
# F/A-18 Electronic Warfare Suite Cost and Operational Effectiveness Analysis Methodology: Phase 1—Radio-Frequency Countermeasures

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The cancellation of the Airborne Self-Protection Jammer Program created a potential shortfall in the protection of the Navy's F/A-18 aircraft from radio-frequency threat systems. To address this issue, the Naval Air Systems Command requested that the Applied Physics Laboratory perform a cost and operational effectiveness analysis (COEA) of electronic warfare suite alternatives for the F/A-18. As a result of this analysis, a new program was initiated to procure an improved electronic warfare suite for F/A-18 aircraft. This article summarizes the methodology used in Phase 1 of the COEA, in which radio-frequency countermeasure alternatives were examined, and presents unclassified examples to illustrate the nature of the results.
(Keywords: COEA, Electronic warfare, F/A-18 aircraft.)

## INTRODUCTION

Prior to its operational evaluation, the airborne self-protection jammer (ASPJ) was to be included in the baseline electronic warfare (EW) suite of the F/A-18E/F aircraft, and the EW suite of the F/A-18C/D aircraft was to be upgraded by replacing the ALQ-126B jammer with the ASPJ. However, because the ASPJ failed its operational evaluation and the program was canceled, the plans for the F/A-18 EW suite had to be reexamined. In a letter to Senator Pryor dated 8 September 1993, the Honorable John M. Deutch (Under Secretary of Defense for Acquisition) described his intent to direct the Navy to conduct a cost and operational effectiveness analysis (COEA) of the F/A-18 EW suite. As a result, the Naval Air Systems Command (NAVAIR) requested that APL perform the COEA. The Oversight Board for this COEA was co-chaired by a representative from the Chief of Naval Operations (CNO) and the Deputy Assistant Secretary of the Navy for Research, Acquisition and Development. Other members of the Oversight Board were representatives from other offices in CNO and from the F/A-18 (PMA-265) and Tactical Aircraft Self-Protection (PMA-272) program offices in NAVAIR.

As shown in Fig. 1, a COEA is just one of the steps in the Department of Defense (DoD) acquisition process, which begins when the operational community expresses a need for an improved capability. This need is formally documented by the CNO requirements

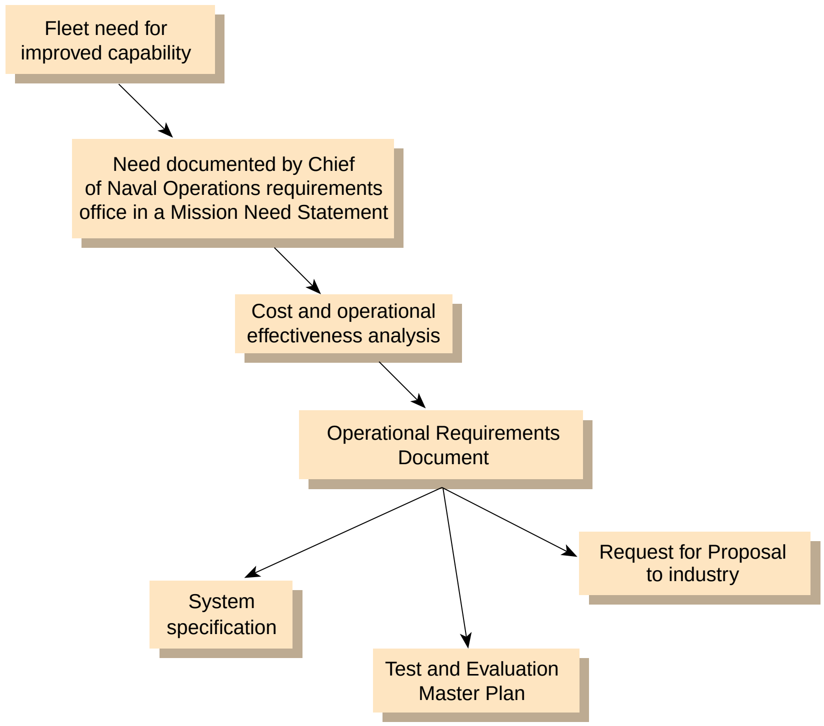


**Figure 1.** The steps in the Department of Defense acquisition process.

office in a Mission Need Statement. Although a Mission Need Statement identifies a need, it does not specify how that need should be addressed. That is the purpose of a COEA, in which analysis and simulation are used to evaluate the cost and performance of alternatives that may meet the identified need. The results of the COEA are also used to identify key performance parameters for the new system and to set thresholds for those parameters, which are included in the Operational Requirements Document. The Operational Requirements Document is, in turn, the basis for the Request for Proposal that is sent to industry, the specification for the new system, and the Test and Evaluation Master Plan. When the system is built and tested, the decision makers evaluate the performance of the system on the basis of the thresholds specified in the Test and Evaluation Master Plan, which must be linked to the results of the COEA.

For the F/A-18 EW suite COEA, the applicable Mission Need Statement was the Integrated Defensive Electronic Countermeasures (IDECM) Mission Need Statement. This document discusses several deficiencies related to tactical aircraft self-protection. Because of the nature of these deficiencies, the COEA was divided into two phases to allow the components of the EW suite to be acquired independently. In Phase 1, alternatives for the radio-frequency countermeasure (RFCM) portion of the F/A-18 EW suite were considered. RFCMs are designed to protect an aircraft from missile and gun systems that use radio-frequency (RF) signals for target acquisition, tracking, and missile guidance. These systems are referred to as "RF threats" throughout the remainder of this article.

