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Integration of Tactical Imagery in the F/A-18 Super Hornet

A Thesis Presented for the Masters of Science Degree

The University of Tennessee, Knoxville

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Abstract

In the spring of 2004 the Department of the Navy issued requirements for the F/A-18E/F Super Hornet to integrate tactical imagery for precise machine to machine targeting and real time mission assessment. The operational intent was to increase the contribution of the F/A-18 to the kill chain for ground targets.

In response to that requirement the F/A-18 Advanced Weapons Laboratory (AWL) began work with Boeing on the H2E+ Software Configuration Set (SCS) program which consisted of:

1. Software and hardware changes to aircraft mission computers to support
    a. image viewing and editing in the cockpit
    b. image transmission and reception over tactical datalinks
    c. capture and save of images from onboard sensors
2. Solid State Recorder (SSR) integration
3. Software changes to Mission Planning stations to support preflight imagery planning and post flight imagery review

The AWL/Boeing team began flight test with H2E+ and SSR in January 2005. After extensive test and evaluation, the H2E+ SCS with SSR was found to increase the capability of the F/A-18 to execute certain steps in the kill chain. However several deficiencies were found that warrant further development.

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List of abbreviations, acronyms, and terms

A/G	Air to Ground
ACAS	Advanced Close Air Support
Ack	Acknowledgement
AGM	Air to Ground Missile
AMU	Advanced Memory Unit
AWL	Advanced Weapons Laboratory
BHA	Bomb Hit Analysis
BIT	Built in Test
BOSS	Battlespace Operations Software System
CAS	Close Air Support
COTS	Commercial Off The Shelf
CVRS	Cockpit Video Recording System
DDI	Digital Display Indicator
DCS	Digital Communication System, F/A-18 implementation of VMF
DMMT	Digital Machine to Machine Targeting
DPSS	Digital Precision Strike Suite
EE	EagleEye
EEE	Electronics Emissions Evaluation
EO	Electro-Optical
FAC	Forward Air Controller
FAC(A)	Forward Air Controller (Airborne)
FLIR	Forward Looking InfraRed
FTXT	FreeTeXT
GBU	Guided Bomb Unit
GP	General Purpose
GPS	Global Positioning System
H2E+	Name of SCS upgrade
HMD	Helmet Mounted Display (aka JHMCS)
HOTAS	Hands On Throttle And Stick
HUD	Heads Up Display
ICAT	Image Capture and Transfer
ICP	Interface Change Proposal
IR	InfraRed
JDAM	Joint Direct Attack Munition
JHMCS	Joint Helmet Mounted Cueing System
JITC	Joint Interoperability Test Command
JMPS	Joint Mission Planning System
JPEG	Joint Photographers Expert Group
JSOW	Joint Stand Off Weapon
JTIDS	Joint Tactical Information Distribution System
JU	JTIDS User
Kill chain	Series of steps used in air to ground engagements
L16	Link-16
LGB	Laser Guided Bomb
Link ack	Link acknowledgement
LMAV	Laser Maverick
LOS	Line of Sight
LVT	Low Volume Terminal
MC	Mission Computer
MDR	Mission Data Recorder

META	MEnsuration daTA
MFD	Multi-Function Display
MIDS	Multi-function Information Distribution System, F/A-18 implementation of Link-16
MPCD	Multi-Purpose Color Display
MSOFD	Mission System Operation and Function Description
MSP	Maintenance Status Panel
MTCF	MIDS Terminal Control Format
NATOPS	Naval Air Training and Operating Procedures Standardization
NPG	Network Participant Group
NCTSI	Navy Center for Tactical System Interoperability
NITF	National Image Transmission Format
NTISR	Non-Traditional Intelligence Surveillance Reconnaissance
OSR	On Station Report
PCMCIA	Personal Computer Memory Card International Association
PPLI	Precise Participant Location and Identification
PVI	Pilot-Vehicle Interface
RAIDER	Rapid Attack Information Dissemination Execution Relay
RMM	Removable Memory Module
ROE	Rules of Engagement
RTMA	Real Time Mission Assessment
SA	Situational Awareness
SCS	System Configuration Set (bundle of software and hardware updates)
SSR	Solid State Recorder
T/R	Transmit/Receive
TADIL	TActical Data Information Link
Talk-on	Use of voice description to assist in locating a target
TDMA	Time Division Multiple Access
TIFF	Tagged Image Format File
TLDHS	Target Location and Designation Handoff System
TN	Track Number
TST	Time Sensitive Targeting
TTI	Time To Impact
TUC	Target Under Cursor
UFCD	Up Front Control Display
UPC	User Planning Component
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
VCS	Voice Call Sign
VMF	Variable Message Format
WGS	World Geodetic System
WSO	Weapons System Operator

Part 1: Introduction

1. **Introduction:** The following information is provided as information about this document and its author.

1.1. **Objective**: This paper will discuss successes and failures of the U. S. Navy acquisition community to provide a well integrated tactical imagery capability that enhanced the ability of the F/A-18E/F to perform its missions. Specifically the paper will follow the integration of the H2E+ SCS, which was a collection of hardware and software upgrades that were delivered in a group. Objectives of the document are:

- Provide background information
- Discuss changes made to enable tactical imagery
- Discuss results of test and evaluation of tactical imagery
- Make recommendations for further development to improve tactical imagery

1.2. **Scope:** All aspects of the H2E+ SCS and SSR underwent extensive testing. For the purposes of this document, the discussion will be limited to those aspects of H2E+ and SSR that directly contribute to tactical imagery capability. This document will not cover:

- H2E+ capability upgrades other than tactical imagery
- Evaluation of H2E+ without SSR
- Capabilities of versions of the F/A-18 that could not be upgraded to the H2E+ SCS

1.3. **Author**: The author was a developmental test pilot with the U.S Navy. He worked as the H2E+ and SSR project officer from March 2004 until April 2006. As project officer he was responsible for and executed:

- Aircrew input for initial design
- Test planning
- First flight of H2E+ with SSR
- Numerous flight test events for imagery exchange
- Aircrew input for design changes
- Deficiency documentation and classification
- Training for fleet operators

See the vita for further discussion of the author’s background.

Part 2: Background

2. **Description of the F/A-18 Super Hornet:** The F/A-18E/F Super Hornet is a multi-role carrier-based tactical aircraft capable of air to air and air to ground missions using a wide variety of onboard weapons, sensors, and communications systems. Figure 2.1 shows the F/A-18 E/F Super Hornet. The F/A-18 is capable of autonomously employing Global Positioning System (GPS) guided weapons, laser guided weapons, and free fall weapons. F/A-18 onboard sensors include multi-mode radar capable of detecting and tracking air and ground targets, a variety of targeting pods that use infrared and optical sensors to find and track air and ground targets, and Joint Helmet Mounted Cueing System (JHMCS) for rapid designation of visually significant targets. For a complete description of the F/A-18 refer to the Naval Air Training and Operating Procedures Standardization (NATOPS) manual and the Goldbook, references [a] and [b].

   2.1. **Basic avionics**: The F/A-18E/F incorporates a wide variety of computers, sensors, weapons, and displays. The avionics system uses two mission computers that control all other system components via mux busses. Figure 2.2 shows a simplified schematic of relevant avionics components. Reference [b] contains a complete schematic of all avionics components. Each component will be discussed at length in the following text.

Figure 2.1; F/A-18F Super Hornet

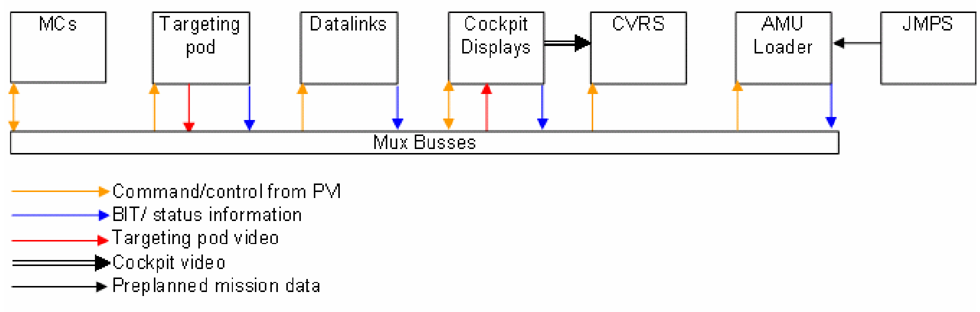


Figure 2.2; Simplified avionics diagram of the F/A-18 Super Hornet

2.1.1. **Mission Computers (MCs):** The F/A-18E/F has two high speed, stored program, general purpose computers with core memory called MC1 (Mission Computer 1) and MC2 (Mission Computer 2). They serve four main functions:

- compute and control the data sent to the cockpit displays,
- compute missile launch and weapons release commands,
- provide mode control and option for various avionics systems, and
- generate BIT initiate signals to and equipment operation status from various avionics systems (ref [a], page I-2-133)

The mission computer software can be updated to provide new control data to the displays, new mode control for existing avionics, and mode control for new avionics systems.

2.1.2. **Cockpit displays:** The F/A-18E/F cockpit has 4 Multi-Function Displays (MFDs) as well as a Heads Up Display (HUD) and Joint Helmet Mounted Cueing System (JHMCS). All displays receive information from the MCs, convert that information into symbology, and present navigation, aircraft attitude, and weapons attack symbology. Figure 2.3 shows the general configuration of the Super Hornet cockpit. The four MFDs are configurable displays with pushbuttons that can be used to select various displays and system operating modes. Left and right displays are called Digital Display Indicators (LDDI and RDDI). The lower center display is called the Multi-Purpose Color Display (MPCD). The center display is called the Up Front Control Display (UFCD). The MPCD and DDIs have active pushbuttons around the edges that allow aircrew to select new displays or command a mode change. The UFCD can be configured as a display or can be configured to a keypad display to

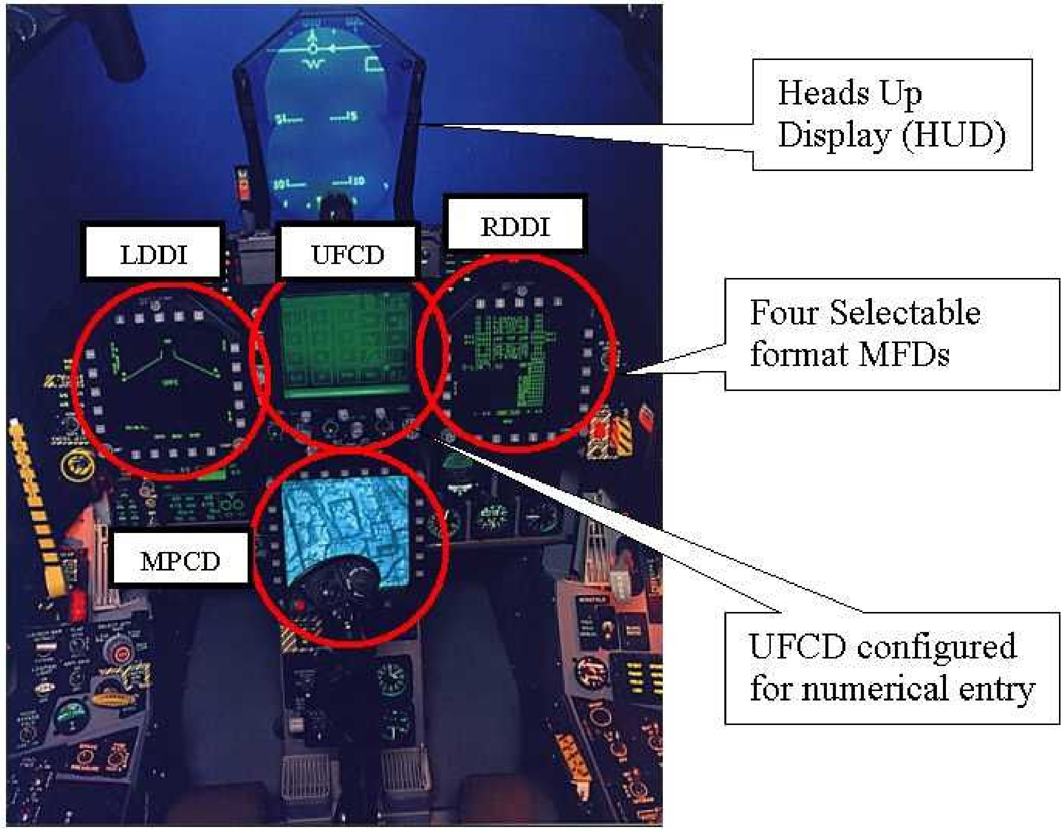


Figure 2.3; Cockpit of the F/A-18 Super Hornet

allow entry of numerical data via touch screen technology. The labels and unctionality of the display pushbuttons are determined by software in the mission computer.

2.1.3. **Targeting pod:** A targeting pod is the primary sensor used to find, identify, and track ground targets. Targeting pods incorporate both Electrical Optical (EO) and Infra Red (IR) sensors that can each provide video and targeting data to the aircraft. EO sensors are also known as TV sensors and rely on visible contrast (black vs white in the visible spectrum) to produce a visible image. IR sensors are also known as "heat seekers" and rely on thermal contrast (hot vs cold in the IR spectrum) to produce a visible image. Figure 2.4 shows a typical targeting pod as installed on an F/A-18. Targeting pods allow aircrew to perform the following:

2.1.3.1. **Sensor to detect ground targets:** Aircrew can use other sensors to point the targeting pod toward suspected targets. The EO and IR sensors then allow the aircrew to see the target area and locate the precise position of the

Figure 2.4; Targeting pod installed on the F/A-18 Super Hornet

target. The target area is presented as a visual scene in the cockpit and aircrew can then command the sensors to slew up/down/left/right to center the presented video on the target position.

2.1.3.2. **Sensor to track ground targets:** Once A/G targets are located, targeting pods incorporate tracking modes that allow EO and IR sensors to stabilize on points of visual or IR contrast. These track modes reduce aircrew workload and take advantage of pod sensors to provide best stabilization.

2.1.3.3. **Sensor to derive target coordinates**: Targeting pods use their current position, sensor pointing angles, and range-to-target information to derive a physical location for the object being tracked. These locations are generally expressed in Latitude/Longitude/Elevation using the World Geodetic System 84 (WGS-84) datum.

2.1.3.4. **Laser designator for laser guided weapons:** Most targeting pods incorporate laser target designators that fire laser energy along the pod line of sight. This laser energy can be used to guide certain weapons that detect and track laser energy. Laser guidance is generally performed by pointing the pod EO/IR sensors at the desired target and actuating switches or pushbuttons to begin laser emission.

2.1.3.5. **Super Hornet integration:** The Super Hornet is able to carry one targeting pod on a fuselage station as shown in Figure 2.4. When equipped with a targeting pod, the MCs generate a targeting pod display (called the FLIR page) that combines targeting pod video with mission computer generated symbology. The targeting pod video contains video from the sensor to include target coordinates, track mode symbology, and advisories that indicate pod status. The MC generated symbology includes pushbuttons to command mode changes, pushbuttons to operate the laser, and pushbuttons to change pod setup. In later software versions, a North up arrow was generated by the MCs from targeting pod data to show the orientation of features in the targeting pod video. A representative FLIR page is shown in Figure 2.5. For a complete description of targeting pod integration see ref [b] page 5-85.

2.1.4.**Tactical datalinks:** The F/A-18E/F uses several tactical datalinks to exchange digital data with other users, to include other aircraft and ground stations. Two prevalent tactical datalink systems in use with the Super Hornet are Link-16 and VMF.

2.1.4.1. **Link-16:** Link 16 (a.k.a. TADIL J (Tactical Data Information Link J), JTIDS (Joint Tactical Information Distribution System)) is a secure, jam resistant, digital datalink used to transmit tactical information between datalink participants. Figure 2.6 shows typical Link-16 users.

2.1.4.1.1. **Users:** L-16 is the primary tactical datalink in use in U.S military tactical aircraft. Link-16 is integrated in U.S Navy surface ships, U.S Navy aircraft, USMC aircraft, and USAF aircraft. In addition, several command and control ground stations have Link-16 capability. Basic requirements to use Link-16 are: integration of a L-16 terminal (an

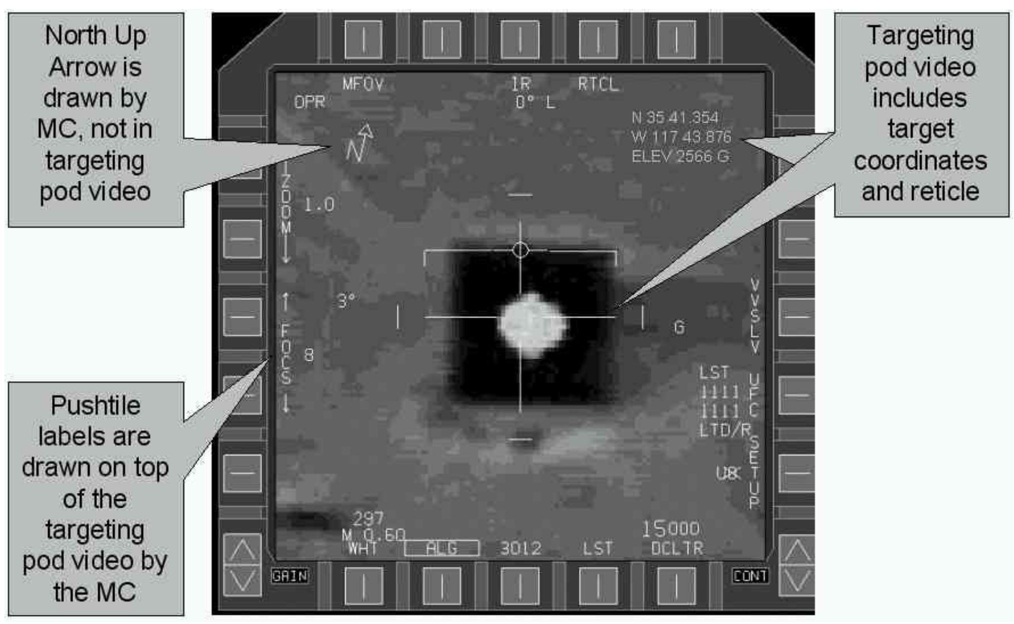


Figure 2.5; Super Hornet FLIR page

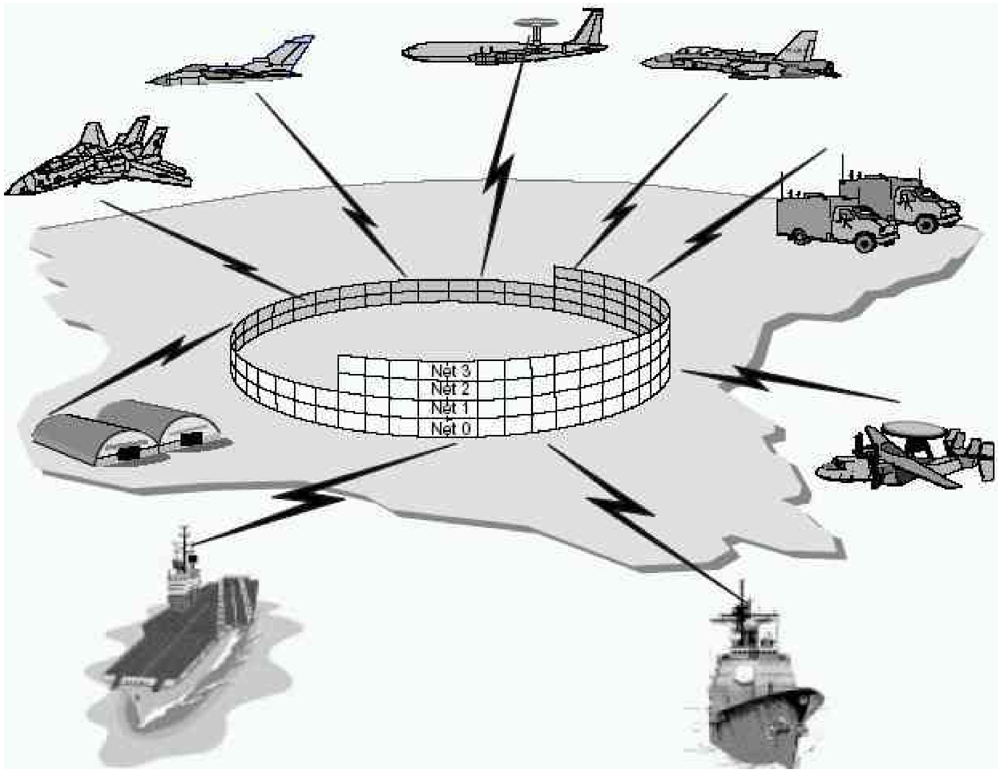


Figure 2.6; Graphical depiction of Link-16 users (ref [c], page 1-9)

example of which is shown in Figure 2.7) and software and displays capable of presenting the L-16 messages in a tactically usable format.

2.1.4.1.2. **Description:** Link 16 is a Time Division Multiple Access (TDMA) system that uses a repeating pattern of time slots, standardized message format, and multiple layers of deconfliction. Link-16 is capable of servicing hundred of users simultaneously due to NPG and net number options. Individual users are assigned time slots during which they are able to send or receive the standardized Link-16 messages.

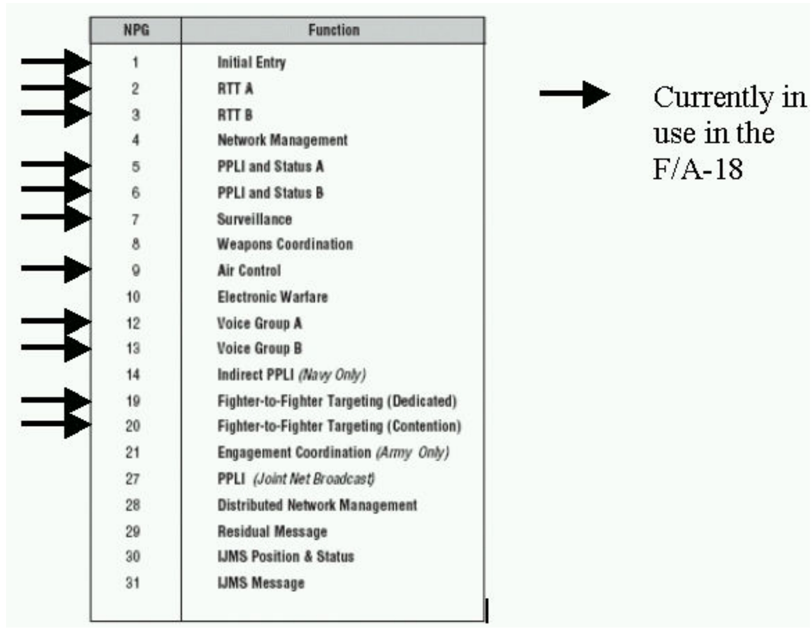
2.1.4.1.2.1. **Network:** A Link-16 Network data load (network) is a pre-arranged list of users as well as standardized assignments for when and where those users will send and receive their Link-16 messages. Users in a Link-16 network are identified by their Track number (TN), also known as a JTIDS User (JU) number. A TN is a 5 digit alphanumeric identifier that is unique to that user. In order for two L-16 users to have datalink connectivity, they must be working on the same network or they will not agree on time slot

Figure 2.7; Link-16 Low Volume Terminal (LVT)

assignments and messages will not get through. Hundreds of networks are available for use, but in general each geographical area (training range or operation area) will have only one network in use at a time. Changes in timeslot or NPG assignment are made by requesting a new or modified network. New or modified networks can be designed and released by the Joint Network Design facility.

