Report of the Defense Science Board Task Force on Aircraft Assessment

February 1993

OFFICE OF THE UNDERSECRETARY OF DEFENSE FOR ACQUISITION
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DEFENSE SCIENCE
BOARD

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MEMORANDUM FOR DIRECTOR, DEFENSE RESEARCH AND ENGINEERING

SUBJECT: Report of the Defense Science Board Task Force on Aircraft Assessment

I am pleased to forward the report of the DSB Task Force on Aircraft Assessment.

The Task Force was convened to respond to the National Defense Authorization Act for Fiscal Year 1993, which directed a technical assessment of particular issues related to the DOD Tactical Aviation Modernization Program. As directed, our study focused on technical risks associated with three aircraft programs -- F-22, F/A-l8E/F and A/F-X; the advantages and disadvantages of prototyping the F/A-18E/F and competitively prototyping the A/F-X; and ways that aircraft can be adapted so that a single aircraft type can be used by both the Navy and the Air Force in parallel missions. The Task Force% findings are summarized on pages two through four of the report.

John Foster

John S. Foster, Jr.
Chairman

Attachment

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INTRODUCTION

Purpose

The Defense Science Board Task Force on Aircraft Assessment[1] was convened to respond to direction received from Congress in the National Defense Authorization Act for Fiscal Year 1993, (Public Law 102-484). The Authorization Act requested that the Defense Science Board address two issues that are related to the DOD Tactical Aviation Modernization Program. The two issues pertain to (1) potential common aircraft/avionics for use by the Navy and Air Force for parallel missions, and (2) technical risk assessments for the F-22, F/A-18E/F, and A/F-X aircraft. The terms of reference (TOR) for the Task Force from USD(A)/DDR&E expanded the issues to include consideration of the desirability of prototyping the F/A-18E/F and A/F-X aircraft.[2] The four issues the Task Force addressed are:

Issue 1: Assess the technical risks associated with the F-22, F/A-18E/F, and A/F-X.

Issue 2: Assess the advantages and disadvantages of prototyping the F/A-18E/F.

Issue 3: Assess the advantages and disadvantages of competitively prototyping the A/F-X.

Issue 4: Assess the ways that current aircraft, upgrades to current aircraft, and new design aircraft can be modified or otherwise adapted so that a single aircraft type can be used by both the Air Force and the Navy in parallel missions.

Task Force Approach

The Task Force first met on January 21; OSD requested the report be provided on February 25. During this time the Task Force met seven times. Briefings and information were received from the military services and OSD, and visits made to Lockheed Aircraft and McDonnell Aircraft to receive further briefings and information on the F-22 and F/A-18E/F programs.[3] The members also made use of other available reports.[4]

Issues 1, 2, and 3 are of more immediate concern. They are relevant to three specific programs, the F-22, F/A-18E/F, and A/F-X. Issue 4 is more general and was addressed in the context of longer-term trends in tactical aviation missions and force structure.

Considerable uncertainties exist in future aircraft acquisition planning. Radical changes in the international scene, and resulting reappraisals of strategy, mission, and force levels are under way. Because studies being conducted on roles and missions and on the affordability of combat aircraft forces had not been completed at the time of these assessments, the probable types and numbers of combat aircraft to be acquired over the next two decades could not adequately be factored into the Task Force's work

Program Descriptions

F-22 Program

The mission of the F-22 aircraft is theater air superiority. It is an essentially new aircraft that incorporates multiple advanced features, including low-observable characteristics in a highly maneuverable supersonic aircraft, supersonic cruise capability, two-dimensional vectoring engine

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1 The Task Force members are listed in Appendix A.

2 The congressional language is in Appendix B and the terms of reference are in Appendix C

3 The Task Force schedule is presented in Appendix D.

4 Those reports are listed in Appendix E.

nozzles, software-intensive integrated avionics, and an extensive use of composite and low-observable materials. The F-22 has been in Engineering and Manufacturing Development (E&MD) since August 1991. The advanced nature of the F-22 should be put into the context of the risk reduction achieved prior to E&MD start An extensive Demonstration and Validation (Dem/Val) program was performed with competitive flying prototypes of the airframe/engine configurations and avionics flying testbeds including brass board components.

F/A-l8 Program

The F/A-18E/F is a multi-role fighter/attack aircraft for the Navy. It has been in E&MD since May 1992. In contrast to the F-22, the F/A-18E/F is an evolutionary development based on the F/A-18C/D. The F/A-18E/F airframe is a scaled-up version of the F/A-18C/D with a new engine derived from the A-12 program and other recent engines. The avionics are planned to be almost a direct carry-over from the F/A-18C/D. Important performance goals are increases of 30 percent mission radius and 60 percent bring-back weight, and enhanced survivability including reduced signatures, relative to the F/A-18C/D.

A/F-X Program

The A/F-X is being designed as a multi-role attack/fighter aircraft for the Navy and a deep interdiction aircraft for the Air Force in response to a joint operational requirements document. The A/F-X is expected to have a new airframe configuration that incorporates advanced low-observable and associated materials technologies. The engine will be from a new generation of engines exemplified by significant improvements in thrust-to-weight ratio and operation at high levels of turbine inlet temperature. The aircraft's avionics suite is expected to draw heavily on the integrated avionics from the F-22 program. The A/F-X is being prepared to enter Dem/VaL

SUMMARY

Issue 1 Findings: Technical Risk Assessments

The Task Force reviewed the technical risks associated with the three tactical aircraft programs. Because technical risk cannot be entirely separated from schedule and cost risks, the Task Force also examined those aspects of the programs. Sources of cost risk that all programs are currently exposed to are the growth in overhead costs as a consequence of decreases in the business bases of the prime contractors and suppliers, reductions in planned production rates, and disruption of planned funding profiles for programs.

Both the F-22 and F/A-18E/F programs could become budget-driven rather than event-driven and may therefore encounter further difficulties. Funding of risk reduction efforts in E&MD must be maintained for the F-22 and F/A-18E/F aircraft programs if program milestones and technical risk reductions are to be achieved without undue increases in overall program risk A more detailed discussion of specific risk areas is included in the Discussion section.

