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Report to the Chairman, Subcommittee on National Security, Veterans' Affairs, and International Relations, Committee on Government Reform, House of Representatives

May 2000

JOINT STRIKE FIGHTER ACQUISITION

Development Schedule Should Be Changed to Reduce Risks

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Abbreviations

DOD	Department of Defense
JSF	Joint Strike Fighter
TRL	technology readiness level

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United States General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

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May 9, 2000

The Honorable Christopher Shays
Chairman, Subcommittee on National Security,
Veterans' Affairs, and International Relations
Committee on Government Reform
House of Representatives

Dear Mr. Chairman:

The Joint Strike Fighter Program is intended to produce an affordable, next-generation aircraft to replace the Department of Defense's (DOD) aging aircraft inventory. The first aircraft deliveries are scheduled to begin in 2008. As currently planned, the program will cost about $200 billion to develop and procure over 3,000 aircraft and related support equipment for the Air Force, the Marine Corps, the Navy, and Great Britain.

DOD has designated the Joint Strike Fighter Program as a flagship program for acquisition. To date, the program has awarded contracts totaling over $2 billion to Boeing and Lockheed Martin for the current concept demonstration phase. Under these contracts, both contractors will build the aircraft they plan to fly in the demonstration phase and also design the aircraft they plan to build in the next phase of the development program—engineering and manufacturing development. During engineering and manufacturing development, the Joint Strike Fighter will be fully developed, engineered, designed, fabricated, tested, and evaluated to demonstrate that the production aircraft will meet stated requirements. DOD is scheduled to award the contract for engineering and manufacturing development to either Boeing or Lockheed Martin in April 2001.[1]

At your request, we reviewed the Joint Strike Fighter Program to (1) provide information on the acquisition strategy and (2) to determine whether the strategy is being implemented in a manner that will ensure that the acquisition strategy objectives will be achieved. With your permission, we discussed a draft of this report during a March 16, 2000, joint hearing by

[1] At the time of this report, the Under Secretary of Defense for Acquisition, Technology, and Logistics was reviewing competition and industrial-base implications of the Joint Strike Fighter acquisition strategy.

the Subcommittees on Military Procurement and on Military Research and Development, House Committee on Armed Services. At the time of the hearing, we had not received DOD's comments on our report. This report contains DOD's comments and our evaluation of them.

Results in Brief

The key objective of the Joint Strike Fighter acquisition strategy is affordability—reducing the development, production, and ownership costs of the program relative to prior fighter aircraft programs. DOD expects the Joint Strike Fighter acquisition strategy to save nearly $18 billion (in fiscal year 1995 dollars) in development costs. To achieve its affordability objective, the Joint Strike Fighter program office has incorporated various DOD and commercial acquisition initiatives into the Joint Strike Fighter acquisition strategy. These initiatives include modifying the traditional weapons acquisition cycle, revising the requirements determination process, and developing critical technologies to a level where they represent low technical risk before the engineering and manufacturing contract is awarded. The expectation is that incorporating these initiatives into the Joint Strike Fighter acquisition strategy will result in a better match between the maturity[2] of key technologies and the aircraft's requirements. Matching the requirements and the maturity of technology when a program enters engineering and manufacturing development is a critical determinant of a program's success. Once the development phase begins, a large, fixed investment in the form of human capital, facilities, and materials is sunk into the program and any significant changes will have a large, rippling effect on cost and schedule. Beginning the engineering and manufacturing development phase when critical technologies are at a low level of maturity serves to significantly increase program risk and the likelihood of schedule delays, which in turn result in increased program costs.

The Joint Strike Fighter program office's implementation of its acquisition strategy will not ensure that the Joint Strike Fighter program will enter the engineering and manufacturing development phase with low technical risk. The aircraft being produced during the concept demonstration phase are not intended to demonstrate many of the technologies considered critical for achieving Joint Strike Fighter program cost and performance requirements. Instead, many of these technologies—such as avionics, flight

[2] A technology is considered to be mature when it has been developed to a point that it can be readily integrated into a new product and counted on to meet product requirements.

systems, manufacturing and producibility, propulsion, supportability, and weapons delivery system—will only be demonstrated in laboratory or ground-testing environments. Therefore, these critical technologies will be at low levels of technical maturity when the engineering and manufacturing development contract is scheduled to be awarded. In addition, when the competing contractors experienced design problems and cost overruns, DOD restructured the program in a manner that will provide less information than originally planned prior to selecting between the two competing contractors. Specifically, this program restructure moves away from best commercial practices that were evident in the original strategy, where technology was being developed ahead of the product. Instead, DOD's approach moves toward the traditional practice of concurrently developing technologies and products, which often raised cost-benefit issues as a result of cost increases and schedule delays as problems are encountered in technology development.

To demonstrate DOD's commitment to acquisition reform, follow best commercial practices, and reduce the risk of future cost growth, the program office should focus on risk reduction efforts by maturing critical technologies prior to entering engineering and manufacturing development, and it should be allowed to do so without the penalty of withdrawal of funding support. We make a recommendation that the Joint Strike Fighter program office adjust its currently planned engineering and manufacturing development decision date of March 2001 to allow adequate time to mature critical technologies to acceptable maturity levels before awarding the engineering and manufacturing development contract.

Background

The Joint Strike Fighter is the centerpiece of DOD's tactical aircraft modernization plan, which includes the Air Force F-22 Raptor and the Navy F/A-18 E/F Super Hornet. The program is structured to use a common production line to produce three aircraft variants that meet conventional flight requirements for the U.S. Air Force, short take-off and vertical landing characteristics for the Marine Corps, and carrier operation suitability needs for the U.S. Navy. The program will also provide aircraft to the British Royal Navy and Air Force. Table 1 shows current service plans for Joint Strike Fighter use.