In Phase 2, the results of separate COEAs for two other components of the EW suite were combined with the results from Phase 1 to determine the most cost-effective F/A-18 EW suite. APL was responsible for integrating the Phase 1 and Phase 2 results and performed most of the Phase 1 effectiveness analysis. This article describes the analysis methodology for Phase 1 and uses unclassified examples to convey the nature of the Phase 1 results. The actual Phase 1 results cannot be included in this article because they are classified. The numbers, ranges, and relative rankings shown are for illustrative purposes only; no actual capability is implied nor should be inferred.

## EFFECTIVENESS ANALYSIS

A block diagram of the Phase 1 effectiveness analysis process is shown in Fig. 2. This portion of the COEA consisted of one-on-one, mission-level (many-on-many), and multimission analyses. The primary purpose of the one-on-one analysis was to determine all of the inputs for the mission-level analysis. These inputs represented the effects of each EW suite alternative against each type of threat system in the operational scenarios. Digital Monte Carlo simulations were used to perform the mission-level analysis. For each alternative, each mission was performed multiple times to obtain statistically significant results. So that the alternatives could be compared on an equal-effectiveness basis, a series of missions was simulated until the mission objective was achieved in each case. Each part of the block diagram shown in Fig. 2 is described in greater detail in the following subsections.

### EW Suite Alternatives

The EW suite alternatives that were examined in Phase 1 ranged in capability from the system currently operational on the F/A-18C/D aircraft to systems proposed by industry in response to the IDECM Request for Information. All of the alternatives were approved by the COEA Oversight Board. Each alternative

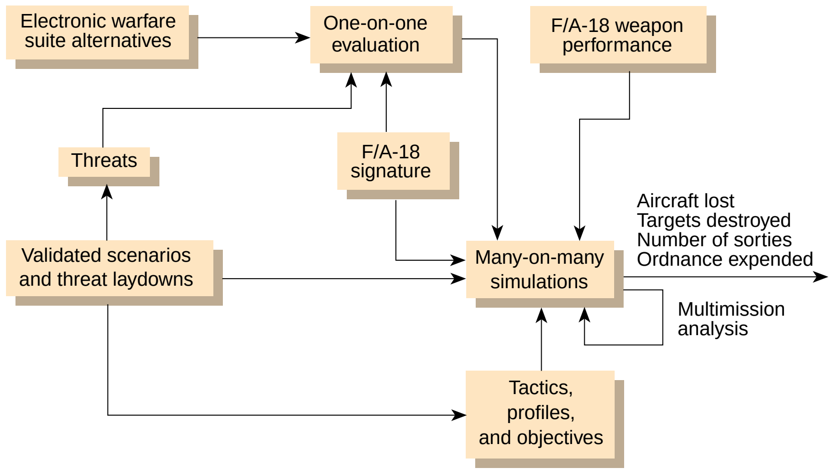


**Figure 2.** Block diagram of the cost and operational effectiveness analysis methodology.

consists of a common set of systems to which one or more RFCM systems are added. There are some differences between the F/A-18C/D and F/A-18E/F alternatives because the baseline suite that is currently operational on the F/A-18C/D differs somewhat from the baseline suite planned for the F/A-18E/F. For the sake of brevity, this article will only describe the alternatives that were considered for the F/A-18E/F.

For the F/A-18E/F, the common set of systems consisted of the ALR-67(V)3 radar warning receiver (RWR), a generic missile approach warning system (MAWS), the ALE-47 countermeasures dispensing system, and expendables. An RWR is designed to detect the RF signals transmitted by many threat systems. It can identify the type of threat (and, in some cases, the stage of the engagement sequence) by measuring signal characteristics such as frequency, pulse width, and pulse repetition frequency. A MAWS is intended to detect missiles approaching an aircraft and to provide a few seconds' warning time in which to perform last-ditch countermeasures (CMs). Various systems and technologies have been proposed for the MAWS. In Phase 1, a generic MAWS was modeled by specifying the MAWS performance without identifying a particular MAWS. The countermeasures dispensing system can dispense expendables on pilot command or automatically in response to cues from the RWR or MAWS. A variety of expendables can be deployed, including flares that are designed to counter missiles equipped with infrared (IR) seekers and chaff that is designed to counter RF threats.

In addition to the common set of systems, the F/A-18E/F EW suite alternatives included an onboard jammer or a towed decoy or both. A towed decoy is an RF transmitter that is towed a few hundred feet behind the aircraft. Two basic types of towed decoy were considered in Phase 1: the existing advanced airborne expendable decoy and a new fiber-optic towed decoy. The advanced airborne expendable decoy is basically a repeater with its own receive and transmit antennas. The fiber-optic towed decoy has only transmit antennas; its receive antennas and technique generator are on board the aircraft. When a threat signal is detected, the appropriate jamming modulation is created by the technique generator and sent across the fiber-optic tow line for transmission by the fiber-optic towed decoy. EW suites that included both an onboard jammer and a towed decoy could transmit jamming signals from the aircraft, from the decoy, or from both.

## Scenarios and Threat Laydowns

Two Defense Planning Guidance scenarios for the year 2010 were used as the basis for the scenarios examined in Phase 1. The threat laydown (i.e., the types of threats and their specific locations) for each scenario was taken from a Multi-Spectral Force Deployment database that was approved by the Defense Intelligence Agency.