F-22 Program

The Task Force views the area of highest technical risk in the F-22 program as the integrated avionics and its associated integration software. Other risk areas include low-observable materials and structures, engine durability, and weight and drag management, The Task Force believes that the critical risk areas have been clearly identified, are being addressed to the extent commensurate with their importance and are being adequately managed. Particular note is taken of the extensive avionics flying testbed program. The compounding of the technical challenges, potential adverse economic factors, and cost uncertainties, as described in the first paragraph of these findings, could pose serious risk to the program. The F-22 program was recently rescheduled for funding and other reasons. The first flight date was delayed 11 months. Further schedule delays at this time due to reduced E&MD funding are unlikely to reduce risks and will increase costs.

F/A-l8E/F Program

Risks are seen as relatively low in the F/A-18E/F program due to the evolutionary development nature of the aircraft, Risk areas include weight management, airframe materials, and the new larger engine that is an outgrowth of the A-12 engine. The F414 first-engine-to-test will be in May 1993. Again, the Task Force believes that the critical risk areas have been clearly identified, are being addressed to the extent commensurate with their importance, and are being adequately managed. As is the case with the F-22, the F/A-l 8 E/F first flight has recently been rescheduled, being extended by two months due to lower than planned appropriations. The previous discussion of schedule and cost risk implications of program delays due to funding reductions is equally relevant to the F/A-18E/F program.

A/F-X Program

Because the A/F-X program is still undergoing a design competition before Dem/Val, it is simply too early for the Task Force to make a technical risk assessment of the A/F-X aircraft. The A/F-X mission requirements for both the Navy and Air Force appear to be achievable, and the Navy is managing the program at this time to ensure adequate performance margins, including carrier suitability. Tradeoffs of cost, performance, and other requirements have been important elements of the current phase of the program Once prototype designs are submitted, a meaningful assessment of the A/F-X aircraft's technical risk can be made. The planned Dem/Val program appears to be structured to accommodate a substantial risk reduction effort

Issue 2 Findings: Prototyping the F/A-18E/F

The Task Force could not find any basis for prototyping the F/A-18E/F aircraft. The F/A-18E/F is not a high-risk program in terms of concept, design, performance or operational suitability. In many ways the F/A-18C/D can be considered a prototype of the F/A-18E/F. The aerodynamic and structural concepts for the F/A-18E/F are essentially the same as those of the F/A-l8C/D. Aerodynamic and other design models and tools used in the F/A-l 8E/F program have been calibrated and validated using data from earlier WA-18 flight testing. This has provided information of the kind that would be available from a flying prototype. Technical risks remaining in the program (e.g.. weight) can only be confronted in the E&MD program with E&MD-designed hardware including flight-test articles. E&MD flight testing using the first two flight-test articles can provide sufficient information to assess important performance parameters prior to large production funding commitments. The additional costs (in time and money) of disrupting the E&MD program and building additional flying prototypes far outweigh the value of any potential risk reductions.

Issue 3 Findings: Prototyping the A/F-X

Current A/F-X requirements call for a level of &sign innovation that justifies a flying prototype before the start of E&MD. The A/F-X program is planned to follow an acquisition strategy for competitive prototyping of the aircraft during Dem/Val. If the design competition leading to Dem/Val provides a clear winner, then a single design could be prototyped. Because the A/F-X is likely to employ avionics concepts and common equipment from the F-22 program, avionics prototype testing in a flying testbed may be required only for selected components, systems integration and software.

Issue 4 Findings: Common Aircraft/Avionics Programs

Aircraft used by more than one service can result in lower development, production and support costs. Multi-role aircraft within a service achieve the same ends. The components of an aircraft system (airframe, engine, and avionics) may also be modified to adapt to a new mission or to modernize the system. For example, avionics, which in recent years have on average been modernized within a 10- to 15-year cycle, may account for up to one-third of a fighter/attack aircraft's system acquisition costs. The measures of merit to use in deciding whether to design a new aircraft (or modify an existing aircraft) for multi-role or multi-service applications should be mission effectiveness and life-cycle cost of the force.

Factors that affect these decisions include (1) mission assignments of force elements within the operational force structure, (2) size and composition of forces required to meet national strategies and objectives in the face of anticipated threats, (3) timing and phasing of aircraft programs, and (4) the current trend toward longer operational life of aircraft, including upgrades.

In spite of the potential advantages of common aircraft, each service has had compelling reasons to acquire some aircraft with characteristics primarily designed for its most demanding missions, with minimum compromise for multi-role or multi-service use. Navy aircraft must be carrier-suitable and the requisite structural and aerodynamic features must be part of the design from the beginning. Although these features impose weight, performance, and cost penalties over a similar aircraft designed for land operation only, historically, variations in ship and land-based versions have led to workable solutions for near-common missions.

The economic dimension to acquisition decisions is enlarged upon in the subsequent discussions. In the future, the greater economic constraints and lower rates and quantities of combat aircraft to be acquired will tend to make the use of common aircraft and/or component subsystems more attractive than it has been in the past, although this may require some compromise in mission capabilities.

Although the A/F-X is still in an early stage of development, the Navy and Air Force are succeeding in arriving at a high degree of compatibility in the aircraft characteristics to meet their respective mission requirements. It is also planned that this aircraft will incorporate avionics having a substantial degree of commonality with the F-22.

The multi-role F/A-18E/F is planned for acquisition by the Navy only. Although geometrically similar in configuration to the F/A-18C/D, the F/A-18E/F has a larger airframe and engine and is linked to the F/A-18C/D mainly by common avionics. The F/A-18E/F could be employed by the Air Force for operation from land bases. However, it is substantially heavier and more costly than the aircraft the Air Force envisions as a replacement for its multi-role fighter/attack aircraft (currently the F-16). A new multi-role fighter/attack aircraft is not expected to be required to become operational for perhaps 20 years. The Air Force, however, has proposed that the Navy join it in examining the possibility of a joint program to acquire such an aircraft, the Multi-Role Fighter (MRF) in this longer time frame.

DISCUSSION

Technical Risk Assessments

The Task Force was asked to assess the technical risks of the F-22, F/A-18E/F, and A/F-X aircraft programs. Technical risk is a subjective assessment regarding the likelihood or probability of not achieving a specific objective by the time established and with the resources provided or requested. It is also usually a relative assessment in that one program can be viewed as lower or higher risk than another. Since it is difficult to completely separate technical risk from schedule and cost risks, the Task Force also considered those aspects of the programs to the extent that they might have significant impact on technical risks. For instance, sources of cost risk that all programs are currently exposed to are the growth in overhead costs as a consequence of decreases in the business bases of the prime contractors and suppliers, reductions in planned production rates, and disruption of planned funding profiles for programs.

