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The Role Of Simulation In The Test And Evaluation Of A Man In The Loop Weapon System

Keith Matthew Henry
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Keith Matthew Henry entitled "The Role Of Simulation In The Test And Evaluation Of A Man In The Loop Weapon System." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

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We have read this thesis and recommend its acceptance:

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Accepted for the Council:
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Vice Provost and Dean of the Graduate School

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                                 Anne Mayhew
                                 Vice Chancellor and
                                 Dean of Graduate Studies

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THE ROLE OF SIMULATION IN THE TEST AND EVALUATION
OF A MAN IN THE LOOP WEAPON SYSTEM

A Thesis
Presented for the
Masters of Science
Degree
The University of Tennessee, Knoxville

Keith Matthew Henry
August, 2005

ABSTRACT

The Department of Defense has attempted to use recent advances in modeling and simulation to improve the acquisition process for weapons systems. This Simulation Based Acquisition brought advances in the process, but considerable disagreement remains over the universal applicability of this approach. This paper focuses on the challenges of applying modeling and simulation to the Test and Evaluation of a weapon system with significant Pilot-Vehicle interface concerns.

The Standoff Land Attack Missile Expanded Response (SLAM ER) is an aircraft-launched missile with GPS/INS guidance for navigation to the target area and Man In The Loop (MITL) control in the terminal phase. The MITL control is conducted through a two way video and control data link which transmits infrared video from the missile seeker to the control aircraft and guidance update commands from the pilot back to the missile. After initial fielding of the weapon system, two preplanned product improvement programs were begun to add both an Automatic Target Acquisition (ATA) functionality to aid in pilot target identification as well as a capability to engage moving targets at sea (ASuW). Both Software in the Loop and Hardware in the Loop simulations were available for the testing of both these SLAM ER improvements. This paper focuses on the utility of this simulation support in the Test and Evaluation prior to delivery to the operational users. Though the management issues of cost and schedule can be large drivers in the use of modeling and simulation, this paper will focus on the performance aspect of weapon system evaluation.

Through the course of both the ATA and ASuW evaluations, simulation was able to provide very limited contributions to evaluations of system performance when MITL control was a concern. Simulation was useful in providing data on easily quantifiable parameters, such as seeker scan rates. However, flight tests with a physical prototype provided the only effective data when subjective measures such as pilot workload and pilot target identification were a concern. The simulators available did not effectively replicate the pilot interface or workload environment to the level required for valid MITL data. Only when an issue with the pilot interface was easily defined in quantifiable engineering data was simulation useful in identifying a possible solution – one that had to be further evaluated in subsequent flight testing.

As the quality of models and simulations continue to improve with advances in computing, modeling of the pilot vehicle interfaces may improve in the future. Until that time, management controls will be essential to correct application of modeling and simulation in areas where MITL is a concern. The development of models and simulations should begin early in the acquisition effort with robust verification and validation devoted to the pilot interface. Early identification of the areas in which simulations can contribute to the MITL evaluation effort as well as recognition of the limitations of models and simulations. Finally, the validated simulations should be viewed as an enhancement to the evaluation effort with live testing of the physical prototype forming the basis of the MITL evaluation, particularly when the system approaches the final phases of Developmental Testing and prepares for Operational Testing.

PREFACE

The presentation of this material, to include analysis, opinions, conclusions and recommendations, represents solely the views of the author and is not meant to imply an official position of the United States Navy, the Naval Air Systems Command or any of its subordinate offices. This document is intended solely for fulfillment of the author's thesis requirements. Although the author was the Flight Test Pilot and Project Officer for the majority of these evaluations, the testing referenced in this document was conducted solely in support of an approved Developmental Test and Evaluation program. Portions of the information contained in this thesis were derived from publications not readily available to the public, limited distribution documents. However, none of the information in this thesis is classified.

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ABBREVIATIONS

ASuW	Anti-Surface Warfare
ATA	Automatic Target Acquisition
ATR	Automatic Target Recognition
AWDL	Advanced Weapon Data Link
DOF	Degree of Freedom
DT&E	Developmental Test and Evaluation
GNU	Guidance and Navigation Unit
GPS	Global Positioning System
HWIL	Hardware in the Loop
IR	Infrared
MC	Mission Computer
MCOFS	Mission Computer Operational Flight Software
MITL	Man-In-The-Loop
NAS	Naval Air Station
NAWS	Naval Air Weapons Station
OT&E	Operational Test and Evaluation
OA	Operational Assessment
PMA	Program Manager Aircraft
PP	Preplanned
SLAM	Standoff Land Attack Missile
SLAM ER	Standoff Land Attack Missile Expanded Response
SSV	Software Suite Version
SVS	Software Validation Station
SWIL	Software in the Loop
T&E	Test and Evaluation
TOO	Target of Opportunity

CHAPTER I
WEAPON DESCRIPTION

Program History

In the mid-1980's a requirement was created for a long range, standoff weapon capable of high accuracy. To fulfill the requirement, one company, hereafter referred to as the Contractor, developed a weapon using primarily parts of various currently fielded weapons. The core of the weapon was the Harpoon anti-ship missile. Using the engine, flight controls, warhead and navigation system, the Contractor placed an infrared seeker on the front, a data link on the back, and added a GPS receiver. After updating the mission computer software, the missile was fielded as the Standoff Land Attack Missile (SLAM). This weapon allowed the aircrew to remain over 50 nm from a target and hit the target with notable accuracy.

However, after many years of operational experience, a number of shortcomings in the system were noted. SLAM was a very difficult weapon to mission plan. It was not well integrated into the various aircraft which carried it. The standoff range, though notable, was becoming insufficient for some threats fielded in the 1990's. The infrared seeker did not produce video images of a high enough quality for high confidence target identification. And finally, the operator interface was not user friendly.

To compensate for these shortcomings, a new program was initiated. This program was designed to update the baseline SLAM system in an attempt to eliminate most of these shortcomings. The Contractor retained the infrared seeker and the Harpoon engine, but made a number of significant modifications. The navigation system was replaced by a much more accurate system. The mission computer was updated with an improved aircraft interface. The warhead was totally redesigned. The data link was greatly improved over the SLAM system. New wings and fins were added for greater range and maneuverability. The new weapon system, called Standoff Land Attack Missile Expanded Response (SLAM ER), was successfully fielded in 2000. Many of the shortcomings of the baseline SLAM were overcome by the new SLAM ER.

Missile Description

General

SLAM ER combines various off the shelf components to provide a highly accurate, standoff targeting capability. A diagram of the various components are shown in figure A-1 in the Appendix. The missile can be launched over 75 nm from the target. It will navigate to the target area via a preflight planned mission route. Once in the target area, SLAM ER will transmit IR images of the target back to the launching aircraft, normally stationed over 75 nm away. The pilot in the controlling aircraft can then send targeting updates to the missile based upon the infrared seeker images.

SLAM ER can be launched in one of three modes: Preplanned (PP), Target of Opportunity Land (TOO Land), or Target of Opportunity Anti-Surface Warfare (TOO ASuW). In the PP mode, up to three missions are planned on a mission planning computer prior to takeoff. None of the mission parameters can be modified by the pilot after takeoff. Once launched, the missile will navigate to the target area via the planned

route. In the target area, the missile will radiate infrared video and allow the pilot to update the desired aim point. In the TOO modes, the mission parameters can be modified by the pilot after takeoff. Like PP, the TOO modes are programmed for the missile to radiate infrared video in the target area allowing the pilot to update the aim point. Designed for use against moving targets, TOO ASuW has the added ability for the pilot to provide updates in target position via data link to the missile after launch but before seeker video is transmitted.

Guidance Section

The guidance section of the missile consists primarily of the seeker, the Guidance/Navigation Unit (GNU) and the Advanced Weapon Data Link (AWDL). The infrared seeker is used in terminal guidance to generate a video scene of the target area. Two fields of view, narrow and wide are selectable by the controlling pilot. The seeker internally has the necessary signal processing for target lock-on and tracking once commanded by the pilot. The GNU consists of the Mission Computer (MC), a ring laser gyro assembly, an Air Data System and a GPS receiver. All the mission data is stored in the MC and is acted upon post launch. The mission data provides the navigation system with necessary information to navigate the missile into the target area prior to the missile radiating seeker video. The Advanced Weapon Data Link (AWDL) provides an RF link between the SLAM ER and the control aircraft. The AWDL transmits seeker video from the missile to the control aircraft, and receives post launch Man-In-The-Loop commands from the control aircraft.

As an aide in training for actual employment, a simulation mode was provided in the design of SLAM ER. In this mode, the missile is flown through a route while loaded on the wing of an FA-18. At the launch point, the pilot carrying the weapon selects an option which actives the guidance section but does not release the weapon. The pilot then flies the preplanned route and the weapon will transmit target area video for targeting via data link. The pilot can transmit targeting updates to the missile which are reflected by corresponding refinements in the missile seeker pointing. This simulation mode was used extensively during the test and evaluation of the weapon system during development in order to reduce the number of missile firings required. Though it could be argued this capability was a contribution of simulation to the Test and Evaluation effort, this paper will attempt to focus on simulation used outside of flight testing. This simulation mode of SLAM ER did not reduce the data collection requirements in live testing with a physical prototype. It merely reduced the number of live missile firings required.

Warhead Section

The warhead/exercise section contains the warhead, planar wings, and the Wing Deployment Unit. The planar wings are folded under the missile body during carriage on the aircraft. After launch, the wings are deployed by gas generators within the Wing Deployment Unit. When fully extended, the wings provide improved aerodynamics and increased range over the baseline SLAM.

In some missiles, the warhead is replaced by test electronics. The section contains a telemetry system, a beacon, a flight termination system and an antenna. These

systems are used to monitor various missile parameters real-time and to provide tracking and termination capabilities during live fire evolutions in a test environment. Missiles so equipped are labeled exercise missiles.

Sustainer Section

The sustainer section, unchanged from Harpoon and baseline SLAM, contains the fuel tank and a turbo-fan engine. As an upgrade over baseline SLAM, the engine speed is adjustable by the GNU to further increase SLAM ER's range.

Control Section

The control section contains the control fins and their actuators as well as the AWDL antenna. The control actuators drive the fins based upon signals sent from the GNU. The AWDL antenna is mounted on the control section to optimize the RF path to the control aircraft for transmitting video and receiving commands.

Anti-Surface Warfare

Background

During the original SLAM ER evaluation, some issues were discovered with the ASuW mode. Due to the desire to rapidly deliver the SLAM ER capability to the operational Navy, the decision was made to release the missile with PP and TOO Land modes, but without a clearance for the ASuW mode. In the meantime, changes were made to the missile software and these modifications were incorporated. This software update also provided ATA capability, for testing purposes only. This software update was designated MCOFS 1.5.

