To the Graduate Council:

I am submitting herewith a thesis written by Mark P. Stucky entitled "Increasing Mission Effectiveness of a Modern Fighter Aircraft Through the Use of Multi-Source Integration, Weaponry, Display, and Human Factors Enhancements". I have examined the final 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.

Ralph D. Kimberlin

Ralph D. Kimberlin, Major Professor

We have read this thesis and recommend its acceptance:

Uwe Peter Solies

Donald D. Tiggett

Accepted for the Council:

C W Minkel

Associate Vice Chancellor

and Dean of the Graduate School

INCREASING MISSION EFFECTIVENESS OF A MODERN FIGHTER AIRCRAFT THROUGH THE USE OF MULTI-SOURCE INTEGRATION, WEAPONRY, DISPLAY, AND HUMAN FACTORS ENHANCEMENTS

A Thesis
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DISCLAIMER

The technical data included in this thesis are the result of actual flight test and flight simulator evaluation of the F/A-18 Hornet. All deficiencies and enhancements attributed to the aircraft and its systems are the opinion of the author and may or may not represent the official position of the Naval Weapons Center, the Naval Air Systems Command, the United States Marine Corps, or the United States Navy. Similarly, the recommended corrections to the deficiencies documented by the author should not be considered attributable to any of the aforementioned authorities or for any purpose other than fulfillment of the thesis requirements.

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ABSTRACT

Since the first World War, the fighter pilot's axiom has been "he who sees the enemy first, wins". Because of the great advantage enjoyed by the fighter that senses the enemy first, great emphasis has been placed on the development of sensors to aid in the venture. With the rapid advances in technology a plethora of sensors are now available to the combat pilot. Such sensors include radar, forward looking infrared, passive radio frequency, and optical.

As the amount of information available to the combat pilot mounts, it gets increasingly difficult for him to simultaneously assimilate the data from the various sources and use it tactically. With the development of the United States Air Forces' Advanced Tactical Fighter (ATF), effort is being made to integrate the various sensors into a battlefield manager.

Although the ATF is nearly a decade from operational use, the U.S. Navy along with McDonnell Aircraft Company, has developed the software to integrate the F/A-18 Hornet with its various sensors and sources of information using a process called Multi-Source Integration (MSI). MSI, along with additional weapons and human factors enhancements was incorporated in Operational Flight Program 91 for use in the F/A-18. This study analyzes the need for, development, and testing of MSI and Operational Flight Program 91.

Operational Flight Program 91 was a major advancement for the F/A-18 Hornet. Individual sensor performance was increased, human factors enhancements decreased pilot workload, and the Multi-Source Integration effort had a synergistic effect on the capability of the aircraft. Perhaps the most long-reaching benefit that OFP 91 gave the Hornet was that of growth potential. As future sensors are developed, the integration of them into the aircraft will be logical, enhance MSI capabilities, and increase mission capability. The author presented many recommendations addressing the MSI algorithm itself, weapons, display, and human factors enhancements.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

BACKGROUND

The cornerstone of current fighter aircraft is the air-to-air radar, designed to detect and track aircraft, and support guided missiles. Once the radar became the accepted means of "seeing" other aircraft then a means to detect these radar transmissions soon became apparent. Such equipment was designed for defensive measures and dubbed Radar Homing and Warning (RHAW) gear. In recent years a great deal of emphasis have been placed on the development of additional sensors. An infrared search and track (IRST) system was outfitted to the F-106 in 1962 but had limited success due to its short range capability and its requirement to be behind aircraft in order to detect them. The IRST concept was largely shelved by the U.S., however, the Soviets continued with developing the technology and currently have improved systems flying on their operational Mig-29 and Su-27 aircraft. Both the F-4E and F-14 have fielded optical sensors to help with the problem of daylight visual identification and raid counts. Interest in IRST systems has been rekindled in the U.S. (perhaps due to the Soviet success) and the F-14D houses an IRST in addition to its optical television system. The F/A-18 was designed to carry a forward looking infrared (Flir) set, initially for night designations of surface targets but through software modifications it has been made into an effective air-to-air sensor. All U.S. Navy tactical aircraft are also equipped with a two way radio frequency data link, allowing an individual fighter and its radar controller to share tactical information.

In an effort to find avionics solutions to the problem of fleet air defense of its surface ships, the United States Navy undertook a five year study and demonstration entitled "Fighter/Attack Avionics Targeting Demonstration (F/AATD) [Ditzler,1]. The use of various sensors, their individual mission applications, and multi-sensor targeting were studied during the F/AATD program using ground based sensors. Limitations to the test program included the lack of:

- target identification
- sensor cueing and slaving
- weapons hand-off (slaving and launch)
- optimized displays

The test program was successful enough to warrant continued effort. The F/A-18 Hornet was chosen to be the lead aircraft for the multi-source integration effort. The Hornet is an advanced aircraft and has set the standard for a modern software driven combat fighter.

PURPOSE

This thesis addresses the testing of Operational Flight Program 91 in the F/A-18. This software program offers the Hornet pilot many new capabilities, weapons, and human factors enhancements, a major part of which was the first implementation of multi-source integration in a fighter aircraft.

DESCRIPTION OF THE F/A-18 HORNET

The F/A-18 Hornet is a multi-mission strike fighter designed to replace the aging fleets of A-7 Corsair light attack and F-4 Phantom fighter aircraft. The Hornet is an extremely agile aircraft capable of carrying a vast array of ordnance in accomplishment of its missions. Integral to the aircraft is the internal M61 gun capable of both air-to-air and air-to-ground modes. Additional air-to-air ordnance includes various missiles: the short range infrared seeking AIM-9 Sidewinder, the medium range radar guided AIM-7 Sparrow, and the medium range radar and data link guided AIM-120 AMRAAM. The Hornet can also carry a wide array of unguided and guided bombs, rockets, and missiles for the air-to-ground role. The tactical information available to the pilot can be supplied by both on-board sensors and external sources via a radio frequency (RF) data link. There are two major types of Hornets, the F/A-18A/B and the F/A-18C/D. Only the F/A-18C/D has the increased computer capacity, updated avionics bus system, and other assorted changes required for multi-source integration. All references to the F/A-18 in this thesis will actually be referring to the latter model. The aircraft physical description, cockpit layout, and sensor capability are contained in Appendix A, Figures A-1 through A-6; and Navair [2].

Avionic System Overview. The aircraft has three distinct master modes: Navigation, Air-to-Air, and Air-to-Ground. Display defaults, sensor, and switch responses are dependant upon the master mode selected. The backbone of the avionics are the two mission computers which, together with the avionics buses, tie together virtually all aircraft systems and computers. The mission computers are identical, possessing a programmable memory of 262,144 sixteen bit words. Mission computer 1 (navigation computer) is reserved for navigation, display management, aircraft Built-In Test (BIT), and status monitoring. Mission computer 2 (tactical computer) performs the air-to-air and air-to-ground processing and tactical display management. In case of failure of either mission computer, the other automatically assumes a limited back-up capability. The mission computer software is updated on a biannual process with what are termed Operational Flight Programs (OFPs). The OFPs are referenced to the fiscal year in which they were first generated (e.g. OFP 87). Typically, the OFP is not fielded to operational units until after approximately one to two years of developmental and operational testing.

The aircraft uses a military standard 1553 bus system comprised of five, redundant path, time-multiplexed buses. Each bus functions asynchronously, responding to commands from the various avionic equipment with the mission computers serving as the bus controllers. The information flow consists of commands, data, and status responses. A schematic of the avionics multiplex system showing the various channels and equipment is contained in Figure A-2 [McDonnell, 3].

Cockpit Configuration. The primary data displays consist of four cathode ray tube (CRT) units, three of which are head-down, the fourth projecting upward onto a dual combining glass which comprises the Head-Up Display (HUD). The left and right CRTs are referred to as Multipurpose Display Indicators (MDI's) while the center display is called the Multipurpose Color Display (MPCD). All three are identical in area with a display size measuring 5" x 5". Figure 1-1 depicts a MDI. The HUD is a projection covering a 20° X 20° field-of-view, and is the primary flight instrument of the aircraft, displaying attitude, navigation, and weapons employment information. The HUD displays only one format although the data content and general arrangement is modified dependant upon aircraft master mode. The two MDIs and MPCD are functionally interchangeable, each being able to display any of the various display formats selected by the aircrew. The chief difference is the MPCD has full color capability for displaying the many shades required for the digital moving map display. Because of this capability it is normally reserved for displaying navigational information. Although the MDIs are capable of three colors only one format currently uses this capability.

A three inch circular CRT called the Azimuth Display Unit (ADU) is used solely for the display of ALR-67 Radar Warning Receiver information. Although some ALR-67 information can also be displayed on the HUD, the ADU is used as the primary display of threat radio frequency data. The ADU has four rings, the inner most is used to display ALR-67 messages such as built-in test failures. The subsequent rings display the lethality of the detected signals using an "increasing lethality out" concept as depicted in Figure 1-2. These criticality rings are etched onto a glass cover which is raised approximately 3/8 of an

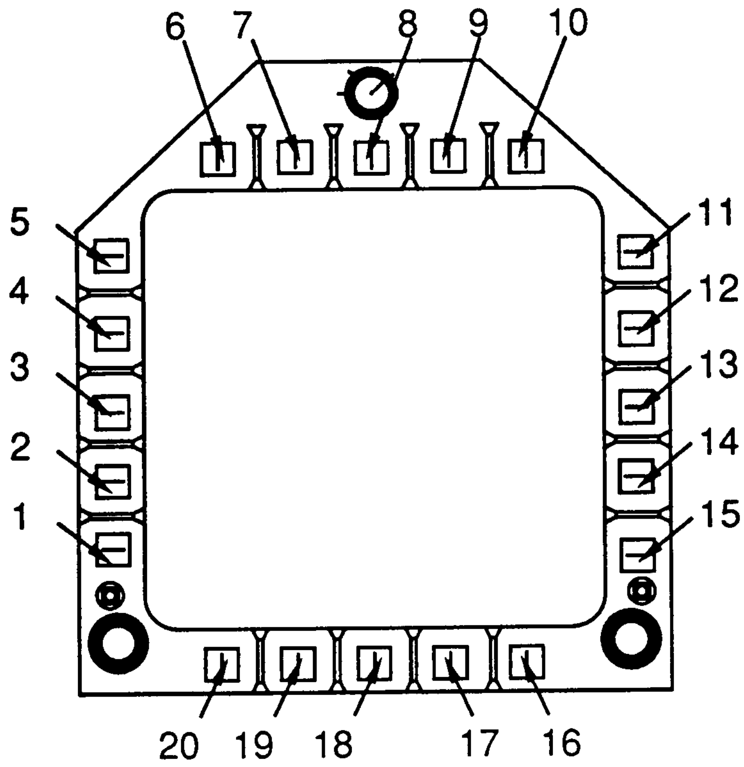


Figure 1-1. MDI Configuration & Pushbutton Layout

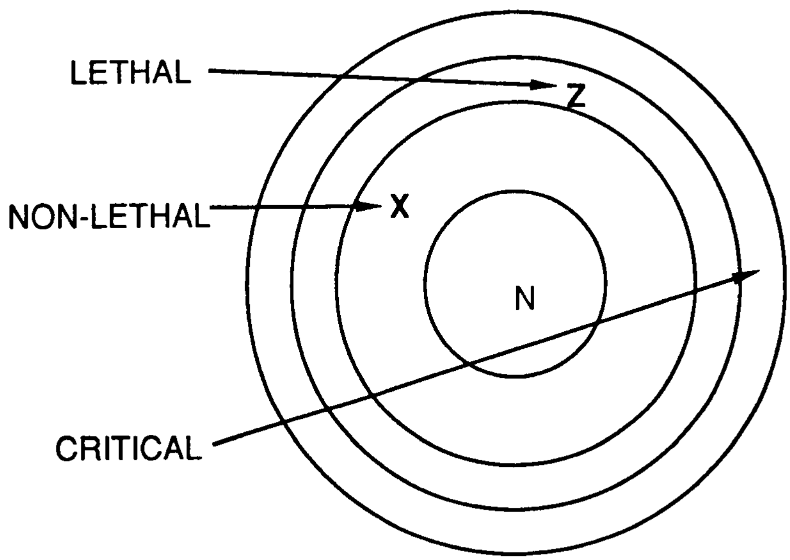


Figure 1-2. ALR-67 Azimuth Display Unit (ADU)

inch from the CRT itself. This, coupled with the location of the ADU, causes parallax error when viewing making it hard to distinguish which ring a specific emitter is in.

The MDIs and MPCD both have five pushbuttons on the outside of each of the four sides which are used for various functions dependant upon which format is being displayed. The pushbuttons are referred to by numbers from one to twenty starting from the bottom tile of the left vertical row and proceeding in a clockwise direction as depicted in Figure 1-1. Additionally, the Up-Front Control (UFC) which is located just below the HUD is used with all displays to enter navigation, sensor, weapons employment data; and access communication, automatic pilot, Identification Friend or Foe (IFF), Instrument Landing System (ILS), Tactical Air Navigation (TACAN), Data Link, Radar Beacon, and Automatic Direction Finding (ADF) equipment. The main instrument panel layout is diagrammed in Figure A-3.

HOTAS Controls. Despite the myriad of pushbuttons, in the combat environment any switch actuations which require the pilot to remove a hand from either the throttles or control stick may be detrimental, impacting pilot workload at best and his survival at the worst. To ameliorate this, the F/A-18 maximizes the use of "Hands on Throttle and Stick" mechanizations commonly referred to as HOTAS. Both the throttles and the control stick have a variety of switches which have multiple functions dependant upon aircraft master mode and the displays selected, allowing for easy selection during critical flight regimes while still enabling full aircraft control. A diagram of the various switches and functions is contained in Figure A-4. The three primary HOTAS controls are the Throttle Designator Controller (TDC), the Sensor Control switch, and the Air-to-Air Weapon Select switch.

The TDC is a force-controlled switch primarily used for the slewing of target designations, acquisition cursors, and the line-of-sight (LOS) of sensors. The Sensor Control switch is a four position switch used to assign the TDC to the various displays and to also command sensor acquisition. The A/A Weapon Select switch is used to select the M61 gun or the various A/A missiles. It can additionally be used to select various A/A radar parameters and sets the aircraft to A/A master mode if not previously set. Despite its nomenclature, this multi-position switch is used extensively to cycle the radar to the desired default conditions for each weapon. The following default radar parameters can be set for each missile: pulse repetition frequency (high, medium, or interleaved), range scale, azimuth sweep, vertical bar scan (number of selected differing horizontal sweeps of the radar antenna which when combined with the azimuth scan determine the search volume), and target aging (duration in seconds that a single radar hit is displayed prior to being blanked). The pilot typically uses this capability to have the radar "tuned" for several anticipated conditions such as long range search, all aspect search, and short range search. If parameters have been changed from the selected missile's default, a quick cycling to another missile and back will reinitialize all parameters except the previous operating mode (range-while-search or track-while-scan). If the M61 gun is selected and then a missile, the radar is initialized to range-while-search with the default conditions.

DESCRIPTION OF SENSORS

The sensors being evaluated include the APG-65 Radar, the AAS-38 Forward Looking Infrared set (Flir), the ALR-67 Radar Warning Receiver, the AGM-88 High Speed Anti-Radiation Missile (HARM), and the RT-1379 Data Link. All sensors have both air-to-air and air-to-ground mission applicability. Additionally, other sensors exist solely for the air-to-ground role. For purposes of this thesis, only the air-to-air mission capabilities will be addressed. Much of the specifics regarding individual sensor tactical performance and limitations are classified and therefor beyond the scope of this thesis. The author has tried to use as much depth as possible within the required security guidelines.

Flir. The Flir is an external pod, mounted on the outboard edge of the left engine inlet (Figure A-5). Like all imaging infrared detectors, it operates according to Planck's Law of Radiation: all objects in nature emit radiation as a function of absolute temperature. Two types of imaging infrared detectors are in common use: those designed for the 3-5 micron wavelengths and those optimized for the 8-12 micron range. Unlike other sensors which may be designed for wide ranges of frequency and application, infrared detectors are essentially limited to these two regions since their detection capability can be greatly decreased by atmospheric absorption. The major causes of this absorption are water, carbon dioxide, and ozone molecules. The effect of these molecules is reduced dramatically in the 3-5 and 8-12 micron regions [Seyrafi, 4]. The former "near-infrared" region is used by sensors designed for detecting jet engine exhaust and hot tailpipes (e.g. heat seeking missiles), while the latter "far-infrared" sensors detect thermal radiation from the aircraft structure itself. The F/A-18 Flir operates in this 8 -12 micron region.

Capable of both day and night detection of airborne targets it has an outstanding capability for detecting multiple targets within the resolution of the radar. The Flir has an excellent field-of-regard ($\pm$ 540° in roll and +30° to -150° in pitch) allowing coverage of targets that are outside of a 30° cone about the tail of the aircraft. Due to it's below the wing mounting on the left side of the airplane, the Flir can be masked on the right by the aircraft fuselage and centerline fuel tank, and on the left by ordnance, external wing fuel tanks, and even the wing itself (Figure A-6). The Flir has both a 12° and a 3° field-of-view, the latter is used almost exclusively in the air-to-air mission. There are presently three mission computer commanded pointed modes and also a single-target-track (STT) mode. In the pointed mode the Flir can be slaved toward the radar target (or MSI target with OFP 91), toward a selected inertial line of sight, or to aircraft boresight. Flirs manufactured since 1986 have provisions for incorporation of a laser for target designation and ranging information. Due to developmental problems with the laser subcontractor, this capability has not yet been fielded.

Flir strengths include:

- day and night capability
- outstanding resolution
- precise line-of-sight angle and angle rates
- entirely passive
- not susceptible to target maneuvers at long range

Flir weaknesses include:

- signal attenuation by weather (dust, humidity, clouds)
- ownship masking of large portions of the field-of-regard
- acquisition of high line-of-sight rate targets is difficult
- acquisition and track is difficult in a clutter environment
- specific target identification difficult

Radar. The radar is the primary air-to-air sensor. Operating in the X band, it is a coherent radio frequency, multiple pulse repetition frequency (PRF), frequency agile, multi-mode radar capable of detecting and tracking multiple fighter sized targets at ranges in excess of 50 kilometers. The radar searches only in front of the F/A-18, having a field-of-regard of ±70° in elevation and azimuth. In both search and track modes the radar provides the mission computers with target range, range rate, angle, velocity, and acceleration. It can also provide both the pulse doppler illumination required for AIM-7 Sparrow post-launch guidance and the data link updates required for long range AIM-120 AMRAAM guidance support. Lastly, the radar can provide target identification.

Radar strengths include:

- all weather capability
- long range detection and track
- multiple target capability
- accurate line-of-sight, range, and range rate parameters

Weaknesses of the radar include:

- active transmissions can "highlight" the aircraft
- vulnerability to electronic countermeasures
- limited performance of some waveforms against low closure targets (e.g. high PRF vs a low altitude, low closure target)
- poorer resolution than some other sensors (e.g. Flir)

HARM. Although designed for air-to-surface launch against enemy radars, the High Speed Anti-Radiation Missile is also capable as an Electronic Signal Measurement (ESM) for the detection of airborne radar emissions. Carried externally (Figure A-5), it can provide all weather long range target detection, identification, and radial line-of-sight. The HARM has a fixed non-scanning antenna.

Data Link. In the air-to-air master mode, the Data Link receives and transmits tactical data to either ground, naval, or airborne (E-2 Hawkeye or E-3 AWACS) terminals. All terminals can provide multiple target information and specific information on individual targets. Since it is truly an off-board sensor, the data link can provide spherical coverage about the F/A-18. There is no capability to directly data link information between fighter aircraft.

Strengths of the Data Link system are:

- all weather operation
- long range spherical coverage

The primary weaknesses of the Data Link are:

- target positions limited by reported position accuracy of the networked aircraft
- slow data update rate

ALR-67. The Radar Warning Receiver is used to detect radar transmissions. Utilizing multiple antennas, the ALR-67 has nearly spherical coverage and can provide target identification, lethality, and directional line-of-sight.

Strengths of the Radar Warning Receiver are:

- all weather spherical coverage
- target identification
- target lethality

Weaknesses of the Radar Warning Receiver are:

- Direction of arrival inaccuracies (antenna placement limitations)
- No target elevation or declination information
- Only receives those active radio frequency targets within its bandwidth
- No direct indication of target range

Due to the direction of arrival inaccuracies and lack of elevation information, it was decided to exclude the ALR-67 from use as a contributor in the Multi-Source Integration effort.

SENSOR AND WEAPONS CAPABILITY BEFORE OFP 91

Although the F/A-18 has been the hallmark of integration, the level seen has simply been the capability of the various "black boxes" to talk with each other. For instance in many aircraft the onboard radar and radar warning receiver are not in communication with one another. Obviously if the radar warning receiver does not know what the aircraft radar is doing then it may be very prone to interference and false alarms from its own system. Typically such problems are dealt with by locating individual antennas in such positions as to minimize such interference. Since all such systems on the F/A-18 communicate via the avionics buses, such integration issues are much easier (in theory) to correct. As an example, the radar provides the warning receiver with each transmission pulse type, frequency, and time tag, allowing the interference blanker to remove these signals prior to their being displayed on the ADU.

Where the integration suffers, however, is in the ability to provide tactical data to the pilot and his capability to employ weapons using this data. The aforementioned sensors can either detect and/or track targets, yet each sensor has its own specific display. Although the F/A-18 has more cockpit displays than other operational fighters, the number of available sensors far exceeds the number of available displays and often a display is reserved for other purposes (e.g. the MPCD is commonly reserved for the Horizontal Situation and Moving Map display). Additionally, only those targets detected with the radar are provided with launch zone information and air-to-air missiles can only be guided at the radar target or those seen visually. So although the Flir, HARM, or data link could tell the pilot that targets were nearby, he could not employ any weapons against such targets until he acquired them with onboard radar or visually saw them. A summary of this capability is depicted in Figure B-3.

The newest fleet released software update is OFP 89. This software does provide limited HUD cueing for Flir targets and provides for the slewing and lock-on of the AIM-9 Sidewinder against such targets. Unfortunately the Sidewinder is a short range dogfight missile and Flir operation is extremely pilot intensive at such ranges against a maneuvering target. OFP 91, which has recently entered developmental flight test, is the first software to attempt integration of all available sensors with weapons employment.

THE REQUIREMENT FOR MULTI-SOURCE INTEGRATION

Since the development of the Soviet Su-27, Mig-29, and the French Mirage 2000; there now exist a large number of extremely capable and potentially threatening aircraft. With the worldwide recognition of the value of stealth technology, future aircraft will have increasingly smaller radar cross sections (RCS) decreasing the utility of active radar transmissions especially in light of the increasing number of RF detectors [Sweetman, 5]. To effectively use narrow field-of-view passive sensors, the pilot needs cueing for proper sensor line-of-sight positioning. This cueing can also be useful for active sensors e.g. if an AWACS with its much greater radar power detects a low RCS target it can provide Data Link cueing to the fighter which can then slave all capable sensors in a concentrated scan about that line-of-sight, thereby decreasing time to detection. Since all sensors have strengths and weaknesses, the proper fuzing of sensor data can provide capabilities not available from any single sensor and with a combined synergistic effect of increased strengths and decreased weaknesses.

With the addition of increasing numbers of sensors on aircraft, it becomes even more important to have the capability of employing weapons using any means of target detection or trackfile support. Since there are more sensors than cockpit displays, the pilot workload would be intolerable if he were to attempt to manage multiple sensors and correlate the raw track data himself.

ARGUMENT AGAINST MULTI-SOURCE INTEGRATION

One of the arguments against MSI is that the nominal fleet Hornet pilot has the radar as his only sensor on the majority of his flights. Dedicating a weapons station to a HARM missile just to provide an ESM identification capability must be weighed against the added weight and drag of the missile, angle of attack limitations caused by the lateral weight asymmetry of carrying one HARM, and loss of the pylon station for carrying an external fuel tank. The Flir mounting is close enough to the aircraft centerline that weight asymmetry considerations may be ignored, however, its carriage is in place of a flush mounted AIM-7 or AIM-120 air-to-air missile. Another drawback is the Flir to F/A-18 ratio is only 1:3. Since a shortage exists, they typically are sent to deployed squadrons. This means that staying current in Flir tactics is difficult and cyclical in nature.

OFP 91 MULTI-SOURCE INTEGRATION DISPLAYS

Attack Display. The previous radar display has been modified and is now labeled the Attack format. Retaining all previous radar control functions, the Attack format is a range versus azimuth display (see Figure 1-3). Range scale is selectable from 5 to 160 nautical miles while the azimuth is a constant $\pm 70°$ (although smaller radar azimuth coverages may be selected). Those trackfiles which do not have a resolved range are placed in the "dugout", the new horizontal corridor at the top of the tactical region. The area outside the 4" X 4" tactical region is called the non-tactical region and is reserved for control selections such as radar mode, elevation and azimuth coverage, range scales, etc. Radar search target hits that have not yet formed a MSI trackfile are depicted as small rectangles, once a trackfile is formed, a Hostile, Ambiguous, Friendly, Unknown (HAFU) symbol is displayed along with its numerical ranking and aspect vector.

