

March 1999

# F-22 AIRCRAFT

## Issues in Achieving Engineering and Manufacturing Development Goals



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**National Security and  
International Affairs Division**

B-280222

March 15, 1999

Congressional Committees

As required by the National Defense Authorization Act for Fiscal Year 1998 (P.L. 105-85), we reviewed the Air Force's F-22 engineering and manufacturing development (EMD) program. This report, an update to a report we issued last year,<sup>1</sup> presents our conclusions regarding whether the Air Force is likely to complete the EMD program without exceeding the cost limitation established by the act. The act also requires us to certify whether we had access to sufficient information to make informed judgments on matters covered by this report.

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**Results in Brief**

The Air Force estimates it can complete F-22 EMD within the cost limitation. However, during much of 1998, the F-22 contractor cost and schedule plans, as defined in 1997, were not fully accomplished. Costs exceeded the budgets established to accomplish planned work, and work planned was not always completed on schedule. The Air Force viewed the potential for further cost growth as a threat to completing EMD within the cost limitation. Although the Air Force devised ways to avoid and reduce costs, we question whether EMD, as planned, can be completed within the cost limitation. Our conclusion is based on the following:

- Cost reviews by the Air Force and the contractors in 1998 identified a potential program cost growth of \$482 million that, if not addressed, could increase program costs above the cost limitation of \$18.939 billion. Air Force and contractor plans to address this potential cost growth have not all been finalized. These plans include eliminating some planned EMD activities. Further, unless the plans are successful, additional measures will be necessary to reduce costs.
- The contractor has notified the Air Force that F-22 EMD program costs may increase if sales of C-130J aircraft, which are manufactured in the same plant as the F-22, are lower than anticipated because the F-22 program will have to absorb a higher share of the plant's overhead costs.
- Deliveries and first flights of the next four flight-test aircraft are expected to be late, reducing flight-testing time available before planned EMD completion. Unless the Air Force can successfully compress or

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<sup>1</sup>F-22 Aircraft: Progress in Achieving Engineering and Manufacturing Development Goals (GAO/NSIAD-98-67, Mar. 10, 1998).

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reduce the remaining flight tests to complete EMD as scheduled, EMD costs will increase.

- There have been delays in developing the F-22's integrated avionics<sup>2</sup> systems, and the schedule for completing avionics development appears unrealistic. If avionics development requires an extension of EMD, additional costs will be incurred.

The Air Force currently estimates that the F-22 will meet or exceed all its required performance parameters. The estimates are based on computer simulations, studies, and flight-test data. The Air Force expects additional flight testing to confirm the estimates. As of December 1998, the Air Force had completed about 200 flight-test hours and the selected performance demonstrations and events required by the Under Secretary of Defense for Acquisition and Technology before F-22 production activities begin. In December 1998, the Secretary of Defense submitted a report about F-22 testing and production risks to the Congress, and the Air Force awarded a contract to initiate production activities.

The Air Force and the contractors gave us access to sufficient information to make informed judgments on the matters covered in this report.

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## Background

The F-22 is an air superiority aircraft with advanced technology features, including integrated avionics. The objectives of the F-22 EMD program, which began in 1991, are to (1) design, fabricate, test, and deliver 9 F-22 flight-test vehicles, 2 ground-test vehicles, and 26 flight-qualified engines; (2) design, fabricate, integrate, and test the avionics suite; and (3) design, develop, and test the support and training systems. The F-22 is being developed under cost-type contracts with Lockheed Martin Corporation (for the aircraft) and Pratt & Whitney Corporation (for the engines).

Concerned about the growing costs of the F-22 program, the Assistant Secretary of the Air Force for Acquisition in June 1996 established the Joint Estimating Team (JET) to estimate the most probable cost of the F-22 EMD and production programs. The team consisted of personnel from the Air Force, the Department of Defense (DOD), and private industry.

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<sup>2</sup>F-22 avionics are expected to be much more advanced than those of previous fighter aircraft. A common computer, rather than multiple computers, will receive, process, and display information to minimize the pilot's workload and provide previously unmatched awareness of potential threats and targets.

The JET concluded in 1997 that additional time would be required to complete EMD and estimated that EMD costs would increase to \$18.688 billion. The JET recommended several changes to the program's schedule, including slower manufacturing for a more efficient transition from development to low-rate initial production and an additional 12 months to complete avionics development. The JET did not recommend changing F-22 performance goals. The Air Force and the Under Secretary of Defense for Acquisition and Technology generally adopted the JET's recommendations<sup>3</sup> to extend the F-22 EMD schedule, including the dates for accomplishing interim events and completing EMD. We used the cost and schedule plans established in 1997 as a result of the JET study as an analytical baseline to assess whether cost and schedule goals for F-22 EMD are being met.

The National Defense Authorization Act for Fiscal Year 1998 established a cost limitation of \$18.688 billion (an amount that mirrored the JET estimate) for the F-22 EMD program and \$43.4 billion for the F-22 production program. The act instructed the Secretary of the Air Force to adjust the cost limitations for the amounts of increases or decreases in costs attributable to economic inflation after September 30, 1997, and compliance with changes in federal, state, and local laws enacted after September 30, 1997. Since then, the Air Force has adjusted the EMD program's cost limitation to \$18.939 billion.

In May 1998, the Under Secretary of Defense for Acquisition and Technology directed the Secretary of the Air Force to modify the F-22's acquisition strategy. This direction designated the first two aircraft as production representative test vehicles and the purchase of six aircraft as the first low-rate initial production lot. It also required the Air Force to brief the Defense Acquisition Board in November 1998 on the progress made toward meeting performance criteria established in the directive. The criteria were to

- initiate flight testing of the second EMD aircraft;
- conduct flight operations on the first two EMD aircraft, including flight operations at specified speeds and altitudes, the first air refueling, the first supersonic flight, the first flight above 30,000 feet, and the first flight above an 18-degree angle of attack;

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<sup>3</sup>For more information on the JET's recommendations, see [Tactical Aircraft: Restructuring of the Air Force F-22 Fighter Program](#) (GAO/NSIAD-97-156, June 4, 1997).

