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Integration of the Multi-Functional Information Distribution System F-15 Fighter Data Link into the F-15C Eagle

Colin Robert Miller

To the Graduate Council:

I am submitting herewith a thesis written by Colin Robert Miller entitled "Integration of the Multi-Functional Information Distribution System F-15 Fighter Data Link into the F-15C Eagle." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Frank Collins, Major Professor

We have read this thesis and recommend its acceptance:

Uwe Solies, Fredrick Stellar

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Dr. Frank Collins, Major Professor

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U R Solies

Dr. Uwe Solies, Ph.D.

Fred Stellar

Mr. Fredrick Stellar

Accepted for the Council:

Interim Vice Provost and
Dean of The Graduate School

INTEGRATION OF THE MULTI-FUNCTIONAL INFORMATION DISTRIBUTION SYSTEM F-15 FIGHTER DATA LINK INTO THE F-15C EAGLE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee

Colin Robert Miller
May 2001

DEDICATION

This thesis is dedicated to my loving wife, Jacquie, and my amazing daughter, Katherine. Their selfless support has literally enabled me to climb beyond my highest dreams.

ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Frank Collins, for his guidance and support. I would also like to thank Dr. Solies and Mr. Stellar for their advice and service as committee members. I am also indebted to 1stLt Shelly Bruemmer of the 46th Test Squadron, 46th Test Wing, Eglin AFB, Florida, for her guidance in preparing this thesis and her tireless work in getting the critical enabling technology of the Multi-Functional Information Distribution System to our troops in the field.

ABSTRACT

The Multi-Functional Information Distribution System (MIDS) provides improved information distribution, position location, and identification capability for the forces of the U.S. Air Force, U.S. Army, U.S. Navy, U.S. Marine Corps, United Kingdom, France, and the North Atlantic Treaty Organization (NATO). The system is currently implemented through the use of a variety of terminals and tailored interface configurations designed to meet the needs of specific users.

This paper describes the MIDS Fighter Data Link as it is implemented in the F-15 fighter aircraft. It describes system architecture, F-15 aircraft integration, and system testing. The paper explains the effectiveness of the system by presenting the information management challenge involved in accomplishing the F-15's mission of gaining and maintaining air superiority, and outlining the awesome capability of the Fighter Data Link to meet this challenge. Finally, the paper proposes an application of the MIDS Fighter Data Link System to the challenges of commercial aircraft separation and control in a congested environment.

The paper is written from the author's perspective as a user and tester of the Fighter Data Link System. The author was first introduced to the system in 1994 when he performed an assessment of the system's utility as an operational F-15C fighter pilot participating in a special project at Mountain Home Air Force Base. Since that time, the author completed test pilot training and is currently involved in both developmental and operational test of the production version of the system. Recent testing has included both ground and flight test of system integration, as well as assessment of technical performance and operational effectiveness.

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AAI	Air-to-Air Interrogator
AATIS	Advanced Airborne Test Instrumentation System
ACW	Air Control Wing
ADatP-16	Allied Data Publication-16
ADS-B	Automatic Dependant Surveillance-Broadcast
AFOTEC	Air Force Operational Test and Evaluation Center
ASETS	Airborne Seeker Evaluation Test System
AWACS	Airborne Warning and Control System
BIT	Built In Test
C2	Command and Control
DI	Designation and Interrogation
DP	Data Processor
DPD	Data Processor and Display
DT	Developmental Test
DTM	Data Transfer Module
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ETR	External Time Reference
EXC/IPF	Exciter/Interference Protection Feature
FDL	Fighter Data Link
FRB	Failure Review Board
GPS	Global Positioning System
HPA	High Power Amplifier
HUD	Head Up Display
ICD/ICDA	Interface Control Document/Interface Control Document Addendum
IFF	Interrogation Friend or Foe
IJMS	Interim JTIDS Message Standard
INE	Initial Net Entry
INS	Internal Navigation System
IOP	Interface Operation Procedure
IPF	Interference Protection Feature
IPS	Internal Power Supply
IPT	Integrated Product Team