The HAFU shape reflects the target's identification: a wedge for hostile, semi-circle for friendly, or an open box for unknown or ambiguous. Whether the identification is provided via an onboard or offboard sensor is indicated by the vertical orientation of the HAFU. Those trackfiles with radar as a contributor have circles around the rank number. Example HAFUs are shown in Figure B-1.

The aspect vector depicts the angular relationship between the target's nose and line-of-sight to ownship. The aspect vector is preferred to a heading vector because it is easier to interpret target threat at various azimuths using aspect e.g. if the target has his aircraft pointed at ownship the target aspect vector points directly at the bottom of the Attack display. Various aspects and azimuth angles are depicted in Figure B-2.

The numerical ranking is computed by the tactical mission computer using a computation of range divided by range rate. The pilot can designate two trackfiles for special ranking. The first designation is called the Launch and Steering (L&S) target. All HUD displays such as the Target Designator (TD) box, weapon launch acceptability regions (LARs), allowable steering error (ASE) circle and aim dot, and SHOOT cue; reference the

L&S target. The mission computer number one ranked target can quickly be designated the L&S by a depression of the control stick mounted undesignate button. A second designation is called the Designated Target #2 (DT2). The DT2 target has weapons LARS depicted on the Attack display only, and has a higher than standard ranking for automatic radar scan centering in the track-while-scan radar mode. If the right MDI has a display which can not accept TDC assignment (i.e. no cursor commands for slewing or designating) an actuation of the Sensor Control switch toward the display (right) initializes the display to the Attack format.

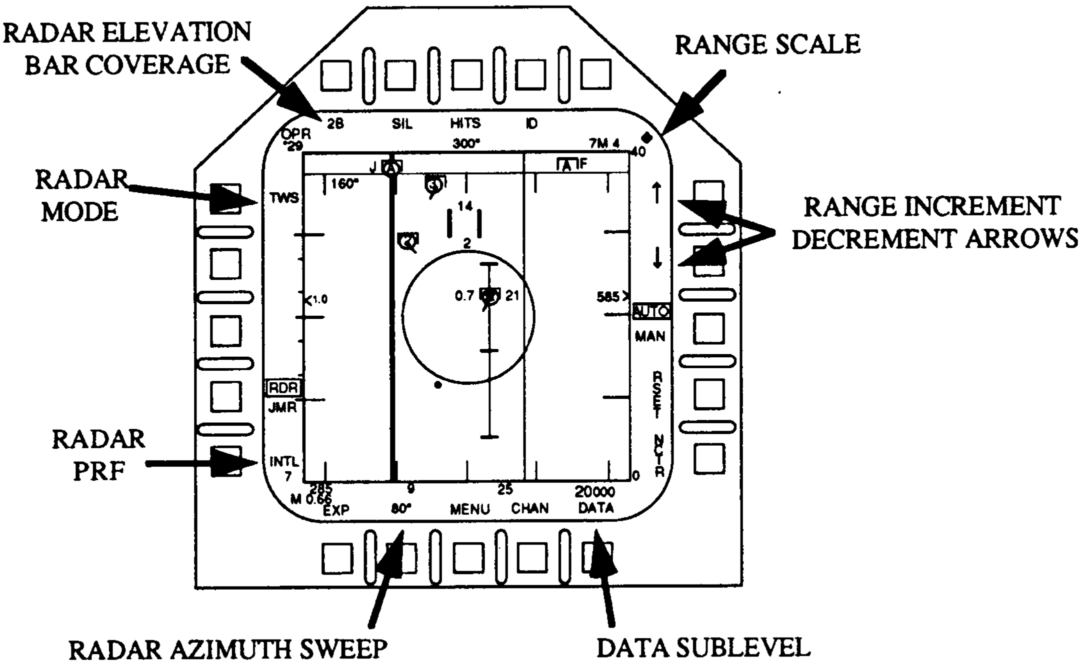


Figure 1-3. Attack Format

<u>Situational Awareness (SA) Display</u>. The SA display (Figure 1-4) is a growth from the previous Data Link display. The aircraft is center referenced and targets are depicted using a "God's eye view". MSI target HAFUs are shown at their applicable range and bearing from ownship and heading vectors are depicted vice the aspect vectors displayed on the Attack display. Range scales are selectable from 320 NM down to 5 NM in one half range scale increments. Sensor fields-of-regard are labeled and depicted as arcs along the circumference of the compass rose. Data Link message commands are displayed in boxes on the outside of the display. If the sensor control switch is activated toward the

horizontal situation indicator (HSI) display, the display is cycled to the SA display (and vice versa). If a 40 NM or less range scale is selected the digital map set provides an overlay of the moving map display. Therefor the SA display is normally viewed on the MPCD for full color map symbology.

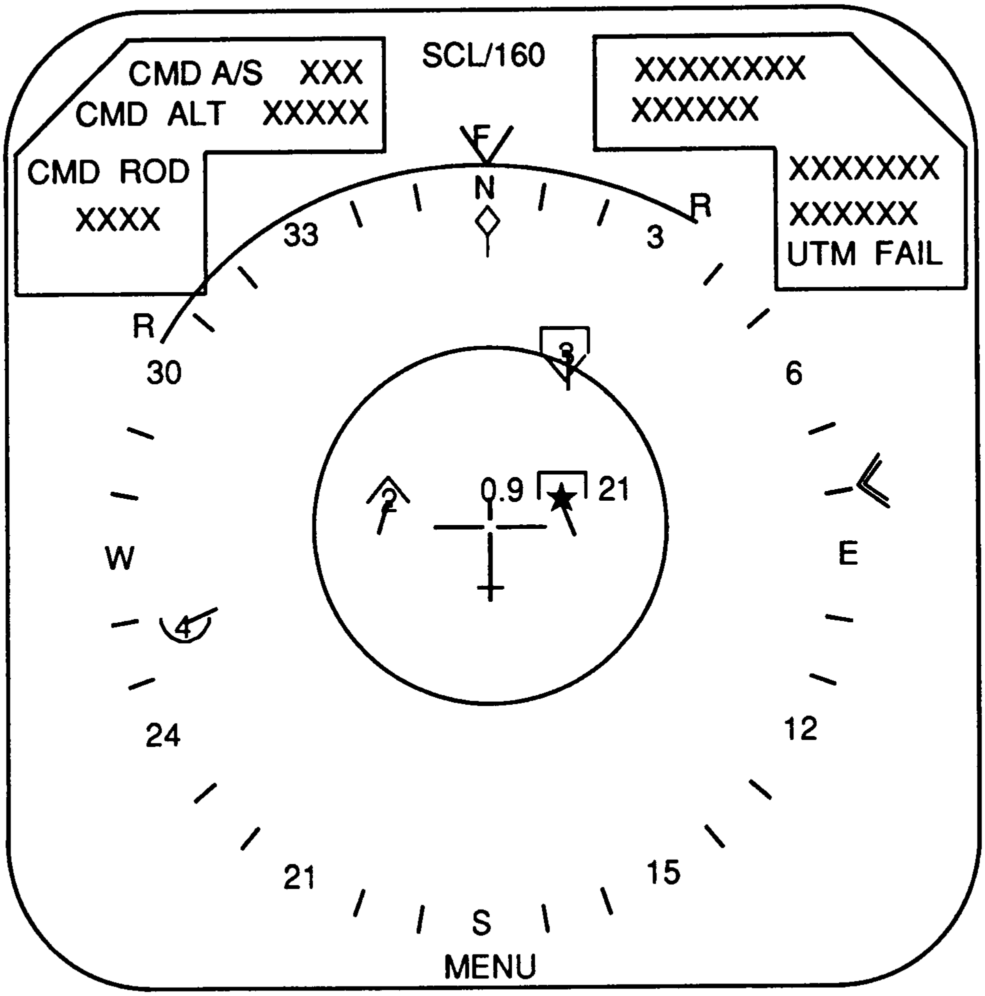


Figure 1-4. Situational Awareness Display

Az/El Display. A new display format which shows azimuth versus elevation is called the Az/El display (Figure 1-5). Like the Attack display the azimuth covers ±70°. The elevation display is selectable to either ±15°, 30°, or 70°. The Az/El display was designed to provide another dimension of information for angle only trackfiles (those without range). Sensor fields-of-view are depicted on the Az/El display making scan centering changes of all applicable sensors quick and easy. Unlike the other displays a separate Az/El display exists for each slewable sensor (radar, FLIR, and HARM). Although all sensor fields of view are depicted on each Az/El display, only the field of view of the applicable sensor is slewable on that level. Additional options that pertain to the individual sensor are located on that sensor's Az/El display.

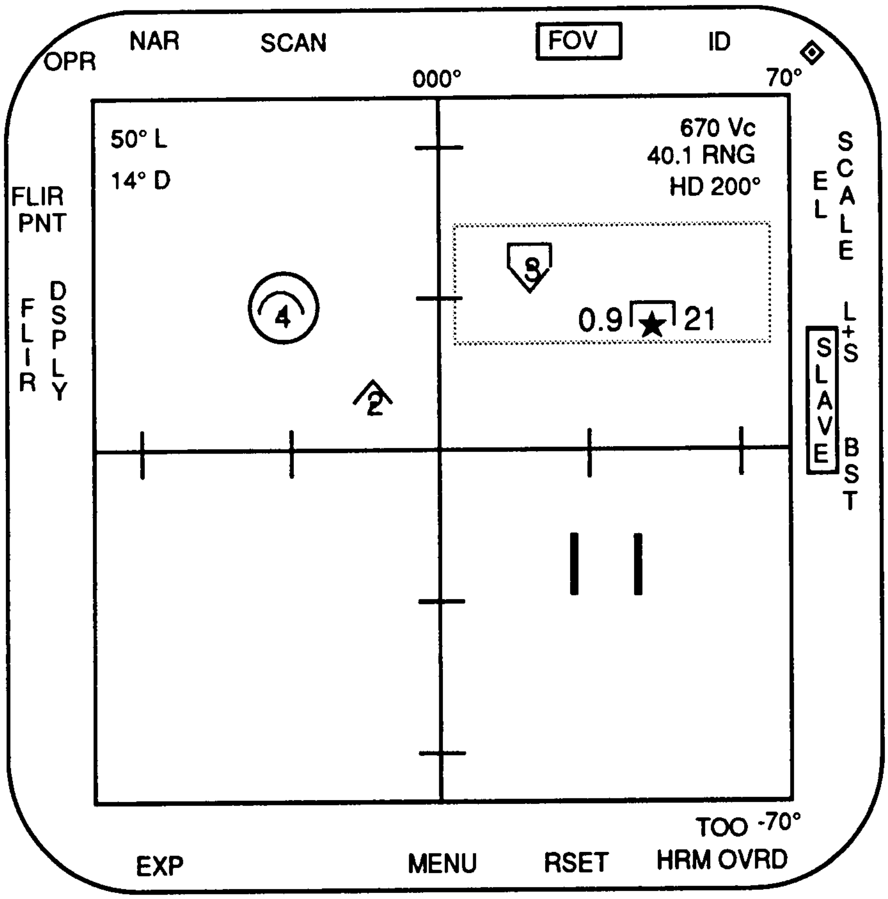


Figure 1-5. Azimuth/Elevation Display (Flir Format)

Head-Up Display. Figure 1-6 shows a sample HUD format with a Launch and Steering target and an AIM-7 Sparrow as the selected weapon. OFP 91 added several new descriptors to provide amplifying information:

- If a launch mode other than the normal default is selected, a cue is provided beneath the weapon selected cue e.g. "LOFT".
- "M" next to the target designator box indicates multiple targets about the L&S.
- If optimum conditions for launch are not met a cue is provided beneath the target designator box e.g. "GO STT".
- "X" indicates line-of-sight to Designated Target #2 (DT2)

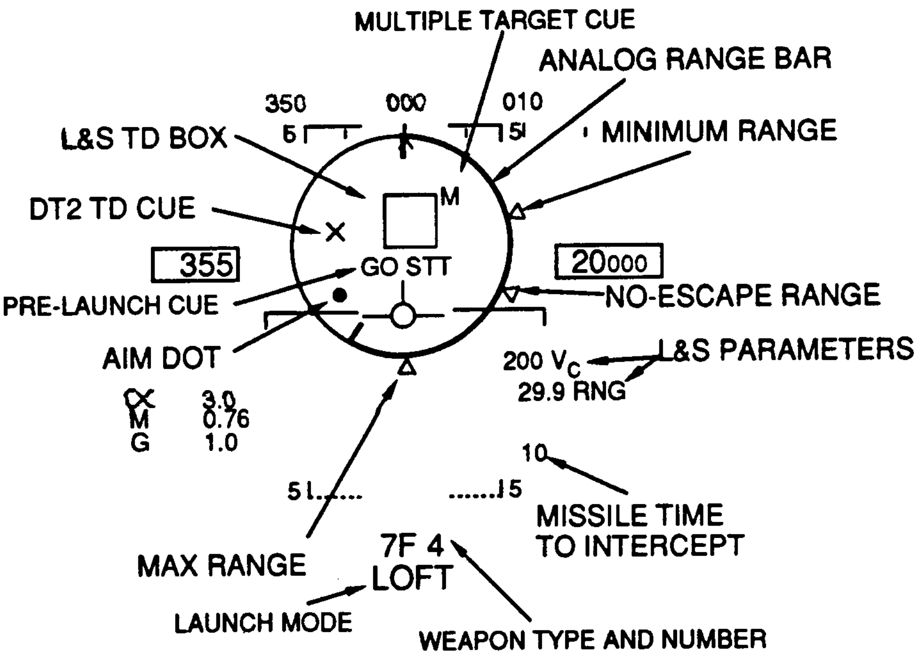


Figure 1-6. AIM-7M Head-Up Display

AIM-9 Sidewinder. In OFP 89, the infrared guided Sidewinder could be slaved and launched at a target positioned at either the aircraft boresight, radar line of sight, or Flir line of sight (if they were within the slaving gimbal limits of the missile). Starting from boresight, the seeker was sequenced to the radar target, then to the Flir target using quick actuations of the throttle mounted cage/uncage switch. Those target states which did not exist, were skipped. The line of sight of the seeker is depicted by a 1.5° diameter circle on the HUD.

In an effort to increase the launch envelope of the missile, an option was given the pilot allowing him to override the aircraft stores management set threshold. This aircraft threshold was designed artificially higher than the missile's internal tracking ability. The purpose of this threshold was to reduce the possibility of the seeker locking onto background radiation. In look-up situations without any background clouds, this threshold appreciably reduced the launch range of the missile. This new mode was labeled "override" and was selected by depressing and holding the cage/uncage button for greater than 0.8 second. Once selected, the AIM-9 seeker was immediately allowed to track any signal seen along the Flir or radar line of sight. If insufficient infrared energy was present, the seeker would drift from the target. To minimize pilot action, the stores management set automatically slaved the seeker back to the target line-of-sight once the seeker had drifted beyond 3°. Once sufficient energy existed to track the target the seeker would stay within the 3° angle of coincidence and the missile could be fired if within its kinematic capabilities [McDonnell, 3].

The OFP 89 AIM-9 mechanization was an outgrowth of the original simple mechanization in which the Sidewinder could only be slaved to either aircraft boresight or the radar line-of-sight and there was no override capability.

The mechanization was simplified somewhat with OFP 91. Since the pilot had the option of making any MSI target the L&S, the slaving options were reduced to either boresight or the L&S target. Selection of override mode still required holding the cage/uncage button depressed for greater than 0.8 second. The flow diagram delineating OFP 91 Sidewinder employment is contained in Figure C-1.

AIM-7 Sparrow. In previous OFPs the AIM-7 could only be launched at the radar STT target (a non-STT backup mode does exist but is limited to visual employment and used as a last resort only). If the radar was in track-while-scan mode and Sparrow launch was commanded, the radar would transition to STT prior to the launch. With OFP 91, the AIM-7 can be launched against any MSI target within the field-of-regard of the radar. If the radar is not in STT prior to launch a "GO STT" cue is displayed directly underneath the target designator box on the HUD. In any case, the radar will transition to STT upon trigger squeeze. Additionally, if the radar loses track of the target, MSI will automatically provide multi-sensor support to drive the radar back to the proper line-of-sight and command reacquisition. If reacquisition is not achieved, the radar will be slaved to the MSI target line-of-sight, and still provide the pulse doppler illumination required for Sparrow guidance.

An additional enhancement was the automatic selection of AIM-7M H-build Sparrow lofted guidance. The H-build version of the missile has a much greater kinematic capability than earlier versions of the AIM-7. This longer range capability is possible because the missile initially follows a lofted trajectory vice the conventional proportional navigation course [Zarchan, 6]. The pilot can maximize the missile's potential if he pulls the aircraft into the proper climb angle alleviating the missile from having to perform the maneuver itself. In some scenarios, the pilot may not desire to climb prior to the launching the missile. To give the pilot flexibility the software allows him to choose lofted or conventional steering. In OFP 89, the option of lofted or conventional steering required head down pushbutton actuation on the Stores format. If lofted steering was not selected, then the missile followed conventional guidance. In OFP 91, lofted or conventional steering is selected by toggling the cage/uncage button. If lofted steering is not selected the missile will perform the loft itself giving the pilot a compromise between having to perform an aircraft climb or being forced to the shorter range capability of conventional guidance.

AIM-120 AMRAAM. The AMRAAM has three basic launch modes: Command Inertial Active (CIA), Inertial Active (IA), and Visual. The primary method of employment, Command Inertial Active uses post-launch RF data link updates from the APG-65 radar until the AMRAAM is within range of its active RF seeker. The radar interleaves the data link messages into its STT and track-while-scan timelines. An Inertial Active launch passes the target's inertial position along with its velocity to the missile at launch. The missile's autopilot commands a flight path to a point where the active seeker should be able to find the target for terminal guidance. Although this requires no post-launch emissions from the launching aircraft ("fire and forget"), it can be defeated if the target maneuvers to a point outside the missile's field-of-view during the missile time of flight. The Visual launch mode also uses no post-launch support, the pilot simply puts the target within the AMRAAM seeker field-of-view depicted on the HUD and pulls the trigger. The missile seeker immediately locks on and guides toward the first target it sees.

With OFP 91, the AMRAAM can be launched against any target within the radar field-of-regard. In theory it is possible to perform an inertial active launch against a target outside the radar field-of-regard but the missile would sacrifice a great amount of energy maneuvering to a collision course. Since such a target would most likely be an MSI file with large variances the probability of success would most likely be intolerably low.

M61 Gun. The M61 gun is a six barrel Gatling gun mounted in the nose of the aircraft. The magazine holds up to 578 rounds of 20 millimeter diameter ammunition which can be fired at 6000 or 4000 rounds per minute. The F/A-18 has two types of air-to-air gunsights, the type used dependant upon pilot selection and whether or not the radar is in single-target-track [McDonnell, 3].

The director sight is the default mode if the radar is in STT and is shown in Figure 1-7. To assist the pilot with achieving a radar lock, a medium PRF, 5 nm range, automatic acquisition, 20° X 20° dogfight radar mode is automatically enabled. The radar inputs the target's range, velocity, range rate, and acceleration to the mission computer which computes the required lead angle using bullet ballistic equations and predicted time-of-flight. The gun pipper indicates the point in the plane of the target's range where bullet impact is predicted. The pilot is tasked with maneuvering the aircraft to put the pipper on the target. To aid in recognizing an in zone condition the mission computer displays a "SHOOT" cue directly above the HUD target designator box. The cue is enabled when the target is within gun maximum range, computed miss distance is less than twenty feet, and the aircraft constraints (Gun armed or simulated training mode, and aircraft airborne) are met. On the surface, it appears as if the director gunsight is a "death dot", that is, if the pipper is on the target and the trigger depressed then the bullets will impact the target. The mission computer, however, is not clairvoyant and does not know what the target will do during the bullet time-of-flight. It therefor assumes no change in acceleration and velocity. A prudent target pilot would attempt to evade the bullets once he saw them fired. Typical bullet time-of-flights range from several tenths of a second to over one second. Additionally, the radar STT filters required to attenuate the angular noise inherent due to target scintillation [McDonnell, 3] cause approximately a one second delay in director gunsight reaction to target maneuvers. Especially at longer ranges, the possibility of evading an accurately aimed gun shot exists.

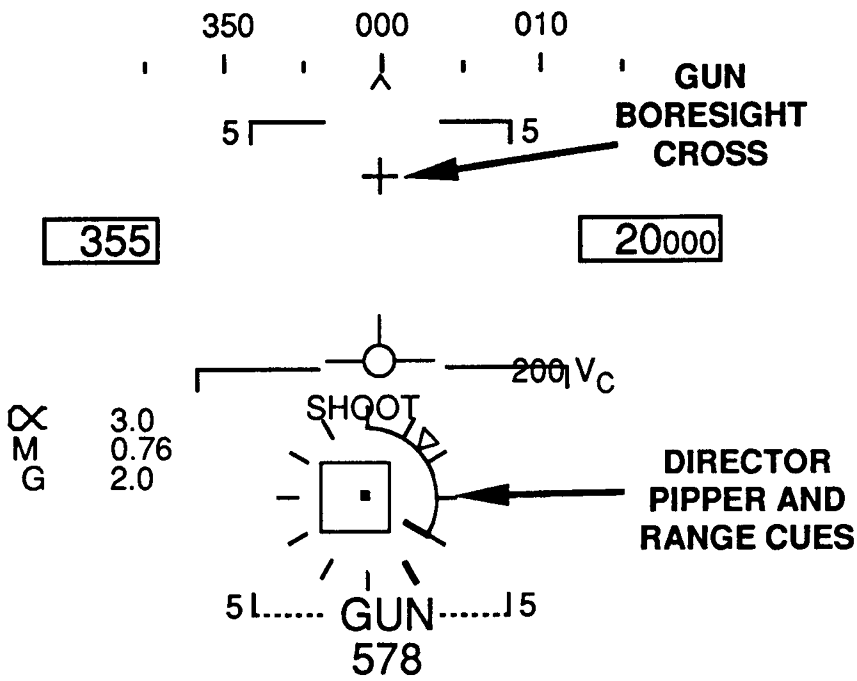


Figure 1-7. OFP 91 Director Gunsight (Radar STT)

If the radar is not in STT, the disturbed mode shown if Figure 1-8 is the default. Since specific target parameters are either not known (no MSI trackfile) or of insufficient quality for firing use (i.e. a range-while-search or track-while-scan MSI trackfile), the mission computer must approximate target conditions using a mix of ownship data and fixed values. Angular rates are derived using ownship velocity and acceleration. Range rate is fixed at a -30 knots, and target range is fixed at either 2000 ft or 1000 ft dependant upon cage/uncage switch actuation. Since the ownship dynamics affect the sight greatly, any changes in body rates are immediately reflected in the pipper. The pipper is dampened somewhat to increase stability for such instances. The side effect of the damping is an induced settling time of approximately one second. Although less sophisticated, the disturbed sight is a very capable gunsight when the pipper is stabilized on the target at the selected range. To aid the pilot in estimating target range, a 12.5 milliradian circle is displayed about the gun pipper, representing the wing span of a 25 foot target at a 2000 feet range. If the 1000 feet solution is selected with the cage/uncage button, the circle reflects the range by changing size to 25 milliradians. Unfortunately, in the age of increasingly agile fighters, it is virtually impossible to stabilize at a specific range against anyone with even a modicum of training and a desire to live!

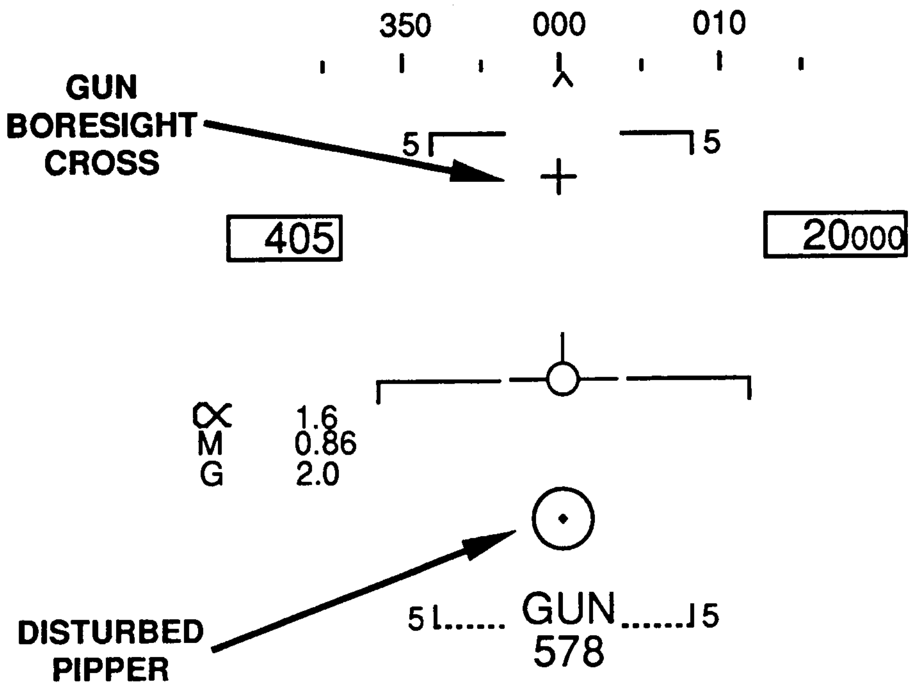


Figure 1-8. OFP 91 Disturbed Gunsight (Non-Radar STT)

Due to its inherent superiority it would appear the director mode would be used exclusively, however, in practice this is not the case. Most gun firing opportunities are "snap shots", that is, a highly dynamic situation characterized by high line-of-sight rates and little time to achieve a radar STT. Often, the disturbed mode is the only gunsight available.

