F/A-18 E/F Program Independent Analysis

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The F/A-18 Program Office (PMA-265) has instituted several new and innovative program management tools, including a Program Independent Analysis Team, during engineering and manufacturing development of the F/A-18 E/F aircraft. The Applied Physics Laboratory was invited to join this team shortly after it was established in mid-1992. As a key member of this team, the Laboratory acts as an independent technical evaluator, applying a wide range of technical and programmatic experience to the success of the F/A-18 E/F Program.
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INTRODUCTION

The Navy conducts its carrier-based air-to-air and air-to-ground missions with a mix of fighter (F-14), strike (A-6E), and multirole strike/fighter (F/A-18) aircraft. The F/A-18 E/F (single-seat/dual-seat) aircraft is being developed as a major modification of the existing F/A-18 C/D aircraft. The F/A-18 E/F aircraft will provide increased mission radius, additional payload flexibility, enhanced survivability, greater payload recovery capability, and space for future avionics growth.

Since mid-1992, the Laboratory has been a key technical member of the F/A-18 E/F Program Independent Analysis (PIA) Team. This team is chartered with providing independent, nonadversarial, proactive analyses of technical and programmatic issues affecting the F/A-18 E/F airframe and F414 engine engineering and manufacturing development programs. This article describes the Laboratory's role on PMA-265's PIA Team and highlights selected areas of technical contribution.

PROGRAM INDEPENDENT ANALYSIS

In May 1992, the F/A-18 E/F Program entered the engineering and manufacturing development phase of the defense acquisition process, after the Undersecretary of Defense for Acquisition approved the Navy's request for development of the F/A-18 E/F aircraft (Fig. 1) as a major modification of the existing F/A-18 C/D aircraft. At the program's outset, the F/A-18 Program Office (PMA-265) instituted several new and innovative program management tools. These tools were introduced to avoid some of the difficulties encountered with the A-12, P-7, and other recent naval aircraft acquisition programs and to facilitate PMA-265's transition to an integrated program team culture. They included a formal risk management program, rigorous cost/schedule control system criteria, cost-type contracting with unusually high award fee content, and the PIA Team.

The charter of the PMA-265 PIA Team is to independently identify, investigate, and report upon issues

Figure 1. First flight of the F/A-18 E/F aircraft (U.S. Navy photo).

that may affect the success of the F/A-18 E/F Program. The team reports to the PMA-265 PIA Director and has the authority to evaluate all areas and levels of the F/A-18 E/F Program. In conducting these evaluations, the team has access to all government and contractor sources of program data and information.

The PIA Team is a group of individuals from non-advocacy organizations with the multidisciplinary expertise to independently assess all areas of the F/A-18 E/F Program.[1] It currently includes technical experts from the Laboratory and operational and flight test experts from Rail Company. This Navy PIA Team conducts its own independent analysis efforts. It also coordinates these efforts with corporate-sponsored PIA teams from McDonnell Douglas Aerospace and Northrop Grumman Corporation, the aircraft's main airframe developers, and General Electric, the aircraft's engine developer.

Once an evaluation topic is identified, the Navy PIA Team members conduct their research and analysis with cooperation from knowledgeable contractor and NAVAIR personnel. Where appropriate, investigations are also conducted jointly with one or more of the contractor PIA teams. A typical evaluation requires between 30 and 60 days to complete. It culminates in the publication of a final report that summarizes relevant findings and recommendations. PIA uses a familiar green, yellow, and red rating scale to communicate its findings and recommendations. Green indicates that the subject activity is within specification, performing to plan, and progressing satisfactorily. Yellow indicates that some event, action, or delay has occurred or is anticipated that requires additional effort and attention. Red indicates that an event, action, or delay has occurred that will impair progress toward major objectives or requirements.

PIA findings and recommendations are reported to the F/A-18 Program Management Team via formal reports and regularly scheduled briefings. The Program Management Team retains responsibility, accountability, and authority for the program's success and conducts a thorough review of the PIA Team's findings and recommendations before implementing appropriate actions.

The PMA-265 PIA Director has taken advantage of the Laboratory's technical and programmatic expertise since July 1992. APL experts in heat transfer, thermodynamics, fluid mechanics, aerodynamics, propulsion, structures, composites, avionics, chemical analysis, electronic warfare, software integration, Global Positioning System design and integration, manufacturing technologies, and test and evaluation have independently investigated and reported on a wide range of technical concerns to the F/A-18 Program Management Team. Firsthand experience in related weapon system development programs such as the Joint Standoff Weapon, the Standoff Land Attack Missile/Extended Range, and the Joint Direct Attack Munition has also been applied to address issues outside the purview but inside the sphere of interest of the F/A-18 Program.

The next sections highlight selected evaluations in which the Laboratory played a significant technical role in support of PMA-265's PIA Team.

FLIGHT TEST PLANNING

A major milestone in the acquisition process for the F/A-18 E/F aircraft will be the successful completion of an extensive 3-year engineering and manufacturing development flight test program. This flight test program began in February 1996 and is scheduled for completion in December 1998. The test program is being conducted primarily at the Naval Air Warfare Center Aircraft Division (NAWC/AD), Patuxent River, Maryland, by an integrated test team that includes both Navy and contractor personnel.

In early 1994, the Navy PIA Team conducted an independent evaluation of the scheduling risk for the F/A-18 E/F flight test program. During this evaluation, the PIA Team applied the mathematics of the binomial distribution to develop a simple but useful model of F/A-18 E/F flight test scheduling risk. This model provided an independent and statistically based method for quantifying flight test scheduling margin and assessing the potential effects of various risk mitigation strategies.

The master test plan for the F/A-18 E/F flight test program provided the framework for the model development effort. An integrated Navy/contractor test team had developed this master plan based on F/A-18 A/B flight test experience from the early 1980s and actual F/A-18 E/F flight test requirements. According to the master test plan, approximately 2000 successful test flights in 13 distinct categories are required to fulfill the demonstration and test objectives for the F/A-18 E/F aircraft.

A unique set of resource requirements and weather constraints applies to each of the 13 flight test categories in the master test plan (Table 1). For example, the requirements for a *flying qualities* type of flight include an E/F test aircraft, a safety chase aircraft, NAWC/AD's Remote Telemetry Processing System (RTPS), and visual flying conditions. High angle of attack flights, on the other hand, require an E/F test aircraft, a safety chase aircraft, RTPS, NAWC/AD's Chesapeake Test Range, and visibility to an altitude of 35,000 ft. Thus, the success of any given flight depends on the type of test conducted and the time of year that the test occurs.

From a scheduling perspective, a prospective test flight results in only one of two possible outcomes—success or failure. In the event of a success, the appropriate resource requirements and weather constraints are satisfied, and the applicable demonstration and test requirements are accomplished during an actual flight test. When a failure occurs, the flight test is canceled because one or more of the required resources failed to support the test and/or the weather failed to cooperate.