JSTARS	Joint Surveillance Target Attack Radar System
JTD	JTIDS Test Device
JTIDS	Joint Tactical Information Distribution System
LSF	Link-16 Support Facility
LVT	Low Volume Terminal
MATES	Mux Analysis and Terminal Evaluation System
MCP	Mode Control Panel
MIDS	Multi-functional Information Distribution System
MIP	Material Improvement Program
MNS	Mission Needs Statement
MPCD	Multi-Purpose Color Display
MSIP	Multi-Stage Improvement Program
NPG	Net Participation Group
NTR	Net Time Reference
OPFAC	Operational Facility
ORD	Operational Requirements Document
OSP	Operational Special Project
OT	Operational Test
pDAS	programmable Data Acquisition System
PPLI	Precise Participant Location and Identification
PRIMES	Preflight Integration of Munitions and Electronic systems
RELNAV	Relative Navigation
R/S	Receiver/Synthesizer
RTI	Receiver Transmitter Interface
RWR	Radar Warning Receiver
SA	Situational Awareness
SACP	Stand Alone Control Panel
SMP	Signal Message Processor
SNE	Start Net Entry
SPO	System Program Office
SSS/SSSA	System Segment Specification/System Segment Specification Addendum
TACAN	Tactical Air Navigation
TADIL-J	Tactical Digital Information Link-J
TCAS	Traffic Alert/Collision Avoidance System
TCG	Time Code Generator
TDMA	Time Division Multiple Access
TEAM	TACAN Engineering Adapter Mount

TIM	Terminal Input Message
TM	Telemetry
TOA	Time of Arrival
TOM	Terminal Output Message
TSPI	Time Space Position Information
UHF	Ultra-High Frequency
USAF	United States Air Force
USD[A&T]	Office of the Secretary of Defense for Acquisition and Technology
UTC	Coordinated Universal Time
VSD	Vertical Situation Display

1. INTRODUCTION

This paper describes the integration and testing of the Multi-Functional Information Distribution System (MIDS) F-15 Fighter Data Link (FDL), an advanced digital data link system being fielded in the F-15 fighter aircraft. It summarizes the system aspects of FDL, describes how the system was tested, and illustrates how it radically improves F-15 mission effectiveness by providing the pilot with real-time tactical information and intelligence data.

1.1. BACKGROUND

The F-15 Eagle is a single-seat, twin-engine, U.S. Air Force all-weather air superiority fighter (Figure 1).

Figure 1. The F-15 Eagle

The mission of the Eagle is to detect, identify, intercept, and if necessary, destroy enemy aircraft. The F-15 relies on three key capabilities for mission success:

1. A robust airframe,
2. Effective weapons, and
3. Usable, real-time, reliable information.

The first requirement is met by the advanced titanium airframe, state-of-the-art flight controls, and reliable, powerful engines of the Eagle. These systems enable the F-15 to traverse a great distance in a short period of time, arrive in the tactical arena in a position of advantage, and outmaneuver its opponent to achieve weapons firing parameters.

The requirement for effective weapons is exceeded by the compliment of advanced air-to-air missiles and internal cannon incorporated in the Eagle. These offensive systems enable the F-15 to engage and destroy targets well beyond visual range (BVR), and in the visual arena.

The third requisite for F-15 effectiveness, the availability of usable, real-time, reliable information, presents the greatest potential for improvement. On a typical mission, an F-15 pilot must assimilate a staggering amount of information from many diverse sources. These sources include voice messages received via radio, radar data displayed in the cockpit, threat information exhibited by tones in the pilot's headset and symbols on a display, and visual information from cues outside the cockpit. The speed of modern fighters requires F-15 pilots to integrate this eclectic information in a very short period of time and develop a four dimensional understanding of the tactical situation (three dimensions in space and one in time). This understanding must include knowledge of the F-15's exact location and the location and identity of all other entities in the area of operation. When a pilot has developed an accurate mental image of the situation, he is said to have "situational awareness" (SA). Pilots use SA to make quick, life-or-death decisions.