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- complete full ground vibration tests on the first EMD aircraft;
  - complete the critical design review for block 2 avionics; and
  - complete initial release of the first block of software to the flying test bed.<sup>4</sup>

The Strom Thurmond National Defense Authorization Act for Fiscal Year 1999 (P.L. 105-261), prohibited the Air Force from obligating funds for advance procurement of the first six production aircraft until the Secretary of Defense submitted a report that either

- certified that 433 flight-test hours (about 10 percent of the planned flight-test program) were completed or
- identified the number of flight-test hours completed, the reasons for the Secretary's determination that fewer than 433 flight-test hours are sufficient to decide to proceed to production, the extent to which the Secretary's determination is consistent with each major aircraft acquisition decision made by the Defense Acquisition Board since January 1997, the amount of flight testing completed that was or was not sufficient to justify a decision to proceed to low-rate initial production (applies to major aircraft acquisition programs), and a determination by the Secretary that it is more financially advantageous for the Department to proceed to production than to delay production until completion of 433 hours of flight testing, together with the reasons for that determination.

As of December 1998, the Air Force had accepted two flight-test aircraft and completed about 200 flight-test hours, about 5 percent of the total planned flight-test hours for the EMD program. In December 1998, the Secretary of Defense submitted a report to the Congress as required by the Strom Thurmond National Defense Authorization Act for Fiscal Year 1999, and the Air Force awarded contracts for two production representative test aircraft and to initiate production activities for six production aircraft.

Through fiscal year 1999, the Congress had appropriated about \$15.6 billion for F-22 EMD, or 82 percent of the cost limitation. About \$3.3 billion remained to be appropriated.

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<sup>4</sup>The flying test bed is a Boeing 757 designed to test avionics before they are installed on the EMD aircraft.

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## Extent to Which the F-22 Program Is Meeting the Cost Goal for the EMD Program

Contractor cost experience and studies in 1998 indicated cost growth threatened the Air Force's ability to complete EMD within the \$18.939 billion cost limitation. As of January 1999, the Air Force estimated that the F-22 EMD program will cost \$18.911 billion, \$28 million less than the cost limitation. However, the Air Force and Lockheed Martin have identified potential program cost growth of \$482 million. Successful implementation of plans to reduce the cost growth is essential if the program is to be completed within the cost limitation. A factor the Air Force did not consider in its estimate of potential cost growth was the possibility that the F-22 program may have to absorb a higher share of the manufacturing plant's overhead costs if the contractor does not sell enough C-130J aircraft, which are produced at the same plant as the F-22.

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## Contractor Costs Exceeded Budgets for Planned Work

Lockheed Martin reports to the Air Force monthly concerning its progress compared with planned costs and schedules. These reports define the cost and schedule variances from the contract plans. Through 1998, Lockheed Martin reports showed a worsening trend of costs that exceeded its budgets for work that had been completed. For example, through January 1998, Lockheed Martin reported that costs exceeded its budgets by \$14.4 million. By June 1998, costs exceeded budgets by \$93.3 million.

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## Studies Identified Additional Potential Cost Growth

In early 1998, because contractor costs were exceeding budgets and planned work was behind schedule, Lockheed Martin and the Air Force studied the EMD program's estimated costs and identified potential cost growth of \$482 million.<sup>5</sup> A Lockheed Martin team identified potential cost growth of about \$240 million, and an Air Force team identified an additional potential cost growth of \$242 million. As a result of these studies, Lockheed Martin requested in November 1998 that the Air Force add \$240 million to the EMD contract. Air Force officials advised us, however, that the increase may be less than \$240 million. The Air Force

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<sup>5</sup>Air Force and contractor evaluations indicated potential cost growth of \$667 million, which could be offset by \$185 million in management reserves available in the contract price. The net growth, accordingly, is about \$482 million.

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plans to reallocate funds within the total program to accommodate the cost growth and keep the EMD cost within the congressional limitation.<sup>6</sup>

The primary causes for the potential cost growth were identified as (1) designing, modifying, and manufacturing airframe<sup>7</sup> components and (2) developing and integrating the avionics. Cost growth for the airframe was attributed to problems in manufacturing the castings that attach the wing to the aircraft's body, the aft fuselage, the horizontal tails, and the engine air inlets; more manufacturing changes than anticipated; and additional required analyses. Avionics development experienced cost growth because of problems with the technical complexities of the system and the delivery by subcontractors of insufficiently developed software.

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## Plans to Address Potential Cost Growth

Because cost growth of \$482 million would cause the EMD program to exceed the cost limitation, the Air Force has developed plans to reduce F-22 EMD costs. Plans call for eliminating and deferring program elements. For example, planned actions include

- deferring external weapons testing until after EMD is completed (\$140 million),
- reassessing the effort required to conduct flight testing for use of a helmet targeting system and the AIM-9X missile and reducing the estimated cost of testing (\$110 million),
- reducing contractor laboratory costs for the test program (\$100 million),
- reducing other government costs such as special studies (\$50 million), and
- implementing Lockheed Martin cost reduction plans (\$80 million).

According to the Air Force, testing to certify that the F-22 can effectively use externally mounted weapons will be deferred until after EMD is completed. Regarding the \$80 million in potential reductions expected to come from Lockheed Martin's cost reduction plans, the contractor said that it had validated only \$20 million as firm cost reductions through November 1998.

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<sup>6</sup>In February 1999, the Air Force stated that additional costs would be incurred because of problems manufacturing wings. The Air Force estimated that additional cost growth of \$22 million will occur in addition to the potential cost growth identified in 1998. As a result, the Air Force will be required to identify offsets to remain within the cost limitation.

<sup>7</sup>Airframe refers only to the structural part of the aircraft.