Table 1: Military Service Needs for the Joint Strike Fighter

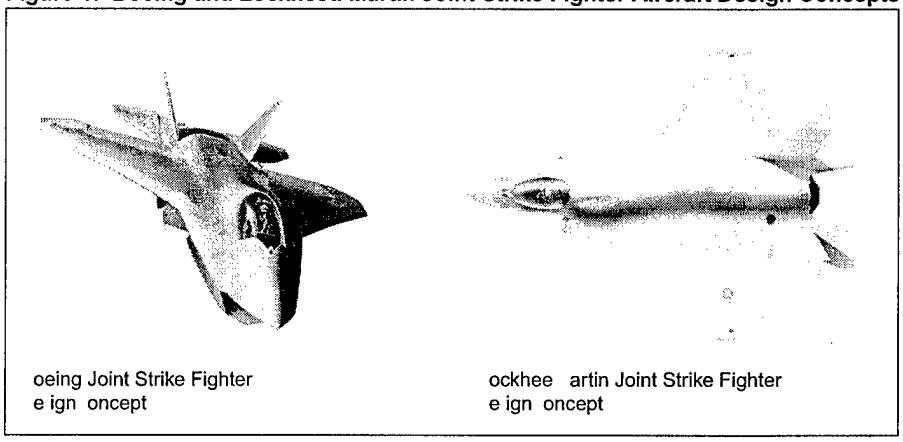
Service	Quantity	Planned use
Air Force	1,763	Replacement for F-16 and A-10; complement to the F-22
Marine Corps	609	Short take-off and vertical landing aircraft to replace AV-8B and F/A-18 C/D
Navy	480	Carrier-based, multi-role, first day of war survivable strike fighter to complement the F/A-18 E/F
Great Britain	150	Short take-off and vertical landing replacement for the Sea Harrier and GR.7

Source: Joint Strike Fighter program office.

DOD expects the Air Force variant of the Joint Strike Fighter to cost about $28 million per unit; the Navy variant to be between $31 million and $38 million; and the Marine Corps variant to cost between $30 million and $35 million.[3] Independent estimates are not so optimistic. For example, in congressional hearings held in March 1999, the Congressional Budget Office estimated that the unit cost of the Joint Strike Fighter could be as much as 47 percent to 51 percent higher than expected, depending on which variant was procured. DOD and the Congressional Budget Office estimates vary as a result of differing estimating techniques, including estimating the cost of incorporating stealth technologies into the Joint Strike Fighter design. Figure 1 shows planned Joint Strike Fighter aircraft designs by contractor.

[3] Expected costs include the cost to produce the basic aircraft, propulsion system, and avionics. Costs are stated in fiscal year 1994 dollars.

Figure 1: Boeing and Lockheed Martin Joint Strike Fighter Aircraft Design Concepts



Source: Joint Strike Fighter program office.

Acquisition Strategy Designed to Achieve Affordability Goals Through Reduced Program Risk

The focus of the Joint Strike Fighter Program is affordability—reducing the development, production, and ownership costs of the program relative to prior fighter aircraft programs. To achieve this objective, the Joint Strike Fighter program office has incorporated various DOD and commercial acquisition initiatives into the Joint Strike Fighter acquisition strategy. These initiatives include modifying the traditional weapons acquisition cycle, revising the requirements determination process, and advancing the maturity level of critical technologies so they represent low technical risk before the engineering and manufacturing contract is awarded. The expectation is that incorporating these initiatives into the Joint Strike Fighter acquisition strategy will avoid cost growth, schedule slippage, and performance shortfalls that have been experienced in other weapons acquisition programs.

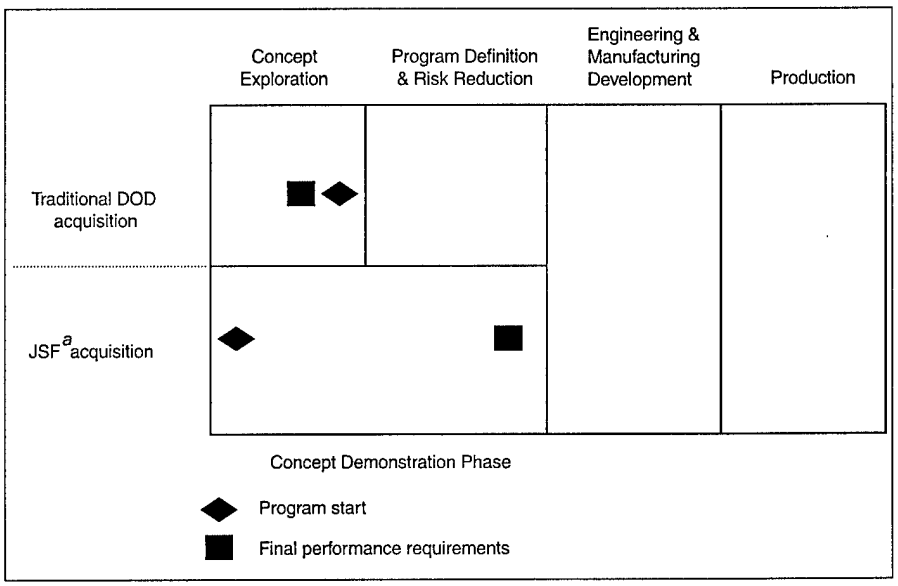
Acquisition Strategy Modifies Traditional Acquisition Cycle

The Joint Strike Fighter acquisition strategy modifies the cycle that weapons acquisition programs normally follow. For example, the Joint Strike Fighter program office was created earlier in the acquisition cycle than it would have been in a traditional DOD weapons system program. This enabled DOD to obtain early input from relevant stakeholders (operators, maintenance personnel, industry representatives, government engineers, and officials within the intelligence community) to ensure that all aspects of cost, schedule, performance, and resource constraints are included in decision-making. In addition, the program has encouraged

greater involvement from the international community, which provides both monetary and technical support (see app. I).

The traditional acquisition cycle has also been modified by combining the first two traditional acquisition phases—Concept Exploration and Program Definition and Risk Reduction—into one phase, known as Concept Demonstration. Under the traditional DOD acquisition cycle, final performance requirements are developed early in the Concept Exploration phase (see fig. 2); in the Joint Strike Fighter program, final requirements are determined later in the acquisition cycle. Program officials state that this modification provides the flexibility needed to conduct cost and performance trade-offs before requirement and design decisions become final.

Figure 2: Comparison of Traditional and Joint Strike Fighter Acquisition Cycles



[a]Joint Strike Fighter.

Source: Joint Strike Fighter program office.

Acquisition Strategy Revises the Requirements Determination Process

In what is known as an Operational Requirements Document, DOD defines aircraft program requirements (such as range, speed, and acceleration) very early in the acquisition cycle and before considering the aircraft design necessary to meet these requirements. For the Joint Strike Fighter, performance requirements are instead defined in five phases; in each phase, specific aircraft design characteristics are determined as performance requirements are set. During each phase, performance requirements are considered in terms of the established cost targets so that trade-offs in performance capabilities can be made as necessary.[4] The most significant trade-off to date in the Joint Strike Fighter Program was the decision to equip the aircraft with one versus two engines. Identifying trade-offs to balance requirements for the affordability, effectiveness, and supportability[5] of the aircraft design concept represents an ongoing effort between the government and the two competing contractors.