The disturbed mode is also pilot selectable with a radar STT, however, there is no tactical value of such a selection unless the director is unusable due to "noisy" track conditions. Such conditions may occur due to target electronic counter measures or ownship radar waveform limitations. In such cases it is next to impossible for the pilot to select the Stores format and select the disturbed gunsight option while the firing opportunity exists. A sight "stiffening" capability for use in such instances is available by depression of the cage/uncage button. The stiffened director is of little tactical value since the sight dynamics are negligibly effected.

The only gunsight change in OFP 91 was the addition of a small cross displayed at the gun boresight of +3°. The gun cross is displayed in all air-to-air modes to assist the pilot with setting the proper plane of motion. If the aircraft is stable, and in the same maneuvering plane of motion as the target, the bullets would appear to move vertically in the HUD away from the gun cross. At close ranges with short times-of-flight and negligible gravitational effects, the gun cross could be of value for achieving hits in a snap shot environment.

2. MULTI-SOURCE INTEGRATION THEORY

BACKGROUND

MSI has many potential applications [Bar-Shalom, 7; G.W. Univ., 8]. It is obvious that if different sensors have different scan rates that the temporal coverage of targets can be increased. If the sensors detect differing frequency spectrums then they can give alternate spectral views of the same targets or search volume. With proper algorithms MSI has the potential to improve:

- Target detection and tracking
- Target identification
- Vulnerability to specific sensor weaknesses
- Aircraft capability (sensor, weapons, human factors)
- Aircraft survivability

Detection and Tracking. To function properly, MSI algorithms must track multiple targets and associate the various targets with the proper trackfiles. Initial attempts at MSI used relatively simple fixed gains for tracking, and the "nearest neighbor" approach for trackfile association [Bar-Shalom, 7]. The algorithm simply fuzed the trackfiles which were closest to each other regardless of their kinematics. This had obvious shortcomings, especially when differing sensors saw different targets in proximity to each other. The fixed-gain filters worked well if the targets did not maneuver but were inadequate if the converse was true. Due to recent advances in technology, the computational capabilities of "flyable" computers has increased greatly. This increased capability allows for the use of more advanced hypotheses and tracking methods.

Identification. Of paramount tactical importance, identification processing has received a great deal of emphasis in recent years. Unclassified public sources [Ditzler, 1; Bar-Shalom, 7; and Gunston, 9] name several methods of identification:

- Radar classification has become possible with advances in digital processing and synthetic aperture techniques.
- Classification of engines is possible due to their unique spectral characteristics. An engine identification, however, is usually not a specific aircraft identification since few engine types are only used in one model of aircraft.

• Target shape identification is possible through inverse synthetic aperture techniques [Stimson, 10] or by using very short wavelengths such as millimeter radar.

• Since received radar signal strength is a function of target range and RCS, if range is known then cross section can be determined. RCS alone can not determine identification since computed values can vary greatly for equivalently dimensioned aircraft.

• RF transponders, commonly referred to as "Interrogation Friend or Foe" (IFF) are in common use among air defense fighters. IFF equipment interrogate unknown aircraft. A proper reply is classified "friendly" while no reply or an improper reply may be considered "hostile". Obvious risks with IFF are equipment malfunction, human error (failing to set proper codes), or exploitation of the system by the enemy (spoofing).

• Classification of target RF emissions through the use of ESM sensors. Future sensors need to have greater specificity than earlier models since the recent trend in fighter radars have been toward the same frequency, PRF's, and pulse widths.

• Flight path correlation through the use of planned routing (flight path and altitude) of friendly aircraft or expected routing of enemy aircraft. Potential problems with such a method exist. Is an aircraft following the friendly routing definitely friendly or could he be following a friendly aircraft or have figured out the routing through intelligence methods? Knowledge of expected enemy routing requires "a priori" knowledge although through the use of strategic assets (satellites, reconnaissance aircraft, and other signal intelligence gatherers) this may be possible.

MSI IN OPERATIONAL FLIGHT PROGRAM 91

Operational Flight Program 91 contains the first attempt at fielding a multi-source integration (MSI) algorithm. The MSI algorithm receives spatial kinematic and attribute data from the individual contributing sensors as shown in Table 2-1.

The algorithm merges the data from the correlating sensors forming "fuzed" MSI trackfiles. The data from individual contributors are assigned weight factors or "gains" based on the variances of the various sensor states. The algorithm uses these gains in a synergistic manner, the end result being the MSI trackfile possesses quality and continuity superior than any of the individual sensor trackfiles. Such performance improvements have obvious benefits such as increased tracking accuracy against targets using hard maneuvering or electronic counter measures.

Table 2-1. MSI Inputs and Outputs

	INPUT SOURCES				MSI
	FLIR	RADAR	HARM	DATA LINK	OUTPUT
LOS (N,E,D)	X	X	X	X	X
LOS RATE	X	X		X	X
RANGE		X		X	X
RANGE RATE		X		X	X
IDENTIFICATION		X	X	X	X

THE CORRELATION AND ASSOCIATION PROCESS

The MSI algorithm correlates the trackfiles by computing the standard differences between the individual sensor trackfiles and the previous MSI trackfiles:

$$\frac{(\text{sensor state - MSI state})^2}{(\sigma^2_{\text{sensor state}} + \sigma^2_{\text{MSI state}})}$$

Note: "σ" is the state standard deviation and "σ^2" is the variance. The standard difference is computed for four states: the direction cosines (North, East, and Down) and range. The total standard difference is obtained by averaging the individual state standard differences. The total standard difference is then biased using both trackfile age and range. The age bias is intended to bias the trackfile association toward those MSI trackfiles which have already been established. The age biasing is equal to the logarithm of the trackfile age in seconds if the file is a non-STT file; or a constant if the file is a STT trackfile. This biasing is intended to decrease the possibility of an MSI trackfile falsely splitting into multiple trackfiles. The range bias is equal to [1- 0.05(range standard difference)], and biases the association toward those MSI trackfiles which have a known range value. This bias is intended to prevent closely spaced trackfiles of unknown range (angle only) from intermittently correlating to those trackfiles possessing valid range. The first step in the correlation process is to eliminate obvious mismatches by using a windowing equation:

$$(\text{sensor state - MSI state})^2 < 16\,(\sigma^2_{\text{sensor state}} + \sigma^2_{\text{MSI state}})$$

If the window test for the state is passed, the windowing equation is applied to the next state. If a window test is failed the standard difference is set equal to infinity. Agreement matrices are created for each sensor with each element representing the total standard difference value of the sensor tracks and MSI tracks. The correlation is performed on each matrix, using a global process for near optimal association as depicted in Figure D-1. Multiple trackfiles from an individual sensor are never combined into the same MSI trackfile.

Each sensor has individual variances for each of their provided states. These variances are used in determining the gains to be applied when merging the state into a "fuzed" MSI trackfile. Although specific values are classified, their relationships are delineated in Table 2-2. The variances may either be fixed or vary in size. The specific variance types are presented in Table 2-3. The fuzed MSI trackfile has smaller variances than those of the individual correlating sensors [McDonnell, 11].

Table 2-2. Target State and Variance Relationship

Target State	**Variance Relationships (smaller to larger)**			
Direction Cosines	Flir	Radar	HARM	Data Link
Direction Cos Rate	Flir	Radar	Data Link	
Range	Radar	Data Link		
Range Rate	Radar	Data Link		

Table 2-3. Sensor Variance Types

Sensor	**Variance Type**
Radar	Variable - function of range
Flir	Fixed
HARM	Variable - function of angle off boresight
Data Link	Fixed

MISSION COMPUTER THROUGHPUT IMPLICATIONS

The tactical mission computer performs the MSI processing at various rates. Single-target-track data is processed at a 5 hertz rate while multi-target-track data is processed at a 1/2 hertz rate. A few input/output operations are performed at 20 hertz. Processing rates effect the correlation process, the faster the processing, the more accurate the reported sensor states will be. The main constraint on the processing rates is mission computer throughput. The algorithm designers had to choose the shortest processing frametime within the limitations of the mission computer capability and MSI coding effort.

In certain cases a hard link condition is set between a sensor STT trackfile and the MSI trackfile. By "hard link" it is meant that a particular sensor STT track, rather than being recorrelated every 5 Hz, is correlated only once at the initial link, and no further correlations are performed. This hard link is set in an effort to decrease the chances of trackfile splitting. When the radar is a contributor to a MSI trackfile, it is hard linked to the trackfile upon entry into radar STT. Flir STT trackfiles are only hard linked when the angular rates exceed a relatively high value. Hard linking is required in this case because the mission computer Kalman filter can not handle the accelerations when the processing is done at 5 hertz.

MSI FILTERING OF SENSOR TRACK DATA

The first step of an MSI fusion algorithm is "what sensor data should be combined?" Either raw detection data from the individual sensors or full trackfile data could be input to the algorithm. If raw data is input, then MSI receives the quickest detection information. The drawback of this approach is it forces the MSI algorithm to do the signal processing required for each sensor. Unfortunately, it would be very difficult for a single generic algorithm to perform adequately since such processing tends to be very dependent upon the sensor type. As an example, although in principle it may track similar to other electromagnetic radiation sensors, an imaging infrared sensor has an extremely high data rate due to the amount of information (pixels) which must be processed. To perform detection and tracking requires high speed special purpose parallel processing [Bar-Shalom, 7]. On the other hand, if only full trackfiles are input to the fusion algorithm then the display of detections may be delayed significantly. Additionally, some data may be lost, especially if an individual sensor has no data storage capability.

Using the philosophy that each tracking sensor should be in charge of its trackfiles, MSI does not refilter a sensor's trackfile data, nor display trackfiles prior to their being declared a sensor trackfile. For instance, the radar internally creates a trackfile after an initial search detection. The radar does not, however, display the trackfile until after a second confirming "hit". MSI performs the windowing and correlation on the internal trackfile and if it correlates with an existing MSI trackfile the information will be used immediately. Consideration was given to have MSI use raw radar data to correlate to MSI but it was decided that the radar had been through years of testing and optimization and it was somewhat parochial to assume the mission computer programmers could come up with better algorithms without similar time and effort expended. Since differing sensors mature at different rates, individual projects may or may not have budgets providing for updating algorithms and it may someday be beneficial for the mission computers to provide a "fine-tune" capability for specific sensors.

MSI TRACKFILE INITIALIZATION AND DELETION

OFP 91 has the capability of maintaining up to sixteen trackfiles. When a sensor track does not have a correlated MSI track, it is copied into the first empty MSI trackfile slot. If the trackfile bank is full then the new trackfile will replace the lowest ranked existing MSI trackfile if it has a higher rank. Trackfile ranking is based upon range divided by range rate meaning the highest ranking (number one trackfile) is assigned to that trackfile which will get to the ownship at the earliest point in time. In the case of angle-only trackfiles, the ranking is based upon angle from aircraft boresight, those closest to boresight having the higher ranking.

MSI trackfiles which are not being updated with new data are extrapolated accordingly. Using the premise that it's more efficient for an individual sensor to perform its own extrapolation, MSI only extrapolates those files whose previously contributing sensors can not. Currently, only the radar performs its own trackfile extrapolation. The trackfile kinematics are extrapolated along with the variances. Extrapolating trackfiles are indicated to the pilot by the flashing of the trackfile symbol on all MSI displays. Extrapolation time is based on range and contributor status, with a 15 second minimum extrapolation time. The MSI trackfile is invalidated and removed when the extrapolation expires. In the case of a radar track-while-scan trackfile, the radar deletes the trackfile after a certain number of radar frames without an update.

The mission computer will track the 16 highest priority trackfiles. Full HAFU symbols are displayed for the top eight, small green "+" symbols are used to depict the eight possible low priority symbols.

MSI RANGE ESTIMATION OF ANGLE ONLY TRACKFILES

Since only the radar and Data Link can provide direct range indications, the mission computer is used to compute trackfile range using line-of-sight rates. If the trackfile does not have any range inputs, the airplane must be maneuvered to generate ownship line-of-sight rates. The MC algorithm uses trigonometric functions and displays the trackfile range along with the estimated error tolerances. The range accuracy and error tolerances are reduced as the passive ranging maneuvering continues. If a trackfile with valid range subsequently loses the range input, the last known range is immediately used to "jump start" the passive ranging algorithm.

CONDITIONS WHEN MSI IS ENABLED

The MSI algorithm is only enabled in the air-to-air master mode. Additionally, the algorithm is disabled and all MSI trackfiles removed when an air combat maneuvering (ACM) radar mode is enabled. Although thought has been given to having a version of MSI tailored for the air-to-ground master mode, it is beyond the capability of the current mission computers.

SENSOR CONTRIBUTOR INITIALIZATION

The mission computer automatically inventories which sensors are onboard the aircraft and communicating on the avionics mux system. All communicating sensors are initialized as contributors and listed on the "Sensor" sublevel of the Situational Awareness display. Sensors may be deselected from the contributor list by unboxing their option on this sublevel. Deselecting a sensor as a contributor does not inhibit the ability to use it as a sensor, its trackfiles will simply never correlate to the MSI trackfiles. If a sensor is communicating but unable to provide data to MSI their option is crossed out to cue the pilot to take corrective action (e.g. turn the Flir from Standby to Operate).

3. TESTING RESULTS AND ANALYSIS

The author's evaluation of the MSI algorithm and OFP 91 consisted of nearly one hundred flights from November 1990 through November 1991. It is important to note that Operational Flight Program 91 had not yet completed developmental testing. The mission computer software had completed the design and debug process but could not complete the verification and validation phase until the radar OFP completed its design and debug phase. There was much effort going into the radar OFP, many design enhancements which would be used by MSI were still being incorporated. Numerous versions of the mission computer and radar OFPs were tested, each one an attempt to fix known problems and incorporate additional design features. The MSI algorithm, sensor performance, controls and displays, and weapons employment are addressed individually. Results are presented at the qualitative "user" level since specific numerical data is classified by the United States Navy.

MSI PERFORMANCE

By the time OFP 91 entered the verification and validation stage, the MSI algorithm was performing well The algorithm did a good job of not falsely correlating individual trackfiles just because their line-of-sights crossed. Conversely, the algorithm properly correlated separate sensor trackfiles when, in fact, they represented a single target.

Problems with miscorrelations did occur when Flir trackfiles with their small variances had similar line-of-sight positions as trackfiles with large variances (HARM & Data Link). On several occasions the author noted the correlation of a Flir and radar trackfile broken if a HARM or Data Link trackfile was nearby. In such cases the radar trackfile lost the Flir contribution and the HARM or Data Link trackfile gained it. The radar trackfile was never miscorrelated because it was hard linked to the track. Proper age biasing may help to alleviate this problem and it is still being worked. Alternative solutions such as hard linking the Flir trackfile to the radar trackfile are "band-aid" type approaches which go against the intent of MSI. **The author recommends that until the miscorrelation problem is solved, fleet pilots be trained to deselect HARM and Data Link as contributors to MSI once they have their desired initial trackfiles.**

MSI increased the aircraft's passive capability in both the intercept and weapons employment phases. The radar could actively detect targets and a Flir single target track achieved on the target of choice. The radar could then be switched to a standby mode and the target's range and velocity would be extrapolated. When the velocity extrapolation time limit was reached, the target mach, closure velocity, and aspect vector were removed from the MSI displays. The length of the range extrapolation is a function of the target range, the longer the range, the longer the extrapolation permitted. When desired, the pilot could turn the radar transmitter back on to quickly update the trackfile's range and velocities. Such tactics were virtually impossible in previous operational flight programs.

IDENTIFICATION CORRELATION

Multi-source integration gave the F/A-18 a new capability, the ability to have multiple identifications from separate onboard sensors. Since none of the target identification methods are yet 100% error free, the ability to have multiple identification sources is useful operationally. Such a capability is important since combat rules of engagement sometimes require two independent identifications as a requisite for clearance to shoot.

The pilot could read the multiple identifications in data windows on the Az/El and Attack displays, however, the HAFU symbol was driven by the highest ranking identification. This ranking is shown in Table 3-1.

Table 3-1. Identification Ranking Priority

ID RANKING PRIORITY	ID SOURCE
1	PILOT
2	RADAR
3	HARM

MSI algorithms should do more than simply use identifications for trackfile biasing. As pointed out in Chapter 2, multiple identification methods exist. Multiple identifications can be used to confirm the true target identity. For instance, a target following the friendly routing but transmitting enemy radar characteristics and not indicating a proper IFF response is most likely a hostile aircraft. Additionally, the algorithm could fuze any radar engine type, airframe shape and RCS data to give a high confidence specific identification. Note that the author does not intend to imply whether such capabilities do or do not exist in current aircraft! Instead of having a cut and dry ID ranking table, the algorithm could assign weighting factors to pick the best identity. **It is recommended the MSI**

algorithm assign gains to individual identification sources and use these gains to determine the most probable target identity if the MSI trackfile has sufficiently small variances to indicate the multiple identifications are from a single target. Although such processing would most likely be very memory intensive the pilot could gain greatly from the increased situational awareness it would provide.

Unfortunately, in OFP 91 the MSI algorithm did not even perform any identification correlation. Although it would involve a great deal of programming effort, multiple identifications could be used with trackfile correlation [McDonnell, 11]. For instance, conflicting high-confidence identifications most likely indicate multiple aircraft and therefor could be used to bias a single trackfile into two separate files. Although there are proponents of this, the author believes concurring identifications should not be used to bias separate trackfiles together because the identifications could be caused by a formation of closely spaced targets. **The author recommends dissimilar identifications on a single trackfile be used to bias the trackfile apart.**

With or without identification correlation, the pilot needs better cueing of multiple identifications. During a combat intercept the 45° rotation of the HUD target designator box cues the pilot to look at the Attack or Az/El display for the identification. There is no "head up" cueing if a second identification occurs. This forces the pilot to scan between the outside environment and the head down displays. The pilot must strive to look outside as much as possible because his chances of successfully defeating an enemy missile increase dramatically if he sees it. Since the rocket burn of air-to-air missiles is normally only several seconds in duration fixation on a single display can be deadly. **The author recommends cueing the pilot of multiple identifications by cycling the HUD target designator box from a square to a diamond. Additionally, cycle the HAFU symbols to reflect the appropriate identifications on the Attack, Az/El, and Situational Awareness displays at a two hertz rate.**

SENSOR PERFORMANCE WITH OFP 91

Flir. The targeting Flir was evaluated in the standard fleet configuration, without any capability to generate track-while-scan trackfiles. One of the most important aspects of the Flir and MSI was the ability for the Flir to be commanded to single-target-track a radar range-while-search target. In previous OFPs, Flir STT was only operationally feasible if slaved to a radar STT target, and then only by looking at the Flir video format, slewing the Flir reticle over the target and commanding acquisition.

With OFP 91, the Flir could be slaved to any MSI trackfile. If the line-of-sight rate of the target was low, the MSI target line-of-sight was often accurate enough to command Flir STT directly from the Az/El format. Although Flir STT was not directly entered the majority of the time, the Flir video display was automatically commanded upon the acquisition attempt and the radar MSI target would virtually always be within the field-of-view of the Flir video. This allowed the pilot to quickly slew the Flir reticle over the target and reattempt acquisition.

If the MSI trackfile had large angle variances such as those with HARM or Data Link contributors only, then the Flir would typically have to be commanded into STT at ranges in excess of twenty miles. If the pilot waited until the range decreased, he would often have to slew the Flir video display blindly around the reported line-of-sight in an attempt to find the target. In all cases, if STT was not achieved and high line-of-sight rates existed then the Flir slew rate was inadequate to recenter the target and command acquisition. **The author recommends increasing the Flir manual slew rates.**

The F/A-18 Flir output is designed for cockpit display and is not optimized for digital tracking and data processing [Bar-Shalom, 7]. It is important to note that new target processor modules have been designed which will give the Flir a track-while-scan capability with a scanning field-of-view of 6° x 20°. With this new processor the Flir will generate trackfiles without having to enter Flir single-target-track. Such a capability will increase the Flir utility as an MSI sensor tremendously. **It is recommended that the Flir with advanced controller processor be flight tested and fielded if successful.**

The shoulder mounting of the Flir caused major voids in its coverage due to aircraft blockage (Figure A-6). Since the Flir could be used without having the Flir video displayed, it required conscious thought on the pilot to keep from both attempting Flir acquisitions on targets hidden by aircraft structure and to keep from maneuvering the aircraft so as to block a Flir tracked target. **The author recommends a masking of the aircraft blockage be provided on the Az/El display. Indicate blockage by masking the appropriate portion of the Flir field-of-view indicator.** The proposed mechanization is depicted in Figure 3-1. **It is recommended that consideration be given to finding a mounting location more suitable for MSI usage in future Hornet design upgrades such as the F/A-18E/F.**

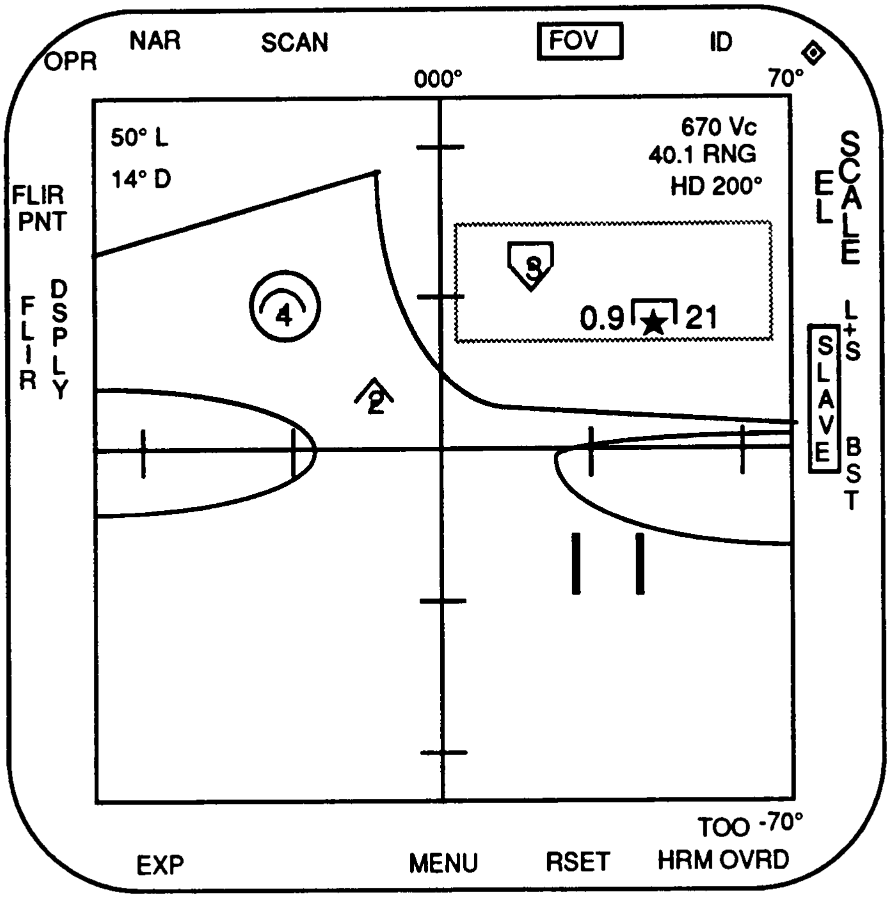


Figure 3-1. Proposed Flir Az/El Format With Aircraft Masking Indicator

Radar. Even without any sensors other than the radar onboard, MSI allowed for display of radar trackfiles under conditions which would have resulted only in the display of raw hits with previous OFPs. The end result was the pilot could use range-while-search mode of the radar with its superior flexibility and resolution, and receive information analogous to the track-while-scan mode. This offered the pilot increased situational awareness as compared to previous OFPs.

Operational Flight Program 91 made using the radar silent (transmitter standby) mode much easier. In previous OFPs, selection of silent was only available in range-while-search and would immediately erase any radar raw hits. With OFP 91, the selection of silent would not cause an immediate loss of pilot situational awareness. If the radar was the only contributor to the trackfile, selection of silent would cause an immediate extrapolation of the trackfile. If the radar was not the only contributor to the trackfile then only the radar data to the MSI algorithm was extrapolated. For instance, the pilot could command FLIR STT from active radar range-while-search. If silent was then commanded, the full trackfile would continue to be displayed and the target range and velocities were extrapolated. Although the velocities aged out quickly, the range extrapolation was dependant upon the last valid range (longer ranges allowed for longer extrapolations). The pilot could command an active frame to update the trackfile's ranges and velocities prior to their deletion. The spotlight mode which was designed in OFP 89 for an active radar sort mode, had additional application if in silent. The major benefits of spotlight in such an instance was: the small 22° scan meant quick frame times and shorter duration transmissions when an active frame was commanded, and the small scan was heading stabilized so it was unlikely the trackfiles would fly outside the narrow azimuth coverage even during ownship maneuvers. **The author recommends the advantages of using spotlight with the silent mode be included in fleet OFP 91 training.** Although it required more concentration than a fully active intercept, the use of the silent mode with active updates was manageable and such emissions control could reduce cueing opposing aircraft of the F/A-18's presence or intentions.

