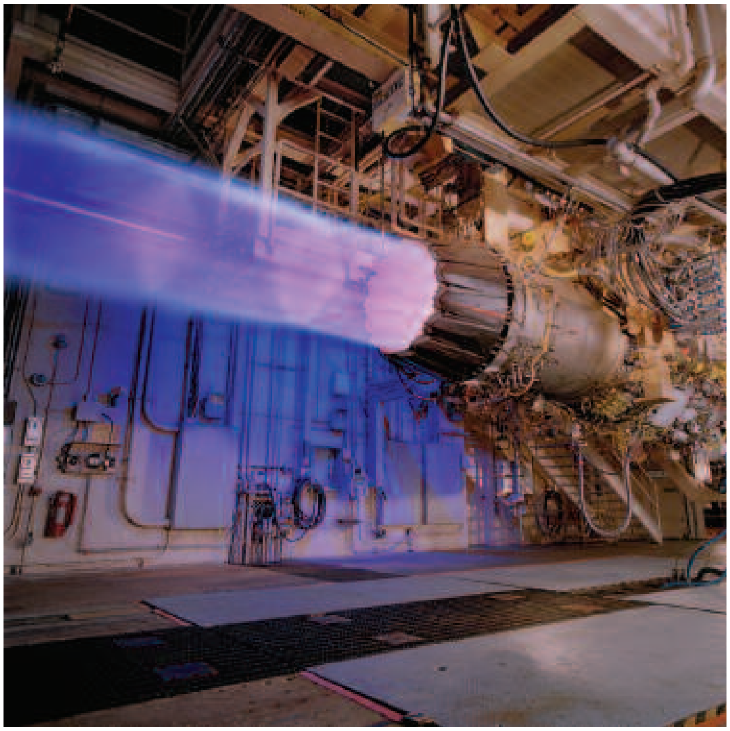
Competition is the driving force in market economics. The theory of supply and demand argues that if each buyer and seller of a product pursues self-interest in a free and open market, the optimum outcome will be spontaneously achieved through the balancing of supply and demand at the lowest feasible price. Economist Adam Smith referred to this dynamic as the “invisible hand,” because it relies on human nature to produce the best results without any intervention by external regulators. A similar dynamic drives the evolutionary process of natural selection, and the logic of competitive equilibrium underpins the system of checks and balances built into the federal constitution.

However, the beneficial effects of competition depend upon a free and open market. In economic theory, a situation of “perfect competition” is said to prevail when there are many buyers and sellers of a product, the product is identical from one supplier to the next, sellers have minimal control over pricing, buyers have complete knowledge about the products they are purchasing, and there are no barriers to any party entering or exiting the market. Unfortunately, none of these conditions exist in the market for military goods. In a respected study of that market published by MIT Press in 1980, analyst (and future policymaker) Jacques Gansler identified 30 fundamental “imperfections and failures” in military markets that impeded the free play of competitive forces. For example:

• There is only one buyer (the government) rather than many.
• There are only a few suppliers of any given product.
• The barriers to entry or exit of the market are very high.
• The differences between products are complex and considerable.

Although commercial markets sometimes exhibit similar defects, no area of economic activity deviates more markedly from the conditions required for perfect competition than the defense sector. According to Gansler, "In order to understand the economic operation of the U.S. defense industry, it is first absolutely essential to recognize that there is no free market at work in this area and that there likely cannot be one because of the dominant role played by the federal government. The combination of a single buyer, a very few large firms in each segment of the industry, and a small number of extremely expensive weapons programs constitutes a unique structure for doing business." He goes on to warn that trying to introduce free-market principles into this alien landscape on a piecemeal basis will probably backfire, generating greater inefficiency rather than benefits.

It is not hard to find cases where this warning has come true. For instance, a move by Congress to preserve competition in the construction of submarines when the cold war ended resulted in very high prices for new subs, because depressed demand was spread inefficiently among multiple suppliers. In order to avoid such costly outcomes, the government usually does not compete major weapons programs after a winning design is selected. In the case of the Joint Strike Fighter, the airframe and every system on it except the engines will be built by a single company, because trying to compete items across the life-cycle of the aircraft would require the government to sustain redundant industrial facilities and supply chains.