Acquisition Strategy Designed to Reduce Technical Risk

According to the Joint Strike Fighter Single Acquisition Management Plan, a principal objective of the program is "to demonstrate to a low level of technical risk those critical technologies, processes, and system characteristics necessary to produce an affordable family of strike aircraft that meets all participants' needs." To achieve that objective, the Joint Strike Fighter acquisition strategy is designed to lower technical risk through aircraft flight demonstrations and advanced technology development prior to awarding the engineering and manufacturing development contract. Specifically, during the current concept demonstration phase, DOD requires each contractor to

- demonstrate specific aircraft capabilities by designing and building actual flying models,
- conduct demonstrations of key technologies and processes unique to each contractor's aircraft design, and
- submit their preferred Joint Strike Fighter design concept.

[4] This process is referred to as using Cost as an Independent Variable.

[5] The degree to which system design characteristics and planned logistics resources, including manpower, meet system peacetime readiness and wartime utilization requirements.

Each competing contractor is required to design and build two aircraft to demonstrate the following:

- commonality/modularity to validate the contractors' ability to produce three aircraft variants on the same production line;
- short take-off and vertical landing, hover, and transition to forward flight to demonstrate the aircraft's ability to perform specific Marine Corps and Royal Navy missions; and
- satisfactory low airspeed carrier approach flying and handling qualities to demonstrate the aircraft's ability to perform specific Navy missions.

Each contractor will also be required to submit a Preferred Weapon System Concept, which outlines their preferred design concept for developing an affordable Joint Strike Fighter aircraft to meet the goals specified in the final requirements document. The Preferred Weapon System Concept will include results from the flight and ground demonstrations and will ultimately be used by DOD to select the winning aircraft design and to award the engineering and manufacturing development contract.

Implementation of Acquisition Strategy Will Not Ensure That Program Objectives Are Achieved

Contrary to its acquisition strategy, the Joint Strike Fighter Program will not enter the engineering and manufacturing development phase with low technical risk. The aircraft to be used in the concept demonstration phase are not intended to demonstrate all of the Joint Strike Fighter critical technologies. Therefore, these technologies will be at low levels of technical maturity when the engineering and manufacturing development contract is scheduled to be awarded. In addition, when the competing contractors experienced design problems and cost overruns, DOD restructured the program in a manner that is moving away from the best commercial practices that were evident in the original strategy and is instead moving toward traditional practices that have caused problems on other programs.

Critical Technologies Not Developed to Acceptable Levels

The aircraft being produced during the concept demonstration phase are not intended to demonstrate many of the technologies considered critical for achieving Joint Strike Fighter Program cost and performance requirements, such as those for integrated avionics. Instead, many of these technologies will be demonstrated only in laboratory or ground-testing environments and, therefore, will be at low levels of technical maturity when the engineering and manufacturing development contract is scheduled to be awarded.

Matching the aircraft requirements and the maturity of technology as a program begins is perhaps the most important determinant of a program's success. Once a program begins, a large, fixed investment in the form of human capital, facilities, and materials is sunk into the program and any significant changes will have a large, rippling effect on schedule and cost. In the case of critical technologies, beginning an acquisition program when the technologies are at a low level of development increases program risk and the likelihood of schedule delays, which increases program costs.

Measuring Technology Readiness

At our request, the Joint Strike Fighter program office identified eight technology areas that are considered critical to meeting Joint Strike Fighter cost and/or performance objectives. These technologies address areas such as avionics, flight systems, manufacturing and producibility, propulsion, supportability, and weapons delivery system.[6] We requested the program office to assign maturity levels for these critical technologies using a tool referred to as technology readiness levels (TRLs). The TRLs were pioneered by the National Aeronautics and Space Administration and adopted by the Air Force Research Laboratory[7] to determine the readiness of technologies to be incorporated into a weapon or other type of system. The Joint Advanced Strike Technology Program—from which the Joint Strike Fighter Program evolved—used TRLs to assess early maturity levels for many of the current Joint Strike Fighter technologies. In response to our prior work, DOD has agreed that TRLs can be used to help guide technology maturation and transition decisions.[8] Detailed descriptions of technology readiness levels can be found in appendix II.

In conjunction with the program office and the two competing contractors, we determined the readiness levels of critical technologies when the Joint Strike Fighter Program was started in 1996. That assessment showed that when the Joint Strike Fighter Program entered the concept demonstration phase, most of the critical technologies were well below maturity levels

[6] Due to the current Joint Strike Fighter competition, the critical technologies are not specified so as not to associate them with the respective contractors.

[7] The Air Force Research Laboratory is a science and technology organization that matures advanced technologies to the point that they can be included in weapon system programs and be expected to perform as required. The Laboratory uses the TRLs to assess the maturity of the technologies before they are handed off to programs.

[8] *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes* (GAO/NSIAD-99-162, July 30, 1999).

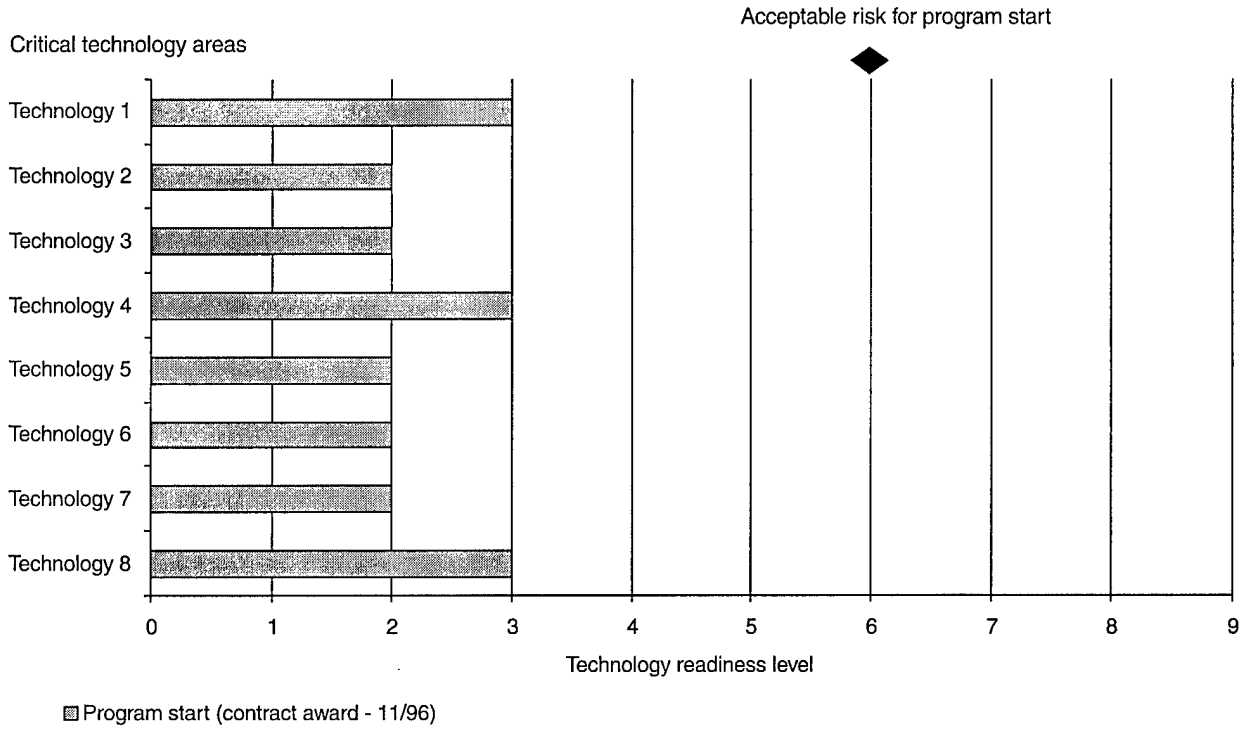
considered acceptable for low risk by the Air Force Research Laboratory or by leading commercial firms.