The F-22 incorporates revolutionary advances in airframe, low-observable technology, maneuverability, engines, materials, and integrated avionics systems. The F/A-18E/F, on the other hand, is an evolutionary development of a scaled-up F/A-18C/D multi-role fighter/attack aircraft While the overall airframe structure is almost completely new, the aerodynamic performance is relatively well-understood because of extrapolation from the performance of the F/A-18C/D design. Also, avionics is the same as on the F/A-18C/D. and the F414 engine, although a new design, is derived from earlier engines, primarily the F412 designed for the A-12.

A great deal of risk reduction had already taken place in both the F/A-18E/F and F-22 programs before their respective E&MD starts. The F-22 E&MD was preceded by an extensive Dem/Val program specifically designed to prototype the highest risk technical areas with competitive ground and flying prototypes of the airframes, engines, and avionics (including flying test beds). The F/A-18E/F benefits from the application of F/A-18C/D experience, wind-tunnel testing, and engine component testing. The following subsections contain comments on each program concerning challenges that have been revealed during E&MD. Also noted are the schedule and cost risk impacts of program changes which have affected both developments.

The Task Force believes it is too early to make a technical risk assessment of the A/F-X aircraft because the design concept is not firm. However, it is not too early to comment on the relative technical ambition of the A/F-X program implied by its mission requirements.

F-22 Program

The F-22 E&MD program has experienced difficulties typical of aircraft programs in E&MD. Airframe design refinements have had negative impacts on weight and drag. In particular, "bumps" resulting from the repackaging of internal systems have caused increased drag. However, there is still margin in currently estimated levels of weight and drag to meet the System Operational Requirement Document (SORD) and Approved Program Baseline (APB) performance goals. Lockheed Aircraft has identified areas for additional fuel tankage as a hedge against possible increases in weight, drag and specific fuel consumption (SFC) at mission design points.

The F119 engine began ground testing in December 1992. Difficulties revealed in ground testing included performance shortfalls in the fan and turbine and high stresses in the second fan blade and low-pressure turbine blade. Lower-than-expected fan efficiency presents a risk in meeting subsonic SFC specifications. However, with identified planned improvements for several components, SFC is predicted to surpass specifications. Overall engine weight is below specification, but the nozzle is above its allocation; because of the nozzle's aft location, this may have implications for the aircraft's center of gravity (CG). The new materials technology associated with the nozzle may present durability problems.

The highest technical risk in the F-22 program stems from a new concept in aircraft avionics - a highly integrated avionics functionality expected to reduce pilot workload substantially and provide the pilot with unprecedented situation awareness. During the Dem/Val phase of this program, algorithms for data fusion and software development were examined, and a flying testbed was used to reduce the risk for some elements of the avionics. During E&MD a new computer processor is being designed, considerable software will be written and ground tested, and avionics system and software integration will be accomplished on the flying testbed before integration into the F-22 aircraft. The newness of the concept (compared to the avionics architecture of what is flying now) and the extensiveness of the integration represent a technical risk that warrants continuing aggressive management attention.

Low-observable and other new composite materials present another area of risk, as is the case in most advanced low observable aircraft. The radar radome, which is part of the aircraft's integrated forebody, requires relatively risky materials/manufacturing concepts that deal with the offsetting requirements of radar detection range, aerodynamic performance, and radar cross-section.

The F-22 program was recently rescheduled due to funding shortages. The rescheduling resulted in an 1l-month delay in the first flight date (to 59 months from E&MD start, twice as long as average recent experience) and an 18-month delay in the planned Milestone III date. These delays should not be misconstrued as further reducing risks since resource shortages are not allowing known technical risks to be attacked as soon and as aggressively as they could be. An important exception is in the area of software and processing, where the contractor has maintained the original schedule and staffing plans.

Because certain fixed costs are associated with development programs over their duration, the schedule expansion will probably result in increased E&MD program costs. As in other current programs, additional decreases in the business base of F-22 contractors due to the cancellation or extension of other programs would result in additional cost risk, such a decrease could adversely impact overhead burdens on the F-22 program.

F/A-18E/F Program

The F/A-18E/F has experienced typical development difficulties. The most serious technical problem encountered is a shortfall in predicted maneuver performance at high angles of attack This shortfall was discovered in wind-tunnel testing in June 1992. The problem has been addressed through redesigned fuselage leading edge extensions (LEX) and attendant modification to other affected parts of the aircraft. Unfortunately, a weight penalty of about 250 pounds is associated with the new design; this represents a considerable portion of the 450-pound E&MD (pre-first flight) margin for empty weight. Although avionics software is a low-risk area for the F/A-18E/F program (because most of it is carried over from the F/A-18C/D), software growth of approximately 15 percent has already been experienced in the combined F/A-18C/D and F/A-18E/F effort Low-observable and other somewhat new composite materials present another area of risk.

Component testing is well underway in the engine program for the F/A-18E/F. The first F414 engine to test is scheduled for May 1993. Testing to date indicates that thrust and SFC performance should be met. One problem that emerged during testing was a shortfall in predicted fracture mechanics life of the stage-one disk This problem can be addressed through shortened inspection intervals (1,000 flight-hours versus the specification of 2,000 flight-hours) or through design changes with small weight penalties.

The previous discussion of schedule and cost risk implications of program changes for the F-22 is equally relevant to the F/A-18E/F program. The F/A-18E/F's first flight date has only been stretched-out two months so far during E&MD from 42 months to 44 months. Additional program changes due to insufficient funding could increase program risks.