## Tactics, Profiles, and Objectives

Since the F/A-18 is a multirole aircraft, three types of mission were examined in Phase 1: strike/interdiction, close air support, and air-to-air. Although F/A-18 aircraft may perform other missions, these three are the ones in which the EW suite will contribute most significantly to F/A-18 effectiveness and survivability. The objectives, plans, tactics, and flight profiles for each mission type were developed in conjunction with operational personnel and approved by the Oversight Board. Operational personnel included representatives of Experimental Aircraft Squadron Nine (VX-9), the Naval Strike Warfare Center (NSWC, or Strike U.), the Naval Fighter Weapons School (NFWS, or Top Gun), and the Marine Air Warfare Training Squadron One (MAWTS-1).

As noted previously, multiple missions of each type were simulated until the F/A-18 aircraft achieved a predefined objective. For strike missions, the objective was to destroy a certain percentage of the primary targets. For close air support missions, the objective was to completely destroy two targets (each one a group of three tanks). The objective for the air-to-air missions was to shoot down all four enemy aircraft.

## F/A-18 Signature and Weapon Performance

Descriptions of the radar cross section and IR signature of the F/A-18 were required to perform both the one-on-one and mission-level analyses. The signature data were obtained from the F/A-18 program office. Data on the performance and effectiveness of the weapons used by the F/A-18 aircraft in each type of mission were obtained from the Joint Munitions Effectiveness Manual and the Navy program offices responsible for each weapon system.

## One-on-One Evaluation

### *EW Suite Performance*

For any given EW suite, the CMs that the aircraft will use against a threat depend on many factors. For example, expendables and maneuvers may be used preemptively to counter threats that are unlikely to be detected by the RWR or MAWS. Additional expendables and maneuvers may be used reactively in response to RWR or MAWS warnings. In some cases, the desired response to a warning might be to dispense a particular sequence of expendables. However, sufficient expendables may not be available, so the pilot might have to choose some other response. To account for these possibilities, a hierarchy of CM options was developed for each EW suite. For example, if the suite included an onboard jammer, a towed decoy, and expendables, a notional list for a given threat might look like the following:

1. Dispense expendables; use the towed decoy and the onboard jammer.
2. Use the towed decoy and the onboard jammer.
3. Dispense expendables and use the onboard jammer.
4. Use the onboard jammer.

The first option is the preferred response, but if the aircraft has run out of expendables or lost all of its towed decoys, one of the other options will be used.

The performance of each threat system against the F/A-18 was characterized by a set of probability of kill ($P_k$) values, i.e., the probability that the F/A-18 would be killed by the threat during an engagement (missile salvo or gun burst). Both "dry" (without CMs) and "wet" (with CMs) $P_k$ values were developed for input to the mission-level models. The effect of CMs on the performance of each threat system was determined by a variety of methods, including modeling and simulation, an exhaustive review of existing test and analysis results, and use of expert opinion and engineering judgment. The result of this evaluation was a set of $P_k$ degrades (expressed as percentages). For each threat system and CM combination, the $P_k$ degrade is a measure of the reduction in $P_k$ of the threat caused by the CM. The wet $P_k$ values were then calculated from the dry $P_k$ values using

$$P_{k,\text{wet}} = (1 - \text{degrade}/100)P_{k,\text{dry}} .$$

For various reasons, including variations in F/A-18 radar cross section and RFCM signal strength with aspect angle, wet $P_k$ is typically dependent on engagement range and aspect angle. As a result, a $P_k$ lookup table (referred to hereafter as a "template") rather than a single value is required. A notional wet $P_k$ template is shown in Fig. 3. At the center of the template is the silhouette of an F/A-18 heading toward the top of the page. The color-coded regions show where CM performance is expected to be good (green), fair (yellow), or poor (red), and the numbers indicate the aircraft $P_k$ values in each region. The location of the threat site with respect to the aircraft at the time of intercept determines the $P_k$ value that is used to determine the outcome of the engagement. $P_k$ templates were developed for the following classes of threats: RF missiles, antiaircraft artillery guns, and IR missiles.

Because different types of RFCMs are effective at different times during engagements involving RF missiles, it was necessary to create two F/A-18 $P_k$ templates for each RF missile threat: one for the probability that the missile will reach the final engagement phase (FEP, defined as the last few seconds before intercept or closest approach), and the other for aircraft $P_k$ given that the missile reaches the FEP. The associated probabilities are denoted by $P_{FEP}$ and $P_{k|FEP}$, respectively. Notional $P_{FEP}$ and $P_{k|FEP}$ degrades are shown in Table 1. The first column under each CM is the $P_{FEP}$ degrade,

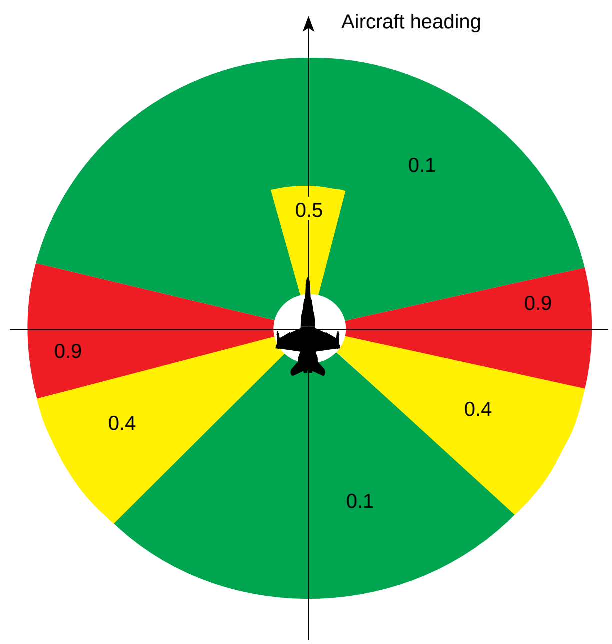


**Figure 3.** A notional probability of kill ($P_k$) template for one threat and countermeasure combination. The color-coded regions show where countermeasure performance is expected to be good (green), fair (yellow), or poor (red), and the numbers indicate the aircraft $P_k$ values in each region.