The current process of developing SA for F-15 pilots is inadequate for a number of reasons. First of all, current systems place a great burden on the pilot by requiring him to scan, understand, evaluate, and integrate information from a variety of disjointed sources. Second, the process requires the pilot to analyze information one piece at a time, which slows the SA building process. For example, F-15 pilots must "sample" radar targets one at a time to discover which direction, at what altitude, and how fast the target is traveling. After the pilot samples a target, he must remember its parameters as he breaks his radar lock and samples another. Third, critical information is not adequately shared among flight members and information sources. For instance, a command and control radar platform may know the location and identity of a particular radar contact but not pass this critical information to a group of F-15s, simply because the F-15s did not ask for it. An example of such a case was the tragic 1994 shoot-down of two U.S. Army helicopters by F-15 fighters in the Persian Gulf. The shoot-down was a direct result of an information distribution deficiency. Both the F-15s and the friendly helicopters had been in contact with the same command and control platform, yet neither the F-15s nor the helicopters were aware of the other's presence.

1.2. FDL REQUIREMENTS

The MIDS F-15 FDL (referred to as "FDL") was developed to address deficiencies in tactical information distribution, position location, and identification capabilities of U.S. and Allied command and control (C2) systems. MIDS evolved from the Joint Tactical Information Distribution System (JTIDS), which has been in development since the early 1970s, when the Air Force and Navy Integrated Tactical Navigation System programs were combined (Hill, 1991). The JTIDS/MIDS system requirements are outlined in the Multiple Required Operational Capability (MROC) for the JTIDS, a Joint Chiefs of Staff publication (Joint Chiefs, 1989, MJCS-193-89). The requirements describe a robust, secure system, which provides participants with the position and identification of all JTIDS compatible users. In addition, the specifications require high capacity connectivity between a large number of diverse users to ensure they can share tactical information. A summary of MROC requirements for the JTIDS/MIDS is shown in Figure 2.

The MIDS meets MROC requirements by providing information distribution, position location, and identification capabilities in an integrated form for surface, airborne, and sea-based military operations. These capabilities result from the MIDS unique signal structure and logical architecture which allow it to distribute information at high rates, encrypted in such a way as to provide security, and with sufficient jam resistance to yield high reliability communications in a hostile electromagnetic environment.

1.3. DATA LINK INTEROPERABILITY

The MIDS F-15 FDL is interoperable with JTIDS/MIDS terminal configurations including the Class 1, Class 2, Class 2H, Class 2M, MIDS-Low Volume Terminal (LVT) and MIDS LVT(2) terminals. These terminals, and the respective platforms in which they will be fielded, are listed in Table 1.

JTIDS/MIDS Multiple Required Operational Capability

- INFORMATION DISTRIBUTION
  - Broadcast and Point-to-Point
  - Jam Protection
  - Non-Nodal
  - Secure
  - High Capacity
- POSITION LOCATION
  - Common Grid (Relative and Geodetic)
  - High Accuracy
- IDENTIFICATION
  - Direct
  - Indirect

Figure 2. MROC Requirements

Source: Joint Chiefs of Staff. (1989). Multiple Required Operational Capability for the Joint Tactical Information Distribution System (MJCS-193-89). Joint Staff, Pentagon, Washington, DC. Classified Document.

Table 1. JTIDS/MIDS Platforms

Terminal	Description	Platforms
Class 1	The Class 1 TDMA terminal is an already-developed high power terminal currently used in large C^2 platforms. Class 1 processes IJMS only.	E-3, CRC (ASIT) (US & NATO)
Class 2	The Class 2 terminal is a smaller unit than the Class 1 terminal and was developed for use in both small and large tactical platforms. The Air Force will use bilingual terminals, which can exchange IJMS and Link-16 messages. The Navy will use Link-16 exclusively.	F-15* F-14D, JSTARS, ABCCC, MCE, MAOC
Class 2H	The Class 2H terminal consists of a Class 2 Terminal combined with the High Power Amplifier (HPA). The Air Force will use bilingual terminals, which can exchange IJMS and Link-16 messages. The Marine Corps and Navy will use Link-16 exclusively.	CVs & CGs, E-2C, E-3, TAOM/ATACC
Class 2M	The Class 2M terminal is smaller, lighter, and more reliable than the Class 2 terminal. The Class 2M terminal is bilingual, intended for Army ground applications; however, the Class 2M will support the reception of the surveillance air picture and other information/data transmitted from C^2 platforms through an air-to-ground downlink.	PATRIOT, $FAADC^2I$, JTAGS, THAAD
MIDS LVT	The MIDS LVT is an international (US, France, Germany, Italy, Spain) cooperative program established to develop and produce tactical information system terminals that are smaller, lighter, fully compatible with, and as capable as, JTIDS Class 2 terminals.	F/A-18, F-16, AMX, Rafale, Ground C2, Ship, Army Ground, EF2000, SAMOC, Frigate 124
MIDS LVT(2)	The MIDS LVT(2) is a variant of the MIDS LVT used by the Army as an upgrade to the Class 2M.	CORPS SAM, MEADS
MIDS F-15 FDL	The FDL terminal is a smaller, less capable (lower power, no voice, no Tactical Air Navigation [TACAN]) unit than the Class 2 Terminal intended to meet an urgent schedule need for the F-15 platforms.	F-15
* 20 F-15C/Ds at Mountain Home AFB, ID have flown with Class 2 terminals for over 7 years under an Operational Special Project (OSP).		