Because a scheduled test flight results in only one of two possible outcomes, it can be treated statistically as a Bernoulli trial. Additionally, because each of the 13 test categories comprises a series of independent Bernoulli trials, with identical probabilities of success, they can be treated as Bernoulli processes. For a Bernoulli process with probability of success equal to p, the probability of observing r successes in n independent trials can be expressed as a binomial distribution of the form

$$P(R=r/n,p)=\frac{n!}{r!\,(n-r)!}\,p^{r}(1-p)^{n-r}\ .$$

The preceding binomial distribution provides the mathematical foundation for the F/A-18 E/F flight test scheduling risk model. The cumulative results for this distribution apply to each flight test category; thus, the distribution can be used to determine the number of n test windows needed to ensure that at least r successes are achievable at a specified appropriate confidence level.

The probability of success p for the events in a particular test category is unique; however, it varies seasonally because weather affects flying conditions. Monthly probability of success figures are computed using resource reliability and weather data applicable to the Patuxent River Naval Air Station. These monthly figures are used to compute the number of test windows required per month. The monthly requirements are combined for the entire 3-year test program

Table 1. Projected requirements for the F/A-18 E/F flight test program.

	No. of	Flight test resource						
Flight test category	required flights	TA	CA	TI	RTPS	CTR	ORD	Weather
Flying qualities	265	Y	Y	Y	Y	N	N	a
Performance	125	Y	Y	Y	Y	N	N	a
Propulsion	130	Y	Y	Y	Y	N	N	a
High angle of attack	250	Y	Y	Y	Y	Y	N	a,b
Flutter	255	Y	Y	Y	Y	N	N	c
Empennage buffet	25	Y	Y	Y	Y	N	N	a
Noise/vibration	30	Y	Y	Y	Y	N	N	a
Flight loads	195	Y	Y	Y	Y	N	N	a
Dynamic store release	40	Y	Y	Y	Y	Y	N	a,d
Carrier suitability/ground loads	173	Y	N	Y	Y	N	N	a
Mission systems	74	Y	Y	Y	Y	N	N	a
Weapons separation	267	Y	Y	Y	Y	Y	Y	a
New technology	10	Y	Y	Y	Y	Y	N	a

Notes: TA = F/A-18 E/F test aircraft, CA = chase aircraft, TI = flight test instrumentation, RTPS = remote telemetry processing system, CTR = Chesapeake Test Range, ORD = ordnance, Y = yes, and N = no.

[a]Visual flight rules apply.

[b]Visibility to an altitude of 35,000 ft required.

[c]Smooth air required.

[d]Ground visibility from 5,000 to 20,000 ft required.

to determine the overall number of required test windows for each flight test category.

The overall flight test scheduling risk is quantified in terms of T_m, the available scheduling margin. T_m is calculated for a specified appropriate confidence level as the difference between T_a, the overall number of available test windows, and T_r, the overall number of required test windows. T_a is defined as the total number of daylight hours available for flight testing during a 5-day workweek divided by the duration (1.4 h) of a typical flight test. T_r is defined as the overall sum of the respective test window requirements for each of the 13 flight categories.

Representative results from the flight test scheduling risk model are presented in Fig. 2. The model provides quantitative insight into the flight test scheduling margin available under a given resource and requirement scenario. The results from multiple runs can be compared to quantitatively assess the potential impact of various risk-mitigation alternatives, such as aerial refueling. Figure 2 demonstrates that enhanced aerial refueling capabilities effectively reduce T_r, resulting in increased T_m. Aerial refueling reduces the overall number of required test windows by extending the duration of successful test flights. This enables the data collection requirements of multiple flights to be accomplished during a single operation.

The flight test scheduling model has been used to quantitatively assess other risk mitigation strategies as well, including a 6-day workweek, compressed work schedules, the addition of other flight test resources, and enhancements in the reliability of available test resources. The model is available for use in future PIA evaluations that address flight test scheduling margin and the potential impact of risk mitigation strategies on the F/A-18 E/F flight test program.

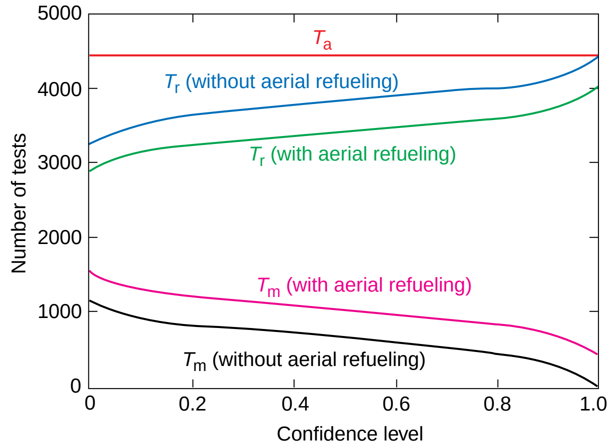

Figure 2. F/A-18 E/F flight test scheduling margin. T_a = overall number of available test windows, T_r = overall number of required test windows, and T_m = available scheduling margin.

ALR-67 PROGRAM RISK IMPACT

Early in the F/A-18 E/F development, the Program Manager directed the PMA-265 PIA Team to independently investigate an issue of particular importance and timeliness to an impending programmatic decision: the selection of ALR-67 radar warning receivers for the F/A-18 E/F aircraft.

As an outcome of a joint electronic systems review with PMA-272 (Advanced Tactical Aircraft Protection System Program Office), PMA-265 recognized that two versions of the ALR-67 would be available during the development of the E/F aircraft—the ALR-67 (v)2 ECP 510 and the advanced ALR-67 (v)3. Each version was different, but the (v)3's capability to handle threats included those of the (v)2, and each could be incorporated into the F/A-18 E/F aircraft. PMA-265 encountered a particularly challenging decision when the ALR-67 selection had to be made because each of these radar warning receivers was still under development. It would be acceptable if the E/F used the (v)3 and the C/D used the (v)2. However, if the E/F chose the (v)3 and the receiver was not successfully developed in time for the E/F's operational evaluation (OPEVAL), then the C/D would have the (v)2 ECP 510 receiver and the E/F would have none, thereby threatening the E/F's development schedule. An overriding program requirement that the E/F aircraft's capabilities must be at least equivalent to the C/D's capabilities also had a major effect on this decision.

When the PIA evaluation was conducted, the ALR-67 (v)2 ECP 510 receiver had completed both its technical evaluation and OPEVAL and was preparing to enter full-rate production. PMA-272 had identified several technical issues that affected this system's integration with the F/A-18 C/D and E/F aircraft. These included the incompatibility of pre- and post-ECP 510 receivers [there are earlier versions of the (v)2], the need to aggressively finish the integration of interfaces, and the need to rewrite (v)2 ECP 510 software in a higher order language to support advanced sensor integration.

In the other ALR-67 development effort, the v(3) receiver had fallen behind schedule, and its supplier had overrun its fixed-price contract. This effort was replanned, and the supplier continued to work under its own funds toward completion. The supplier's development effort was focused on producing service modules for bench and range tests that would lead to technical evaluation and OPEVAL over the next three years. Before completing OPEVAL, two low-rate initial production decisions were scheduled.