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**Potential Impact of C-130J Sales on Program**

The potential cost growth identified by the Air Force and contractor does not include the effects that lower than anticipated sales of C-130J cargo aircraft by Lockheed Martin may have on F-22 program costs. Lockheed Martin, which produces the C-130J and the F-22 in its Marietta, Georgia, plant, has notified the Air Force that the F-22 EMD program will have to absorb a higher share of the plant's overhead costs if fewer C-130Js are sold than expected. The Air Force has not taken into account the potential impact of this cost increase, which could amount to between \$150-\$160 million per year if C-130J production were to cease, according to the Defense Contract Management Command in Marietta. DOD officials advised us that increased costs would have to be absorbed only partially by the F-22 EMD program and that other business may develop. They indicated that Lockheed Martin was negotiating with several foreign governments for potential sales of C-130J's.

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**Extent to Which the F-22 Program Is Meeting the Schedule Goals for the EMD Program**

The Air Force is not achieving several of the planned events that were established in 1997 as a result of the JET review. In particular, planned events for producing EMD aircraft and developing avionics were not being met through December 1998. One effect of this is that test aircraft are being delivered later than planned, thus preventing flight-test activities from being completed as planned. In March 1998 we reported that there were delays in achieving these milestones.<sup>8</sup>

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**Contractor Did Not Accomplish Work as Scheduled**

Through 1998, Lockheed Martin reports showed a worsening trend in the accomplishment of its planned work. For example, through January 1998, Lockheed Martin reported that it had not completed planned work valued at \$70.9 million. By June 1998, it reported that the value of planned work not accomplished had increased to \$111.5 million.

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**Manufacturing Problems Caused Late Deliveries and Reduced Flight- and Ground-Testing Time**

The first two F-22 EMD aircraft were flight-tested through most of December 1998. The first aircraft began flight tests about 3 months later than planned, but the second aircraft began testing on time. Because of manufacturing problems, however, the Air Force estimates that the next four flight-test aircraft will be delivered late. Flight testing is expected to

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<sup>8</sup>F-22 Aircraft: Progress in Achieving Engineering and Manufacturing Development Goals (GAO/NSIAD-98-67, Mar. 10, 1998).

begin between 2 weeks and over 5 months later than was planned in 1997. Also, the two ground-test aircraft are expected to start testing 6 to 8 months later. As a result, the Air Force has 16.9 fewer flight-test months available to complete the flight-test program. Air Force officials said they have eliminated the impact of this reduced time by making some flight-test aircraft available for testing for longer periods than previously planned and by deferring some testing until after the EMD program is completed. According to the officials, the Air Force is also studying ways to reduce the required flight-test hours. If the Air Force plan to revise the flight-test schedule is not successful, additional deferments, or deletions will be needed to remain within the cost limitation.

Table 1 compares the 1997 scheduled first flight dates with the expected first flight dates as of January 1999.

**Table 1: Comparison of Schedules for First Flights of EMD Aircraft**

EMD aircraft	First flight as scheduled in 1997	Expected first flight as of January 1999	Months of delay in first flight
4001	May 29, 1997	September 7, 1997 <sup>a</sup>	3.3
4002	July 9, 1998	June 29, 1998 <sup>a</sup>	-0.3
4003	June 16, 1999	November 22, 1999	5.2
4004	August 17, 1999	February 3, 2000	5.6
4005	January 11, 2000	March 31, 2000	2.7
4006	May 18, 2000	May 30, 2000	0.4
4007	September 25, 2000	September 25, 2000	0
4008	February 2, 2001	February 2, 2001	0
4009	June 1, 2001	June 1, 2001	0
<b>Total aircraft flight test months of delay</b>			<b>16.9</b>

<sup>a</sup>Actual date of first flight.

The delays in first flights are being caused by problems in manufacturing wings and fuselages. Wings are expected to be delivered later than the 1997 schedule because of problems with the development and manufacture of large titanium castings that attach the wing to the aircraft's body. As of January 1999, the Air Force and the contractor were working to resolve the problem. The Air Force expected Lockheed Martin to receive the wings for the next four flight-test aircraft and both ground-test articles between

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2 weeks and over 6 months late.<sup>9</sup> The Air Force also expected the aft fuselage—the rear aircraft body section—to be delivered late for the next four flight-test aircraft and two ground-test articles because of late deliveries of parts and welding difficulties caused by the very small tolerances allowed when fitting fuselage parts together. Air Force officials said they had identified a solution to the welding problem.

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## Avionics Development Is Behind Schedule

Development of avionics systems for the F-22 is behind the 1997 schedule. Although radar system development activities have been completed generally on schedule, development problems with the communication, navigation, and identification and the electronic warfare systems<sup>10</sup> have caused schedule delays and cost growth in avionics development. Lockheed Martin and the Air Force have included these cost increases in their estimates of potential cost growth.

Because of these problems, the Air Force developed a new avionics schedule in August 1998, allocating more time to complete the first two major avionics segments, known as blocks 1 and 2.<sup>11</sup> The subcontractors for both systems have had problems integrating the various modules and sections of the software, so the process is taking longer than expected. Several communication, navigation, and identification sensors failed testing and have required further development time and effort. Electronic warfare hardware problems have been reportedly caused by problems such as faulty designs of some sections and late supplier deliveries. Furthermore, officials at Boeing Military Aircraft, a subcontractor that operates a key avionics integration laboratory, told us they have been receiving late deliveries of software that is insufficiently developed. This has added to the time and effort needed to integrate the avionics software.

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<sup>9</sup>In February 1999, the Air Force stated that wings for the third through the sixth test aircraft will be delayed 10 to 15 weeks more than anticipated by the revised schedule. They also said they were pursuing mitigation actions to avoid further delays in first flights.

<sup>10</sup>The communication, navigation, and identification system integrates these three functions to give pilots greater awareness of the surrounding situation. The electronic warfare system warns the pilot of air or ground radar and missile threats and provides countermeasures.

<sup>11</sup>Blocks 1, 2, 3S, 3, and 3.1 are each designed to have increased capability over the previous block. The last phase of development for each block begins when it is placed on the aircraft for testing.