All JTIDS/MIDS terminals, except the Class 1 terminal, use the Tactical Digital Information Link-Joint (TADIL-J) message protocol, also designated Link-16 by the US Navy. The Interim JTIDS Message Standard (IJMS) used by the Class 1 terminal, was a precursor to Link-16 and is compatible. The primary difference between JTIDS and MIDS is the terminal hardware. MIDS is a lower cost version of the JTIDS Class 2 terminal and operates at a reduced power level. In addition, it lacks the JTIDS secure digital voice channel (JTIDS Voice) for network voice communication. MIDS F-15 FDL, or "FDL," is the specific MIDS terminal hardware configuration designed to fit in the F-15. A picture of the FDL is provided in Figure 3.

1.4. FDL FEATURES

Key Features. Key features of the FDL terminal include its Link-16 waveform compatibility, Tactical Digital Information Link-J (TADIL-J) message specification capability, and its capability to fit in the F-15 fighter aircraft.

System Architecture. The FDL uses the JTIDS/MIDS Time Division Multiple Access (TDMA) system architecture. By dividing time into a recurring cycle of time

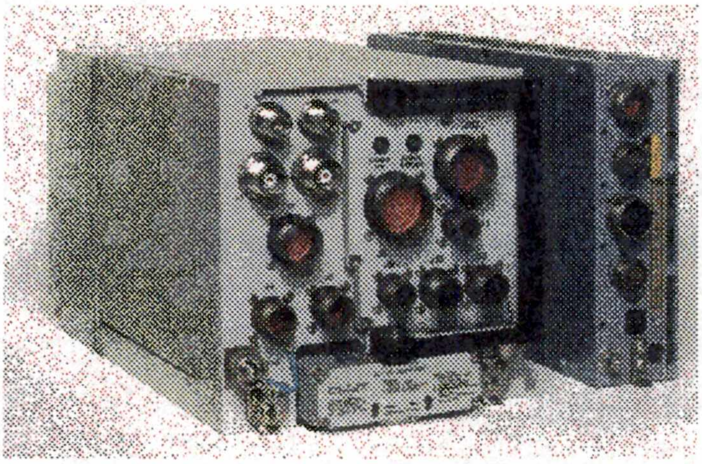


Figure 3. FDL Terminal

slots, and combining these time slot cycles with multiple pseudorandom frequency-hopping sequences across 51 channels, FDL provides a multi-user, multi-net capability. Various access modes enable network designers to tailor time slot usage to meet operational needs.

Position Location. FDL provides a position location capability, which allows an FDL-equipped element to locate itself with a high degree of accuracy in a geodetic and/or relative grid system. Each terminal determines its position location by synchronizing to system time and measuring the time-of-arrival (TOA) of position reports transmitted by FDL and other Link-16 participants.

Electronic Jamming Protection. FDL uses Reed-Solomon encoding and direct sequence spread-spectrum techniques to generate a jam-resistant error-tolerant waveform.

Data Distribution. FDL uses the JTIDS TADIL-J/Link-16 message standard to distribute digital information among system users. MIL-STD 6016, Link-16 Message Catalog specifies the Link-16 message formats, conventions, rules, protocols and procedures which must be followed to participate on the Link-16 interface. Allied Data Publication-16 (ADatP-16) specifies the Interface Operating Procedures (IOP). Through the periodic transmission of Link-16 Precise Participant Location and Identification (PPLI) messages, FDL provides a secure identification capability to all net participants. Link-16 also supports the exchange of surveillance (air, ground, maritime, subsurface, and electronic warfare), control, and special purpose information.