Because of overlapping development and production schedules, the ALR-67 receiver implementation decision had to be made for the E/F aircraft before it was made for the C/D aircraft. As noted previously, the developmental status of the receiver programs and the overriding requirement for equivalent capabilities made this a particularly challenging decision. If the C/D was able to use the (v)3 receiver after the E/F had selected the (v)2 receiver, then the E/F would not have equivalent capability. On the other hand, if the E/F chose the (v)3 receiver and it was not successfully developed in time for the E/F OPEVAL, then the C/D would get the (v)2 ECP 510 receiver and the E/F would be without one, unless the aircraft was wired to accommodate both receivers.

The history of each ALR-67 development program was complex, but a large amount of information was available. The technical issues associated with the ALR-67 were sufficiently understood, and it was generally accepted that the ALR-67 (v)3 receiver would give the E/F aircraft increased technical capability. It was not clear, however, to what extent the developmental problems of the (v)3 receiver would impact the development of the E/F aircraft. Additionally, PMA-265 wanted to know whether pursuit of a dual-wiring approach that would interface with either receiver was a worthwhile risk given the difficulties that the (v)3 development effort was encountering. Through the application of a formal risk evaluation method, the PIA Team found that it is an acceptable risk for the E/F development program to maintain the option of using either version of the ALR-67. By assuming a slightly higher risk, the potential for a higher technical payoff was preserved and the E/F development schedule was protected. An independent evaluation was needed to examine the technical and the programmatic risks facing the F/A-18 Program in its decision to select an ALR-67 radar warning receiver.

For this evaluation, the PIA Team selected a risk quantification method developed by the Defense Systems Management College.[2] This method models risk in a development program as the interaction of two parameters: the probability of failure (P_f) and the consequences of that failure (C_f). The probability of the failure is quantified by looking separately at the degrees of hardware maturity and complexity, the degrees of software maturity and complexity, and the dependencies on other items such as test facilities or associate contractors. The consequences of failure are quantified in terms of effect on overall technical, schedule, and cost performance. The model is expressed mathematically as the union of two sets, P_f and C_f, and an integrated risk factor R_f of the following form:

$$R_f = P_f + C_f - (P_f)(C_f) .$$

Table 2 outlines the details of the evaluation matrix used. In practice, this method would be applied to many elements of a program, and a risk factor would be obtained for each element. The risk areas would then be prioritized, and a program "watch list" would be generated. For this evaluation, the risk model was applied to a single program element, the development of the ALR-67 radar warning receiver. Two questions were formulated and addressed during this investigation:

- Question A: What is the integrated risk factor for PMA-265 in obtaining an ALR-67 (v)3 for the F/A-18 E/F development on time, within budget, and with satisfactory performance?
- Question B: What is the integrated risk factor for PMA-265 in obtaining an ALR-67 (v)2 ECP-510 for the F/A-18 E/F development on time, within budget, and with satisfactory performance?

The risk assessment method included weighting factors that modify the elements of probabilities and consequences of development failure. It was judged that the factors associated with the technical development should be assessed by the appropriate engineers from both PMA-265 and PMA-272. The programmatic consequences should have a strong program management input. PMA-265 and PMA-272 provided the weighting factors for the P_f elements (Table 3). Only PMA-265 provided weighting factors for the C_f elements, because the evaluation was being conducted from its programmatic viewpoint. Both PMAs tended to give hardware maturity and hardware complexity more weight than the other three probability of failure factors. PMA-265 weighted the consequence factors about equally, and gave, relative to the technical consequences, slightly more weight to schedule consequences and slightly less weight to cost consequences.

For the ALR-67 v(3), the PIA Team learned that the basic design was complete and that some adjustments were being made as testing proceeded. The hardware was judged to be extremely complex, requiring rebuilding of the computer, the special receiver, the quadrant receivers, and the antennas. The baseline software had been written and was operational but required testing and additional optimization; the software performs a large amount of complex analyses. The increased complexities are attributed to the higher capability of the v(3) over that of the v(2). Dependency factors identified included the aircraft preparation needed to incorporate v(3) kits, the movement of forward antennas into the wings, additional space requirements to accommodate an additional special antenna, and a radome redesign for the wing. Additionally, there was a strong programmatic dependency in that if the (v)3 was incorporated into the production F/A-18 C/D, then the v(3) must be on the F/A-18 E/F for the latter to conform to its operational requirements. The technical consequences of failure were judged minimal because the system was meeting its specification. In the cost arena, expenditures were tracking the current plan; the ultimate estimate of unit

Table 2. Mathematical model for risk assessment.

$$\text{Risk factor, } R_f = P_f + C_f - P_f C_f$$

$P_f = a P_{Mhw} + b P_{Msw} + c P_{Chw} + d P_{Csw} + eP_D$,
$C_f = f C_t + g C_c + h C_s$,

where

P_{Mhw} = probability of failure due to degree of hardware maturity,
P_{Msw} = probability of failure due to degree of software maturity,
P_{Chw} = probability of failure due to degree of hardware complexity,
P_{Csw} = probability of failure due to degree of software complexity,
P_D = probability of failure due to dependency on other items
($a,b,c,d,$ and e are weighting factors whose sum equals one),
C_t = consequence of failure due to technical factors,
C_c = consequence of failure due to changes in cost, and
C_s = consequence of failure due to changes in schedule
(f, g, and h are weighting factors whose sum equals one).

	Maturity factor (P_M)		Complexity factor (P_C)		
Magnitude	Hardware (P_{Mhw})	Software (P_{Msw})	Hardware (P_{Chw})	Software (P_{Csw})	Dependency factor (P_D)
0.1	Existing	Existing	Simple design	Simple design	Independent of existing system, facility, or associate contractor
0.3	Minor redesign	Minor redesign	Minor increase in complexity	Minor increase in complexity	Schedule dependent on existing system, facility, or associate contractor
0.5	Major change feasibility	Major change feasibility	Moderate increase	Moderate increase	Performance dependent on existing system, facility, or associate contractor
0.7	Technology available, complex design	New software, similar to existing	Significant increase	Significant increase/major increase in no. of modules	Performance dependent on new system schedule, facility, or associate contractor
0.9	State of the art, some research complete	State of the art, never done	Extremely complex	Extremely complex	Schedule dependent on new system schedule, facility, or associate contractor

Magnitude	Technical factor (C_t)	Cost factor (C_c)	Schedule factor (C_s)
0.1	Minimal or no consequence, unimportant	Budget estimates not exceeded, some transfer of money	Negligible impact on program, slight development schedule change compensated by available schedule slack
0.3	Small reduction in technical performance	Costs estimates exceed budget by 1 to 5%	Minor slip in schedule (less than 1 month), some adjustment in milestones required
0.5	Some reduction in technical performance	Cost estimates exceed budget by 5 to 20%	Small slip in schedule (1–3 months)
0.7	Significant degradation in technical performance	Cost estimates exceed budget by 20 to 50%	Development schedule slip in excess of 3 months
0.9	Technical goals cannot be achieved	Cost estimates increased in excess of 50%	Large schedule slip that affects segment milestones or has possible effect on system milestones

Note: This table is reprinted from Ref. 2 by permission.

Table 3. Weighting factors for ALR-67 evaluation.

