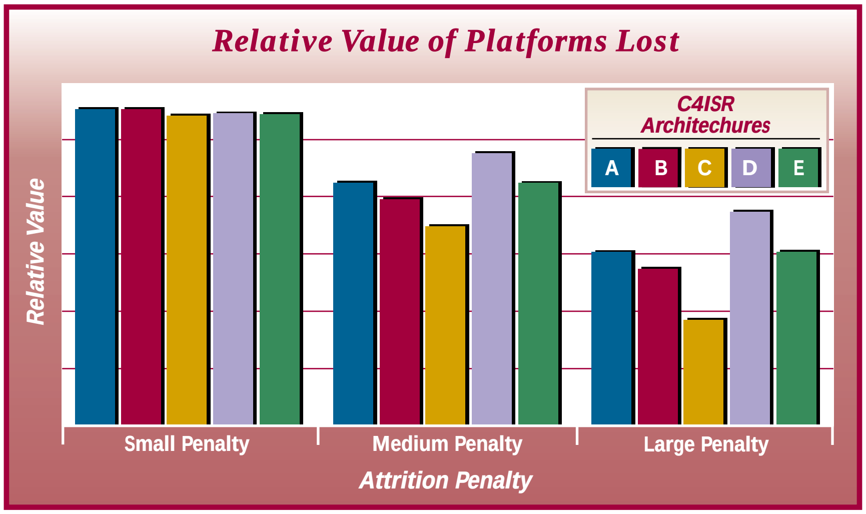

Figure 5. Relative Value of Blue Strike Platforms Lost as a Function of C4ISR Architecture and Penalty for Blue Attrition

as to optimally support a specific set of warfighting tasks from a system-of-systems perspective. Thus, this methodology and modeling construct can be used to show in a quantitative fashion the dependence of strike efficiency on the quality of targeting support—a necessary prerequisite to any analysis of potential C4ISR / strike system investment trades.

Example Results

ICATS began in 1998 as an IDA central research project. Subsequently, IDA was requested by both DARPA and OSD to use ICATS to examine the potential utility of selected ISR systems in a JSEAD / strike scenario and to explore potential tradeoffs between C4ISR and strike resources. Figure 5 shows an example result from this work. This chart shows how the relative value of Blue aircraft lost varies as a function of C4ISR architecture and the degree to which penalties are imposed for suffering attrition. As the attrition penalty increases, the absolute value of attrition decreases and the sensitivity of attrition to ISR architectural performance becomes more pronounced. Thus, as the commander's emphasis on minimizing attrition increases, the potential importance of ISR system performance also increases.

Future Directions

ICATS has significant potential for further expansion and improvement. One area that will receive particular attention in the coming year will be to develop and implement an ICATS analytic framework and tool set to support the analysis of C4ISR impacts on maneuver warfare.

AIM-9X: A Modeling & Simulation Success Story

INTRODUCTION

Since the end of WWII, the United States has been dominant in the arena of air-to-air combat. This dominance rests on the technological superiority developed and maintained by U.S. government laboratories and our nation's industry. The development of the Sidewinder and Sparrow in the 1950s and 1960s ushered in a new age of air-to-air combat based less on aircraft performance, and more on the performance of the sensors and computers needed to create effective guided missiles. This process has most recently resulted in the fielding of AMRAAM, the replacement for Sparrow and the preeminent radar guided missile in the world today. In the infrared domain of air-to-air guided weapons, after a slow start, the U.S. has initiated the development and acquisition of AIM-9X, the new generation of short range, infrared guided missiles.

AIM-9X brings to the air-to-air fight a missile with greatly increased range, speed, maneuverability, and most significant of all, the capability to shoot without the need to point the nose of the aircraft toward the intended target—a capability referred to as “off-boresight.” This off-boresight capability depends crucially on a specially designed aircrew helmet that allows the pilot to shoot at what he is looking at, without maneuvering the aircraft. Known as the Joint Helmet Mounted Cueing System (JHMCS), the helmet is being developed in parallel with the missile. Both programs are joint programs intended for immediate fielding on U.S. Air Force F-15 and F-16 aircraft and the Navy’s FA-18E/F aircraft.