Developing and testing two different engine designs for an aircraft is much more expensive than developing only one design.

The Department of Defense has concluded that these realities militate against buying rival engines for the F-35. In the words of the Government Accountability Office, the department finds that "(1) no net cost benefits or savings are to be expected from competition and (2) low operational risk exists for the warfighter under a sole-source engine supplier strategy." Thus, Pentagon policymakers have repeatedly sought to eliminate funding for the F136 alternate engine. But Congress has restored the funding, contending that aircraft engines are one area of military contracting where competition could be beneficial. The preponderance of evidence does not support that view.

THE ALTERNATE ENGINE WILL NOT SAVE MONEY

In commercial markets, competition disciplines the price behavior of suppliers by raising the specter of losing market share to lower-priced rivals. The same dynamic might operate in annual competitions between the F135 and F136 engines, but it would not result in net savings to the government because of the unique structure of the defense sector. As the sole customer for engines used in only one type of military aircraft, the government would need to cover all the costs of developing, producing and sustaining two engines. Not only would this require duplicative investments at each stage in the evolution of the engines, but it would undercut economies of scale by splitting business among competing suppliers. Half a dozen studies commissioned by Congress and the Defense Department have raised doubts about whether the price-disciplining effects of competition would be sufficient to cover all the costs associated with sustaining two engine-makers.

To grasp why the cost benefits of competition are in doubt, it is necessary to understand how military aircraft engines evolve. Military engines have a "life-cycle" similar to the stages in a human life. In their infancy, they are conceived and designed for a future operating environment. They then gradually grow to maturity in a multiyear development process that yields a producible engine. The production phase of the life-cycle usually stretches out over many years, during which time engines are introduced into the world of operations to begin their service life. The engines are continuously monitored, maintained and repaired throughout their long service lives, but even with excellent care they eventually wear out and must be retired. The next generation of engines that follows typically reflects lessons learned from the previous generation.

Two key points about cost emerge from this description of the engine life-cycle. First, different assets and skills are required to sustain an engine program at each stage in its evolution. Second, costs to the user do not cease once a mature engine has been manufactured — the cost of maintaining and repairing an engine during its operational lifetime is almost always greater than the cost of developing and building it, because parts must be repeatedly inspected and replaced over a period of decades. The cost burden the government customer faces in sustaining competition for the Joint Strike Fighter engine is that at each stage in this protracted life-cycle, it must pay for duplicative assets and skills to keep two different engines viable:

- In the development phase, the government must cover the costs of rival design, engineering and testing teams.
- In the production phase, the government must cover the costs of duplicate tooling, parts inventories, assembly sites, management systems, work forces and supplier networks.
- In the operational phase, the government must cover the cost of separate repair facilities, supply chains, maintenance procedures and administrative organizations.

The federally-funded Institute for Defense Analyses has estimated that the additional investment cost to the government of supporting rival engine teams across all the phases of the life-cycle is about $9 billion in today's dollars. The institute's assistant director for cost analysis told Congress in March of 2007 that to recover all these additional costs in manufacturing "would require a savings rate during the production phase of 40% on a net present value basis," an outcome he labeled "implausible." If the period in which added investment costs could be recovered were extended to encompass the entire life-cycle, the institute estimated that lifetime savings of 18% would be required. The institute's representative noted in his congressional testimony that because the Department of Defense has little experience with integrating procurement and operational sustainment in competitions, there was no way of reliably estimating whether savings of such magnitude can be achieved.

This assessment is consistent with the findings of several other studies. A Program Management Advisory Group funded by the Defense Department reported in 1998 and 2002 that the cost benefit of buying the alternate engine was "marginal." A 2007 study by the Pentagon's Cost Analysis Improvement Group found that it would cost $60 billion (in 2002 dollars) to acquire and support 3,089 engines from one source across the lifetime of the Joint Strike Fighter program, compared with $60.3 billion to acquire and sustain the same number of engines from two sources. It also calculated that "the procurement unit cost savings necessary from competition to achieve breakeven was 21.1 percent." It argued that while such a rate of savings was "plausible" based on past experience, "it is not considered likely to occur in this case." It concluded that "engine life-cycle cost estimates alone do not provide a compelling case for or against use of a competitive acquisition strategy."