Weighting factor	PMA-265 value	PMA-272 value	Combined value
a (hardware maturity)	0.25	0.28	0.26
b (hardware complexity)	0.25	0.24	0.25
c (software maturity)	0.14	0.17	0.15
d (software complexity)	0.14	0.21	0.17
e (dependency)	0.22	0.10	0.17
f (technical consequence)	0.33	[a]	0.33
g (cost consequence)	0.30	[a]	0.30
h (schedule consequence)	0.37	[a]	0.37

[a] Only PMA-265 provided weighting factors for the C_f elements.

costs depended on the volume and rate of orders. At the time of the evaluation, the Navy was the only customer for this system. The schedule consequences differed, depending on whether the aircraft would be equipped with or without dual wiring. Because of the dual-wiring option, two versions of question A, A(1) and A(2), were considered. These questions correspond to an aircraft without and with dual wiring, respectively.

The hardware and software for the ALR-67 v(2) already existed and had passed OPEVAL tests. The v(2) had some new weapon replaceable assemblies, including new quadrant receivers and a new computer. There were some software changes to accommodate new functions, and although operational, the software was to be converted to a higher-order language in a separate development program. The forward antennas also had to be moved into the wings. The failure consequences were projected to be minimal because the system had passed OPEVAL tests, the cost estimates were firm, 230 units had already been produced, and follow-on production was about to begin pending a contract award from PMA-272.

Tables 4 and 5 present the risk factor calculations for each question. The rationale that led to the assignment of a value is listed. For question A, values for the consequences of failure due to schedule effects include those with and without the dual-wiring option.

Table 4. Risk factor analysis for question A (ALR-67 (v)3 for E/F).

Factor	Magnitude	Rationale
P_{Mhw}	0.3	Basic design complete; some adjustments required as testing proceeds.
P_{Msw}	0.3	Software baseline written and working; requires testing and additional optimization.
P_{Chw}	0.9	Extremely complex; requires rebuilding of computer, special receiver, quadrant receiver, antennas.
P_{Csw}	0.9	Extremely complex; performs a large degree of analysis.
P_D	0.5	Airplane must be prepared to accept (v)3 kit. Movement of forward antennas to wing. Additional space may be required to accommodate extra polarity antenna; radome design required for wing. If (v)3 is on production C/D, then it must be on E/F.
C_t	0.1	System will meet (Nov 1992) specification.
C_c	0.3	Current expenditures tracking current plan. Estimates of unit costs depend on volume and rate of orders. Currently Navy is only customer.
C_s	0.5(A1)	(A1) Without dual wiring.
	0.1(A2)	(A2) With dual wiring.

Note: See Table 2 for definitions of factors.

Figure 3 summarizes the integrated risk factor calculations for questions A(1), A(2), and B. For comparison, the influence of the weighting factors on the results is shown. Calculations were performed using PMA-265 factors and PMA-272 factors separately and using the combined numerical averages of the PMA-265 and PMA-272 factors. As a control, the effect of using equal weighting factors ($a, b, c, d, e = 0.20$) also was computed. For these cases, the general result seems insensitive to the weighting factor differences. The integrated risk factor for questions A(1) and A(2) are in the 0.60 to 0.70 range. For question B, this figure is approximately 0.35. An interpretation of these results is necessary.

Figure 4 illustrates the integrated risk factor as a function of P_f and C_f. In this evaluation, the PIA Team did not attempt to modify the method; the assignment of values in the discrete set of 0.1, 0.3, 0.5, 0.7, or

Table 5. Risk factor analysis for question B (ALR-67 (v)2 ECP 510 for E/F).

Factor	Magnitude	Rationale
P_{Mhw}	0.1	Existing hardware that has passed OPEVAL.
P_{Msw}	0.1	Existing hardware that has passed OPEVAL.
P_{Chw}	0.5	Some new weapon replaceable assemblies in system; new quadrant receivers and new computer required.
P_{Csw}	0.5	Some software changes to accommodate new functions. Software conversion to higher order language needed in a separate development program.
P_D	0.3	Movement of forward antennas to wing.
C_t	0.1	Passed OPEVAL.
C_c	0.1	Cost estimates firm; production ready to go; contract awarded by PMA-272 (22 Apr 1993).
C_s	0.1	Production schedule within manufacturing capability; 230 units already delivered.

Note: See Table 2 for definitions of factors.

0.9 was permitted only for any component risk factor. Thus, the integrated result must fall into the trapezoidal area bounded by P_f = 0.1 and 0.9 and by C_f = 0.1 and 0.9, as shown in Fig. 4. The lowest integrated risk factor achievable by this method is 0.19; the highest is 0.99. Risk factors in the range from 0.80 to 0.90 can result from high probabilities of development failure and/or high consequences of that failure. The method does not specifically indicate which values are associated with high-, moderate-, or low-risk levels.

To aid in the assignment of high, moderate, or low risk to a value for R_f, the P_f–C_f trapezoidal regime in Fig. 4 is divided into three equal areas in the R_f–P_f plane. By this partition, a low-risk area ranging from R_f = 0.190 to 0.628, a moderate-risk area ranging from 0.628 to 0.810, and a high-risk area ranging from 0.810 to 0.990 are illustrated. Based on these ranges, question A(1) would fall into the moderate-risk area, question A(2) would fall just within the low-risk area, and question B would fall well within the low-risk area.

High and moderate risks do not necessarily forecast failure; they only point out areas of the program in which risk mitigation is required to promote overall success. In an evaluation of a system's risk, the integrated risk factor should be interpreted in conjunction with the technical benefits. For the ALR-67 risk assessment evaluation, the PIA Team concluded the following: a planned use of the ALR-67 (v)3 version in the F/A-18 E/F development presented a moderate risk (without dual wiring) to low risk (with dual wiring) with high technical benefits, and a planned use of the ALR-67 (v)2 ECP-510 version presented a low risk with moderate benefits. Based in part on this independent analysis, PMA-265 chose to pursue a dual-wiring option for ALR-67s during the E/F development program, thus keeping open the option for a higher technical payoff, maintaining a low-risk approach, and protecting the E/F's OPEVAL schedule if the ALR-67 (v)3 were incorporated first into the production C/D aircraft.

COMPOSITE MATERIALS

Composite materials constitute a significantly higher percentage of the F/A-18 E/F's structural weight and external surface area than the currently produced F/A-18 C/D aircraft (Fig. 5). The use of high-specific-strength

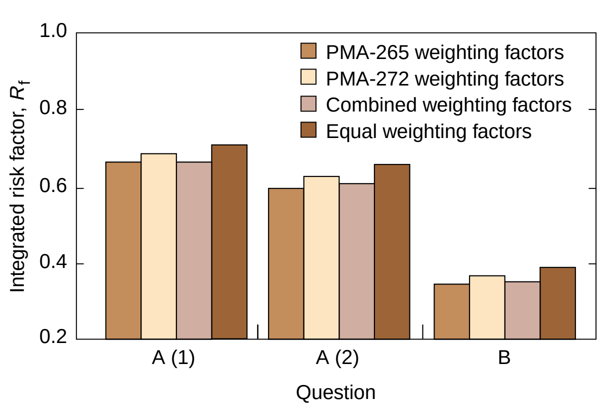

Figure 3. Calculated risk factors for F/A-18 E/F development program use of ALR-67.