Upon entry into single-target-track (STT), the other hits and trackfiles continued to be displayed as they were extrapolated. Additionally, the cursors were not removed from the display. This allowed the pilot to quickly enter STT in order to achieve the most accurate parameters on that target and retain situational awareness on the position of the other targets. If STT was exited prior to deletion of the other trackfiles, they were quickly updated, usually without any interruption in the trackfile display.

Additionally, it was possible to enter STT on one target and subsequently transfer the STT directly to another extrapolating radar target without having to return to a radar search mode in between. This was evaluated as beneficial in several situations. First, it allowed for quick sampling of multiple MSI targets to quickly receive the most accurate STT target parameters. Secondly, when the pilot desired the most accurate tracking of two targets e.g. if desiring to shoot an AMRAAM at each target, he could first get situational awareness from seeing the multiple targets using a radar search mode, then command radar STT and immediately FLIR STT on one of the targets (the time required to achieve Flir STT is minimized if the target is already in radar STT). Once FLIR STT was achieved he could immediately command radar STT on the other extrapolating target; the end result being both targets tracked by individual sensors in the space of only several seconds.

Track-while-scan, Raid, and Scan Raid were not adequately evaluated due to the immaturity of the radar OFP. A new "one look" Raid was evaluated in it's infancy. One look Raid was always active in STT and attempted to use doppler techniques to resolve multiple targets within the STT beam width. Although it suffered from false alarms, it did function well when multiple targets were within the 3.5° beam. Such targets were indicated to the pilot in various ways depending upon the level of resolution and examples are provided in Figure 3-2.

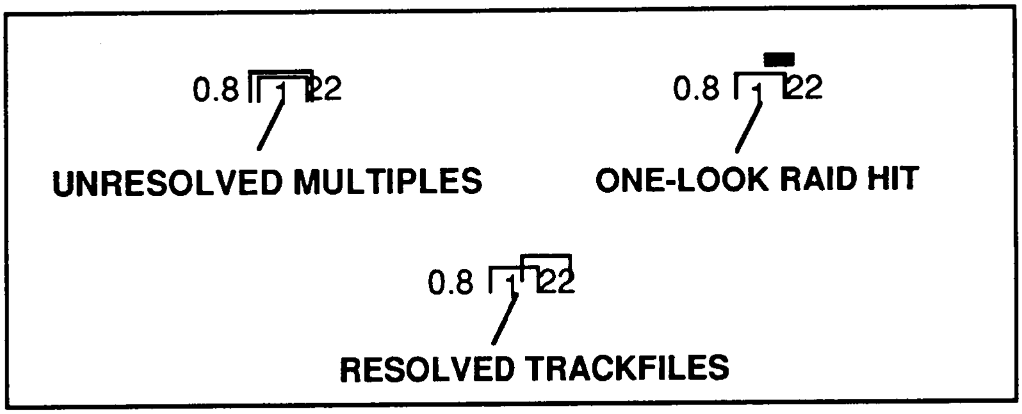


Figure 3-2. Multiple Target Cues In Radar Single-Target-Track

With multiple in beam targets, the one look Raid feature was valuable, however, if the false alarming is not reduced to an acceptable level then the pilot should be given the option of having it enabled or disabled. **The author recommends making a specific option on the radar data sublevel for disabling one look Raid.**

Since radar guided missiles can be fired beyond visual range, a common defensive tactic is a hard turn to beam aspect to kinematically defeat any missiles which may have been fired at long range. This is a risky maneuver since it will exceed the radar's azimuth gimbal limit thereby dropping all search or track data from the targets of interest. The pilot now has his work cut out for him because turning back into the target and finding it on radar can be extremely difficult due to the rapidly changing line of sights. Failure to find the target on radar before the target finds you will most likely end in defeat.

Since range-while-search trackfiles were extrapolated by MSI, such targets could still be seen on the Situational Awareness display as the F/A-18 maneuvered beyond radar gimbal limits. If the pilot maneuvered back to within radar coverage prior to the deletion of the extrapolating target then reacquisition was much easier. The author found the Az/El display very useful in such situations for scan centering the radar coverage over the extrapolated file. The actual target would invariably show up within several cursor widths of the extrapolation. Since MSI does not extrapolate those trackfiles which the radar has extrapolated this tactic only worked for range-while-search targets. STT and track-while-scan targets were quickly extrapolated internally to the radar and dropped from all displays shortly, forcing the pilot to mentally extrapolate the target's position. Radar extrapolation duration must be a compromise between accuracy and situational awareness. **It is recommended that MSI extrapolate the radar L&S trackfile for 30 seconds when the extrapolation is due to exceeding radar gimbal limits.**

HARM. Although not slewable, the HARM did provide useful data to the MSI algorithm. The HARM showed the ability to generate an angle only trackfile and identify it using the target 's radar emissions. The sensitivity of the HARM varied according to the date (block number) the missile was manufactured. Only the block III and IV versions were evaluated. Although both types worked, the block III missile suffered from track discontinuities. The use of the HARM as an electronic surveillance sensor proved useful, however, it was not designed for such a role and had severe limitations.

Probably the most severe limitation of the HARM as a tactical sensor is its fixed seeker and poor direction of arrival accuracy as the target line-of-sight increases from the seeker centroid. To provide line-of-sight data accurate enough for MSI, the tactical mission computer only allows trackfiles within a 10° diameter cone about the missile boresight to be used. This severely limits the tactical usage, requiring the pilot to keep the HARM pointed at the MSI target if he desires it to contribute to the trackfile and provide identification. The 10° field-of-view was not indicated on the Az/El display. **The author recommends showing the 10° HARM field-of-view circle on the Az/El display.** Since the seeker is not slewable it could only realistically be used to contribute to MSI trackfiles whose bearing was provided either from other sensors or a radar ground controller. An additional fallout of the fixed seeker is it inhibits the performance of a passive ranging maneuver against a HARM provided trackfile since such a maneuver would pull the seeker away from the trackfile, causing a quick extrapolation and deletion of the trackfile.

If there was only one non-HARM target providing correlating information, then the pilot liked the fact that the HARM provided identification and correlation of the target. The problem of false correlations was, unfortunately, prevalent. Since the angle variances are large, the HARM angle-only-trackfiles tended to correlate quickly to an existing MSI trackfile with similar direction cosines. If multiple trackfiles existed, the HARM correlation could cycle between the trackfiles at the 1/2 hertz correlation frametime.

The HARM provided a unique, albeit rudimentary capability but showed the value of an ESM sensor. Other sensors exist which provide wideband coverage and excellent line-of-sight accuracy [Sweetman, 5]. Such a sensor would provide an outstanding enhancement to the F/A-18 sensor suite. **The author recommends a wideband ESM sensor with a large field-of-regard and accurate line-of-sight information be incorporated as a baseline sensor on the F/A-18.**

An additional human factors deficiency was noted with regards to the HARM. To enable the missile as an air-to-air sensor, it first had to be selected on the air-to-ground stores format. This was judged to be a minor annoyance.

Data Link. The RT-1739 Data Link was the only MSI sensor which provided all aspect coverage. Although this capability was not new to this OFP, the ability to designate the trackfile and slew other sensors to it was. It was especially interesting to slew the FLIR to the trackfile and get a raid count as the F/A-18 headed away from the airborne target! One of the major limitations to the Data Link was the slow data rate. The slow update rate along with the relatively poor spatial data resulted in trackfile jumpiness as range to the trackfile decreased. This jumpiness increased to the point that FLIR and Sidewinder slaving to the trackfile was not possible and head up display line-of-sight cueing was so far off as to be a detractor to the pilot. At ranges inside ten miles it was not unheard of to see the trackfile not only jump from one side of the aircraft to the other side with each update but to also even jump from a position ahead of the F/A-18 to a position behind!

The poor spatial data was due to the combined effects of the E-2C's outdated inertial navigation system and the inadequacy of its surveillance radar to provide fire control quality tracking data. Although with the incorporation of the satellite navigation global positioning system, E-2 position data will be improved; it alone will not fix the update rate and surveillance radar inadequacies. Consideration was given to having a range cut-out where MSI would stop using Data Link information for correlation. This was deemed an extensive change and viewed by the author as unnecessary since F/A-18 pilots have had to compensate for the Data Link system inaccuracies in earlier OFPs. **It is recommended that fleet F/A-18 pilots be trained to supplement trackfiles that have Data Link as the sole contributor with other sensors before closing to within fifteen miles of the target.**

With its surveillance radar, the E-2 can determine target position, however, like the F/A-18 some types of radar jamming can deny the E-2 the target's range. In such cases, the E-2 can link the bearing of the jammer to the fighters. If the target's jammer covered a wide frequency band then it would be possible that the F/A-18 could also only resolve the target azimuth. Although neither aircraft could resolve the target's range, the point of intersection of the two jam strobes would show the geographic position of the target. This position data could then automatically be used by the MSI algorithm for correlation purposes. In OFP 91, however, only those targets with resolved inertial positions are used for MSI.

Several things must be considered before MSI uses intersecting jam strobes to compute kinematic and spatial data. The first issue is the accuracy and resolution of the strobes. Although fighter radars are capable of building trackfiles from a jamming strobe, the accuracy is much less in a search mode than in a STT angle-only-track (which actually gives a more precise angle than a non-jamming STT). The precision of the E-2's strobe is not as good, however, and any inaccuracies could give large position errors as the range of the target from the E-2 increased [Bar-Shalom, 7]. Since the E-2 tries to stay as far away as feasible from the battle area, these errors could be quite substantial.

Aside from intersecting jam strobes to determine range, any angle only trackfile information could be used. For instance, it would theoretically be possible for the MSI algorithm to use an ESM bearing from the E-2 and a Flir bearing from the F/A-18 to determine target position. A problem which must be solved, however, is that of "ghosting" [Ditzler, 1; Trunk, 12]. As depicted in Figure 3-3, the algorithm would have to interpret which intersections of the strobes were the targets. Were they at positions one and four or two and three? This can be solved if either source can determine a range or if the strobes lie in differing planes.

Because of the complex issues, OFP 91 chose to accept for MSI correlation only those data link trackfiles with resolved spacial data. Before deciding whether to use jam strobes for MSI correlation several issues must first be studied:

- Are such wideband jammers a realistic threat or would separate platforms be used to jam the E-2 and the F/A-18's?

- Would the possible position errors be so large that the required variances would tend to correlate targets which could actually be relatively far apart?
- Is the result gained worth the time, effort, money, and mission computer code space?
- Is there a less complicated mechanization which will satisfy the F/A-18 pilots?

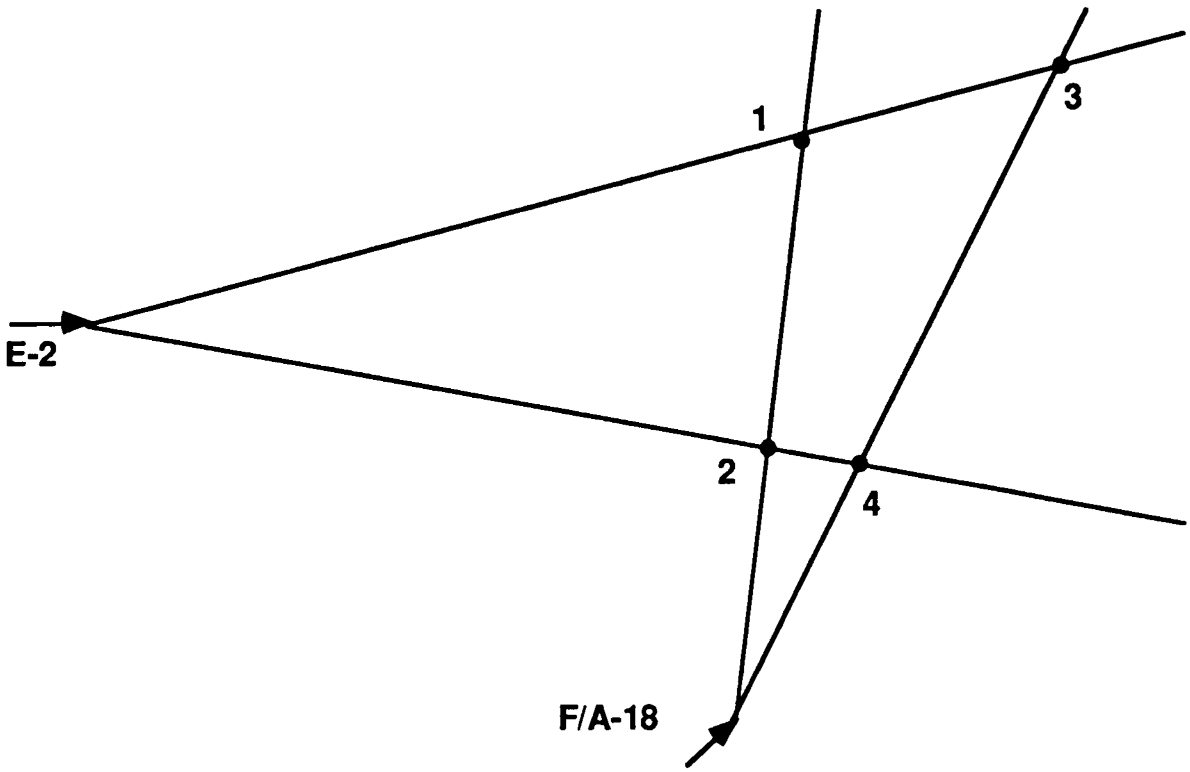


Figure 3-3. Ghosting of Angle Only Trackfiles

While the author feels these ideas deserve consideration he **recommends that the intersection(s) of offship data linked angle only trackfiles and ownship angle only trackfiles be indicated on the Az/El display**. This would allow the pilot to slew the Flir over the intersection and use the Flir video for targeting and raid count. A proposed display using a hollow cross to denote the intersecting strobes is depicted in Figure 3-4.

Although a valuable contributor to MSI, the true value of Data Link will only be realized when an updated system with quicker updates, more accurate data, and a fighter to fighter capability such as the Joint Tactical Information Distribution (JTIDS) system [McDonnell, 13] is fielded.

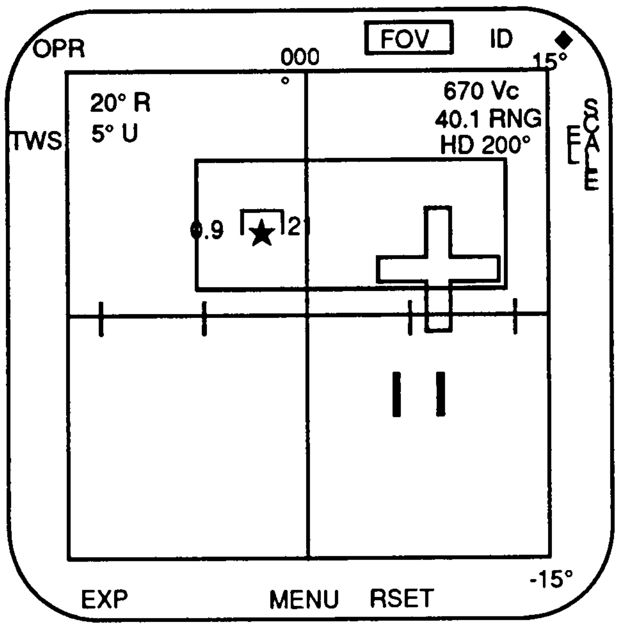


Figure 3-4. Proposed Az/El Display of Intersection of Onboard and Offboard Jam Strobes

EVALUATION OF CONTROLS AND DISPLAY INTEGRATION

TDC Assignment and Acquisition. With previous OFPs, the sensor control switch could only assign the TDC to the radar display. Rocking the sensor control switch in the other three directions commanded various dogfight modes of the radar. If the pilot wanted to command the FLIR to single-target-track he had to first select the Flir video format from the menu format, and then select a TDC pushbutton option prior to commanding acquisition. Only the acquisition command was possible using HOTAS controls. With OFP 91, TDC assignment is straight forward, the pilot simply rocks it in the direction of the display desired. After rocking the sensor control switch towards the HUD, the mission computers command air combat maneuvering (ACM) mode and all radar dogfighting modes are now selectable using the sensor control switch. A quick depression of the un-designate button exits ACM mode and again allows the sensor control switch to be used for TDC assignment.

In earlier OFPs radar acquisition was commanded by rocking the sensor control switch to the right with TDC assignment to the display. This meant that if the radar display was on the right MDI the pilot rocked the sensor control switch *toward* the display. If the radar was on the left MDI he still rocked the sensor control switch to the right but now it was *away* from the display. FLIR acquisition, on the other hand, was commanded by rocking the sensor control switch *towards* the FLIR display (which also could be either left or right) after the TDC option on the FLIR display was was depressed. The TDC assignment and acquisition commands are much more straightforward with OFP 91, the pilot rocks the sensor control switch towards the display to assign TDC priority and then simply rocks it towards the display again to command acquisition independent of the selected sensor. The author found the TDC assignment and acquisition controls much easier to use as implemented in OFP 91.

Use of the Undesignate Button. As in previous OFPs the undesignate button on the back of the control stick served multiple purposes. The original use of the button was to provide a means of returning the radar from single-target-track to a search mode. Starting several years ago, additional functions were added to the switch for cases where the radar is not in single-target-track.

If the radar is not in STT the first depression of the button causes the number one ranked target to become the launch and steering (L&S) target. If an L&S already exists, subsequent depressions cycle the L&S through all the ranked targets. If a second designated target exists (DT2), undesignate button depression only cycles the DT2 and L&S targets. Although this sounds complicated, it is actually quite straightforward and easy to perform in flight.

In previous OFPs it was obvious to the pilot when he was in radar STT since a single target HAFU was displayed and the cursors were removed. In OFP 91, multiple HAFUs are often displayed since other sensor trackfiles are displayed on the Attack display and the radar can also breakout multiple targets using the one look Raid feature. The end result is it is easy for the pilot to forget he is in STT and attempt to use the undesignate button to cycle the L&S from one target to another. What occurs, of course, is the radar breaks STT and returns to search. Although it is easy to recommand acquisition it is usually enough of a surprise to the pilot that several seconds are wasted. Although both the return to search command and L&S stepping can be commanded via the TDC, it requires slewing the cursor to the appropriate point and then TDC depression, which takes more concentration during maneuvering flight. Since the author could not think of a suitable substitute mechanization he **recommends that emphasis be placed on the subtleties of the undesignate switch operation during fleet training on OFP 91.**

Unintentional MSI Shutdown. As pointed out in the introduction, cycling the weapon select switch through guns and then to the appropriate missile is used to set the desired default radar search parameters. Unfortunately, such an action momentarily sets the ACM condition, thereby disabling all MSI trackfiles. This is an unfortunate by-product and requires the changing of habit patterns if the pilot does not desire to have to regenerate the trackfiles. **The author recommends that fleet pilots be informed the recommended way to initialize radar default parameters is to cycle the weapon select switch from one missile to another which initializes the PRF, range scale, azimuth sweep, bar scan, and target aging; but use the TDC controlled cursor or pushbutton to select the desired radar search mode.**

Display Initialization. The default formats of having the Az/El on the left and the Attack on the right displays, respectively, was natural and worked well. Use of the SA display was dependant upon attack geometry and whether aft field-of-view sensors were onboard. Even without the use of such sensors, the ability to quickly cycle between the SA format and the Horizontal Situation navigation format was used extensively.

EVALUATION OF MSI DISPLAYS

Attack Display. The Attack display functioned well as implemented. The ability to directly compare radar data with other sensor trackfiles was a great step forward. Since the display is a substitute for the previous Radar display, the Attack display has display logic which is different from the other head down MSI displays. Unlike the Az/El and SA displays, in range-while-search the Attack display only displayed radar raw hits unless the trackfile had a non-radar contributor or was the L&S or target under the cursor, in which case the full trackfile symbology was displayed. This logic was decided upon in order to keep the Attack display less of a radical departure from the previous OFP's Radar display. The decision to use a small circle around the ranking number to indicate those trackfiles with radar contribution was especially beneficial on the Attack display. In cases when the number of trackfiles exceeded the number of targets, knowing whether or not they were induced by the radar was useful for the pilot in making decisions as to which were valid, which sensors should be slaved where, and for debugging purposes during post mission video tape review.

Since the Attack display has additional functions than the previous OFP's Radar display, some of the functions which are seldom changed in flight have been moved to a sublevel data display. This sublevel is enabled by pushing the Data option located at pushbutton 16. While the overall implementation was good, several negative results were noted. Since target aging is rarely changed in flight and can be set by the pilot to different default values depending upon weapon selection, it has been moved to the Data sublevel. None of the options on the Data sublevel are HOTAS capable, requiring the pilot to use the push tiles to change values. This is somewhat cumbersome since target aging can be 2, 4, 8, 16, or 32 seconds; the values cycled with multiple button depressions. Since target aging is not accessible on the Attack display toplevel format the author **recommends displaying the current aging value in the non-tactical region under pushbutton number ten.**

The push button to command radar Silent (transmitter to standby) has been relocated on the Attack toplevel and is no longer capable of HOTAS selection. Although transmitter operation can also be shut off by pushing the emissions control (EMCON) button on the up front control panel or rotating the radar power knob to Standby, the author believes HOTAS selection is important since active radar transmissions can highlight the ownship position to enemy ESM systems. **It is recommended that a mechanization be incorporated which would allow the pilot to quickly shut off active radar transmissions. The method should not only be a HOTAS selection, it should also not require any cursor slewing. Additionally, it should not command the aircraft to ACM mode, thereby disabling the MSI algorithm. The author recommends that three quick actuations of the sensor control switch towards the attack display within a period of 1.2 seconds command the radar to silent.**

Unlike other operational fighter aircraft, the Hornet allows for the HOTAS selection of many options about the periphery of the non-tactical region of the radar (Attack) display. A certain amount of dexterity is required to quickly slew the cursor over the desired option and depress it to select the option. The mission computer reads the trailing edge of the TDC switch actuation, that is, nothing occurs until it is released. It is not uncommon for the pilot to inadvertently move the cursor away from the desired point during the selection process. Since competent use of the TDC requires practice, many pilots simply choose to use the pushbuttons to make the desired selection. The author feels that the HOTAS concept is good, however, those selections which are required often and are time critical should be made easier.

The best examples of such options are the radar azimuth sweep and the radar range scales. It is common to select various azimuth and range parameters during a single intercept. To change the azimuth the pilot slews the cursor over the current azimuth and the range of options appear. He then depresses and releases the TDC over the desired selection. Note the proximity of the various azimuth sweep selections to each other in Figure 3-5. If he chooses to use the pushbutton then he must depress it repeatedly as it cycles the sweep through the range of options. Selecting the various range scales is somewhat easier, the pilot depresses and releases the TDC over the appropriate up or down arrow.

The F-16 aircraft has much less HOTAS ability than the F/A-18, however, the functions they do have are easier to use [USAF, 14]. For instance, range and azimuth selections are enabled by simply "bumping" the cursor off the ends and sides, respectively, of the radar display. With each bump, the azimuth or range scale increments one value. The F/A-18 can not use an identical mechanization since, unlike the F-16, the Hornet has a non-tactical region with multiple HOTAS windows. The pilot would not want the range scale to increase when he put his cursor at the top of the display to change the vertical bar scan. The author has designed a usable mechanization [Stucky, 15] which is based on the F-16 bump feature:

- If the cursor is moved without depression into the non-tactical region and back into the tactical area in less than 0.8 second then the appropriate range or azimuth bump selection will be made.
- If the cursor was bumped off the top of the tactical display the range scale will double.
- If the cursor was bumped off the bottom, the range will be be halved.
- If the cursor was bumped off the left side, the azimuth scale will increase by one increment.
- If the cursor was bumped off the right, the azimuth scale will decrease by one increment.
- For all cases, a "wrap-around" feature will be used, e.g. if the maximum range scale of 160 nm is selected, bumping the cursor to the top will select the 5 nm scale.