From its inception, the AIM-9X program was viewed as a model for the “new way” of doing business, relying heavily on the concept of Integrated Process Teams (IPTs) and the use of modeling and simulation for much of the test and evaluation. With a very early mindset of collaboration between the various government agencies involved in the acquisition process, major issues were openly discussed and areas of possible conflict were resolved early in the program. For the AIM-9X program, the IPT process worked essentially as a form of peer review, allowing external criticism and open discussion before any decisions were made. A major outcome of this process was the decision to use modeling and simulation to assess weapon system performance in meeting the operational requirements. This decision was made possible by the identification of a statistical methodology to validate the primary simulation of the weapon system, known as the Integrated Flight Simulator (IFS), in a manner that could stand up to rigorous scientific scrutiny. The IPT that reached this consensus included the prime contractor (Raytheon Missile Co.), the Program Office, the operational test centers (AFOTEC and OPTEVFOR), DOT&E/IDA, the Joint Accreditation Support Activity (JASA), and a wide range of experts drawn from government, industry, and academia.

Figure 1. AIM-9X Missile

System Description

AIM-9X is built around the existing AIM-9 rocket motor and warhead and incorporates a new imaging infrared array for the seeker and a new fin design that integrates vector thrust control for maneuvering. The seeker processing is essentially implemented in software, so major improvements can be incorporated by a simple upload of new software. The flight control system relies totally on onboard kinematic sensors and computer control. This allows the missile to be dynamically unstable which, in turn, allows a significant reduction in the size of the stabilization fins, with greatly decreased drag and greatly increased range. The weapon can be slaved to the fire control radar, thereby allowing off-boresight launches (up to the limits of the radar) without the use of the helmet cueing system. With the helmet cueing system, launches at off-boresight angles exceeding 90 degrees are possible. Figure 1 shows a fully assembled missile.

Modeling and Simulation

Simulation was key to this program from inception. A roadway of modeling and simulation was laid out that would permit the operational testers to satisfy all system performance requirements through the use of simulation. To this end, the AIM-9X IPT invested heavily in the development of a Modeling and Simulation suite capable of replicating, in a fully deterministic way, actual AIM-9X missile performance (in terms of kill probability) against threat targets in a wide variety of realistic scenarios. These scenarios include a very wide range of engagement geometries and conditions, and extensive use of various backgrounds (i.e., clutter, blue sky, clouds, etc.) and countermeasures.

Led by the prime contractor, with strong Service and OSD scrutiny, a fully deterministic simulation capable of reproducing live fire results with high confidence was developed. Known as the Integrated Flight Simulation (IFS), it is a fully-digital simulation that uses a synthesized infrared target and background, simulated missile components, and the actual missile flight software. The output of a typical IFS missile engagement is a vector miss distance relative to the target, which is then processed through the government-furnished fusing / warhead model, known as the Joint Services EndGame Model (JSEM), to yield a kill probability for the engagement.

The IFS is built on first-principle knowledge of the physics involved and is supported by an extensive body of data collected through captive-carry flights and actual missile firings. The simulation is further supported by three complementary but independent simulations: the "PSIM" (a simulation of the target acquisition process); a hardware-in-the-loop (HWIL) simulation that evaluates the emulation of missile components; and the SPIL (signal processor in the loop), which is an independent, government-developed integrated AIM-9X simulation that incorporates actual missile computer elements and serves as an independent check on the Raytheon simulation. The overall test and evaluation strategy for the program is to validate the IFS using live missile firings against QF-4 targets and then to use the validated IFS to assess missile performance against the primary threat.