A/ F-XProgram

Because the A/F-X program is still undergoing a design competition before Dem/Val, it is simply too early for the Task Force to make a technical risk assessment of the A/F-X aircraft. The A/F-X mission requirements for both the Air Force and Navy appear to be reasonable and achievable, and the Navy is managing the program at this time to ensure adequate performance margins, including carrier suitability. Tradeoffs of cost, performance, and other requirements have been important elements of the current phase of the program. Once prototype designs become firm, a meaningful assessment of the A/F-X aircraft's technical risk can be made. However, the planned Dem/Val program including prototype flight tests appears to be structured to accommodate a substantial risk reduction effort

Summary

The Task Force considers the F-22 to have higher technical risk than the F/A-18E/F. It is the judgment of the Task Force that the F-22's and F-18E/F's critical risk areas have been clearly identified, are being addressed to the extent commensurate with their importance and are being adequately managed. There is a danger that both the F-22 and F/A-18E/F programs may become budget-driven rather than event-driven and may thereby encounter further difficulties. Full funding of E&MD for the F-22 and F/A-18E/F aircraft programs is required if program milestones and technical risk reductions are to be achieved.

Common Aircraft/Avionics

Multiple applications of aircraft/avionics and other major components ate fundamentally related to cost-savings or affordability issues but the effect of such a strategy on the effectiveness of the force structure relative to other options must be carefully weighed. Key factors affecting cost-effective choices of aircraft systems include:

- mission assignments of force elements within the operational force structure,
- size and composition of forces required to meet national strategies and objectives in the face of anticipated threats,
- timing and phasing of aircraft programs, and
- the current trend toward longer operational lives of aircraft, including upgrades.

With the radical changes taking place in the international community, and the reappraisals of force levels and compositions in light of these changes, the studies of roles and missions and of affordability of aircraft force structures under way will have a major effect on the types and numbers of aircraft to be acquired over the next several decades.

Common Aircraft and Parallel Missions

The use of common aircraft has two dimensions-the use of common aircraft for parallel missions across military services and the use of common aircraft within a service for multiple missions. Both uses can reduce overall development, production, and support costs. Aircraft may be adapted or designed in several versions from the outset to perform multiple missions within a service or parallel missions across services. The measures of merit to use in deciding whether to design a new aircraft (or modify an existing aircraft) for multi-role or multi-service applications should be mission effectiveness and life-cycle cost of the force.

Critical mission requirements and design considerations can dictate whether a particular aircraft has the potential for other missions within a service or similar missions across services. The services' experience has been that some, but not all missions demand aircraft whose design is strongly focused on a single mission with minimum multi-role compromise. The two most notable examples are theater-level air superiority (dominating airspace over hostile territory and over friendly territory) and deep strike. In both cases, life-cycle cost must consider outside support required to perform the mission effectively-air refueling, defense suppression, escort, airborne surveillance support, and overhead support. Since both missions must be performed deep in hostile territory, outside support can be difficult and costly to achieve and may result in high attrition in supporting forces.

The specialized aircraft that fulfill the most demanding missions (e.g., theater air-superiority and autonomous deep strike) make up the high end of the force mix. Multi-role and multi-service aircraft have been successfully employed in the less-demanding aspects of both air-to-air and air-to-ground missions; these aircraft constitute the low-end of the force mix. Within their own domains (i.e., air-to-air or air-to-ground), the high-end aircraft could fulfill most of the less-demanding missions. However, because low-end multi-role aircraft have historically cost half as much as high-end aircraft (e.g., F-16 vis-a-vis F-15). they have provided a much more affordable means of providing an adequate force structure.

Modern aircraft designed for the air superiority role have been successfully adapted to the air-to-ground mission to include part of the deep-strike mission. The high thrust-to-weight ratio and low to moderate wing-loading characteristics of an air superiority design provide the ability to carry significant ordnance loads while preserving the maneuvering performance needed to enhance survivability. The avionics suite needed for a modem air superiority aircraft provides flexibility to adapt to air-to-ground demands. Both the Navy and the Air Force adapted the F-4, originally designed as the Navy's primary air warfare aircraft to an air-to-ground role. However, the reverse is not true: deep strike or attack optimized aircraft cannot be modified to an air superiority/air warfare role.

Similarly, naval aircraft must be designed first and foremost to be suitable for aircraft carrier operations. The requisite structural and aerodynamic features must be part of the design from the beginning. These features impose weight, performance and cost penalties over similar aircraft designed for land operations only. Carrier-suitable Navy aircraft have been successfully used by the Air Force in the middle range of mission demands (the F-4 and A-7 are notable examples), but there are no examples of Air Force aircraft being modified to Navy carrier-suitable missions.

The most unsuccessful common use attempt was the effort to field a truly common, multi-role, multi-service aircraft, the F-111 program, which attempted to span too large a range of disparate missions. In the end, the aircraft was considered unsuitable for both Navy carrier operations and Air Force multi-role operations. After extensive and costly modification, the aircraft became the most capable deep-strike aircraft. In the end, the common, multi-role design became the Air Force's most specialized, single service, single-role aircraft fulfilling what was the original Air Force mission requirement for the F-111A (although it was later modified again to the EF-111).

Another trend of importance has been a significantly extended useful operational life for fighter aircraft. Up to the 1970s. fighter aircraft tended to become obsolete in their primary design mission in five to ten years. In contrast, the F-15 and F-14 have served as the Air Force and Navy primary air superiority/air warfare aircraft for almost twenty years and must continue to serve that role for at least another ten years. The F-22 will then assume that role for the Air Force. The previous plan was for a naval variant, the NATF, designed for carrier operations, with common engines, avionics, and low-observable and airframe technology, to serve the Navy's future high-end air superiority needs. The A/F-X is currently planned to complement the F/A-18E/F in the Navy's air warfare missions.

Table 1 presents past, present and future Navy/Marine Corps and Air Force tactical aircraft and possible future options of upgrades and new designs as they relate to missions. In the 1970s, there were approximately two dozen aircraft types in this matrix; now there are about one dozen. As the table indicates, possible future options might result in further reductions in type, although such reductions should not be judged on the basis of commonality alone. Compromises are made in mission effectiveness to achieve aircraft/avionics commonality.

Table 1. Aircraft-Mission Match

Mission	1970s	1990s	2020s	
			Modern	Aging
Theater Air Superiority				
Air Force	F-15, F-102, F-104, F-106, F-101B	F-15A/C	F-22	F-15C ?
Battle Group Air Superiority				
Navy/Marine	F-14, F-4, F-8	F-14A/D	F/A-18E/F A/F-X	F-14 ?
Strike/Attack				
Air Force	F-111, F-100, F-105, A-7, A-10	F-15E, F-117, F-l 11, A-10	A/F-X	F-15E, F-117
Navy/Marine	A-6, A-4, A-7, AV-8A	A-6, AV-8B	A/F-X	
Multi-Role				
Air Force	F-4	F-16A/C	MRF	F-16C ?
Navy/Marine	F-4	F/A-18A/C	F/A-18E	FA/-18C ?