The author strongly feels these features would be universally used by fleet pilots. Incorporation of the bump mechanization would allow for the removal of the range selection arrows, opening up at least two additional HOTAS windows. **The author recommends incorporation of his range and azimuth scale bump mechanization on the Attack display.**

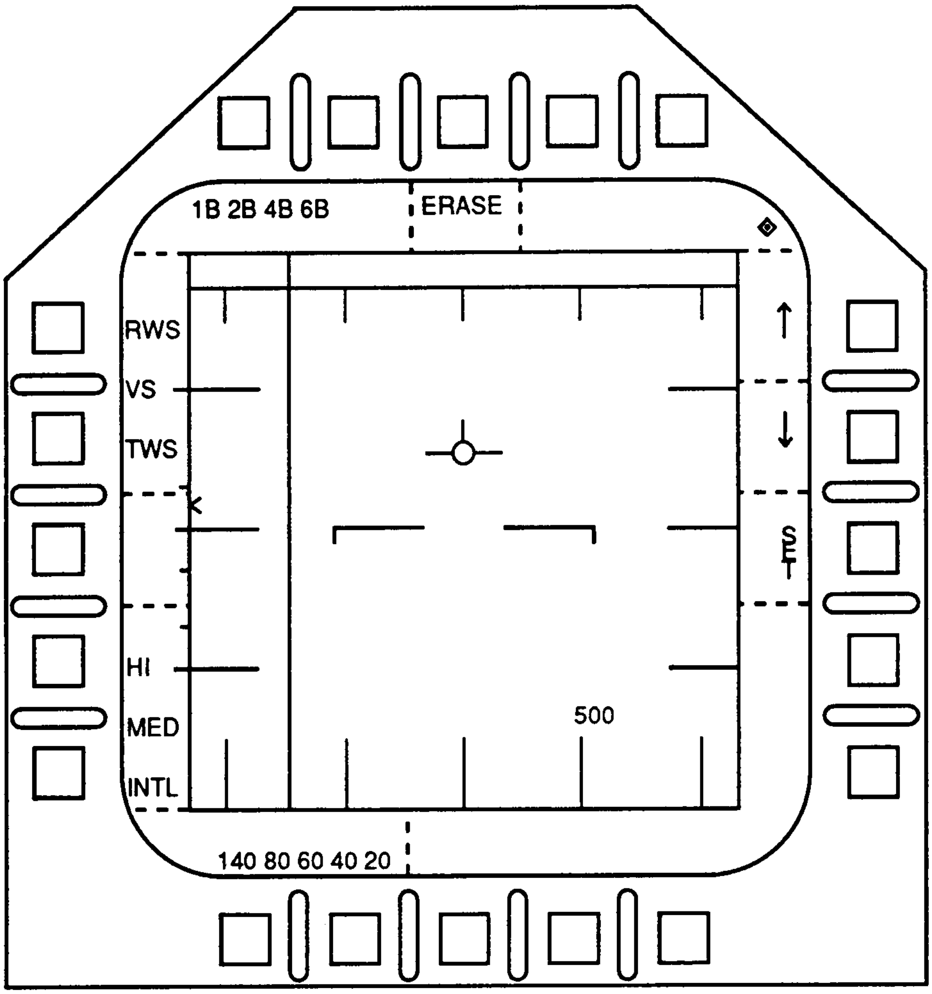


Figure 3-5. Attack HOTAS Options

Az/El Display. The Az/El display was very useful. It added a "third dimension" to the trackfiles and the sensor field-of-view cues provided a true indication of how great of volume of space was being searched. No other display was as versatile at indicating which sensors were looking at which trackfiles. The display was especially helpful for quickly getting each sensor to look at a particular trackfile. For instance if the E-2 data linked a target, the pilot could use the Az/El format to slave a sensor to that line-of-sight, quickly select another sensor and repeat the process. Although this was a major step up from previous software versions, the author found he desired a one-button depression which would slave all sensors to a particular point or trackfile. **The author recommends adding a "slave-all sensors" option to the Az/El format, independent of the selected sensor. If this option is selected and the cursor is depressed over a trackfile then all sensors would slave to that file. If no file was under the cursor then all sensors would be slaved to the inertial line-of-sight.**

Even though trackfile altitude (if known or approximated by the mission computer) was provided on the Attack and Situational Awareness displays, it was much easier to interpret trackfile relative altitudes on the Az/El display. If the pilot was observing several targets on the Attack display he typically would only notice that a particular target was flying outside of the radar elevation coverage when it was already outside the coverage and began its flashing extrapolation. On the Az/El display, even radical target maneuvers were obvious to the pilot and the sensor field-of-view cues made for quick repositioning of the scan center as required. The ability to change the scan center with a single TDC depression on the Az/El was quicker and easier than the alternate method of using the Attack display and changing the azimuth scan center with the cursor and elevation center with the throttle mounted thumbwheel.

As previously discussed on page 36, **the author recommends displaying a 10° HARM field-of-view circle on the Az/El format.**

During testing certain environmental conditions such as adverse backgrounds or obscuring clouds could preclude a successful FLIR STT. If such conditions existed, the pilot often found repeated attempts at acquiring STT to be a waste of time. In such cases, there was no HOTAS method provided to reselect the Az/El display. Although the pilot only had to reach up and push the "MENU" option and then rock the sensor control switch toward the display, it was not as well liked as the HOTAS method allowed from the comparable HARM sublevel format of the Az/El. **The author recommends implementing a HOTAS method of selecting the Az/El format from the FLIR video format.**

Head-Up Display. The additional HUD cues were judged to provide useful information without unnecessary clutter. These cues included:

• An "M" adjacent to the TD box if multiple targets were detected about the L&S target. The multiple target cue was useful with radar one-look Raid breakouts and also when separate targets tracked by multiple sensors slowly crossed flight paths.

• "GO STT" cue beneath the TD box to recommend the pilot enter radar single-target-track prior to commanding Sparrow launch. This cue was helpful since L&S target symbology looked virtually identical, independent of whether the radar was in a search or STT mode.

• "VISUAL" or "IA" underneath the AMRAAM cue to remind the pilot that the visual or inertial active launch modes were commanded. Although these launch modes were more obvious to the pilot, the cues were still helpful because since so many more functions are added to the cage/uncage button, the chances of an unwanted actuation are increased with OFP 91.

• "LOFT" underneath the Sparrow cue to remind the pilot that aircraft lofted steering is selected. This was especially helpful since lofted steering could quickly be selected and deselected by use of the throttle mounted cage/uncage button. It also alleviated any requirement to reference the Stores format to see the launch mode selected.

The HUD formats were superior to previous OFPs. In OFP 89 the target designator (TD) box could signify the line-of-sight of a radar target or Flir target, dependant upon which existed. If both a radar and Flir target existed the TD box indicated the radar target and an "X" indicated the Flir target, unless the AIM-9 was slaved to the Flir target, then the TD box indicated the Flir line-of-sight! This was simplified greatly with OFP 91 since any trackfile could be designated. The TD box always indicated the line-of-sight of the L&S target and the "X" indicated the line-of-sight of the DT2 target.

The problem with these line-of-sight indicators is they are only accurate if the targets are within the HUD 20° x 20° field-of-view. If the target is outside the field-of-view then the cue is flashed at the edge of the HUD. To get sight of such a target the F/A-18 pilot looks at either the Az/El or Attack displays and notes what the bearing and inclination of the target is and then tries to estimate what that equates to outside the cockpit. As mentioned earlier, being able to see opposing aircraft at the earliest opportunity is of paramount importance, the chances of defeating an enemy missile increase dramatically if the pilot sees it being launched.

A simple solution is to display a "target locater line" for the L&S target [Stucky, 16]. The line would be a short arrow extending radially outward from the center of the HUD towards the L&S target. The radial angle along the plane formed by the line would be displayed at the end of the arrow. The target locater line would only be displayed when the TD box was HUD limited. **The author recommends displaying a HUD target locater line.**

As previously mentioned, the target's aspect is of vital importance to the F/A-18 pilot. Unfortunately, the target may maneuver drastically while the pilot searches visually for it. Since changes in the line-of-sight to the target are not easily apparent without a target locater line, the pilot may not notice that a flanking target has suddenly turned nose on solving the required lead angle to shoot. **The author recommends providing an indication of the L&S target's aspect on the HUD** [Stucky, 17]. A proposed mechanization for the target locater line and target aspect cue are shown in Figure 3-6.

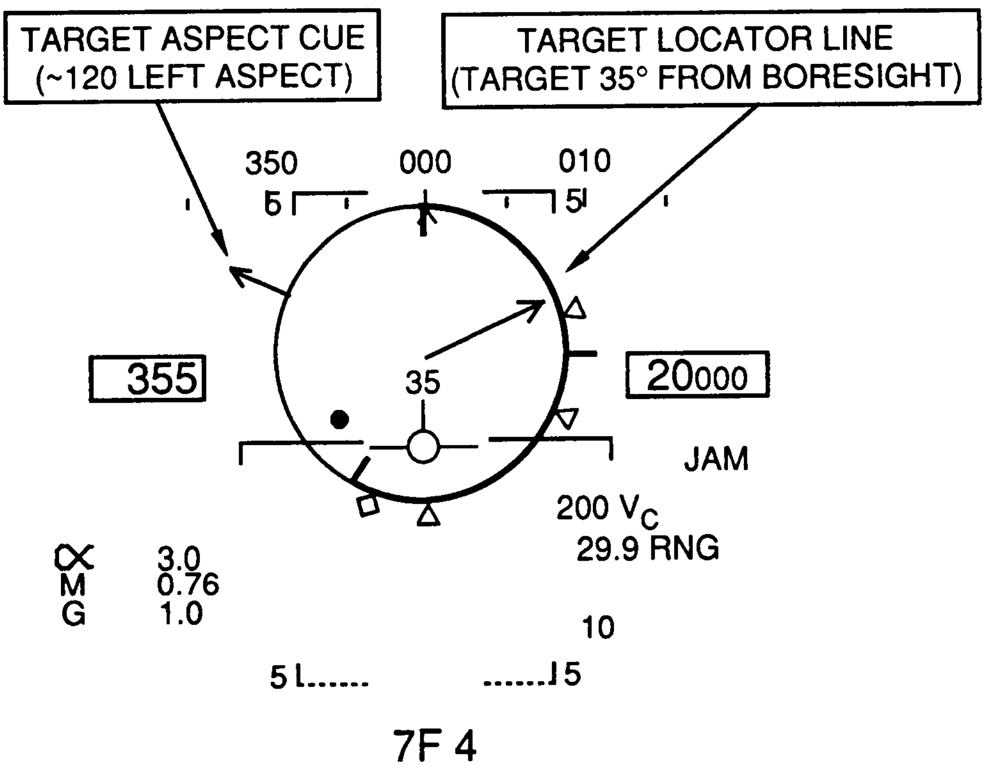


Figure 3-6. Proposed HUD Target Locater Line and Aspect Cue

Situational Awareness Display. The Situational Awareness display served multiple useful functions. The ability to quickly cycle the SA and HSI formats while retaining a background moving map display allowed for many of the fleet's desired enhancements [Stucky, 18 &19] without cluttering up the navigational display with tactical information or vice versa. The God's eye view helped indicate target formations relative to geographical positions and made intercept geometry easy to interpret. The sensor field-of-view arcs were beneficial, the author especially liked being able to see the geographical coverage of the selected radar azimuth at 40 nm range. Since the field-of-view arcs were not staggered both the arcs and the letter descriptors tended to overwrite each other e.g. if the radar and Flir were in single-target-track on the same target the field-of-view carets exactly overwrote each other and the "R" and "F" descriptors appeared to be a single "R", leaving the pilot to wonder where the Flir was pointing unless he referenced other displays. Since the radar was normally the only slewable sensor that had a field-of-view of significant size this was not normally a detriment. If additional sensors such as a scanning Flir or a RF Emitter Locater System [Sweetman, 5] are added, the arcs will be impossible to distinguish from each other. **The author recommends staggering the sensor field-of-view arcs and letter descriptors on the Situational Awareness display. Consider moving the data link command windows to a spot underneath the compass rose in order to increase the critical space at the top of the display for the staggered arcs.**

The great benefit of the SA display is it is the only display which allows the pilot to "see" behind the aircraft. Unfortunately displayed targets beyond the $\pm 70°$ azimuth limits of the Az/El and Attack displays can not be designated. This significantly hampers the pilot since he can not slave the Flir to a trackfile beyond the limits of the Az/El display unless the trackfile is the L&S target. **The author recommends the addition of cursors to the Situational Awareness format to allow for designations and normal "target under cursor" commands.** The author's proposed Situational Awareness display is depicted in Figure 3-7.

The "Step" option of the SA display allows the pilot to step an exclusion box to the desired target. Once a target is stepped to, additional data link options are displayed along with the option of entering a pilot identification. The pilot may identify a target as either hostile or friendly. The exclusion box is centered on the "stepped" target, occluding all other targets within it, to facilitate reading of the desired target parameters. If targets are in close proximity to each other, it may be impossible to read the file ranking within the

HAFU unless the exclusion box is used. The exclusion box is only displayed on the SA format. Since in practice it is relatively easy to step the exclusion box to the wrong target, the need exists for the pilot to "undo" a pilot identification. **The author recommends adding an "unknown" identification option to the Situational Awareness display.**

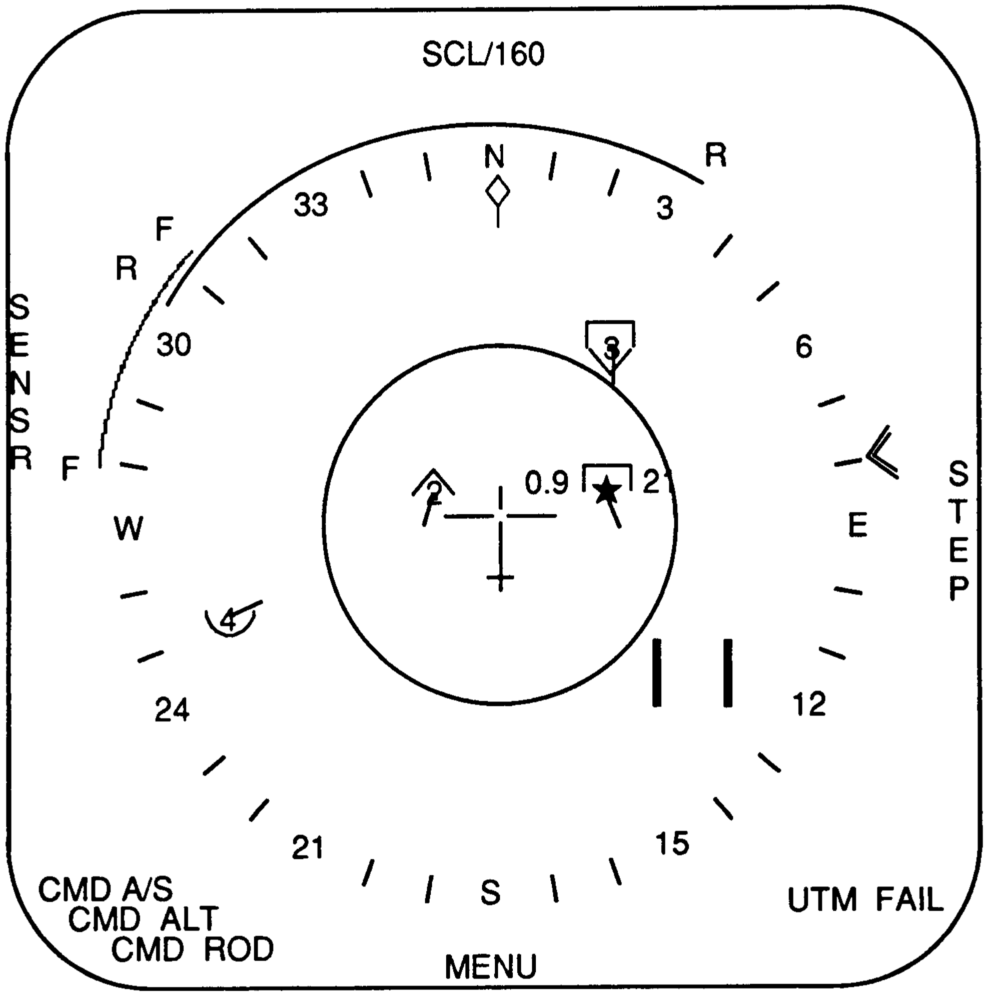


Figure 3-7. Proposed Situational Awareness Display

AIR-TO-AIR WAYPOINT

One of the often voiced concerns from the F/A-18 Desert Storm veterans was the lack of having an air-to-air "bullseye" or waypoint which was separate from the navigation waypoint. Since OFP 87, the capability existed to reference targets with respect to the selected navigation waypoint [Stucky, 20]. Having a common reference point such as this makes targeting and situational awareness information much easier between differing aircraft or groups of aircraft. Unfortunately, this bullseye point is usually not the same point that the pilot wants to have selected as a navigational "steer to" point.

OFP 91 enabled the selection of an air-to-air waypoint that was separate from the navigation waypoint and displayed independently on the HSI display. Although the author liked the intent, he felt the mechanization was cumbersome. To select the air-to-air waypoint the pilot had to select the waypoint data sublevel of the horizontal situation display, sequence to the desired waypoint and push the A/A waypoint option. Since multiple bullseyes are often used, if the pilot wanted to change to a secondary A/A waypoint it took several steps.

The author recommended a new mechanization in which the A/A waypoint option was always enabled; the default A/A waypoint was the selected steerpoint and changed as the steerpoint changed. If the pilot chose to tie the A/A waypoint to a specific point independent of the steerpoint then he simply pushed the A/A waypoint pushbutton. This new mechanization was put in OFP 91 and offered greater flexibility:

- If the aircraft was part of a package that was following the same navigational route the default A/A waypoint initialization allowed the flight members to quickly reference detected targets to the current steer point.
- If the aircraft was part of a large integrated package with separate flights handling the air-to-air and air-to-ground missions, the use of a common bullseye which was independent of the navigational routing was used.
- If the aircraft was part of a fighter force which was tasked with ensuring that aircraft returning to friendly territory were following one of the several pre-planned "safe return-to-force" routing then the pilot could enter the border waypoints from the various routes into one navigational sequence. With the default A/A waypoint moding he could quickly sequence between the points on the toplevel HSI format to ensure detected targets were following the required routing.

The new air-to-air waypoint mechanization offered a great increase in flexibility to the pilot and increased situational awareness by allowing him to reference targets to the waypoint not only on the Attack display but also on the SA, HSI, and moving map display formats.

Since the map scale references the scale of the selected format, an additional use of the quick cycle feature between the SA and HSI formats was the ability to quickly cycle map scales. For instance the pilot normally has the HSI display with 10 mile scale selected for a low level navigation route. If he selects 40 mile scale on the SA display, a quick cycle of displays will bring up the 40 mile map allowing the pilot to quickly see points of interest on the map which are beyond the 10 mile navigation scale, and then quickly return without any button pushing. This feature was used often during night low level missions using night vision devices and a navigational Flir. Helping the pilot by reducing any head-down button pushing is important during such missions.

USE OF COLOR ON MSI DISPLAYS

Aside from the full color moving map display that can be the background for the Situational Awareness format, the only MSI display that uses color is the Attack display. Color was used to indicate trackfile identification: green for friendly, red for hostile, and yellow for unknown. Yellow was also used to color the cursor. This was well liked and was conspicuously missing on the other displays. Color aids the pilot in distinguishing targets as the display starts to get cluttered. It would also help the pilot with quickly mentally correlating the same target on the differing displays. Although color would benefit all displays, it was missed most on the Situational Awareness format where many trackfiles could be jumbled in close proximity of each other due to the long range selections possible. **The author recommends the addition of color to indicate trackfile identification on all MSI displays.**

Since the cursor could be moved so easily from one display to another, a bad side effect of this was it was easy to "lose" the cursor. The pilot would have to quickly scan from display to display to see which one had TDC priority. **The author recommends colorizing both the cursor and the TDC priority symbol yellow on all display formats.**

The sensor field-of-view cues were beneficial but could be confusing. Although the selected sensor's FOV cue was displayed at a higher intensity than the others', it was often not easy to quickly discern which cue pertained to which sensor. **The author recommends using yellow to indicate the selected sensor field-of-view cue on the Az/El display.**

The "+" symbols used to display low priority trackfiles did reduce clutter, however, they performed this mission at a sacrifice of pilot situational awareness. The pilot only knew a trackfile existed, he had no idea of whether it was supported by onboard or offboard sensors, or whether it was identified. Mr. Harlan Kooima of McDonnell Aircraft suggested to the author the possibility of using miniature HAFU symbols to represent low priority trackfiles. The author supported that idea since a small HAFU symbol can declutter the MSI displays without a significant decrease in information. **The author recommends using miniature HAFU symbols to represent low priority trackfiles. The low priority HAFU symbol should reflect whether the trackfile is identified (color and shape) or supported by an onboard (upright) or offboard (inverted) sensors. To reduce clutter on those low priority trackfiles with both onboard and offboard sensor support, only the upright portion of the HAFU should be displayed.**

ALR-67 AZIMUTH DISPLAY UNIT (ADU).

The ALR-67 display was unchanged from earlier OFPs. Unlike other great air-to-air fighters such as the U.S. Air Force's F-15 Eagle, the F/A-18 pilot uses his radar warning receiver as a cue that he is in trouble, vice as a sensor for situational awareness. Software changes have enhanced the ALR-67's ability to detect and identify airborne radars, however, the entire concept of how to best use it needs to be changed in order to increase its usefulness.

To maximize the potential of the current ALR-67 as a situational awareness sensor, it should integrate more with MSI. Although the direction of arrival accuracy is poor with respect to the other MSI sensors, and should not be used in any correlation or merging process, the ALR-67 information should not be completely ignored. ALR-67 trackfiles could be used to cue the pilot to slew other sensors in a specific direction to detect the ALR-67 target. If ALR-67 trackfiles were displayed on the MSI displays, the pilot could perform a "mental correlation" comparing the ALR-67 information with the trackfiles of other sensors. Although the ALR-67 can detect surface and airborne emitters, only priority airborne intercept radars should be displayed on the MSI formats. The number of ALR-67 trackfiles should be kept small (i.e. four) to minimize pilot interpretation overload.

Since the ALR-67 trackfiles would function differently than MSI trackfiles, they should use unique symbology. Because the ALR-67 does not provide any indication of detected signal inclination or range, the trackfiles should be displayed in the dugout on the

Attack display, at the perimeter of the SA format, and in a dugout on the Az/El display. Note the Az/El format does not have a dugout in OFP 91. **It is recommended that the four priority airborne intercept ALR-67 trackfiles be displayed in the angle-only-trackfile region of the Az/El, Attack, and Situational Awareness formats. The trackfiles should use unique symbology and not be used by MSI for any correlation or merging.**

Even with the aforementioned changes, the ALR-67 still suffers at its task of displaying RF emitters. The author feels the best way to enhance the ALR-67 is by making use of a better display since the ADU is limited by its small size and limited character set. In 1986, the author submitted a proposal to display the ALR-67 format on a standard MDI [Stucky, 21]. An update of that proposal is presented herein.

An EW format should be selectable on any MDI or MPCD. The author has designed a format which he feels gives the pilot a much easier interpretation of the detected threat. Instead of being limited to the two character descriptors shown on the ADU, the proposed symbology set follows the precept that a picture is worth a thousand words.

The best situational awareness the pilot could get from a radar warning system would be an accurate presentation of the detected emitter positions. The author has been a vocal advocate of the value of displaying tactical information as an overlay on the moving map display. His first proposals were put in OFP 87 and resulted in the display of the radar L&S target on the moving map and the option to overlay the Data Link display [Stucky, 19]. The concept has since grown with the new Situational Awareness display in OFP 91. To fully appreciate how great a value it would be to accurately display emitter location on the moving map we should first consider how the pilot handles the ALR-67 information.

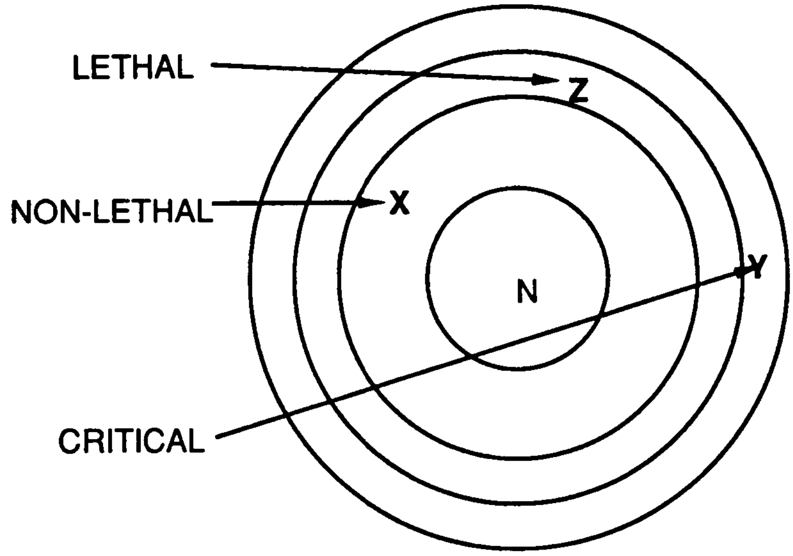
Before flying over enemy territory, the pilot will study the latest electronic order of battle (EOB). The EOB shows the location and type of detected emitters, whether they are surveillance radars, fire control radars associated with missiles, mobile anti-aircraft artillery, etc. The prudent pilot plots these positions on a map with rings around them showing the detection and lethal ranges of the site.

Airborne, he now sees detected emitters on the ADU. He notes the emitter types and which criticality rings they are in. He then tries to mentally associate the detected signal with the EOB. For instance, the ALR-67 indicates surface-to-air missile X in the lethal ring. The pilot remembers the rule-of-thumb for the maximum lethal range for that missile. He then must remember that the ALR-67 indicates "lethal" when the detected signal strength is within 1.5 times the maximum head-on lethal range of the missile. With that mentally calculated range he now visualizes its geographic position and then makes the final decision on whether his heading, speed, and altitude place him inside the missile's firing envelope. Although on the surface, the criticality ring concept appears simple, in reality it is only that simple for the weakest of pilots.