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**Revised Avionics Schedule  
Appears Unrealistic**

The Air Force's August 1998 revised schedule postponed the planned completion dates for blocks 1 and 2 but did not change the completion dates for subsequent blocks 3 and 3.1,<sup>12</sup> even though the majority of initial software development tasks related to these last two segments have been delayed between 1 and 18 months. In 1997, the JET had concluded that avionics development could take as much as 12 months more than planned because of delays in all four avionics blocks (1, 2, 3, and 3.1).

Even though blocks 1 and 2 are behind schedule and will probably be completed later than planned in 1997, the revised schedule shows avionics blocks 3 and 3.1 being completed over 5 months before the completion dates that the JET considered realistic in 1997. If blocks 3 and 3.1 take longer than planned to be completed under the revised schedule, additional costs will be incurred.

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**Significance of Avionics  
Flight Testing**

Integrated avionics is a critical technology advancement for the F-22, and substantial flight testing is planned to demonstrate and evaluate its capability. The Air Force has planned a substantially higher number of avionics flight-test hours in the F-22 program than in previous fighter programs. Table 2 compares F-22 avionics flight-test hours to those of other fighter programs.

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<sup>12</sup>The revised schedule also adds block 3S between blocks 2 and 3. In adding this block, the Air Force moved some block 3 activities ahead for earlier evaluation. This did not, however, change the planned completion date for block 3 activities.

**Table 2: Avionics Flight-Test Hours Planned for the F-22 and Completed by Other Fighter Aircraft Programs**

Aircraft type	Number of test aircraft	Avionics flight hours
F-14	4	1,168
F-15	3	819
F-16	1	488
F-18	1	591
F-22	6	1,574

## Extent to Which the F-22 Program Is Meeting the Performance Goals for the EMD Program

In December 1998, the Air Force estimated that by the end of the EMD program, the F-22 would meet or exceed the goals for the major performance parameters. These include 10 parameters on which the Air Force reports regularly to DOD and 2 additional performance features we reviewed that relate to other critical characteristics of the F-22. The Air Force performance estimates were based on flight-test data, computer models, ground tests, and analyses.

As we reported last year, we reviewed 2 additional features—situational awareness and low observability—that are not among the 10 major performance parameters but that both the Air Force and we consider critical for the aircraft’s ability to operate as intended. We are therefore reporting on the Air Force’s progress in developing these two features. Greater situational awareness improves response time to threats, increasing the lethality and survivability of the aircraft, while the aircraft’s low observable, or stealth, features allow it to evade detection by enemy aircraft and surface-to-air missiles.

The 10 parameters and 2 additional features, shown in table 3, are described in detail in appendix I. Table 3 shows the goal for each parameter, the estimated performance achieved for each parameter as of December 1998, and the Air Force’s current estimate of the performance each parameter is expected to achieve by the end of the EMD program. Most of the goals and related performance information are classified and are therefore shown as percentages rather than numbers.

**Table 3: Estimates of Performance for Selected Parameters and for Additional Features**

<b>Key performance parameters</b>	<b>Goal (acquisition program baseline)</b>	<b>Estimated performance 12/98</b>	<b>Estimate at EMD completion</b>
Supercruise	100%	115%	115%
Acceleration	100%	115%	115%
Maneuverability	100%	104%	104%
Airlift support (C-141 equivalents)	8	7.7	7.7
Sortie generation rate	100%	100%	100%
Radar cross section (front sector only)	100%	Favorable	Favorable
Mean time between maintenance (hours)	3.0	3.1	3.1
Payload (missiles)	4 medium range 2 short range	6 medium range 2 short range	6 medium range 2 short range
Combat radius	100%	124%	124%
Radar detection range	100%	117%	117%
<b>Additional features reviewed by GAO</b>	<b>Goal<sup>a</sup></b>	<b>Estimated performance to date</b>	<b>Current estimate at EMD completion</b>
Situational awareness	100%	Favorable	Favorable
Low observability	100%	Favorable	Favorable

<sup>a</sup>These goals are not acquisition program baseline numbers. We assigned a value of 100 percent to evaluate the features.

## Initial Production Activities Approved

The Air Force accomplished the test events required by the Under Secretary of Defense and achieved about 200 hours of flight testing through December 1998. The Air Force briefed the Under Secretary on the results of the accomplishments on December 17, 1998. On December 23, 1998, the Secretary of Defense reported to the Congress that the F-22 program was meeting its objectives and that the risk of producing two production representative test aircraft and obligating advance procurement funds for the first six production aircraft was acceptable. The Under Secretary approved award of the contracts for the two production representative test aircraft and the advance procurement for the first six production aircraft.

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## Conclusions

It is unlikely that the Air Force will be able to complete the F-22 EMD program, as planned, within the cost limitation set by the National Defense Authorization Act for Fiscal Year 1998. Our conclusion is based on incomplete Air Force cost reduction plans, the potential for increased overhead costs if C-130J sales are lower than expected, late deliveries and first flights of EMD aircraft, reduced flight-test months, schedule delays in developing avionics, and a revised avionics schedule that is not realistic.

The Air Force has revised its avionics development schedule by postponing dates for early development activities but not for later tasks. It has thus compressed the schedule in a way that may not be realistic, especially considering the delays experienced so far and the high number of avionics flight-test hours planned. If it takes longer to complete avionics development than planned, additional costs will be incurred or actions will be necessary to address these costs.

The Air Force is estimating that the F-22 will meet or exceed all its required performance parameters. Through December 1998, about 5 percent of the flight-test program had been completed to verify these estimates.

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## Recommendations

We recommend that the Secretary of Defense direct the Secretary of the Air Force to formulate a more realistic avionics development schedule. We recommend that in doing so, the Secretary consider the progress to date, the JET's avionics schedule, and the impact a more realistic schedule would have on the EMD program's estimated cost.