2. INFORMATION DISTRIBUTION

The basic characteristics of the FDL are presented in Table 2. The system operates in the radio frequency band of 960 to 1215 megahertz, and transmits a bit-oriented message information form, which permits the use of highly efficient digital message construction.

2.1. FDL ARCHITECTURE

The Link-16 network employs the principal of Time Division Multiple Access (TDMA), an automatic function of the FDL terminal. TDMA facilitates communication between users by defining an integrated, time-based, talk-and-listen schedule for all participating units. All network users are pre-assigned sets of time slots in which to transmit their data and in which to receive data from other users. This structure divides time over a 12.8 minute epoch into 7.8125 millisecond time slots, resulting in 128 time slots/sec/net and 98,304 time slots/net in an epoch. The 7.8125 millisecond time slot is divided into a variable start interval (jitter), a synchronization preamble, the information (message) transmission, and a propagation time period. The propagation time period

Table 2. FDL Characteristics

Parameter	*Characteristic*
Bit Oriented Messages	225 bits to 1860 bits plus header
Radio Frequency Spectrum	960 to 1215 MHz, 153 MHz bandwidth
Frequency Hopping	51 Frequencies spaced 3 MHz apart
Radio Frequency Pulse	
Center Frequency	Hopped over 51 frequencies
Duration	6.4 microseconds
Bandwidth	3 MHz
Symbol Encoding	
Pulses per symbol	1 or 2
Bits per pulse	5

allows for the propagation of messages to a normal range of 300 miles, or an extended range of 500 miles in the extended range mode, before a new time slot starts. The Link-16 TDMA structure is depicted in Figure 4.

Frequency hopping patterns are used by the network to provide anti-jam capability. The FDL terminal continuously hops between 51 discrete frequencies in a pseudo-random pattern that is impossible to predict. This weakens the effects of potential threat jammers by forcing them to spread their jamming energy over the entire Link-16 frequency spectrum.

Another benefit of frequency hopping for the FDL is that different frequency hopping patterns can be used to transmit multiple parallel data exchanges, increasing throughput. These frequency hopping patterns are called "nets" (Figure 4). One hundred twenty seven such nets can operate simultaneously in synch, producing a network. A designated terminal in a group of users, designated the Net Time Reference (NTR), acts as the time reference for all nets in a single network structure, and causes the time slots of each net to exactly coincide. Any terminal can be designated the NTR, and the NTR can be changed during network operations. This creates a survivable, "nodeless" architecture.

2.2. LINK-16 MESSAGE STRUCTURES

Network transmissions in each time slot consist of a train of pulses organized in a symbol signal structure. Each symbol conveys 5 bits of data using either one 6.4 microsecond pulse in a 13 microsecond period, or two 6.4 microsecond pulses in a 26 microsecond period. In the 26 microsecond double pulse approach, both pulses