The Moving Target Problem

The significant standoff range which SLAM ER permits created a problem with a moving target. The potential exists that a fast moving target could be outside the seeker field of view after an extended flyout against a specific Latitude and Longitude. To rectify this problem, SLAM ER incorporated a method by which the launching aircraft could pass updated target coordinates to the missile after launch. This option required the aircraft to have a target tracked via other sensors. With this track information, the pilot could send the updated coordinates to the missile via the AWW-13 Data Link Pod. Upon receiving the new coordinates, the missile would then navigate towards the new coordinates. Called a Course Update, this action could be performed as often or as little as the pilot desired during the missile time of flight.

Even with the ability to pass real time coordinates to the missile during missile flyout, it was believed there still existed the possibility the missile would not be staring directly at the target when the seeker video was transmitted in the vicinity of the target. For this reason, a second feature was added in the TOO ASuW mode - a scanning seeker. When the video was transmitted to the aircraft, the seeker would stare at the target coordinates for six seconds and then commence a scan. The volume of the scan was dependent upon a number of factors, including distance from the target and time since last Course Update. The scan would progressively increase in volume until it reached a maximum value (in degrees left and right of course line). Sending a Course Update

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would reset the scan volume down to a smaller value. Once the pilot identified the target in the seeker video, he could stop the scan and designate the target for more accurate terminal guidance.

Automatic Target Acquisition

Background

Even though SLAM ER provided numerous improvements over baseline SLAM, it was still handicapped by the low quality of the infrared seeker video. The highly accurate navigation system coupled with the greatly improved pilot interface masked many of the problems with late target identification. However, an improvement was needed. Rather than take the high risk and costly approach of adding a new seeker, another approach was undertaken. The missile was outfitted with the hardware and software required for the missile to attempt to identify the target in the infrared seeker field of view. The capability, called Automatic Target Acquisition (ATA), was intended to provide cueing to the pilot to aide in target identification. The pilot could then use the cueing to prosecute the target with increased confidence

Hardware description

The hardware and software was an off the shelf solution used in another weapon system. The hardware addition to the missile was called an Automatic Target Recognition (ATR) unit. During mission planning, satellite imagery is downloaded to a mission planning system. The imagery is modified for the specific mission, formatted for download to the missile and stored on a memory unit. After aircraft engine start, the imagery is then downloaded from the memory unit to the missile and stored in the ATR unit. After missile launch, the missile navigates to the target via normal means. Once the missile closes on the target and the infrared seeker is operating, the ATR unit attempts to obtain a scene match between the seeker video and the stored image. This was done by grabbing frames from the infrared seeker, rotating and scaling both the seeker and satellite images, and then attempting to match the two. Once a match was obtained, the information was passed to the GNU for display to the pilot via the data link. If the pilot did not take control of the missile, the SLAM ER mission computer could slew the seeker to the target at close range if sufficient thresholds had been met and the match from the ATR unit was tagged as high confidence. For the purposes of this thesis, the term "ATA" will be used to refer to both the process and capability described in the above paragraph. In the limited instances where this thesis refers to the installed hardware, the term "ATR unit" will be used.

AWW-13 Data Link Pod Description

The AWW-13 Data Link Pod is an external pod carried on a weapon station on suitably configured aircraft. It is designed to permit two way data link communications with compatible weapons after launch. The data link permits the reception of video from weapons as well as the transmission of control signals to the weapon. The AWW-13 has internal antennas which are used for both the transmission and reception of signals. In addition to the transmitter and receiver hardware, the AWW-13 has an internal video recorder for mission recording as well as interface wiring for the carrying aircraft. The

interface wiring permits weapon video to be presented in the cockpit for pilot display as well as for receiving command signals from the aircraft for transmission to the weapon.

The AWW-13 Data Link Pod could be configured for either autonomous or cooperative modes of control for SLAM ER. In the autonomous mode, the aircraft which fired the SLAM ER would also control the missile in the terminal phase. In this case, with the aircraft carrying both a SLAM ER and an AWW-13 Data Link Pod, the pod would automatically configure itself to control the missile once the missile was launched. As an alternative, the launch and control responsibilities could be split between two aircraft. This second aircraft, carrying an AWW-13 Data Link Pod, used the cooperative mode. The cooperative mode required more extensive cockpit setup than the autonomous mode. However, once a given AWW-13 Data Link Pod was properly configured, the signals transmitted to SLAM ER were identical. This design permitted multiple aircraft to be available to control a given missile.

FA-18 Description

The FA-18C Hornet is a single piloted, twin engine, strike fighter aircraft. The aircraft is powered by two General Electric F404 turbofan engines with afterburner. Maximum fuel capacity is 16,460 pounds (10,160 pounds internally, and 6,300 pounds in a maximum of three external fuel tanks). The FA-18D, a two seat version flown primarily by the U.S. Marine Corps, has identical capabilities as the FA-18C, but carries slightly less fuel. The FA-18C/D can employ both air-to-air and air-to-ground weapons including Harpoon, SLAM, and SLAM ER.

Tactical displays for the pilot are presented on any of three digital displays. The three displays present information in a multi-color format. The information presented can be any combination of raw video or aircraft computer generated symbols. The displays are surrounded by 20 pushbuttons which are used to make selections from display driven menus. Additional tactical controls may be exercised through a variety of throttle and control stick mounted switches. These controls, known as Hands on Throttle and Stick (HOTAS), allow the pilot to exercise certain tactical options without releasing the aircraft controls. The options available to either a display push button, control stick switch or throttle switch are driven by the specific display presented at the time of switch actuation. A complete description of the FA-18C/D aircraft is contained in the Naval Air Training and Operating Procedures Standardization (NATOPS) Manual.

Any FA-18C/D aircraft configured with the then current Software Configuration Set (SCS) 13C or later could be used to support SLAM ER, however, SCS 15C Build 4.2 or later was required to support ATA. The test aircraft used in the conduct of the tests referenced in this thesis were configured with a variety of additional equipment to enhance data collection. Any one of a number of cockpit video recording systems were installed to document the controls and displays presented to the pilot. All Bus (ALBUS) recorders were installed in order to monitor and record computer bus traffic between the aircraft avionics systems. The aircraft were configured with internal beacons or external tracking pods for improved ground tracking during flight events. The test aircraft also included RF telemetry of selected aircraft parameters which were monitored real time and recorded for subsequent analysis.

CHAPTER II
GOVERNMENT TEST AND EVALUATION

The Program Manager

Overall program management responsibilities for a weapon system rest with the Program Manager Aircraft (PMA). The responsibilities of the PMA cover the full life cycle of the weapon system - to include product conception, test and evaluation, production, operational Navy delivery, and program termination. Though the testing of a new weapon system is an important part of the life cycle, it represents a small fraction of the overall program management concerns for the PMA.

The Contractor

Like the PMA, the Contractor is concerned with and involved in the full life cycle of the weapon system. However, unlike the PMA, a major portion of their effort is devoted to the development and testing of the weapon system. During the product development phase, laboratory, ground, and limited flight testing is performed by the Contractor. This testing both satisfies their performance concerns as well as helps in meeting the contractual requirements. The laboratory testing involves component level testing and development of the software and hardware using models and simulations. The ground testing is limited to emulators which simulate the aircraft interface. For most weapon systems, contractor flight testing is limited to the flying of portions of the weapon system on a system test bed, rather than on the actual combat aircraft for which the weapon will ultimately be fielded.

Government Test and Evaluation

In an attempt to provide a government evaluation, the PMA contracts out to a government Test and Evaluation (T&E) Office to perform laboratory, ground and flight testing of new missile systems. The SLAM T&E Office, based at Naval Air Station (NAS) Point Mugu, CA, is responsible for the Developmental Test and Evaluation (DT&E) of the Harpoon missile, SLAM, and SLAM ER.

A second layer of Government evaluation has been in place since the 1980's. This follow-on phase is known as Operational Test and Evaluation (OT&E). Unlike the DT&E Office which is funded by the PMA, OT&E is funded and answers to a chain of command outside of the T&E community. This system was designed to provide a more independent, final evaluation of a weapon system before it is fully paid for and fielded. A second important distinction between Developmental Testing and Operational Testing is the pilots involved. In Developmental Testing, the pilots are Test Pilots to provide the necessary engineering background as well as ensure a certain level of safety. In Operational Testing, the pilots are direct from the operational Navy to ensure the system is suitable for all pilots.

During the early phases of DT&E, the government T&E office is intimately involved with the engineering and design of a weapon system. This focus has to shift as the system approaches the end of DT&E. The closer the evaluation is to completion, the more the focus must be on the operational utility of the weapon system. A perfectly

engineered system would be useless if it is not operationally useable. By having this operational focus towards the end of an evaluation, the DT&E effort will minimize the chances of a failure during OT&E and maximize the chances of the operational Navy ending up with a truly enhancing system.

Members of the T&E Office may observe testing done by the Contractor during the development phase of a weapon. The degree of T&E Office involvement will vary between programs based upon the level of integration between the government and contractor teams as well as the product development timeline. In the case of SLAM ER, this observation was relatively limited and did not constitute the official evaluation phase for the government team. Regardless of the level of integration in the early development phases, the Contractor will ultimately deliver prototypes to the T&E Office for an independent evaluation. Some initial testing may repeat laboratory testing done by the Contractor. However, the majority of the focus is devoted to ground and flight testing of the weapon on the ultimate aircraft. In many cases, this portion of the weapon development is the first time the weapon has fully interfaced with an actual aircraft and flown on that aircraft.

The degree of the upgrade or modification determines the level of testing required in each case. In the case of both ATA and ASuW, these were upgrades to an already proven weapon system. As such, the focus in the government testing was toward limited ground testing to ensure safety of flight items, immediately followed by actual flight testing to fully exercise the weapon in an operationally representative environment.

The end product of any government weapon system evaluation is at the discretion of the PMA. The end product tends to vary based upon the degree of the modification or upgrade. For the original release of SLAM ER, the SLAM T&E Office produced an extensive report detailing all aspects of the evaluation and the weapon system. This reporting requirement was significantly reduced in the case of ATA. The formal report was very limited in scope and focused primarily on the overall effectiveness. ATA was a new capability, but it still represented a relatively minor modification to an existing weapon system. In the case of ASuW, the report was even more limited, in the form of a short Naval Message to the PMA.

Simulation Based Acquisition

With the recent improvements in computing power, modeling and simulation have developed a more integral role to the defense acquisition process. This has been a continually evolving process within each phase of the acquisition process. However, recent Department of Defense guidance has incorporated a push to ensure that the use of modeling and simulation is integrated across all the phases of an acquisition process. This emphasis is an effort to ensure that the efforts in modeling and simulation in the initial requirements process directly support and grow into the engineering and development process. These efforts should then flow into the T&E process and ultimately support fielding and training with the system in the operational Navy.