We also recommend that the Secretary of Defense evaluate how decisions regarding C-130J production are likely to impact F-22 EMD and assess the Air Force's ability to negate additional overhead costs that may be allocated to F-22 EMD.

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## Agency Comments and Our Evaluation

DOD agreed that avionics development and integration is a challenging area for the F-22 program and that reduced quantities of C-130J aircraft could have a cost impact on the F-22 EMD program.

DOD did not agree that the Secretary of Defense should, at this time, direct the Secretary of the Air Force to formulate a more realistic avionics

schedule. DOD officials said the Office of the Under Secretary of Defense and the Air Force are both aware that schedule pressures resulting from emphasis on block 1 avionics will have an impact on development and integration of later software blocks. Because the Office of the Under Secretary of Defense is aware of potential impacts and is monitoring Air Force efforts to mitigate any further schedule impacts, DOD officials believe it is unnecessary at this time for DOD to issue further guidance to the Air Force about the need to keep the F-22 program on schedule and within available funding.

We believe DOD needs to ensure that a realistic avionics development schedule is formulated and that DOD is aware of any subsequent impact on the program schedule or estimated program cost. We continue to believe the recommendation is valid, although we understand that the intent of the recommendation may be achievable without issuing formal guidance to the Secretary of the Air Force.

DOD partially agreed with our recommendation to evaluate how decisions regarding C-130J production are likely to impact the F-22 EMD program and assess the Air Force's ability to nullify additional overhead costs that may be allocated to the F-22 EMD program. DOD agreed that a significant change to previously anticipated C-130J production volume would have an adverse impact on the F-22 program. Until a specific C-130J buy profile is available and overhead rates associated with that profile are calculated, DOD said it would be unable to determine the specific impact on the F-22 program. DOD also said that programs at Lockheed Martin other than the C-130J could impact the F-22 EMD program.

DOD said its ability to nullify/offset additional overhead costs is limited only by the number of cost reduction plans that can be generated, funded, and successfully implemented. DOD said the Air Force and Lockheed Martin are continually searching for opportunities to reduce the cost of the F-22 program.

We continue to believe that the Secretary of Defense should assess how changes in Lockheed Martin's overall business base would affect the F-22 EMD program. Because the Air Force estimates the F-22 EMD program is near its cost limitation, any significant impact as a result of changes in Lockheed Martin's business base could require the Air Force to identify mitigation actions to remain within the cost limitation. Therefore, we



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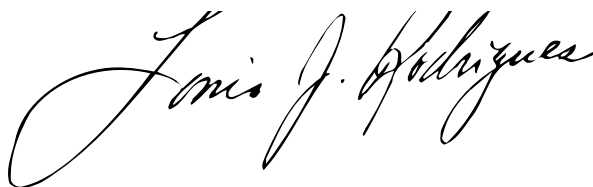
believe our recommendation is still appropriate, as the assessment must be completed in time for the Air Force to act on its results.

DOD's comments are included in appendix III of this report.

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We are sending copies of this report to the Secretaries of Defense and the Air Force and the Director, Office of Management and Budget. Copies will also be made available to others on request.

Please contact me at (202) 512-4841 if you or your staff have any questions concerning this report. Major contributors to this report are listed in appendix IV.

A handwritten signature in black ink that reads "Louis J. Rodrigues". The signature is written in a cursive style with a large, looping initial "L".

Louis J. Rodrigues  
Director, Defense Acquisitions Issues

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List of Congressional Committees

The Honorable John W. Warner  
Chairman

The Honorable Carl Levin  
Ranking Minority Member  
Committee on Armed Services  
United States Senate

The Honorable Ted Stevens  
Chairman

The Honorable Daniel K. Inouye  
Ranking Minority Member  
Subcommittee on Defense  
Committee on Appropriations  
United States Senate

The Honorable Floyd D. Spence  
Chairman

The Honorable Ike Skelton  
Ranking Minority Member  
Committee on Armed Services  
House of Representatives

The Honorable Jerry Lewis  
Chairman

The Honorable John P. Murtha  
Ranking Minority Member  
Subcommittee on Defense  
Committee on Appropriations  
House of Representatives

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### **Abbreviations**

DOD	Department of Defense
EMD	engineering and manufacturing development
JET	Joint Estimating Team
RCS	radar cross section

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# F-22 Performance Parameters

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## Supercruise

Supercruise is the aircraft's ability to sustain supersonic (greater than mach 1)<sup>1</sup> speed without using its afterburners. Supercruise saves fuel and helps reduce the aircraft's infrared signature, thus making the F-22 harder for the enemy to detect. The goal for the F-22 is to supercruise at a speed considerably greater than mach 1 in a stable, level flight at an altitude of 40,000 feet. The Air Force estimates the F-22 will exceed the supercruise goal by about 15 percent. This estimate was determined through an analysis of computer models and flight testing completed so far. The computer models use data such as the engines' thrust and fuel flow characteristics. Flight testing of the aircraft propulsion characteristics began in 1998 and is scheduled to continue into the second quarter of 2000.

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## Acceleration

Acceleration is a key parameter because the F-22 must fly faster than enemy aircraft and exit an area quickly after it employs air-to-air or air-to-ground munitions. The acceleration parameter refers to the amount of time it takes the aircraft to go from 0.8 mach to 1.5 mach speed at an altitude of 30,000 feet. The Air Force estimates that the F-22 will exceed its acceleration goal. This estimate was determined through an analysis of computer models, propulsion ground testing, and flight testing. Flight testing of the aircraft's propulsion characteristics began in 1998 and is scheduled to continue into the second quarter of 2000.

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## Maneuverability

Maneuverability is the maximum force the aircraft can generate while turning at 0.9 mach speed at an altitude of 30,000 feet without losing speed or altitude. Many additional measures of aircraft maneuverability exist, but the Air Force has determined that this measurement is the most appropriate to demonstrate the F-22's overall maneuverability under key flight conditions. The Air Force estimates the F-22 will exceed its maneuverability goal by 4 percent. The estimate was determined through an analysis of computer models with data on the major subparameters affecting maneuverability and flight testing. Flight performance testing began in 1998 and is scheduled to end in the third quarter of 2001.