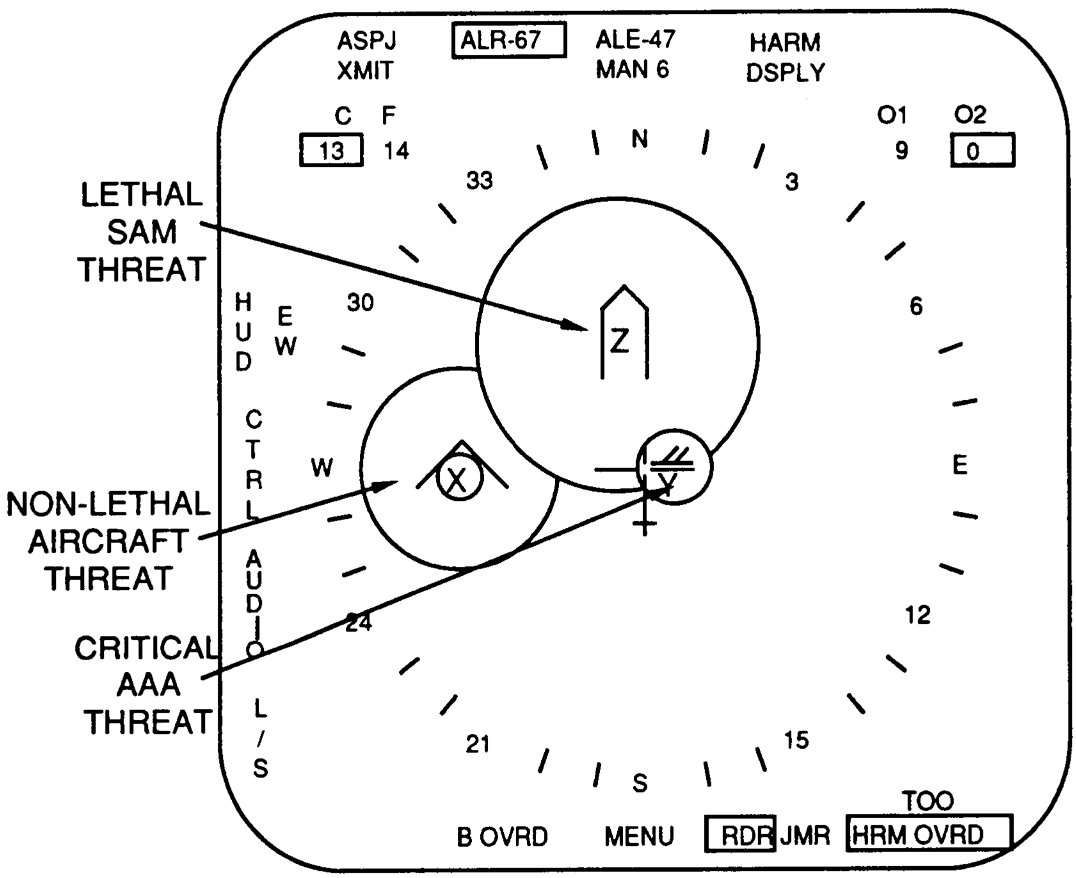
To show the pilot the emitter's geographic position it first must know the range. This can not be measured directly with the current antennas but can be approximated using the look-up table which already exists in the ALR-67. The signal strength would be compared to the nominal emitter power and the equivalent range could then be computed. Although the strength of specific systems can vary due to various reasons, as systems get more advanced they tend to be more consistent. For example, the author expects virtually identical performance from the APG-65 radar no matter which of the squadron's aircraft he flew on a particular day.

Although not yet implemented, the pilot could input the EOB into the aircraft mission computers. The digital map computer could then display threat rings about the appropriate geographical positions. If the ALR-67 displayed the computed geographic position of the detected emitters, it would be a simple matter for the pilot to note if they fell within the expected rings and were, most likely, the known sites. From that "correlation" he would know the exact location of the emitters.

Such an EW display would be indispensable for the combat pilot. It would provide the most information if it was an overlay to the moving map. Since the Horizontal Situation and Situational Awareness formats also are most useful when displayed as a map overlay, the EW format should be added to the format cycling commanded by rocking the sensor control switch toward the HSI display. A comparison of the current ADU and the proposed EW display is depicted in Figure 3-8. Note the capability to select ALR-67 control options on the display itself vice the ALR-67 control panel on the lower center console in between the pilot's shins.



CURRENT ADU DISPLAY (LETHALITY OUT)



EW DISPLAY - RANGE VS AZIMUTH WITH THREAT RINGS DEPENDANT UPON THREAT LETHALITY

Figure 3-8. Comparison of ADU and Proposed EW Display

The author recommends the EW display should:

- **Be a circular azimuth versus range format identical to the HSI and with the same range scale selections**
- **Be selectable on any MDI or MPCD**
- **Be added to the HSI - SA format cycling**
- **Allow preflight entry of threat rings using a mission planning system**
- **Provide symbology enhancements to indicate important parameters such as type of emitter, emitter single-target-track, lethality, missile launch, etc.**
- **Allow for pilot selection of ALR-67 control options**

WEAPONS EMPLOYMENT EVALUATION

Due to the immaturity of the radar software, no air-to-air missiles were fired during this evaluation. Many simulated launches were conducted and no degradation in performance was noted when compared to earlier OFPs. The main tactical enhancement was the capability of launching any missile against any MSI target within the particular missile's capability. This will greatly increase the tactical flexibility of the aircraft. Specific comments will be covered in the specific weapon's section.

AIM-9. Like OFP 89, override is only allowed against a target tracked by another sensor. In the fast paced world of modern air-to-air combat, the need exists for the pilot to be able to visually acquire a target and immediately launch a Sidewinder. Any delay in weapons employment puts the fighter further into the opposing aircraft's weapons envelope. This is especially critical with heat seeking missiles since time of flight is short and no further support of the missile is required after launch. The current mechanization of override is inadequate in that not only can it not be used against non-MSI targets, it also requires 0.8 second to initiate the mode. If the pilot desired to use the mode against a visually acquired target, he would typically command radar STT using the boresight dogfight radar mode and once STT was established, would command override. This scenario takes several seconds at best and results in active RF emissions which would immediately tip off the opposing fighter of the direction to the F/A-18.

Since the reason for aircraft thresholding was to reduce false lock-ons, it may be deleted if a suitable alternative to the false lock-on problem is used. The author has designed an entirely new mechanization for the Sidewinder based on his personal requirements. The proposed mechanization is shown in Figure C-2.

The new design must:

- Enable Sidewinder acquisition at the earliest possible opportunity
- Allow passive launching at a boresight target without aircraft thresholding
- Automatically slave to the L&S line-of-sight
- Change line-of-sight between L&S slaved and boresight with one quick action
- Allow for automatic lock-on at a boresight target
- Avoid false lock-on
- Allow for pilot override of angle-of-coincidence requirements
- Delete aircraft thresholding requirements from the "SHOOT" cue criteria
- Be as simple to the pilot as possible

The proposed mechanization deletes the aircraft thresholding requirement, making the previous "Override" the normal mode. Aircraft thresholding is not required to avoid false locks due to the angle-of-coincidence logic. In cases where the angle-of-coincidence logic may cause problems (such as against a jammer which causes erratic angle tracking), it may be "disengaged" by a long depression of the cage/uncage button. Shoot cue logic, which had been dependant upon the missile seeker signal exceeding the aircraft thresholding, was changed to reflect only that the angle-of-coincidence requirements had been met for 2.0 seconds and the target was also within the launch acceptability region. The two second delay was required to ensure the missile was tracking the target, vice simply pointed at the target during the automatic slaving functions which occur approximately every 1.5 seconds until the seeker receives sufficient energy to lockon.

The author was a member on an Aircrew Systems Advisory Panel (ASAP) evaluation of various F/A-18 changes including his proposed Sidewinder mechanization and various gunsights. The evaluation was conducted using advanced 360° domed visual simulators against both computer and human controlled targets. This evaluation was conducted at McDonnell Aircraft Company facilities in St. Louis, Missouri. ASAP members also included several representatives from Navy Fighter Weapons School (TOPGUN), Operational Test and Evaluation Force (VX-4/5), Marine Weapons and Tactics Squadron One (MAWTS-1), and the Naval Weapons Center. The proposed mechanization was unanimously liked by the ASAP members. **The author recommends incorporating the proposed AIM-9 Sidewinder mechanization.**

AIM-7. The main enhancement was the automatic selection of lofted guidance for the missile and the use of the cage/uncage to select or deselect lofted steering. This mechanization was what had been recommended in 1988 [Stucky, 22]. In practice, it was a straightforward mechanization, easy to use, and eliminated the requirement to have the Stores format displayed in order to select or check the AIM-7 launch mode.

As mentioned earlier, lofted guidance can dramatically increase the launch envelope of the Sparrow. Unfortunately, the lofted launch envelopes are not displayed in OFP 91. There are five velocity constraints which are used to compute maximum range, the most stringent limit selected by the mission computer to determine the displayed maximum range:

- Maximum distance between missile and ownship at intercept
- Minimum maneuvering velocity at intercept
- Minimum missile closing velocity at intercept
- Maximum missile seeker gimbal limit
- Maximum missile guaranteed battery life

The constraint used is dependant upon the launch range and intercept geometry. In head-on scenarios, where lofted guidance offers the greatest increase in maximum range, the main constraint is the missile battery life. The battery was built to government specifications which have not changed in its nearly three decades of use despite numerous upgrades including longer burn rocket motors. Without lofted guidance, the guaranteed battery life is not significantly less than the missile's kinematic capability. But because long range lofted shots have significantly greater times-of-flight, the battery constraint now seriously impacts employment maximum ranges. In reality the battery lasts several times longer than the specification. **The author recommends removing the battery life constraint from AIM-7 maximum range calculations. Additionally, display accurate AIM-7 maximum launch ranges dependant upon normal or lofted guidance mode and normal or lofted steering.**

With an actual or simulated AIM-7 launch, the mission computer continuously computes missile time to intercept and displays it underneath the triangular missile symbol. If the MC ever computes that the time to intercept exceeds the missile's kinematic capability, a "LOST" cue is displayed, flashed for 5 seconds and the missile symbol removed. A LOST cue may often result if the target maneuvers sufficiently after a missile launch outside of no-escape range but less than maximum range. Once "LOST" is displayed, the tactical computer no longer performs the dynamic calculations for the missile, leaving the pilot unsure of how much longer the missile could truly fly. In many tactical situations it is typical for an aircraft to turn away from its target for a short period of time and then return back to a pursuit course. In many such cases the missile could actually intercept the target, however, since the pilot has no indication of this he will most likely shoot an additional missile. **It is recommended that the mission computer continuously compute and display missile time to impact if it is within the missile's capability to intercept, including cases in which a "LOST" condition temporarily existed.**

The ability to initiate a launch from a non-STT condition gave the pilot greater flexibility and increased his chance of surprise. The capability of the MSI algorithm to maintain the trackfile during the launch and radar acquisition phase increased the probability of a successful STT. **The author recommends emphasis be placed on operational testing to ensure an acceptable probability exists for the radar to support an AIM-7 fired against non-STT radar targets and targets without radar contribution.**

AIM-120. The tactical employment if the AMRAAM was significantly more flexible with OFP 91. The capability to support a Command Inertial Active launch from range-while-search radar mode was new and well liked during simulated launches. If a launch was desired from range-while-search, the only launch zones displayed on the attack format was for the L&S (unless sensors other than the radar were providing a DT2 trackfile or the target was underneath the cursor). If the pilot launched and stepped the L&S to a new target (so that target could be fired upon), the missile symbols from the prior L&S were removed. This caused the pilot to question the status of the missiles and how much time remained until they were predicted to go active. Since occasions will arise where the pilot wants to launch multiple AMRAAMs at multiple targets using range-while-search, both the L&S and DT2 trackfiles should always be displayed even if the trackfiles are only supported by radar. **The author recommends that the L&S and DT2 trackfiles always be displayed in range-while-search. Trackfiles with missiles in flight at them should be displayed along with the missile symbols until the time-to-intercept of the last missile for the respective trackfile is zero.**

M61 GUN. No live firing was conducted to evaluate the gun boresight cross. Simulated firings were conducted by the author using typical snap shot scenarios. The author judged the gun cross beneficial, however, felt it to be an incomplete mechanization for a non-lock radar sight.

The F/A-18 was the first aircraft to field a director sight and little emphasis was placed on the disturbed sight since it was considered more of a backup mode. Other operational aircraft such as the F-15 and F-16 which did not have a director sight had better non-STT gunsights than the F/A-18 disturbed sight. Instead of using a single circle with a selection of two fixed ranges, they displayed a "tracer line" which indicated the bullets flight path had they been fired one time-of-flight ago [Womer, 23]. Tic marks were placed at various points on the line to signify solutions at various target ranges. Although such a sight showed historical impact points throughout the bullet's time-of-flight, it still required the pilot to accurately estimate target range. The author feels this is only possible to the degree required against targets which the pilot is intimately familiar with. Because it is difficult (if not impossible) to train against potential enemy aircraft, the pilot needs a better way to discern target range without a radar lock.

Since the director sight may not represent the actual bullet impact against a target with changing accelerations or maneuvers during the bullet time-of-flight, there exists no way to adequately evaluate the success of the firing run unless actual bullets are fired. Because this is impractical and in most cases not desired, it would be beneficial if the aircraft would provide a gun shot evaluation cue [Stucky, 24]. Since the target range is accurately known in the director mode and the bullet ballistics are well understood, it is reasonable to expect the mission computer to be able to provide an indication of where the bullets were when they reached the target range. Such a cue should be provided on the HUD and be inertially stabilized so as not to be influenced by ownship maneuvering after the bullets have been fired (or simulated fired). The cue must accurately reflect the six milliradian dispersion of the M61 gun.

Over the space of nearly fifteen years, the Enhanced Envelope Gunsight (EEGS) was designed by an engineer for General Electric Corporation [Tye, 25]. The EEGS sight was a radical departure from earlier gunsights in that it displayed not only a director type pipper but simultaneously included a range of solutions encompassing the maneuvering possibilities of the target during the bullet time-of-flight. Due to the high firing rates of the M61, an adequate density of rounds on target will still occur even if a strafing technique is used. Utilizing such technique the pilot could cover the potential maneuvering range whether the target was reacting in the maneuvering plane of the F/A-18 or perpendicular to it.

For cases where the radar was not providing full STT information, a unique disturbed sight was used. Instead of being a single circle at a defined range or tracer line, the

EEGS displayed a funnel. The pilot input the expected target wingspan (or a suitable approximation) and the span of the funnel matched that size from the minimum safe range of the gun out to 3000 feet (or bullet maximum range if less). Again using a strafe philosophy, the pilot would attempt to match the target's plane of motion and place the target at one end of the funnel. He could then commence firing, allowing the target to track to the other end of the funnel, ensuring that at least some bullets overlapped the actual target range. The EEGS was incorporated in the USAF F-16C and was so well received [Bosworth, 26] that it was quickly retrofitted to all USAF F-16 models. Several foreign countries have also purchased the gunsight for their F-16's. It is rumored that the Soviet Union has developed their own version of a funnel gunsight for the Mig-29.

The same Aircrew Systems Advisory Panel that evaluated the proposed Sidewinder changes also evaluated various potential gunsights. They included changes to both the director and disturbed modes and included gunsights varying from tracer lines to EEGS type functions using HUD formats designed by the author. Although inaccuracies were present in the simulation, the group consensus was that the EEGS gunsight would offer the fleet F/A-18 pilot a major increase in air-to-air gun capability. Figures 3-9 and 3-10 show the proposed non-radar STT and radar STT gunsights. **The author recommends incorporation of the Enhanced Envelope Gunsight with the following changes:**

- **Set default target wingspan to 40 ft.**
- **Display the currently selected wingspan on the Stores gun format adjacent to the UFC option.**
- **Display a range dot at 1000 ft and 2000 ft in the level two non-STT funnel.**
- **Funnel should reflect Rmax changes due to differing ammunition types (MK-55 or PGU-28) and changes in altitude/airspeed. In cases where Rmax exceeds 3000 ft, limit the funnel to 3000 ft.**
- **Need a non-STT training mode so that only the funnel is displayed with a full radar lock but with a gun shot evaluation cue enabled. Propose this be toggled on & off by using the cage/uncage button.**
- **Do not display AIM-9 Rmin cues on the gun range bar.**
- **Display closing velocity (Vc) and range, when known, in stationary windows. When range is less than 1.0 nm it should change to hundreds of feet e.g. 55 = 5,500 ft.**

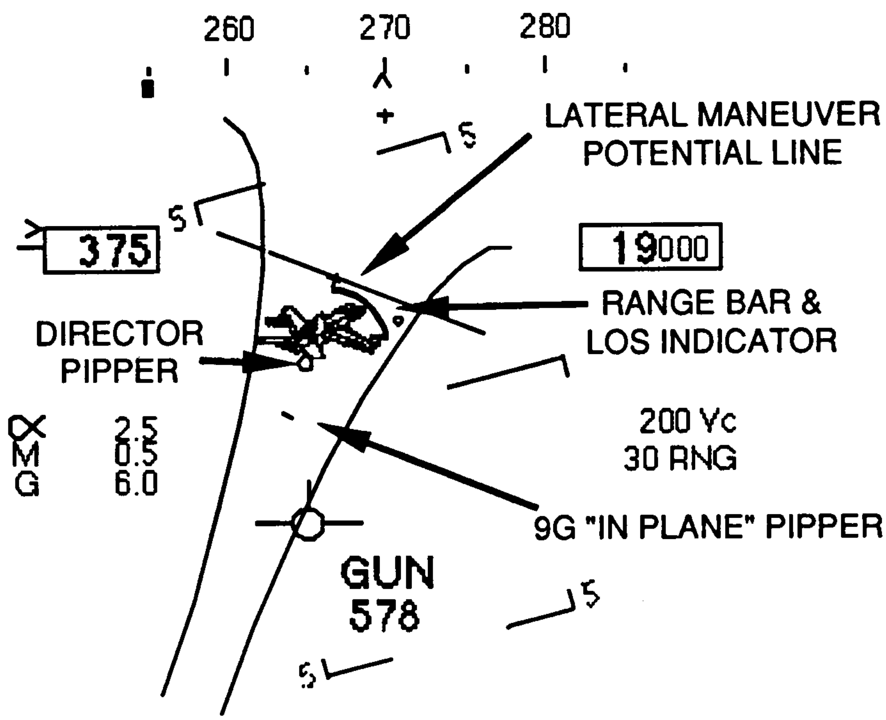


Figure 3-9 Proposed Enhanced Envelope Gunsight With Radar STT

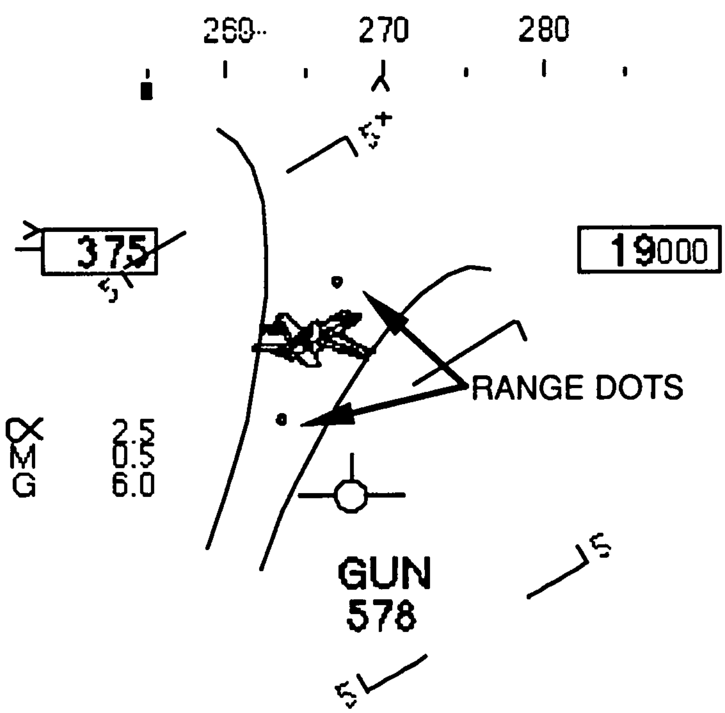


Figure 3-10. Proposed Enhanced Envelope Gunsight Without Radar STT

• **Use a gun boresight cross half-way in size (38 display units) between the current OFP 91 and back-up cross.**

• **Set an occlusion window about the director pipper of sufficient size to occlude all non-gun symbology within the box formed by the maneuver potential lines.**

• **Enable the "SHOOT" cue when within range and the line between the 1G and 9G pipper (inclusive) is within 20 feet of the target centroid.**

Bullet maximum range is determined using the minimum range computed of the following three constraints:

- Maximum time-of-flight of 1.5 seconds
- Minimum bullet impact velocity of 500 feet per second
- Minimum bullet airspeed of 1000 feet per second

The 1.5 second constraint was derived in the 1970's for the, then standard, Mark 55 projectile. Recently an updated 20 millimeter round has been fielded. Called the PGU-28, the new bullet has a much higher muzzle velocity and is capable of significantly greater ranges. The 1.5 second maximum range constraint is less than it is capable and the decrease in possible firing opportunities is significant, especially if high closure rates exist. Although kinematically capable of longer ranges in head-on situations, noise in the radar tracking filters makes current gunsights ineffective at ranges in excess of 9000 feet [Tye,26]. After considering typical head-on closing rates, the maximum useable time-of-flight for the PGU-28 was judged to be approximately 3.0 seconds. **The author recommends increasing the maximum bullet time-of-flight constraint to 3.0 seconds if the PGU-28 round is selected** [Stucky, 27].

Longer ranges would be possible if a tracking method which was better than the radar was used. If in single-target-track, the Flir currently provides more precise line-of-sight and angular rate information than the radar. When the internal laser designator/ranger is retrofitted to the Flir pod, the resulting ranging data should also be much more accurate than the radar. **The author recommends using Flir derived target angle, velocity, range rate, and acceleration when Flir STT exists with valid laser range and the target is the launch and steering target.**

During head-on intercepts the first gunshot opportunity can occur at ranges where the target subtends a visual arc only slightly larger than the one mil pipper. It is extremely difficult for the pilot to aim such a shot, make corrections, and prepare for a break-off maneuver to avoid the potential mid-air collision which such a shot sets up. An automatic capability utilizing the aircraft autopilot was demonstrated by a modified F-15 Eagle in the mid 1980's. As the gunsight and the ammunition becomes more capable, the author **recommends incorporation of a flight control program which automatically steers the aircraft to a proper gun solution** [Stucky, 28].

4. CONCLUSIONS AND RECOMMENDATIONS

GENERAL

Operational Flight Program 91 was a major advancement for the F/A-18 Hornet. Individual sensor performance was increased, human factors enhancements decreased pilot workload, and the Multi-Source Integration effort had a synergistic effect on the capability of the aircraft. Perhaps the most long-reaching benefit that OFP 91 gave the Hornet was that of growth potential. As future sensors are developed, the integration of them into the aircraft will be logical, enhance MSI capabilities, and increase mission capability. Emphasis should be placed on incorporating the following sensor capabilities:

- Passive ESM
- Interrogator Transponder
- Fighter to fighter data link
- Advanced large net data link
- Track-While-Scan FLIR

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Problems with miscorrelations did occur between small variance trackfiles (i.e. Flir) and those with large variances (e.g. HARM). **The author recommends that until the miscorrelation problem is solved, that fleet pilots be trained to deselect HARM and Data Link as contributors to MSI once they have their desired initial trackfiles.**

MSI increased the aircraft's passive capability in both the intercept and weapons employment phases.

Instead of having a cut and dry ID ranking table, the algorithm could assign weighting factors to pick the *best* identity. **The author recommends the MSI algorithm assign gains to individual identification sources and use these gains to determine the most probable target identity if the MSI trackfile has sufficiently small variances to indicate the multiple identifications are from a single target.**

The MSI algorithm did not perform any identification correlation. **It is recommended that high-confidence dissimilar identifications on a single trackfile be used to bias the trackfile apart.**

The pilot needs better cueing of multiple identifications. **The author recommends cueing the pilot of multiple identifications by cycling the HUD target designator box from a square to a diamond. Additionally, cycle the HAFU symbols to reflect the appropriate identifications on the Attack, Az/El, and Situational Awareness displays at a two hertz rate.**

The MSI target line-of-sight was often accurate enough to command FLIR STT directly from the Az/El format. This increased the Flir capability. If acquisition was missed and high line-of-sight rates were present, the manual slew rate of the Flir was often insufficient to command reacquisition. **The author recommends increasing the Flir manual slew rates.**

The capability to generate trackfiles without having to enter Flir single-target-track will increase its utility as an MSI sensor tremendously. **It is recommended that the Flir with advanced controller processor be flight tested and fielded if successful.**

Since the Flir could be used without having the Flir video displayed, it required conscious thought on the pilot to keep from both attempting Flir acquisitions on targets hidden by aircraft structure and to keep from maneuvering the aircraft so as to block a Flir tracked target. **The author recommends showing a graphical depiction of aircraft masking of the Flir field-of-regard on the Flir Az/El display. Consideration should be given to finding a mounting location more suitable for MSI usage in future Hornet design upgrades such as the F/A-18E/F.**

MSI allowed for display of radar trackfiles in radar range-while-search mode and multiple trackfiles in single-target-track, giving the pilot increased situational awareness as compared to previous OFPs.