The Government Accountability Office (GAO) came to a somewhat different conclusion in a 2007 report entitled "Analysis of Costs for the Joint Strike Fighter Engine Program." GAO found that "continuing the alternate engine program for the Joint Strike Fighter would cost significantly more than a sole-source program but could, in the long run, reduce costs and bring other benefits." It argued that while additional investment of $3.6 billion to $4.5 billion might be required beyond funds already committed to the alternate engine program to make it a viable alternative to the Pratt & Whitney propulsion system, "it is reasonable to assume that competition on the JSF engine program could yield savings of at least that much." This contention was based mainly on the results of a previous competition between Pratt & Whitney and General Electric to provide engines for the F-16 fighter. However, GAO did not identify other military engine competitions where sizable net savings were realized by the government, raising the possibility that the circumstances surrounding the F-16 engine rivalry were unique. Most of the reasons GAO cited for favoring competition in powering the Joint Strike Fighter were non-financial in nature, such as enhanced readiness and improved contractor responsiveness.

Yet another study by the research firm of Whitney, Bradley & Brown found little basis for believing that competition would yield savings in the production phase of the F-35 engine program: "By the time both engines are mature enough to compete, any savings in acquisition cost created by competition will be offset by the negative effects of decreased quantities and inefficiencies generated by the split procurement." In other words, the price discipline induced by competition will be eclipsed by the need for each contractor to spread fixed costs over a smaller business base, and by the need to fund duplicate capabilities at each stage in the engine life-cycle. The burden imposed on the government by duplicate capacity grows as the range of potential competitive outcomes expands, because each supplier must have enough capability to accomplish the maximum allowable workload. Thus, at any given time the government will be paying at least one contractor (and quite possibly both) to maintain excess production capacity. Narrowing the range of possible competitive outcomes would mitigate this problem, but it would also reduce incentives to compete vigorously.

The Whitney, Bradley & Brown study also provided an explanation of how competition could increase costs during the operational sustainment phase of the engine life-cycle. The government plans to have engines repaired by the original manufacturers under "performance-based" logistics agreements designed to encourage efficiency. That portion of the program probably will not be competed because each manufacturer has unique understanding of its own engine. However, because there will be two different engines to be supported rather than one, the opportunities for savings under performance-based logistics contracts will be constrained. With dual supply chains there will be twice as many vendors (each performing less work), duplicate repair equipment, duplicate parts inventories, duplicate skill sets among workers, and more complicated oversight requirements for the government. If there were only one supply chain supporting one engine, there would be half as many vendors (each performing more work), consolidated equipment, consolidated parts inventories, a consolidated workforce, and simplified oversight requirements. There would also be more latitude for negotiating vendor price reductions on big orders.

Because the Joint Strike Fighter is a single-engine aircraft, each engine must be extremely reliable to guarantee the safety of pilot and plane.

THE ALTERNATE ENGINE WILL NOT ENHANCE SAFETY

Performance and safety matter more than cost in awarding aircraft engine contracts, because a lower-priced engine that can't reliably deliver the required performance is no bargain — it is an invitation to disaster. That is doubly true in the case of the Joint Strike Fighter, since it is equipped with only one engine. Twin-engine fighters such as the Air Force F-22 and Navy F/A-18 can survive an engine failure, but the same failure on an F-35 results in loss of the aircraft (and possibly the pilot). Some proponents of competition have argued that by developing two different engines for the F-35, the government can enhance the overall safety and reliability of the aircraft. In fact, the opposite is true.