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<sup>1</sup>The ratio of the speed of the aircraft to the speed of sound. Mach 1 is about 738 miles per hour.

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## Airlift Support

This parameter measures the number of C-141 transport aircraft equivalents required to deploy and maintain a squadron of 24 F-22 aircraft for 30 days without resupply. The goal is to be able to provide this support with no more than 8 C-141 equivalents, thereby reducing the assets needed to deploy and the deployment costs. The Air Force estimates the F-22 will require less than 8 C-141 equivalents. A squadron of F-15 aircraft requires 19 C-141 equivalents. The F-22 estimate will not be verified until a mobility demonstration takes place in 2004, when the 24<sup>th</sup> production aircraft is scheduled to be delivered.

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## Sortie Generation Rate

Sortie generation rate is the average number of sorties or missions that can be flown per aircraft per day in the first 6 days of a conflict. This parameter measures the degree to which the F-22 will be available during the first few days of a conflict to achieve and maintain air superiority. The Air Force estimates the F-22 will meet the sortie generation rate goal. This estimate was based on the results of a computer model using data on maintenance characteristics, the availability of support equipment and resources, and aircraft maintenance policy. F-22 maintainability demonstrations to verify the estimates are scheduled to be completed by 2002.

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## Radar Cross Section

The radar cross section (RCS) parameter essentially refers to how large the F-22 appears to enemy radar. The smaller an aircraft's RCS, the harder it is for enemy radar to detect and track the aircraft. A small RCS, along with several other factors,<sup>2</sup> contributes to an aircraft's low observable, or stealth, characteristics. Although an aircraft has over 200 RCS measurement points, the Air Force considers what is known as the front sector RCS—how the aircraft is viewed from the front by enemy radar—the most important one. The Air Force estimates that the F-22's front sector RCS will be smaller than its goal. The estimates were based on component models that predict the RCS of major components, such as wings and engine inlets, and use this data to predict the RCS of an entire aircraft. RCS design validation and specification compliance activities are also being conducted with a full-scale model of an F-22. This testing will continue into 1999. In-flight measurements are scheduled to begin in 2000.

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<sup>2</sup>These include infrared signature, electromagnetic signature, acoustic level, and visibility.

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## Mean Time Between Maintenance

Mean time between maintenance is a measure of aircraft reliability defined as the total number of aircraft flight hours divided by the total number of aircraft maintenance actions in the same period. The F-22's goal is 3 flight hours between maintenance actions by the time the F-22 reaches system maturity (100,000 flight hours, in about 2008). The Air Force estimates that by the time the F-22 reaches system maturity, it will only require maintenance every 3.1 flight hours. The estimate was calculated using a reliability computer model that uses factors such as the design of the aircraft's systems and scheduled maintenance activities. Maintenance data will be collected from the 500<sup>th</sup> through the 5,000<sup>th</sup> hour of flight testing throughout the development and operational flight-testing phases to update the maintenance estimate. To verify the requirements, data will continue to be collected through system maturity.

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## Payload

The payload parameter is the number of medium- and short-range air-to-air missiles the F-22 can carry when performing an air superiority mission without attacking ground targets. Payload is a key parameter because the F-22 is designed to carry missiles in its internal weapons bay, not externally. Carrying weapons externally increases an aircraft's RCS and allows easier detection by enemy radar. The Air Force estimates that the F-22 will meet the payload goal of carrying six AIM-120C medium-range missiles and two AIM-9X short-range missiles internally. Weapons bay testing is scheduled for mid-2000 to determine how well the missiles can exit the weapons bay when launched.

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## Combat Radius

Combat radius is the number of nautical miles the F-22 must fly to achieve its primary mission of air superiority. This requires the F-22 to fly a certain distance subsonically (below mach 1 speed) and a certain distance supersonically. The Air Force estimates that the F-22 will exceed its combat radius goal by 24 percent. According to the Air Force, unfavorable estimates for two of three major subparameters—fuel usage and aircraft weight—are not unfavorable enough to prevent the F-22 from meeting its combat radius goal. Performance flight testing to help compute the aircraft's combat radius performance, as well as other aerodynamic capabilities, began in 1998 and will continue into the third quarter of 2001.

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## Radar Detection Range

Radar detection range is the number of nautical miles from which the F-22 should be able to detect potential enemy threats or targets. The aircraft's radar must be able to detect enemy targets that have small radar signatures at sufficient distance to ensure that the aircraft can engage the enemy first. The Air Force estimates that the F-22's radar will exceed the established goal by 17 percent. This estimate is based on digital simulations, models, and flying test-bed flight-test results dedicated to radar testing. Radar detection performance is scheduled to be verified against the simulations and models in an avionics laboratory until the third quarter of 1999. Actual flight testing of the radar in F-22 EMD aircraft is scheduled to begin in 1999 and continue until at least the second quarter of 2001.

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## Situational Awareness

The situational awareness parameter refers to how the F-22's sensors and avionics systems can make pilots aware of the surrounding situation. The planned integration of avionics systems and sensors is meant to (1) minimize the pilot's own management and interpretation of sensors and (2) provide previously unmatched awareness of potential threats and targets. According to the Air Force's estimates of the major avionics subparameters affecting situational awareness (including radar; electronic warfare; and communication, navigation, and identification systems), the F-22 will meet the situational awareness goal. Development of the integrated avionics, however, is still in the early stages, and the first major segment of avionics is not scheduled to be ready for placement on EMD flight-test aircraft until April 1999, with four subsequent major segments (blocks 2, 3S, 3, and 3.1) still to be completed. Block 3.1 is not scheduled for placement on EMD flight-test aircraft until April 2001.