Readiness levels are measured on a scale of one to nine: Studies of the basic concept have a readiness level of one; laboratory demonstrations have a readiness level between three and six; and technologies that have been proven through integration on the intended product have a readiness level of nine. With this measurement tool, the program office can gauge the likely consequences of placing various technologies at a given maturity level into a development program and make informed choices and trade-offs if necessary to meet program goals.

Maturity Levels of Joint Strike Fighter Critical Technologies

The Air Force Research Laboratory considers a technology readiness level of six an acceptable risk for a weapon system entering the program definition stage, the point at which DOD typically begins its weapon programs. At a lower level of technology readiness, the technology's ability to meet the intended product's cost, schedule, and performance requirements is uncertain. Reaching a maturity level of six denotes a significant transition point for technology development—as the technology moves from component testing in a laboratory environment to demonstrating a model or prototype in a relevant environment. Figure 3 shows the maturity levels for the eight critical Joint Strike Fighter technologies in November 1996, shortly after the Joint Strike Fighter Program was started.

Figure 3: Joint Strike Fighter Critical Technology Readiness Levels at Program Start



Note: Due to the current Joint Strike Fighter competition, the critical technologies are not identified so as not to associate them with the respective contractors.

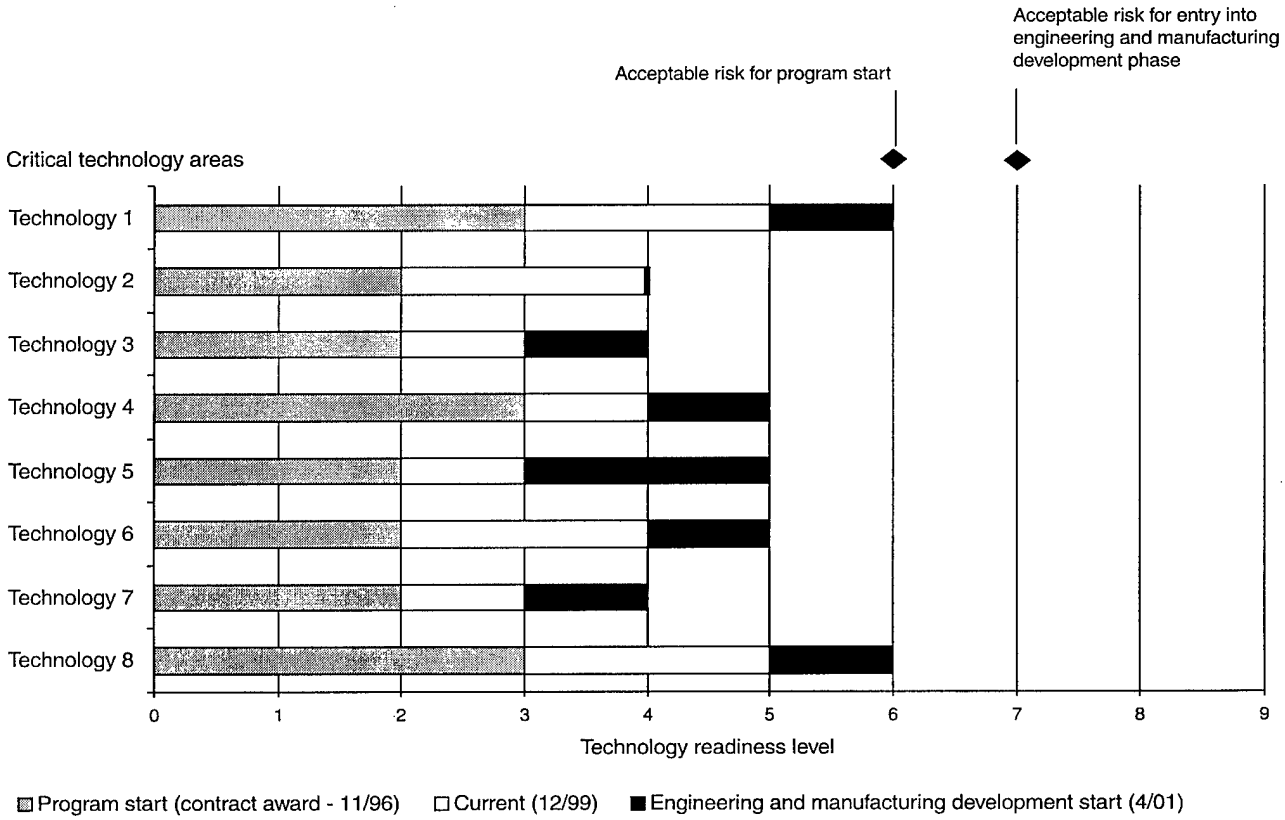
Source: Joint Strike Fighter program office.

As shown in figure 3, none of the Joint Strike Fighter critical technologies had achieved the desired technology readiness level of six by program start. Instead, all of the technologies were at readiness levels of two or three, which means that, at best, analytical and laboratory studies had been completed or very early components had been developed.