Past experience indicates that fighter engines matured on twin-engine aircraft have better safety records when they are later installed on single-engine aircraft than engines that see their first service on single-engine planes. For example, the safety record of the Pratt & Whitney F100 engine on the F-16 fighter is 18% better than that of the General Electric F110 engine, mainly because the Pratt & Whitney propulsion system saw initial service on the twin-engine F-15 fighter before being installed on the single-engine F-16, whereas the General Electric system debuted on the F-16. The reason for the disparity in safety is that new engines often encounter problems during their early years of service that cannot be fixed until they are revealed in day-to-day operations. Sometimes the problems are intrinsic to the design, sometimes they are traceable to deficient vendor parts, sometimes they result from sub-optimal maintenance procedures, and sometimes they reflect lack of pilot awareness about engine performance features. Whatever the source of the problems, they are less likely to lead to catastrophic mishaps when they occur on twin-engine aircraft than when they occur on single-engine planes, because there is more margin for recovery.

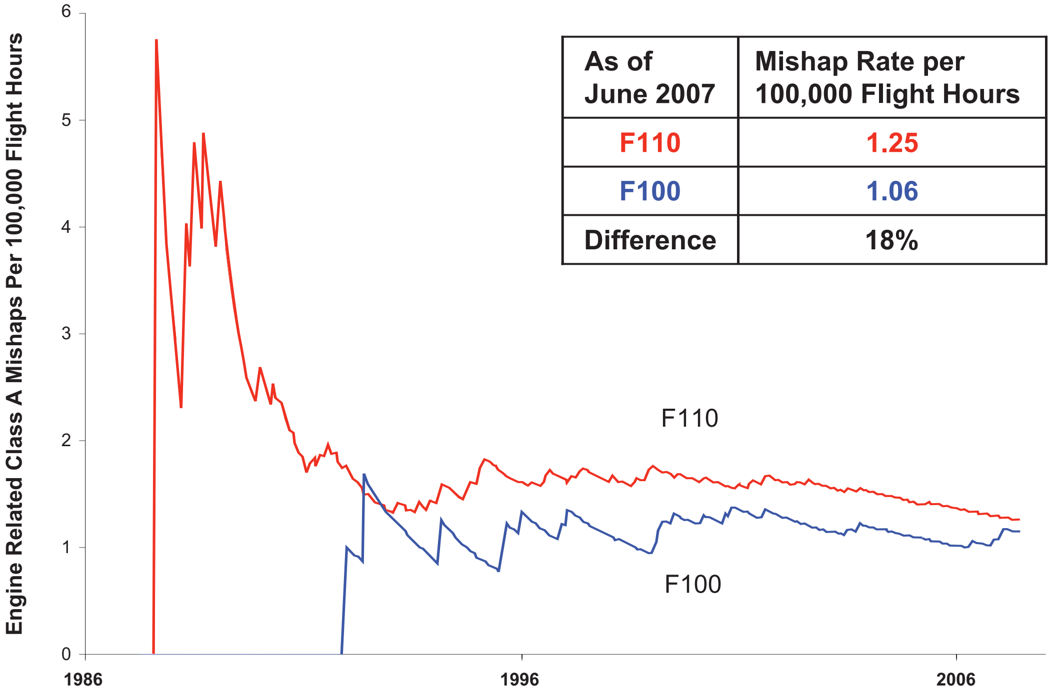
Unfortunately, the plan to purchase competing engines for the Joint Strike Fighter is likely to repeat the safety disparities noted on the F-16 by debuting the F136 alternate engine on a single-engine aircraft. Because the Pratt & Whitney F135 engine is an evolved version of the propulsion system used on the twin-engine F-22, the basic design will have seen hundreds of thousands of hours of operation before the Joint Strike Fighter is fielded, during which time deficiencies will have been detected and fixed. The F136, using different components from different vendors, will go through the same trial-and-error process on a plane that does not have a second engine to provide backup in the event of an emergency. So regardless of what other price and performance benefits the alternate engine delivers, it is likely to detract from the overall safety of the F-35 program during its early years of operation.