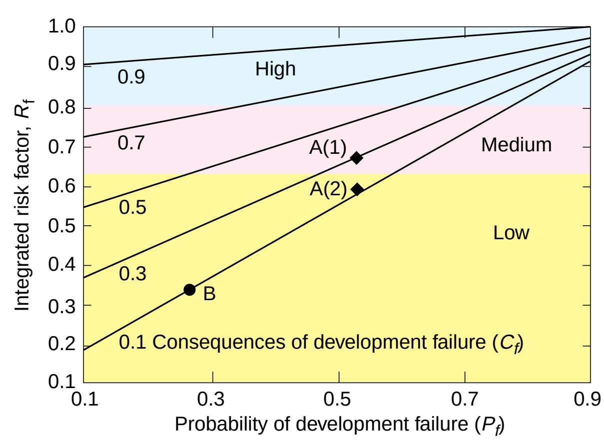

Figure 4. Integrated risk factor plotted as function of P_f and C_f.

materials is an increasingly attractive option for high-performance military aircraft because of recent developments in composites design, fabrication, and repair technology. Composites technology will play an increasingly critical role in the life-cycle cost and performance of the F/A-18 E/F aircraft.

Since July 1992, APL has participated in approximately 25 PIA evaluations of issues related to the application of composites on the F/A-18 E/F aircraft (Table 6). These evaluations have focused state-of-the-art in-house composites design and fabrication capabilities on both near- and long-term technical concerns regarding the use of composites, as well as other non-metallic coatings, adhesives, sealants, and materials. The scope of these investigations has been particularly broad and has encompassed a wide range of composites design, fabrication, maintenance, and repair issues. These efforts have been conducted with close cooperation and support from organizations throughout the country who have an interest in the effective use of composites on the F/A-18 E/F aircraft. These organizations included NAVAIR, McDonnell Douglas Aerospace, Northrop Grumman Corporation, General Electric, naval aviation maintenance organizations (organizational, intermediate, and depot level), the Naval Aviation Engineering Service Unit, the Naval Aviation Training Group and Detachment, composite fabrication equipment and materials suppliers, the Great Lakes Composite Consortium, and other naval aviation acquisition programs. Highlights from selected composites evaluations follow.

Materials Selection

Before the F/A-18 E/F Engineering and Manufacturing Development Program began, engineers realized that the composite structures on the F/A-18 E/F aircraft would require increased stiffness to accommodate significantly higher structural loads than those encountered during flight of the F/A-18 C/D aircraft. This realization led to the selection of Hercules IM-7 reinforcing fibers for the composite structures on the E/F aircraft. The microstrain capabilities of these stiffer fibers exceeded those of the Hercules 3501-6 resin system used on the C/D aircraft and demanded that materials experts also identify a toughened epoxy resin system for the E/F aircraft.

In January 1992, Fiberite 977-3 was chosen as the epoxy resin system for the composite structures on the F/A-18 E/F aircraft. The materials selection process entailed a complex trade-off of competing design, manufacturing, and quality control requirements with equally important cost, delivery, and vendor support issues. Shortly after the PIA Team was established in July 1992, the NAVAIR Materials Division requested an independent technical evaluation of the material selection process to ensure that the proper resin system had been chosen. The Navy PIA Team, led by an APL

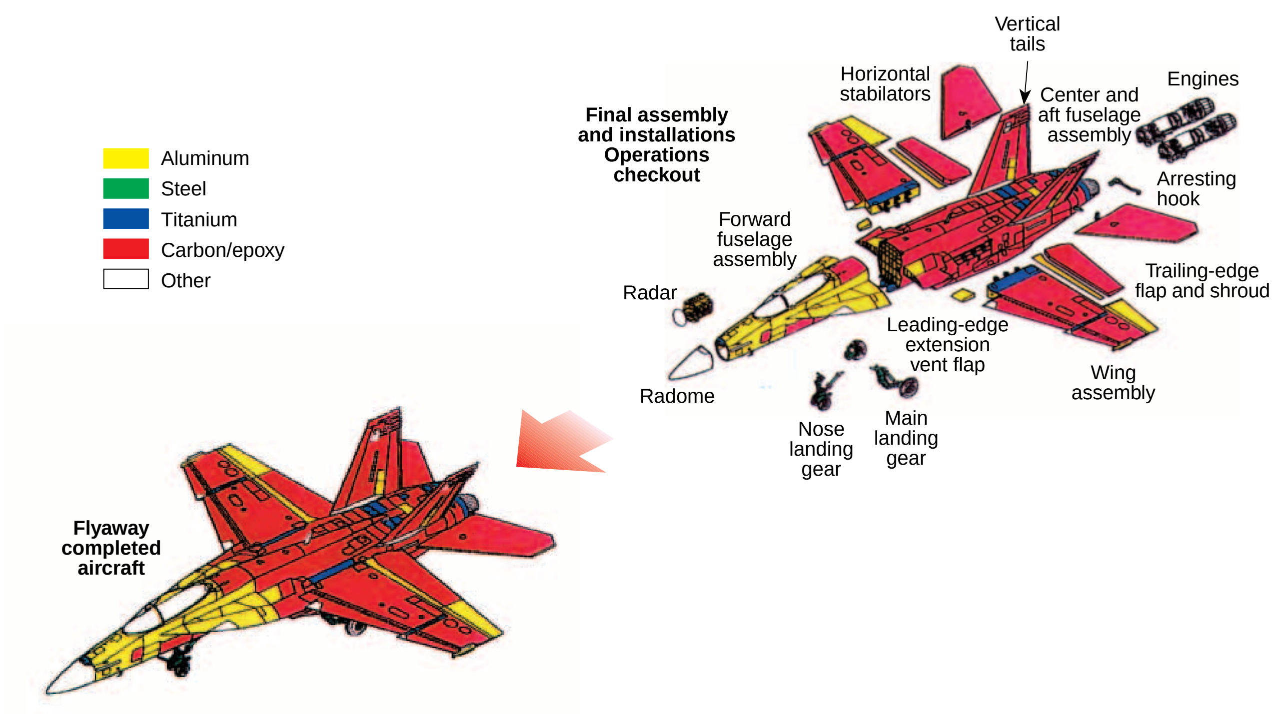

Figure 5. Composite materials will comprise 19% of the structural weight and 60% of the external surface area of the F/A-18 E/F aircraft.

Table 6. List of selected PIA evaluations on composite materials.