**Table 1.** Notional degrades (%) for radio-frequency (RF) missiles.

| Threat type | RF countermeasures | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | | B | | C | | D | | E | | F | | G | |
| 1 | 75 | 0 | 70 | 0 | 40 | 0 | 0 | 85 | 75 | 85 | 75 | 0 | 75 | 75 |
| 2 | 80 | 0 | 85 | 0 | 0 | 50 | 0 | 0 | 85 | 80 | 20 | 50 | 85 | 80 |
| 3 | 10 | 0 | 50 | 0 | 0 | 50 | 0 | 95 | 50 | 95 | 50 | 50 | 50 | 95 |
| 4 | 20 | 0 | 55 | 0 | 0 | 80 | 0 | 95 | 55 | 15 | 55 | 95 | 0 | 95 |
| 5 | 0 | 0 | 60 | 35 | 0 | 95 | 0 | 85 | 50 | 95 | 15 | 95 | 55 | 0 |
| 6 | 0 | 0 | 55 | 0 | 0 | 75 | 40 | 95 | 55 | 80 | 55 | 95 | 55 | 95 |
| 7 | 0 | 20 | 35 | 0 | 0 | 50 | 40 | 95 | 35 | 95 | 35 | 50 | 35 | 95 |
| 8 | 0 | 0 | 65 | 0 | 40 | 95 | 0 | 40 | 55 | 75 | 55 | 95 | 55 | 0 |
| 9 | 10 | 0 | 40 | 0 | 0 | 45 | 0 | 80 | 40 | 20 | 40 | 45 | 40 | 90 |
| 10 | 0 | 0 | 50 | 0 | 0 | 40 | 0 | 90 | 45 | 90 | 45 | 40 | 45 | 90 |
| 11 | 0 | 0 | 85 | 0 | 0 | 90 | 0 | 85 | 75 | 95 | 85 | 40 | 85 | 95 |
| 12 | 0 | 0 | 85 | 0 | 0 | 95 | 0 | 95 | 85 | 20 | 85 | 95 | 85 | 55 |

High (70–100%)
Low (10–39%)
Medium (40–69%)
None

Note: The first column under each countermeasure is the degradation to $P_{FEP}$, and the second is the degradation to $P_{k|FEP}$.

and the second column is the $P_{k|FEP}$ degrade. For example, there is a 75% degrade to $P_{FEP}$ and a 0% degrade to $P_{k|FEP}$ for RFCM A against threat type no. 1.

As noted previously, variations in F/A-18 radar cross section and RFCM signal strength with aspect angle give rise to $P_{FEP}$ and $P_{k|FEP}$ values that are a function of intercept range and angle. This is because, in general, jammers and towed decoys must produce a minimum jam-to-signal ratio to be effective. The $P_{FEP}$ and $P_{k|FEP}$ degrades were applied to the dry $P_{FEP}$ and $P_{k|FEP}$ templates only in the regions in which the jam-to-signal ratio was greater than or equal to the minimum value.

Dry $P_{FEP}$ values were set equal to a constant that was chosen on the basis of intelligence estimates of the reliability of the threat systems. The dry $P_{k|FEP}$ templates were developed from expected missile miss distances derived from test results and $P_k$ data as a function of miss distance provided by the Naval Air Warfare Center Weapons Division (NAWC/WD) China Lake, California. The $P_k$ data as a function of miss distance were generated using the Modular Endgame Computer Algorithm (MECA). Given the position of a particular missile type relative to an aircraft at the time of warhead burst, MECA models blast effects and traces warhead fragments through a vulnerability model of the aircraft to determine $P_k$. For this study, miss distance, warhead burst point, and intercept angle were parameterized in multiple MECA runs that produced the required $P_k$ data as a function of miss distance for each type of missile involved in the Phase 1 analysis.

To account for the possibility that an F/A-18 aircraft would survive an RF missile engagement but have a towed decoy shot off in the process, towed decoy $P_k$ templates were also created for each threat and decoy type. Among the considerations in this part of the analysis were missile guidance mode and missile fuze type, frequency, and operating mode. Towed decoy $P_k$ was an important consideration because a limited number of towed decoys will be carried by each F/A-18.

The dry $P_k$ templates for antiaircraft artillery gun threats and the $P_k$ degrades for preemptive maneuvers against these threats were developed using the Radar-Directed Gun Simulation. NAWC/WD China Lake made all of the radar-directed gun simulation runs that were required to assess the performance of each of the antiaircraft artillery threats involved in the Phase 1 scenarios.

The effectiveness of flares against IR-guided missiles was evaluated using the Threat Engagement Analysis Model, which was developed by the Air Force Information Warfare Center. The Threat Engagement Analysis Model results were verified by infrared CM experts at NSWC Crane, Indiana.