MSI made using radar silent (transmitter standby) tactics easier. The spotlight mode had additional application if in silent. **The author recommends the advantages of using spotlight with the silent mode be included in fleet OFP 91 training.**

With multiple in beam targets, the one look Raid feature was valuable, however, if the false alarming is not reduced to an acceptable level then the pilot should be given the option of having it enabled or disabled. **The author recommends making a specific option on the radar data sublevel for disabling one look Raid.**

If radar antenna gimbal limits were exceeded, the radar STT and track-while-scan targets were extrapolated internally to the radar and quickly dropped from all displays, forcing the pilot to mentally extrapolate the target's position. **It is recommended that MSI extrapolate the radar L&S trackfile for 30 seconds when the extrapolation is due to exceeding radar gimbal limits.**

The HARM had the capability to detect and identify targets but had limited tactical capability. **The author recommends a wideband ESM sensor with a large field-of-regard and accurate line-of-sight information be incorporated as a baseline sensor on the F/A-18.**

RT-1739 Data Link information degraded pilot situational awareness at shorter ranges. **It is recommended that fleet F/A-18 pilots be trained to supplement trackfiles that have Data Link as the sole contributor with other sensors before closing to within fifteen miles of the target.**

MSI does not make use of data linked angle only trackfiles. **The author recommends that the intersection(s) of offship data linked angle only trackfiles and ownship angle only trackfiles be indicated on the Az/El display.**

The undesignate button has many uses dependant upon the radar mode. **The author recommends emphasis be placed on the subtleties of the undesignate switch operation during fleet training on OFP 91.**

Cycling the weapon select switch through Guns to reinitialize the radar default parameters deletes all MSI trackfiles. **It is recommended that fleet pilots be trained to initialize radar default parameters by cycling the weapon select switch from one missile to another and using the TDC controlled cursor or pushbutton to select the desired radar search mode.**

The display initializations, cycling, and functions were logical, functional, and performed well.

Moving the radar target aging to the Data sublevel made it difficult for the pilot to quickly check the selected aging. **The author recommends displaying the current aging value in the non-tactical region of the Attack display under pushbutton number ten.**

Since active radar transmissions can highlight ownship position to enemy ESM systems the author **recommends a HOTAS mechanization be incorporated which would allow the pilot to quickly shut off active radar transmissions without requiring any cursor slewing.**

Changing range scales and azimuth coverages on the attack display was too cumbersome. **The author recommends incorporation of a range and azimuth scale bump mechanization on the Attack display.**

There was no method to quickly point all slewable sensors at a trackfile or inertial point. **The author recommends adding a "slave-all sensors" option to the Az/El format, independent of the selected sensor.**

Since the tactical mission computer limited the effective HARM seeker field-of-view to a narrow 10° cone, the Az/El format should indicate this to the pilot. **The author recommends displaying a 10° HARM field-of-view circle on the Az/El format.**

There was no HOTAS method of selecting the Az/El display from the Flir video format. **The author recommends implementing a HOTAS method of selecting the Az/El format from the FLIR video format.**

The author recommends displaying a HUD target locator line and target aspect cue.

The field-of-view arcs on the Situational Awareness display were not staggered and both the arcs and the letter descriptors tended to overwrite each other. **The author recommends staggering the sensor field-of-view arcs and letter descriptors on the Situational Awareness display. Consideration should be given to moving the data link command windows to a spot underneath the compass rose in order to increase the critical space at the top of the display for the staggered arcs.**

There was no way to designate targets on the Situational Awareness format. **The author recommends the addition of cursors to the Situational Awareness format to allow for designations and normal "target under cursor" commands.**

There was no method for the pilot to undo a pilot identification. **The author recommends adding an "unknown" identification option to the Situational Awareness display.**

The new air-to-air waypoint mechanization offered a great increase in flexibility to the pilot and increased situational awareness.

The Attack format is the only MSI format to make use of the color capability of the displays. **The author made the following recommendations with regards to the use of color:**

• Use color to indicate trackfile identification on all MSI displays.

• Color both the cursor and the TDC priority symbol yellow on all display formats.

• Use yellow to indicate the selected sensor field-of-view cue on the Az/El display.

The "+" symbols used to indicate low priority trackfiles gave too little information. **The author recommends using miniature HAFU symbols to represent low priority trackfiles.**

The ALR-67 can be used to increase pilot situational awareness. **It is recommended that the four priority airborne intercept ALR-67 trackfiles be displayed in the angle-only-trackfile region of the Az/El, Attack, and Situational Awareness formats. The trackfiles should use unique symbology and not be used by MSI for any correlation or merging.** The ADU display was inadequate for conveying information. **The author recommends incorporation of the integrated EW display.**

The AIM-9 Sidewinder mechanization was improved over OFP-89 but was found to be cumbersome and failed to address the fleet requirements for disabling aircraft threshold in the boresight missile mode. **The author recommends incorporating the proposed AIM-9 Sidewinder mechanization.**

The AIM-7 mechanization was judged to be straightforward, easy to use, and eliminated the requirement to have the Stores format displayed in order to select or check the AIM-7 launch mode. The H-build missile variant possesses much greater range capability than displayed by the mission computer launch zones. **The author made the following recommendations with regards to the AIM-7 mechanization:**

• Remove the battery life constraint from AIM-7 maximum range calculations.

• Display accurate AIM-7 maximum launch ranges dependant upon normal or lofted guidance mode and normal or lofted steering.

• Have the mission computer continuously compute and display missile time to impact if it is within the missile's capability to intercept, including cases in which a "LOST" condition temporarily existed.

The radar and MSI interface was not adequately tested. **It is recommended that emphasis be placed on operational testing to ensure an acceptable probability exists for the radar to support an AIM-7 fired against non-STT radar targets and targets without radar contribution.**

The post launch missile symbols were useful both in training and actual live missile firings. The capability was degraded in range-while-search if multiple aircraft were targeted with AMRAAM missiles since the symbols were only displayed on the Attack format with missiles in flight on displayed trackfiles. **The author recommends that the L&S and DT2 trackfiles always be displayed on the Attack format in range-while-search. Trackfiles with missiles in flight at them should be displayed along with the missile symbols until the time-to-intercept of the last missile for the respective trackfile is zero.**

The gunsight was inadequate in snap shot situations and against radically maneuvering targets in radar STT. **The author made the following recommendations with regards to the A/A gunsight:**

- **Incorporate the modified Enhanced Envelope Gunsight.**
- **Increase the maximum bullet time-of-flight constraint to 3.0 seconds if the PGU-28 round is selected.**
- **Use Flir derived target angle, velocity, range rate, and acceleration when Flir STT exists with valid laser range and the target is the launch and steering target.**
- **Incorporate a flight control program which automatically steers the aircraft to a proper gun solution for head-on shot opportunities.**

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REFERENCES

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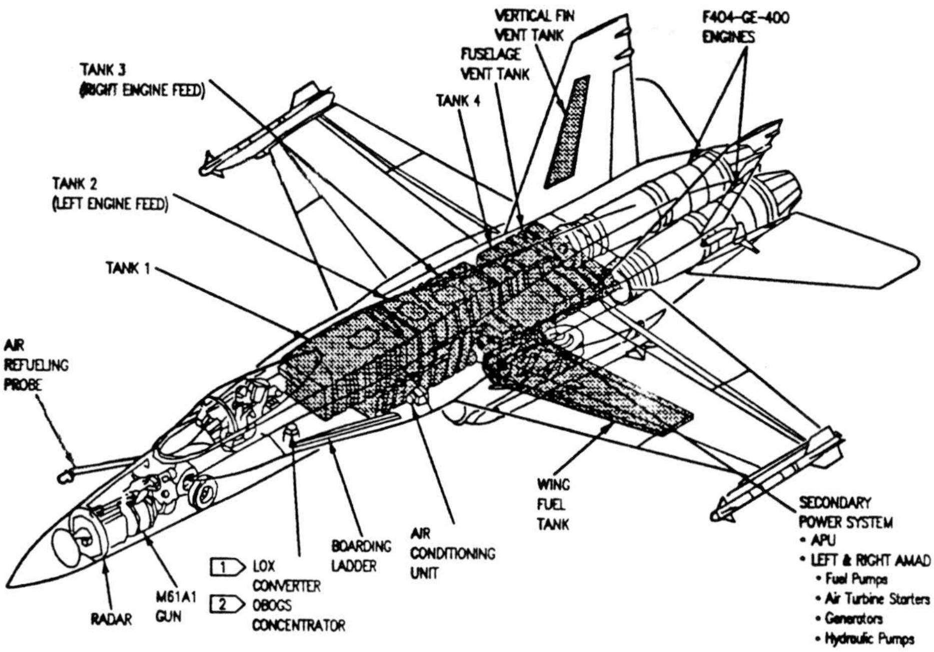
APPENDICES

APPENDIX A



Span (without missiles)	37.5'
Length	56.0'
Height	15.3'
Weight empty	23,500 lbs
Weight (combat takeoff)	37,000 lbs