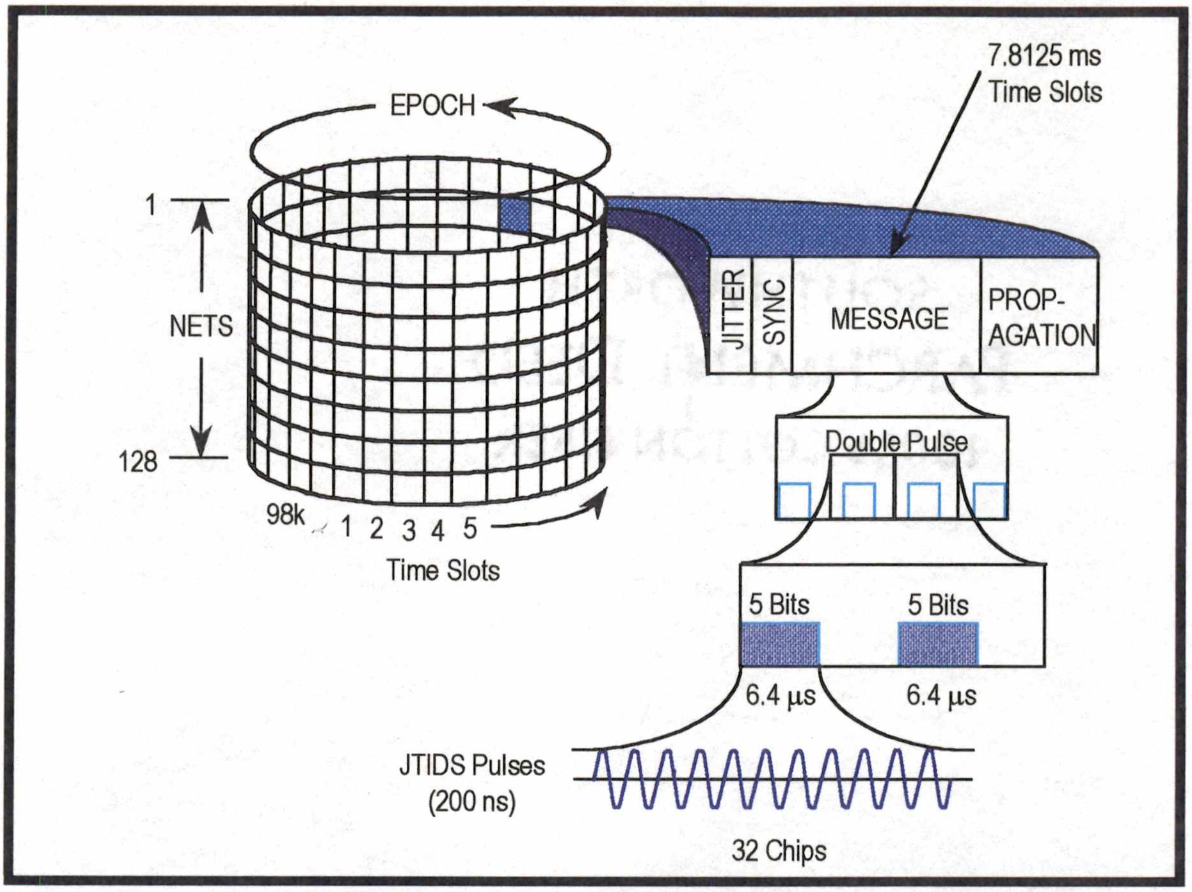


Figure 4. Link-16 TDMA Architecture

Source: Adapted from: Logicon, Inc. (1996). Understanding Link-16, A Guidebook for New Users. San Diego, CA.

contain the same 5 bits of data (symbol). In secure modes of operation, the data is encrypted.

The message structures available for use with the Link-16 time slot are shown in Figure 5. The various structures provide different information capacities, which can be matched to the type of information being transmitted. The standard, double-pulse structure is the most robust from a performance standpoint. Other structures permit the packing of two and four messages in the time slot through the use of the single pulse structure and/or the deletion of the message starter (jitter). These densely packed structures offer increased throughput, up to 238 kb/s, which is about 8 times as fast as the