### *Threat Warning*

Since the use of CMs by the F/A-18 depends in part on the threat information available to the EW suite and the pilot, the performance of systems that provide threat warning (RWR and MAWS) must be included in the mission-level simulation. RWR performance was modeled by specifying a probability of detection of target tracking radar and of target illumination radar or missile guidance signals for each type of RF threat. The MAWS probability of detecting an approaching missile was the same for all missile types. The probabilities of the pilot's visually detecting an approaching missile were also input to the mission-level simulation. These probabilities were a function of missile type and angle of approach. The latter dependency arises from the fact that it is more difficult for the pilot to see a missile approaching from the rear of the aircraft than it is to see a missile approaching head-on.

## MISSION-LEVEL ANALYSIS

The two models used in the many-on-many analysis were the APL version of the Multiple Battlefield Engagements and Reactions (APL MBER) model and SUPPRESSOR. APL MBER was used in the surface-to-air analysis (strike and close air support missions), and SUPPRESSOR was used in the air-to-air analysis. Both models are mission-level, Monte Carlo models. A sufficient number of replications were made for each alternative to obtain accurate results. The principal outputs of the models are the number of F/A-18 aircraft shot down and the number of targets destroyed. In the interest of brevity and since the results of the strike mission were the most useful in differentiating between alternatives, the remainder of this article will focus on the methodology used in the analysis of the strike missions.

Substantial modifications to APL MBER were made so that the performance of the EW suite alternatives could be modeled properly. Figure 4 shows the logic used in APL MBER each time that an RF surface-to-air missile (SAM) engages an F/A-18. The boxes with rounded corners indicate branch points. At each of these six branch points, a uniformly distributed random number between 0 and 1 is drawn and compared to the appropriate user-input probability value. If the random number is less than that probability, the YES branch is selected; otherwise, the NO branch is selected. At the first branch point, the path that is chosen depends on whether or not the SAM site involved is firing at the aircraft for the first time. The decisions made at the remaining six branch points are based on the user-input probabilities.

The only input parameter identified in Fig. 4 that has not yet been defined is the probability that a pilot will jettison ordnance upon visual or MAWS detection of an approaching missile. Discussions with operational personnel indicated that in some circumstances the pilot would jettison his ordnance and execute a last-ditch maneuver in an attempt to defeat the missile during the last few seconds of the engagement. Although jettisoning ordnance (which allows a more drastic maneuver) may enable the aircraft to survive the engagement, it would no longer be able to strike its intended target(s), and a "mission kill" would result. In reality, a pilot whose aircraft has sustained a mission kill may choose to exit the threat area and return to

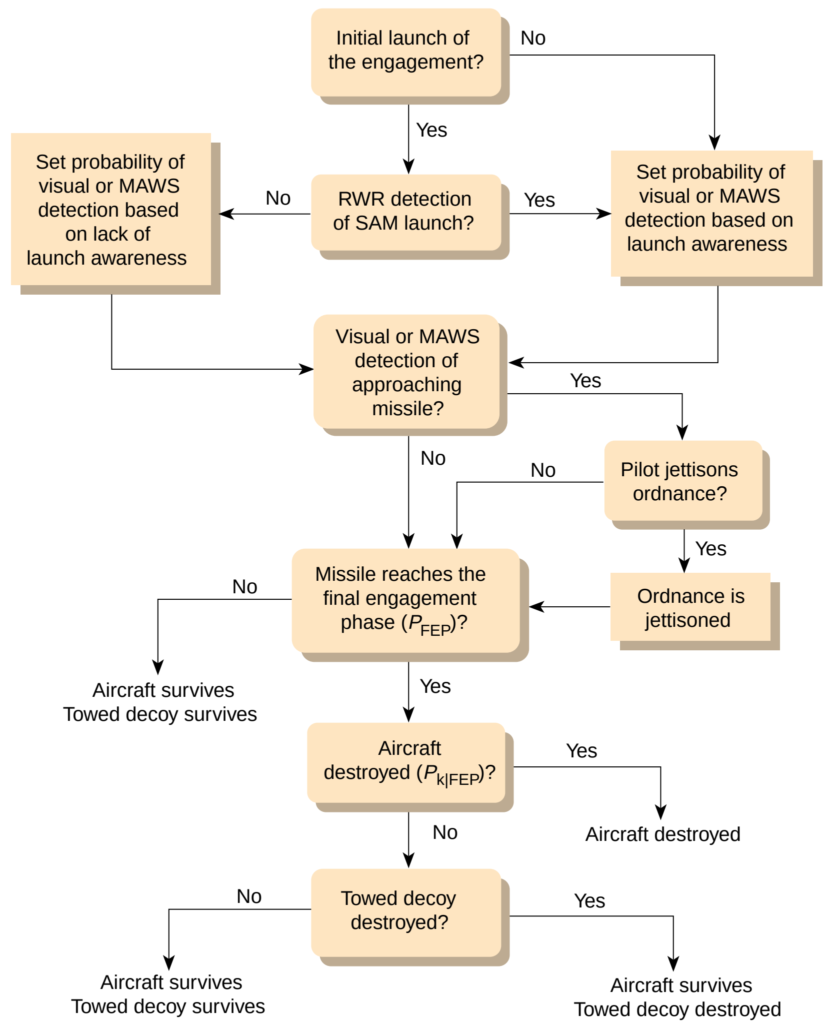


**Figure 4.** The logic used by the APL version of the Multiple Battlefield Engagements and Reactions (APL MBER) model to evaluate the outcome of an engagement by a radio-frequency surface-to-air missile (SAM). MAWS = missile approach warning system; RWR = radar warning receiver; $P_{FEP}$ = probability that missile will reach the final engagement phase (FEP); $P_{k|FEP}$ = aircraft probability of kill ($P_k$) given that the missile reaches the FEP.

base; however, because of APL MBER limitations, aircraft that jettisoned their ordnance continued on their preplanned flight path.