Beyond this challenge in developing new propulsion systems, there are other reasons for suspecting that buying competing engines will undermine safety. Senator Tom Harkin of Iowa identified one such problem during deliberations on whether to fund the alternate engine program in September of 2007. Harkin recalled his experience as a naval pilot, when he was transferred from a squadron operating only one type of plane to a squadron operating two types. He noted that in the first squadron operations unfolded smoothly, but in the second, "there was a series of supply problems and mix-up problems with parts." Harkin's point was that operational sustainment of military aircraft is one place where complexity is no virtue. Each system on an aircraft requires unique parts and maintenance procedures to remain operational. When those inputs are not provided in a timely fashion, unit productivity and safety will suffer. So there are compelling reasons for keeping the sustainment process as simple as possible, a goal that is not served by buying two different engines to do the same job.

Proponents of competition often make the point that by purchasing two different engines for the same plane, the possibility of an entire fleet being grounded due to safety concerns is reduced. However, that argument ignores two key facts. First, while there is decreased likelihood a whole fleet would be grounded by propulsion-related problems in a dual-engine scenario, there is increased likelihood that some portion of the fleet would be grounded because the number of vendors, parts and procedures would be doubled. In other words, there are more opportunities for someone somewhere in the system to make a mistake that leads to safety problems. Second, there have not been many fleet-wide groundings of military aircraft due to engine problems in recent years. The Air Force has seen only two such groundings since 1990. According to the consulting firm Whitney, Bradley & Brown, the Navy issued 27 engine-related grounding bulletins between 1997 and 2006, but over half of those concerned a single aircraft, the AV-8B Harrier jumpjet. Only three of the Navy groundings affected the F/A-18 fighter, the carrier-based plane that most closely resembles the Joint Strike Fighter; there were two groundings of the newer Super Hornet variant and one of earlier variants.

Aside from fleet groundings, the safety metric most frequently applied by experts to judge the reliability of military aircraft is "mean time between failures" — the average amount of time equipment operates before it encounters problems with a part or component. The mean time between failures on fighter engines manufactured by both Pratt & Whitney and General Electric has improved significantly in recent years, even in the absence of competition, due to the introduction of new materials, technologies and processes. However, it should be noted that making such safety-related improvements becomes harder when two different engines must be upgraded, because it costs more to upgrade two designs than one. For instance, the Air Force has a component improvement program aimed at enhancing flight safety and affordability, but it would need to invest twice as much money to develop the same safety enhancements in a dual-engine scenario as in a single-engine scenario. It cannot improve the performance of one engine without improving the other too, since that would violate the requirement that the engines be functionally interchangeable. Thus, the existence of competing engines increases the cost and decreases the incentives to improve safety.

F-16 Engine Related Mishap Rates



The F100 engine which debuted on the twin-engine F-15 fighter had a better safety record when used on the single-engine F-16 fighter than a competing engine that first saw service on the single-engine plane.

THE ALTERNATE ENGINE WILL NOT BOLSTER PERFORMANCE

The same dynamic that impedes improvements in safety and reliability when two different engines are being used on one type of aircraft also interferes with the introduction of other performance enhancements. Proponents of competition often argue that by purchasing rival engines for the Joint Strike Fighter, the government can tap into the market forces driving innovation in the commercial world. In highly competitive commercial markets such as automobiles and consumer electronics, companies must continuously improve the performance of their products in order to keep up with the offerings of other suppliers operating in the same segment of the market. If they fail to innovate at the rate of their rivals, they will lose market share and eventually be forced out of business.

In theory, it should be possible to fashion a similar structure of incentives for the propulsion system used on the Joint Strike Fighter by awarding annual contracts to competing manufacturers on a "best value" basis that rewards performance enhancements. After all, the companies building the F135 and F136 engines innovate constantly in the commercial turbofan market in order to maintain the appeal of their products to airlines and aircraft leasing organizations. However, there is a crucial difference between competition for commercial turbofans and the competition for engines on the Joint Strike Fighter. Airlines typically acquire only one make of engine to equip a given type of aircraft, and they seek an engine that will help them beat the pricing structure of their rivals. The Joint Strike Fighter program is buying two makes of engine for the same aircraft type, and the two engines must be physically, functionally and operationally interchangeable. Thus, the commercial customers are seeking the best possible performance from the engine make they buy, whereas the government must avoid performance enhancements in one engine that are not matched by the other engine.