Within the T&E phase, the mindset has historically been one of build, test, fix, test. This process would continue iteratively until a design suitable for operational use was produced. By integrating modeling and simulation into the early phases of acquisition and ensuring their growth into the T&E process, the belief is that this

historical T&E mindset will change. STEP is the acronym associated with this mindset change and it stands for Simulation Test and Evaluation Process. With STEP, the past T&E process should become one of model, simulate, fix, test, iterate. This process consumes the early part of development and the contractor proceeds to prototype only when the model is mature. This ensures the T&E process is starting with a more complete system.   Additionally, the early phases of the T&E process should support model and simulation refinement. This allows the models and simulations to be validated to the level that they can be reliably used to support the conclusions T&E is striving for.

DOD Directive 5000.2R mandates the use of modeling and simulation throughout the life cycle of a weapon system. Furthermore, it directs modeling and simulation to be used as an integral part of T&E. However, it also directs the use of actual systems or meaningful surrogates for OT&E. A weapon system may not proceed beyond the low rate initial production decision based solely on modeling and simulation for OT&E.

CHAPTER III

TEST AND EVALUATION EQUIPMENT

Ground Test

A test facility called the Missile Subsystem Test Set (MSTS) was located at NAS Point Mugu. This was a facility for robust functional test of SLAM ER rounds. The system was built primarily by the Contractor and was supported by them with software updates. The system permitted power up and testing of the subsystems within the missiles. The tests could be run on both full up rounds with live warheads and exercise rounds with test packages installed in place of the warhead. Though each missile delivered by the Contractor would be subjected to the MSTS as a first step, this was not an integral part of DT&E. Rather, this was used as a baseline to establish properly functioning missiles and to identify possible defective missiles. The tests conducted by this facility could be used to establish reliability data. However, the interface was not robust enough to be viewed as a HWIL level of test equipment to support DT&E.

Additionally, SLAM ER specific test boxes were supplied by the Contractor. These boxes presented less robust test capability over the MSTS. They were used primarily to support on-site tests for aircraft related events. These boxes also provided limited ability to isolate problems on-site for weapons deployed in the Navy. Once again, these boxes were not used in the T&E process, other than to support reliability data.

Since SLAM ER was designed and delivered as an All-Up Round, the government T&E facilities for ground testing focused on interfacing with the entire missile system, rather than individual components. As such, the interfaces for ground DT&E of the rounds were designed primarily to test and evaluate the aircraft interface. In the majority of cases, this involved build-up testing to verify proper aircraft-missile interface prior to flight testing. Simulated aircraft interfaces were available through the Advanced Weapons Laboratory at Naval Air Weapons Station (NAWS) China Lake. These interfaces used a mixture of HWIL and SWIL setups to verify missile responses to aircraft signals. After initial testing in this manner, the missiles would then be connected to a physical aircraft. With ground power applied to the aircraft, the missile could be powered up and have numerous tests conducted on it. These tests focused primarily on proper aircraft interface, but limited testing of missile performance was also be conducted. These data points were primarily preflight checks and limited investigation into missile responses to cockpit switch actuations.

Flight Test

SLAM ER rounds used in T&E were primarily of the exercise configuration. Presenting more than just an additional safety layer, the exercise configurations permitted much higher volumes of data to be produced. The telemetry system in the exercise rounds monitored and transmitted a significant number of missile parameters. This telemetry could be monitored on both ground testing and airborne testing. Key telemetry parameters could be monitored real time to ensure validity of test data. In some cases, this permitted critical testing to be repeated immediately if a parameter of interest was out of the desirable range. All telemetry from test events was recorded for later analysis.

This permitted closer scrutiny on a higher volume of missile parameters than is possible real time with limited personnel in the monitoring rooms.

Though standard FA-18 configurations would have provided acceptable test vehicles, heavily instrumented FA-18s were typically used during the course of the evaluation. The instrumented FA-18s permitted monitoring of a significant number of aircraft parameters. For the purposes of SLAM ER testing, the FA-18 parameters were normally constrained to only those aircraft parameters having a direct effect on SLAM ER performance. Portions of this aircraft data were monitored real time while the bulk of the data was recorded for later analysis.

The majority of the testing utilized ground targets located in the vicinity of NAWS China Lake as well as ground and sea targets off NAS Point Mugu. Targets on these ranges presented reasonable surrogates for the tactical targets for which SLAM ER was designed. The targets were typically mock ups constructed to a level of fidelity that satisfied the test objectives. Use of targets on these two ranges also permitted the use of the real time telemetry monitoring of both missile and aircraft parameters using the ground support in place.

Government Simulation Capabilities

By the time of the ASuW evaluation and the ATA evaluation on SLAM ER, the weapon system had progressed through a number of years of engineering and development. This process had been accompanied by the development of a variety of simulation capabilities. The majority of these simulation capabilities were conceived to evolve with the missile throughout the development process. These simulation capabilities provided significant insight into the missile early in its development as well as contributing to the data set during early testing with All-Up Rounds, both on the ground and in flight.

Government SLAM ER simulation capability existed at both NAS Point Mugu and NAWS China Lake. The two simulation capabilities utilized some similar components, but the utility of the two systems was totally different. The system at NAS Point Mugu was a software-only simulation used for low level verification of guidance section functionality inside a computer-generated simulation environment. The system at NAWS China Lake used the same software, but incorporated it into a Hardware In the Loop (HWIL) system. This system was used for more robust testing of the SLAM ER system as an adjunct to flight testing, rather than in direct support.

NAS Point Mugu

Hardware

The simulation capability at NAS Point Mugu was a 6 Degree of Freedom (DOF) software simulation supplied by the Contractor. This simulation was titled the Air Vehicle Performance Simulation (AVPSIM). AVPSIM provided a performance analysis simulation capability for testing the actions and responses of the MCOFS to a variety of programmable stimuli. In order to ensure maximum fidelity, AVPSIM used the actual MCOFS software, as coded in ADA. Interface environments were programmed in Fortran. The device and utilities were programmed in C. The software was hosted on Sun computers running a Unix environment.

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The Mission Computer is at the center of the SLAM ER system. The Mission Computer is responsible for interfacing with, and in many cases controlling, items such as flight controls, engine control, seeker, GPS, Air Data System, warhead control and AWDL. For this reason, the focus of the simulation at Point Mugu was the SLAM ER Mission Computer. This permitted investigations into the functioning of a wide range of missile performance items.

System Advantages

The primary advantage of the SLAM ER 6 DOF simulation was the relatively simple setup. It had a relatively simple operating environment and required minimal support personnel. The rapid setup and run times permitted large volumes of valid data to be produced.

The SLAM ER 6 DOF simulation was also co-located with the DT&E office for SLAM ER. This decreased the turnaround time when an item in question was tagged for simulation investigation.

System Limitations

The SLAM ER 6 DOF simulation was heavily reliant upon Contractor products. The SLAM ER software as well as some of the environment software was supplied by the Contractor. This placed limitations upon the growth capability of the simulation.

The SLAM ER 6 DOF simulation was a low fidelity simulation. It accurately modeled and simulated the MCOFS environment. However, it provided limited insight into hardware issues and into software performance from subsystems outside of the mission computers.

NAWS China Lake

The SLAM ER simulation capability at NAWS China Lake was maintained by the Missile Simulation Section in support of the SLAM Office NAWS China Lake. This simulation setup was designed to provide insight into a larger range of environments from the actual flight tests. This relationship accurately reflected the purpose of this simulation capability - to complement rather than directly support flight testing. The simulation test objectives were generally created separately from flight test objectives. This allowed greater autonomy in pursuing areas of advertised SLAM ER capabilities which flight test could not or would not test.

Hardware

The SLAM ER simulation setup at NAWS China Lake was a Hardware in the Loop (HWIL) simulation and was referred to as the Software Validation Station (SVS) Automatic Target Acquisition (ATA) simulation. A block diagram of the set up is shown in figure A-2.

Software Validation Station

The heart of the setup was the SVS. The SVS was a legacy setup which was modified from a simulation capability used in testing the original baseline SLAM missile in the late 1980's. This system was then modified and used to test the non-ATA SLAM ER missile in the late 1990's. The SVS uses the same 6 DOF simulation used at NAS

Point Mugu. However, in the SVS, the GNU and ATA software modules were removed. Both were functionally replaced by the actual hardware. Figure A-2 depicts the ATR unit as external to the SVS for clarity (the original SLAM ER SVS used in the late 1990's did not contain an ATR unit). Both the GNU and the ATR unit were loaded with and ran the latest Contractor released versions of the respective software load.

Seeker Interface

The SVS ATA simulation used a physical SLAM ER seeker mounted on a 3 axis Carco Flight Table. The use of a physical seeker allowed for maximum fidelity in the simulation by maximizing the HWIL. The seeker outputs were fed directly to the GNU and the ATR unit just as they would be in the actual missile.

IR Scene Generation

IR scenes were dynamically projected to the seeker. The scenes were rendered by a Silicon Graphics Onyx2 Infinite Reality Scene Rendering Computer. The scenes were rendered based upon position, velocity, and time information fed from the SVS. The results were fed to Computer Science Applications (CSA) electronics which created the timing and video signals necessary to drive the 512x512 WISP resistive array. The output of this array was passed through a collimator to present a 2D scene to the seeker with the correct wavelength, look angle, and position relative to the target.

GPS Simulator

The GPS simulator was used to stimulate the SVS as if it were receiving actual GPS signals. GPS ephemeris data was used to derive the viewable constellation based upon SVS position, velocity, and time information. This information was then used to create RF signals which were fed directly into the GPS antenna ports on the GNU. The GNU then reacted to those signals as if it were actually flying a route.

System Advantages

This simulation capability presented a robust HWIL testing capability. Using many of the physical subsystems from the missile with minimal emulation required, system performance was more confidently modeled than in the SLAM ER 6 DOF simulation.

Verification and validation of the IR scene models presented was initially dependent upon flight testing with an actual SLAM ER. Once this was completed, the SVS ATA simulation was able to investigate system reaction to those scenes through a much wider range of conditions than was available on a limited flight test schedule.

The SVS ATA simulation was built and maintained by government workers. The SLAM ER hardware and the respective software were Contractor produced. However, the entire setup was much more responsive to changes dictated by the direction of DT&E than was the SLAM ER 6 DOF simulation.

System Limitations

The test setup and maintenance were considerably more man-hour intensive than the SLAM ER 6 DOF simulation. It was never a foregone conclusion that an investigation of a specific data point was either quicker or cheaper than actual flight test.

However, the independent nature of the SVS ATA simulation did allow data to be created concurrently with the flight test schedule, thus improving the overall quantity of data points.

The infrared scene models used to stimulate the seeker were not easily produced. There was considerable overhead and lead time required to model any desired scene. Once available, the scene then required validation in connection with flight test data. As a result of this significant restriction, the SVS ATA simulation was able to contribute data on a very limited number of potential targets, all of which had been investigated partially through flight testing.

The quality of the resistive array used to directly stimulate the infrared seeker presented an additional modeling concern. This limitation was primarily driven by budgetary constraints forcing the use of less than perfect arrays. Given the low resolution of the infrared seeker on SLAM ER, this appeared to have negligible effect on the ATA functioning. However, it did present a significant issue with the universal acceptance of the results of SVS ATA simulation runs.