We also obtained program office and contractor data assessing the expected maturity levels for the Joint Strike Fighter as it enters engineering and manufacturing development in March 2001. The Air Force Research Laboratory considers TRL 7 as acceptable for low risk when entering the engineering and manufacturing development stage. This maturity level represents an advanced prototype of each of the critical technologies

demonstrated in an operational environment, such as on a flying test bed or another aircraft similar to the Joint Strike Fighter. A prototype at this stage would include all of the components of a critical technology in a configuration that is very close to the size, weight, and configurations as that expected for the Joint Strike Fighter. While the Joint Strike Fighter Program has seen improvement in many technology areas since the program started, maturity levels have not improved enough to indicate a low-risk transition into the next phase. Figure 4 summarizes this data.

Figure 4: Joint Strike Fighter Critical Technology Readiness Levels at Program Start and Projected for Entry Into Engineering and Manufacturing Development



Note: Due to the current Joint Strike Fighter competition, the critical technologies are not identified so as not to associate them with the respective contractors.

Source: Joint Strike Fighter program office.

As shown in figure 4, all of the Joint Strike Fighter critical technologies are expected to be at maturity levels lower than that considered acceptable for low risk when entering engineering and manufacturing development (TRL 7). Six of the technologies will still be below the level of maturity (TRL 6) that is considered low risk for entering the demonstration phase (program start), which the Joint Strike Fighter Program entered over 3 years ago.

Should any of these technologies be delayed or, worse still, not be available for incorporation into the final Joint Strike Fighter design, the impact on the program would be dramatic. For example, if one of the above critical technologies needed to be replaced with its planned backup, DOD could expect an increase of several billion dollars in production and operation and support costs.[9] The backup technology would also significantly increase aircraft weight, which could negatively affect aircraft performance. The currently planned technology is expected to be TRL 5 at the beginning of the engineering and manufacturing development phase, which indicates that substantial technology development must still occur during that phase.

DOD Response to Contractor Cost and Schedule Problems Is Inconsistent With Acquisition Strategy Goals

Recent contractor reports indicate that both competing contractors have cost growth and schedule concerns. In response to concerns over its ability to meet program requirements, Boeing has redesigned its preferred design configuration, including changing the wing shape; adding a horizontal tail, which lengthens the fuselage; and switching from a forward sweep air intake to a rearward sweep. According to a Lockheed Martin program official, the company underestimated the cost of producing the two demonstrator aircraft. In addition, Joint Strike Fighter Program documents suggest that, due to manufacturing delays, the flight-test schedule for both competing contractors' Marine Corps variant could be at risk.

As a result of cost concerns, DOD restructured the Joint Strike Fighter Program to allow each contractor leeway in correcting deficiencies. For example, the Joint Strike Fighter flight-test program has been decreased, which will reduce the data available for final proposal evaluation. Joint Strike Fighter Program officials stated that with these flight-test reductions, only the minimum acceptable flight quality demonstrations are

[9] Specific details cannot be provided due to the competitive nature of the Joint Strike Fighter Program.

expected. The number of preferred weapon system design updates has also been reduced, which means that the contractors will provide DOD with less information than originally planned prior to the submission of their proposals. Finally, DOD has eliminated risk-reduction efforts and delayed other technology demonstrations, which will increase the program's technical risk as it transitions into engineering and manufacturing development (see footnote 8).

Traditional Approach to Problems Is Underlying Cause of Increased Risk

DOD's traditional approach to weapon systems acquisition is to mature technology at the same time the product is being developed. This approach differs from best commercial practices, in which technology is developed separately and ahead of the product. Pressures exerted on weapon system programs create incentives for programs to include immature technologies that may offer significant performance gains. This pressure can come from users who demand performance improvements that necessitate the application of unproven technologies to stay ahead of the perceived threat. Another source of pressure is from technologists, who see a new weapon system as an opportunity to apply a new technology. Also, the competition for funds can encourage performance features—and requisite technologies—that can distinguish the new weapon system from competitors.

Once in a product development environment, external pressures to keep the program moving (such as preserving cost and schedule estimates to secure budget approval) become dominant. For example, DOD policies require that a program be funded in the current year and that funds be made available over the next 6 years in the DOD planning cycle. If a program manager decided that an additional year was needed to reach the desired level of technical maturity during the risk reduction/concept demonstration phase, the planned start of the engineering and manufacturing development phase could be delayed. This delay could jeopardize funding for that phase, thus risking the funding support for the entire program. Consequently, the program manager may be more likely to accept the risk of moving forward with a lower level of technology maturity rather than risk losing the program. That decision would raise cost-benefit issues because cost increases and performance compromises would likely occur.

Conclusions

The Joint Strike Fighter Program's acquisition strategy was to develop and field an affordable aircraft that will meet each of the military services' requirements goals. However, a key objective of the acquisition strategy—entering into engineering and manufacturing development with low technical risk—will not be achieved due to the manner in which the Joint Strike Fighter program office is implementing the acquisition strategy. On its current schedule, the program will enter the engineering and manufacturing development phase without having reduced to an acceptable level the technical risk of technologies that the program office has identified as critical to meeting the program's cost and requirement objectives. This approach is not consistent with best commercial practices in which technologies are more fully developed before proceeding into product development. It is also not consistent with DOD's planned approach to developing the Joint Strike Fighter. Instead, the program office's revised approach is consistent with DOD's traditional approach in weapon system programs of concurrently developing technologies and products. This traditional approach has often raised cost-benefit issues as a result of cost increases, schedule delays, and compromised performance as problems arose in completing technology development.

The Joint Strike Fighter Program is at an early development stage and, therefore, DOD still has the opportunity to both demonstrate its commitment to acquisition reform and chart a course to avoid the problems that often befall major weapon systems. A decision to allow the Joint Strike Fighter to proceed as planned, without mature critical technologies, would compromise DOD's position on acquisition reform, set aside best commercial practices, and would perpetuate conditions that have led to cost growth and schedule delays in many prior DOD weapon system acquisition programs.

Recommendation

To demonstrate DOD's commitment to acquisition reform and to reduce the risk of future cost growth, the program office should focus on risk reduction efforts by maturing critical technologies prior to entering engineering and manufacturing development, and it should be allowed to do so without the penalty of withdrawal of funding support. Therefore, we recommend that the Secretary of Defense direct the Joint Strike Fighter program office to adjust the currently planned March 2001 engineering and manufacturing development decision date to allow adequate time to mature critical technologies to acceptable maturity levels, thereby closing the gap between technology and requirements, before awarding the

engineering and manufacturing development contract. Options that the program should consider include

- delaying the selection of a single contractor for the engineering and manufacturing phase of the program until the program's critical technologies have been developed to an acceptable level or
- selecting a single contractor, but providing the time and funding for additional risk reduction and technology maturation efforts, so that this contractor can mature critical technologies to acceptable levels before a decision is made to begin engineering and manufacturing development.