2.1.4.1.2.1.1. **Time slots:** The centerpiece of L-16 TDMA architecture is the definition and assignment of time slots. All L-16 users must be time synchronized to allow definition of time slots. Once all users are synchronized, the L-16 network provides detailed assignment for each time slot.

2.1.4.1.2.1.2. **Network Participation Group (NPG):** An NPG is a group of time slots that are assigned for common uses. For example, all time slots dedicated to mission assignment commands are sent out over one NPG and all targeting messages between fighters go out over a second NPG. The use of multiple NPGs provides vastly improved flexibility as multiple messages can be transmitted during the same time slot, as long as they are sent on different NPGs. Figure 2.8



NPG	Function
1	Initial Entry
2	RTT A
3	RTT B
4	Network Management
5	PPLI and Status A
6	PPLI and Status B
7	Surveillance
8	Weapons Coordination
9	Air Control
10	Electronic Warfare
12	Voice Group A
13	Voice Group B
14	Indirect PPLI *(Navy Only)*
19	Fighter-to-Fighter Targeting (Dedicated)
20	Fighter-to-Fighter Targeting (Contention)
21	Engagement Coordination *(Army Only)*
27	PPLI *(Joint Net Broadcast)*
28	Distributed Network Management
29	Residual Message
30	IJMS Position & Status
31	IJMS Message

Figure 2.8; Link-16 NPGs (ref [c], page 6-15)

shows a list of NGPs and highlights those in use on the Super Hornet.

2.1.4.1.2.1.3. **NPG net:** Link-16 users can set each NPG to a different net or channel. Users must be on the same net number to share information. Selectable net numbers allow groups of users to communicate without conflicting with other groups using the same NPG.

2.1.4.1.2.2. **Types of messages:** Link-16 uses a standard set of messages that can be transmitted or received. Each type of message is assigned to an NPG where those types of messages will be transmitted and received. Figure 2.9 shows a representative list of Link-16 messages available for use.

2.1.4.1.3. **Super Hornet integration:** F/A-18 integration of Link-16 includes a Multi-Functional Information Distribution System Low Volume Terminal (MIDS LVT) installed in the avionics bay and aircrew interface through two displays that can be selected on any of the 4 MFDs. The MIDS Terminal Control Format (MTCF) display allows aircrew to verify and modify operation of the terminal, and the Situational Awareness (SA) page to display the Link-16 information in a graphical format. For a handful of critical NPGs, the displays in the Super Hornet allow aircrew

TADIL-J Message Catalog

Network Management	
J0.0	Initial Entry
J0.1	Test
J0.2	Network Time Update
J0.3	Time Slot Assignment
J0.4	Radio Relay Control
J0.5	Repromulgation Relay
J0.6	Communication Control
J0.7	Time Slot Reallocation
J1.0	Connectivity Interrogation
J1.1	Connectivity Status
J1.2	Route Establishment
J1.3	Acknowledgement
J1.4	Communicant Status
J1.5	Net Control Initialization
J1.6	Needline Participation Group Assignment
Precise Participant Location and Identification	
J2.0	Indirect Interface Unit PPLI
J2.1	Indirect Supporting Unit PPLI
J2.2	Air PPLI
J2.3	Surface PPLI
J2.4	Subsurface PPLI
J2.5	Land Point PPLI
J2.6	Land Track PPLI
Surveillance	
J3.0	Reference Point
J3.1	Emergency Point
J3.2	Air Track
J3.3	Surface Track
J3.4	Subsurface Track
J3.5	Land Point or Track
J3.6	Space Track
J3.7	Electronic Warfare Product Information
Undersea Warfare	
J5.4	Acoustic Bearing and Range
Intelligence	
J6.0	Intelligence Information
Information Management	
J7.0	Track Management
J7.1	Data Update Request
J7.2	Correlation
J7.3	Pointer
J7.4	Track Identifier
J7.5	IFF/SIF Management
J7.6	Filter Management
J7.7	Association
J8.0	Unit Designator
J8.1	Mission Correlator Change
Weapons Coordination and Management	
J9.0	Command
J9.1	TMD Engagement Coordination
J9.2	ECCM Coordination
J10.2	Engagement Status
J10.3	Handover
J10.5	Controlling Unit Report
J10.6	Pairing
Control	
J12.0	Mission Assignment
J12.1	Vector
J12.2	Precision Aircraft Direction
J12.3	Flight Path
J12.4	Controlling Unit Change
J12.5	Target/Track Correlation
J12.6	Target Sorting
J12.7	Target Bearing
Platform and System Status	
J13.0	Airfield Status Message
J13.2	Air Platform and System Status
J13.3	Surface Platform and System Status
J13.4	Subsurface Platform and System Status
J13.5	Land Platform and System Status
Electronic Warfare	
J14.0	Parametric Information
J14.2	Electronic Warfare Control/Coordination
Threat Warning	
J15.0	Threat Warning
J16.0	Imagery
J17.0	Target Weather
National Use	
J28.0	U.S. National 1 (Army)
J28.1	U.S. National 2 (Navy)
J28.1.2	TBMD Training
J28.2	U.S. National 3 (Air Force)
J28.3	U.S. National 4 (Marine Corps)
J28.4	French National 1
J28.5	French National 2
J28.6	U.S. National 5 (NSA)
J28.7	U.K. National 1
J29.1	U.K. National 2
J30.0	German National 1
J30.1	German National 2
J30.2	Italian National 1
J30.3	Italian National 2
J30.4	Italian National 3
J30.5	French National 3
J30.6	French National 4
J30.7	French National 5
Miscellaneous	
J31.0	Over-the-air Rekeying Management
J31.1	Over-the-air Rekeying
J31.7	No Statement

Figure 2.9; Link-16 messages (ref [c], page 4-7)

to verify net number for their own aircraft and for other Link-16 participants. In addition for these NPGs the aircrew are able to modify their own net number via entry from the UFCD. Figure 2.10 shows the MTCF and the UFCD configured to enter Link-16 net numbers. For a complete description of Link-16 integration see ref [b] page 2-242.The SA page shows other Link-16 participants as Precise Participant Location and Identification (PPLI) symbols. Figure 2.11 shows the SA page with representative Link-16 symbology. In addition the SA page shows targeting commands and advisory information that have been received. Aircrew are provided with cursors that can be slewed on the SA page. When the cursors are slewed over a Link-16 symbol the SA page changes to a Target under Cursor (TUC) state where information about the TUC symbol is displayed in the lower corners of the display. When the TUC is a PPLI the information includes net numbers. PPLIs can be selected as flight member or track donors on the SA page. This

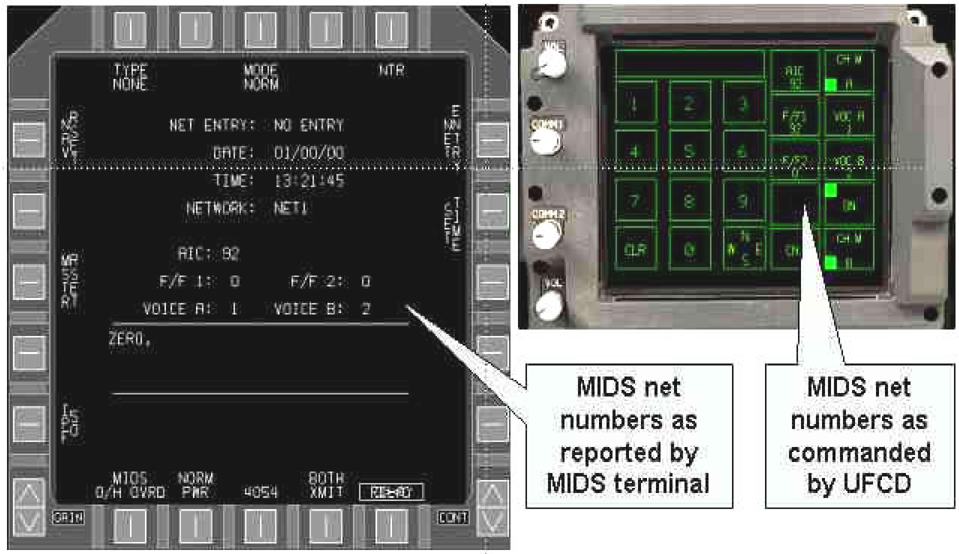


Figure 2.10; MTCF and UFCD displays for controlling the Link-16 terminal

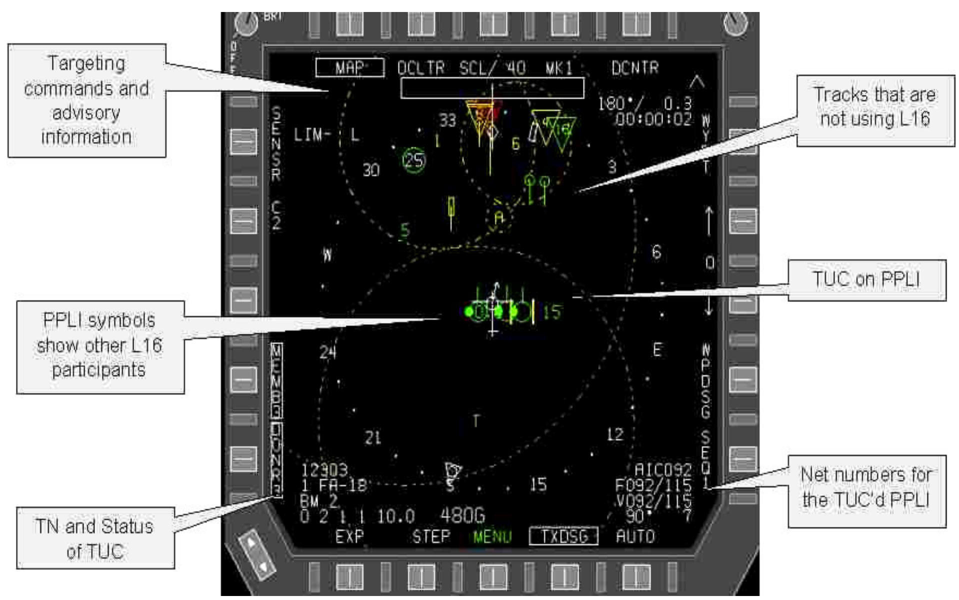


Figure 2.11; Super Hornet SA (Situational Awareness) page

allows aircrew to choose which Link-16 participants contribute to their symbology.

Incoming Link-16 messages are filtered by the mission computer for relevance and displayed in priority order. Most outgoing Link-16 messages are sent automatically but select few require pilot action to send. When certain L-16 messages arrive the aircrew are provided with a cue in the HUD (TGT CMD, DATA) that alerts them to the presence of new data on the SA page. The cue flashes for 10 seconds. Figure 2.12 shows the placement of the Link-16 message cue. In general, when Link-16 messages are sent the receiving terminal sends a link acknowledgement or “link ack” of message receipt back to the sending terminal. This link ack is the digital handshake that closes that transaction and prompts both terminals to move on to the next message. If a sending terminal does not receive a link ack it will attempts to resend that message during later transmit time slots.

2.1.4.1.4. **Strengths of Link-16 as a tactical datalink:**

2.1.4.1.4.1. **Secure via encryption:** Link-16 terminals incorporate encryption methods that make messages accessible only to those with similar

Figure 2.12; Placement of the Link-16 message cue

encryption devices. All Link-16 messages are secure and no extra steps are needed to ensure message security.

2.1.4.1.4.2. **Wide interoperability:** Link-16 is the primary tactical datalink in use for tactical aircraft. Link-16 is in use in all major aircraft types in the U.S. Air Force (USAF). Ground based command and control centers have Link-16 display and the ability to direct aircraft via Link-16.

2.1.4.1.4.3. **Long range to include relay:** Link-16 messages are transmitted to all Link-16 participants within line of sight (LOS), which yields a long range for tactical aircraft flying at many thousands of feet. The effective range of Link-16 messages is further enhanced by relaying, which refers to the feature of many Link-16 terminals of re-transmitting messages that are not addressed to them. Relay can drastically extend the effective range.

2.1.4.1.4.4. **Wide variety of message types:** Link-16 supports a wide variety of digital targeting messages that can be used creatively when designing and implementing new tactical capabilities.

2.1.4.1.5. **Weaknesses of Link-16 as a tactical datalink:**

2.1.4.1.5.1. **Not feasible for ground forces on foot:** Link-16 terminals, while easily incorporated into ships and aircraft, have several drawbacks for ground forces. From the perspective of a man who has to put this thing in his backpack, the terminals are large and bulky and require a large electrical load which leads to further weight in batteries. True integration with ground forces, which would require a Link-16 terminal and power supply system that is small and light enough for carriage by foot, is not yet available.

2.1.4.1.5.2. **Not in every platform:** While Link-16 is widely used among tactical aircraft, not all tactical aircraft have operational Link-16 terminals. The USN is still scrambling to retrofit older Hornets with Link-16 and the USMC has no plans to ever integrate Link-16 on its older attack aircraft. While the majority of USAF aircraft have Link-16 installed, some platforms are still integrating Link-16 capability.

2.1.4.2. **Variable Message Format (VMF)**

2.1.4.2.1. **Description:** VMF is a message standard that defines a standardized set of messages. VMF can be implemented in many different forms for transmission method, encryption, and network design.

2.1.4.2.2. **Users:** VMF is incorporated into a handful of tactical aircraft to include F/A-18, AV-8B, F-16, and EA-6B. VMF ground stations designed to be carried by ground troops have been developed and are undergoing operational test.

2.1.4.2.3. **Messages**: The VMF standard defines a standardized series of messages. Each message includes sender, intended recipient, message type, data assurance, and message content. Figure 2.13 shows VMF messages in use in the F/A-18.

2.1.4.2.4. **F/A-18 integration:** The F/A-18 implementation of the VMF message set is known as Digital Communication Suite (DCS). It allows mission planning of a DCS network, inflight modification of DCS network, transmission and reception of VMF messages through the ARC-210 radio, and interpretation of the VMF messages into cockpit symbology. Super Hornet integration of VMF was designed for execution of the Close Air Support (CAS) mission, to be discussed later. Therefore all VMF messages are CAS related and are manually sent and received via the CAS page. Mission computer logic converts CAS mission data (a shown in the cockpit) into standardized VMF messages that can be sent to other VMF users via the DCS radios. VMF messages are only sent when manually commanded. Figure 2.14 shows the Super Hornet CAS page with controls for sending VMF messages. For a complete description of VMF integration see ref [b] page 2-80.

VMF Msg #	Message Title
K01.1	Free Text
K02.33	TAR Aircrew Briefing (Close Air Support)
K02.34	Aircraft On Station (On Station Report)
K02.35	Aircraft Depart Initial Point (DPIP)

Figure 2.13; VMF messages (ref [d], page B-2)

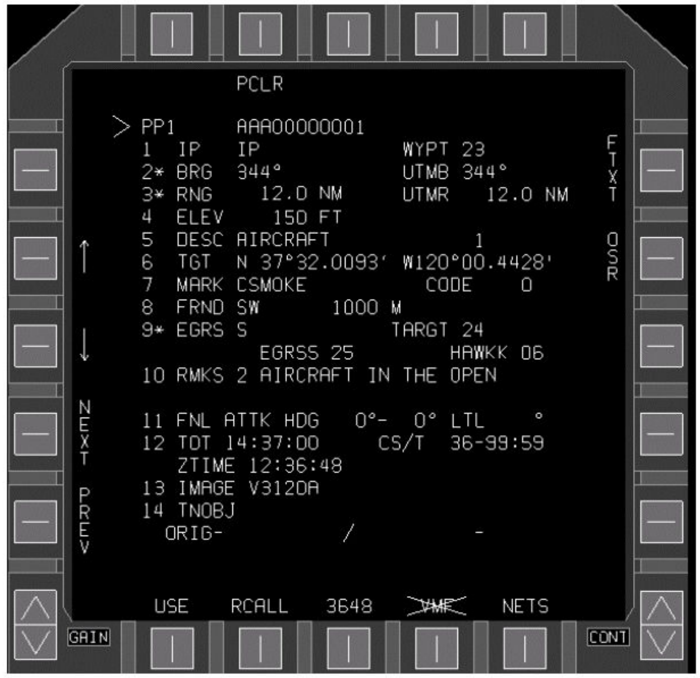


Figure 2.14; Super Hornet CAS page

2.1.4.2.4.1. **Network:** A DCS network consists of a list of users and their node information (analogous to email address). All users in a network must agree on transmission method, encryption method, and network setup (user names and node information) in order to pass VMF messages. The DCS network data is editable in the cockpit on the VMF NETS page. Figure 2.15 shows the Super Hornet VMF Nets page.

2.1.4.2.4.2. **Nodes:** DCS uses a node based network which uses direct communication between participants. DCS users must establish themselves as a node and ensure that all other users know their node information. A DCS network can handle up to 8 nodes but may start to miss messages if more than 4 nodes are in a network. DCS uses TDMA architecture to deconflict the 8 nodes.

2.1.4.2.4.3. **Message reception:** When the mission computer recognizes that a VMF message has been received and is ready to view, a cue (CAS or FTXT or OSR) is flashed in the HUD to alert the aircrew to the presence of a newly received VMF message. The cue flashes until the message is requested on the CAS page.

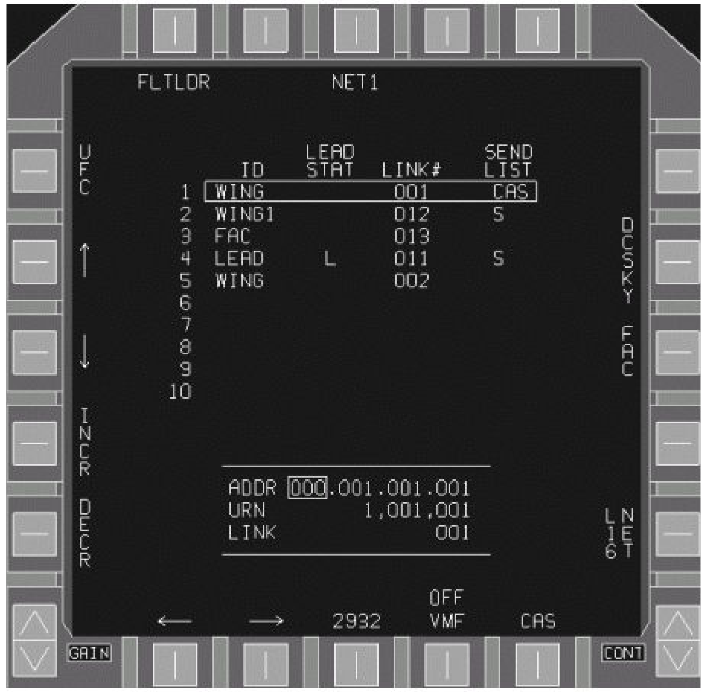


Figure 2.15; Super Hornet VMF NETS page

Figure 2.16 shows the placement of the VMF message cue. An aircraft sending VMF messages will request a digital acknowledgement of message receipt from the receiver aircraft known as a link acknowledgement or “link ack”. This link ack is the cue to both aircraft that the message is complete and both aircraft begin working on the next message. If a sender aircraft receives no link ack it will attempt to resend the message.

2.1.4.2.5. **Strengths of VMF as a tactical datalink:**

2.1.4.2.5.1. **Compatibility with ground troops:** VMF ground stations are under test that would allow ground troops to carry VMF messaging capability with them. The VMF system allows direct contact between air power and ground troops.

2.1.4.2.5.2. **Small list of customers:** Due to the relatively low numbers of tactical aircraft using VMF, the F/A-18 program has been able to work closely with the VMF ground station contractors to shape VMF ground station requirements and VMF message standards. The small VMF world is highly adaptable and can be influenced by the Hornet community.

Figure 2.16; Placement of the VMF message cue

2.1.4.2.6. **Limitations of VMF as a tactical datalink:**

2.1.4.2.6.1. **Use of aircraft radios to transmit/receive:** As integrated into the Super Hornet, all VMF messages are transmitted and received via the ARC-210 radio. This requires that one radio be used primarily for VMF messages and very sparingly for voice. The ARC-210 radio provides an audible “click” when VMF messages traffic is moving to provide aircrew with clear indication of VMF operation. Use of VMF requires aircrew to time-share one of the two aircraft radios during message exchange.

2.1.4.2.6.2. **ARC-210 encryption:** VMF messages are not inherently encrypted but contain critical information about target location, friendly locations, and friendly operations. The ARC-210 radio can be commanded to perform encryption of outgoing VMF messages and decryption of incoming VMF messages. However the encryption/decryption process significantly slows down VMF message transmission times.

2.1.4.2.6.3. **Limited range:** The poor integration of VMF signals in the F/A-18 (poor antenna properties for this waveform) limits the usable range of this system. VMF users must be relatively close to ensure reliable reception of each other's messages. The limited range of the VMF system requires that CAS aircraft hold closer than tactically desired to the ground controller during VMF message exchange.

2.1.4.2.6.4. **Very limited interoperability:** While VMF is in use on several tactical aircraft, the DCS integration of the VMF message (as implemented in the Super Hornet) is not compatible with any other aircraft VMF system. VMF interoperability is very limited with platforms outside the Hornet world. While several ground stations are in work to provide operation VMF message exchange capability, there are no ground systems in operational use today using this capability. VMF is only usable between Hornets.

2.1.5. **Cockpit Video Recording System (CVRS):** The cockpit video record system in the F/A18E/F consists of two 8mm tape recorders that are driven by a record control panel in the cockpits. Aircrew can turn the record system on/off and select which of the displays should be routed to the 2 recorders through the record panel.

2.1.5.1. **Record media**: The removable media to which cockpit video is recorded consists of two 8mm tapes with 90-minute record capacity, the ability to play back in an 8mm VCR, and no self-destruct capability.

2.1.5.2. **Record hardware:** The record hardware consists of two TEAC 8 mm tape record boxes that fit in an avionics bay behind the ejection seats. The TEAC recorders are controlled by switches on the record control panel.

2.1.5.3. **Record control panel:** The record control panel consists of three toggle switches with three positions for each switch. The first toggle switch controls overall record status and is labeled OFF-MAN-AUTO. The other two toggle switches allow aircrew to choose which display should be recorded. Figure 2.17 shows a typical record control panel. Recording is commanded by selecting the OFF-MAN-AUTO switch to the MAN or AUTO positions.

2.1.5.4. **Record indications:** Record status is indicated by the RCDR ON light on the warning and caution panel just to the right of the UFCD. The RCDR light illuminates when power is applied to the CVRS system. The RCDR ON light only indicates that power is applied to the record system and is not an actual indication that recording is in progress. The RCDR ON light will be illuminated when the record switch is on regardless of tape run to the end, CVRS recorder problem, or no tape installed.