Equally important with the application of common aircraft, the application of common aircraft components provides opportunities for life-cycle cost savings. Major components (engines, airframes, avionics, and weapons) may be integrated in differing overall system configurations. For tactical fighter/attack aircraft, engine Research, Development, Test and Evaluation (RDT&E) and unit flyaway costs may account for 15-20 percent of total vehicle system cost, with avionics typically accounting for 25-35 percent. Thus, it is possible that up to 50 percent of vehicle system RDT&E and flyaway costs may be based on common component development and production even with differing airframe configurations. There are many examples of successful common component applications, particularly a long history of multiple engine applications going back to the first generation of J33 and J35 turbojets. The TF-30 engine was used in the F-l11, A-7 and F-14A. More recently, the F100 engine was used on models of the F-15 and F-16 aircraft, and the F110 engine, on models of the F-16 and F-14 aircraft. Numerous similar examples exist for electronics/avionics equipment.

Possible Common Aircraft/Avionics Options

The cost-effectiveness of using common aircraft/avionics for a specific application will depend upon the degree to which costs savings and other commonality advantages are offset by the disadvantages inherent in commonality.

Program managers, if given the choice between off-the-shelf or new common aircraft equipment will usually make a decision from a program perspective and not the full life-cycle view of the system user or the overall DOD budget impact. It is essential that the technical “price” of using common items be carefully evaluated in relation to the full life-cycle cost savings implications. The ability of common items to ease system integration, reuse software, avoid development duplication, lower production cost, and reduce support cost must be fully weighed against the inefficiencies (lower performance, higher weight, etc.) that may be introduced by using common items. Table 2 lists some advantages and disadvantages of aircraft/avionics commonality.

Table 2. Advantages and Disadvantages of Aircraft/Avionics Commonality

Advantages	Disadvantages
• Decreased development cost and technical risk through reduction in systems, subsystems or components that must be developed - Decreased production costs through economies of scale -Decreased operating and support costs by reduced spares costs and test equipment needs • Reduced avionics software and integration costs and technical risks through use of standard interfaces and protocols provided by common modules and by increased software reuse - R&D technology base funds can be better focused on critical technology issues by the reduction of duplication of systems/subsystems across services	- Aircraft/avionics mission performance, weight, and volume will be less than optium for a given application • Military application of technology may not advance as [illegible] apidly - Administrative burden to achieve an effective common equipment program across weapon platforms and across services may be significant • Some loss of industrial infrastructure may occur with fewer suppliers • Specific problems in design, manufacture, and operation can affect more programs •Cross-service logistic infrastructure requirement may increase costs

The area of avionics needs careful examination with regard to upgrades of existing systems in the future. Electronics technologies can provide a common integrated architecture and allow commonality at the module level while still achieving technology advances in selected modules through pre-planned product improvements. Such a standard architecture has been defined by the Joint Integrated Avionics Working Group (JIAWG). Within-platform avionics commonality is more readily achieved, as exemplified by the wide application of JIAWG common modules within the F-22, because it is generally consistent with the contractor and government program managers' objectives. Across-program commonality (such as applying F-22 avionics modules to the A/F-X) is more difficult because it requires coordination across program offices and makes the following program dependent on subsystems and technology that may be viewed as obsolescent and less subject to control by the program manager.

The potential for the cost-effective application of almost identical aircraft and components for a variety of missions and in varying environments depends in large measure on how dissimilar the missions the aircraft is intended to perform are. Also important is the degree of overlap or complementarity of other aircraft types included in the overall force structure in which the specific aircraft is to be included. Major factors influencing costs are the numbers to be produced for each mission category or service environment and the timing and phasing of programs. If small numbers of aircraft are to be produced for each mission or service, then the relative advantage from RDT&E costs in common will offset to a considerable extent the potentially higher unit costs ("technical price" and non-optimized unit cost) of a single aircraft system or component to perform well in multiple missions and multiple environments. Another important factor is the phasing of force modernization across the services and mission areas. Although a new aircraft design may have the potential for application across missions or services, there may be no near-term need for a new aircraft in more than one application

The Task Force has identified several possible future options for common aircraft in both the high and low ends of the aircraft performance spectrum, for subsystem upgrades to current aircraft, and for new design aircraft, although most of the options do not reflect current requirements or planned acquisitions of this service

- For Upgrades to Current Aircraft:
  - Navy F/A-18E/F upgraded with modernized avionics for future Air Force multi-role fighter (air superiority and ground attack) for the low end of the force mix.

- Air Force growth F-16 upgraded with modernized avionics for Air Force multi-role fighter for the low md of the force mix.

- For New Aircraft:
  - A/F-X for the Navy and Air Force high end of the force mix to serve as the future ground attack and interdiction aircraft In its multi-role Navy version it would also serve as the Navy's future air warfare aircraft. The Navy and Air Force are working jointly on this Navy-led program. The A/F-X avionics can be derived from F-22 JIAWG-type avionics.
  - Multi-Role Fighter (MRF) is being considered for the low end of the Air Force tactical air force mix for both air superiority and ground attack The MRF program is intended to start toward the end of this decade or beginning of the next decade. It could also serve the Navy as a replacement for the F/A-18 if designed from the outset for carrier suitability. (Airframes might differ to a considerable degree but this is not a given, however. Both services could use the same engine and avionics).
  - F-22 upgrade to perform the Air Force high end of the tactical aviation ground attack role (similar to F-15E upgrade from F-15C) and/or F-22 avionics upgrade to perform an electronic combat role.

The current common-use aircraft program, the A/F-X seems reasonably well on track. Although both services seem committed to a common-use design, it is far too early in the program to make judgments about the outcome. Both services will clearly need a follow-on deep strike aircraft to replace the aging A-6 and F-l11 and eventually the F-l17 and F-15E.