Consider the example of thrust, the forward force generated by energy exiting the rear of the engine. Over time, the introduction of new products and processes will probably enable manufacturers of the Joint Strike Fighter engines to boost the thrust of their engines. However, because the engines have different designs (using different parts from different vendors), it is likely that some innovations relevant to thrust will be better suited to one engine than the other. Unfortunately, the design specification for the engines dictates they must have equal performance that is transparent and predictable to the pilot. It would be confusing and potentially dangerous if the thrust available in an operational setting varied depending on the make of the engine. The government therefore might have to forego a performance-enhancing innovation because it is using two different engines on the same fighter.

In situations where the same performance enhancement is available from both engines, the government would still have to pay more money to introduce that enhancement into the fleet since modifications would need to be developed for each of the two designs and then those modifications would have to be rigorously tested before they were qualified for operational use. Once they were fielded, the upgrades would then have to be supported by redundant supply chains and duplicative maintenance procedures applied to smaller, less efficient workloads. It is not clear that the price-constraining effects of competition would be sufficient to compensate for the other inefficiencies created by a dual-sourcing arrangement. Even if they were, the savings from competition would accumulate over time whereas the additional costs required by competition would be concentrated in the early stages of implementing a performance enhancement — creating a disincentive to pursuing the enhancement at all.

The existence of such disincentives to innovation helps explain why studies in 1998 and 2002 by the Joint Strike Fighter Program Management Advisory Group found that the alternate engine would generate only "marginal" benefits in engine growth potential. The desire of engine makers to win a larger share of annual awards would undoubtedly spur both teams to investigate performance enhancements, but the need to implement equivalent improvements in both engines would mitigate the appeal of new ideas. The inducements to innovation would be further undermined by the realization that, unlike in the commercial world, the builders of the F135 and F136 do not have to worry about being forced out of the market by a rival's superior performance. Once the government spends the money to develop two different engines, it will have to assure that each team receives enough work annually to stay in the business. Some analysts believe that with no prospect of winning or losing all the business, the two competitors would settle into a leader-follower relationship in which each team simply tried to maximize profits within a stable market share. If that were to occur, the existence of two sources could actually retard improvements in engine performance rather than promote them.

THE ALTERNATE ENGINE WILL NOT STRENGTHEN INDUSTRY

Beyond the various price and performance benefits that proponents of competition claim will result from buying two different engines for the Joint Strike Fighter, there are additional, indirect advantages often attributed to the development of an alternate engine. One of the most frequently cited such advantages is that developing and sustaining two engines will be beneficial to the U.S. industrial base. The reasoning behind this assertion takes several forms, but it always comes down to the core contention that a split buy of engines will strengthen American industry more than procuring all the engines from one source would. However, on close inspection the claim of industrial benefits proves highly doubtful.