The two boxes labeled "Missile reaches the final engagement phase ($P_{FEP}$)" and "Aircraft destroyed ($P_{k|FEP}$)?" are where RFCMs can degrade threat performance. The CMs used at these decision points depend on the preemptive CMs being used, the detection of the approaching missile visually or by the MAWS, and the availability of expendables and towed decoys. Depending on these conditions, APL MBER selects the appropriate template from the user input data.

## MULTIMISSION ANALYSIS

As mentioned previously, Navy operational personnel planned the missions for each type of F/A-18 mission. For the strike mission, the mission planners opted for one or more initial strikes devoted solely to suppression of enemy air defenses (SEAD) because of the numbers and capabilities of the threat systems present in each scenario. During these strikes, referred to as standoff SEAD strikes, no F/A-18 aircraft entered the engagement envelopes of the threat systems. Instead, tactical air-launched decoys were used to stimulate the enemy air defense system, and long-range SEAD weapons were used to reduce the defenses. Once the defenses were degraded sufficiently, strike aircraft penetrated the envelopes of the remaining threats to attack the primary targets (e.g., bunkers, bridges, and hangars) and the remaining threat sites. A notional multi-axis strike plan is shown in Fig. 5. In addition to strike aircraft, each strike package included tactical air-launched decoys, standoff SEAD aircraft, and EA-6Bs for support jamming. F-14 aircraft on combat air patrol provided protection for the strike and SEAD aircraft from enemy fighters.

Since APL MBER is a mission-level model rather than a campaign-level model, a methodology was developed to permit the use of APL MBER for a multimission analysis. A block diagram of this methodology is shown in Fig. 6. APL MBER was used to obtain expected aircraft attrition, the expected number of primary targets destroyed, and the expected number of expendables used in each strike. A minimum of 100 replications was performed to obtain accurate estimates of these expected values. Of course, it was not necessary to make APL MBER runs to obtain results for the standoff SEAD-only strikes in which no F/A-18s entered the threat envelope. Therefore, in standoff SEAD strikes, no aircraft were lost, no primary targets were destroyed, and fixed numbers of expendables were used as preemptive CMs.

A variety of SEAD weapons were used during each strike mission. Some types of weapons are more effective than others. For example, it was assumed that if one type of weapon "killed" a SAM radar, the radar could be repaired or replaced by the time of the next strike. (However, it was also assumed that the radar could be repaired or replaced only once.) Rather than make additional modifications to APL MBER to account for such considerations, SEAD spreadsheets (one

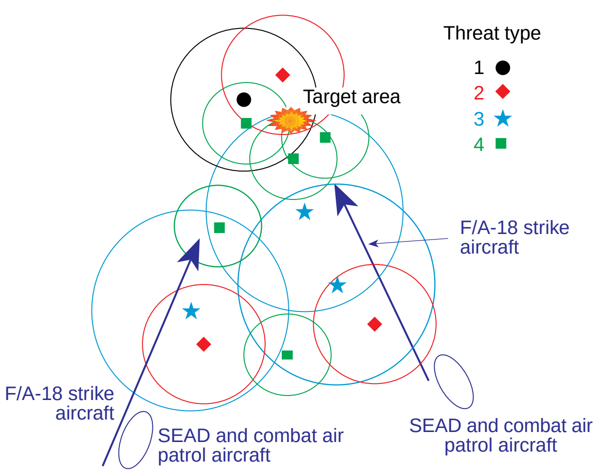


**Figure 5.** The flight paths of the F/A-18 strike aircraft and support aircraft (suppression of enemy air defenses [SEAD] and combat air patrol) are shown in this notional strike plan. The locations of the threat systems and their nominal engagement envelopes are also indicated.

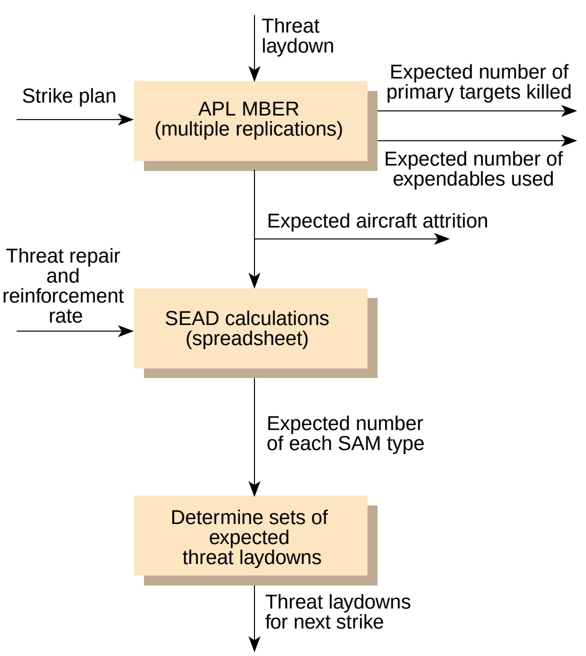


**Figure 6.** Block diagram of the multimission analysis process. SAM = surface-to-air missile; SEAD = suppression of enemy air defenses; APL MBER = APL version of the Multiple Battlefield Engagements and Reactions model.

for each SAM type) were developed. These spreadsheets use probability theory to calculate the expected number of SAM sites of each type remaining after each strike. The inputs to the SEAD spreadsheets include the numbers and types of weapons assigned to each site in each strike; the probabilities of targeting, acquisition, and kill for each weapon/target type combination; the threat repair and reinforcement rate; and expected aircraft attrition for that strike and all previous strikes in the series (from APL MBER).