Matters for Congressional Consideration

To ensure that the Joint Strike Fighter Program enters the engineering and manufacturing development phase with low technical risk, as envisioned by the original acquisition strategy, Congress may wish to consider requiring the Secretary of Defense to identify which of the eight critical technologies discussed in this report will be incorporated on the Joint Strike Fighter and certify that each of the identified technologies has been demonstrated in a form that is the right size, weight, and configuration needed for the Joint Strike Fighter aircraft. For any of the eight technologies not initially included on the Joint Strike Fighter, the Secretary of Defense should develop a plan showing the strategy for demonstrating these technologies in the right size, weight, and configuration; showing the approach for including them onto the Joint Strike Fighter; and the cost impact if these technologies do not become available as planned. Congress may also want to consider restricting DOD from obligating funds made available for the engineering and manufacturing development phase of the program until it receives this information from DOD.

Agency Comments and Our Evaluation

In written comments on a draft of this report, the Director of Strategic and Tactical Systems, within the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, disagreed with our conclusions and recommendation. DOD stated that our conclusion was based on misinterpretation of the use of technology readiness levels to determine the readiness of the critical technologies to enter engineering and manufacturing development. In addition, DOD stated that (1) only the maturity of the technology, not its integration onto the Joint Strike Fighter, should be rated to determine its readiness to enter engineering and manufacturing development; (2) our use of technology readiness levels does not recognize that an evolutionary acquisition approach is being

applied to the Joint Strike Fighter Program; and (3) its own risk reduction efforts are more meaningful than using technology readiness levels.

Contrary to DOD's comments, there was no misinterpretation by us, the contractors, or the program office representatives about what constituted a readiness level of seven—the level considered necessary for acceptable risk for entering engineering and manufacturing development. As pointed out in this report, the readiness level definitions clearly state that for a technology to be rated at a level seven, it must be demonstrated using prototype hardware, such as a complete radar subsystem that is the same size, weight, and configuration planned for the Joint Strike Fighter in an operational environment. This definition was developed by the Air Force Research Laboratory and was provided to the contractors prior to their scoring of the critical technologies, and we discussed them at length during several days of meetings when the contractors, with DOD program office personnel present, assigned the readiness levels for the critical technologies. During those discussions, we made it clear that demonstrating the technology in a relevant environment would include demonstrating the technology in a flying test bed aircraft, such as an F-16 or some other existing aircraft, and not necessarily on an actual Joint Strike Fighter aircraft. As a result of those discussions, there was agreement on the readiness levels assigned to each of the critical technologies discussed. The program office then independently scored the critical technologies. The program office scores, which are those used in this report, were consistent with the contractors' scores.

DOD stated that the Joint Strike Fighter Program will address the integration risk of the critical technologies during, rather than prior to, the engineering and manufacturing development phase. As indicated in our report, we agree that the risk of integrating a subsystem–such as a radar–onto the actual Joint Strike Fighter aircraft is an activity that is acceptable for the engineering and manufacturing phase. However, we do not agree that integrating various components of a subsystem—such as an antenna, receiver, transmitter, and processor that make up a radar subsystem—into a configuration that can be inserted into the Joint Strike Fighter is a task to be left for the engineering and manufacturing development phase. In that regard, commercial firms have told us that a key part of technology development is getting the technology into the right size, weight, and configuration needed for the intended product. Once this has been demonstrated, the technology is at an acceptable level for engineering and manufacturing development, where the emphasis should be on building the actual Joint Strike Fighter aircraft. In separate technical comments on this

report, DOD acknowledged that the highest program risks will come from integrating critical technologies, which it intends to do during engineering and manufacturing development. DOD's approach, of developing technology during engineering and manufacturing development, represents a fundamental difference between best commercial practices and DOD practices and has been a leading reason for DOD's weapon programs incurring cost growth, schedule slippage, and technical problems.

In its comments, DOD described an evolutionary acquisition approach being applied to the Joint Strike Fighter Program as a way to further mitigate technology and program risk. This approach means that the Joint Strike Fighter Program will use time-phased requirements and capabilities, and only those technologies and capabilities that are mature and at low risk will be installed on the first Joint Strike Fighter aircraft that are produced. Cost and requirement trade-offs will be considered so that technologies will not be included on the Joint Strike Fighter until they have demonstrated an acceptable maturity level. We are concerned that since many of the technologies assessed at low maturity levels in our report are critical to obtaining an affordable aircraft—a primary objective for both the Joint Strike Fighter and DOD's overall tactical aircraft modernization plan—their absence from the Joint Strike Fighter design could result in much higher development, production, and support costs. The impact of developing and producing Joint Strike Fighter aircraft without these technologies must be considered, otherwise, DOD could find itself committed to a program dependent on future maturation of these technologies in order to meet program cost objectives. This would be typical of DOD's historical approach to developing weapon systems, and it indicates that DOD is willing to assume greater risk during engineering and manufacturing development than was envisioned in the Joint Strike Fighter Program's original acquisition strategy.

Finally, DOD stated that its own risk reduction methodology–which include risk mitigation plans and engineering judgment–is a more meaningful measure of risk versus the use of technology readiness levels. We do not share DOD's confidence in this regard. The objective of technology readiness levels is to make decisions based on actual demonstrations that technologies will work as needed for the intended product as opposed to engineering judgment, which is subjective and open to interpretation. Our prior work has shown that in place of risk mitigation plans and engineering judgment, no matter how well intentioned, using technology readiness levels results in a straightforward, objective, and quantifiable process for determining a technology's readiness for proceeding into the engineering

and manufacturing development phase of a program. DOD has recognized the value of the technology readiness level process as indicated by its intention to include the process in the revised acquisition guidelines—commonly referred to as the 5000 acquisition series.

In summary, the information provided by DOD in its comments on our draft report does not change our position that, as currently structured, the Joint Strike Fighter Program will move into the engineering and manufacturing development phase with unacceptable risk levels for many critical technologies. Therefore, we have not changed the recommendation that was in our draft report but we have added some matters for Congress to consider. In essence, we suggest that Congress consider restricting DOD from obligating funds for the engineering and manufacturing development phase of the program until the Secretary of Defense certifies that the program's critical technologies have been demonstrated to acceptable levels of maturity.