Validation of the kinematic performance of the missile has been completed through the use of unguided and guided missile flights. These flights have provided the aerodynamic data needed to compare missile flight performance to the IFS predictions. The agreement between flight data and simulated data is excellent. Figure 2 shows data comparing actual Mach numbers vs. simulated Mach numbers at any time in a flight. A total of about 2,000,000 data points are represented in the figure. The 90th percentile deviation (deviation from the 45 degree line) is less than three percent. Figure 3 shows an analogous plot for angle of attack.

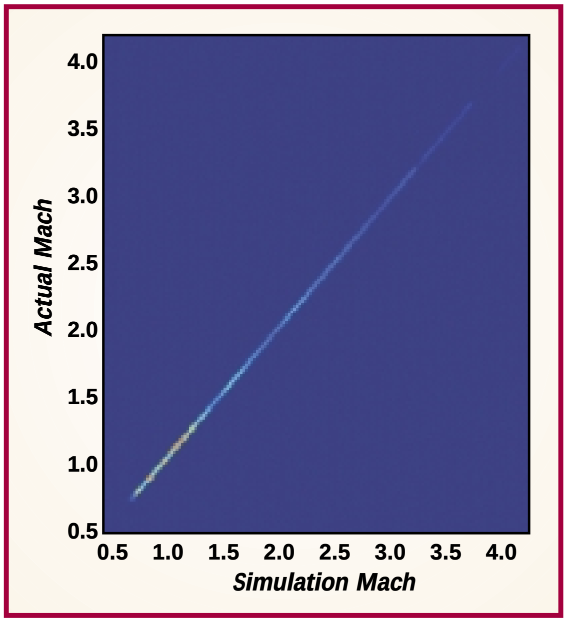

Figure 2.

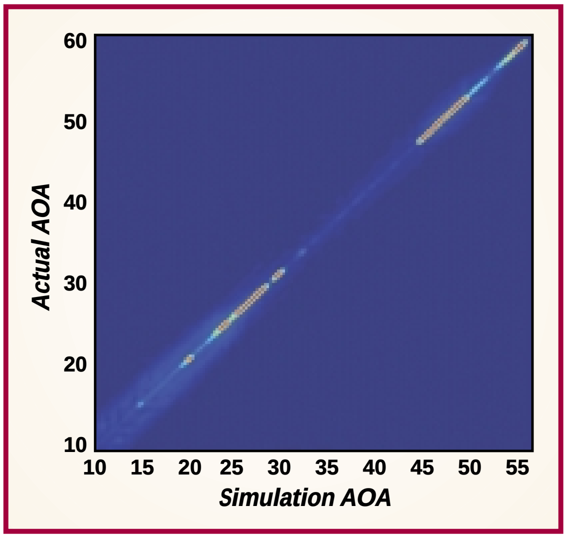

Figure 3.

For the assessment of kill probability, the IPT has identified and selected the use of a formal statistical test that compares simulation predictions with live missile flight results using vector miss distances. The test, known as Fisher's Combined Probability Test, brings scientific rigor to the validation process, an element that has been traditionally missing from most validation efforts. To date, there have been 13 guided missile firings which, when combined with the IFS pre-shot predictions of those flights and subjected to the formal test, show that the IFS is performing remarkably well. By the end of OPEVAL there should be a total of 25 missile flights available for validation, which will provide a more than adequate statistical sample. As a point of reference, this should be compared to the 166 live missile firings that were used to assess AMRAAM performance during its IOT&E.

The Fisher Validation Test

The Fisher validation methodology will be described in detail in an IDA paper now in preparation. The scheme, however, is easy to describe qualitatively. For any missile target engagement, the missile trajectory will pass through a point near the target's center of mass in a plane perpendicular to the direction of missile arrival. This point, called the point of closest approach, is not unique for any given set of initial conditions, but has a two-dimensional distribution or probability density function (PDF) arising from the fact that perfect repeatability from shot to shot is not possible. Natural variations in the controlling parameters result in some finite scatter, as shown in Figure 4.