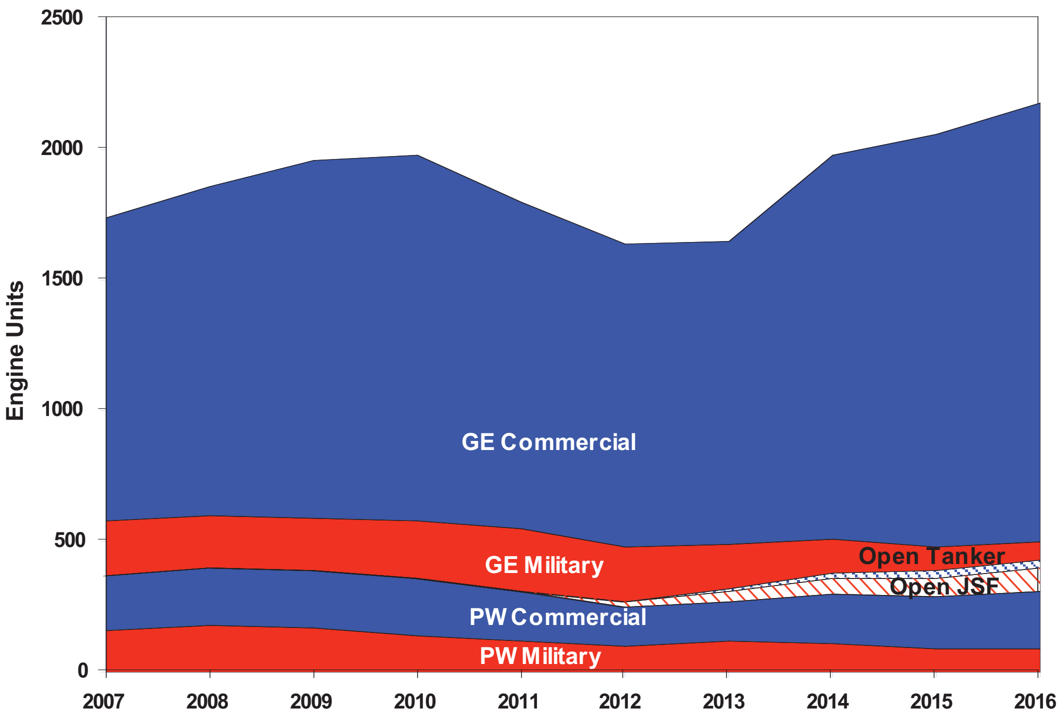
The most obvious reason why the claim should be questioned is that the number of engines to be bought remains the same regardless of which acquisition approach is used. Thus, splitting the manufacturing and sustainment of engines between two teams means that each supplier and vendor participating in the program will get less work than they would have if all the engines were purchased from a single source. When workloads shrink, the potential for economies of scale are reduced. Fixed prices must be spread over a smaller business base and there are fewer opportunities to compete vendors or negotiate price reductions on big orders. In other words, split procurement and sustainment is intrinsically less efficient unless the alternative is an unresponsive sole source with no incentives to improve performance. Since the latter problem can be easily remedied by an adjustment in contract terms, it appears that the most likely consequence of dividing the manufacture and sustainment of F-35 engines will be to make industry less efficient — a goal not usually associated with strengthening the industrial base.

Obviously, a less efficient industry is likely to require more inputs of capital and labor, making it bigger than it otherwise might have been. For example, developing two engines requires maintaining dual teams of designers, engineers and testing technicians, so the industry will sustain a larger pool of skilled employees. More facilities and workers will be needed at each subsequent stage in the engine life-cycle too. But arguing that this bolsters the industry amounts to equating bigness with strength, and is an implicit justification for industrial subsidies. Such reasoning might make sense if the propulsion units of Pratt & Whitney and General Electric operated exclusively in the federal marketplace, but since they also do business in the commercial engine market, paying them to retain redundant capacity could be argued to undermine global competitiveness rather than strengthen it. At the very least, it interferes with the culture of continuous improvement that drives most world-class commercial competitors.

There is another facet of the industrial benefits argument that seldom is discussed publicly but shapes much of the congressional maneuvering on the alternate engine. Pratt & Whitney and General Electric are the two major producers of turbofan engines in the United States, and the Joint Strike Fighter program is just the latest front in their long-running rivalry for market dominance. In recent years, General Electric has been winning most of the battles, and as a result it is now the leading supplier to both military and commercial markets (its junior partner on the alternate engine, the British company Rolls-Royce, is also a major player in both market segments). If General Electric were to secure a sizable share of the Joint Strike Fighter engine business, that would probably cement GE's dominance over its smaller domestic rival in the federal marketplace until mid-century, if not forever.

For instance, General Electric makes all the engines for the Navy Department's F/A-18 fighter, the most heavily produced domestic fighter over the last two decades. Each F/A-18 carries two General Electric

GE and P&W Large Engine Production Forecast



General Electric is the dominant U.S. supplier of large turbofan engines to military and commercial markets, making it less vulnerable than competitor Pratt & Whitney to a loss of business.