Figure A-1. F/A-18C Physical Layout

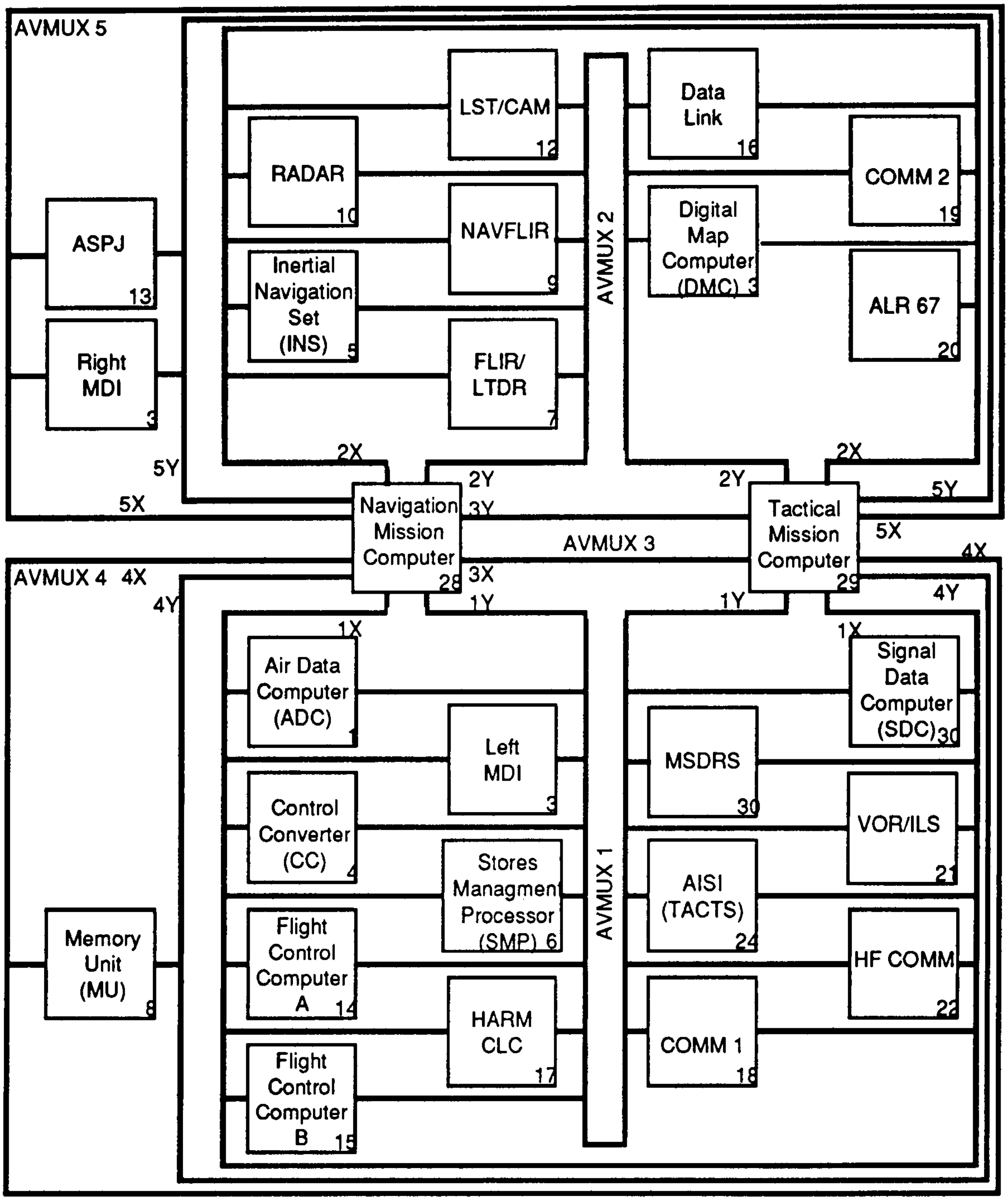


Figure A-2. F/A-18C Avionics Multiplex Overview

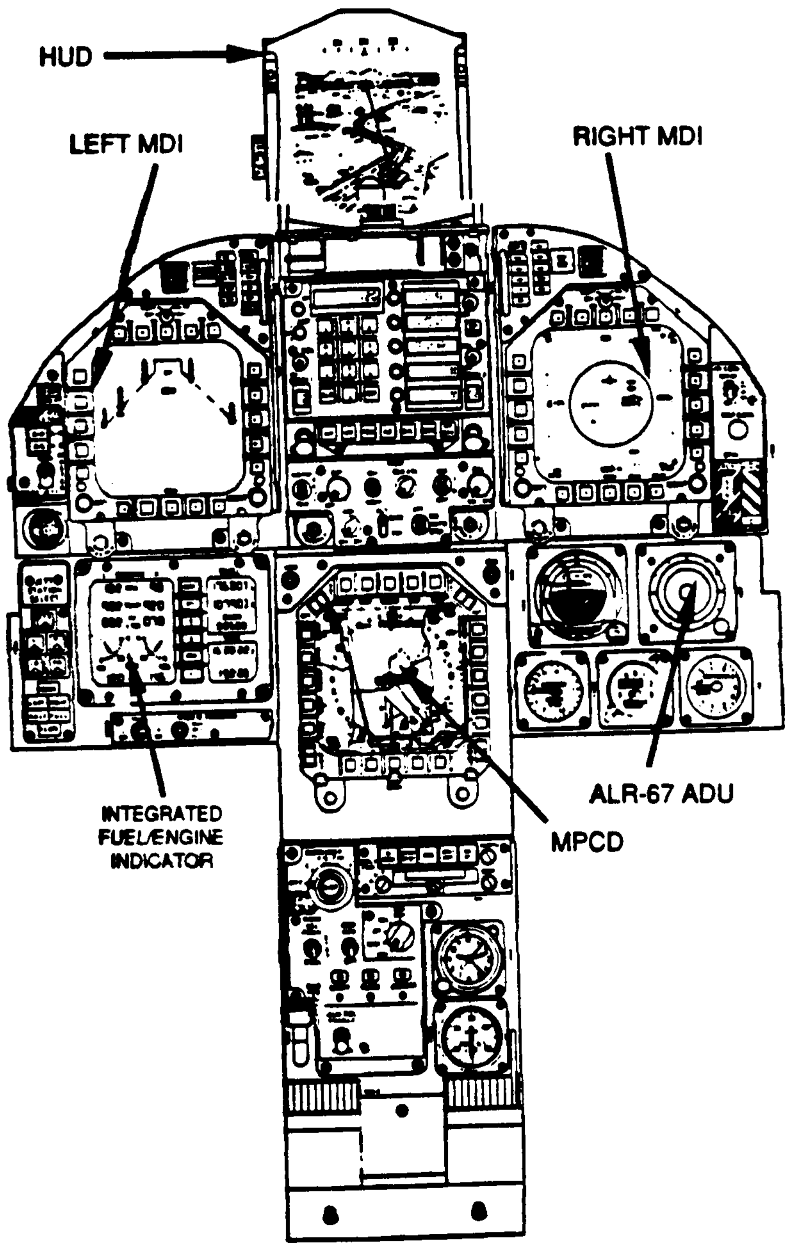


Figure A-3. F/A-18C Main Instrument Panel

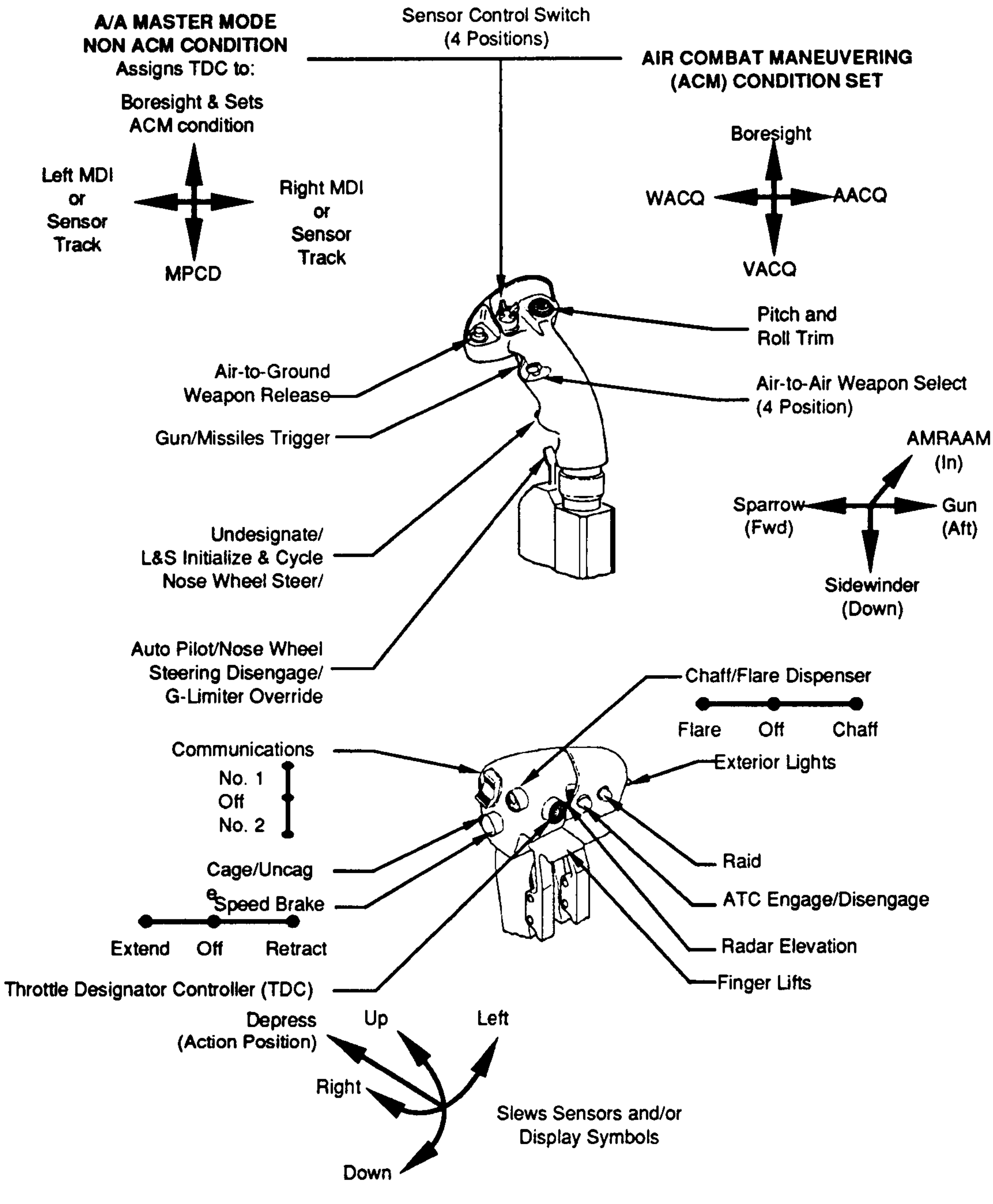


Figure A-4. Flight Control Stick and Throttle Switches

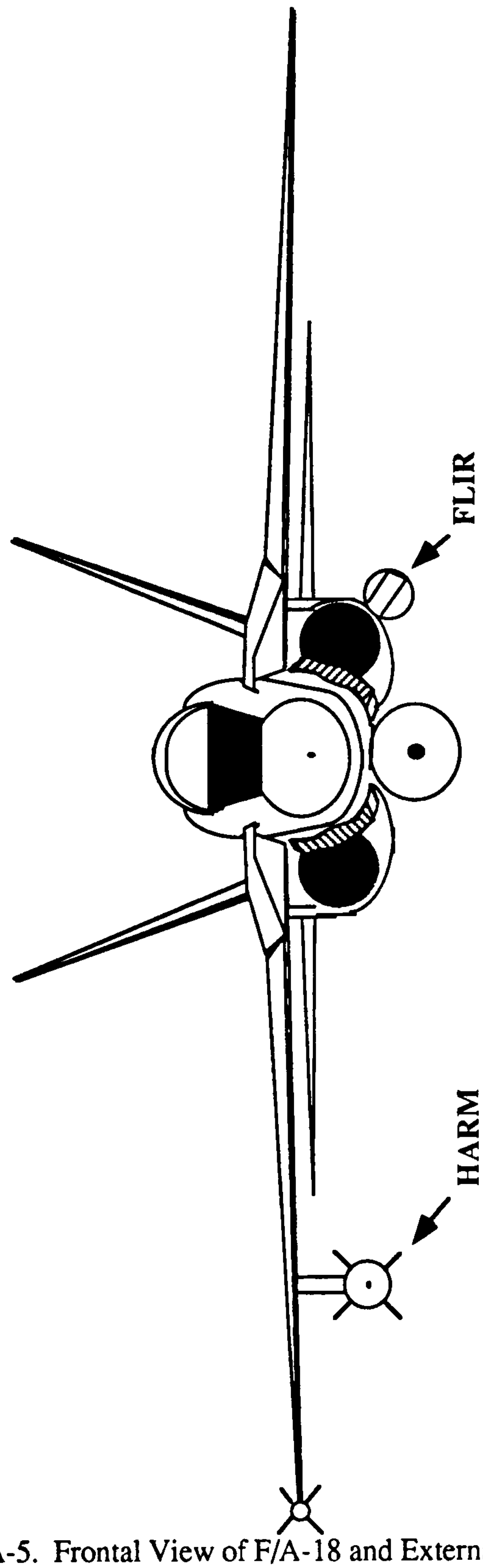


Figure A-5. Frontal View of F/A-18 and External Sensors

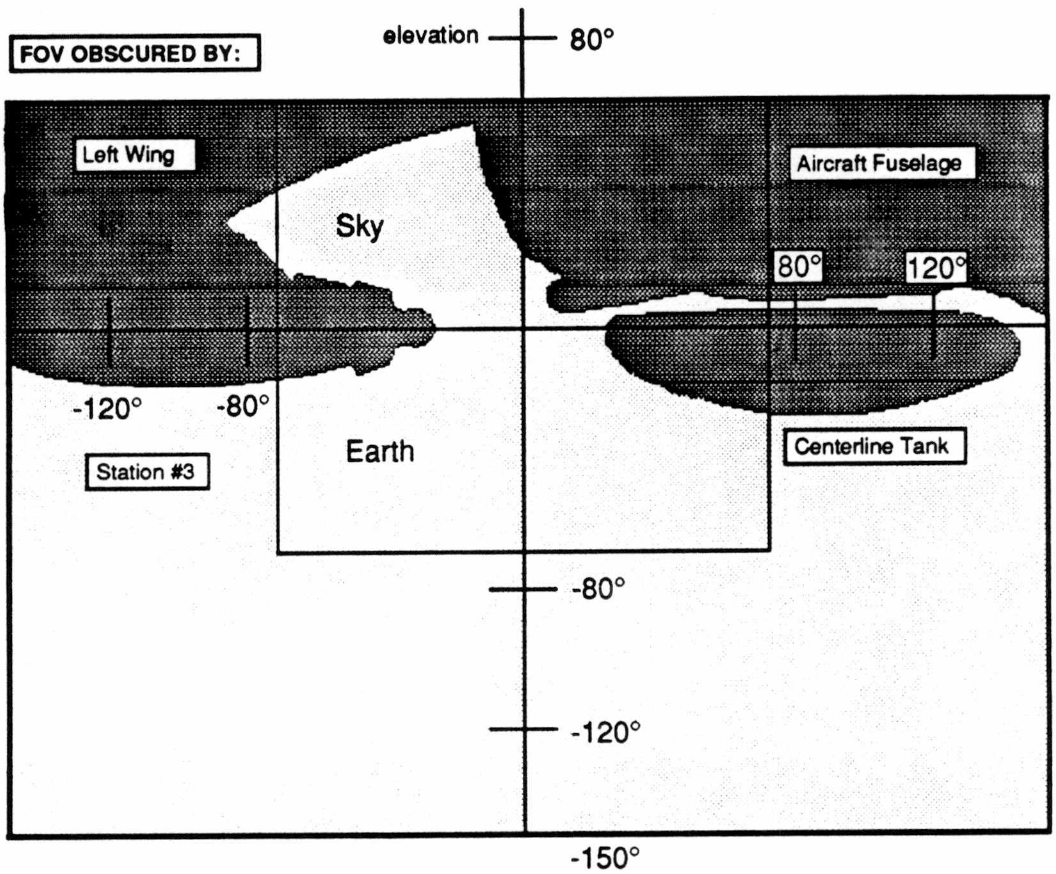


Figure A-6. F/A-18C FLIR Field-of-Regard

APPENDIX B

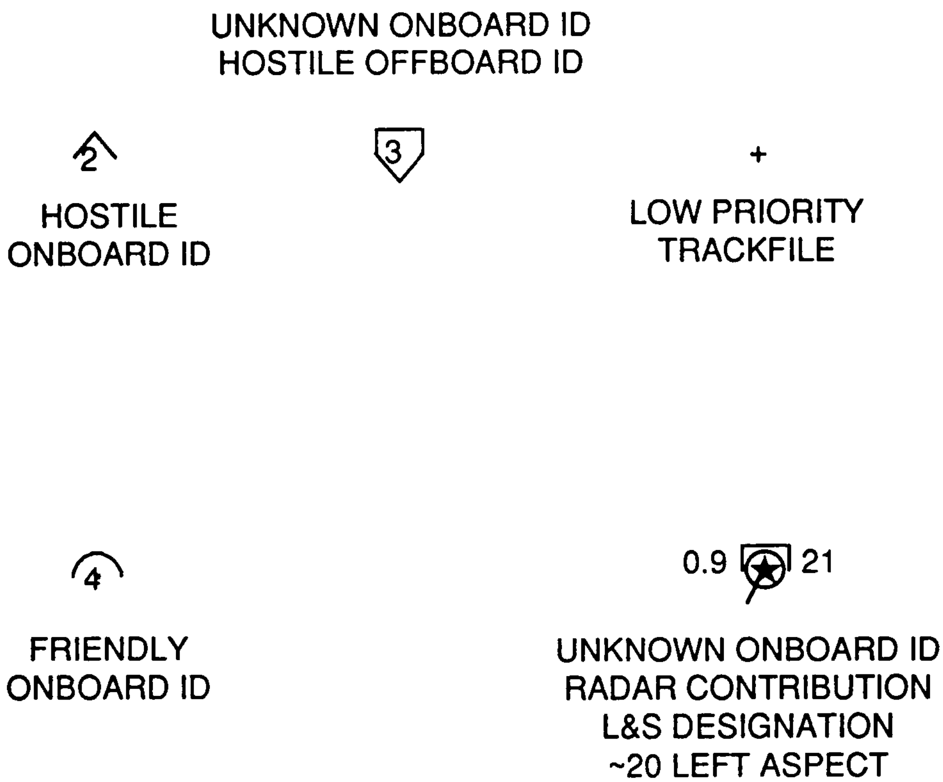


Figure B-1. Example HAFU Symbols

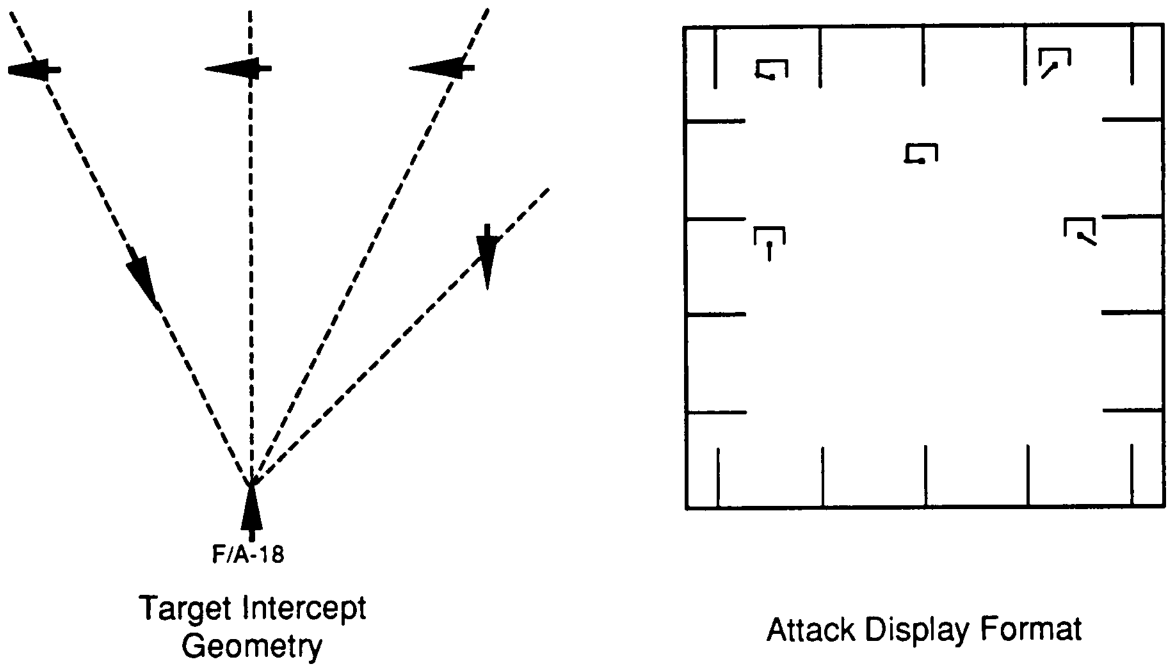


Figure B-2. Target Intercept Geometry Versus Target Aspect

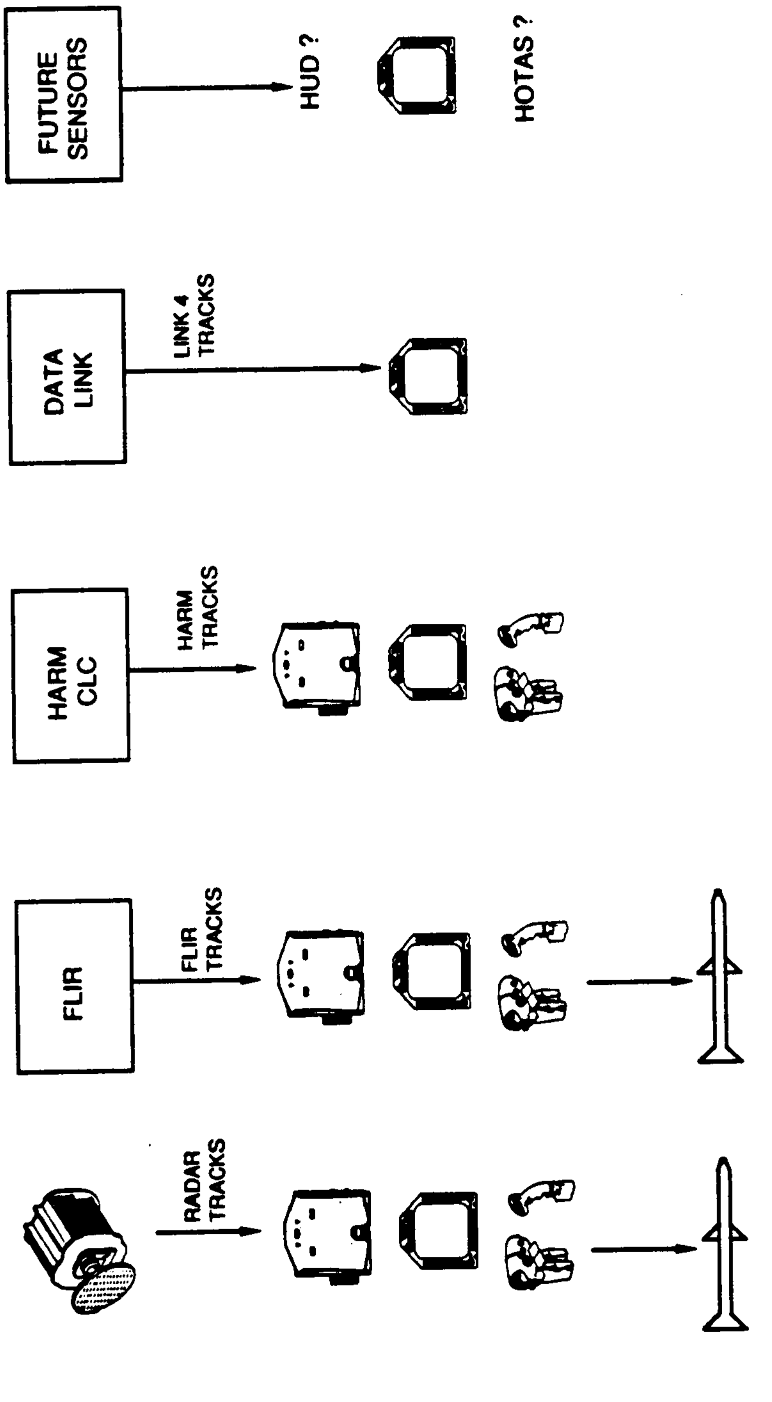


Figure B-3. Sensor, Display, and Weapons Capability Before MSI

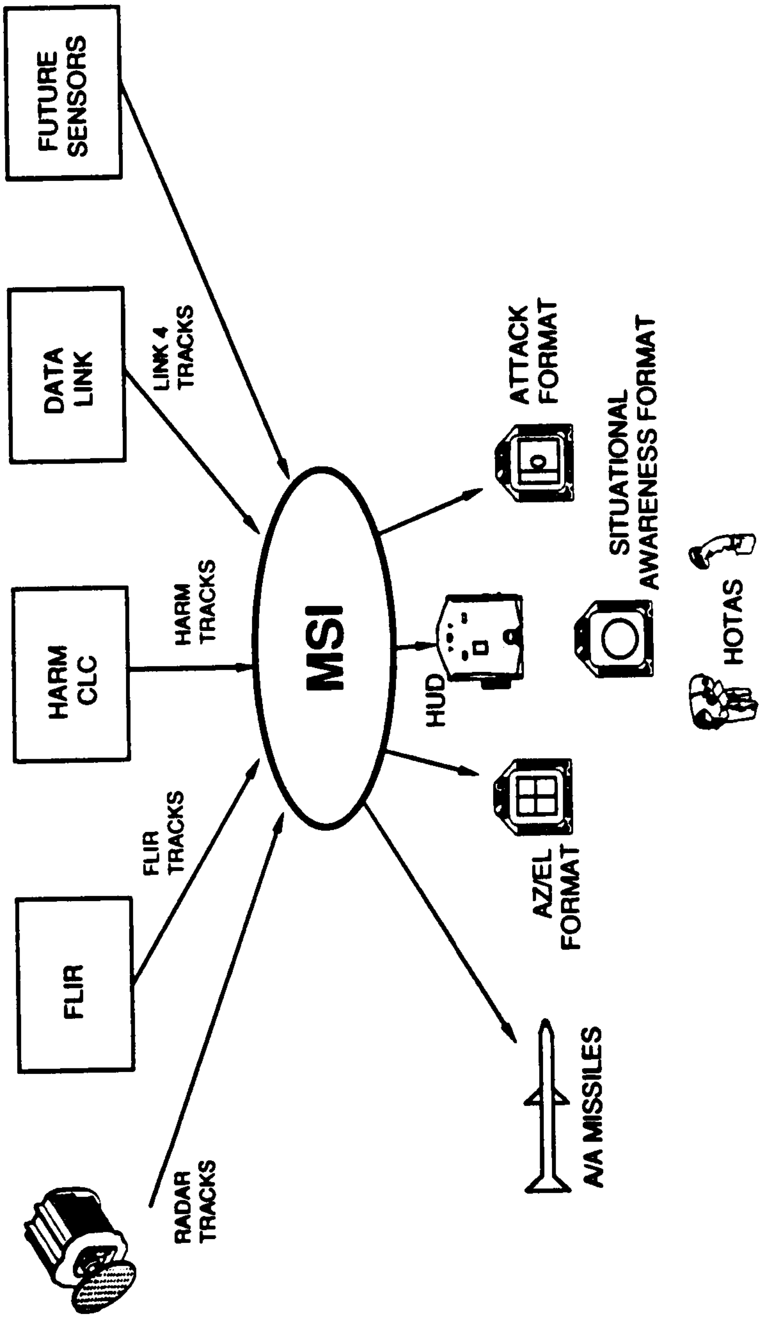


Figure B-4. Sensor, Display, and Weapons Capability With MSI

APPENDIX C

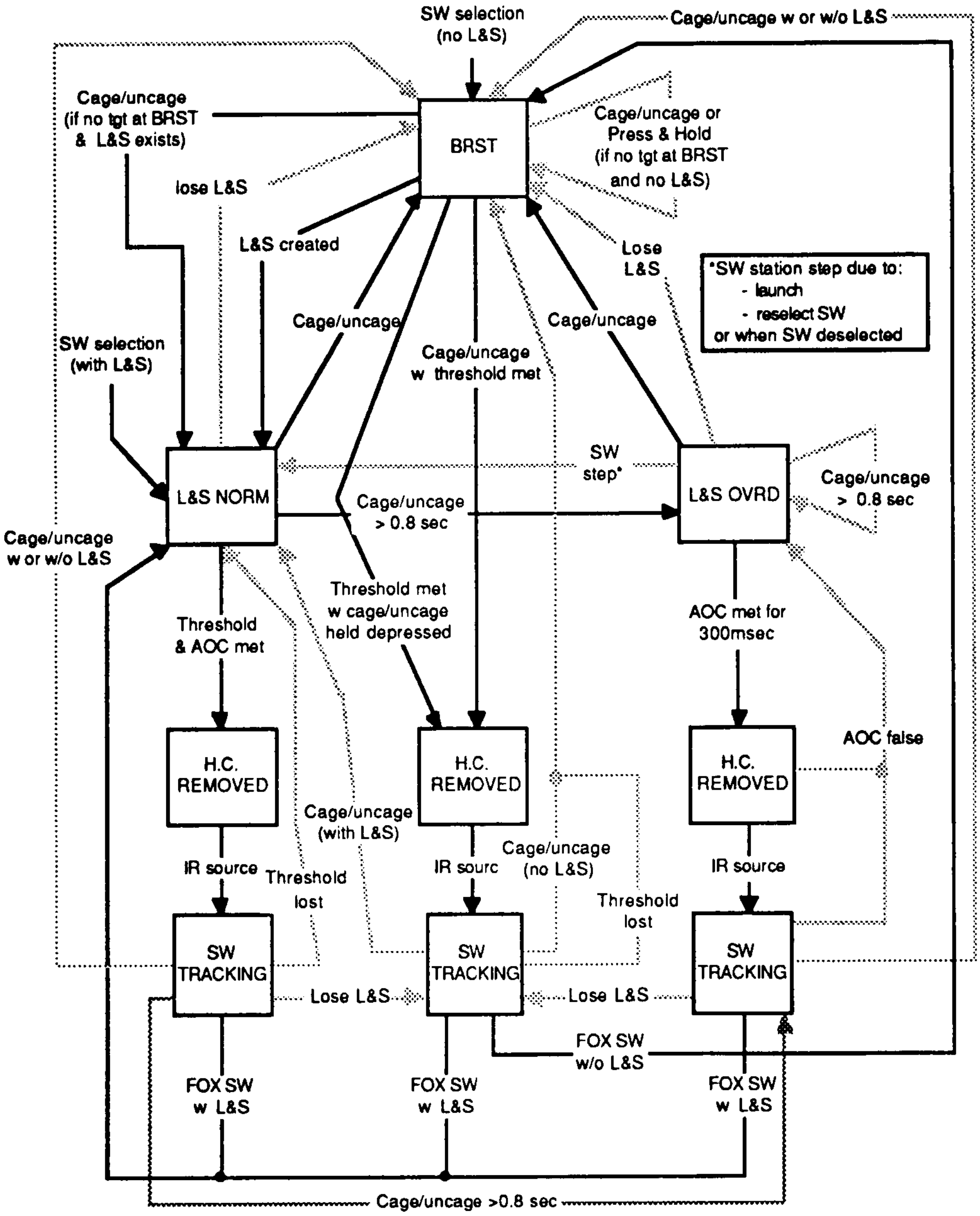


Figure C-1. OFP 91 AIM-9 Sidewinder Flow Diagram

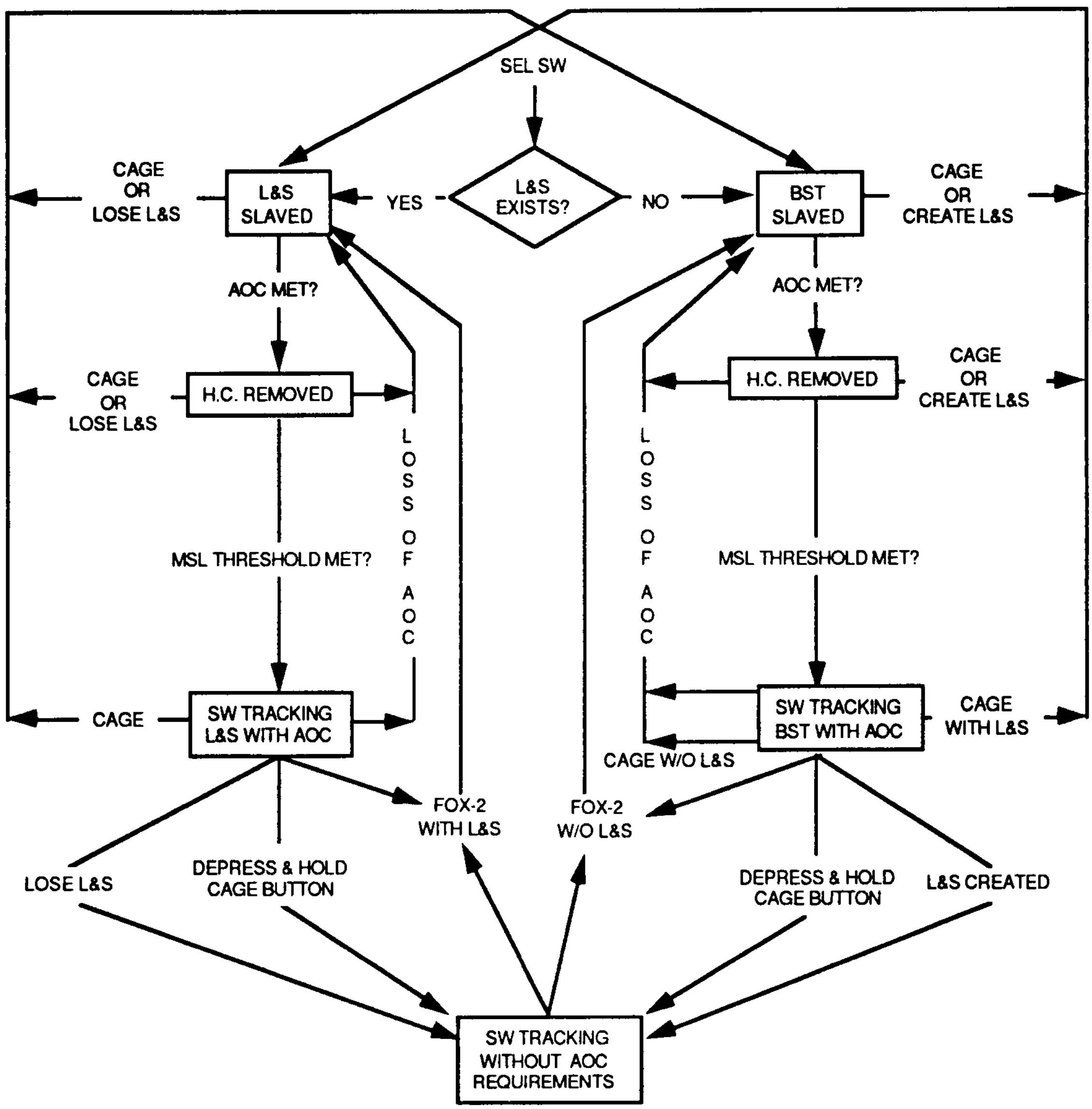


Figure C-2. Proposed AIM-9 Sidewinder Flow Diagram

APPENDIX D

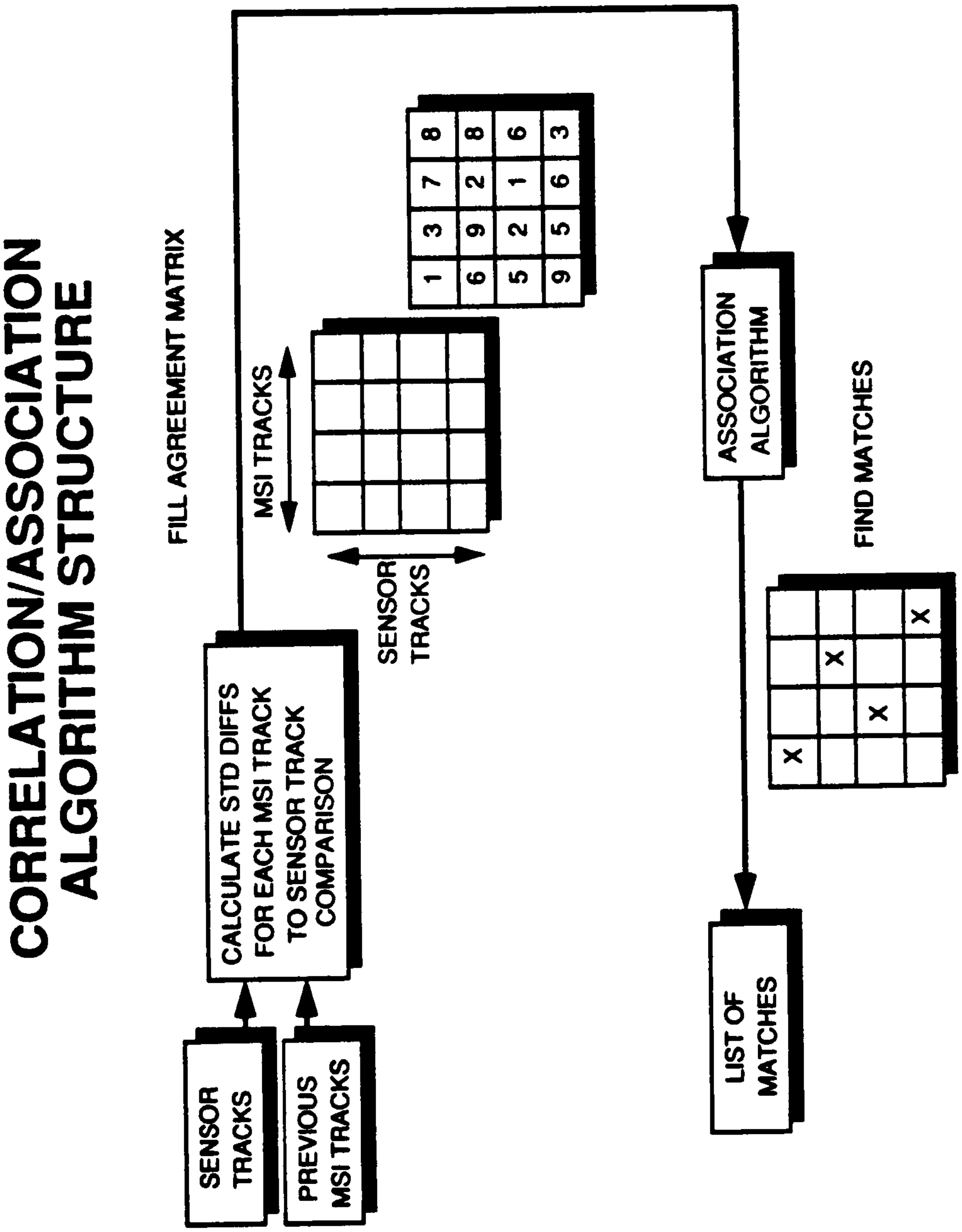


Figure D-1. MSI Global Association Process

LIST OF ABBREVIATIONS

AAA. Anti-aircraft Artillery

ACM. Air Combat Maneuvering

ADF. Automatic Direction Finder

ADU. Azimuth Display Unit

AMRAAM. Advanced Medium Range Air-to-Air Missile

ASAP. Aircrew Systems Advisory Panel

ASE. Allowable Steering Error

Az/El. Azimuth versus Elevation

CIA. Command Inertial Active

CRT. Cathode Ray Tube

DT2. Designated Target #2

EEGS. Enhanced Envelope Gunsight.

EMCON. Emissions Control

EOB. Electronic Order of Battle

ESM. Electronic Signal Measure

EW. Electronic Warfare

FLIR. Forward Looking Infrared

HAFU. Hostile, Ambiguous, Friendly, Unknown

HARM. High Speed Anti-Radiation Missile

HOTAS. Hands On Throttle And Stick

HSI. Horizontal Situation Display

HUD. Head Up Display

IA. Inertial Active

IFF. Identification Friend or Foe

ILS. Instrument Landing System

IRST. Infrared Search and Track

LAR. Launch Acceptability Region

L&S. Launch and Steering

MDI. Multipurpose Display Indicator

MPCD. Multipurpose Color Display

MSI. Multi-Source Integration

OFP. Operational Flight Program

PRF. Pulse Repitition Frequency

RCS. Radar Cross Section

RF. Radio Frequency

RHAW. Radar Homing and Warning

RWR. Radar Warning Receiver

SA. Situational Awareness

SCS. Sensor Control Switch

STT. Single-Target-Track

TACAN. Tactical Air Navigation

TD. Target Designator

TDC. Target Designator Controller

TWS. Track-While-Scan

UFC. Up-Front Control

VITA

Mark P. Stucky was born November 9, 1958 in Minneapolis, Minnesota. He was raised in Salina, Kansas and graduated from Kansas State University in 1979 with a Bachelor of Science degree in Physical Science. Mark was commissioned in the United States Marine Corps and sent to Pensacola, Florida in 1980 to attend Naval Flight Training. After graduating and receiving his "wings" he was assigned to the Fleet Marine Force flying F-4 Phantom aircraft. During this tour he graduated from the U.S. Navy Fighter Weapons School (TOPGUN). In 1986 he transitioned to the F/A-18 and received orders to Air Test and Evaluation Squadron Four. He served two years as the F/A-18 Operational Test Director before attending the United States Air Force Test Pilot School at Edwards Air Force Base. Upon completion of Test Pilot School he was relocated to his current job at the Naval Weapons Center, China Lake, California; where his primary duty is serving as the F/A-18 developmental test pilot.