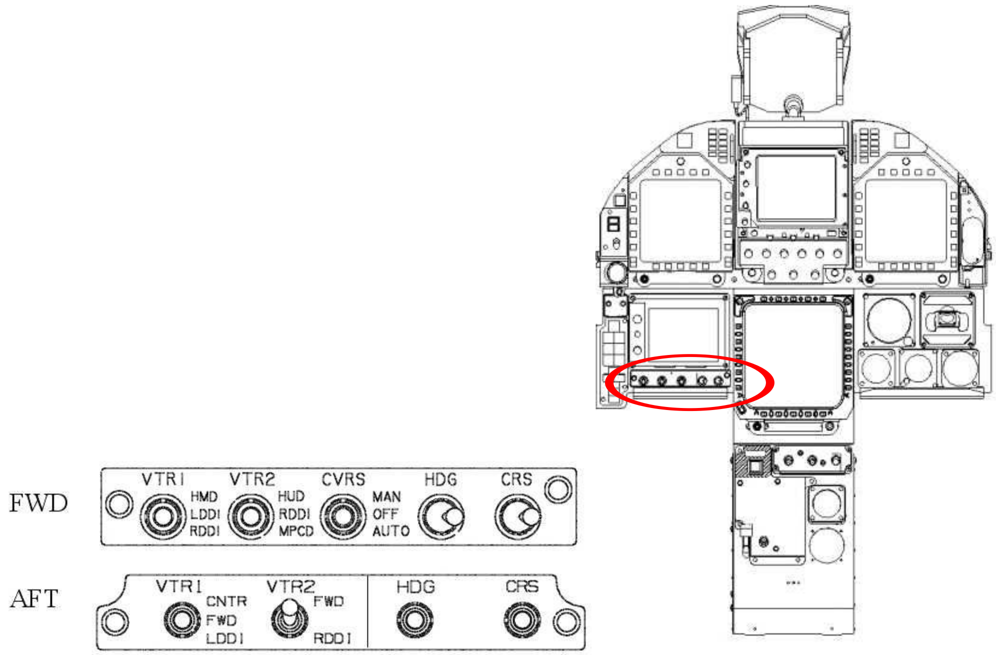
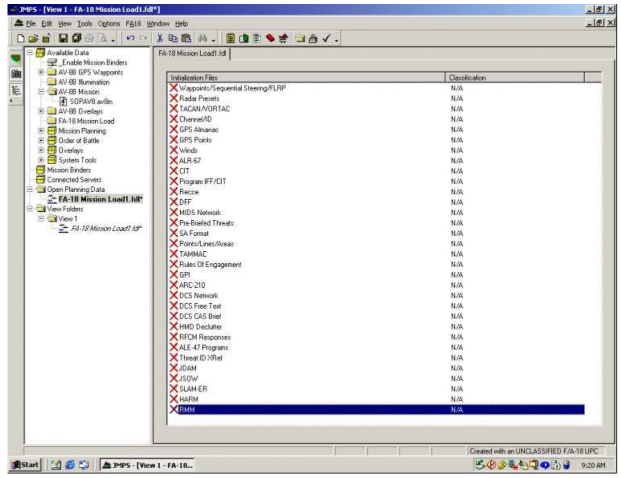


Figure 2.17; Record control panel

2.1.5.5. **Mission limitations:** The cockpit video record system should allow aircrew to quickly determine the health and record status of the CVRS system, however the existing CVRS system provides no indication of record time remaining, end of tape reached, no confirmation that recording is actually underway, and provides very little information about its health and record status.

2.1.6.**JMPS/Advanced Memory Unit (AMU) loader:** The JMPS/AMU loader system allows aircrew to preplan mission data at a laptop computer then use removable media to move the preplanned mission data to the aircraft. JMPS is a computer-based mission planning workstation that allows aircrew to plan waypoints, aircraft mode settings, weapons data, and MIDS information. The AMU card is a removable PCMCIA card to which JMPS can write. The AMU loader is a PCMCIA receptacle in the aircraft that moves JMPS files to the appropriate aircraft avionics system (MCs, MIDS terminal). Prior to start the aircrew place the AMU into the aircraft AMU loader and upon power application the AMU data is downloaded to the appropriate avionics system via the mux bus. Upon completion of the mission the AMU contains weapons release data, mission completion data, and maintenance data that assist aircrew with mission debriefing and maintenance status of the aircraft. Figure 2.18 shows the JMPS mission planning system.



Laptop based hardware   Windows based software

Figure 2.18; JMPS (Joint Mission Planning System)

2.1.7. **Built in Test (BIT) Status**: The configurable MFDs in the F/A-18 provide a BIT page that lists status of onboard equipment. Common BIT status indications are NOT RDY, IN TEST, GO, DEGD, and NO GO. These BIT indications provide information about the health and operational readiness of the affected system. When a system changes BIT indications (for example from GO to DEGD) a BIT advisory is set to alert aircrew that some onboard system has changed BIT status. The BIT advisory cues the aircrew to select the BIT page for viewing of the BIT status of relevant systems, at which time the BIT advisory is cleared and reset.

2.1.8. **Control of classified material:** Many aspects of F/A-18 missions have classification considerations to include point of origin, route of flight, targets against which weapons are employed, parameters at which weapons are employed, and tactics that aircrew use to employ the weapon system. The classification of many segments of the mission results in the need to closely control storage of classified data to non-volatile storage. When any classified data is stored to any of the usual storage areas, the mission computers flag that storage area as classified and provide cockpit cues that onboard systems are classified. In addition the mission computers provide the ability to erase onboard classified material inflight or after landing, allowing aircrew to clear any unwanted classified material. This ability to declassify the aircraft is particularly important if performing an emergency divert to a country that is not a very close ally (such as the EP-3 that was forced to land on a Chinese island).

2.1.8.1. **CDATA:** When classified material is detected in onboard storage, a CDATA advisory is set on the DDIs and Maintenance Status Panel (MSP) codes are set to indicate which aircraft components are classified. The CDATA advisory provides aircrew with a top-level cue that classified data is present in the aircraft.

2.1.8.2. **Classified erase:** When classified data has been detected in onboard memory, the aircraft presents ERASE pushbuttons that provide a means for aircrew to erase the classified files. Upon completion of the erase the aircraft systems are unclassified.

2.2. **Single/dual seat:** The F/A-18E/F is built in both single seat and dual seat configurations. Integration of the aft seat adds 4 more aft seat MFDs as well as an aft seat JHMCS. Single seat aircraft are used almost exclusively as carrier based operational strike aircraft. Two seat Hornets are used both as carrier based operational strike aircraft and as trainer aircraft. Operational dual seat aircraft incorporate a Weapons Systems Officer (WSO) in the aft seat who is dedicated to the use of onboard sensors to complete the air to air and air to ground missions. Incorporation of two aircrew eases cockpit workloads associated with complex air to air and air to ground missions, but the prevalence of single seat aircraft requires that aircraft designs focus on well integrated systems that provide the aircrew with minimal additional workload during critical phases of flight.

3. **Air to ground missions of the Super Hornet:** The Super Hornet executes a wide variety of air to ground missions.

3.1. **Kill chain:** All air to ground (A/G) missions of the F/A-18 are variations on the same sequence of events known as the kill chain. The kill chain describes the sequence of events used to prosecute ground targets. The kill chain has six steps:

- Find: Determine the presence of the target and derive very rough target location.
- Fix: Determine the precise location of the target.
- Target: Hand the target off to local firepower with location and orders to engage
- Track: Update target position with high quality location suitable for weapons engagement
- Engage: Apply firepower to the target (the killing part of the kill chain)
- Assess: Determine if the firepower had the desired effect and call for follow on attack if necessary.

As a tactical aircraft with relatively short range sensors, the F/A-18 generally relies on external command and control assets to perform the first few steps of the kill chain. However, some missions allow the Super Hornet greater mission flexibility to perform earlier parts of the kill chain.

3.2. **Strike mission:** We will define a “strike” mission as a mission where aircrew receive their assigned target prior to their flight briefing and takeoff. The Find, Fix, Target, and Track links of the chain are completed by external assets. Due to the highly dynamic nature of modern battlefields, the strike mission is becoming less prominent than during previous conflicts. Key properties of a Strike mission:

- The kill chain is complete up to Track with time to provide target information and imagery prior to the flight briefing.
- The aircrew are able to study maps and imagery of the target area during their flight briefing.
- Aircrew have high quality target coordinates for their weapons and sensors loaded in their systems at takeoff.

Aircrew can concentrate on the Engage and Assess portions of a strike mission.

3.3. **Time Sensitive Targeting (TST) mission:** We will define a “time sensitive strike” as a mission where the aircrew receive their tasking after their flight briefing. The Find, Fix, Target, and Track links are completed by external assets but cannot be communicated to the aircrew prior to the flight briefing. Key points of a time sensitive strike:

- Aircrew do not have precise target coordinates or imagery during their flight briefing and are unable to familiarize themselves with the target during the briefing.
- The handoff of targeting data is performed in flight from a command and control platform, either airborne or ground based command and control center.
- Handoff of target data would most likely include target coordinates and target description

Aircrew listen to a verbal description of the target area over the radio and must use the verbal description to find the target upon arrival. If they are able to find the target they complete the Engage and Assess portions.

3.4. **Close Air Support (CAS) mission**: We will define a CAS mission as a mission where aircrew receive their tasking in-flight from a ground controller who is in direct contact with enemy ground forces. The ground forces provide most steps of the kill chain and then hand off the target to the CAS aircraft via a standardized CAS briefing that includes target coordinates and verbal description. Key components of a CAS mission:

- Aircrew do not have precise target coordinates or imagery during their flight briefing and are unable to familiarize themselves with the target during the briefing.
- The handoff of targeting data is performed in flight via voice communications with ground troops in close contact with enemy forces
- Target handoff would include target coordinates, description, run in heading, and voice "talk-on".

Voice talk-on consists of the ground controllers using visually significant ground features to guide the aircrew eyes and targeting pods to the desired target. The talk-on might consist of large visual features (river, highways, towns) and would then get more specific with comments such as "on the west bank of the northern-most bridge" or "one block southeast of the road intersection". The talk-on is necessary due to the close proximity of friendly and hostile forces. In order to employ weapons in a CAS scenario the ground controller and aircrew must be absolutely certain of the target in order to prevent aircraft dropping weapons on friendly troops (friendly fire).

One major challenge of the visual talk on from a ground controller is the difference in perspective from the ground troops point of view and the CAS aircraft point of view. Those features which are visually significant to the ground troops (hiding behind building in the target area) may be drastically different from those that are visually significant to the aircrew (flying above the target area). Finding a common visual reference point is the cornerstone of visual talk on.

3.5. **Forward Air Controller (Airborne) (FAC(A)) Mission:** We will define a FAC(A) mission as an airborne controller for aircraft executing CAS. A FAC(A) will have limited ordnance but will be able to assign CAS aircraft against targets that the FAC(A) can find but cannot engage. The FAC(A) aircraft must perform the first four steps of the kill chain autonomously and then provide target handoff to the CAS aircraft as described in 2.4. Key components of the FAC(A) mission:

- FAC(A) aircrew do not have precise target coordinates or imagery during their flight briefing and are unable to familiarize themselves with the target during the briefing.
- FAC(A) aircrew must find and maintain a list of multiple targets for distribution to CAS aircraft
- The handoff of targeting data is performed in flight via voice communications between aircraft
- Target handoff would include target coordinates, description, run in heading, and voice “talk-on”.

Voice talk on would be the same as listed for CAS but the FAC(A) is now performing the talk on. The FAC(A) has the advantage of looking at the target area from a perspective similar to that of the CAS aircraft so those feature that are visually significant to the FAC(A) should also be visually significant to the CAS aircraft.

3.6. **Weapons:** The F/A-18E/F can use several general types of weapons to perform the “Engage” step of the kill chain.

3.6.1. **General Purpose (GP) bombs:** GP weapons or “dumb bombs” are unguided weapons that are visually aimed at the target prior to release. No midcourse guidance is available and the accuracy of the weapon is very dependent upon the release parameters. Accurate delivery of GP weapons from aircraft requires visual or targeting pod contact with the target must be maintained until weapon release. Super Hornets delivery GP weapons autonomously using an onboard visual or targeting pod designation.

3.6.2. **Laser guided weapons:** Laser guided weapons are guided weapons that are guided to their target by laser energy. Laser energy can be provided by an onboard targeting pod, targeting pods on other airborne assets, or by a ground based laser marker. Laser guided weapons can be gravity or forward firing (Laser Guided Bomb (LGB) or laser guided missile). Accurate delivery of laser-guided weapons from aircraft requires that the weapon is released with general knowledge of target location and that laser energy is provided on the target throughout weapon time of fall (until weapon impact). Super Hornets can delivery laser guided weapons autonomously (target location and laser energy from onboard targeting pod) or cooperatively (target location from onboard systems, laser energy provided by offboard targeting pod).

3.6.3. **GPS guided weapons:** GPS guided weapons are munitions that use a GPS signal to navigate to pre-determined target coordinates. Examples are the Guided Bomb Unit (GBU)-31/32/38 JDAM family and the Air to Ground Missile (AGM)-154 JSOW family. Target coordinates can be loaded during mission planning or can be sent to the aircraft in-flight via tactical datalink. Accurate delivery of GPS weapons requires very precise target coordinates. Super Hornets can deliver JDAM using preplanned target coordinates, can manually enter new target coordinates in flight, or can employ JDAM against targets that are designated by the targeting pod.

3.7. **Bomb Hit Analysis (BHA):** For all weapon impacts, a critical part of weapon delivery is the collection of cockpit video that includes all aspects of the weapon event. All BHA information will be roughly assessed inflight and reviewed in detail during the post mission debriefing.

3.7.1. **Weapons release:** At weapon release the aircrew must record their release parameters, which will be compared against planned parameters to ensure safe and effective technique was used. Additionally aircrew must record the target information at release to include target coordinates, source of the coordinates, and spatial relationship of the aircraft to the target.

3.7.2. **Weapon impact:** Aircraft equipped with a targeting pod will point the targeting pod at the target throughout the time of fall of the weapon. At weapon impact the aircrew assess the actual point of impact and weapon fuzing. Aircrew must ensure that the actual point of impact is recorded for comparison against the intended point of impact. Small differences in actual vs. intended impact can alter the effect of the weapon. The aircrew can easily assess weapon fuzing by watching for an initial explosion.

3.7.3. **Post impact:** Some weapon impacts will exhibit secondary explosions that will provide information about the type of target and provide valuable intelligence. Aircrew will make a rough assessment of the secondary effect of the explosion. Additionally some targets will exhibit obvious damage that can be reported after review is complete.

3.8. **Debriefing:** F/A-18 aircrew conduct extensive debriefings following training flights to evaluate the aircraft and aircrew performance and derive lessons learned and corrective actions for future flights. For best efficiency, the post flight debriefing must contain appropriate data to piece together the major events of the mission and determine areas where execution needs to improve.

3.8.1. **Tactical decisions:** Aircrew review the overall flow of the flight as well as targeting command and targeting decisions to ensure that intended command on control plan was executed.

3.8.2. **BHA:** Aircrew will review their weapons release parameters as well as review the target location to ensure proper technique was used. In addition aircrew will review cockpit video and targeting pod video to watch for other items of interest from the aircraft side (mode selected, pod indications) or from the target side (other targets in the area, overall effect of the weapon on the desired target)

3.8.3. **Lessons learned**: Aircrew derive lessons learned from the command and control plan, the tactical decisions made in flight, and the weapons release parameters. The accuracy and utility of these lessons learned depends on the quality and accuracy of the debriefing tools available, of which the most important is cockpit video.

Part 3: Changes to enable tactical imagery

4. **Operational intent and requirements:** The operational intent and requirements provide the background for design of system changes.

4.1. **Operational intent:** The operational intent of integration of tactical imagery was to provide digital machine-to-machine targeting (DMMT) and real time mission assessment (RTMA).

4.1.1. **DMMT:** The intent of DMMT was the use of datalink instead of voice to exchange digital targeting data. DMMT includes digital target coordinates (a separate discussion) and a digital image of the target. This digital information is particularly useful when engaging targets in an unfamiliar target area. Key concepts of DMMT are:

- Digital datalinks are encrypted and provide better security
- Digital datalinks provide highly precise and dependable exchange of data
- A picture is worth a thousand words

DMMT targeting has limited use for the Strike mission but has great value for the TST mission, the CAS mission, and the FAC(A) mission.

4.1.1.1. **TST Mission:** With tactical imagery capability the command and control platform can send an image of the new target area along with the new target coordinates. While enroute to the new target area aircrew can familiarize themselves with features of the target area and their relationship to the newly assigned target. Imagery can move a time sensitive strike very close to a strike mission, where aircrew can familiarize themselves with imagery of the target prior to arrival at the target. While in the target area the aircrew can focus on the “Engage” portion of the kill chain.

4.1.1.2. **CAS mission:** While many elements of the CAS mission remain unchanged, with DMMT capability between ground troops and aircraft the handoff of targets can become much simpler. Digital targeting coordinates put the aircrew eyes and targeting pods in the targeting area and the image shows the relationship of the target to other features in the target area. The key part of the visual talk-on is establishing a common visual reference point from which all targeting corrections will take place. Tactical imagery is capable of passing a target area with visually significant features that can then be used as common reference points, after which the rest of the visual talk on should be quick and simple. Imagery can provide quicker and easier visual talk-ons by providing both ground troops and aircrew with confidence in common visual reference points.

4.1.1.3. **FAC(A) mission:** Tactical imagery is a very powerful tool for a FAC(A), whose most important job is to put the eyes and targeting pods of other aircraft on known ground targets. Again digital target coordinates are used to put the CAS aircraft eyes and targeting pod into the targeting area and common visual references, established by the target area image, provide the foundation for quick and easy talk on. Since the FAC(A) is taking imagery from a targeting pod presumed to be similar to those on other aircraft, the imagery quality and content should be very similar (same hot/cold/black/white spots)

4.1.1.4. **Non-Traditional Intelligence/Surveillance/Reconnaissance (NTISR**): The ability to capture onboard targeting pod images and send them to ground stations allows a new NTISR mission to be executed. Aircraft can be sent to take imagery of suspected hostile areas and the imagery can be sent to ground stations or intelligence centers for imagery evaluation. Furthermore, some ground stations advertise the ability to perform computer correlation of tactical imagery with existing imagery databases to use a tactical image to derive high quality targeting coordinates. The NTISR role requires that certain image "properties" data be sent with the image in order to enable correlation

4.1.1.5. **DMMT scenario:** One example of intended use for imagery in DMMT is a CAS scenario with Super Hornets working as FAC(A) and CAS aircraft. The FAC(A) aircraft may be working with a ground FAC or independently to locate enemy forces on the ground. After locating the ground target the FAC(A) would build a CAS mission and prepare to talk the CAS aircraft onto the intended target. With these system changes the FAC(A) would be able to point the targeting pod at the target and take a still image of the target area and surrounding features. During CAS mission assignment the FAC(A) would then be able to send this image along to the CAS aircraft. The CAS aircraft would be able to view the image and determine the general layout of the target area as well as position of the intended target within the target area. During the target acquisition phase of the CAS mission the CAS aircraft would be able to compare the image against the real time video from onboard target pod, allowing direct correlation of the two scenes and more rapid acquisition of the intended target.

4.1.2. **RTMA:** RTMA refers to the tailoring of onboard systems to perform the Assess step of the kill chain in flight, in particular to evaluate mission effectiveness and determine if further attacks against that target are required. Execution of the assess portion include evaluation of weapon impact and fuzing as well as preliminary evaluation of the effects of the weapon on the intended target.

4.1.2.1. **Challenges to RTMA:** Historically the Super Hornet systems have not been well suited for in cockpit mission assessment. The only RTMA available was watching the displays live to observe as many parameters as possible. However a target area is very busy places for strike aircraft as the tasks of target acquisition, weapons system setup, threat avoidance, aircraft placement for weapons release, communications with the friendly troops, and visual contact with other aircraft must all be performed. That left little time for gleaning information from displays in the short period of time when the specific events were happening. Aircrew, particularly single seat aircrew, were not in a good position to stare at the targeting pod video real time to evaluate the finer points of the delivery or the impact. With the ability to capture still images of bomb impacts the aircrew would be able to concentrate on execution in the target area and use the review the saved images after egressing the target area when workload would be lower.

4.1.2.2. **FAC(A) mission:** While performing a FAC(A) mission an imagery capable aircraft could take images of the CAS aircraft weapon impacts, thereby assist other aircraft with their RTMA and completing that step of the kill chain for them.

4.1.2.3. **RTMA scenario:** One example of intended use of the RTMA capability involves a single aircraft performing a strike mission against a ground target. The strike aircraft would release weapons against the target and continue to point the targeting pod at the target area to get BHA video of the weapons impact. After egressing the target area and when clear of threats the strike aircraft would report mission results to the command and control agency that assigned the mission. With the integration of tactical imagery a Super Hornet would be able to capture images before and after weapon impact. After egressing the target area the Super Hornet aircrew would be able to view the before and after images and make an initial assessment of mission success. Additionally the Super Hornet would be able to send the “before and after” images to the command and control agency for analysis by intelligence personnel. This provides real-time feedback to the aircrew about mission success, provides the command and control center with near-real-time feedback about mission success, and allows the command and control center to rapidly update their target list and most efficiently task and re-task airborne strike assets.

4.2. **System requirements to enable tactical imagery:** The following general requirements were defined in order to enable tactical imagery:

4.2.1. **Load images during preflight planning:** Allow aircrew to use JMPS during pre-flight mission planning to pick images to be loaded, annotate those images if desired, and load them to a memory module that moved between JMPS and the aircraft. Specific elements of the requirement included the ability to:

- Load 20 images during mission planning
- Determine which available images contain a desired target area
- Plan images taken from map database resident on JMPS
- Plan up to 5 annotations on the image

4.2.2. **Receive image (L-16/VMF):** Allow aircrew to receive inflight images from offboard sources via Link-16 and VMF datalink. Specific elements of the requirement included the ability to:

- Set up the systems to enable imagery
- Determine from cockpit cues that an image had arrived
- Accept or reject the image as desired
- Determine the image source (who sent the image)

4.2.3. **Capture onboard images:** Allow aircrew to capture still images of targeting pod video inflight and save the image within the aircraft for later viewing. Specific requirements included the ability to:

- Enable or disable the capture system
- Clearly tell when capture was available
- Rapidly “point and shoot” capture single images with the targeting pod
- Capture multiple images from the targeting pod around the time of weapon impact
- Calculate mensuration Data (META) for each image to include latitude/ longitude/ elevation of the center and four corners of the image, and sensor pointing information (this would enable image correlation for capable ground stations)

4.2.4. **Save/recall multiple images:** Allow the aircrew to save multiple images, both from onboard capture and from offboard imagery, which can be retrieved and viewed in flight. Specific requirements included ability to:

- Store 100 images
- Delete unwanted images
- Find and recall particular images from out of the list
- Determine the source of all images in the list

4.2.5. **Display images inflight:** Allow the aircrew to view images inflight. Specific requirements included the ability to:

- Quickly switch between images
- View the images with multiple compression types
- View the image using multiple compression ratios.

4.2.6. **Annotate image:** Allow the aircrew to mark points of interest in an image. Specific requirements included the ability to:

- Add 5 annotations to each image inflight
- Select the position and size of the annotations on the image.