Unlike the SLAM ER 6 DOF simulation, the SVS ATA simulation was not co-located with the SLAM ER DT&E office. This contributed to the conclusion to create separate test objectives for the test and evaluation. It also increased the turnaround time required to investigate a given test item.

Though the HWIL simulation presented a robust test environment for the SLAM ER subsystems, there was no pilot-vehicle interface available. FA-18 cockpit mockups were available at NAWS China Lake, but a decision was made to limit the integration effort on the SVS ATA simulation. This served to decrease the time required to develop the SVS ATA simulation. But it also restricted its utility, particularly in the latter stages of DT&E, when operational testing objectives were at the forefront and Human Factors a significant area of investigation.

Contractor Simulation Capabilities

The contractor had a variety of simulation levels available for their use. The simulations varied from very basic code development simulations up to a robust, HWIL simulation. These simulations were used by the Contractor in the development of the SLAM ER system. In particular, the Contractor simulation capabilities supported the conduct of formal tests to validate software performance and adequacy prior to releasing the software to the Navy. This development testing was complemented by a missile mockup flown on a King Air aircraft. However, the Contractor did not have the organic ability to flight test a physical SLAM ER on an FA-18. Thus, the Contractor relied heavily upon simulation as their primary means of system development.

The most robust Contractor simulation setup was very similar to the SVS ATA simulation and incorporated many identical hardware and software components. One significant difference between the two simulations was the transmission of video scenes to the GNU and ATR unit. While the SVS ATA simulation used an actual infrared seeker, the Contractor chose to inject infrared images from the scene generation computer directly into the GNU and ATR unit. This difference meant that SVS ATA simulation presented a more realistic test of the stand-alone missile system. A second significant difference was the ability to perform MITL actions while the simulation was conducting

a run. Both the SLAM ER 6 DOF simulation and the SVS ATA simulation accepted MITL commands, but they had to be programmed prior to the initiation of the run. Conversely, the Contractor incorporated a rudimentary cockpit mockup with a screen projecting the real time IR scenes generated by the scene rendering computer. This presented the opportunity to solicit limited aircrew feedback prior to actual flight test.

Though government personnel frequently observed simulation tests done by the Contractor, these tests generally did not contribute directly to the government testing of the end item. The simulation capability at the Contractor was viewed as proprietary and independent of the government conducted evaluation of the SLAM ER system. However, this simulation was frequently used by the Contractor while troubleshooting issues which arose during government flight testing - problems which could not be immediately resolved.

The utility of the Contractor simulation was also restricted in its remoteness from the SLAM ER DT&E office. Turnaround time was significant, particularly in cases where aircrew involvement was deemed necessary.

CHAPTER IV

SIMULATION IN THE ASUW EVALUATION

ASuW Evaluation Purpose

The basic missile configuration that completed developmental testing and entered the Navy for operational use contained the software functionality for ASuW. However, specific clearance for operational use of ASuW was restricted until completion of testing on this mode. Such a release with an operational restriction expedited the baseline capabilities to the deployed Navy while reducing the schedule constraints of the T&E process. The specific testing of the ASuW capability was designated DT-IIC. As stated in the Flight Test Plan for SLAM ER MCOFS 1.5 ASuW Enhancements:

"The primary purpose of this test is to gather sufficient data to evaluate the ASuW mode of the SLAM ER weapon system to determine readiness for Fleet use. A secondary purpose is to obtain a preliminary look at ATA to identify any potential problems prior to commencing DT IIID."[3]

Once sufficient data was gathered to confirm the proper functionality of the ASuW mode and a missile firing was conducted, the software would be certified for use in the operational Navy.

Scope Of Test

This test phase was planned to be a limited scope evaluation over the course of five to eight captive carry flights followed by one live missile firing. The missile configuration had been thoroughly tested prior to release to the operational Navy and the ASuW mode had been functionally tested as part of that evaluation. This test phase was planned to focus on ASuW objectives and retest only selected objectives of the original set to ensure backward compatibility of SLAM ER performance. The testing was envisioned to primarily take an operational look at the ASuW mode and determine if it was suitable for the average pilot to employ properly. The testing was envisioned to focus heavily on live testing with a physical prototype flown on an FA-18 aircraft against target ships. This mode of testing was known as captive carry testing, denoting that the missile was carried on the aircraft with no intention of being launched. Simulation had contributed heavily to the original evaluation of this software, DT-IIA, and was envisioned to have only a limited role in this brief revisit of the software.

Method Of Test

The captive carry testing was normally conducted with two FA-18 aircraft, each loaded with a SLAM ER and an AWW-13 Data Link Pod. Each aircraft had missions loaded into the missile after engine start. However, the ASuW mode was a Target of Opportunity (TOO) mode, meaning that the mission data normally had to be entered by the pilot during the airborne portion of the mission. After health testing of the missile on deck via telemetry, the aircraft would take off and proceed to the test area. Testing was normally conducted cooperatively.

Since the primary focus in this test phase was to evaluate the usability of this mode, cooperative testing was the preferred arrangement. Due to the artificiality of captive carry, flying a close approximation of an actual missile profile against a moving target normally precluded autonomous control of the missile during that profile. The second aircraft, the control aircraft, provided targeting and control of the missile under more realistic stand off ranges and without the artificial workload conditions involved in captive carry.

Being a TOO mode, the pilots had much more flexibility in launch point. Once a launch point was agreed upon and both aircraft were in position, the missile aircraft would place the missile into the simulation mode and commence a profile towards the target. The control aircraft would use one of a variety of targeting sensors to maintain a track on the target. This track information was periodically sent to the missile to update the target location towards which the missile was flying. Approaching the target, the SLAM ER would transmit target area video to the control aircraft. The control aircraft would then attempt to find the target in the seeker video. Unlike the ATA evaluation where the missile was flying directly towards a fixed point, in the ASuW mode the missile was merely flying towards the general area of the target. The pilot of the control aircraft was responsible for designating the target in the seeker video which would then provide guidance commands accurate enough to hit a moving target.

As part of this terminal control, the pilot would note ranges at which he achieved target acquisition. On all runs, the pilot of the control aircraft was also asked to note the spare mental capacity available during the task of designating the target in the seeker field of view. The pilots used the Bedford Workload Rating scale at the completion of each run in an attempt to consistently quantify their subjective assessment of workload. This permitted evaluation of the ASuW functionality in the context of realistic workloads. Additionally, as part the debriefing evolution for each flight, general pilot comments were noted as well in order to try to ascertain pilot reaction to the targeting evolution for each run. A variety of pilots were used in the control aircraft to maximize the qualitative comments. A sample data card is shown in figure A-3. The Bedford Workload Rating referenced on the card is shown in figure A-4. Occasionally, aircraft problems or other conditions forced the runs to be conducted autonomously. The system could be operated end to end with only one aircraft. However, these runs were used primarily to check missile functionality, as the Bedford Workload Ratings indicated the non-representative condition of flying the missile and controlling it in the ASuW mode. The captive carry altitudes and dive angles used by the FA-18 aircraft did closely match those that were expected to be experienced by the missile during an actual firing.

The captive carry tests would be conducted against any targets which could be scheduled within the constraints of range and aircraft availability. A variety of targets were available, but each had its advantages and disadvantages. The NAWC WD target ship could be easily scheduled and presented a suitable sized target, but the slow speed limited the useful data points. USCG patrol craft were relatively easily scheduled and could achieve high speeds, but their small size presented restrictions on the volume of target identification data. USN warships could provide a suitable target presentation at a variety of speeds, but higher priority commitments made the scheduling of test events very difficult.

Pilot Workload

 Since SLAM ER had already achieved Initial Operational Capability and had proven its technical functioning in the DT&E process, a significant portion of the ASuW testing evolution was concerned with the MITL interaction of the system. This reflected the operational focus necessary as the capability was about to be cleared for use in the operational Navy. These concerns with Human Factors are shown in table A-1. The data areas shown are general areas within which each datum was to be further broken down if problems should be identified.

 When the evaluation of the ASuW mode began, it became quickly apparent there was a significant problem with overall pilot workload. The workload required to effect a hit on a moving target was significantly higher than for hitting a fixed target, as seen in the original SLAM ER DT&E and the preliminary ATA evaluation. The multitude of pilot steps required made effective target prosecution very difficult. The pilot had to ensure proper video and data link with the missile. He had to maintain an accurate aircraft sensor track on the target. This track information had to be periodically sent to the missile via a data link Course Update command in order to ensure that the missile was flying near the target. When the missile began transmitting video, the pilot had to acquire the target, stop the seeker scan and provide a missile seeker designation on the target. This designation then had to be updated periodically up to the point of impact.

 An unexpected area of high workload on the early captive carry flights turned out to be attempting to stop seeker scan. In other modes of SLAM ER, target prosecution was relatively straightforward. The pilot merely had to stare at the display while SLAM ER flew directly at the target. With good target coordinates, the target would eventually come into view in the seeker and require minor updates to the designation within the seeker field of view. With ASuW however, the target was moving. In order to maximize the chances of finding a moving target from potentially time-late coordinates, the seeker was set to scan across the area where the target was estimated to be. Once the target was identified by the pilot, the seeker scan had to then be stopped before the target could be designated in the seeker. Due to recognition time, data link transmission delays and a relatively high rate of seeker scan, the seeker rarely stopped with the target in the seeker FOV. Thus, the pilot then had to slew the seeker back towards the target prior to designating the target. This frequently required numerous updates to the designation as the seeker field of view was progressively moved back to the target. These steps necessary to fix the seeker on the target consumed valuable terminal control time and often resulted in reduced accuracy or occasional misses.

 Initial discussions with the PMA and the Contractor indicated major changes to the seeker mechanization in ASuW were unlikely. The timing of the discovery of this issue was out of sync with the planned software updates for ATA. Minor software changes might be entertained, but no minor changes could be quickly identified. Additionally, there was considerable unease at removing the scanning functionality in ASuW. Though aircraft navigational system accuracy and targeting system precisions had increased in recent years, it was felt there was an unacceptable probability that a target could be outside the seeker field of view if it were not scanning against a moving target.

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With this guidance in mind, the problem was discussed among the pilots and DT&E team. After reviewing the pilot comments from the captive carry missions, it was decided the most objectionable portion of the designation problem was the high seeker scan rate. The pilots were relatively comfortable with the switch actuations required to stop the scan and to move the seeker onto the target. The problem was that the seeker was scanning too fast for the time required for the switch actuations.