The full text of DOD's comments are included in appendix III. DOD also provided separate technical comments that we have incorporated into the report as appropriate.

Scope and Methodology

To determine the acquisition strategy for meeting affordability goals through reduced risk prior to awarding the engineering and manufacturing development contract, we reviewed program documentation on acquisition strategy and acquisition reform initiatives and discussed these materials with DOD and program officials. These materials include data such as the Joint Strike Fighter Single Acquisition Management Plan, the Interim Test and Evaluation Master Plan, Joint Interim Requirements Document, Key Performance Parameters in the draft Joint Operational Requirements Document, and Cost as an Independent Variable documentation.

To determine whether the program office is implementing the Joint Strike Fighter acquisition strategy in a manner that will reduce risk and meet Joint Strike Fighter cost, schedule, and performance goals, we collected data and interviewed officials at various DOD locations, the Joint Strike Fighter program office (Arlington, Virginia), and cognizant Navy, Marine Corps, and Air Force requirements organizations. We interviewed officials and collected contractor data from Lockheed Martin Tactical Aircraft Systems, Fort Worth, Texas, and Palmdale, California; the Boeing Company, Seattle, Washington, and Palmdale, California; General Electric, Cincinnati, Ohio; and Pratt & Whitney, West Palm Beach, Florida.

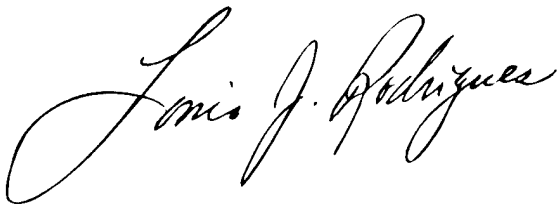
To assess the maturity levels of key technologies, we used information provided by the Joint Strike Fighter program office and contractors and used the technology readiness level tool developed by the National Aeronautics and Space Administration. On separate visits to the contractors, with DOD program office personnel present, we provided relevant technology managers the TRL scoring sheet found in appendix II of this report. After significant discussion, and additional TRL information, we asked these managers to score those technologies they considered critical to enable their Joint Strike Fighter design to meet DOD requirements for the aircraft. Upon reviewing these scores with the program office and in order to gain an overall Joint Strike Fighter Program perspective on technical maturity, the Joint Strike Fighter office agreed to provide us with TRL scores for the eight technologies they considered critical for meeting program cost and performance requirements. Those scores are presented in this report.

We conducted our review from September 1998 through January 2000 in accordance with generally accepted government auditing standards.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from its issue date. At that time, we will send copies to the congressional defense committees; the Honorable William S. Cohen, Secretary of Defense; the Honorable F. Whitten Peters, Secretary of the Air Force; the Honorable Richard Danzig, Secretary of the Navy; General James L. Jones, Commandant, U.S. Marine Corps; and the Honorable Jacob J. Lew, Director, Office of Management and Budget. We will also make copies available to other interested parties on request.

Please contact me at (202) 512-4841 if you or your staff have any questions concerning this report. Key contributors to this assignment were Steve Kuhta, Brian Mullins, Delores Cohen, and Matt Lea.

Sincerely yours,



Louis J. Rodrigues
Director, Defense Acquisitions Issues

International Participation in the Joint Strike Fighter Program

Full collaborative partner

- full access to program data and structure, including representative personnel within the program office
- ability to influence requirement definition and performance characteristics
- Great Britain is the only participant in this category, committing $200 million for the concept demonstration phase

Associate partner

- limited access to data and limited requirements influence
- representative personnel resident within the Joint Strike Fighter program office
- all aspects of participation are negotiated with the Joint Strike Fighter program office
- Denmark, the Netherlands, and Norway formed a group and committed a total of $30 million to participate at this level

Informed customer

- limited access to program information and representation within the program office is negotiable
- no influence on requirements
- Canada and Italy have committed $10 million each to participate at this level

Major participants

- recently created category; also referred to as Foreign Military Sales participation or Fee for Service
- negotiate directly with the program office for specific Joint Strike Fighter Program information (e.g., Cost and Operational Performance Trade processes and modeling and simulation studies)
- no representative personnel resident within the Joint Strike Fighter program office
- Singapore, Turkey, and Israel are currently participating at this level

Technology Readiness Levels and Their Definitions

Technology readiness level	Description
1. Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties
2. Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.
3. Analytical and experimental critical function and/or characteristic proof of concept.	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4. Component and/or breadboard validation in laboratory environment.	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
6. System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond the breadboard tested for technology readiness level (TRL) 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.
7. System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.
8. Actual system completed and "flight qualified" through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon systems to determine if it meets design specifications.
9. Actual system "flight proven" through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

Source: *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes* (GAO/NSIAD-99-162, July 30, 1999).

Comments From the Department of Defense

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

ACQUISITION AND TECHNOLOGY

OFFICE OF THE UNDER SECRETARY OF DEFENSE

3000 DEFENSE PENTAGON
WASHINGTON DC 20301-3000

17 APR 2000

Mr. Louis J. Rodrigues
Director, Defense Acquisitions Issues
National Security and International
Affairs Division
U. S. General Accounting Office
Washington, DC 20548

Dear Mr. Rodrigues:

This is the Department of Defense (DoD) response to the General Accounting Office (GAO) draft report, "JOINT STRIKE FIGHTER ACQUISITION: Development Schedule Should be Changed to Allow Risks to be Reduced," dated February 24, 2000 (GAO Code 707386/OSD Case 1952). The Department of Defense does not concur with the recommendation in the draft report (see enclosure).

The draft report states that the implementation of the Joint Strike Fighter Program's acquisition strategy will not ensure that the program will enter the Engineering and Manufacturing Development (EMD) phase with low technical risk. The Department does not agree with this conclusion, which is based on misinterpretation of a process for determining the readiness of technologies for incorporation into major systems.

The Joint Strike Fighter Program Office, in conjunction with each competing contractor, has identified critical technologies, processes, and system characteristics required for the program, tailored to each contractor's design. Risks have been identified, baselined, and tracked to document the specific events required to reduce the risk of these critical technologies, processes, and system characteristics to a low level prior to EMD initiation. Implementation of this acquisition strategy has not changed significantly since the program entered the Program Definition and Risk Reduction phase in 1996.