4.2.7. **Send image (L-16/VMF):** Allow aircrew to send images to other datalink participants via Link-16 and VMF. Specific requirements included the ability to:

- Choose single recipient or group of recipients
- Monitor transmission progress

4.2.8. **Review images during postflight review:** Allow aircrew to use JMPS after the flight to review and save images that were captured or received during flight. Specific requirements included the ability to:

- Download from a memory unit
- View images to include in-flight annotations

5. **System changes to enable tactical imagery:** The changes to incorporate tactical imagery included new hardware, software changes, and datalink changes.

5.1. **General design philosophy:** The general design plan was to integrate a solid state recorder (SSR) that would replace the existing 8mm recorders and provide storage of:

- Recorded cockpit video
- Recorded targeting pod video
- Still images

The two buzzwords of SSR integration were COTS and form-fit-function. The project management made the assumption that a COTS (commercial off the shelf) product would function exactly as advertised. The project management also wanted to make SSR look and function as closely to 8mm tapes as possible to minimize integration costs, therefore insisted on form-fit-function mindset when possible.

In order to exchange imagery between aircraft and between aircraft and ground stations, software changes were designed to allow imagery to be moved over two parallel datalink systems, Link-16 and VMF. This would allow best flexibility for image exchange with the maximum number of platforms. Additionally datalink network and message standards changes were required to use Link-16 and VMF to move imagery. Most of the aircraft architecture, including cockpit displays and the mux bus that connected avionics components, was already capable of displaying and transferring imagery.

Changes were required in several areas (VMF, Link-16, SSR, mission computer software) in order to provide tactical imagery capability. In order to consolidate these changes and ensure proper system integration, these changes were combined into one set of changes and named the H2E+ SCS. The SCS philosophy (consolidation of many small updates into one larger update) was intended to provide the best product to the operational users by ensuring minimum impact and maximum increase in operational capability. Additionally the SCS philosophy provided best evaluation of interaction between the modified subsystems.

5.1.1. **Video storage:** Cockpit video would be recorded to the SSR and stored on a removable memory module (RMM). The RMM could be used to transport video between aircraft and JMPS machine for video playback.

5.1.2. **Image storage:** Received or captured images would be stored as image files on the RMM. Maintaining the image files on the RMM would allow aircrew to move images between JMPS and the aircraft to allow preflight planning and post flight image review.

5.1.3. **Image capture:** Image capture would be performed by taking still video frames from the recorded targeting pod video. The recorded targeting pod video would be time stamped and the aircrew would be given a pushbutton that would allow them to command an image capture. The time of the image capture command would be noted by the mission computer and that time would be used to search the targeting pod video in the SSR for the video frame that corresponded to the capture command time. That video frame would be extracted from the video, turned into an image file, and saved to the RMM.

5.1.4. **Imagery over datalinks:** Image files were too big to be moved as a whole over either tactical datalink. Therefore, prior to sending the images would be compressed and then divided into small image “packets” that would be small enough to fit into the Link-16 and VMF time slots. Image compression would be available via two different compression methods, EagleEye and JPEG. This would allow maximum flexibility for working with many different platforms. The receiver could then receive a series of image packets, re-assemble the image packets into an image, and view the image on cockpit displays. For VMF a new image message was required that would allow a multiple image packets to be sent between participants. For Link-16 the J16.0 imagery message and the Imagery NPG (NPG 11) already existed but were not in use in the F/A-18.

5.2. **System changes:** A simplified impression of the Super Hornet avionics system after changes were made to enable tactical imagery is shown graphically in Figure 5.1. Important changes to note are:

- Replacement of the CVRS with a SSR
- Flow of BIT/status information from SSR to mux bus (not present with CVRS)
- Flow of video record to the SSR
- Flow of targeting pod video between the targeting pod and the SSR
- Flow of imagery between MCs, displays, datalinks, and SSR

5.2.1. **Solid State Recorder (SSR):** The F/A-18 AWL was directed to integrate the TEAC Aerospace MDR-80 SSR with 25 Gigabyte RMMs. The MDR-80 was designed to replace the TEAC 8mm recorders that are the recording platform for the existing CVRS system. The MDR-80 size and shape are nearly identical to the profile of the 8mm recorders. Figure 5.2 shows the SSR and RMM chosen for Super Hornet integration. The MDR-80 included 4 video connections, a power connection, and a control connection designed to allow mission computer control of the SSR via the mux bus.

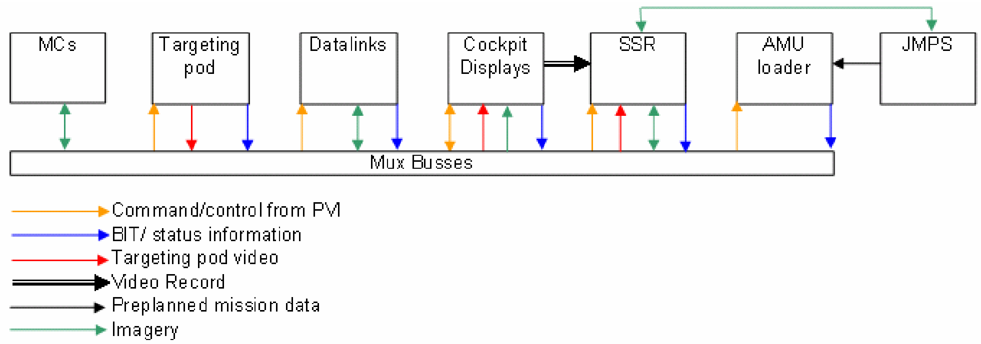


Figure 5.1; Simplified avionics schematic showing changes to support imagery

Figure 5.2; TEAC Aerospace MDR-80 SSR and 25G RMM

5.2.1.1. **CVRS replacement:** The MDR-80 was intended to be a form/fit/function replacement for the dual TEAC 8mm recorders. The existing CVRS interface was used to turn on recording and select the two displays to be recorded. In order to maintain the existing interface, only two of the four video connections could be used. The very poor but pre-existing video record indication (RCDR ON light) was also used to show that recording had been commanded. Thus the requirement to make the SSR a form/fit/function replacement was followed to a fault.

5.2.1.2. **Recording targeting pod video**: To enable image capture from the targeting pod, the SSR was required to record targeting pod video from which still video frames could be extracted. The third video connection was used to input targeting pod video. Along with each frame of video the SSR recorded the sensor pointing angles and latitude/longitude of the center and four corners of the image. The requirement was to record "raw" targeting pod video, which was straight from the targeting pod and contained no mission computer symbology. This was intended to minimize the clutter for viewing the image and to assist in image correlation on ground stations.

5.2.1.3. **Video connections:** Two of the SSR's four video connections were used as inputs for cockpit video as commanded by the CVRS control panel. The third was used to record targeting pod video to enable image capture. The fourth video connection was left dormant as a growth feature for future development. Figure 5.3 graphically shows SSR connections with the aircraft, including the unused Video out connection.

5.2.1.4. **RMM properties**: The TEAC RMM was a bundle of PCMCIA cards that had been hardened for airborne use. It was essentially a ruggedized external hard drive that advertised a 25 Gigabyte capacity. It could be connected via fire-wire to a computer where it inventoried as removable media. It could be connected to a JMPS machine to allow preflight planning of images, postflight review of images, and postflight video review. The RMM internal file structure was set up with "video" directories to which video was recorded, an "image" directory to which images were saved, and a "log" directory where command/ control and record status data was archived.

5.2.2. **VMF message standards:** No imagery message was defined in the VMF message standards (see Figure 2.13). A new message was required to handle the large volume of data in an imagery message. Boeing applied to the Joint Services VMF subgroup and received approval for a new K04.17 imagery message.

5.2.3. **Link-16 network**: In reviewing current Link-16 network architecture, a design decision was required to decide which NPG Hornets should use to exchange

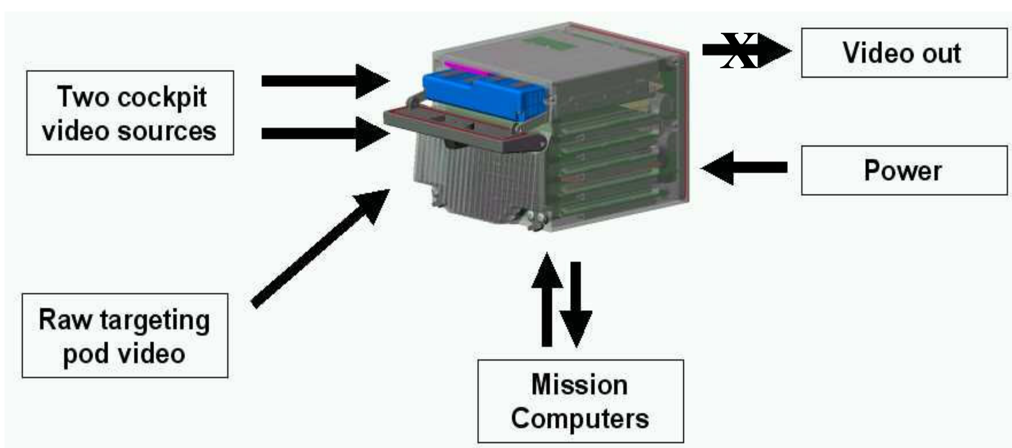


Figure 5.3; Physical connections of SSR to aircraft

imagery. The prime candidates were NPG 19, which was already in use in Hornets and easy to implement, or adding the use of NPG 11, which is reserved for imagery but had not previously been used by Hornets. Analysis of the two designs showed that the use of NPG 11 would incur more short-term costs but promised greater flexibility and growth potential.

5.2.3.1. **NPG 11:** Network changes were required to give F/A-18s the ability to use NPG 11. This included changing time slot assignments so that F/A-18s now had both transmit and receive time slots on NPG 11.

5.2.3.2. **Network design:** The F/A-18 AWL applied to NCTSI for two stages of network modifications. The first was the building of a new image capable test network that could be used to confirm the correct operation of the imagery systems. The second stage was modification of all operational networks to provide NPG 11 transmit and receive time slots for F/A-18s. The first stage was completed prior to the arrival of the first build of H2E+ and the test network was used throughout the test program, with a few notable exceptions. The second stage of network modification was ongoing at the time of writing and had not yet been applied to all networks. At the time of writing some major operating and training areas had imagery capable networks but several stragglers were still getting caught up.

5.2.4. **JMPS:** JMPS changes were required to support several new imagery functions to include preflight planning and postflight review of the RMM, preflight selection of imagery capable network, preflight selection of imagery recipients, and post flight video review.

5.2.4.1. **Imagery preflight:** A new JMPS interface was added to allowed preflight selection, annotation, and loading of tactical imagery to the RMM. When the RMM planning UPC was opened JMPS provided the ability to browse for pre-existing images, save JMPS chart databases as images, and check which images were relevant to the target by checking image coverage against entered target coordinates. Figure 5.4 shows an example of the image planning interface. During preflight planning the aircrew could select images from the default imagery folder, browse to other folders to find images, check target coverage, see thumbnails of selected images, see image detail, and plan annotations. The annotation planning included the ability to draw basic geometric shapes, text boxes, and arrows on the image to enable aircrew to mark tactically significant features of the image, for example known location of friendly or hostile forces. Figure 5.5 shows an example of an image

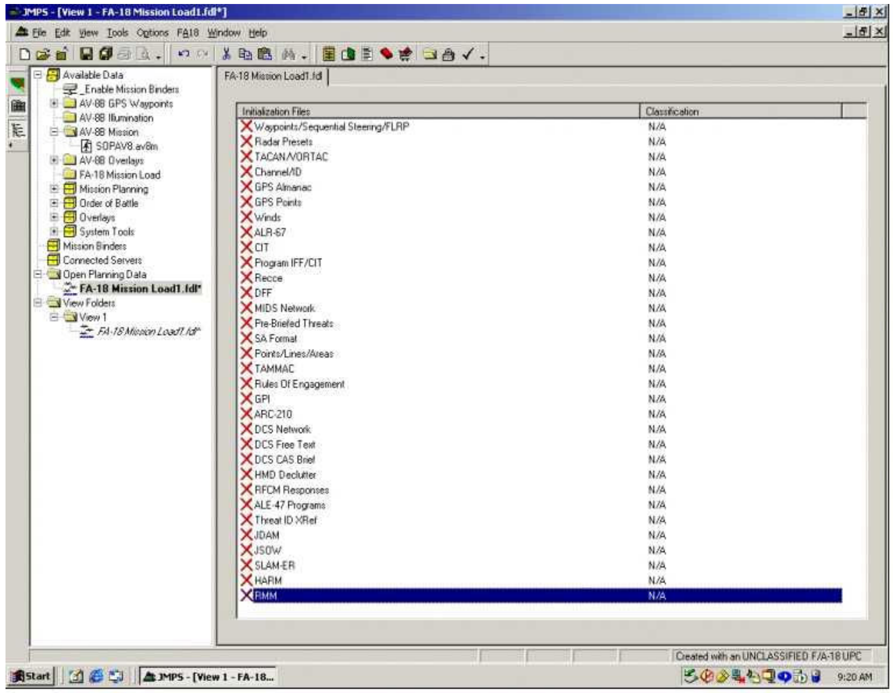


Figure 5.4; JMPS image planning

Figure 5.5; JMPS preflight image annotation

annotation interface. The types of annotations are shown along the left side of the image. Up to 20 images could be grouped into one mission and the missions could be saved as part of a F/A-18 mission for loading to the RMM.

5.2.4.2. **Post flight imagery review:** A new JMPS interface was added to support post flight review of images from the RMM. After returning from a mission with newly captured or received images, the new interface allowed aircrew to quickly open up the images from the RMM for viewing and save them to the JMPS computer. The interface was very similar to the preflight planning interface to include thumbnails of the images, image detail shown below, and ability to annotate if desired. In addition the images could be save to the computer for use on later missions.

5.2.4.3. **Selection of MIDS network:** When image capable MIDS networks were built by NCTSI they included NPG 11 timeslots in their network design documentation. These networks could then be put on a JMPS machine and loaded into one of the three networks that can be loaded to the AMU during mission planning. MIDS networks available for download in JMPS are labeled by their 9 digit alpha-numeric network ID, for example ADJE0006A.

5.2.4.4. **Preflight planning of image recipients:** Mission computer changes provided a new display format that showed which Link-16 tracks were potential image recipients. During mission planning JMPS allowed aircrew to identify up to 8 Link-16 users (identified by Link-16 Track Number) that would be put into the image recipient list. This list of recipients would load to the AMU and then on to the mission computer.

5.2.5. **F/A-18 mission computer software changes to support imagery:** Mission computer changes to implement imagery included creation of new display pages, modification of existing display pages, additional logic to enable and perform onboard image capture, and additional logic to enable send and receive of images over datalink.

5.2.5.1. **New displays:** The following new displays were implemented:

5.2.5.1.1. **Image Browse:** The Image Browse page was selected by pushing a new IMAGE pushbutton on the top-level display menu. The Image Browse page was designed to show aircrew the list of images that resided in the aircraft as well as show basic SSR status. Images in this list could be selected for viewing, annotation, or sending offboard via datalink. Additionally the Image Browse page showed the amount of record time available on the RMM as “SSR REMAINING XX:XX” at the bottom of the page. Finally the Image Browse page included a pushbutton labeled CAPTURE that enable or disabled the image capture. Figure 5.6 shows a representative Image Browse page with two preplanned images present on the RMM.

5.2.5.1.1.1. **Imagery list:** The list of images shown on the Image Browse page was derived from the image directory on the RMM, the location where all preplanned, captured, and received images were stored. The list consisted of 100 files into which images could be saved. Each line of the list was given a file number 1-100. Updates to the Image directory on the RMM triggered updates to the list of images in the Image Browse page. Images were presented in pages of 10 and aircrew were provided a means to scroll down the list to the image limit of 100. Scrolling could be performed one image at a time or by pages of 10.

5.2.5.1.1.2. **Information for all images:** For all images the Image Browse page showed the image name and image source. Possible labels to indicate image sources were:

- PRE: image had been loaded to the RMM during mission planning
- OWN: Image had been captured from own targeting pod

Figure 5.6; Image Browse page

- L16 VCS or VMF VCS: image had been received in-flight from the named datalink participant.

Possible images names were:

- For PRE images, any alpha-numeric that was entered in JMPS
- For OWN images, F18-ZZZZZZ-CCC where ZZZZZZ was the Hours, Minutes, and Seconds in Zulu time and CCC was a sequential counter for images captured during that flight. The counter started at 1 at the beginning of the mission and counted up with every image. The counter number was specific to that image throughout any changes made to the image or to the Image Browse list.
- For images received via datalink, as labeled by the sender. Any alphanumeric if coming from a platform other than Super Hornet. Images received from other F/A-18s would be labeled in the F18-ZZZZZZ-CCC format.

5.2.5.1.1.3. **Selected image:** The Image Browse page incorporated a select box that graphically showed which image was currently selected for viewing, sending, and presentation of more detailed information. The select box could be stepped by use of pushbuttons labeled with up and down arrows. For the currently selected image an additional set of image data was shown as highlighted in Figure 5.6. The selected image was "under the trigger" for viewing or sending when the Image View or Image T/R pages were selected.

5.2.5.1.1.4. **Imagery deletion:** Images could be deleted from the Image Browse page by selecting the image to be deleted and selecting the DELETE pushbutton. ACPT/REJ confirmation was required to delete an image. The image list was top justified and deletion of an image resulted in all images below moving up one space to fill the gaps. This resulted in a change of file numbers for all images below the one deleted as they moved up one file number to fill the gap. Deletion could only be performed one at a time and no "group delete" or "delete all" functions were provided.

5.2.5.1.2. **Image View page:** The Image View page was reached from the Image Browse page by selecting the VIEW pushbutton. The new Image

View page was designed to allow viewing and modification of the images that were listed in the Image Browse page. This retrieved the selected image from the RMM and loaded the image into the MC, which then sent image data to the cockpit displays to draw the image. Annotations that were received with the image would also be displayed. If META data were present with the image, a North up arrow would be drawn on the image to graphically show the orientation of visual features. Aircrew were provided a means to delete images from the View page with a mechanization identical to that used on the Image Browse page. Figure 5.7 shows a typical Image View page.

5.2.5.1.2.1. **Step between images:** The Image View page included the ability to step between adjacent images without returning to the Browse page. Two pushbuttons of the Image View page were labeled with up and down arrows to allow selection of next and previous image. During the design phase it was decided that the up and down arrows should follow the convention of the up and down arrows on the Image Browse page, wherein an “up” selection moved the selection box closer to the top of the list (to a lower file number) and “down” moved the step box lower in the list (to a higher File number).

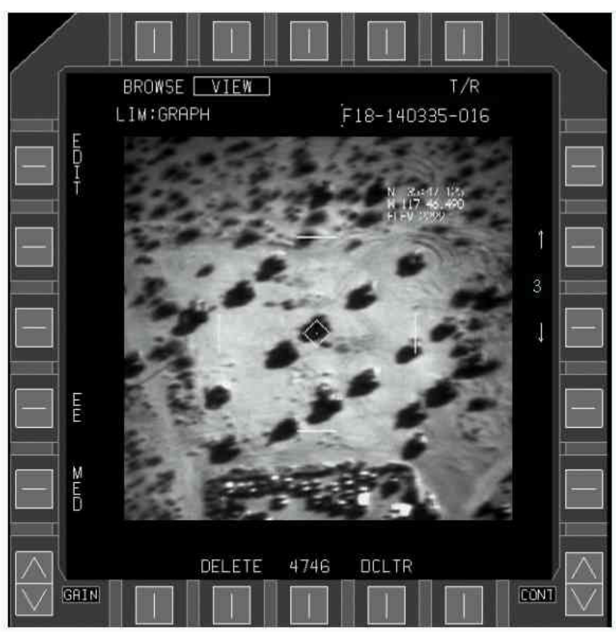


Figure 5.7; Image View page

5.2.5.1.2.2. **Annotation:** Aircrew were provided a means to annotate areas of interest on an image during flight. The Image View format included an EDIT button which when pushed enabled the image annotation features. Pressing EDIT then ADD put a triangle on the image. The triangle could then be sized and positioned on the image using Hands On Throttle And Stick (HOTAS) controls in either the front or aft seat. Subsequent selections of ADD provided up to 5 triangles for each image. Each could be individually sized and located on the image or deleted if no longer desired. The active annotation was displayed in yellow and inactive annotations were displayed in white. When annotation was complete the annotations could be saved. If further editing of annotations was performed the SAVE option would once again be presented. Figure 5.8 shows the Image View format with annotation symbology.

5.2.5.1.2.3. **Compression level:** For images that were captured onboard, the Image View page included a pushbutton to allow selection of compression level. The pushbutton toggled between FAST, MED, and SLOW which were representative of relative time required to

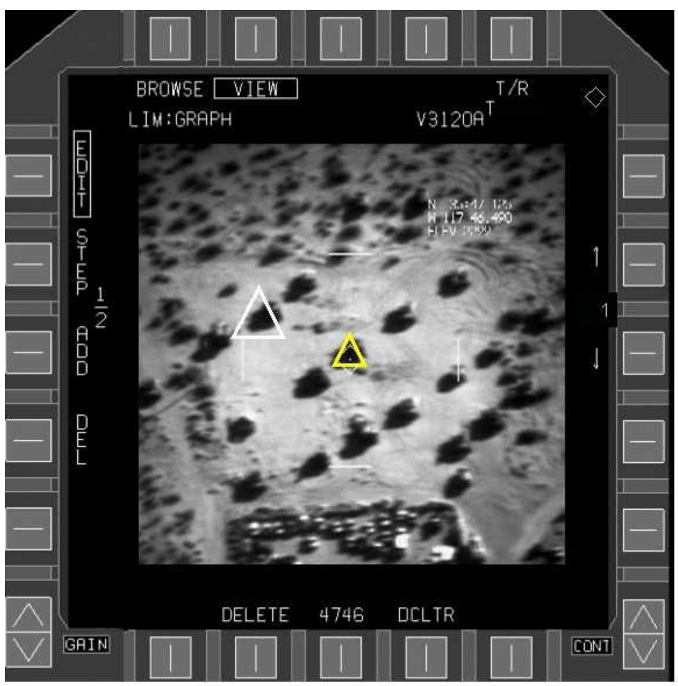


Figure 5.8; Image View with annotation

retrieve and transmit the image as the compression level was changed. The actual compression ratio associated with the FAST, MED, and SLOW selections was determined by mission computer code. Each actuation of the compression level pushbutton commanded a re-retrieval of the image using the newly selected compression level.

5.2.5.1.2.4. **Compression type:** For images captured on board, the Image view page included a pushbutton to select the compression type. Aircrew were able to select JPEG or EagleEye compression by pushbutton actuation. When the compression type pushbutton was activated the MC re-retrieved the image using the newly selected compression method. Compression types are discussed below.

5.2.5.1.3. **Image Transmit/Receive (T/R) page:** The Image T/R page was reached by selecting the T/R pushbutton from the Image View or Image Browse pages. The Image T/R page was designed to allow aircrew to manage incoming/outgoing imagery messages traveling either Link-16 or VMF. It was graphically and functionally divided into a top half for managing image transmission and a lower half for managing image reception. Figure 5.9 shows a representative Image T/R page.