After a thorough review of the factors affecting seeker scan rate, a possible solution which did not require missile software changes was quickly identified. One of the parameters which contributed to the extent of the scan was a value called Target Uncertainty. This value was set to a default unless modified by the pilot prior to missile launch. The value, read in feet, was a measure of the targeting error expected with the given aircraft sensor utilized. The default value in the preflight mission planning software was set to the maximum value acceptable by the missile. This value was not unreasonable based upon earlier FA-18 radar software capabilities as well as uncertainties in older FA-18 navigation systems. Newer FA-18 radar software produced targeting improvements which would allow the pilot to confidently reduce the size of this uncertainty value. The confidence in reducing the value was further enhanced by the recent proliferation of GPS hardware into the deployed FA-18 navigation systems.

Since the time to complete one seeker scan was a set value, it was believed a decreased scan extent should equate to a slower scan rate. This slower scan rate would provide the pilot with more reaction time for identifying the target and stopping the seeker scan prior to the target passing out of the seeker field of view. The end result should be a decrease in pilot workload with an accompanying increase in terminal accuracy.

Unfortunately, the ASuW evaluation was to be conducted on a limited budget - part of which had already been spent arriving at this problem statement. In addition, sea based target availability (USN warships, USGS ships, etc.) continued to restrict the evaluation. A decision needed to be made on whether this solution may be acceptable or whether a MCOFS change would be required.

Simulation Contribution

The ASuW mode was extremely MITL intensive. None of the available government simulations could provide the interface necessary to evaluate the MITL interaction. The SVS ATA simulation was extremely limited in the IR scene modeling and was not designed to evaluate moving targets. The SLAM ER 6 DOF simulation had no pilot interface displays. Control inputs to the missile were provided by a preprogrammed computer interface. Furthermore, neither of the simulations fed information to a flight representative environment, such as a cockpit mock up. Any data from the simulations were quantitative, dealing primarily with hardware and software performance. This is not to say simulation had not been used during the design and development of the pilot interfaces for ASuW. Extensive use of FA-18 cockpit simulators at both the contractor and at NAWS China Lake had provided qualitative data on the interface. However, both of these simulators were driven by a computer model of SLAM ER's performance. This provided sufficient data for adequate design of the

controls and displays. However, these computer models represented optimum system performance and could not be easily tailored.

At this point in the development of SLAM ER, the focus was on operation and performance of the system. This required the bringing together of all the pieces in action, to include pilot performance in a representative environment. Through the live, prototype testing conducted to date, the pilot interface problem was reasonably understood. More importantly, this specific problem area was easily reduced to a quantifiable parameter – seeker scan rate. Additionally, sufficient flight test data was available as a starting point for the investigation.

The SLAM ER 6 DOF simulation located at NAS Point Mugu was the focal point for investigation of this problem area. Multiple simulation runs were conducted with the Target Certainty varied between runs. These simulation runs were conducted in minimal time and with little additional cost. Since the problem had been reduced to a specific parameter, the simulation runs produced high quality data. Initial simulation runs were conducted with a wide range of Target Certainty values. Brief qualitative reviews of the results indicated four values were suitable for repeated runs and further evaluation. Figure A-5 and figure A-6 are outputs from the SLAM ER 6 DOF simulation for a representative run. Figure A-5 represents the entire terminal phase while figure A-6 shows only the first full seeker scan. 6250 ft represents the default value. This produced a scan extent of 5.3 degrees, which led to the high scan rates seen during flight testing. 2000 ft, 1000 ft, and 500 ft represented values which were investigated as potential alternatives to the default value. As seen in figure A-6, 2000 ft produced a scan extent of 2.7 degrees. This reduced scan extent yielded a scan rate half the objectionable value experienced during flight testing.

Other factors had to be accounted for before considering it acceptable to reduce the Target Uncertainty value. It had to be proven to a reasonable degree of probability that the moving target would not be outside this reduced scan extent. The major items to consider were accuracy of Midcourse Updates, target speed and time since last update. The comprehensive flight test data from the previous ASuW captive carry missions provided the basis for evaluating the targeting accuracy. The SLAM ER Operational Requirements Document provided the acceptable values for target speed and established a theoretical maximum value. Time since last target position update had to include the potential worst case. Setting this value to missile launch (i.e. no target position updates via data link) represented the worst case. Once again, the SLAM ER Operational Requirements Document provided a launch range suitable for this investigation. With these values in hand, it then became a relatively simple time-distance-heading problem to ensure the target would remain within this reduced scan extent.

Since the pilot interface was not accurately modeled in the SLAM ER 6 DOF simulation, an acceptable scan rate could not be positively identified. However, rough qualitative judgments could be made based upon the problems observed in flight. The switch actuations required to stop the scan and reposition the seeker on the target were well quantified in the previous tests. Given the fixed value for the SLAM ER seeker field of view, the scan rates were readily converted into times that the target might potentially be visible in the seeker. Comparing these times, a small range of Target Uncertainty values were identified as a possible solution.

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Since this pilot interface problem focused on the MITL control and no suitable simulation was available, the proposed values for Target Certainty would have to be evaluated during live testing with the physical prototype. Runs were conducted on the ensuing test events with the values of Target Certainty varied between runs. The default, maximum value was also used to ensure data relevance to previous testing. As expected from the evaluation of the simulation results, smaller Target Certainty values did significantly reduce pilot workloads. More importantly, the workloads were reduced to a level that was considered acceptable by the pilots and, thus, required no aircraft or missile software changes to correct the problem. As a Target of Opportunity mode, the pilot would have to modify mission parameters inflight prior to employment. So, it was not considered a significant issue for the pilot to have to modify Target Certainty as well as launch point and target information. The actual value used would depend upon the accuracy of the targeting system and the pilot's confidence in that system. However, values lower than the default of 6250 and larger than the anticipated accuracy of the Hornet targeting system were demonstrated to provide positive effects on scan rate. Additionally, the mission planning software could be updated in future releases to incorporate the lessons learned from this test evolution. These updates could include a change to the default value to better reflect the balance of targeting system accuracies versus seeker scan rate.

CHAPTER V

SIMULATION IN THE ATA EVALUATION

ATA Evaluation Purpose

SLAM ER had passed the full rate production decision, known then as Milestone III decision. The configuration of SLAM ER which passed the Milestone III decision did not include the ATA functionality. ATA was considered a preplanned product improvement upon the baseline configuration of SLAM ER. The specific testing of the ATA improvement with the associated software was designated DT-IIID. As stated in the Flight Test Plan for SLAM ER ATA Software Suite Version (SSV) 1.6:

"The purpose of this test is to evaluate SLAM ER ATA with SSV 1.6 on the FA-18C/D aircraft to determine readiness for Fleet use. Specifically, testing will be performed to:
  1)   Verify retention of non-ATA SLAM ER capabilities, as demonstrated in previous test phases,
  2)   Verify satisfactory correction of SLAM ER SSV 1.5 deficiencies,
  3)   Evaluate ATA as a pilot cueing aide,
  4)   Evaluate autonomous mode (no pilot intervention, a.k.a. ATA "only") of ATA operation,
  5)   Captive carry testing to evaluate, and prepare for, proposed free-flight launch scenarios, and
  6)   Gather ATA performance data to support tactics development."[1]

Scope Of Test

The ATA evaluation was a more comprehensive evaluation than that seen in the very limited scope ASuW testing. The ATA phase of testing was designed to begin with ground testing, both simulation and with physical prototypes. The simulation efforts were to be conducted in both the 6DOF and the SVS ATA simulations, concurrently with the physical prototype testing. The physical prototype would be subjected to ground tests both in isolation and when loaded on the aircraft. Once the ground testing had progressed satisfactorily, the testing would move to live testing with the physical prototype on an airborne aircraft flying against surrogate targets, known as captive carry testing. These flights were to utilize the simulated mode of SLAM ER in the approximate profiles seen by the missile during an actual launch. They would be flown against tactically representative targets. This procedure would allow verification of missile performance as well as pilot interaction with the terminal targeting system in realistic conditions. Upon successful completion of the captive carry phase, the test would then progress on to a series of live missile firings against surrogate targets. For the purposes of this thesis, the relevant data points were reached during the captive carry portion of the testing.

Though this phase of testing was designed to be a comprehensive evaluation of the ATA functionality, limited changes would be possible in response to any anomalies detected. At this point in the acquisition process, SLAM ER was a mature system, already in operational use in the Navy. Additionally, having been implemented as an off the shelf solution, the ATR unit was a fixed design. The DT&E effort viewed the ATR

unit as a black box to which no changes were possible. The SLAM ER mission computers did have some effect on the ATR unit interface as well as ATA success and limited changes to the mission computer software were possible. Given these technical limitations, this phase of testing assumed much more of an operational evaluation flavor than previous DT&E events with SLAM ER.

An ideal test and evaluation process would allow for testing under a multitude of environmental factors against a variety of targets. The realities of budgetary and schedule limitations prevented this for the flight test portion. The captive carry testing would test against a variety of targets in various environments, but it would not be inclusive of all the Navy's operational environments. It was hoped that SLAM ER simulation capabilities would help in this respect.

Method Of Test

In support of the objective to evaluate ATA as a pilot cueing aide, the testing focused primarily on collecting data on the range at which the pilot achieved target identification in the seeker video. This was to be evaluated both aided and unaided by ATA on the same or similar targets. This would permit evaluation of the degree of enhancement provided by ATA. Pilot workload information was collected concurrently. The evaluation of pilot detection ranges was normally conducted in parallel with the functional evaluation of the ATR unit via telemetry data. This functional evaluation supported both the verification of legacy SLAM ER functionality was well as correction of various outstanding system deficiencies. ATA only functioning of the missile was also conducted on selected runs. Since the critical data point was pilot target identification ranges, it was acceptable for the missile to fly to the target without targeting updates from the pilot, and thus collect data on ATA while the pilot noted target identification range, hands off.

The captive carry testing was normally conducted with two FA-18 aircraft, each loaded with a SLAM ER and an AWW-13 Data Link Pod. Each aircraft had up to three preplanned missions saved on the FA-18 Memory Unit, which transferred the mission data to the missile after aircraft engine start. After health testing of the missile on deck via telemetry, the aircraft would take off and proceed to the test area. Testing was conducted either autonomously or cooperatively between aircraft.

When conducted autonomously, the primary focus was on evaluating the ATA performance independent of pilot input. The pilots would proceed to the launch point for the loaded mission, initiate the simulated flight mode of the missile and then fly the route into the target area with a dive attack into the target. Though SLAM ER can impact a target from a variety of vertical impact angles, safety limitations prevented an accurate reproduction of these angles during captive carry flight. The majority of the runs were at representative approach altitudes, but unrealistically shallow dive angles. A limited number of runs were conducted from steep dive angles, albeit with artificially high approach altitudes to start these dives. Multiple runs would be conducted on each flight.