The scatter plot of Figure 4 may be interpreted as a sampling of the "underlying" PDF for the shot. The kill probability of the shot is the mean value of the kill probabilities of each individual point in the plot. Generally, each point results in a 0 (miss) or a 1 (kill), but some near-misses may result in a non-integer probability. The goal of simulation is to predict this underlying probability density function.

In a real-world experiment, the underlying PDF would be predicted by a Monte Carlo set of simulated engagements leading to data like those shown in Figure 4. To validate the accuracy of the simulation, one could then compare the predicted PDF distribution to a number of live-fire missile shots, measure the points of closest approach for each, and then ask the statistical question: is the distribution of the live-fire points the same as the simulated distribution? To achieve any reasonable statistical confidence, this would require a large number of missile firings. The Fisher test allows the comparison to be made using only one real data point (live missile shot) for each underlying distribution (set of initial conditions) and allows the data from very different distributions to be combined.

The theory behind the Fisher test has its source in the property of cumulative distributions that makes a random sampling of such distributions uniformly distributed between zero and one. In our missile problem, the cumulative distribution is derived from the underlying PDF as determined by simulation and randomly sampled by a live-fire event. Figure 5 shows a hypothetical case where a live-fire result (red dot) is to be compared with the underlying PDF as determined by a set of Monte Carlo simulations (blue circles).

To apply the Fisher test, the simulated data points are first converted into a contour plot representing the underlying PDF for the event. Then the integral under the PDF from the peak value to the contour level containing the live-fire result is computed. One minus this value then defines the so-called "tail probability" for this event. This tail probability is not kill probability, but rather an

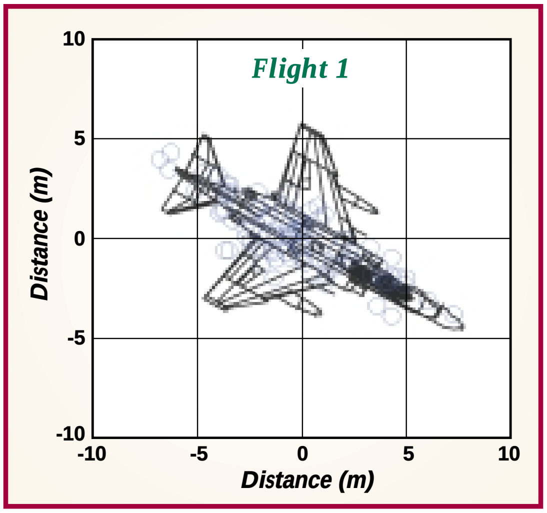

Figure 4.

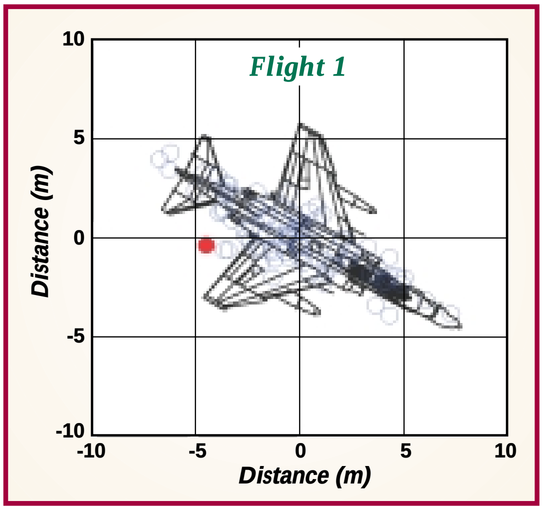

Figure 5.