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## Low Observability

Low observability refers to the aircraft's "stealth," or its ability to evade detection by enemy radar long enough to be the first to detect the enemy and fire. Five features contribute to an aircraft's observability: its RCS and its infrared, electromagnetic, visual, and acoustic signatures. The F-22 does not have a requirement for acoustic signature. The Air Force estimates that the F-22 will meet the low-observability performance goals. Specification compliance of the most critical feature, RCS, is being checked with a full-scale model of an F-22 and will continue into 1999. In-flight RCS measurements will begin in 2000 and continue into 2002. Flight testing to measure the F-22's infrared signature is scheduled for the third quarter of 1999.



**Appendix I**  
**F-22 Performance Parameters**

**Table I.1: F-22 Performance Parameters and Major Subparameters**

<b>Performance parameter</b>	<b>Major subparameter</b>
Supercruise	Engine thrust
Acceleration	Aircraft weight
Maneuverability	Airframe drag
Airlift support	Number of support equipment items
	Airlift loads required to deploy support equipment
	Maintenance manpower required
Sortie generation rate	Mean time between maintenance
	Maintenance personnel hours/flying hour
	Number of support equipment items
	Maintenance personnel required
Radar cross section	27 subparameters
Mean time between maintenance	Airframe
	Avionics
	Engines
Payload	No subparameters
Combat radius	Fuel usage
	Aircraft weight
	Airframe drag
Radar detection range	Range in searching for targets
	Range in searching for targets by tracking target speed
	Time taken to search for targets
	Time taken to search for targets by tracking target speed
<b>Additional features measured by GAO</b>	<b>Major subparameter</b>
Situational awareness	Radar function
	Electronic warfare function
	Communication, navigation, and identification functions
Low observability	Infrared signature
	Electromagnetic emissions signature
	Visual signature
	Radar cross section

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# Objectives, Scope, and Methodology

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Our objectives were to determine whether the Air Force is likely to complete the F-22 EMD program within the congressional cost limitation.

To determine whether the program is likely to meet the cost limitation, we examined (1) the extent to which the EMD cost goals are being met; (2) Air Force plans to fund the program for the following year; and (3) the consistency between the program funding plan and the cost limitation. We compared the estimated cost at completion for the prime contracts with planned amounts, evaluated cost variances identified in the contractors' cost reporting system, and reviewed the status of initiatives designed to avoid cost growth.

To determine whether the program is expected to meet schedule goals, we reviewed the program and avionics schedules and discussed potential changes to these schedules with F-22 program officials. We also tracked progress in the flight-test program. In addition, we evaluated schedule variances in the contractors' performance management system and compared planned milestone accomplishment dates with actual dates. We tracked technical problems in manufacturing and assembling the EMD aircraft.

To determine whether the program is expected to meet the F-22 performance goals, we analyzed information on the performance of key performance parameters and of those important subparameters that are measured. To determine whether estimated performance had changed, we compared the Air Force's current estimate for these parameters with previous estimates.

To evaluate the bases for the Air Force's current performance estimates, we collected information on the goals established for those major performance subparameters that are critical components of performance parameters. To determine whether the Air Force estimates seemed reasonable, we collected and analyzed information on Air Force estimates, as of December 1998, toward meeting the goals of these subparameters. For example, each major subparameter for airlift support--the number of airlift support equipment items, the airlift loads needed to transport support equipment items, and the maintenance personnel required for a squadron of F-22s--has its own performance goal, just as the overall parameter has a performance goal. The performance parameters and their associated subparameters are shown in table I.1.

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**Appendix II**  
**Objectives, Scope, and Methodology**

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In performing our work, we obtained information and interviewed officials from the Office of the Secretary of Defense, Washington D.C.; the F-22 System Program Office, Wright-Patterson Air Force Base, Ohio; the Defense Contract Management Command, Marietta, Georgia; Lockheed Martin Aeronautical Systems, Marietta, Georgia; Lockheed Martin Tactical Aircraft Systems, Fort Worth, Texas; and Boeing Military Aircraft, Seattle, Washington. We performed our work from April 1998 through March 1999 in accordance with generally accepted government auditing standards.

# Comments From the Department of Defense



ACQUISITION AND  
TECHNOLOGY

## OFFICE OF THE UNDER SECRETARY OF DEFENSE

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19 FEB 1999

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

Dear Mr. Rodrigues:

This is the Department of Defense (DoD) response to the General Accounting Office (GAO) Draft Report, "F-22 AIRCRAFT: Issues in Achieving Engineering and Manufacturing Development Goals," dated January 25, 1999 (GAO Code 707344), OSD Case 1741.

The F-22 is an event-driven program with program exit criteria in each major area of the program. The event-based criteria for judging program progress are aimed at demonstration of a high standard of success before the program is permitted to proceed into the next phase.

Avionics development and integration is a challenging area for the F-22. The program met the two avionics criteria established for the most recent acquisition decision in December 1998. There are three avionics-related criteria that have been established for the Low-Rate Initial Production (LRIP) milestone decision in December 1999. Development and integration of Block 1 avionics has taken longer than anticipated. The Air Force and its contractors are currently reviewing the overall avionics plan, including the work to be accomplished, to determine the impact to the future schedule, and to identify mitigation plans where necessary. The Department is closely monitoring program progress, and will ensure that avionics status is fully understood as we progress toward the LRIP milestone.

The Department agrees that a reduction in production quantities of C-130J could have a cost impact for the F-22, and this is an area of concern. The potential impact is based on changes in the business base at the Marietta plant, which could affect the allocation of overhead to the C-130J, F-22, and other plant work. We are also aware that there are other potential contracts recently awarded or pending that would potentially improve the business base at the Lockheed Martin, Marietta, GA facility. The Department is tracking this potential problem and will ensure that periodic audits confirm that charges to F-22 are appropriate in amount and allocation.




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**Appendix III**  
**Comments From the Department of Defense**

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The enclosure addresses the specific GAO matters in more detail. Also, we have separately provided changes that the Department feels are important to correct errors in factual accuracy. The Department appreciates the opportunity to comment on the draft report.