Subject	Objective
Quality assurance	Evaluate the adequacy of quality assurance procedures to address the increased quantity and complexity of composite structures on the F/A-18 E/F aircraft.
Materials selection	Confirm that an appropriate toughened epoxy resin system was selected for the F/A-18 E/F aircraft.
Carbon/carbon brakes	Determine the cause of lost brake efficiency on the F/A-18 C/D aircraft.
Fiber placement technology	Assess the risk associated with application of fiber placement technology to fabricate composite parts for the F/A-18 E/F aircraft.
Resin transfer molding technology	Assess the risk associated with application of resin transfer molding technology to fabricate composite parts for the F/A-18 E/F aircraft.
Composite repair technology	Examine the technology and infrastructure available to support an increased level and complexity of composite repair activities for the F/A-18 E/F aircraft.
Advanced composite materials supportability	Evaluate the status of plans and processes for ensuring the supportability of advanced composite materials in the fleet.
Shelf-life critical repair materials	Evaluate the ability of the supply infrastructure to properly handle shelf-life critical composite repair materials for the F/A-18 E/F aircraft.
Future environmental regulations	Investigate the impact of changing environmental regulations on the manufacture and repair of composite parts.

composites expert, completed this investigation in October 1992. On the basis of an in-depth analysis of mechanical, physical, and manufacturing test data from the materials selection process, the PIA Team concluded that Fiberite 977-3 would satisfy the operating requirements of the composite structures for the F/A-18 E/F aircraft. The extended temperature capabilities of the stiffened fiber resin system ultimately led to the increased use of composites on the E/F aircraft and, as a result, reduced weight and improved performance.

Fiber Placement Technology

The Navy has encouraged its airframe and engine suppliers to pursue a prudent number of new technology demonstrations during engineering and manufacturing development of the F/A-18 E/F aircraft. The benefits of and lessons learned from these demonstrations are to be applied during the follow-on phases of the F/A-18 E/F Program. With this philosophy in mind, the airframe suppliers decided to explore the use of fiber placement technology to fabricate a selected set of F/A-18 E/F composite parts.

Fiber placement technology uses a specially designed roller head to contact and press multiple fiber-resin bundles, or tows, into the desired location on a tool surface to form composite parts. Parts curing occurs at the appropriate temperature on the surface of the fiber placement tool itself or after the parts are transferred to a separate cure tool. The technology provides an attractive alternative to hand lay-up methods for fabricating relatively complex composite parts. For the F/A-18 E/F aircraft, the selected set of parts included engine intake ducts, horizontal stabilizer skins, and rear-body panel skins.

Before investment in fiber placement equipment occurred, a joint Navy, McDonnell Douglas, and Northrop Grumman PIA evaluation was conducted to assess the technical risk associated with the use of fiber placement technology to fabricate composite parts for the F/A-18 E/F aircraft. This evaluation focused on three key technical questions:

- Could fiber placement technology produce composite parts for the F/A-18 E/F aircraft that are equivalent to manually produced parts?
- Should a slit tape or pre-impregnated tow raw material feedstock be used if fiber placement technology is pursued?
- Which manufacturer's fiber placement equipment best suited the needs of the program?

To address these questions, the PIA Team visited the industry leaders, Cincinnati Milacron and Hercules, Inc., to witness fiber placement equipment demonstrations and to inspect composite parts fabricated with fiber placement technology. On the basis of these site visits and a comprehensive review of manufacturing and test data, the PIA Team concluded that equivalent parts could be produced using fiber placement technology, either feedstock form was acceptable (economics should drive the choice), and either manufacturer's equipment could satisfy the requirements of the F/A-18 E/F aircraft.

Shelf-Life Critical Repair Materials

Composite repair materials frequently require refrigerated storage because of their limited shelf lives under ambient storage conditions. Thus, the ability to effectively repair the composite structures on the F/A-18 E/F aircraft will depend heavily on the packaging, handling, storage, and transportation (PHS&T) of shelf-life critical materials.

Considering the enhanced use of composites on the F/A-18 E/F aircraft, the PIA Team conducted an independent evaluation of the supply system's capability to support the projected composite repair requirements during deployment. This evaluation entailed a comprehensive review of the projected requirements for F/A-18 E/F composite repair materials and examination of the practices and procedures that the supply system uses to package, handle, store, and transport shelf-life critical materials.

The PIA Team discovered during its investigation that the PHS&T of composite repair materials involves a complex network of individuals and organizations. The team formulated its findings based on meetings and discussions with PHS&T experts from NAVAIR, the Naval Aviation Engineering Service Unit, the Defense Logistics Agency, the Aviation Supply Office, the Ships Parts Control Center, the General Supply Agency, and organizational, intermediate, and depot-level maintenance organizations. More importantly, the PIA Team discovered that some organizations treat shelf-life critical composite materials differently. These PHS&T differences were attributed to a variety of operational, equipment, and training issues. For example, the need to expeditiously clear the flight deck after an at-sea replenishment, the lack of adequate hazardous material refrigeration and freezer space on combat stores and support ships, and the failure of some personnel to understand the temperature sensitivity of composite repair materials has frequently led to the inadvertent exposure of composite materials to temperatures that reduce their usable lifetime.

As an outcome of this evaluation, the PIA Team recommended that PMA-265 choose a single organization to develop an integrated support plan that addresses the PHS&T requirements for composite repair materials for all F/A-18 aircraft. In response to the team's recommendation, PMA-265 requested that the Naval Inventory Control Point form a team to investigate the PIA Team's findings further and to develop an appropriate integrated support plan. A representative of the Navy PIA Team was assigned to support this team's efforts.

WINDSCREEN COATINGS

Transparent conductors are being routinely incorporated today into a variety of state-of-the-art electronic and optoelectronic devices—from electrodes and heating elements to anti-reflective, anti-static, and anti-electromagnetic solar coatings. Because these conductors provide a means to reversibly modulate the optical characteristics of different transparent materials, both the commercial and military aviation communities are interested in the utility of thin-film ionic coatings in aircraft windscreen applications.

In late 1995, an F/A-18 E/F supplier was encountering difficulty in applying stable and consistently uniform solar films on F/A-18 E/F windscreens. These transparent-conductive films must satisfy stringent electrical resistance and optical transmission requirements to comply with the overall performance specification for the F/A-18 E/F aircraft. The windscreen supplier was unable to routinely meet these requirements when the PMA-265 PIA Director asked the Navy PIA Team to provide an independent technical review of the process that was being used to apply solar coatings on F/A-18 E/F windscreens.

A PIA Team representative conducted an on-site review of the manufacturer's solar-coating application operation in October 1995. The key elements of the process used to apply solar coatings on F/A-18 E/F windscreens are similar to those used in APL's Milton S. Eisenhower Research and Technology Development Center and Microelectronics Facility. Windscreen coating occurs in an 8-ft-dia. by 20-ft-long cylindrical chamber using an appropriately designed target. The chamber is pumped down before coating deposition. The windscreen is held in close proximity to the target while the solar coating is applied.

Following the on-site review, scientists from the Milton S. Eisenhower Research and Technology Development Center also performed in-house chemical and physical analyses of solar-coated samples furnished by the F/A-18 E/F windscreen manufacturer. These analyses focused on four key performance-related parameters:

- Chemical composition using energy dispersive analysis for X rays
- Electrical properties using the van der Paaw technique
- Structural characteristics using X-ray scattering methods
- Optical properties from dual-beam absorbance measurements

On the basis of its findings, the PIA Team prepared a comprehensive final report for PMA-265 and the windscreen manufacturer. In addition to summarizing the quantitative results of the team's investigations, this report recommended the implementation of three important process modifications:

- Altering the shape of the target
- Adjusting the oxygen concentration in the coating atmosphere
- Allowing sufficient time for annealing of the windscreen after the solar coating is applied

These investigative results and recommendations helped the manufacturer overcome its processing difficulties and produce solar-coated windscreens that comply with the overall performance specification of the F/A-18 E/F aircraft.