F404 or F414 engines, creating a manufacturing and sustainment opportunity similar in size to that generated by the entire domestic buy of Joint Strike Fighter engines. In fact, the Teal Group consulting firm forecasts that General Electric will produce more engines for the F/A-18 during the period 2007-2016 than Pratt & Whitney does for all of its fighter programs — the F-15, F-16, F-22 and F-35. In addition to its Navy business, General Electric has a big role in providing engines for legacy Air Force fighters that are expected to remain in the force for decades to come. So when the Joint Strike Fighter alternate engine is added to GE's order book, its presence in the federal marketplace begins to dwarf that of Pratt & Whitney. GE holds an even larger lead in the commercial turbofan market that private forecasters project will persist through 2025.

Although proponents of the alternate engine have argued that failure to give General Electric a role in Joint Strike Fighter propulsion will endanger its military engine business, the numbers suggest a different conclusion. Permitting Pratt & Whitney to retain its original, sole-source status for supplying the Joint Strike Fighter engine may be necessary simply to assure that competition continues in the domestic turbofan market. Otherwise, General Electric threatens to become so dominant in the marketplace that Pratt & Whitney's capacity to sustain its role over the long run would be in doubt. Since the parent companies of both Pratt & Whitney and General Electric's engine unit are industrial conglomerates with a longstanding pattern of moving in and out of businesses as market conditions dictate, it cannot be assumed that either enterprise would remain committed to the engine business in the face of deteriorating returns. That is not the situation either company confronts today, but funding an alternate engine when the Pratt & Whitney product was judged superior to the GE offering in a series of competitions early in the Joint Strike Fighter program could one day produce the exact opposite of a strengthened industrial base — a sector that has shrunk down to one major domestic supplier.

The success of the Joint Strike Fighter in sustaining U.S. dominance of global markets for tactical aircraft is closely tied to its affordability.

CONCLUSION: THE ALTERNATE ENGINE DOESN'T MAKE SENSE

It isn't hard to see why so many people believe that developing an alternate engine for the Joint Strike Fighter makes sense. Experience with commercial markets constantly reinforces the message that competition is good and monopolies are bad. But the military engine business is not a normal market — the government customer must cover all the costs of sustaining multiple suppliers in the sector. That simple fact obliterates most of the benefits that would accrue from competition, transforming it from a driving force for efficiency into a negative influence at every stage in the product life cycle. In particular:

- The alternate engine will not save money, because the cost of sustaining two engine teams across a service life of several decades will eclipse any price discipline realized through competition. In all likelihood, the alternate engine will drain money from defense accounts rather than saving it by requiring the government to fund redundant engineering teams, production tooling, manufacturing sites, parts inventories, supply chains, repair facilities and management systems.

- The alternate engine will not enhance safety because it will make every facet of operational support more complicated while raising the cost of safety modifications. In addition, the alternate engine will debut on the single-engine Joint Strike Fighter without first proving itself on a twin-engine aircraft, increasing the likelihood of problems that degrade operational safety.

- The alternate engine will not bolster performance in engines because the two engines used on the F- 35 must be functionally interchangeable, and it is harder to upgrade two designs than one. Not only will funds for performance enhancements have to support equivalent improvements in both designs, but in cases where enhancements are better suited to one engine than the other, the government may have to forego them entirely to avoid disparities in the operational performance of the two engines.

- The alternate engine will not benefit American industry because it will distribute a fixed workload among twice as many companies, making each participant in the program less efficient than it otherwise would have been. In addition, the alternate engine rewards the dominant domestic supplier of turbofans even though its offerings were judged to be inferior at an earlier stage in the Joint Strike Fighter program, increasing the likelihood that its main competitor will eventually be forced out of the market despite having a better product.

None of these findings should be regarded as calling into question the value of competition in markets that are truly free and open. Competition will remain the motive force behind much of the progress in the American economy. But when the government is the only customer and taxpayers must foot the bill for every aspect of competing engine systems, the benefits of competition largely disappear while the drawbacks of complexity and redundancy remain.

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