George R. Schneider  
Director  
Strategic and Tactical Systems

Enclosure

GAO DRAFT REPORT DATED JANUARY 25, 1999  
(GAO CODE 707344), OSD CASE 1741

**“F-22 AIRCRAFT: Issues in Achieving Engineering and Manufacturing Development Goals”**

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DOD COMMENTS ON THE GAO RECOMMENDATIONS

**RECOMMENDATION 1:** The GAO recommended that the Secretary of Defense direct the Secretary of the Air Force to formulate a more realistic avionics development schedule. The GAO also recommended that in doing so, the Secretary consider the progress to date, the Joint Estimating Team (JET) avionics schedule, and the impact a more realistic schedule would have on the engineering and manufacturing development (EMD) program's estimated cost. (p. 20/GAO Draft Report)

**DoD Response:** **Nonconcur.** The avionics R-19 schedule was created with the best information known at that time, fully recognizing it maintained schedule pressure on the integrated product teams developing the avionics suite. This plan allowed some schedule slip, but also allowed a reserve to the JET projected software block delivery dates. The F-22 avionics program has made significant progress in the 2 years since the JET conducted a review of the program, including delivering the Flying Test Bed Block 1 software ahead of the R-19 plan. The team aggressively manages the execution of the schedule and creates innovative workarounds to mitigate pending schedule problems, thereby minimizing schedule slips. The team continually revisits the work to go in relation to the avionics schedule to ensure executability.

The program office and the contractors are currently reviewing the R-19 avionics schedule/plan, and expect to publish a revision in the March/April time period. Development and integration of Block 1 avionics has taken longer than anticipated. Even though integration of Block 1 avionics into the Avionics Integration Laboratory has slipped about one month, the current estimate is Block 1 avionics will be available to support the dates for the Operational Flight Program input for Engineering and Manufacturing Development aircraft 4004, the first avionics aircraft.

Schedule pressures resulting from the emphasis on Block 1 avionics development will have an impact on development and integration of avionics Blocks 2, 3.0, 3.1 and 4.0. The Office of the Secretary of Defense is aware of these potential impacts, and is monitoring the Air Force efforts to mitigate any further schedule impacts. No further guidance is necessary now to emphasize the need for success in keeping the F-22 program on schedule and within available funding.

Now on p. 13.

Now on p. 13.

**RECOMMENDATION 2:** The GAO further recommended that the Secretary of Defense (1) evaluate how decisions regarding C-130J production are likely to impact F-22 EMD and (2) assess the Air Force's ability to negate additional overhead costs that may be allocated to F-22 EMD. (p. 20/GAO Draft Report)

**DoD Response:** **Partially Concur.** The Department agrees with the GAO that decisions regarding C-130J production have a direct impact on any government work being performed at that plant, including the F-22 EMD contract. A significant change to the previously anticipated C-130J production volume will result in an adverse impact on the F-22 Program. It should be noted that Lockheed is negotiating potential commercial C-130J sales to Italy, Norway, Australia, and other countries. Impacts to the F-22 EMD program, however, should be less than related impacts to F-22 production due to the EMD program "tailing off" during the time frame in question, while production will represent an increasing share of the plant's business base. Beyond that, we are unable to speculate on specific impacts until a precise C-130J buy profile is determined and Defense Contract Management Command (DCMC) has the opportunity to calculate the overhead rates associated with this profile.

The Department's ability to negate/offset these additional overhead costs is limited only by the number of cost-reduction plans which can be generated, funded, and successfully implemented. In addition to the C-130J and F-22 programs, the Lockheed Martin Marietta facility was recently awarded a \$500M-plus C-5 avionics modifications program, in addition to the S-3/P-3 modifications and spares, and other programs. In addition, the C-130X modification program and the C-5 reengineering and reliability improvement program, which are funded in the FYDP, represent potential new business base opportunities for the Marietta, Georgia facility. The Air Force, along with Lockheed, is continually searching for opportunities to reduce the cost of the F-22 program.

# Major Contributors to This Report

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# Related GAO Products

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F-22 Aircraft: Progress of the Engineering and Manufacturing Program (GAO/T-NSIAD-98-137, Mar. 25, 1998).

F-22 Aircraft: Progress in Achieving Engineering and Manufacturing Development Goals (GAO/NSIAD-98-67, Mar. 10, 1998).

Tactical Aircraft: Restructuring of the Air Force F-22 Fighter Program (GAO/NSIAD-97-156, June 4, 1997).

Defense Aircraft Investments: Major Program Commitments Based on Optimistic Budget Projections (GAO/T-NSIAD-97-103, Mar. 5, 1997).

F-22 Restructuring (GAO/NSIAD-97-100R, Feb. 28, 1997).

Tactical Aircraft: Concurrency in Development and Production of F-22 Aircraft Should Be Reduced (GAO/NSIAD-95-59, Apr. 19, 1995).

Air Force F-22 Embedded Computers (GAO/AIMD-94-177R, Sept. 20, 1994).

Tactical Aircraft: F-15 Replacement Issues (GAO/T-NSIAD-94-176, May 5, 1994).

Tactical Aircraft: F-15 Replacement Is Premature as Currently Planned (GAO/NSIAD-94-118, March 25, 1994).

Aircraft Development: Reasons for Recent Cost Growth in the Advanced Tactical Fighter Program (GAO/NSIAD-91-138, Feb. 1, 1991).

Aircraft Development: Navy's Participation in Air Force's Advanced Tactical Fighter Program (GAO/NSIAD-90-54, Mar. 7, 1990).

Aircraft Development: The Advanced Tactical Fighter's Costs, Schedule, and Performance Goals (GAO/NSIAD-88-76, Jan. 13, 1988).

Aircraft Procurement: Status and Cost of Air Force Fighter Procurement (GAO/NSIAD-87-121, Apr. 14, 1987).

DOD Acquisition: Case Study of the Advanced Tactical Fighter Program (GAO/NSIAD-86-45S-12, Aug. 25, 1986).

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