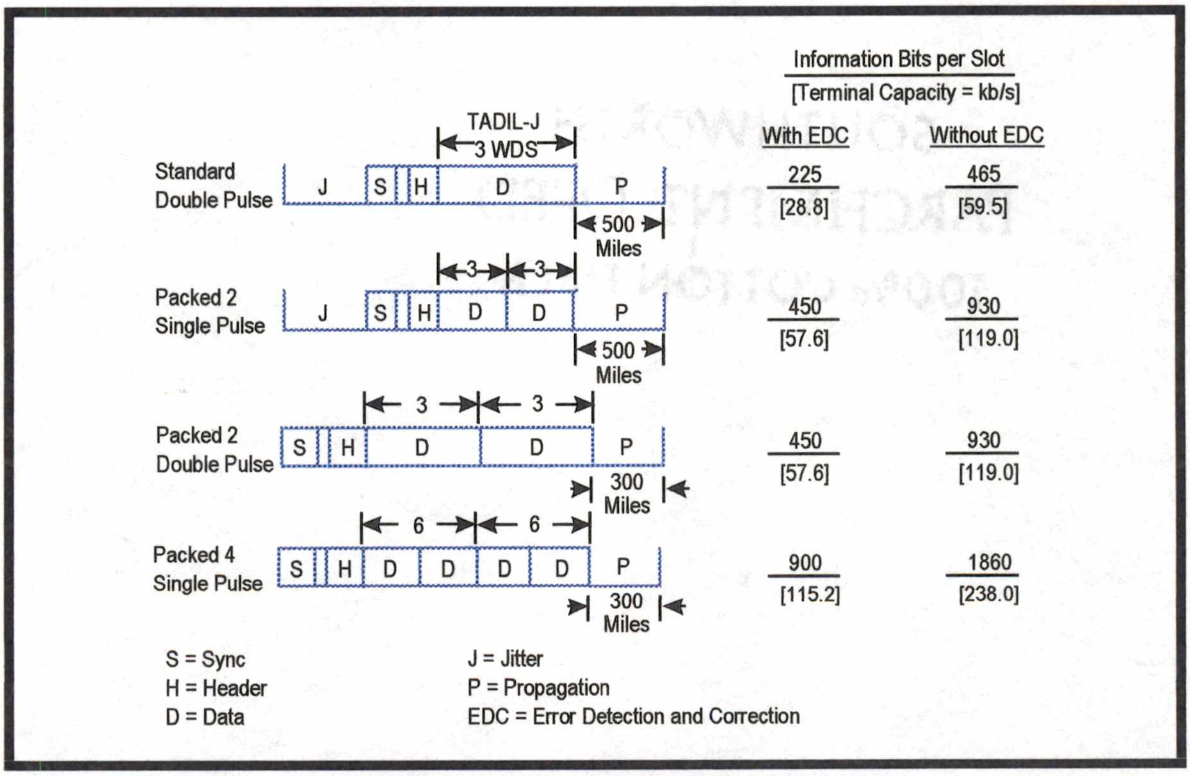


Figure 5. Link-16 Message Structures

Source: Adapted from: Logicon, Inc. (1996). Understanding Link-16, A Guidebook for New Users. San Diego, CA.

best older data links. The penalty for speed however, is range. Some of the more densely packed structures reduce propagation time, limiting range to 300 nautical miles.

The Link-16 message standard was developed by the JTIDS Message Standards Working Group (JMSWG) (Joint Chiefs, 1989, JCS Pub 6-01.1). Link-16 messages are identified by a message type code included in the message header. The type code identifies the message as standard, packed-2 double pulse, packed-2 single pulse, or packed-4, and it states whether or not error detection and correlation is used.

2.3. NETWORK ORGANIZATION

The Link-16 architecture provides building blocks for a wide variety of information distribution techniques that can be configured by the user to match particular needs. Network capacity is apportioned among multiple "virtual circuits" whose transmissions are dedicated to a single function. Participants are assigned to these circuits, or Network Participation Groups (NPGs), as required by their mission and their capabilities. Some of the NPGs in use are: Friendly force identification and position reporting, battle group surveillance, fighter-to-fighter target sorting, air control, electronic warfare reporting and coordination, battle group mission management and weapons control, and two secure voice channels (Logicon, 1996). This division of the net into functional groups allows users to participate on only the NPGs used for functions which they perform. A maximum of 512 participation groups are possible, and FDL terminals allow a single user to participate in up to 32 of them simultaneously (MITRE, 1993).

The FDL terminal automatically transmits and receives data within NPGs at pre-assigned times on pre-assigned nets based on instructions given to it when it is initialized.

Initialization instructions are determined and programmed in advance of operations to support the expected information exchange requirement (MITRE, 1993).

NPGs may operate on a single net or may operate on several nets within a network simultaneously. These nets, which are operating on the same time schedule but on different frequencies are referred to as "stacked nets." Stacked nets are particularly useful for air control NPGs employing mutually exclusive sets of controlling units and controlled aircraft as shown in Figure 6 (Logicon, 1996). The air control NPG's data link typically contains commands to the fighters, responses from the fighters, fighter engagement status, and target reports. Stacking air control NPGs on different nets ensures that fighters do not receive conflicting control instructions from different controlling agencies.