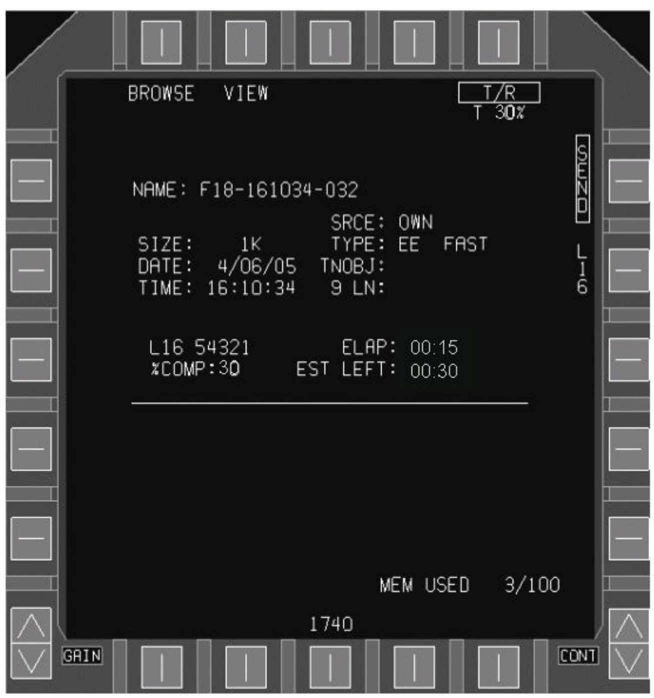


Figure 5.9; Image T/R page

5.2.5.1.3.1. **Image transmission:** The upper half of the Image T/R page was designed for the final send command to initial datalink imagery messages. The name and properties of the selected image were determined by the selection box on the Image Browse page and the compression settings on the Image View page. Recipient(s) for Link-16 imagery messages were determined by settings on the Link-16 NETS page. Recipient(s) for VMF imagery messages were determined by network setup as show on the VMF NETS page. The only options available on the Image T/R page were selection of Link-16 or VMF and the SEND pushbutton that initiated the datalink message. Transmission and image file data from the last sent imagery message were displayed in the top half of the Image T/R page.

5.2.5.1.3.2. **Image reception:** The lower half of the Image T/R page was designed to help aircrew manage incoming imagery messages. A progress cue was presented in the lower half while image reception was in progress. After image reception was complete and the image packets had been re-assembled into an image, a NEW IMAGE WAITING cue was displayed in the lower half of the Image T/R page along with ACPT/REJ options. If the image was accepted the file was stored to the image directory on the RMM. If the image was rejected no file would be stored to the RMM. If no aircrew action were taken (neither ACPT or REJ) the NEW IMAGE WAITING CUE would remain and further imagery messages would be rejected. File and transmission status information for the last accepted imagery message were displayed in the lower half of the Image T/R page.

5.2.5.1.4. **Link-16 NETS page:** The Link-16 NETS page was designed to show aircrew potential recipients for Link-16 imagery. The Link-16 NETS page was functionally and graphically divided into two halves. The right half (labeled OBJECTIVES) was not designed for imagery functions and will not be discussed. The left half was labeled “RECIPIENTS” and was a real time list of Link-16 participants to whom imagery could be sent. Figure 5.10 shows a representative Link-16 NETS page.

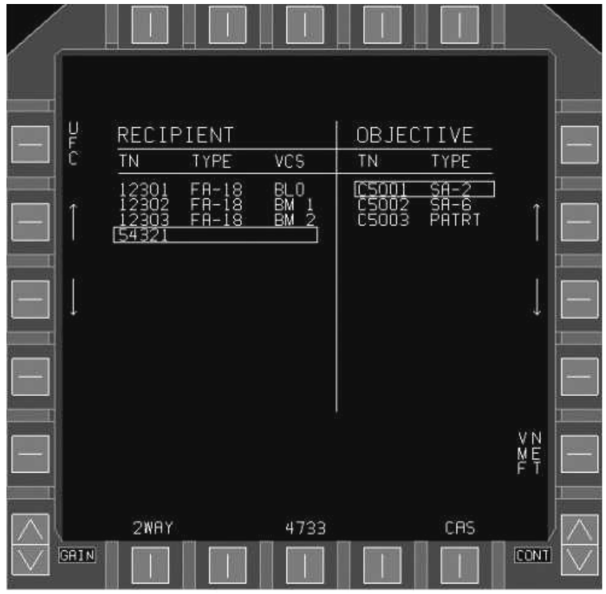


Figure 5.10; Link-16 NETS page

5.2.5.1.4.1. **Participants:** The participants were listed by Link-16 TN and included a Link-16 VCS if they were actively exchanging Link-16 messages. The Recipients list consisted of the following participants:

- Up to 3 participants that had been labeled as flight members (wingmen)
- Up to 4 participants that had been labeled as donors (other tactical aircraft working in the area)
- 8 preplanned participants that could be entered via JMPS (Ground stations, command and control facilities whose TNs were known prior to takeoff)
- 1 participant whose TN could be entered via the UFCD (allowed manual entry of one ground station or command and control platform whose TN was not know during pre-flight planning)

As Link-16 participants were selected as members or donors in flight, their TN and VCS appeared on the Link-16 NETS page. If they were deselected their TN and VCS would be removed from the Link-16 NETS page. This functionality allowed aircrew to manage the participants to whom they desired to send imagery.

5.2.5.1.4.2. **Link-16 transmission method:** The Link-16 NETS page showed a pushbutton to select the transmit method that would be used for Link-16 image transmission. The options were:

- 2 WAY: Image is sent once to a single Link-16 participant. Link acks are expected for each image packet. This was the default setting. Fastest and best message assurance but only works for those who can link ack back.
- 1 WAY: The image is sent three times to a single Link-16 participant. Link acks are not expected. For message assurance the data is transmitted three times. Slower than a 2 WAY but works for all participants regardless of ability to Link Ack.
- Broadcast: The Image is sent three times to all Link-16 TN in the recipients list. For message assurance the data is transmitted three times. Slower than 2 way but goes to multiple TNs at once.

5.2.5.1.4.3. **Link-16 recipient(s):** When an image was sent with broadcast transmission method selected, the entire Link-16 recipients list would be sent an imagery message. When an image was sent via the 1WAY and 2WAY transmission methods only one of the TNs in the list would be sent an imagery message. While these transmission methods were selected the Link-16 NETS page incorporated a step box to show the Link-16 participant who was currently selected to receive Link-16 imagery.

5.2.5.2. **Image capture:** Mission computer capture logic was required to command and control the capture of images from targeting pod video. The MC logic included image capture enable/disable logic, the presentation of pushbuttons that command single grabs, and automatic capture functions when A/G weapons were released.

5.2.5.2.1. **Enable:** Certain conditions were required before image capture was enabled. These included targeting pod installed and operating, A/G master mode selected, and targeting pod video (with time stamps) recording to the SSR. During design a CAPTURE pushbutton was added to the Image Browse page that controlled the SSR recording of the targeting pod video. Figure 5.6 shows the placement of the CAPTURE pushbutton. Additionally MC logic was implemented that allowed manual selection of CAPTURE boxed (pushing the CAPTURE pushbutton) or automatic selection of CAPTURE boxed (CVRS selected on). When CAPTURE was boxed, either manually or automatically, recording of targeting pod video with time stamps was initiated. When this pushbutton was subsequently selected (CAPTURE unboxed or CVRS turned off) the recording of targeting pod video stopped. When all preconditions for image capture were set (targeting pod on, A/G master mode selected, CAPTURE boxed) a GRAB pushbutton was displayed on the FLIR page. Figure 5.11 shows the placement of the GRAB pushbutton. This GRAB pushbutton was a top-level indication that aircrew were ready to capture still images of onboard video.

5.2.5.2.2. **Single image capture:** The single “point and shoot” image capture capability was enabled by placing the GRAB pushbutton on the FLIR format. The GRAB label on the pushbutton indicated to the aircrew that the system was ready to capture images.

5.2.5.2.2.1. **Sequence of events:** Additionally this pushbutton was the aircrew method of commanding a single image capture. Regardless of targeting pod mode, pushing the GRAB pushbutton would command the capture of a single image. The sequence of events during a single capture were:

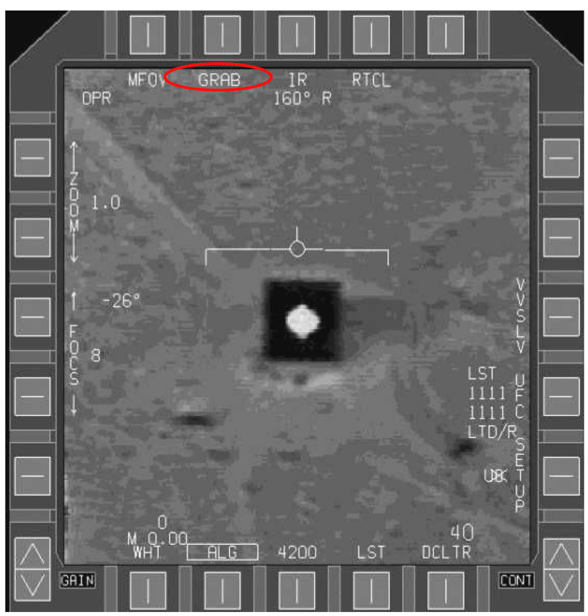


Figure 5.11; GRAB pushbutton

- GRAB presented (system ready to capture, targeting pod video with time stamps being recorded to the SSR)
- Grab commanded by aircrew
  - MC noted “time tag” when GRAB was pushed by aircrew
  - MC presented a box around GRAB on the FLIR format to indicate grab in progress
- Image capture initiated
  - MC sent time tag to SSR
  - MC created an image file name and saved it to the RMM
  - MC calculated Mensuration Data (META) from targeting pod information and saved it in a file on the RMM
  - MC created a blank annotation file and saved it to the RMM
  - SSR found the video frame that corresponded to that time tag
  - SSR saved the video frame as a still image in the image directory
- SSR completed save of the image to include naming the image
  - MC image directory updated to show new image in the Image Browse list
  - MC unboxed GRAB on the FLIR format to indicate to aircrew that system was ready for next GRAB

5.2.5.2.2.2. **Timing:** During design of the image capture system the time projected to complete the single image capture process was 2-5 seconds. While performing image capture, the command of another image capture cancelled the previous image capture. Two simultaneous cues were available for aircrew to determine that the image capture process was complete and that the system was ready for the next capture:

- Image name shows up in the Image Browse list
- GRAB unboxed

5.2.5.2.2.3. **Image capture end product:** The video frames in targeting pod video were 480 x 480 pixels with 8 bits for shades of gray. This image was saved at full resolution to the RMM as TIFF images along with three associated files (ref [e], page 3-10):

- META data file: contains geographic position of the image center and fours corners as well as aircraft and sensor orientation data
- Annotation file: initially blank but could be filled by cockpit annotations
- Image name file: contained the MC generated file name and file management data

This resulted in file sizes of approx 225k on the RMM. Onboard images were named with the convention F18-ZZZZZZ-CCC as described above in paragraph 5.2.5.1.1.2.

5.2.5.2.2.4. **Placement in Image directory:** Newly captured images were placed in the top of the Image Browse list such that the last image captured was always at spot #1. This design was intended to allow aircrew to find the newest images quickly. Previously existing images were bumped down the Image Browse list to the next lower spot.

5.2.5.2.3. **BHA sequence:** The automatic BHA sequence logic was intended to allow aircrew to easily collect still images of the target area around weapon impact. Preconditions to enable the BHA sequence were:

- Release of certain types of A/G weapons for which the mission computer knows the ballistics and can compute the time of impact.
- GRAB present at weapon release

The conditions for GRAB present at release were the same as those for single GRABs. The mission computer contained ballistics and was able to compute a time of impact for all but a few A/G stores. GP bombs, LGBs, Laser Maverick (LMAV), and JDAM weapons were all included in the list of weapons for which BHA sequences would be commanded. For a handful of A/G weapons BHA sequences were not commanded. These weapons included long range weapons (JSOW) for which targeting pods cannot provide adequate imagery and weapons for which the mission computer was unable to determine the time of impact.

5.2.5.2.3.1. **Sequence of events:** Figure 5.12 graphically depicts the timeline of events in a BHA sequence.

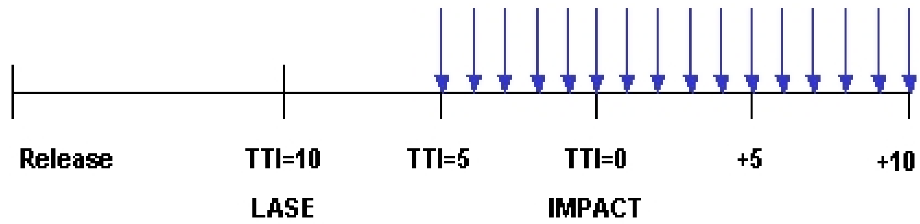


Figure 5.12; Timeline for a BHA sequence

- GRAB presented (system ready to capture, targeting pod video with time stamps being recorded to the SSR)
- A/G weapon release
  - MC confirmed weapon type was list of weapons for which BHA was desired
  - MC calculated time of impact and time tags for 15 images around the time of impact
  - MC pre-commanded capture of the images at those times
- Image capture initiated (5 seconds prior to impact)
  - MC presented a box around GRAB on the FLIR format to indicate grab in progress
  - SSR commanded to save images as the time tags were reached
  - SSR saved 16 still images to the image directory
  - Last image capture commanded at 10 seconds after impact
- SSR completed save of the images to include naming the image
  - MC image directory updated to show new images in the Image Browse list
  - MC unboxed GRAB on the FLIR format to indicate to aircrew that system was ready for next GRAB.

5.2.5.2.3.2. **Timing:** The estimated time to complete BHA sequence capture process (capture/save all 16 images and prepare for next image capture) was approximately 90 seconds. Manually unboxing GRAB while BHA sequence was in progress cancelled the sequence of images. The same cues (image names saved into Image Browse page and GRAB unboxed) provided indications to the aircrew that the system was ready for the next image capture.

5.2.5.2.3.3. **Image capture end product:** The images captured during a BHA sequence had the same properties as those captured as singles. The BHA sequence produced 16 images covering the time slice 5 seconds prior to impact to 10 seconds after impact.

5.2.5.2.3.4. **Placement in image directory:** Newly captured images were placed in the top of the Image Browse list such that the last image captured was always at spot #1. This resulted in the BHA sequence occupying the top 16 spots in the Image Browse list. The image closest to the estimated time of impact was at file #10.

5.2.5.3. **Enable imagery over datalink:** Mission computer changes were required to enable images to be sent and received over tactical datalinks. These changes included compression of outgoing images, recognition of imagery message formats, ability to break imagery into appropriately sized packets for transmission, ability to re-assemble an image from received image packets.

5.2.5.3.1. **Image compression:** The images captured from onboard targeting pod video were too large to move in tactically relevant times. In order to reduce the time required to transmit images, the design called for the mission computer to compress the full resolution images for in cockpit display and offboard transmission. Two types of compression were supported to allow best interoperability with all other imagery platforms.

5.2.5.3.1.1. **EagleEye (EE):** The EE compression algorithm was designed by the Boeing Company to compress images for airborne transmission of military images. EagleEye software was not commercially available. EE was a “near lossless” compression algorithm which made very subtle but irreversible changes to an image during the compression process (ref [f]).

5.2.5.3.1.2. **Joint Photographers Expert Group (JPEG):** The JPEG compression algorithm was designed by the JPEG to provide compression for commercial images. JPEG was a “lossy” compression method which made irreversible changes to the image during the compression process (ref [g], subject 1).

5.2.5.3.1.3. **Compression ratios:** JPEG compression ratios were expressed in “Quality setting” with 100 resulting in the largest file and the highest quality and 1 resulting in the smallest file and the lowest image quality. EagleEye compression ratios were expressed in “Clip setting” with 0 resulting in the largest file and the highest quality and 127 resulting in the smallest file and lowest image quality. Table 5.1 shows the compression ratios used to modify images for offboard transmission.

5.2.5.3.2. **Recognition of imagery messages:** The mission computer was required to recognize and process imagery messages that would previously have been disregarded. The Link-16 J16.0 message and the VMF K04.17 message were defined as imagery messages and were added to the list of expected messages for the mission computer.

5.2.5.3.3. **Definition of image packets:** Based on the transmission method (Link-16, VMF plain, VMF encrypted), the image packets that were sent to the datalinks were required to be different sizes in order to fit into the allocated time slot. The mission computer changes included logic that adjusted the size of the image packets into which an image was divided. The different sizes resulted in different numbers of image packets to send the image and corresponding changes in transmission time.

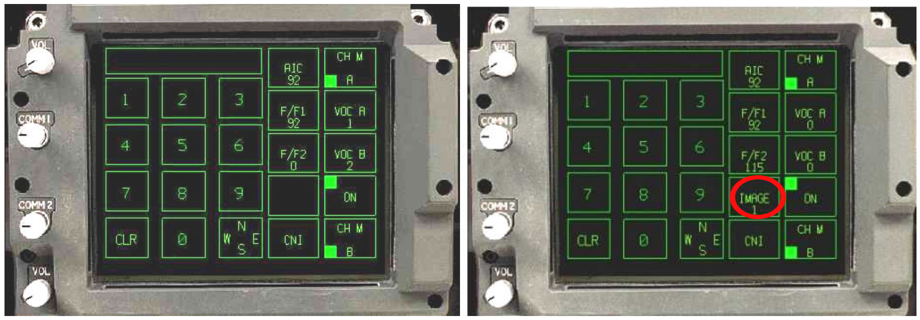
5.2.5.3.4. **Routing of outgoing J16.0 packets:** The mission computer determined the routing of outbound Link-16 messages to the appropriate NPG. Outgoing Link-16 J16.0 messages were required to be routed to the appropriate time slots on NPG 11.

5.2.5.4. **Displays:** The following formats required changes to support imagery:

5.2.5.4.1. **UFCD:** The UFCD could be used to enter MIDS net numbers 0-127. The UFCD previously allowed changes to NPG 9 (labeled AIC), NPG 12 and 13 (labeled VOC A and VOC B), and NPG 19 and 20 (labeled FF1 and FF2. In order to set the net number for the new NPG 11, a previously blank UFCD pushbutton was labeled IMAGE and was used to enter the desired net number to be used on NPG 11. Figure 5.13 shows the updates to the UFCD.

Table 5.1; Image compression ratios (ref [e], page 3-12)

	SLOW	MEDIUM	FAST
EagleEye (1)	10	40	80
NITF JPEG (2)	40	15	7



Before After

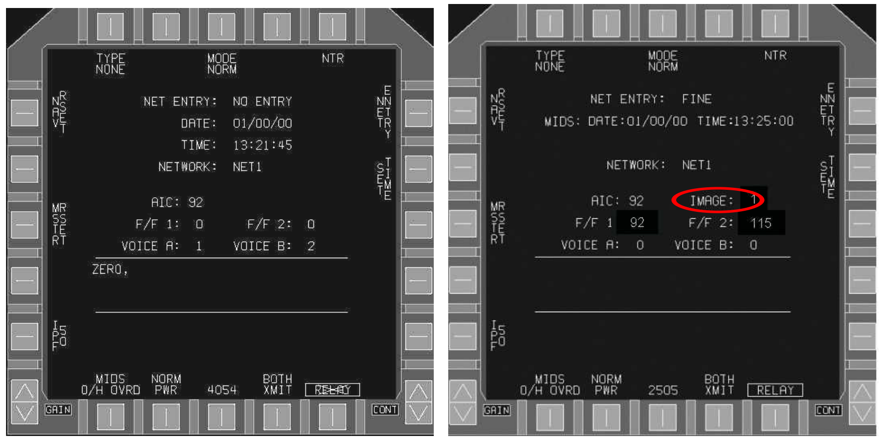
Figure 5.13; UFCD format change

5.2.5.4.2. **MTCF:** The MTCF displayed the currently selected net number for certain NPGs. With the integration of NPG 11 for imagery the MTCF was modified to show the currently selected net number (as selected on the UFCD). Figure 5.14 shows updates to the MTCF.

5.2.5.4.3. **HMD/HUD:** The HUD and HMD used advisory windows to alert aircrew to the recent reception of certain types of Link-16 and VMF messages. With the integration of imagery over datalink an IMAGE cue was added to the HMD/HUD advisory windows to alert aircrew to the presence of a newly received image. Figure 5.15 shows the change to the HMD/HUD advisory window.

5.2.5.4.4. **BIT page:** The BIT page showed the collective status of onboard systems capable of reporting a BIT status. With implementation of Solid State Recorder, which contained BIT functionality, the DISPLAYS sublevel of the BIT page was modified to include SSR status. Due to hardware limitations, the SSR was not given a pushbutton that could be used by aircrew to manually command BIT of the SSR. Figure 5.16 shows the change to the BIT Displays page.

5.2.5.4.5. **Classification of images**: All images were assumed to be classified therefore all media which contained images was also assumed to be classified. A new MSP C-code was added which informed aircrew that the RMM contained classified files. In addition, in order to display the images on the DDIs the MCs had to process the image prior to display. This required the MCs to be flagged as classified as well due to the image data present in the MC memory. Therefore viewing an image would set classified codes for both MCs.



Before After

Figure 5.14; MTCF changes

Before After

Figure 5.15; Updates to HMD/HUD advisories

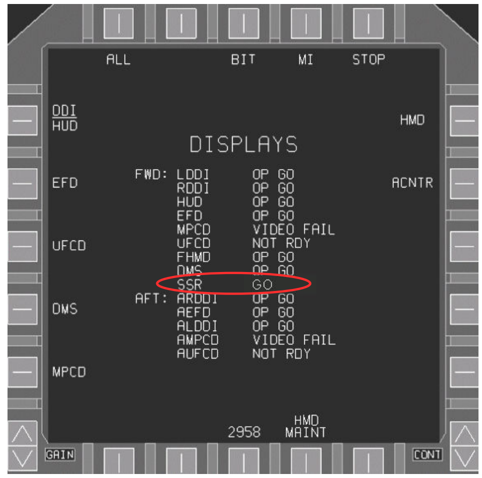


Figure 5.16; Update to BIT Displays page

Part 4: Test and evaluation

6. **Test and evaluation execution:** The U.S Navy test and evaluation community conducted developmental and operational test of the H2E+ SCS with SSR between September 2004 and November 2005.Test and evaluation was performed using a wide variety of test assets and interoperability platforms.

6.1. **Test events**

6.1.1. **Simulation test**

6.1.1.1. **Resources**: The Boeing flight test group operates a dome Super Hornet simulator with the capability to upgrade mission computer software. This allows the U.S. Navy to send aircrew to Boeing to fly the new software upgrades in a simulator prior to flight test. The simulator is an F/A-18F dual seat cockpit with full displays, controls, and switchology. The simulator is able to provide Link-16 connectivity to other simulated aircraft and ground stations. Boeing integrated a SSR into the simulator for dedicated SSR evaluation.

6.1.1.2. **Test events**: Boeing and the AWL arranged two aircrew trips to St Louis to evaluate and familiarize themselves with the H2E+ SCS with SSR. The first simulator session was prior to the first build of H2E+ software and was the very first AWL look at the new SCS. The second simulator session was prior to a late build of the SCS and was used to confirm fixes to previously reported design and implementation problems.