When testing was conducted cooperatively, the primary focus was on evaluating ATA cueing as an aide to pilot target acquisition. One aircraft would orbit a significant distance out the extended attack axis monitoring the cockpit data link display. This aircraft was known as the control aircraft. Meanwhile, the aircraft carrying the missile

flew a reprsentative attack profile. In the target area, the SLAM ER would transmit target area video to the control aircraft. The control aircraft would then control the missile, updating the target designation as required. As part of this control evolution, the pilot would note ranges at which he achieved target acquisition. Runs were conducted both with and without ATA cueing to provide a comparison of the ATA enhancement. On all runs, the pilot of the control aircraft was also asked to note the spare mental capacity available during the task of acquiring the target in the seeker field of view. The pilots used the Bedford Workload Rating scale at the completion of each run in an attempt to consistently quantify their subjective assessment of workload. This permitted the ATA enhancement to be viewed in the context of cockpit workload present during these targeting evolutions. Additionally, as part of the debriefing evolution for each flight, general pilot comments were noted in order to ascertain pilot reaction to the ATA performance for each run. A variety of pilots were used in the control aircraft to vary the perspectives for the qualitative comments as well as show consistency in target acquisition ranges. A sample data card is shown as figure A-7.

Pilot Target Acquisition

Through both simulation testing and live testing with a physical prototype, early indications were the system functioned as anticipated. A high degree of confidence was reached early with respect to the retention of prior SLAM ER capabilities as well as the correction of outstanding deficiencies. Initial ATA runs appeared to show the ATR unit functioning properly.

The focus of the test rapidly progressed towards the next test objectives - evaluate ATA as a pilot cueing aide and evaluate the autonomous mode. These two objectives were interrelated. They depended upon determining a recommended target set for ATA. It was accepted that not all SLAM ER targets would necessarily be ATA targets. The requirements of obtaining satellite imagery and manipulating this imagery as part of preflight planning were labor intensive tasks which may not be necessary for relatively simple target areas. Within the ATA suitable target sets, data was also desired on how to maximize the opportunity for ATA to succeed. There were numerous variables which could enhance or retard the ATA processing, to include fidelity in mission planning, missile ingress altitude and approach angle, among others. The success of the ATA processing within the missile was not the final data point. The ATA capability needed to increase pilot target acquisition ranges to succeed in the evaluation. So, the remaining test objectives became: in what environments does ATA function well and does it improve pilot target acquisition ranges in those environments? It was not enough for ATA to consistently identify the solitary building in an open field if the pilots alone were able to consistently acquire the building at tactically significant ranges.

An additional concern of the testing evolution was the pilot interface of the system. The primary Human Factors concerns are shown in table A-2. The data areas shown were general areas within which data would be further broken down as necessary to verify system performance. These areas were related to the target acquisition range issue. However, they also represented general pilot interface questions which needed to be resolved prior to the weapon system being cleared for operational use.

Simulation Contributions

The SLAM ER 6 DOF simulation was able to provide a reliable test environment for basic ATA functionality. It was able to evaluate the proper functioning of scripted pilot inputs in varying conditions. This was useful to the overall test program in that it considerably reduced the test points required from live, captive carry testing with the aircraft. This was particularly useful in relation to regression testing to ensure ATA did not degrade other functions in the missile. By reducing the required number of scripted switch actuations in flight, the testing could focus on the question of whether ATA worked as a targeting aide. However, the extremely limited modeling of the pilot interface on the SLAM ER 6 DOF simulation severely limited its contribution to the central question of ATA compatible target environments and pilot target acquisition in those environments.

The SVS ATA simulation was able to verify proper functioning of the ATR unit and its interface with the rest of the missile system. Since the ATR unit was being viewed as a black box, this effort was valuable to the overall test and evaluation. It significantly reduced the data points needed with a physical prototype.   More importantly, the SVS ATA simulation held the promise of being able to contribute to the question of ATA compatible target environments. The high fidelity modeling of the interaction between the ATR unit and the seeker held the potential to provide extensive data on ATR unit performance in a variety of target environments. This data would contribute to identifying those environments where ATA could be expected to succeed. Given the limited modeling of the pilot interface, the SVS ATA simulation alone could not answer the question of whether pilot target acquisition ranges were increased with ATA. However, if the target environments in which ATA increased target acquisition ranges could be generalized, then the SVS ATA simulation could contribute through further investigation in those areas than possible through flight test alone.

The SVS ATA simulation had limitations in predicting ATR unit peformance. The primary issue was the effort required to provide a reasonably accurate stimulation for the SLAM ER seeker (which then provided an input to the ATR unit). Hardware issues caused by the quality of the resistive arrays providing input to the seeker presented a hurdle. Another problem was the limited number of infrared scene models available for use as stimulation. One target area was thoroughly modeled as an infrared scene and validated by an earlier weapons program. The SLAM ER effort contributed another four infrared scene models, though these additional models had limited validation efforts conducted. Within these limited target area models, the SVS ATA simulation was able to investigate significant variations in missile flight parameters as well as atmospheric and diurnal variations. This aided the overall evaluation in that it helped identify likely ATR unit reactions to subtle changes from a given flight test data point, without additional flight testing at that specific new data point.   In particular, it did allow more representative dive angles to be used than were possible in captive carry evolutions. However, with an inability to develop target area infrared scene models not seen in captive carry testing, the SVS ATA simulation did not appreciably increase the program's overall data points.

For a given set of conditions where pilot reaction to the ATA cueing was defined from flight test, the SVS ATA simulation could predict how the cueing may vary for given changes in conditions. However, simulation failed to provide useful data on the MITL questions. The simulations were designed with an eye toward hardware and software test and evaluation. Specifically, they were aimed at taking the contractor-supplied parts (software and hardware) and operating them throughout a wider range of test conditions than was possible in flight test. At this they excelled. However, the rudimentary pilot interface was insufficient to draw reliable conclusions. ATA was designed to aid in pilot target detection. Though simulations fed to cockpit mockups aided in evaluating the design of the interface, evaluation of the utility and effectiveness of the system under operationally realistic conditions required live testing with physical prototypes. Being able to put target detection ranges together with an environment that produced acceptable pilot workload ratings was essential to the believability of the results.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Man In The Loop Simulation

DOD Instruction 5000.2R directs PMAs to "identify and fund required M&S resources early in the acquisition life cycle, so that M&S may be integrated with the T&E program."[5] The SLAM ER program followed this direction in developing a robust simulation capability. The Contractor had developed extensive simulation support with varying levels of fidelity. They had continually improved and evolved these simulations through the development phase of the weapon. On the government side, the SLAM ER 6 DOF simulation at NAS Point Mugu was a validated SWIL simulation which provided extensive data with quick turnaround times. The SVS ATA simulation at NAWS China Lake provided a HWIL simulation, to include the stimulation of a physical missile seeker video to provide a high fidelity simulation. Both the Contractor and the government had FA-18 cockpit mockups with low fidelity, computer generated SLAM ER stimulation. As the program progressed in the early phases of DT&E, the simulations were essential in designing and testing the missile capabilities. The contributions even included early design and limited testing of various portions of the pilot interface.

In addressing the conduct of Operational Testing, DOD Instruction 5000.2R directs, "Whenever possible, an OA shall draw upon test results with the actual system, or subsystem, or key components thereof, or with operationally meaningful surrogates. When actual testing is not possible to support an OA, such assessments may utilize computer modeling and/or hardware in the loop, simulations (preferably with real operators in the loop)".[5]   It further directs DT&E to look at operational issues by stating, "Address the potential of satisfying OT&E requirements to the best extent possible by testing in operationally relevant environments (simulated or actual), without jeopardizing DT&E objectives, to reduce overall T&E redundancy and costs."[5] It was in attempting to satisfy this direction that the SLAM ER program found significantly restricted utility in the use of simulations. A conscious decision was made early in the SLAM ER program to develop simulations as a contributor at the engineering level. However, the modeling and simulation of the terminal MITL aspects of the weapon were limited in scope. In the latter stages of T&E, as the DT&E effort became less focused on system development and more concerned with operational testing, the limited modeling and simulation of the MITL interaction could not support the close scrutiny on the pilot interface. This scrutiny on the MITL portion of the weapon tended to limit the contributions of the various simulations in the later stages of DT&E.

As seen in the ATA evaluation, the key parameter which could not be tested in the simulation was pilot target identification ranges while subjected to mission representative work loads. This parameter focused heavily on pilot decision making with the added attention sharing problems of operating the aircraft. This aspect of the evaluation could not be adequately simulated with the facilities available. The DT&E effort was forced to collect data on these parameters exclusively with live testing using a physical prototype against surrogate targets. Simulation was able to increase the total number of data points by evaluating ATA only missile performance against infrared scene models. However,

this information was useful only after live testing with a physical prototype had identified general target classes and environments where ATA aided the pilot in achieving target acquisition.

In the ASuW evaluation, simulation was useful in early development of the pilot interface. However, the unacceptably high workload involved in stopping the scan and slewing the seeker back onto the target was only identified once the pilot was subjected to mission representative workloads during live testing. Once identified, simulation was able to provide value to the refinement of the pilot interface. With the MITL interface problem defined in quantitative, engineering parameters, simulation was used to assist in identifying a potential solution. However, this proposed solution still had to be validated in live testing with a physical prototype.

Recommendations

Modeling and simulation contributed significantly to the early development of SLAM ER. Though this effort did significantly improve the development process, it reached the limits of its utility while attempting to draw conclusions about the pilot interface under operationally representative workloads. Numerous computer advances have occurred since the program was begun. The program also predated the DoD's concept of Simulation Based Acquisition. The DoD's STEP approach, with its philosophy of model, simulate, fix, test, iterate, should increase the use of models and simulations in acquisition programs. This effort should be embraced. However, this effort should be accompanied by realistic control measures to ensure the efforts fully realize the challenges in the development effort for MITL weapon systems.

If a program elects to develop models and simulations to support conclusions on MITL interactions, the model and simulation development must start early in the program with a concerted effort on verification and validation of the pilot interface. With MITL weapon systems, it is not enough to think only about the validation of the models and simulations from an engineering systems standpoint. The pilot interface portion of models and simulations must be constantly scrutinized and improved throughout the engineering development. With a MITL weapon system, the pilot interface cannot be viewed as a limitation to the scope of development of any model or simulation. Early involvement of pilot inputs on the simulation design is crucial. This involvement must focus on the realism of the simulations and not be viewed solely as an objective evaluation of the weapon system design. With this high level of rigor, these models and simulations may be able to support DT&E conclusions on MITL issues.

A point must be identified in the DT&E effort when conclusive data will be needed on the pilot interface under realistic workloads. The program should closely scrutinize the cost benefits of a high fidelity MITL model and simulation when compared with a less robust simulation effort supported by live testing. The point where conclusive pilot interface data is needed will typically come towards the end of the DT&E cycle as the program prepares to enter Operational Testing. However, the more extensive the MITL interface, the earlier the program should consider a transition to live testing with a physical prototype. If the transition is made too late, workload differences between simulations and live flight testing may reveal significant MTIL interface issues late in the DT&E process. Entering Operational Testing based primarily upon simulation data for a

weapon system with extensive MITL interface issues should be viewed as a high risk decision.