That leaves the possibility of a multi-role common-use design as a follow-on to the F-16 and F/A-18. Again, it is far too early to make judgments about the prospects but past experience gives some indicators of the prerequisites for, and likelihood of success. If, as is likely and prudent, the requirement includes advanced low-observable characteristics, the follow-on would need to be a very significant departure from either aircraft. At the same time, the follow-on needs to be significantly lower in cost (nominally half) than the F-22 or the A/F-X to provide an affordable force. Given that aggregate force mission effectiveness and life-cycle cost are the relevant measures of merit, the development cost savings from common aircraft use may not be sufficient when measured against total force life-cycle cost and mission effectiveness considerations. It is too early to make decisions about commonality and effectiveness tradeoffs, prior to a design competition of competing concepts.

Prototyping

A common definition of a prototype as a representative working model used (1) to reduce technical risks in a new system or subsystem, (2) to answer design questions to some degree, and (3) to provide necessary confidence before moving to the next phase of a system acquisition with better technical, schedule, and cost information and estimates for the system.

Both ground and flight prototype testing in the Dem/Val Phase reduce the technical risk of a program, thereby reducing the schedule and cost risks in proceeding to E&MD (and production). Prototyping does not eliminate technical, schedule, and cost risk-that is why there is an E&MD. Prototypes cost money and take time-sometimes they are justified and sometimes not, depending on the degree of technical advance sought in a system or subsystem, the nature of the technical risks and the costs of risk reduction at various stages of an E&MD program.

Flying prototypes may fulfill a number of requirements in a development program and provide data in a variety of ways to reduce technical risks, as listed in Table 3.

Table 3. Flying Prototypes Provide Data to Reduce Technical Risk

Characteristic	Flying Aircraft	Engines	Avionics Testbed
Aerodynamic Performance	Substantial	Substantial	N/A
Weight Data	Limited	Limited	Limited
Flight Control Functions	Substantial (FBW)[a]	Substantial (FADEC)[b]	N/A
Avionics Functions	Limited	Limited	Substantial
Engine Performance	Substantial	Substantial	N/A
Signature	Possible/Substantial	Possible/Substantial[c]	Possible
Airframe Integration			
Structure	Some[c]	Some[c]	N/A
System	Some	Some	N/A
Durability	Limited	Limited	Limited
Producibility	Some	Some	Some
Software	Some	Some	Some

a FBW stands for fly-by-wire.

b FADEC stands for full authority digital engine control.

c Limited in recent prototypes

d Boilerplate structure often used.

In some cases, prototypes may demonstrate and validate certain system performance and mission capabilities or indicate their deficiencies early enough to permit design revisions before large expenditures are committed to E&MD. However, the more complete and representative of the final production system the prototypes are to be, the more of the total detailed design and preflight development and integration effort (including extensive ground testing of components) must be completed before prototype construction and the greater the cost incurred. Carried to the limits of completeness and verisimilitude, a prototype can be essentially equivalent to the flight test aircraft in the E&MD program.

Pre-E&MD prototypes in the recent past (the YF-16, YF-17, and YF-22) have not been complete system prototypes but rather have been bare air vehicles. They have served to verify aerodynamic and flight control characteristics, and airframe-engine interactions affecting flight vehicle performance and operation. They did not demonstrate or validate mission avionics and weapons-delivery capabilities, nor, for the most part, did they validate the structural integrity or weight of the final production aircraft since their structures were not completely representative nor was there sufficient intensity and repetition of loading of the airframe to establish long-term durability and fatigue life of the aircraft. Ground tests typically carried out as part of an E&MD program provide the only development tools available for establishing long-term structural integrity of the airframe and durability of the engine before accumulating thousands of hours on operational aircraft. Pre-E&MD prototype vehicles whose aerodynamic configuration and flight control characteristics are very similar to the final aircraft can validate, and may in some cases modify and improve the accuracy of magnitude and distribution of flight loading (steady, vibratory, acoustic, and transient) to which the structure must be designed. Also, aerodynamic interactions of the airframe and engines can be assessed with greater accuracy than provided by wind-tunnel and ground engine test cells. The likelihood that these characteristics will be significantly different in prototype flight test from those derived from engineering analyses, wind-tunnel, and ground test depends on the degree to which airframe and engine depart from prior recent design configuration and operating regime experience.

Prototyping of various systems and subsystems may be considered for reasons other than technical risk reduction. These include permitting preliminary testing or demonstration of operational utilization and in some cases obtaining technical information needed in development (e.g., qualification testing) earlier and at lower cost than by alternative means. There are also reasons why pre-E&MD flight prototyping may not be desirable, particularly when technical risk is relatively small and time and money is better used in the E&MD program addressing the overall development process. Table 4 summarizes advantages and disadvantages of flight test prototyping.

Table 4. Advantages and Disadvantages of Flight Test Prototyping

Advantages	Disadvantages
• Reduces technical risk in testbed features - Provides better technical, schedule, and cost information and estimates of testbed features - Allows joint ventures and design and management teams to work together early in the program - Can provide data on flight envelope uot available from wind-tunnel tests (aerodynamic and engine performance, flight controls, airframe/engine interface).	- Up-front investment can be substantial - Schedule to Initial Operational Capability (IOC) can be longer - Slows momentum of program - Flight data may not significantly alter wind-tunnel and engine ground test characteristics for conventional desgns - Final E&MD design may differ substantially • Critical structural aud other life-cycle characteristics of aircraft and engine not validated by prototype flight tests

Whether competitive prototypes (which, unless substantial contractor financial participation is forthcoming, are more costly) should be used may be more an issue of acquisition strategy in a particular program than a question of technical risk reduction. On the other hand, it may be both necessary and desirable to pursue evaluation of competitive prototypes as an important element of an acquisition program, particularly if they embody significant departures from recent design experience and also differ substantially from one another. Table 5 summarizes advantages and disadvantages of competitive prototyping of flight vehicles.

Table 5. Advantages and Disadvantages of Competitive Flight Prototyping

Advantages	Disadvantages
• Expands the choices for the government; could result in better product. (best of two versus best of one) • Product could be less expensive • Contributes to industrial base maintenance - Encourages "best efforts"[a] by contractor teams • Increases chances of solving key problems.	- Increases development cost - Increases length of schedule • Government/contractor interaction less focused • Requirements growth harder to control • May detract from more critical risk reduction efforts on critical subsystems in ground tests aud simulations.

a F-22 was result of extraordinary effort by Lockheed late in the program. Without YF-23 competitive pressure, YF-22 prototype program would likely have accomplished considerably less. However, this competition was conducted under fixed price contracts and involved considerable contractor funding of the effort.