TEST ENGINE COMPRESSOR BLADE FOULING

General Electric's F414-GE-400 engine entered a 4-year engineering and manufacturing development test program in early 1993 to verify its capability to satisfy the enhanced thrust and performance requirements of the F/A-18 E/F aircraft. This test program progressively validates the F414 engine's qualifications for F/A-18 E/F flight testing, low-rate initial production, and full-rate production. A significant portion of this test program is being conducted at the Air Force's Arnold Engineering and Development Center (AEDC) in Tullahoma, Tennessee.

In early 1995, AEDC test engineers encountered an anomaly during preflight qualification testing of the F414 engine. They reported unexpected reductions in measured compressor efficiency as engine testing proceeded. Additionally, they noted that measured compressor efficiency recovered mysteriously after overnight shutdown of the AEDC engine test facility. When testing resumed the following day, the compressor efficiency returned to its nominal value. Representatives from NAVAIR, AEDC, General Electric, and APL formed a tiger team to investigate and address the root cause of this anomaly.

Early in the team's investigations, test engineers detected an unusually high amount of unknown deposits on the F414's compressor blades (Fig. 6). Preliminary calculations by General Electric indicated that these residues were the probable cause of the apparent loss in compressor efficiency. Two theories emerged to explain the origin and magnitude of these deposits. First was the hypothesis that the enhanced performance characteristics of the F414 engine, particularly its high bypass ratio, made the compressor increasingly susceptible to the rust and dust buildup that frequently occurs in full-scale test facilities. Second was the theory that the observed coatings originated from an inadvertent increase in rust and dust in the AEDC test facility.

Figure 6. Potassium phosphate deposits on sixth and seventh stage blades of the F414 compressor .

After chemical analyses of the deposits were completed, the team focused its attention on the facility's rust and dust conditions. The analyses indicated that the deposits contained a high concentration of potassium phosphate. The test facility's refrigeration plant was subsequently identified as the likely source of the compressor blade deposits. The plant uses refrigeration coils to cool test air to high-altitude conditions. Antifreeze is sprayed on the refrigeration coils perpendicular to the test air stream to prevent ice buildup during high-altitude engine testing. Potassium phosphate acts as a rust inhibitor in the antifreeze. Some antifreeze droplets were entrained in the test air and proceeded through the demister screens installed to remove them. In the event that a droplet evaporates completely before entering the engine intake, the compressor inlet air includes vaporized antifreeze and a potassium phosphate dust that can collect on the compressor blade surfaces. Those droplets that reach the engine intake before evaporating completely will boil upon contact with the high-temperature compressor blades to produce antifreeze vapor and a potassium phosphate coating as well.

To understand the distribution of deposits in the compressor, APL proposed an initial theory based on how a droplet behaves when it contacts a hot metal surface. This theory also considered the impact of pressure variations in the compressor on the boiling point of antifreeze. Bench tests at APL's Advanced Technology Development Laboratory confirmed that the heat transfer rate to droplets decreases and droplet lifetime increases when the temperature is high enough to produce an insulating film of vapor between the droplet and a hot metal plate. These theoretical and empirical results agreed qualitatively with the observed distribution of deposits through the compressor at different engine test conditions. They also supported the theory that antifreeze droplets were impinging directly on the compressor blades.

As the effort progressed, the team made another important discovery. The antifreeze in the refrigeration plant is circulated through a closed-loop system, and fresh antifreeze must be added periodically to make up for evaporation losses. When antifreeze evaporates, the potassium phosphate rust inhibitor remains behind. As a result, the phosphate concentration had increased considerably over time, resulting in an inadvertent increase in the level of rust and dust circulating through the engine test facility. As soon as AEDC test engineers recognized the problem, they refilled the system with reduced-phosphate antifreeze. Evaporative losses are now made up with phosphate-free antifreeze.

How did compressor efficiency recover overnight? Conditions in the test cell became humid overnight, and NAVAIR pointed out that potassium phosphate has an unusually high affinity for water. Bench tests at the Advanced Technology Development Laboratory confirmed that the compressor blade deposits could extract enough moisture from the test cell air overnight to dissolve themselves. Follow-on tests at AEDC reproduced these results in greater detail.

VERTICAL TAIL ASSEMBLY

The original design philosophy for the F/A-18 A/B aircraft in the late 1970s called for vortex shedding from the aircraft's leading-edge extension and across its vertical tail assembly (VTA) to improve control authority at high angles of attack. At the time, design engineers recognized that the resulting buffet loads would induce fatigue into the VTA. However, the original service use profile indicated that the F/A-18 A/B aircraft would rarely be flown at high angles of attack. Nobody informed the pilots. High angle of attack maneuvering in a controllable fighter gives the pilot a tactical advantage in combat. In fleet service, the pilots routinely flew the plane at high angles of attack, and buffet fatigue resulted. Thus, a considerable maintenance effort was required to keep the F/A-18 A/B aircraft in the air.

When the F/A-18 C/D aircraft was designed, the aircraft's service use profile was adjusted to reflect additional operating time at high angles of attack. The fatigue life of the VTA became a key design parameter for the F/A-18 C/D aircraft. Analyzing and designing structures that will experience fatigue loads in a high buffet environment are relatively complex tasks. Consequently, a high visibility inspection and maintenance effort has been conducted for the F/A-18 C/D VTA as well. The results of this inspection and maintenance effort have validated the success of previous analysis and design efforts, as some F/A-18 C/D aircraft are approaching one service lifetime of use with normal fatigue-related maintenance.

Given the historical significance of the VTA as a high-maintenance item for the F/A-18 aircraft, the Navy, McDonnell Douglas, and Northrop Grumman PIA Teams have coordinated two joint evaluations of issues critical to the development of the F/A-18 E/F VTA. The earlier of these efforts was the first-ever joint PIA evaluation. These evaluations were conducted jointly to ensure that the findings and recommendations were representative of the combined interests of McDonnell Douglas, Northrop Grumman, and the Navy. McDonnell Douglas is responsible for estimating the buffet load spectra; Northrop Grumman is responsible for the VTA's design, fabrication, and testing. Both companies share responsibility for developing the fatigue material allowable stresses for the VTA. These allowable stresses are a function of both VTA material and load profile.

The first evaluation focused on the design effort for the VTA. PIA representatives met for two days at the

McDonnell Douglas facility in St. Louis, Missouri, to interview the personnel who developed the loads and fatigue allowable stresses for the F/A-18 E/F VTA. The team subsequently interviewed the VTA Integrated Product Development Team at Northrop Grumman's facility in El Segundo, California. The PIA Team was impressed with the Integrated Product Development Team's application of lessons learned from previous F/A-18 experience. The primary load-carrying structures in the VTA are either titanium or carbon fiber composite, both fatigue resistant materials. The design team had used the directional material properties of the carbon fiber composite material to give the E/F VTA the same vibration characteristics as the smaller C/D VTA.