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APPENDIX

Nominal Characteristics
Length = 172.0 in.
Diameter = 13.5 in.
Weight = 1,473 lb

Seeker Power Supply
Global Positioning System Antennas
Instrumentation Antenna
PCM Telemetry Tray
Safe/Arm Contact Fuze
Arming Probe
Data Link Antenna
Control Actuators (4)
Control Fins
Turbojet Engine

Nose Fairing
IIR Seeker
+X

Air Data System Probe
Advanced Weapon Data Link
Automatic Target Recognition Unit
Guidance Navigation Unit
Redundant Flight Termination Tray
Start Tank
Battery
Electronic Control Amplifier
Inlet Cover

Guidance Section — **Exercise Section** — **Sustainer Section** — **Control Section**
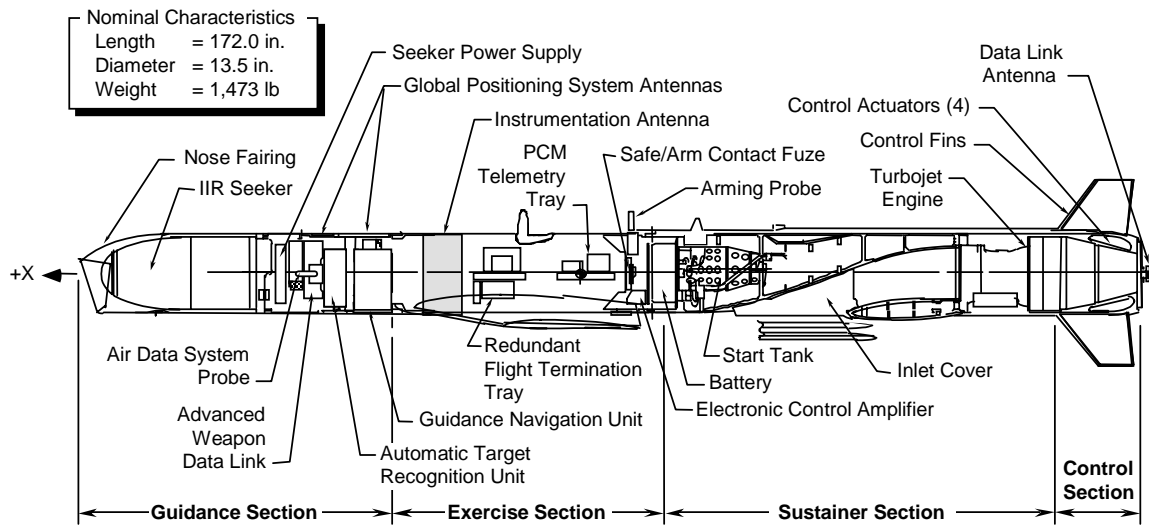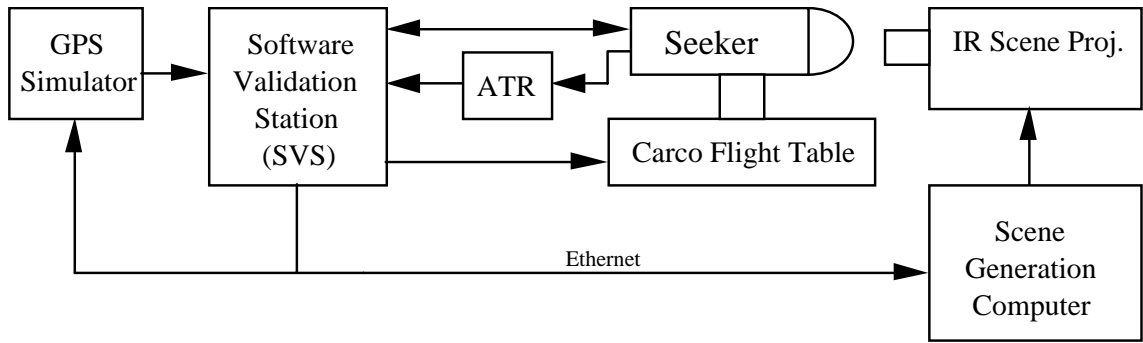
Figure A-1. SLAM ER Components.[1]

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Figure A-2. SLAM ER SVS ATA Simulation.[2]

Controller Record:

HDG/ALT @ Radiate:

_____/_____

RNG/BRG from Target @ Radiate

_____/_____

Range @ Target ID:

_____

RNG/BRG from Target @ Impact:

_____/_____

Bedford Workload Rating:

_____

Comments:

TEST PARAMETERS

- Launch Alt: 2000 ft
- Srch Alt: 700 ft
- TGT Uncertainty: 6520
- **CRSUPs**
  - **20 nmi**
  - **15 nmi**
  - **10 nmi**
  - **5 nmi if req'd**
- **MITL**
  - **Polarity Hot or as req**
  - **Stop Scan as desired**
  - **Cent Trk at 4 nmi**
  - **SMAU's < 2.5 nmi**
- **Aim Pt: Center of vans**
  below RDR TWR

TGT: Speed 10 kts

MST

(carrier flies to CTR SKR pointing cross)

LP RNG: 25 nmi
.82 IMN

SRCH ALT 700 ft

CONTROLLER
10 nmi trail @ MSIM
On shot bearing
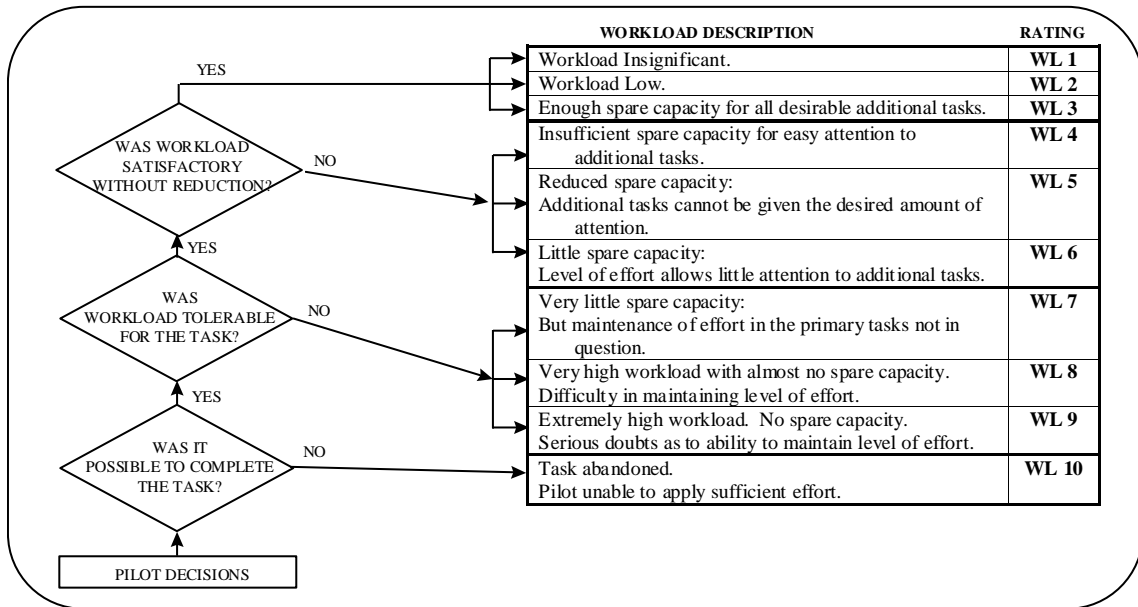**5000 ft, .60 IMN**

Run 3

Figure A-3. Sample ASuW Kneeboard Card.[3]

Figure A-4. Bedford Workload Rating.[4]

Table A-1. ASuW Test Objectives for Human Factors.[3]

OBJECTIVES		CAPTIVE CARRY							FF
		Event 1 - Aspect angles	Event 2 - Land Background	Event 3 - Maneuvering	Event 4 - Large Ship Night	Event 5 - Med Ship Night	Event 6 - Multiple Ships	Event 7 - Workup	MISSILE FIRING
B5	**HUMAN FACTORS**								
5.1	Pilot workload evaluation	X	X	X	X	X	X	X	X
5.2	Data link sync mode evaluation	X	X		X	X		X	X
5.2.1	Reduction in data link time delay	X	X		X	X		X	X
5.2.2	Backup controller is not prevented from sending MITL commands	X	X		X	X		X	X
5.3	Qualitatively evaluate pilot workload to maintain target in FOV for aimpoint selection against jinking/weaving high speed target.		U						
5.4	Measure pilot stress in selecting aim point in scene filled with target				U				

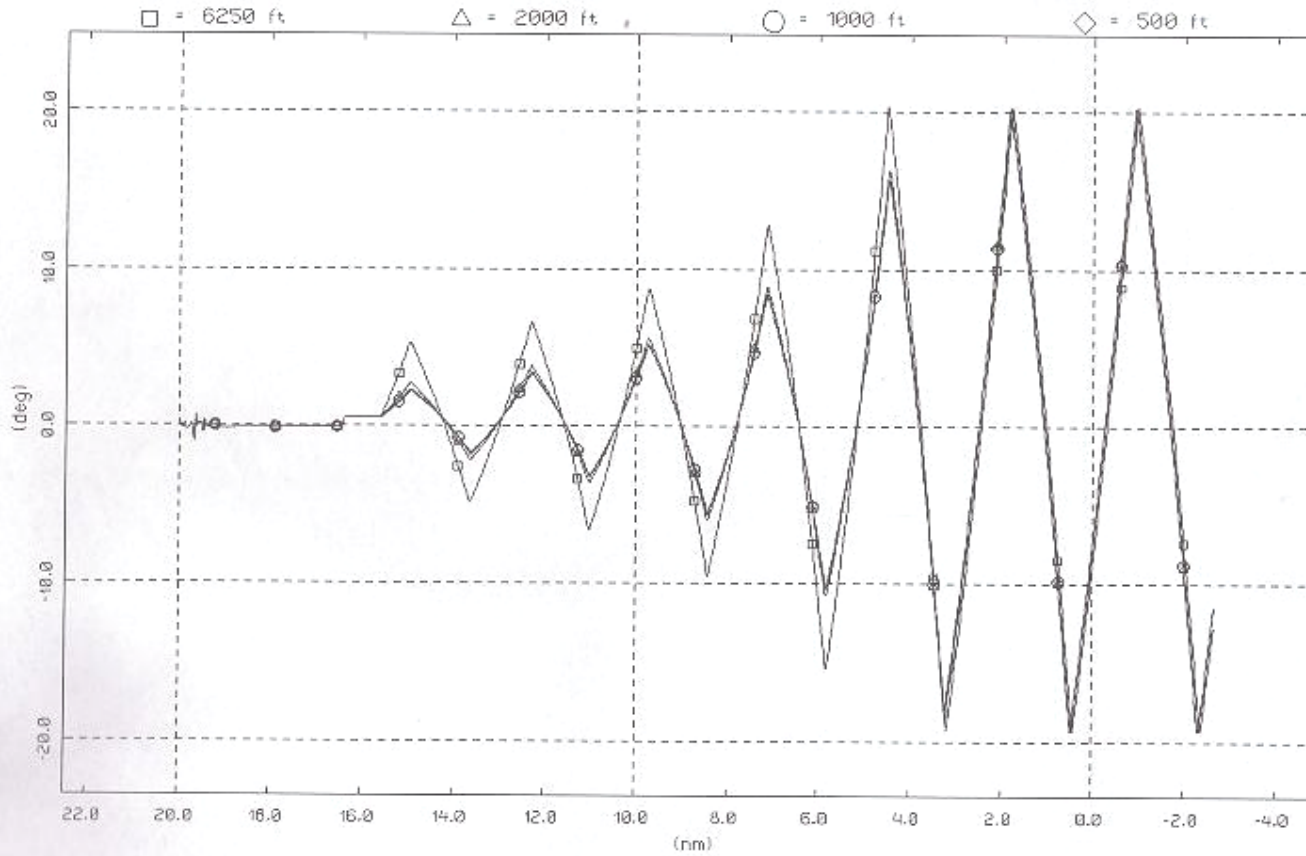NOTES: U - one of the unique / primary objectives for this event

Figure A-5. Effects of Varying Target Uncertainty – Full Run.