Lessons From Recent Prototyping Experience

When significantly new versions of airframe and fight control system configurations are to be developed, pre-E&MD prototypes serve as a powerful tool for risk reduction. However, for aircraft systems similar to already flown and operational airframe and control configurations and subsystem characteristics using existing engines or derivatives or modest incremental modifications of such engines, the benefits of pre-E&MD prototypes may not always justify the price in cost and schedule delay (which can also translate into cost). Thus, for example, there was no pre-E&MD prototype for the F-15 and little indication that such a prototype would have served a useful purpose. Most of the development and operational problems encountered with the F-15 would not have been revealed during test of a pre-E&MD prototype. (The F100 engine for the F-15 was a significant step in engine technology and had a competitive ground test prototype program before full-scale development).

On the other hand, the F-16 embodied radically new aircraft stability interactions with electronic flight control (fly-by-wire) in combination with novel aerodynamic configuration features. Clearly the F-16 could be said to require a prototype test. Similarly, the F-22 represented a pioneering effort to integrate low-observable characteristics into a supersonic and highly maneuverable airframe configuration, and incorporated a number of aerodynamic and engine integration features outside the realm of previous aircraft design experience. Again, prototype flight testing was a prudent step in the development. The point is that air vehicle prototypes are not uniformly cost-effective as risk reduction tools in a development program. Their relative value depends on the degree to which the airframe configuration and engine installation features depart fiom the domain of recent experience.

Within the context of this knowledge, the Task Force examined possible prototyping strategies for the F/A-18E/F and the A/F-X.

Prototyping the F/A-18E/F

The Task Force could not find any basis for introducing flight vehicle prototype into the F/A-18E/F aircraft at the present stage of its E&MD program. The F/A-18E/F is not a high-risk program in terms of concept, design, performance or operational suitability. In many ways the F/A-18C/D can be considered a prototype of the F/A-18E/F. The aerodynamic and structural concepts for the F/A-18E/F are essentially the same as those of the F/A-18C/D. Aerodynamic and other design models and tools used in the F/A-18E/F program have been calibrated and validated using data from earlier F/A-18 flight testing 'Ibis has provided information of the kind that would be available from a flying prototype. Technical risks remaining in the program (e.g., weight) can only be confronted in the E&MD program with E&MD flight-test articles. The additional costs (in time and money) of disrupting the E&MD program and building early flying prototypes far outweigh the value of any potential risk reductions.

Milestones and exit criteria within the F/A-18E/F's E&MD phase can serve as necessary control points for committing large amounts of funding to production and significant production quantities. The Navy Program Review-l (NPR-1) is the first program milestone associated with the commitment of long-lead production funding. The Navy plans to have completed an early operational assessment of the aircraft design based in part on flight performance of the first two E&MD aircraft prior to NPR-1. While some schedule adjustments may be needed to NPR-1 to accomplish this, the program phasing should continue to allow for sufficient evaluation of flight test and other data to provide sufficient confidence in the aircraft design and mission performance prior to commitment to production funding.

Prototyping the A/F-X

Current A/F-X requirements call for a level of &sign innovation that justifies a flying prototype before the start of E&MD. The A/F-X program is planned to follow an acquisition strategy that could accommodate competitive prototyping of the airframe and engine during Dem/Val. If the design competition leading to Dem/Val provides a clear winner, then only a single design might be prototyped. Because the A/F-X is likely to employ avionics concepts and common equipment from the F-22 program, avionics prototype testing in a flying testbed may be required only for selected components, systems integration and software.

APPENDIX A
TASK FORCE MEMBERS

DEFENSE SCIENCE BOARD TASK FORCE ON AIRCRAFT ASSESSMENT

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Dr. Alexander Flax, Co-chair,
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Mr. Brian Long
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Mr. Paul Scheurich
Defense Intelligence Agency

APPENDIX B
EXCERPT FROM THE NATIONAL DEFENSE AUTHORIZATION ACT

CONGRESSIONAL LANGUAGE

Defense Authorization Act for Fiscal Year 1993

(PL 102-484)

Section 902 Tactical Aircraft Modernization Programs.

(a) Funding Limitation Pending Certain Actions-

. . . .

(3) The Secretary of Defense has submitted to the congressional defense committees the technical assessments of the Defense Science Board that are specified in subsection (d.)

(b) Applicability-Subsection (a) applies to the following tactical aircraft programs:

(1) The F-22 Advanced Tactical Fighter (ATF) program of the Air Force.

(2) The F/A-18E/F fighter program of the Navy

(3) The A-X medium attack aircraft program of the Navy.

. . . .

(d) DSB Technical Assessment.-The technical assessments to be undertaken by the Defense Science Board for purposes of subsection (a)(3) are the following:

(1) An assessment of the ways that current aircraft, upgrades to current aircraft, and new design aircraft can be modified or otherwise adapted so that a single aircraft type can be used by both the Air Force and the Navy in parallel missions.

(2) An assessment of the technical risks associated with the three tactical aircraft specified in subsection (b.)

APPENDIX C
TERMS OF REFERENCE

DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

WASHINGTON, DC 20301-3010

5 JAN 1993

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference -- Defense Science Board Task Force on Aircraft Assessment

Section 902(d) of the National Defense Authorization Act for Fiscal Year 1993, Public Law Number 102-484, provides as follows:

> " (d) DSB Technical Assessment.- The technical assessments to be undertaken by the Defense Science Board for the purposes of subsection (a)(3) are the following:
>
> (1) An assessment of the ways that current aircraft, upgrades to current aircraft, and new design aircraft can be modified or otherwise adapted so that a single aircraft type can be used by both the Air Force and the Navy in parallel missions.
>
> (2) An assessment of the technical risks associated with the three tactical aircraft in subsection (b)."

Additionally, page 210 of the Senate report on the Department of Defense Appropriation Bill, 1993, Report 102-408, requests that the Department provide:

> " (d) the results of an examination of the advantages and disadvantages, especially in terms of program cost, schedule, and technical risks, of prototyping the F-18E/F and of competitive prototyping of AX: this examination must be conducted by an independent organization in no way connected with the Navy;"

I request you organize a Defense Science Board Task Force to conduct these technical assessments. Copies of the appropriate sections of the Public Law and report language are attached.