Upon completing its investigation, the PIA Team reported that the technical risks of the VTA development effort were understood and that adequate steps had been taken to mitigate those risks. The team also reported that the development effort faced a significant scheduling risk because of the impact of recent leading-edge extension design changes on the design loads for the VTA. The PIA Team recommended that the program assign an additional stress analyst and computer workstation to alleviate this scheduling risk.

The second evaluation addressed the FT-55 ground test for the VTA. This test was designed to measure the expected fatigue life of the F/A-18 E/F VTA. The FT-55 test requires almost 2 years to complete; it is the most expensive ground test in the F/A-18 E/F Program. Originally, this test called for subjecting the VTA to its expected fatigue-load profile during two service lifetimes, followed by nondestructive inspection to identify any failures in the VTA's composite skins and substructure. After this testing was complete, the plan was to keep the test fixture intact for approximately 2 years until the actual buffet-load profile was measured during F/A-18 E/F flight testing. This approach would enable additional test cycles to be conducted in the event that the actual fatigue-load profile exceeded the expected profile.

As an outcome of its investigation, the PIA Team recommended disassembly and inspection of the FT-55 test article shortly after it is subjected to the expected fatigue-load profile. This recommendation was motivated by the team's concern about the inability of existing nondestructive inspection techniques to detect failures in the composite substructure of the FT-55 test article. Although early disassembly of the test article would preclude follow-on testing if deemed necessary, it would allow for earlier diagnosis of potential fatigue problems while the FT-55 test team is still intact.

GLOBAL POSITIONING SYSTEM WEAPONS/AIRCRAFT INTEGRATION

With the advent of smart weapons and precision guided munitions, such as the Standoff Land Attack Missile (SLAM), the Joint Standoff Weapon (JSOW), and the Joint Direct Attack Munition (JDAM), the interface for communicating Global Positioning System (GPS) information between a military aircraft such as the F/A-18 E/F and its wing- and fuselage-mounted weapons has become increasingly sophisticated. Because of the complexity of this communications interface and the fact that many integration issues fall beyond the formal scope of responsibility of individual aircraft and weapons program managers, the Navy PIA Team selected GPS weapons integration as the topic for two independent evaluations. These evaluations addressed F/A-18 E/F GPS integration with JSOW and SLAM/ER (the expanded response upgrade to SLAM).

Early in these evaluations, the PIA Team discovered that implementation of the MIL-STD-1760B Aircraft/Store Electrical Interconnection System, commonly referred to as 1760B, would play a critical role in the solution of most GPS integration issues. This standard establishes a common hardware interface that supports all aircraft and weapons data communications. It also provides a foundation for integrating advanced weapons with aircraft of other services and other countries (e.g., our NATO allies).

Among the communications issues that 1760B was developed to address is the means by which a military aircraft might transmit raw GPS signals and/or processed GPS data to its wing-mounted weapons. Although SLAM, JSOW, and JDAM do not have an explicit requirement to track GPS "on the wing" today, it is still necessary for their host aircraft to communicate GPS-derived position, heading, and velocity information before weapons launch. Under certain situations, it can be advantageous for the aircraft to provide additional GPS information as well, such as the raw GPS signals received by the aircraft's GPS antennas, or precision timing information derived from these signals by the aircraft's GPS receiver.

From a hardware perspective, the transmission of raw GPS data via the 1760B interface appears to be a rather straightforward procedure. The 1760B standard provides the ability for an aircraft to transmit unprocessed L-band GPS signals to its weapons over a 50Ω coaxial cable known as the high bandwidth-1, or HB-1, line. From a signal processing perspective, however, the transmission of unprocessed GPS signals via the HB-1 line is a considerable challenge. Cable losses, fan-out as the signal is delivered to multiple weapons, and standing-wave ratio changes as weapons are released from the aircraft introduce complex signal handling difficulties.

The transmission of derived information between an aircraft's GPS receiver and its weapon's GPS receivers also represents a considerable challenge. This information is usually broadcast over the digital data link portion of 1760B, the MIL-STD-1553B serial asynchronous interface, which operates at 20 MHz. Whereas using this type of interface can introduce queuing delays in the transmission of GPS-derived information, these delays are considered an acceptable limitation of the 1553B digital data link because an asynchronous data bus greatly simplifies the wiring interfaces between the aircraft's GPS receiver, mission computer, and weapons stations. The 1553B data link can be implemented with a single twisted-pair cable that branches off to multiple equipment and weapons stations. This interface is preferred from a manufacturing and aircraft weight perspective to that needed for a synchronous, parallel data bus such as that used in a personal computer.

In addition to queuing delays, the twisted-pair 1553B interface necessitates complex handshaking and identification protocols. The combined impact of protocol and queuing delays can increase the time required to send a message between the aircraft mission computer and a wing-mounted weapon.

Figure 7. The F/A-18 E/F with its complement of wing-mounted weapons. On the starboard wing from left to right in the picture are the AIM-9, HARM, Harpoon, and SLAM/ER. On the port wing, also from left to right, are JDAM, JSOW, Maverick, and Sidewinder. It is interesting to note the design overlap of some of the weapons. For example, SLAM/ER evolved from the Harpoon antiship missile but also incorporates the sensor from the Maverick missile for infrared imaging. SLAM/ER, JSOW, and JDAM are all GPS-guided weapons. The GPS receivers to be used on the aircraft and on both SLAM/ERand JDAM are slightly different versions of the same receiver and use similar software. (Photograph courtesy of McDonnell Douglas Corporation.)

As a result of these findings, the Navy PIA Team concluded that the F/A-18 E/F aircraft has two realistic options for providing accurate GPS assistance to JSOW and SLAM/ER (Fig. 7). Both of these options involve use of the HB-1 line. The F/A-18 E/F aircraft can forward raw GPS signals from its antenna over the HB-1 line, or the aircraft's GPS receiver can be designed so that high- resolution time-mark information can be transmitted over the HB-1 line to the timing and navigation hardware on the weapon's GPS receiver. The team quantified the performance improvements for each option, as well as the benefits of improved GPS integration in the case of jamming.

For SLAM/ER, the PIA Team recommended that the F/A-18 E/F Program pursue the HB-1 time-mark communications option because these signals are much easier to handle than the low-power, noise-laden, raw GPS signals. For JSOW, the team recommended that the program pursue the HB-1 time-mark communications as well, along with further exploration of the raw GPS alternative.

Additionally, the PIA Team confirmed that these advantages can be gained in the future as planned product improvements through additional or modified electronics equipment and software upgrades without the need for significant change to the existing design of the aircraft. This is an important finding, as it permits PMA-265 to avoid additional cost today while keeping its options open for improved aircraft/weapon integration in the future.

SUMMARY

This article described efforts in which the Laboratory has played a key technical role in support of the PMA-265 PIA Team. The PIA Team continues to conduct independent, nonadversarial, proactive evaluations of a wide range of technical and programmatic issues affecting the success of the F/A-18 E/F Program. The PIA Team's efforts continue to evolve with the F/A-18 E/F Program.

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