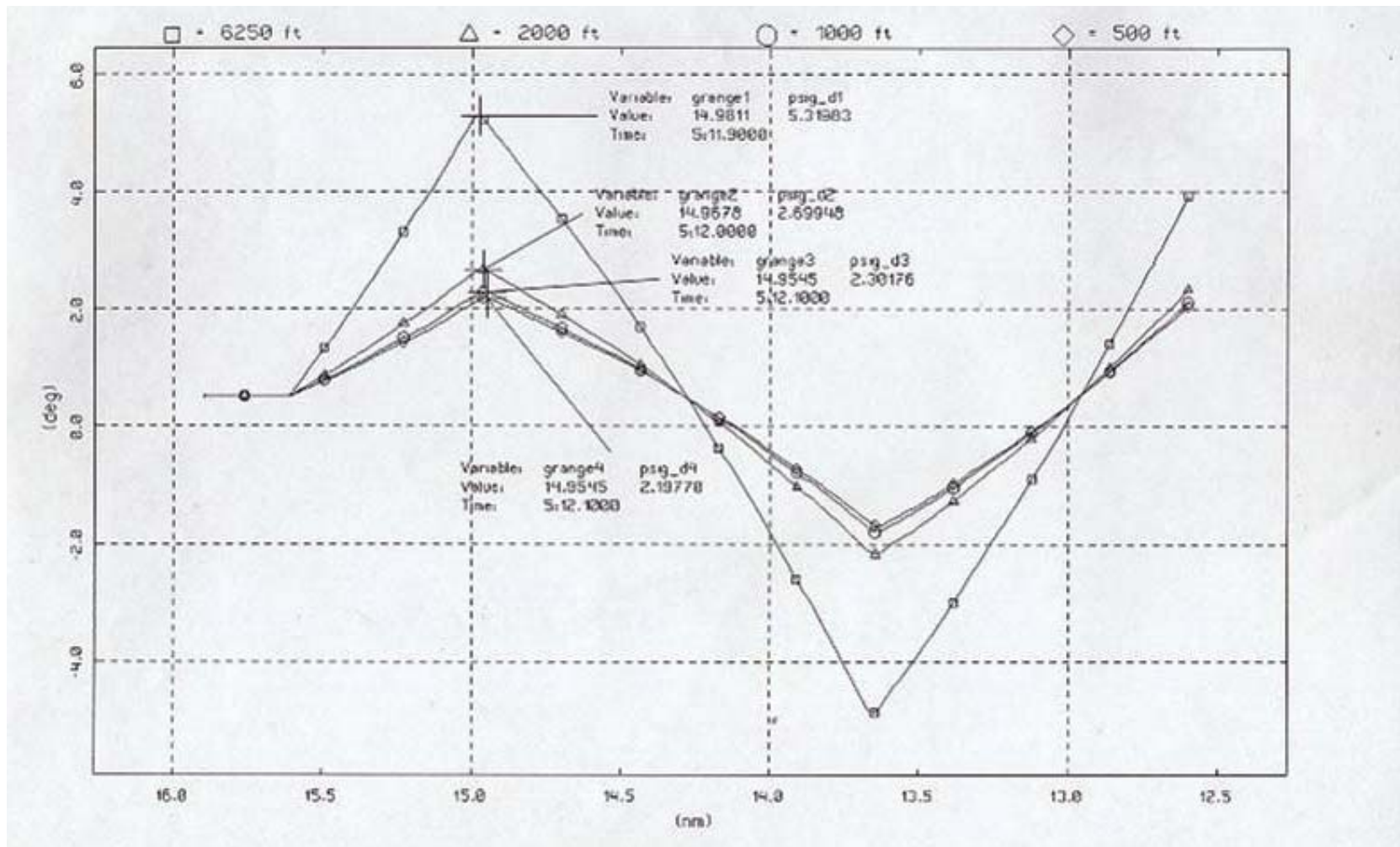**Figure A-6. Effects of Varying Target Uncertainty – One Seeker Cycle.**

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MISSION
Target: Charlie Sam Site   **MU#2 PP1 ATA**

TEST PARAMETERS:

- Srch Alt: 7766 MSL; 5500 AGL
- Aircraft Dive Angle: 10-15°
  - Inside 5.1 nmi to Tgt
- **Endgame: ATA Only**
- **FOV: WFOV**
- **Aim Pt: Small Radar Van**

TGT: Charlie Sam Site
ELEV 2259 MSL

WP01

7766 MSL
240° T
22.2 nmi

.7 IMN
@ 8 nmi

WP11

WP18

7766 MSL
179° T
17.1 nmi

WP19

WP10

7766 MSL
179° T

PP Simflight
DL13 AIRCRAFT: CO-OP CONTROL

a. RECORDS & VIDEO. ....…......ON
1. MASTER MODE……….…...........A/G
A/A mode can be used, however HOTAS controls
(except TDC) are unavail for SLMR control.

STORES Page
2. DL13 ....…....……………......BOX

DL13 DISPLAY
3. WPN..........................……......SLMR
4. DSPLY.......................….......PRE
5. COOP.................…...….........Depress
6. PP.........................….............Select
7. TTV (Time to Video)…....ENTER (UFC)
8. CH / ID.......……….…......Select / Verify
9. ANT...................…......…............As Req'd
10. DL PWR.........................…........HI
11. DSPLY.......................…........POST

Prior to or @ MSIM
12. START TTV.............Depress @MSIM
13. TDC.....…….....Assign to DL13 Display

@ DL Radiate
14. Change   FOV….......Call "Good Video
Good Control"
Note: If no HOTAS controls ensure Post
Display, TDC assigned and A/G selected.
Substitute above Test Parameters for
Steps 15. & 16. in this checklist.
15. Select WFOV/NFOV …..... As req for
Target ID
16. SLAM ER…….…... Control @ 2-3 nm
when Positive ID
17. @ End of run, DL13 / A/G…...UNBOX
17a. RECORDS & VIDEO...............OFF

Aircraft Heading   _____

Target RNG/BRG @ Radiate   _____

Target ID Range   _____

Target Rng/Brg @ Overfly   _____

Bedford Workload Scale   _____

Seeker On:	15.0 nm
Est. TTV:	03+26
Est. TOT:	05+14
FOV:	Wide
Polarity:	Hot
Fuzing:	Instant
Tracking:	ATA

CP1: WP 18 {30 nmi}
CP2: WP 19 {45 nmi}   20,000 MSL 060°T 446 KGS O/B   **1C** (111)

Figure A-7. Sample ATA Kneeboard Card.[1]

Table A-2. ATA Test Objectives for Human Factors.[1]

SLAM ER DT-IIID SSV 1.6 ATA OBJECTIVES MATRIX	SSV 1.5	SSV 1.6					Priority[1]
		Simulation	Laboratories	Ground Tests	Captive Carry	Missile Launch	
B5 **HUMAN FACTORS**							
5.1 Pilot workload evaluation	x					x	1
5.2 Suitability of displays (SCP 26)							
5.2.1 Pilot is confident using ATA cue symbols for target identification	x				x	x	1
5.2.2 Symbology	x		x	x	x	x	1
5.2.3 In-video messages	x		x	x	x	x	1
5.3 ATA-MITL mode transitions							
5.3.1 How much time / effort is required to learn how to transition from ATA to MITL, and MITL to ATA							3
5.3.2 Display clearly shows pilot whether he is in ATA or MITL mode	x		x	x	x	x	1

VITA

Keith Matthew Henry was born in Youngstown, OH in 1969. He lived in Raleigh, NC and then moved to Cheshire, CT, where he graduated from High School in 1987.

He entered the Naval Academy in 1987 where he majored in Electrical Engineering in the Class of 1991. After graduation, he entered flight school in Pensacola, FL. He underwent advanced jet training in Meridian, MS, where he was winged in February of 1995. After winging, LT Henry proceeded to Cecil Field for FA-18 training in VFA-106. He joined the Rampagers of VFA-83 in April of 1995. He served as an LSO while cruising with CVW-17 onboard the USS Enterprise in the summer of 1996 in support of missions over Bosnia and OSW in Iraq. With the Rampagers, he served as Schedules Officer, Aircraft Division Officer and Training Officer.

In July of 1998, LT Henry entered Navy Test Pilot School in Patuxent River, MD. After graduating in 1999 with Class 115, LT Henry moved to Point Mugu, CA to join the Naval Weapons Test Squadron, Point Mugu. He served as the Harpoon/SLAM/SLAM ER Project Officer overseeing the IOC and Fleet Training of SLAM ER, the Milestone II decision on SLAM ER ATA and the developmental testing of Harpoon Block III.

In June of 2001, LCDR Henry received orders to the Dambusters of VFA-195. After a brief stop at Naval Safety School, he joined VFA-195 in Atsugi, Japan in September of 2001. He immediately deployed to Diego Garcia and subsequently the USS Kitty Hawk in support of Operation Enduring Freedom. He served as Safety Officer and Maintenance Officer in the Dambusters. Additionally, he served as Operations Officer during the Dambusters' participation in Operation Iraqi Freedom.

In March of 2004, LCDR Henry reported to Naval Strike Air Warfare Center (NSAWC) in Fallon, NV. He has served as the N5 Sea Trial Branch Head and presently is the N5 Land Strike Branch Head as well as an Overall Instructor for Air Wing Training.

Keith has over 2300 hours in 25 different aircraft, including over 350 arrested landings and over 1500 hours in the FA-18. His awards include Individual Air Medal with "V", Strike Flight Air Medal (Second), the Navy Commendation Medal (Third), Navy Unit Commendation, Meritorious Unit Commendation and the Battle E Award.