The expected numbers of SAM types remaining after each strike were used to determine the threat laydown for the next strike. However, since the expected values are not integers and APL MBER accepts only whole numbers of SAM sites, it was necessary to create multiple threat laydown files for each strike after the first one in a series. The number of replications in which each file was used was determined by the probability of occurrence of the threat laydown described in each file, and the results of the replications made with a particular file were weighted by the associated probability of occurrence.

As a simple example, suppose there is only one SAM type in the scenario and the expected number of sites remaining after the first strike is 2.3. Then two threat laydown files would be required for the second strike. One laydown would have two SAM sites with a probability of occurrence of 0.7, and the other would have three SAM sites with a probability of occurrence of 0.3. If 100 replications of APL MBER were run for the second strike, 70 would use the file with two sites and 30 would use the file with three sites. The aircraft attrition and other results obtained using the two threat laydown files would be weighted accordingly to determine the outcome of the 100 replications. For example, if $A_2$ is the expected F/A-18 attrition for two sites and $A_3$ is the expected attrition for three sites, $(0.7)A_2 + (0.3)A_3$ is the expected attrition for 2.3 sites.

Of course, the situation was more complicated when there was more than one SAM type in the laydown. However, the procedure for calculating the results of a set of APL MBER replications was not fundamentally different; it simply involved more terms. Consider an example with two SAM types in the threat laydown, and suppose that the expected numbers of SAM-1 and SAM-2 sites remaining after the first strike are 2.3 and 1.6, respectively. Four threat laydown files are required for the second strike. The numbers of sites in each of the files and the probabilities of occurrence of each threat laydown in this example are as follows:

| Number of SAM sites | | Probability of |
|---|---|---|
| SAM-1 | SAM-2 | occurrence |
| 2 | 1 | $0.7 \times 0.4 = 0.28$ |
| 2 | 2 | $0.7 \times 0.6 = 0.42$ |
| 3 | 1 | $0.3 \times 0.4 = 0.12$ |
| 3 | 2 | $0.3 \times 0.6 = 0.18$ |

Extending the notation introduced in the previous paragraph, the expected F/A-18 attrition in this case would be equal to $(0.28)A_{21} + (0.42)A_{22} + (0.12)A_{31} + (0.18)A_{32}$.

Figure 7 shows the notional effect of multiple strikes on the expected numbers of enemy air defense sites and primary targets remaining after each strike for one EW suite alternative. In this example, there are 15 threat systems and 96 primary targets at the outset. The first two strikes were standoff SEAD strikes in which no primary targets were destroyed, but the expected number of threat systems remaining was reduced to less than four. In strikes 3 through 5, both air defense sites and primary targets were attacked. At the end of strike 5, the expected number of primary targets remaining is below the threshold shown on the graph, so the mission objective has been achieved, and no additional strikes are required.

For each mission type and EW suite alternative, the expected numbers of F/A-18 aircraft shot down, weapons

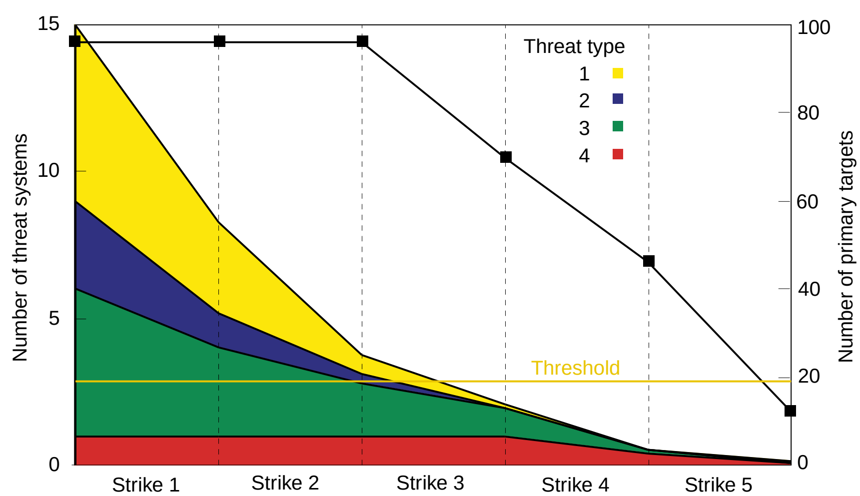


**Figure 7.** Notional results of a series of strikes. The color-coded portion of the plot (axis on the left) shows the number of threat systems at the start and finish of each strike. The black curve (axis on the right) shows the number of primary targets remaining. The mission objective is achieved when the number of primary targets remaining is less than the predefined threshold.

and CM expendables used, and aircraft operating hours spent accomplishing the mission objective were accumulated and fed into the cost-effectiveness portion of the analysis.