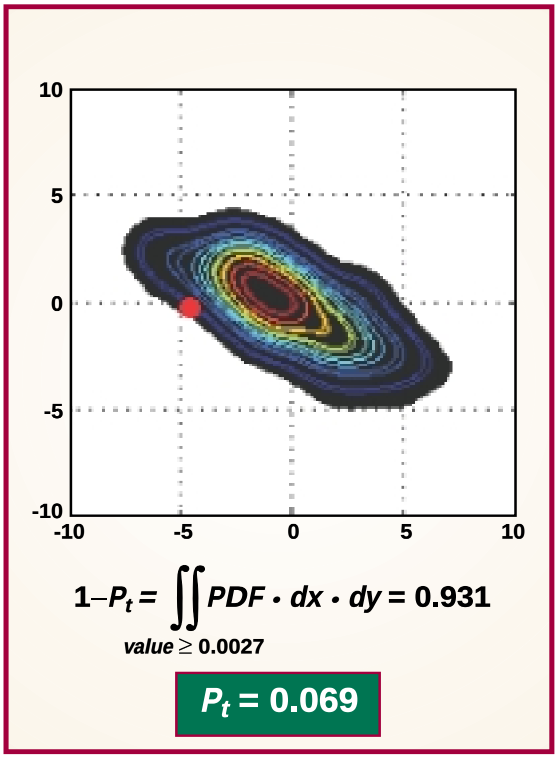

Figure 6.

indication of the agreement between the simulation and the real world data. As such, any set of such tail probabilities must be randomly distributed in the interval zero to one if the simulation accurately reflects the real world.

Figure 6 shows a schematic diagram of the procedure used to compute the tail probability. In this example, the live-fire datum (red dot) falls on the 0.0027 contour level and the resulting tail probability is 0.069.

Validation Results

To date, there have been 13 guided AIM-9X shots. Results from these shots as they relate to the validation process are shown in Figure 7. The figure shows the position of the 13 tail probabilities on the interval [0 - 1]. Although a formal test for uniformity and application of the Fisher procedure is necessary to arrive at a formal statistical result, it is clear from the figure that the data appear to be approximately distributed in a uniform manner, although a slight bias to small values might be present.

These data are preliminary and do not reflect measurement uncertainties. Despite the preliminary nature of the data and the uncertainties in the measurements, it is clear that there are no gross deficiencies. This implies the IFS is correctly representing the real world — a major accomplishment for any simulation effort.

It should be noted that this good agreement does not say anything about weapon performance. The agreement could be perfect, but the weapon could still be a total failure. Fortunately, this is not the case. AIM-9X performance has been excellent. Eleven of the 13 guided missile shots scored direct hits. More importantly, using the IFS to assess the weapon performance over the defining set of launch conditions defined in the requirements document shows that AIM-9X is well on its way to meeting all of its effectiveness parameters.

Conclusions

The AIM-9X program has demonstrated the benefits of a cooperative joint-Service IPT approach that involves the prime contractor, program management, Air Force and Navy developmental test organizations, the operational test centers (OPTEVFOR, AFOTEC), and OSD. The IPT process in this case has successfully produced a practical and credible simulation capable of supporting both missile development and operational test and evaluation in a way that will stand up to serious scientific scrutiny. This has allowed the AIM-9X program to reach milestones with a very limited number of live missile firings. This program stands as a bold example of how modeling and simulation can be used in a successful acquisition strategy.

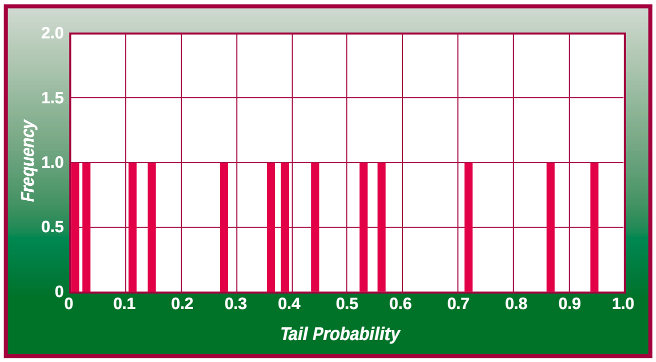

Figure 7.