The scope of the Task Force effort should include the following considerations:

1. <u>AX, F-22, & F/A-18E/F:</u> The DSB shall examine the programs, plans, schedules, funding, and the maturity of the level of technology associated with AX, F-22, and F/A-18E/F programs and assess their feasibility of meeting their stated technical and programmatic objectives. AX and F/A-18E/F COEA and AX Development Options Studies will be briefed by the Navy as part of the review of the requirements. Level of technology

for stealth, avionics & sensors, airframe, and engine features will be viewed in terms of meeting schedules, costs, and requirements. Competitive prototyping on A-X and prototyping of the F/A-18E/F will be assessed to determine its impact on risk reduction with regard to potential cost implications.

2. Current Aircraft: The Navy and Air Force will brief the DSB on Pre-Planned Product Improvement (P3I) and major Engineering Change Proposals (ECPs) planned for current tactical attack/fighter aircraft. Included for current aircraft will be the F-15, F-16, AV-8B, F-14, F-117, F-111, A-10, A-6, and F/A-18 aircraft. Some upgrades/modifications will include new or improved avionics and engines. The DSB will assess the technical merits of further modifying these aircraft to meet other service needs, the attained risks, and the overall feasibility and desirability of such commonality. In performing tasks 1 and 2 above, the DSB will consider the current and projected threat; the current and projected force structure along with aircraft and missions as indicated by the Joint Staff report. The DSB will report whether the technology and potential threats warrant any reconsideration of the aircraft missions in light of potential cost savings and/or enhanced warfighting capability, afforded by new technology.

In order to meet the requirements of section 902 (a), the DSB should submit its final report by February 24, 1993. The report should be so constructed that it can be submitted to congress without compromising any proprietary data or competition sensitive information.

The Director, Tactical Systems will sponsor this Task Force. Dr. John S. Foster, Jr. and Dr. Alexander Flax will serve as Co-Chairmen. CAPT Eric Vanderpoel, USN will be the Executive Secretary and CDR Stephen N. Wiley, USN will be the DSB Secretariat representative. The Director, Tactical Systems will make arrangements and provide funding for a support contractor, should one be required, and will fund all necessary travel.

Victor H. Reis

Attachments

APPENDIX D
TASK FORCE SCHEDULE

TASK FORCESCHEDULE

21 January 1993 Institute for Defense Analyses, Alexandria, VA

0830	Kick-off - Dr. Foster
0830-0845	Standards of conduct Brief - Mr. Cal Voss
08450915	Executive Session - Led by Dr. Foster
09150930	Terms of Reference - Mr. Frank Kendall
0930-0945	Break
0945- 1145	Missions and Requirements-USN&USAF
11451245	Lunch
1245-1445	Missions and Requirements-USN&USAF
1445-1500	Break
1500-1630	F-22 Program-Program Manager
1630-1730	Executive Session

22 January 1993 Institute for Defense Analyses, Alexandria, VA

0800-0830	Executive Session
0830-1000	F/A-18 Program-Program Manager
l000-1015	Break
1015-l 130	Other Navy Upgrade Programs/Activities
1130-1145	Working Lunch Set Up
1145-1300	Other Air Force Update Programs/Activities
1300-1430	AX-Program
1430-1445	Break
1445-1615	AX Program-Program Manager
1615-1700	Executive Session

4 February 1993 Lockheed, Atlanta, GA (F-22 Program)

0800-1230	Group Morning Session &Working Lunch
1230-1730	Split Technical Sessions

5 February 1993 McDonnell. Dougles, St. Louis, MO (F/A-l8E/F Program)

0800-1230	Group Morning Session & Working Lunch
1230-1730	Split Technical Sessions

11 February 1993 Institute for Defense Analyses, Alexandria, VA

0830-0930	Executive Session
0930-1030	Gen. Larry Welch on parallel mission areas
1030-1100	F-22 Alternative Mission Discussions
1100-1300	JIAWG Briefing
1230-1300	Working Lunch
1300-1400	USAF View on Commonalty (F-16 to MRF)
1400-1500	Executive Session
1500-1515	Break
1515-1730	Executive Session

TASK FORCE SCHEDULE (CONT'D)

12 February 1993	**Institute for Defense Analyses; Alexandria, VA**
08004930	A/F-X SubGroup I Briefmg in IDA SCIF (Foster, Flax, Welch, Sylvester & Military Advisors
0945-1000	Executive Session
1000-1030	Affordability-USAF&USN Cost Data [AP&PI]
1030-1200	DSB Executive Session
1200-1230	Working Lunch
1230-1700	DSB Executive Session

18 February 1993	**Institute for Defense Analyses; Alexandria, VA**
0800-1500	DSB Members Review DSB Report and Prepare Briefing

APPENDIX E
REFERENCES

REFERENCES

[1] Conventional Systems Committee. "Integrated Program Assessment, F/A-18E/F." Secret, 27 April 1992.

[2] Conventional Systems Committee. "Advanced Tactical Fighter Technical Risk Assessment." Secret/Proprietary Information, June 1991.

[3] DIA, "The Fixed-Wing Tactical Air Threat-Worldwide for 2000-2005." Secret.

[4] "Independent Review of F/A-18E/F." Briefing.

[5] Harmon, B. R., L. M. Ward, and P. R Palmer. "Assessing Acquisition Schedules for Tactical Aircraft." Institute for Defense Analyses, Paper P-2105, February 1989.

[6] Harmon, B. R, J. R. Nelson, N. L Om, J. M. Sater, and A. W. Salerno. "Schedule Risk Assessments for Tactical Aircraft Programs." Institute for Defense Analyses, Document D-1214, December 1992.

[7] Tyson, K. W., J. R. Nelson, D. C. Gogerty, B. R Harmon, and A. W. Salerno. "Prototyping Defense Systems." Institute for Defense Analyses, Document D-1097, December 1991.

[8] Nelson, J. R., B. L Retterer, and H. A. Cloud. "Organizational Options for Common Electronics Management." Institute for Defense Analyses, Document D-1159, December 1992.