JSF's Single Acquisition Management Plan, approved by the Under Secretary of Defense for Acquisition and Technology on November 15, 1996, clearly states that the goal of the JSF technology maturation program is to evolve the most promising leading-edge technologies to a low level of risk prior to integration during the JSF EMD phase. The GAO ground rules for scoring the Technology Readiness Levels (TRLs) included the risk of integrating the technology onto the JSF platform. The JSF Program Office used those ground rules to arrive at the ratings contained in the draft report, which GAO used as a basis for its conclusion. Upon review and discussion with other users of TRLs, the Program Office determined that only the maturity of the technology, not its integration, should be rated to determine its readiness to enter EMD. When this is done (see enclosure), one finds that technology risk is expected to be at an acceptable level at EMD start.

See comment 1.

See comment 2.

In a response to a previous GAO report, the Department agreed that it is desirable to mature technologies to TRL 7 prior to entering EMD. However, that response also noted: "The Department agrees that TRLs are an important input and are necessary, but adds that they are not sufficient alone to decide when and where to insert new technologies into weapon system programs."

In addition, an evolutionary acquisition approach, which includes time-phased requirements and capabilities, is being applied to the JSF program. This further mitigates both technology and program risks by allowing technologies to be inserted into the program as they mature. This also allows the JSF program to insert the basic functionality of any of these technologies and then to grow that functionality over time. What's crucial is to risk-manage the technologies during EMD and to have fall-back plans in place in the event some fail to mature.

Technical comments for accuracy and clarification have been provided separately.

The Department appreciates the opportunity to comment on the draft report.

Sincerely,

George R. Schneiter
Director
Strategic and Tactical Systems

Enclosure

GAO DRAFT REPORT, Dated February 24, 2000
(GAO Code 707386/OSD Case 1952)

"JOINT STRIKE FIGHTER ACQUISITION: Development Schedule Should Be Changed To Allow Risks To Be Reduced"

DOD COMMENTS ON THE GAO RECOMMENDATION

- RECOMMENDATION: The GAO recommended that the Secretary of Defense direct the JSF program office to adjust the currently planned March 2001 Engineering and Manufacturing Development decision date to allow adequate time for critical technologies to reach acceptable maturity levels, thereby closing the gap between technology and requirements, before awarding the Engineering and Manufacturing Development contract.

- DOD RESPONSE: Nonconcur. JSF critical technologies, processes, and system characteristics will be low risk for EMD entry in March 2001 if the planned program activities are carried out by then.

- JSF reduces risks of individual critical technologies to low risk prior to EMD.
- JSF addresses integration risk of those technologies on a JSF platform in EMD.
- JSF has been consistent in implementation of its acquisition strategy with regard to risk management from program inception. Risks have been identified, baselined, and tracked, documenting the specific events required to reduce the risk of these critical technologies, processes, and system characteristics to low prior to EMD start.
- The GAO's supplied ground rules for scoring the Technology Readiness Levels (TRLs) included technology maturation and the integration risk. The JSF Program Office also re-scored the technology areas using just technology maturation risk. Both of these results are shown in the attached Table. When just the technology maturation risks are addressed, the eight highest-risk technology areas are rated as either TRL 6 or 7 at the start of EMD, which is acceptable for entry into EMD.
- In a DoD response to the GAO Report: "BEST PRACTICES: Better Management of Technology Development Can Improve Weapon System Outcomes" (GAO/NSIAD-99-162), GAO, July 1999, the Department states the following: "The Department concurs with the GAO that the weapon system program manager should assure that technology is matured to TRL 7 before insertion into a new system." The Department has also stated in that response: "...that TRLs are an important input and are necessary, but adds that they are not sufficient alone to decide when and where to insert new technologies into weapon system programs."
- An evolutionary acquisition approach, which includes time-phased requirements and capabilities, is being applied to the JSF program. This further mitigates both technology and program risks by allowing technologies to be inserted into the program as they mature. This also allows the JSF program to insert the basic functionality of any of these technologies and then to grow that functionality over time.

ESTIMATED TRL RATINGS FOR EMD START 2001

AREA	GAO DRAFT REPORT (Technology Maturation and Integration Risk)	RATIONALE	JSF PROGRAM OFFICE RE-SCORING (Technology Maturation Alone)	RATIONALE*
Technology 1	6	Not flown on JSF in a JSF environment.	7	Flying on Concept Demonstrator Aircraft (CDA).
Technology 2	4	One portion not flown in JSF application.	6	Technology already flown in aircraft, helicopter, spacecraft, etc.
Technology 3	4	No equivalent integrated support in current US military service.	6	Many such systems in similar commercial environments, e.g., Caterpillar, FedEx, 777.
Technology 4	5	Not flown on JSF in a JSF environment.	7	Flying on F-16.
Technology 5	5	Not flown on JSF in a JSF environment.	6	Technology has been flown on JSF flying test bed.
Technology 6	5	Not flown on JSF in a JSF environment.	7	Technology has been flown on JSF flying test bed.
Technology 7	4	Not flown on JSF in a JSF environment.	6	Fusion technology has been flown on JSF flying test bed.
Technology 8	6	Limited demonstration on Concept Demonstrator Aircraft.	7	Flying on CDA as well as F-22, F/A-18E/F, Eurofighter, etc.

*Further details, which are proprietary, are available.

Attachment: a/s

The following are GAO's comments on the Department of Defense's (DOD) letter dated April 17, 2000.

GAO Comments

1. DOD provided reevaluated technology readiness levels to indicate that if the risk of integrating critical technologies was not considered, then the technology risk is expected to be at an appropriate level. Notwithstanding our disagreement over whether integration risks should be considered in this assessment, we believe DOD's standards are below minimum acceptable levels. Only half of the critical technologies are projected to be at readiness level 7 while the other half will still be at readiness level 6. We disagree with DOD that readiness level 6 is acceptable for low-risk entry into engineering and manufacturing development. Leading commercial firms typically insist on a readiness level 8–a higher standard than that used by the Air Force Research Laboratory–before a technology can be included on a product.

2. DOD noted that in addition to technology readiness levels, other considerations were necessary to decide when and where to insert new technologies into weapon system programs. While DOD did not elaborate on what other considerations were applicable to the Joint Strike Fighter Program, its similar response to our prior work involving technology readiness levels referred to such considerations as the increasing projected life for new weapon systems, total ownership costs, and urgency based upon threat assessments. Many of the technologies presented in this current report directly address these other considerations and are critical to the success of the Joint Strike Fighter Program. Therefore, using TRLs in the Joint Strike Fighter Program not only allows DOD to manage performance risk, but also to address those technologies critical to meeting these other considerations. With regard to risk assessment, leading commercial firms who have adopted knowledge-based risk assessment approaches, such as TRLs, have produced results such as more technically advanced, higher quality products, in less time and at a lower cost than their predecessors.

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