6.1.2. **Lab/ground test**

6.1.2.1. **Resources:** The F/A-18 AWL had two software labs capable of running the entire H2E+ SCS to include integrating an SSR and a targeting pod. In addition the AWL had access to two aircraft equipped with the H2E+ SCS and SSR for ground test events. The labs and jets were used extensively by AWL flight test engineers to confirm subsystem functionality prior to flight. Aircrew were involved with some lab and ground sessions.

6.1.2.2. **Test events:** Ground test included Electronic Emissions Evaluation (EEE) and Joint Interoperability Test Command (JITC) datalink certification. Specific test events were performed to verify image capture functionality, image transfer between aircraft, and image transfer to ground stations. In addition the labs were occasionally used early during flight test as an extra wingman to which images could be sent.

6.1.3. **Flight test:**

6.1.3.1. **Resources:** The F/A-18 AWL had access to two flight test aircraft equipped with the H2E+ SCS and SSR. These flight test aircraft were highly instrumented and were capable of recording all mux traffic, a wide variety of displays, and specific aircraft status information that would not normally be available.

6.1.3.2. **External assets:** In order to advance image operability many flight test events were planned and executed with any other platform capable of tactical imagery. This included the F-15E Strike Eagle based out of Nellis AFB and the Rapid Attack Information Dissemination and Execution Relay (RAIDER) and Digital Precise Strike Suite (DPSS) ground stations based out of China Lake.

6.1.3.2.1. **F-15E Strike Eagle**: The F-15E Strike Eagle is a multi-role strike aircraft operated by the U.S Air Force. The F-15E executed many of the same A/G missions as the F/A-18. The latest F-15E SCS was in operational test during the test and evaluation of the H2E+ SCS. The new F-15E SCS provided image receive capability via Link-16 with storage and retrieval of up to 10 images. The imagery interface included the ability to zoom in on the viewed image. F-15E datalink design was common with that of the F/A-18 to include use of NPG11 and the J16.0 for image transfer.

6.1.3.2.2. **RAIDER**: The RAIDER system was a vehicle-based ground station that sent and received digital targeting commands to aircraft via tactical datalink. RAIDER incorporated both L16 and VMF datalink systems by which tactical data could be exchanged with F/A-18. RAIDER was able to query a national imagery databases to find up-to-date imagery of target areas then send targeting data and imagery via L16 and VMF. RAIDER was also able to receive images via L16 or VMF.

6.1.3.2.3. **Target Location and Designation Handoff System (TLDHS)**: The TLDHS ground station consisted of a hardened laptop and a PRC-117 radio for transmission of VMF messages. TLDHS was not image capable and did not formally participate in image testing, but provided an important test point for VMF networks with non-image capable participants.

6.1.3.2.4. **DPSS**: The DPSS ground station consisted of a laptop computer with image correlation programs that allowed a ground based operator to correlate aircraft images with a national imagery database. DPSS image correlation depended on the aircraft derived target coordinates and META data to correlate the aircraft image with the image database. Based on aircraft-derived META data that arrived with the image, the

DPSS station attempted to match objects in the image scene with objects in the database scene. If correlation was achieved the DPSS program provided a target coordinate that could then be sent back to the aircraft and loaded into a weapon. The confidence of the coordinate depended on the confidence in the image correlation. The DPSS system was not able to send or receive images during the test and evaluation of H2E+ so images were sent to RAIDER and then hand carried to the DPSS station.

6.2. **Deficiency classification**: The AWL tracked software anomalies and hardware deficiencies using an alphabetical priority system. The classification system consisted of:

- Priority A: Hazard to safety of flight; could cause loss of aircrew, damage to aircraft, or release of weapons against unintended targets.
- Priority B: Negative impact on mission effectiveness with no acceptable workaround; could cause mission abort or failure
- Priority C: Negative impact on mission effectiveness with an acceptable workaround identified and briefed to users; could cause mission degrade or increased cockpit workload
- Priority D: Minor negative effect on mission effectiveness; could cause aircrew nuisance
- Priority E: Enhancement; could increase mission effectiveness or reduce cockpit workload but no requirement was in place to provide this function
- Pre-existing: A problem that was introduced in a previous SCS and for which there was no requirement to improve.

7. **Results of test and evaluation:** The results of evaluation were broken into groups that correspond to phases of an Air to Ground mission. The mission phases discussed will be preflight planning, preflight check, postflight checks, in-flight checks, in-flight operation, shutdown checks, and postflight mission review. While the evaluation of the H2E+ SCS with SSR included many other aspects, only results that directly affect the tactical imagery capability will be discussed.

7.1. **Preflight planning:** Preflight planning was defined as all steps that could be accomplished at a JMPS planning station. Preflight planning was evaluated throughout the developmental test effort to include at the simulator session and throughout flight test. JMPS engineers, flight test engineers, and aircrew were all involved in the JMPS evaluation.

7.1.1. **MIDS planning:** MIDS planning involved finding and loading an imagery capable network, preplanning Link-16 image recipients, and pre-planning Net numbers for all NPGs.

7.1.1.1. **Ability to determine image capability during MIDS network planning:** Aircrew ability to find, verify, and load an image capable network was evaluated during early operational test of the H2E+ SCS. In order to use imagery over Link-16, the JMPS plan must include an imagery capable Link-16 network. Aircrew attempted to load an image capable network without proper training and were required to re-fly two flight events due to lack of image transmission capability when the jet was started. It was determined that it was very easy to inadvertently load a network that was not image capable and end up having no image datalink capability. While the consequences of loading the wrong network were a complete shutdown of imagery, the probability of occurrence was assessed as low for operational squadrons. Major changes to MIDS networks or other JMPS setting would normally only be undertaken by a designated squadron JMPS expert who would have much better understanding of JMPS planning and MIDS network selection. Once set correctly by the JMPS expert all squadron personnel would be able to load an image capable network. Use of a JMPS expert was assessed as an adequate workaround and JMPS planning of imagery capable networks was assessed as satisfactory.

7.1.1.2. **Ability to mission plan Link-16 image recipients:** During JMPS planning for MIDS, a Recipients planning window is presented which allows entry of up to eight Link-16 TNs which would be downloaded and sent to the L16 NETS page as recipients. The window clearly stated the purpose and functionality of the page and aircrew were able to determine where to enter TNs and how many more recipients could be planned. Errors in planning (too many digits, attempting to enter 8s or 9s) were met with error messages that stated the incorrect parameter and assisted with correct format. The planning of Link-16 recipients was assessed as satisfactory.

7.1.1.3. **Inability to mission plan the image net number:** During JMPS planning for MIDS, net number planning was available for AIC, FF1, FF2, VOCA, and VOCB. No option to preplan net number was designed for the Image NPG and this design omission was correctly reflected in the MIDS planning section, where no IMAGE net option was presented. For every MIDS power up the IMAGE net was set to 0. All other image capable platforms (F-15E and RAIDER) were only capable of using Image net 0. There was no method that allowed aircrew to plan the Image net number during mission planning. Aircrew were forced to manually change the net number if a net number other than zero was desired. Aircrew requiring an image net number other than zero will be required to perform additional deck checks to ensure proper system setup. The inability to mission plan the Image net number was assessed as unsatisfactory and assigned a priority E with a workaround of changing the net number in the cockpit. Aircrew recommendation to provide JMPS planning for the Image net number was deferred to a later SCS.

7.1.2. **Image planning:** The ability to select, annotate, and load images from JMPS to RMM was evaluated during both simulator sessions and throughout flight test.

7.1.2.1. **Find compatible images:** Imagery planning began with finding or creating images suitable for loading. The JMPS mission planning system allowed only JPEG or NITF images to be loaded to an RMM.

7.1.2.1.1. **JPEG image planning**: JPEG images could be created on JMPS to include a screen shot of map data imagery from the JMPS chart database. The JPEG query and load functions then allowed that image to the RMM. Overall the integration of JPEG images allowed great flexibility and was assessed as satisfactory.

7.1.2.1.1.1. **JPEG size:** A screen shot of JMPS imagery could result in file sizes much larger than the 1024 x 1024 pixel limit imposed by the RMM. This limit was imposed to prevent the loading of images that were too large to be sent offboard. In this scenario the JMPS image planning UPC flagged the offending image with red text and provided a pop-up window advising of inability to load to the RMM due to image size. The safeguards against improperly sized images were assessed as intuitive and satisfactory.

7.1.2.1.2. **National Image Transmission Format (NITF) image planning**: NITF images available for loading included images taken from intelligence sources and those saved from previous flight. NITF images included data, which allowed determination of the latitude longitude coverage of the image. JMPS was able to generate an imagery request to be sent to the intelligence imagery center that detailed the target area and desired image parameters. The integration of NITF image planning was assessed as satisfactory.

7.1.2.2. **Select desired images:** Once images were found via JPEG query/create, NITF query, and image request, the available images were then listed in an imagery select window. The imagery select window included an area where target coordinates could be entered. JMPS would then compare the entered target coordinates with the latitude/longitude coverage of NITF images to flag those images which included the entered coordinates. All available images could be viewed from the list to determine image content and perspective. The selection of imagery was assessed as satisfactory.

7.1.2.3. **Annotate selected images:** Images that were selected for loading to the RMM were shown as thumbnails in the RMM planning module. Aircrew were able to click on the image and select an Edit button that opened up an Image annotation window. The image annotation window consisted of the image with seven drawing and editing tools that could be used to annotate the image. The tools included several basic geometric shapes, a text tool, and image crop and rotation functions. Following annotation the image could be viewed as it would be presented in flight. Aircrew were able to mark simulated friendly and hostile position as well as label important imagery features. With one notable exception noted below, the image annotation functions were intuitive, easy to use, and assessed as satisfactory.

7.1.2.3.1. **Unable to discern JMPS annotation symbology on light imagery:** Annotation of images was assessed using a wide variety of imagery sources and a wide variety of target scenes. All JMPS generated annotations were white and there were no options to change the color of annotations. When annotating target scenes with large areas of light color (desert scenes, airport parking ramps, light colored buildings), the white JMPS symbology was difficult to find against light colored imagery. Aircrew performing mission planning against targets in light colored areas (deserts, man made structures) will be unable to clearly annotate image features, resulting in confusion about target location. The inability to discern JMPS symbology on light imagery was assessed as unsatisfactory and assigned a priority C with a workaround of changing symbology size to include darker areas of the image. Aircrew recommendation to provide ability to annotate targets in light areas was deferred to a later SCS.

7.1.2.4. **Load images:** After all images had been selected and annotated, the preplanned images could be saved as a part of an overall JMPS mission that included waypoints and MIDS setup. The imagery load process consisted of marking the group of preplanned for download (consistent with other JMPS functions) and selecting download. The JMPS machine then stepped through a series of windows that loaded preplanned images to the RMM and all other mission data to the AMU. The download of imagery to the RMM was assessed as satisfactory.

7.2. **Preflight checks:** Preflight checks were defined as all activities between mission planning and engine start.

7.2.1. **SSR checks:** The outside of the SSR had no controls or indicators that could effect or indicate SSR status. No preflight checks were required for the SSR. SSR preflight checks were assessed as unnecessary.

7.2.2. **Unable to confirm RMM prepared for flight:** RMM preparation flight required checking the RMM to confirm that adequate record capacity remained for the mission. Record capacity remaining could be determined while the RMM was plugged into the JMPS machine and after power was applied to the aircraft. No visual cues were provided on the RMM to indicate record capacity remaining. Aircrew had no method to determine remaining record capacity between JMPS planning and post start checks. Aircrew walking to their aircraft will be unable to quickly confirm their recording media is ready for flight, resulting in a state of reduced record capacity that is not discovered until after engine start, causing mission abort or extra ground time to replace the used RMM. The inability to confirm RMM preparation for flight was assessed as unsatisfactory and assigned a priority E with a workaround of formatting every RMM between flights. The aircrew recommendation to provide a visual cue on the RMM was deferred to a later SCS.

7.2.3. **RMM loading:** During preflight checks the aircrew loaded the RMM into the SSR, much like loading a floppy disk into a disk drive. The RMM and its SSR receptacle were asymmetrical in shape to prevent inadvertent loading of the RMM in the wrong direction. The RMM included a handle on the outside face to allow better grip of the RMM. The combination of shape and handle placement on the RMM provided clear guidance for RMM orientation prior to insertion. The RMM loading was assessed as aircrew-proof and satisfactory.

7.3. **Post start deck checks**: Post start checks were defined as those checks that happened between engine start and takeoff. Following engine start and corresponding application of power to avionics systems, the subsystems performed BIT and download of applicable data from the AMU.

7.3.1. **VMF checks**: No additional VMF checks were required to enable imagery.

7.3.2. **MIDS checks**

7.3.2.1. **Verify image recipients**: The download of image recipients from the AMU was confirmed by selecting the L16 NETS format and checking that appropriate Link-16 TNs were displayed in the recipients list. Link-16 recipients that were currently in the link also showed the VCS as reported by their PPLI. Verification of the Link 16 image recipients was intuitive and assessed as satisfactory.

7.3.2.2. **Verification and selection of own image net number**: Following download of MIDS data from the AMU the preplanned net numbers can be checked on the MTCF (as reported by the MIDS terminal) or by TUCing own aircraft on the SA page (as reported from own PPLI). Image net number was always 0 on startup due to the lack of mission planning for image net number. Though no image net data was available on the SA page, the image net number could easily be determined from the MTCF. Changes to the image net number could be made on the UFCD in a manner consistent with changes to other MIDS net numbers. The verification and selection of own net number was intuitive and consistent with other MIDS net number changes. Verification and selection of own image net number was assessed as satisfactory.

7.3.2.3. **Verification that MIDS network was imagery capable**: Following MIDS startup and network download, aircrew were able to determine whether the currently loaded Link-16 network was imagery capable by checking symbology on the Image T/R format. If MIDS was operative but the network was not imagery capable, the L16 pushbutton on the Image T/R page was displayed with an X to indicate that Link-16 imagery was not currently possible. Aircrew were provided with indications that Link-16 imagery was not currently available. Verification of MIDS network was assessed as satisfactory.

7.3.3. **SSR checks**

7.3.3.1. **Nonexistent SSR BIT performance:** The BIT performance of the SSR, as indicated by the ability of the BIT system to cue aircrew to degraded status of the SSR, was evaluated during lab checks, during ground checks, and in flight. Several operational failures of the SSR were observed during ground and flight test events. These failures were recognized by indications on the top level FLIR page of the SSR “stuck” in image capture process indefinitely. When the BIT status page was referenced following these failures, the SSR status was GO. Analysis of the BIT functions of the SSR showed that the SSR BIT functions would never provide a BIT output indicating a degraded status. The SSR BIT functions reported GO regardless of actual health of the SSR even with failures that were confirmed via other means. Degraded status of the SSR could not be recognized by reference to the BIT advisory or the BIT status page. The nonexistent SSR BIT performance will cause failure of aircrew to recognize losses of system performance, resulting in inability to record video or perform image capture at critical points in a mission. The nonexistent SSR BIT performance was assessed as unacceptable and assigned a priority B, with a poor workaround of SSR operational checks. The aircrew recommendation to provide a useful SSR BIT function was deferred to a later SCS.

7.3.3.2. **Indications of RMM record capacity:** The indications of the RMM record capacity, as indicated by ability of aircrew to determine the hours and minutes of available recording time, was evaluated during simulator sessions and flight test events. Following engine start and a 90 second SSR power up cycle, the SSR presented a time remaining cue on the Image Browse page. The time remaining was a real-time number calculated by dividing available RMM capacity by record rate for 3 video channels (two displays plus raw targeting pod video). The time remaining cue compensated for failed sections of the RMM that were not available for recording and for image and architecture files that were present on the RMM. The SSR remaining cue was a reliable and up to date indicator of remaining record capacity. The indications of RMM record capacity were assessed as satisfactory.

7.3.3.2.1. **Placement of SSR REMAINING cue:** The SSR REMAINING cue was presented on the Image browse page where it could be used to assist in balancing image capture and video record requirements. However the SSR remaining cue was not presented on a top level display for quick reference. If the image format was not currently selected, at least two and most likely three pushbutton actions were required to check record capacity and return to the original display. The poor placement of the SSR REMAINING cue will result in aircrew distraction during high workload mission phases as aircrew try to quickly determine remaining record capacity. The placement of the SSR REMAINING cue was assessed as unsatisfactory but ranked as a priority E due to no requirement to improve on exiting CVRS design.

7.3.3.2.2. **Inability to command maximum record capacity in the aircraft:** Maximum record capacity, to include the overwriting of previously existing video and images, required formatting of the RMM. The JMPS station was capable of formatting the RMM during preflight planning. The SSR incorporated no capability to format the RMM in the aircraft. After leaving the mission planning station the aircrew had no ability to erase previously existing video or images in order to command maximum record capacity. The previous 8mm tape system had no method to rewind the tapes in the aircraft to increase record capacity. Aircrew who have not formatted their RMM prior to flight will have reduced record capacity and may be unable to collect video BHA or capture onboard images, resulting in mission abort or inability to collect BHA. The inability to command maximum record capacity in the aircraft was assessed as unsatisfactory but pre-existing. The aircrew suggestion to provide a “format” pushbutton in the aircraft to achieve best record capacity was deferred to a later SCS.

7.3.3.3. **Record status indications:** The effectiveness of record status indications, as indicated by the ability of aircrew to quickly determine whether cockpit video was being recorded, was evaluated during simulator evaluation session and during SSR integration test flights.

7.3.3.3.1. **SSR REMAINING indicator:** The SSR REMAINING indicator was a real time indicator of record capacity remaining on the RMM. As recording took place and remaining recording capacity decreased the SSR REMAINING indicator decremented accordingly. Aircrew were able to reference countdown of the SSR REMAINING indicator to confirm that recording was underway. The real time nature of the SSR REMAINING indicator (measurement of record capacity and comparison with current record rate) was assessed as an enhancement that should be incorporated in further CVRS/recording designs.

7.3.3.3.2. **Poor mechanization of the RCDR ON Light:** During SSR integration flights the RCDR ON light was illuminated when the record switch was moved out of the OFF position. Post flight analysis of recorded video showed several gaps in recording coverage, with the RCDR ON light illuminated throughout. The RCDR ON light was a top-level indication that recording had been commanded but had no ability to alert aircrew to a degraded recording status. The poor mechanization of the RCDR ON light will lead to unidentified recording failures with resulting inability to confirm weapon delivery and impact. The poor mechanization of the RCDR ON light was assessed as unsatisfactory but pre-existing. Aircrew recommendation to make the RCDR ON light a useful indication of record status were deferred to a later SCS.

7.4. **In-flight checks**: In flight checks were defined as all steps that were completed airborne prior to entering the target area.

7.4.1. **VMF image transmission mechanization**: In-flight checks included confirming/adjusting VMF network participants on the VMF NETS page. Adjustment of the VMF network participants was performed by marking selecting/deselecting existing VMF participants for SEND. The ability to verify proper network setup was evaluated during flight test with one aircraft and two VMF capable ground stations (RAIDER and TLDHS). RAIDER was capable of receiving VMF imagery messages but TLDHS was not. Both were marked as image recipients on the VMF NETS page. During multiple attempts to transmit images, when aircrew attempted to send a VMF imagery message the Image T/R page showed LAST FAIL. Analysis showed that the MC software required all image recipients to return a link ack to the first image packet or image transmission to all recipients would be internally terminated. Since TLDHS was not image capable and therefore did not send a link ack for the first image packet, the image transmission to all recipients was terminated. Aircrew were required to carefully manage the status of the VMF NETS and remove any non-image-capable VMF participants prior to sending a VMF image message. The poor mechanization of VMF image transmission will result in failed VMF image transmissions and high cockpit workload to manage the VMF

NETS setup in order to maintain image capability. The poor VMF image transmission mechanization was assessed as unsatisfactory and was assigned a priority C with a workaround of aircrew managing the VMF NETS setup. Aircrew recommendation to change the VMF image transmission mechanization to make it common with other VMF messages was deferred to a later SCS.

7.4.2. **MIDS checks**: In-flight MIDS checks included confirming/adjusting the image recipient list on the L16 NETS page. The list of potential Link-16 image recipients was shown on the L16 NETS page. The list could be modified by selection or deselection of Link-16 Member/donor status or by UFCD entry of one Link-16 TN. Selection as a member/donor was confirmed graphically on the SA page by the presence of the donor dot on the PPLI. Modifications to the Link-16 image recipients were simple, intuitive, and easily confirmed. In-flight MIDS checks were assessed as satisfactory.

7.4.2.1.1. **Confirmation of recipient image net number**: Net number (for those NPGs which allow net number entry) are sent out in the MIDS PPLI (see paragraph 2.1.4.1.3 and Figure 2.11). The requirements for tactical imagery did not include a change to the PPLI message to include the Image net number. When setting up MIDS to send an image to a certain recipient, the sender was forced to confirm the recipient’s image net number by voice since no cockpit display of the recipient's net number was available. Aircrew were required to use voice to confirm proper image net # setup prior to image transmission. Aircrew will be unable to view other L16 participant’s image net number, resulting in delayed image transmission and voice communications to determine recipient’s net number. The inability view other MIDS participant’s Image net # was assessed as unsatisfactory and was assigned a priority E with a workaround of using voice communications to confirm imagery net number. The severity of this problem was also reduced by the fact that all imagery platforms but F/A-18 were only able to use Image Net 0. Aircrew recommendation to include the Image net number in the PPLI was deferred to a later SCS.

7.5. **In-flight operations**: In flight operations were defined as any steps that contribute to execution of the kill chain.

7.5.1. **Lack of clear indication of record status:** In order to “assess” upon return from the mission, aircrew were required to record cockpit video in-flight. The CVRS control panel was used to command recording. The RCDR ON light and SSR

REMAINING indicator provided recording status information to the aircrew. Several deficiencies are noted above regarding feedback to the aircrew that recording is underway. However most were pre-existing and can be directly attributed to the form-fit-function requirement. One new indication, the countdown of the new SSR REMAINING indicator, did provide indication that recording was underway. Aircrew interface with recording controls and indicators was, by design, largely unchanged.. Aircrew will unknowingly fail to collect cockpit video due to the poor feedback about recording status, resulting in failure to collect BHA. The lack of clear indication of record status was assessed as unsatisfactory but pre-existing. Aircrew recommendation to improve recording feedback to include indications of time remaining and individual display availability was deferred to later SCS.

7.5.2. **Single grab:** The in-flight ability to grab a single image was assessed against targets of opportunity.

7.5.2.1. **Steps to prepare**: Overall aircrew actions to prepare for in-flight grab were selection of SSR recording on, selection of A/G master mode, and targeting pod in an operative mode. Aircrew performing any A/G mission will select A/G master mode, will have their targeting pod in an operating state, and when finding a target of interest will command recording of cockpit displays. By executing usual habit patterns for this mission area, aircrew were unknowingly completing the steps required to prepare for image capture. The preparation for image grab was intuitive and consistent with steps that aircrew were already taking in this portion of the mission. Preparation for image capture was assessed as enhancing and this model for aligning preparation steps with existing tactical steps should be considered in further designs.