## COST ANALYSIS

While the Phase 1 effectiveness analysis was under way, a parallel effort to estimate the life cycle costs of each of the EW suite alternatives was being made by the cost analysis branch of NAVAIR (AIR-4.2.4.1) with assistance from NAWC Indianapolis. The acquisition strategy and production quantities were based on the approved IDECM acquisition plan. All costs were computed in constant Fiscal Year 1995 dollars, and sunk costs as of the end of Fiscal Year 1994 were not included. Furthermore, the EW suite life cycle costs do *not* include the equipment that is common to all of the alternatives (i.e., RWR, MAWS, countermeasures dispensing system, chaff, and flares).

The EW suite life cycle costs consisted of three components: development costs, production costs, and operation and support costs. Development includes design of the suite, building and testing of prototypes, and aircraft integration and testing. Production costs include procurement of the EW suite and installation on the aircraft. Operation and support costs were based on a 10-year life cycle and include spares, hardware and software maintenance, and logistics management. The spares and repairs for each suite were based on the system's "laboratory test" mean time between failures.

## COST-EFFECTIVENESS ANALYSIS

The cost-effectiveness of the various EW suite alternatives is determined by combining the results of the cost analysis with the results of the effectiveness analysis. This is done for each mission type and set of analysis conditions. One way to examine cost-effectiveness is shown in Fig. 8. In this type of presentation, the alternative with the lowest total cost is the most cost-effective. For the notional data shown in Fig. 8, EW suite D is the most cost-effective, with a total cost slightly less than that of EW suite C.

In Fig. 8, the total cost associated with each EW suite consists of three components. The first is the cost of the EW suites on the F/A-18 aircraft that were involved in a given type of mission. For example, if $n$ F/A-18 aircraft entered the threat envelopes in each strike mission (excluding the standoff SEAD strikes) and the F/A-18 aircraft are assumed to have an 85% availability rate, the expected number of F/A-18 aircraft required to perform the strike mission was $n/0.85$. Therefore, the EW suite cost for the strike missions was $n/0.85$ times the average unit cost of the EW suite.

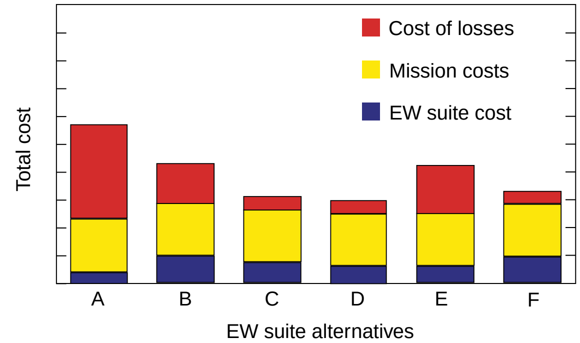


**Figure 8.** Notional cost-effectiveness of the electronic warfare (EW) suite alternatives. For this type of cost and effectiveness trade-off, the alternative with the lowest total cost is the most cost-effective.

The second cost in Fig. 8 is the mission cost. This includes the cost to operate each of the aircraft during the mission, the cost of all the weapons used during the mission, and the cost of all the expendables and towed decoys used during the mission. The third and final cost shown in Fig. 8 is the cost of the losses. It assumes that the value of a lost F/A-18 is the cost of replacing it with an F/A-18E/F in the year 2010, regardless of whether or not lost aircraft would actually be replaced. The cost of losses also includes the cost of training the air crew. However, it does not include intangibles such as the value of human life and the political implications of combat casualties. These factors must also be considered by the decision makers in the process of selecting the most cost-effective EW suite alternative.

## CONCLUSION

In general, when the threat level is low, the least expensive suite is the most cost-effective. As the threat level increases, the more effective suites become the most cost-effective. A similar effect will occur if an aircraft performs many missions. If the threat level in any mission is not zero, the most effective suites will become the most cost-effective suites as the number of missions increases.

## EPILOGUE

After the F/A-18 EW suite COEA was completed, NAVAIR developed an Operational Requirements Document and issued a Request for Proposal to industry for the RFCM portion of the IDECM suite. In the fall of 1995, after proposals from industry were evaluated, a contract was awarded to Lockheed Sanders and ITT Avionics to develop a towed decoy-based RFCM system for the F/A-18.[1]

## REFERENCE

[1] "Sanders, ITT to Build IDECM Decoy System," *Aviat. Week and Space Technol.* **20,** 87–88 (Nov 1995).

ACKNOWLEDGMENTS: Substantial support from other organizations was required to complete Phase 1 of this COEA. NAWC/WD China Lake provided $P_k$ vs. miss distance data for missiles and helped assess the performance of antiaircraft artillery threats. The cost analysis branch of NAVAIR, with support from NAWC Indianapolis, provided life cycle cost estimates for each of the EW suite alternatives. Other organizations, such as NAWC Aircraft Division (AD) Patuxent River and NAWC/AD Warminster, provided valuable assistance with RFCM effectiveness assessments. We also wish to acknowledge the other members of the F/A-18 EW suite COEA team at APL. S. M. Biemer contributed to many aspects of the COEA, including development of the analysis methodology, translation of the threat laydown and F/A-18 mission plans into input that the simulations could use, and assistance with the multimission analysis. J. E. Urban performed the one-on-one evaluation of flares against IR missiles and the mission-level simulation of the air-to-air missions. In addition to being the program manager, A. C. Williamson analyzed the threat systems, performed the RFCM coverage calculations, and helped translate the MECA results into $P_k$ templates. R. T. Cusick led the cost analysis at APL and was the primary interface with the government cost analysts.

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