7.5.2.2. **Confirm ready for image capture**: Aircrew indication that the targeting pod was ready to perform capture was the presence of the GRAB pushbutton on the top level targeting pod format. GRAB was only presented when all preparatory steps had been completed and image capture was standing by for aircrew command. The confirmation of readiness for image capture was presented in a clear manner on the format where it was most useful. Aircrew were able to quickly determine the status of the image capture system. The confirmation of readiness for image capture was assessed as satisfactory.

7.5.2.3. **Capture an image**: When the GRAB pushbutton was presented on the targeting pod page, pushing the GRAB button generally resulted in the GRAB pushbutton boxing. The box remained around GRAB for 5-8 seconds, at which point the box was removed. The GRAB pushbutton was presented at the same time as the targeting pod video such that when aircrew found the item of interest with the targeting pod they were able to immediately command capture of the desired target (“point and shoot”). Since the time stamp mechanization ensured that aircrew got the video frame that they were seeing when they pushed the GRAB pushbutton, aircrew could continue to slew the targeting pod while capture was in progress and be assured that they got the requested image. Aircrew interface to command an image grab was located intuitively and provided clear feedback that a GRAB had been commanded. The aircrew interface for capturing images was assessed as satisfactory.

7.5.2.4. **Aircrew feedback on image capture progress**: Two cues were provided that image capture was complete. While image capture was in progress GRAB was boxed on the targeting pod page. Additionally the image browse page would indicate the presence of a new image by way of the insertion fo a new file at File #1 (the top of the list). The image name was listed as “SAVING” during image capture, after which the full name of the image was presented. The removal of the box around GRAB on the targeting pod page and the presence of the file name on the image browse page indicated that the image capture was complete and that the system was ready for the next command. Aircrew were able to clearly determine the status of image capture.

7.5.2.5. **Find the image**:

7.5.2.5.1. **Immediately after capture**: New images (capture or received) were inserted at the top file (file #1) of the image browse page. The newly captured image could always be found at the top of the image browse page. The time of capture could be confirmed by checking the file name which included Zulu time. Aircrew were able to quickly find a newly captured image.

7.5.2.5.2. **Later in flight**: As other images were captured, received, and deleted, previously existing images were moved up and down in the image browse list. The naming convention of onboard images provided both Zulu time and the MC counter, which could be used to clearly remember/recall an image. The naming convention allowed simple retrieval of the desired image despite the dynamic nature of the image browse list.

7.5.3. **BHA sequence**: The aircrew interface for BHA sequence was designed to be highly automated due to the high cockpit workload at and around weapons employment.

7.5.3.1. **Steps to prepare**: The steps to prepare for BHA sequence included all the steps from a single capture with the additional requirement for selection of a weapon type that had been flagged by the MC as BHA compatible as discussed in paragraph 5.2.5.2.3. Aircrew would be performing all these steps in preparation for weapon employment and preparation for BHA sequence was a byproduct of the steps for weapon employment. The steps to prepare for BHA sequence were consistent with weapon employment steps and provided automatic and nearly transparent BHA sequence capture. The steps to prepare for BHA sequence capture were assessed as satisfactory.

7.5.3.2. **Confirmation of readiness for BHA capture**: Confirmation of the readiness for BHA capture was exactly as described in paragraph 7.5.2.2.

7.5.3.3. **BHA capture execution**: The BHA sequence was automatically performed when a weapon was released with GRAB presented. No aircrew action was necessary to initiate the BHA sequence.

7.5.3.4. **Feedback on progress**:

7.5.3.4.1. **Start of BHA sequence**: At 5 seconds prior to MC calculated impact (which is displayed on the FLIR page) the GRAB option boxes itself. The BHA sequence could be manually cancelled by unboxing GRAB during the BHA sequence. In order to confirm that the BHA sequence had properly started aircrew checked a pushbutton on the top level of the primary targeting sensor. The feedback cue was well placed and provided a quick and easily referenced indication that BHA sequence was underway. The feedback of BHA sequence in progress was assessed as satisfactory.

7.5.3.4.2. **End of BHA sequence**: During BHA sequence capture the MC commanded the capture of multiple 15 images from the SSR. While the capture was in progress (approx 90 seconds) for the 15 images the MC presented a box around the GRAB option on the FLIR page. Additionally on the image page the new 15 images would fill in the top 15 spots and move pre-existing images down the list. Each image was initially marked as SAVING and when save was complete the image name was filled into the Image Browse list. Figure 7.1 shows a representative Image browse page during BHA sequence capture. Simultaneously the GRAB

Figure 7.1; Image Browse page during BHA sequence capture

option unboxed on the FLIR format. Aircrew were provided two cues that the BHA sequence capture was complete, one each on the two formats most related to the BHA sequence. The cockpit indications that the BHA sequence was complete were assessed as satisfactory.

7.5.3.5. **Find BHA sequence images**: The new images were inserted at the top of the Image Browse list in the top 15 files. Previously existing images were moved lower in the list. The images from the latest BHA sequence were easy to find and select for viewing. The viewing of BHA sequence images was assessed as satisfactory.

7.5.4. **Image view:** The image view page showed the actual image for the currently selected imagery file. Preplanned images and received images were shown at native resolution while captured images were initially shown compressed to FAST speed in EagleEye format. The image view page provided an interface to draw annotations on the image to mark points of interest.

7.5.4.1. **Image selection**: The Image view page showed the currently selected image, to include current file number, as well as up and down arrows to allow selection of adjacent images from the image browse list. The Image Browse list was arranged with file #1 on the top with file number counting down the page as shown in Figure 5.6. The mechanization of the up and down arrows on the Image View page was designed to be consistent with that on the Image Browse page, resulting in the up arrow selecting the next smaller file number and the down arrow selecting the next larger file number. Aircrew were initially confused by the mechanization of the up/down arrows but when the consistency with the Image Browse format was explained they were able to use the Up/Down arrows to select the desired image. The mechanization of image selection from the Image View page was assessed as satisfactory with the condition that aircrew training was required. The mechanization of the up and down arrows presented the most interesting human factors design question of this project and consistency with other formats won the day.

7.5.4.2. **Image compression**: Captured images were shown saved at 100% resolution but displayed as compressed images in order to show what could be sent over tactical datalink. The Image View page provided options to select compression rate and compression type. Image compression was a necessary evil due to limitations of available datalinks.

7.5.4.2.1. **JPEG vs EE compression**: Two types of compression were available to provide best flexibility. Some imagery platforms (F-15E) only accepted EE images while other platforms (RAIDER) only accepted JPEG images. Switching an image between EE and JPEG resulting in very little change in the Super Hornet cockpit. The use of two types of compression provided one more potential stumbling block to aircrew trying to send images. The dual compression types were assessed as a necessary evil. The aircrew recommendation was to standardize image types between imagery platforms to minimize potential confusion.

7.5.4.2.2. **FAST vs MED vs SLOW**: For both compression types, three compression rates were available. They were named by relative speed to transmit the images. FAST images were the smallest files and fastest to transmit but were of the lowest visual quality. SLOW images were the largest files and slowest to transmit but were of the highest visual quality. The default setting for captured images was FAST to allow most rapid toggle through the images. Paragraph 7.5.6.2.2.2 contains a full discussion of tactical utility of different compression settings.

7.5.4.3. **Image orientation**: The orientation of images to match aircraft-target relative position was evaluated in flight. The Image View page had no method of rotating or changing the orientation of the image. In flight the aircrew were required to mentally rotate the image to their run in heading to determine how the target would look from the run in heading. Aircrew had no reliable means to rotate or orient the picture in order to show the image from the current perspective of the aircrew. The inability to orient the image to current run-in heading was assessed as unsatisfactory but was assigned a priority E due to the lack of requirements to implement this function. Aircrew recommendation was to provide a UFCD entry for run in heading (for images with META data) or rotation degrees (for images with no META data) that would allow aircrew rotate the image to perspective of the aircrew.

7.5.4.3.1. **North up arrow**: For captured images the MC calculated four corner data that was saved in the META data file. This META data was then used to draw a North up arrow on the Image View page. During flight test the North up arrow was observed to deviate from actual North by up to 180 degrees. Analysis showed that the META data was being incorrectly written by the MCs, which resulted in incorrect orientation of the North up arrow. The incorrect orientation of the North up arrow provided false and confusing information about the orientation of features in the image and therefore provided false cues to aircrew attempting to mentally rotate the image to their perspective. Aircrew who reference the North Up arrow to determine image orientation will see false and misleading information about image orientation, resulting in confusion about relative placement of target area features and potential misidentification of targets. The incorrect orientation of the North Up arrow was assessed as unsatisfactory and assigned a priority C with a workaround of ignoring the North up arrow on captured images. Aircrew recommendation to remove the North up arrow so as to not display false information was rejected by project management. Aircrew recommendation to make the North up arrow point north was deferred to a later SCS.

7.5.4.4. **Image annotation**: Image annotation was assessed using wide variety of target images and target types. Image annotation was performed on the view page using pushbutton selections to command annotations and HOTAS controls to size and slew the annotations. When complete the annotation file was saved as an image overlay and was sent over datalink with the image. The HOTAS controls and PVI were intuitive and provided easy annotation of any desired image feature. The Image annotation provided a powerful tool for pointing out critical points within most images. With the below exceptions, image annotation was satisfactory.

7.5.4.4.1. **Unable to discern annotation symbology on light imagery:** Same issue as described in as paragraph 7.1.2.3.1 also applied to annotations performed in flight. Aircrew attempting to annotate visual features against targets in light colored areas (deserts, man made structures) would be unable to clearly annotate image features, resulting in confusion about annotation placement and potential misidentification of targets. The inability to discern annotation symbology on light imagery was assessed as unsatisfactory and assigned a priority C. Aircrew recommendation to provide the ability to view annotations in light target areas was deferred to a later SCS.

7.5.4.4.2. **Unable to draw different symbols**: Annotation was assessed with images that contained simulated hostile and simulated friendly sites. The only annotation shape available for in-flight annotation was a triangle pointed up. When attempted to point out both friendly and hostile sites aircrew had to use the same shape annotation. Aircrew were unable to differentiate between types of visual features in an image and had only one symbol for use in annotating features with different meanings. Aircrew attempting to mark both hostile and friendly areas in the same image were forced to use the same symbol, resulting in confusion about the meaning of the symbology when sent to other aircraft and potential misidentification of the target. The inability to draw more than one shape of symbol was assessed as unsatisfactory and was assigned a priority E due to lack of requirement to provide this function. Aircrew recommendation to provide at least two types of annotation shape was deferred to a later SCS.

7.5.5. **Image management:** The RMM architecture supported 100 image files that could be filled with preplanned images, captured images, or received images.

7.5.5.1. **Image deletion**: The Image View page provided a DELETE option for the currently selected image. Deletion required a follow on ACCEPT from the aircrew before the image file was deleted. Deletion of the image deleted that image and moved all images that were lower in the Image Browse list up to fill the empty space. Deletion mechanization was limited to one image at a time and there was no method to delete multiple images at once. Aircrew were able to quickly delete single images but were unable to quickly delete groups of images. Aircrew attempting to delete numerous unwanted image will be required to individually delete the images, resulting in higher cockpit workload. The inability to delete groups of images was assessed as unsatisfactory and assigned a priority E due to no requirement to perform group deletion. Aircrew recommendation to provide group deletion functions were deferred to a later SCS.

7.5.5.2. **Maximum number of pictures**: If the image directory was full (all 100 files filled) the GRAB label on the FLIR format was Xd out to indicate to aircrew that image capture was no longer available and that aircrew must go delete images to enable further image capture. The indications of GRAB disabled were displayed on the correct format in an intuitive manner. Cockpit indications of full image directory was assessed as satisfactory.

7.5.6. **Image send**

7.5.6.1. **Image selection/verification:** Image selection was performed by placing the select box on the desired image on the Image Browse page or by viewing the desired image on the Image View page. Throughout the image transmission process, aircrew were able to quickly verify which image was selected for transmission. Image selection and verification were assessed as satisfactory.

7.5.6.2. **Image options**: Once the desired image was selected, aircrew had options to select compression type (will be called image type) and rate of compression.

7.5.6.2.1. **Image type**: Image type options of EE and JPEG were provided to allow maximum flexibility. The default image type for captured images was EE. Certain image platforms were only capable of one type of image (F-15E only able to use EE, RAIDER only able to use JPEG). Selection between types was available on a pushbutton on the Image View page. Sending an incompatible image type resulted in either a failed transmission (LAST FAIL cue on Image T/R page) with no image received or a good apparent transmission (LAST PASS on Image T/R page) with a garbled image on the receiver's displays. Image type selection was easy to perform but was easy to get wrong when sending to image platforms that required a specific image type. While the selection of image type was assessed as satisfactory, overall image compression was assessed as a significant addition of complexity to allow flexibility. Aircrew recommendation to push for overall inter-service and inter-platform agreement on image type to reduce complexity was deferred to a later SCS.

7.5.6.2.2. **Image compression**: Image compression options of FAST, MED, and SLOW were provided to allow aircrew flexibility to send high or low quality images. The default compression setting for captured images was FAST to allow most rapid stepping through the images. Details of image transmission times and image quality are discussed below. While the selection of image compression rate was assessed as satisfactory, overall image compression was assessed as a necessary addition of complexity to allow flexibility. The aircrew recommendation to investigate improved compression or transmission methods to eliminate the need for aircrew to select a compression setting was deferred to a later SCS.

7.5.6.2.2.1. **Transmission times:** For a given image and a given transmission method, image compression rate determined image file size which determined image transmit time. Figure 7.2 shows predicted image transmission times based on theoretical image compression and transmission capabilities. Predicted times assumed specific image sizes based on compression ratios shown in Table 5.1. Figure 7.3 shows actual image transmission times taken from test and evaluation flights. Error bars in the horizontal reflected the presentation of image size to the nearest kb. The wide variety of observed image sizes reflected the difference in compression between images with varying content. Based on differing image content (dark/light pixels) the same compression settings yielded differing compressed image sizes. Dark pictures compressed to smaller images. Changes in compression rate resulted in image transmit times between 15 and 142 seconds.

7.5.6.2.2.2. **Image quality:** The quality of images of different compression was evaluated qualitatively against a wide variety of target areas and target backgrounds. FAST image quality was the lowest quality and provided general target area features only. The target coordinates generated by the targeting pod were unreadable. From a captured image of a vehicle driving on a road, aircrew viewing a FAST image in flight might be able to detect the presence of a vehicle but might be unable to identify which kind of

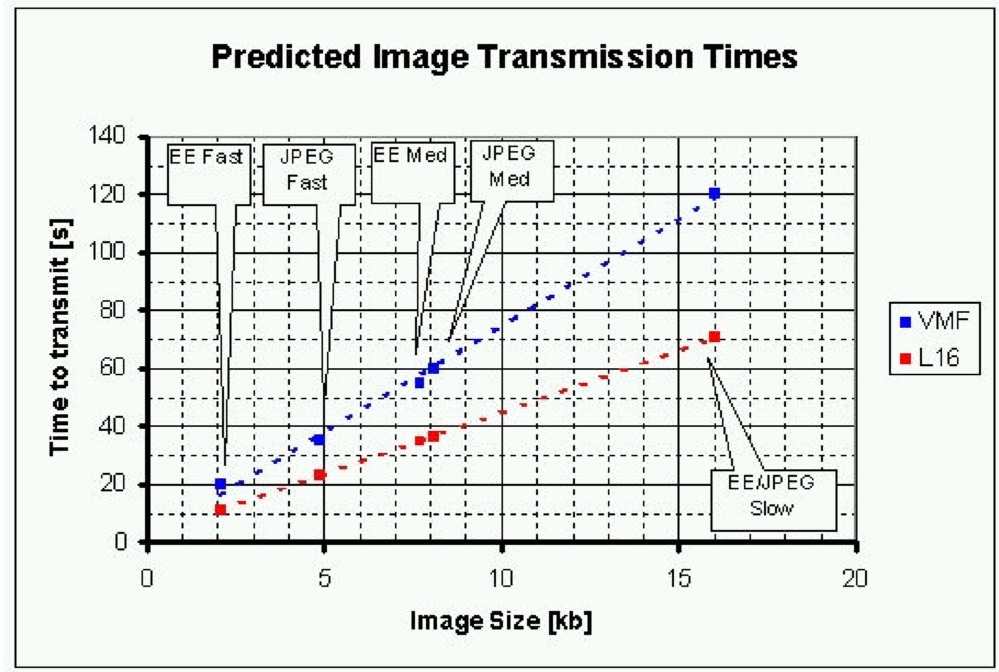


Figure 7.2; Predicted image transmission time

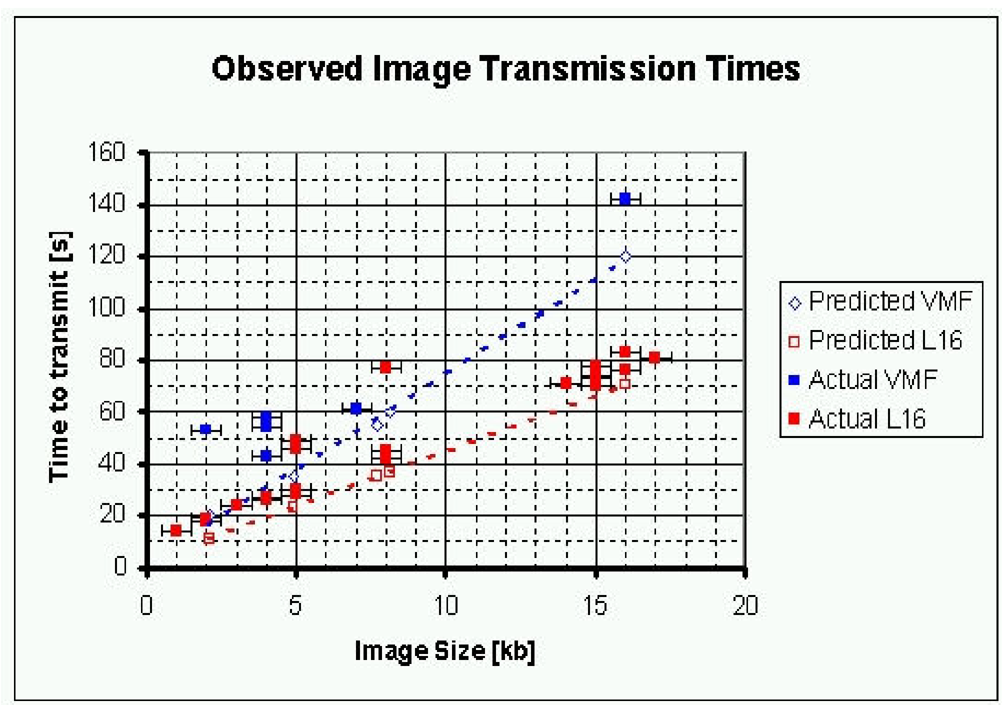


Figure 7.3; Observed image transmission times

vehicle was shown. MEDium images were of intermediate quality and provided most target area features. Targeting pod coordinates were legible and most details that were seen on the targeting pod video when the image was captured were legible when viewed under MED compression in flight. SLOW images were of the highest quality and provided all target area features. When viewed in an F/A-18 cockpit MED and SLOW showed very little difference in target area features. However when viewed in other platforms with the ability to zoom in on the image, SLOW images showed improved resolution when zoomed. All three image compression rates were assessed as having a useful place in tactical imagery. FAST images were used as "thumbnail" pictures that quickly allowed the aircrew to decide if an image should be delete, kept, and/or transmitted. However, FAST images were not assessed to have tactical utility when sent offboard due to the low quality of target area imagery and the unreadable target coordinates. MED provided tactical information to include target coordinates and was the best compromise of speed and quality. SLOW images provided the most tactical utility and were preferred for ground systems using image correlation algorithms to match coordinates.

7.5.6.2.2.3. **Link-16 vs. VMF**: Image transmission was compared between the two parallel datalinks. Figure 7.2 shows predicted image transmission times for VMF and Link-16 with VMF imagery taking approximately twice as long to move the same image. Figure 7.3 shows observed image transmission times. Link-16 imagery transmission times were slightly longer than predicted but were assessed as generally consistent as evidence by linear relationship of image size and transmission time (with a few notable exceptions). While VMF data is limited, VMF transmission times were noticeably longer than those of Link-16 and showed a less consistent image size vs. transmission time trend. The limited VMF data reflects the aircrew preference for Link-16 for imagery exchange due to lower transmission times and more consistent transmission results. While both datalinks were found to be satisfactory for moving images, Link-16 was found to be a faster and more consistent method of image exchange. This assessment was passed along to fleet users as a tactical recommendation to use Link-16 when available and only use VMF with imagery users that were only capable of exchanging pictures via VMF.

7.5.6.3. **Recipient selection**:

7.5.6.3.1. **L-16 recipient**: The L16 NETS page provided a list of all available image recipients. Link-16 participants not currently displayed on the L16 NETS page could be added to the list by way of a UFCD option to enter a Link-16 TN. Options were presented to allow transmission to all TNs on the L16 NETS page or to just one TN that was indicated by the presence of a selection box. Selection of one or all L16 image recipient(s) was assessed as satisfactory.

7.5.6.3.1.1. **Selection of multiple image recipients:** Options were presented to allow transmission to all TNs on the L16 NETS page or to just one TN that was indicated by the presence of a selection box. No option was presented to pick and choose multiple L16 recipients without sending to the entire L16 NETS list. In order to send an image to just three recipients from the L16 NETS list, aircrew forced to send the image three times, once to each of the three recipients. Aircrew attempting to send an image to multiple recipients will be unable to quickly select intended recipients and will be forced to execute extra steps or send the image to unintended recipients The inability to select multiple image recipients was assessed as unsatisfactory and assigned a priority E due to no requirement to perform this function. Aircrew recommendation to provide "pick and choose" capability on the L16 NETS page was deferred to a later SCS.

7.5.6.3.1.2. **VMF recipient**: With the exception of paragraph 7.4.1, selection of VMF recipients was assessed as satisfactory.

7.5.6.4. **Controls and indications of transmit method**: The image transmission could be changes between VMF and L16 using a pushbutton presented on the Image T/R page. The pushbutton showed the currently selected transmission method. If one transmission method was not available that transmission method would be Xd out to indicate not ready to transmit. Aircrew were able to quickly determine currently selected image transmission method and quickly change it of required. Controls and indications of image transmission method were assessed as satisfactory.

7.5.6.5. **Commanding image transmission**: The Image T/R page provided a SEND pushbutton that would send the currently selected image to the currently selected recipient(s) using the currently selected image transmission method (VMF or L16), the currently selected image type (EE or JPEG), and the currently selected compression rate (FAST/MED/SLOW). Commanding transmission was easy and intuitive. Controls to command image transmission were assessed as satisfactory.

7.5.6.5.1. **Feedback of IMAGE transmission progress**: When SEND was selected on the Image T/R page three indicators were presented to the aircrew. The first was an elapsed time counter that displayed time since SEND was selected. The second was estimated time left to complete image transmission. The third was a percent counter that counted from 0 to 100 percent to show transmission of image packets. All transmissions showed a count up of elapsed time. Successful transmissions were indicated by the estimated time left counting down and the percent complete counter counting up. Upon successful link ack back from the last image packet the estimated time left displayed 0 and the percent complete counter showed 100. In addition a LAST PASS cue was displayed in the middle of the IMAGE T/R format to indicate that the last image transmission was successful. Partially successful image transmissions (long range, missed image packets) showed continued elapsed time count up, a stagnant estimated time remaining, and a stagnant % complete counter. Completely unsuccessful image transmissions (network incompatibility, incorrect recipients selected) were indicated by no countdown in estimated time, percent complete stuck at 0, and after 15 seconds of no transmission a LAST FAIL cue accompanied by clearing of all counters to indicate that image transmission had been terminated. Aircrew were able to monitor the real-time status of image transmission using cues on the Image T/R page. The feedback of image transmission progress was assessed as satisfactory.

7.5.7. **Image reception**

7.5.7.1. **Cockpit cues of image enroute**: The lower half of the image T/R page showed reception status. When imagery packets were being received via Link-16 or VMF, the Image T/R page showed a percent complete counter, a time elapsed counter, and an estimated time left counter. No top-level indication was provided to indicate that image reception was in progress. Aircrew were able to monitor image reception if cued by voice communication that an image was enroute. While the cues of image reception were easily missed, this portion of the mission did not require aircrew interaction. Cockpit cues of image reception were assessed as satisfactory.

7.5.7.2. **Cockpit cues of image reception complete**

7.5.7.2.1. **Short duration of the cue of Link 16 image reception**: Upon arrival of a complete L16 image, the HUD and HMD displayed an IMAGE cue that flashed for 10 seconds. Aircrew in the aft seat who had no HUD or HMD had no image cue to indicate the arrival of a new L16 image. Analysis of the design showed the 10 seconds was chosen to be consistent with other MIDS cueing. Additionally analysis of image reception indicated that reception of further images was inhibited until the current image was accepted or rejected. Aircrew will be required to use voice to advise of image transmission to cues image recipients that they should go check for new image. The short duration of the cue of Link-16 image reception was assessed as unsatisfactory and was assigned a priority E due to no requirement to deviate from MIDS convention for message reception. Aircrew recommendation to continue flashing of the IMAGE cue until aircrew select the Image T/R page was deferred to a later SCS.

7.5.7.2.2. **VMF image reception**: Upon arrival of a complete VMF imagery message, the HUD and HMD displayed a flashing IMAGE cue that flashed until the Image T/R page was selected. Aircrew were presented with persistent indications that a new image was available. The cockpit cue of VMF imagery reception was assessed as satisfactory.

7.5.7.3. **Image confirmation**: When the Image T/R page was selected following the reception of a new Link-16 or VMF image, three cues of a new image were presented. A NEW IMAGE CUE was displayed in the bottom of the Image T/R display and REJ and ACPT options were presented. Information about the image (sender, message type) was displayed below the NEW IMAGE WAITING cue. Selecting the REJ option rejected the image which consisted of resetting image receive capability without saving the image to the SSR. Selecting the ACPT option saved the image to the SSR then reset the image reception system for reception of the next image. The image ACPT/REJ functionality allowed aircrew to manage which images were saved to the SSR. The image confirmation was assessed as satisfactory.

7.5.7.4. **Misleading pushbuttons on the Image T/R page following image ACPT**: Upon reception of a new image and selecting ACPT, the new image was saved into the image directory and was available for viewing on the Image Browse page. However the currently selected image did not change with reception of a new image. Therefore the VIEW pushbutton on the Image T/R page commanded display of the currently selected image, which was not necessarily the same as the newly received image. The presentation of pushbuttons on the Image T/R page provided misleading functionality. Aircrew attempting to VIEW a newly received image can select an image that they think is the new image, resulting in confusion as to the features in the target area and potential misidentification of the target. The misleading pushbutton on the Image T/R page following image ACPT was assessed as unsatisfactory and assigned as priority C with a workaround of manually selecting the newly received image. The aircrew recommendation to provide a VIEW NEW pushbutton after image reception was deferred to a later SCS.

7.5.8. **Interoperability considerations:** Test and evaluation with imagery included operations with all available imagery capable platforms to include the RAIDER ground station and the F-15E Strike Eagle.

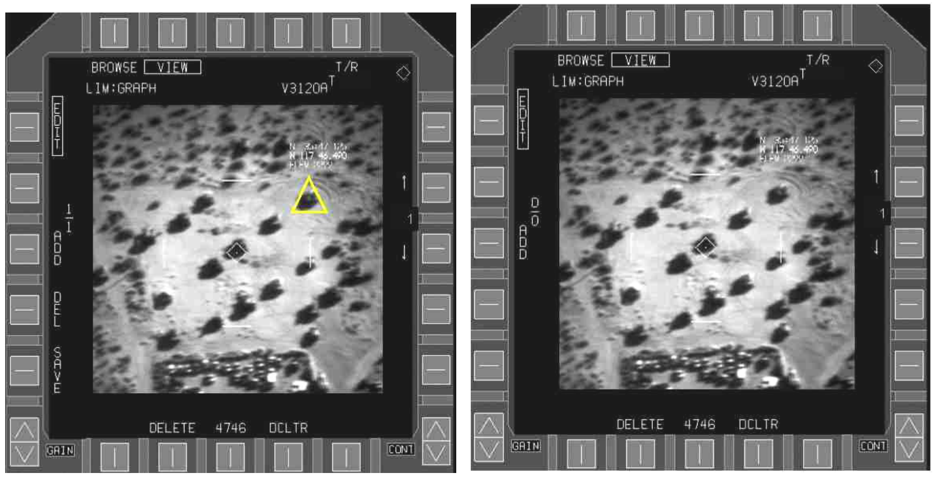
7.5.8.1. **Very few image capable platforms**: During early F/A-18 imagery development numerous airborne and ground platforms advertised the development of imagery transmission and receive capability. However during H2E+ developmental flight test only two other platforms (RAIDER, F-15E) had imagery capability that could be used to check H2E+ interoperability. Other platforms (to include such ground stations as BOSS, TLDHS, DPSS-SOF, and airborne platforms such as the E-3A Sentry and the E-2C Hawkeye) were not available to test. The slow development of other platform's imagery capability posed a risk of interoperability problems due to the completion and fleet release of H2E+. Interoperability problems found with those platforms will have to be found through follow on testing and addressed through a later SCS. The recommendation was made to perform further testing to ensure imagery interoperability with new image platforms.

7.5.8.2. **File types**: See paragraph 7.5.6.2.1. While the selection of image type was assessed as satisfactory, the use of two different image compression methods was assessed as a significant addition of complexity to allow flexibility for interoperability with all platforms. Aircrew recommendation was to push for overall inter-service and inter-platform agreement on image type to reduce complexity.

7.5.8.3. **F-15E considerations:** The F-15E Strike Eagle is a multi-role strike aircraft operated by the U.S Air Force. The F-15E was developing image receive capability to include reception of up to 10 EagleEye images. The imagery interface included the ability to zoom in on the viewed image.

7.5.8.3.1. **Image type**: The F-15E imagery interface accepted only EE imagery. When F/A-18 aircrew attempted to send JPEG images to F-15E, cockpit indications in both aircraft showed good transmission but the F-15E showed that the image type was invalid. Analysis showed that the F-15E was correctly identifying the compression type and rejecting the image as the compression type was not supported. F-15E cockpit indications were clear that the image was not useable.

7.5.8.3.2. **Annotations not displayed in F-15E cockpit**: During flight test with F-15E Strike Eagles, F/A-18 aircrew captured a targeting pod image with the targeting pod pointed toward (but not directly at) the target. The targeting pod reticle, always shown in the middle of the image, was not on the target. The F/A-18 aircrew then annotated a target away from the center of the targeting pod video using the annotation functions on the VIEW page. When the image was received in the F-15E cockpit the annotations were not displayed, causing misunderstanding of the location of the intended target and an aborted attack as the F-15E began an attack on a target other than the intended target. Analysis showed that the F-15E does not use or display the annotation portion of the image file so the F-15E aircrew saw the image with the targeting pod symbology in the middle. Figure 7.4 shows the difference in symbology. F/A-18 aircrew were not able to use annotations to point out targets or significant features in the image. F/A-18 aircrew attempting to use annotations to mark targets with F-15E will not have their annotations show up in the F-15E cockpit, resulting in confusion about target location and potential release of weapons against the wrong target. The lack of annotations in the F-15E cockpit was assessed as an interoperability problem that must be addressed through training. Aircrew recommendation to have F-15E display image annotations was



Sent from F/A-18 Received in F-15E

Figure 7.4; Potential for confusion about target location

met with roaring laughter from the USAF as U.S Navy guys tried to tell U.S. Air Force guys how to make their jet work.

7.5.8.4. **RAIDER ground station:** The RAIDER ground station is a ground based computer system that can send and receive Link-16 or VMF messages. The RAIDER system is designed to be positioned within communications range of a ground command and control station and is used to disseminate targeting data to aircraft. RAIDER capabilities include the ability to generate and send target imagery, the ability to receive imagery from aircraft, and the ability to pass those images on to other ground based applications to include DPSS software.

7.5.8.4.1. **Presence of imbedded targeting pod symbology**: As described in paragraph 2.1.3.5, the targeting pod video from which images are captured includes video imagery and targeting pod generated symbology to include target coordinates, tracking gate symbology, and field of view symbology. The presence of this symbology is controlled by the RTCL option on the FLIR page. When RTCL is boxed (the default state) the symbology is displayed and when RTCL is unboxed (manually selected) the symbology is not presented. Future enhancements to U.S Navy targeting pods will include more symbology in the targeting pod video. During flight test with ground stations using image correlation technology, ground station operators reported poor correlation confidence. Analysis showed that the embedded targeting pod symbology introduced pixels in the image that could not be correlated to features on the ground and reduced the confidence of image correlation algorithms. When attempting to correlate an image with targeting pod symbology, the image correlation algorithm was unable to match the pixels that corresponded to the targeting pod symbology with its imagery database. This resulted in low correlation confidence and inability to mensurate any coordinates out of the image. Aircrew recommendation was to deselect the RTCL option when capturing images intended for transmission to image correlation ground stations, minimizing the extra symbology and allowing best correlation confidence.

7.5.8.4.2. **Image type**: The RAIDER ground station initially accepted only JPEG images. When F/A-18 aircrew sent EE image to RAIDER the aircrew noted LAST FAIL indications and 0 percent complete. Analysis showed that RAIDER was rejecting the EE image packets and that the F/A-18 was correctly identifying the lack of link ack for image packets and failing the transmission. F/A-18 cockpit indications were clear that the image had failed. During later image development RAIDER incorporated both EE and JPEG image types.

7.5.9. **Declassify the RMM in flight**: The ability to declassify the RMM in the aircraft was evaluated during lab and ground test events. Time required to perform classified erase of the RMM was 4 hours and 40 minutes. Most F/A-18 missions are less than 2 hours in duration and most scenarios that require in-flight declassification (emergency divert) involve significantly less than 2 hours of available flight time. The very long time required to declassify the RMM was not useable. Analysis showed that the lack of in-flight erase was no worse than the previously existing 8MM tapes. Aircrew will be unable to declassify the RMM during an emergency divert resulting in potential compromise of classified information at pseudo-friendly divert locations such as Chinese islands. The lack of ability to declassify the RMM in-flight was assessed as unsatisfactory and assigned a priority E based on no requirement to be better than the existing 8mm tapes. Aircrew recommendation to provide rapid erase ”flash” RMMs was deferred to a later SCS.

7.6. **Shutdown checks**: Shutdown checks were defined as all actions required between landing and engine shutdown.

7.6.1. **SSR shutdown**:

7.6.1.1. **Save images for postflight review**: The images and associated files were already saved in a format conducive to save on JMPS. No aircrew action was required to prepare image or video for shutdown.

7.6.1.2. **Switchology for shutdown**: The CVRS record panel provided a record control switch that could be placed to the OFF position to stop recording of displays and raw targeting pod video. There was no adverse effect of performing engine shutdown prior with the CVRS switch not OFF. Switchology for shutdown was assessed as satisfactory.

7.7. **Postflight debriefing:** Postflight debriefing was defined as all activities to reconstruct the flight at the JMPS machine.

7.7.1. **Image debriefing**:

7.7.1.1. **Image download**: Postflight download of images that were captured or received in-flight was performed on JMPS stations. The RMM was connected via external firewire to the JMPS machine. The JMPS menus provided an option to "Extract RMM Data." When this option was selected the JMPS machine read the image directory of the RMM, opened a RMM post flight window, and presented the downloaded images as thumbnails. Individual images were opened in an Image View window with a full resolution view of the image and its associated data (name, data and time take, classification, META data).

7.7.1.1.1. **Image selection**: The Image View showed one image at a time. Selection of adjacent images was performed by closing the Image View window and opening a new Image View window for the adjacent image. There was no method provided to quickly step between images on the image view window. Aircrew attempting to compare adjacent images taken from a BHA sequence were required to open and close images individually. Aircrew debriefing their captured images could miss changes to image content due to the ability to quickly step between images. The inability to compare adjacent images was assessed as unsatisfactory and assigned a priority C with a workaround of using Windows based screen capture to compare images. Aircrew recommendation to provide Next Image/Previous Image selection as well as slideshow mode on the Image View window was deferred to a later SCS.

7.7.1.2. **Image save**: Images could be saved to the JMPS computer for use on later flights or for collection by intelligence personnel to evaluate target imagery. Commanding an image save resulted in the image and its three associated files being grouped and saved into a NITF file.

7.7.1.2.1. **Selection for saving**: The JMPS RMM post flight window provided options to save one image or save all images. There was no option to pick and choose images to be saved. Aircrew had to save image one by one or accept that extraneous images would also be saved. Aircrew attempting to save a partial set of images during post flight debriefing will be required to save the images individually or accept save of extraneous images. The inability to pick and choose images for saving was assessed as unsatisfactory and assigned a priority C with a workaround of saving all images. Aircrew recommendation to allow pick and choose functionality for saving images was deferred to a later SCS.

7.7.1.2.2. **Lack of NITF viewer on JMPS**: JMPS did not include an NITF image viewer. Standard Windows based image viewing applications will not open an image in NITF format. The only method available for viewing NITF images was to simulate planning a new imagery mission, which provided the Image View window with the image displayed. Aircrew were required to use JMPS mission planning software to view images saved to the computers. Aircrew will be unable to quickly view tactical images between flights, resulting in excessive timeline and workaround to view an existing NITF image. The lack of NITF viewer was assigned a priority C with a workaround of using the Image planning UPC to view the images. Aircrew recommendation to provide a NITF viewer was deferred to a later SCS.

7.7.2. **Video debriefing**: The RMM and its associated playback system provided playback of cockpit display video the raw targeting pod video from which the images were captured. Using the image name, which included the time of image capture, aircrew were able to quickly go to the time of image capture to see full resolution video frames and see the flow of the mission before and after the image capture to include image transmission setting and switchology. The video playback allowed aircrew to quickly jump to the desired portion of the mission to reconstruct captured, received, and transmitted images and their contribution to the mission.

8. Conclusions

Overall the tactical imagery integration on the F/A-18 Super Hornet with the H2E+ SCS and SSR provided increased mission capability to the F/A-18 and the ability to shorten and simplify selected steps in the kill chain.

Highlights of the evaluation of tactical imagery as integrated into the Super Hornet with H2E+ SCS and the SSR included:

Strengths:

- Image capture logic is simple and involves steps that were already being executed.
- Image annotation is simple and intuitive.
- Image transfer has proven to work well with compatible platforms.

Weaknesses

- There is no SSR BIT functionality to warn aircrew of a system degrade that could prevent image capture.
- The necessity for image compression (to make images fit within existing datalinks) results in complicated options to prepare an image for datalink transmission.
- There are very few L-16 or VMF image platforms with which images can be exchanged.
- Aircrew are unable to review and capture images from cockpit video recorded to the SSR while in flight.

Overall lessons learned

- Commercial Off The Shelf (COTS) technology must be verified to ensure proper BIT functionality.
- A requirement that strictly limits newer and more capable systems to “Form fit function” replacement can result in squandering significant potential for increased capability.
- It is difficult to develop and test emerging technologies that rely on interoperability due to the limited number of other platforms that are capable of exchanging information.
- Flexibility in design often leads to complexity of design (as exemplified by selectable image compression types and rates)

9. Recommendations

9.1. **Recommendations for use by fleet aircrew:** The following recommendations were distributed during fleet training to squadrons equipped with H2E+ and SSR.

9.1.1. **Mission planning:**

- USE NITF images when possible
- Use JPEG images only when required and carefully monitor the size of image produced

9.1.2. **Preflight checks**

- Format the RMM prior to every flight

9.1.3. **Poststart checks**

- Check SSR GO, SSR REMAINING counter, GRAB functionality prior to launch

9.1.4. **Inflight checks**

- Check SSR GO, SSR REMAINING counter, GRAB functionality prior to commencing operational portion of mission

9.1.5. **Inflight operations**

9.1.5.1. **Capture**

- Singles: CVRS on, A/G, point and shoot
- BHA sequence: Do what you've been doing, images will show up

9.1.5.2. **Image transmission**

- Use Link-16 image transmission when possible
- Use VMF only when required
- Use FAST to toggle through images
- Send MED or SLOW images
- Use voice transmission to advise recipient of incoming image

9.1.5.3. **Image reception**

- Watch for IMAGE cue in HUD/HMD
- Use voice with sender to confirm reception of image
- Carefully check that you select the new image for viewing

9.1.6. **Other platforms**

- When working with F-15E, send EE images with no annotations
- When working with image correlation ground stations, send images with minimal symbology

9.2. **Recommendation for further development:**

9.3. **JMPS development**

9.3.1. **Annotate in black/white/halo**: Make JMPS changes to allow aircrew to clearly annotate images with any color background. Suggested solutions:

- Halo all imagery annotations
- Provide a manual black/white toggle that changes the color of annotation

9.3.2. **Tag Image capable networks**: Make JMPS changes to allow aircrew to clearly tell which MIDS networks are image capable. Suggested solutions:

- During network selection tag all image capable networks with (Image)
- During network selection provide a network filter to allow aircrew to view only networks with specified properties (View only image capable networks).

9.3.3. **Arrows to scroll left/right during debriefing**: Make JMPS changes that allow aircrew to quickly scroll through consecutive images during a post flight image debriefing. Suggested solutions:

- Left/right arrows when an image is being viewed that goes to next image
- Slideshow functionality for automatically stepping between images

9.4. SSR/RMM hardware development

9.4.1. Indications of operational status

9.4.1.1. **BIT performance**: Make SSR changes that provide a robust BIT functionality to allow aircrew to quickly and accurately determine a SSR degrade status.

9.4.1.2. **Record status**: Make CVRS changes that allow aircrew to quickly and accurately determine which display surfaces are being recorded and how much record time is left. Suggested solution:

- Make CVRS control panel changes to incorporate a time remaining counter and real time indications that the selected displays are recording.

9.4.1.3. **Allow command of maximum record capacity in the aircraft**: Make SSR interface changes to allow aircrew to manually command the availability of full record capacity while in the aircraft. Suggested solution:

- Make MC changes to provide a “Format” pushbutton that when pushed commands the SSR to provide full record capacity for the RMM regardless of pre-existing video.

9.4.2. **Useable Erase**: Make Erase changes to allow aircrew to quickly and reliably erase all classified data on the RMM. Suggested solutions:

- Make SSR changes to speed the erase functions
- Make RMM hardware changes to provide “Flash” memory with self destruct capability

9.4.3. **Playback video in the cockpit**: Make SSR interface changes to allow aircrew to view SSR video in flight. Suggested solution:

- SSR hardware changes to connect the fourth video channel to the cockpit displays.
- MC changes to provide VCR functionality to include selection of any recorded display, selection of PLAY/FFWD/REW/PAUSE/STOP/FRAME FWD/FRAM REW functions, and UFCD entry of the desired time for video playback.

9.5. **Mission computer software development**

9.5.1. **VIEW cues when a new image is available:** Provide path for aircrew to view the most recently received image from the Image T/R page. Suggested solution:

- Implement a VIEW NEW pushbutton on the Image T/R format that appears when a new image has been accepted and remains until the new image has been viewed.

9.5.2. **Increased image manipulation/view options:** Provide aircrew with improved option in the cockpit for viewing received and captured images. Suggested solutions:

- Implement haloing of image annotations to allow cockpit annotations to be viewed on light images
- Implement zoom function that allows aircrew to view images at higher resolution
- Implement image rotation functions that allow 2-D rotation of the image to orient the image to the intended run in heading. Also provide an automatic mode that orients the image to the current aircraft to target heading.

9.5.3. **Reduced options for image type**: Provide aircrew with simplified image type options. Suggested solution:

- Eliminate EagleEye compression, all images in JPEG format
- Change current FAST/MED/SLOW mechanization to FAST/SLOW with FAST using current MED compression setting and SLOW using current SLOW compression settings.

9.6. **Datalink development**

9.6.1. **VMF image recipients**: Allow other VMF recipients to get the image even with one non-image capable member. Suggested solution:

- Make VMF imagery message consistent with other VMF messages by sending image packets to those nodes who ack back.

9.6.2. **Image net number improvements**: Provide aircrew the ability to mission plan own image net number and view other Link-16 participants image net number. Suggested solutions:

- Provide JMPS interface to set image net number during mission planning
- Change PPLI architecture to include image net number

9.7. **Development of parallel systems for other image platforms**: Provide datalink capability for other platforms that are potential tactical imagery platforms/customers. Suggested solutions:

- Ground station suitable for deployment with troops on foot
- Ground station suitable for deployment to command centers
- Ship station suitable for deployment on aircraft carriers
- Airborne capability for command and control aircraft
- Airborne capability for UAVs

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[d] *F/A-18E/F H2E+ DCS ACAS Requirements Mission System Operation and Function Description Revision B*. The Boeing Company February 2005

[e] *F/A-18E/F H2E+ Software Configuration Set, Increment 1 Image Capture and Transfer (ICAT) Mission System Operation and Function Description Revision E*. The Boeing Company September 2005

[f] Interview with Mr. Mike Pruitt of the AWL EO/IR task team, lead engineer for SSR integration. January 2006.

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Vita

Jesse Hilliker was born in Jamestown, New York on November 9th, 1974. He graduated from the U.S. Naval Academy in May 1996 with a Bachelor of Science in Physics and was selected to become a naval aviator. Jesse is a 2003 graduate of the United Kingdom's Empire Test Pilot School in Boscombe Down, Wiltshire, England.

Jesse is currently stationed in China Lake, California working as a developmental test pilot assigned to Air Test and Evaluation Squadron 31. He is the project pilot for two major SCS upgrades to the F/A-18 Super Hornet. He has worked since March 2004 as the project pilot on the H2E+ SCS, which includes imagery and Solid State Recorder integration. His aviation experience includes 1400 flight hours on 30 different aircraft types, 1000 F/A-18 hours, and 300 carrier arrested landings.

Jesse is married to Elizabeth Lynn Hepinstall of Spring, Texas. They have two children (Abbey Elizabeth and Wesley Randall) and two dogs who think they are children (Huffy and Huey).

Jesse is currently pursuing his Masters in Aviation Systems at the University of Tennessee Space Institute in Knoxville, Tennessee.