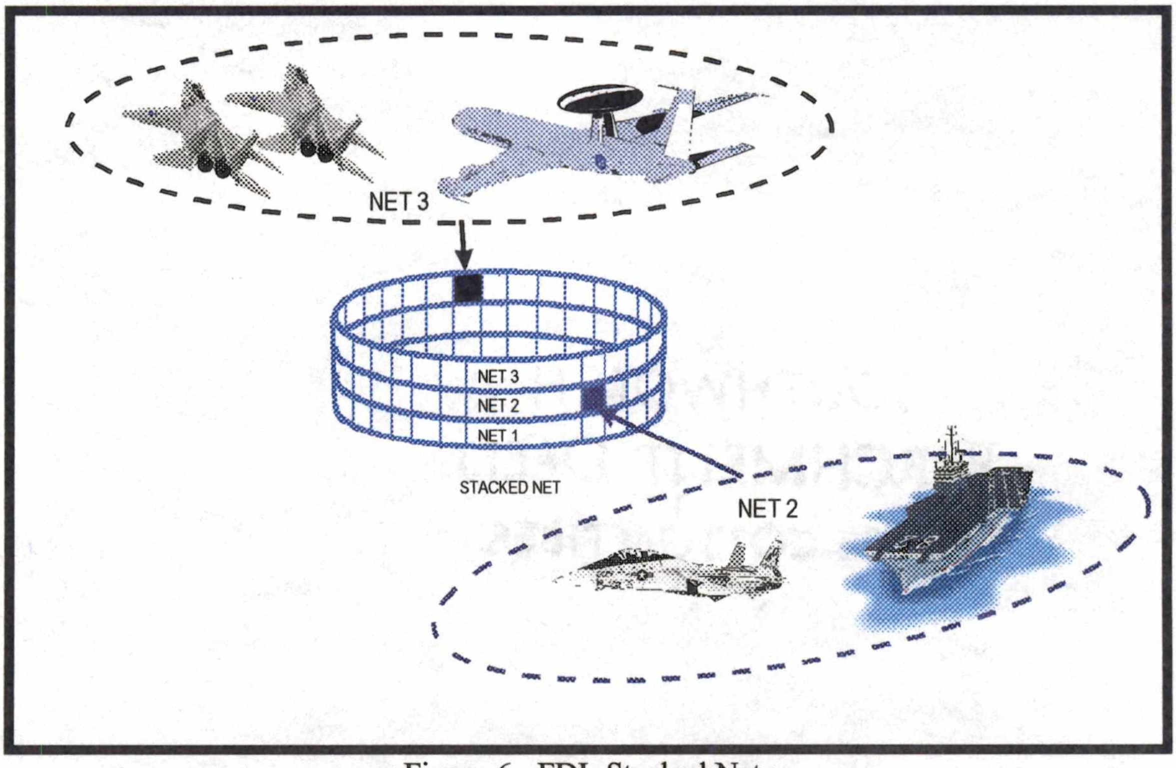


Figure 6. FDL Stacked Nets

3. POSITION LOCATION

Another requirement for the FDL, outlined in the JTIDS MROC, was that it provide the user with accurate position location information. This information is crucial for F-15 pilots who consistently operate near political and operational boundaries and near ground-based threats.

The FDL provides a position capability, which allows the user to determine location with high accuracy (Less than 50 feet) in a geodetic and/or relative grid system (U.S. Atlantic Command, 1995). Position location is determined by measuring the time-of-arrival (TOA) of position reports transmitted by Link-16 participants (Figure 7). The FDL-equipped unit synchronizes to system time and measures the position location message propagation time between the transmitter and itself. This time allows the unit to define its range from the transmitter. Similar range from other transmitters, and/or subsequent range measurements from the original transmitter, combined with knowledge of the transmitters' location, can be processed to calculate the position of the element relative to those sources.

Onboard navigation systems can enable a user to improve FDL position accuracy, and in turn, FDL position information can be used to correct onboard navigation systems. Once position is determined, it can be registered to a three dimensional, common geodetic grid by the use of Link-16 reporting ground sites, which know their position via some other method such as site survey or use of the Global Positioning System (GPS). This geodetic position is reported in terms of latitude, longitude, and altitude. If reference positions cannot be established, FDL position location can operate on a completely relative grid whose origin is designated by any user defined as navigation

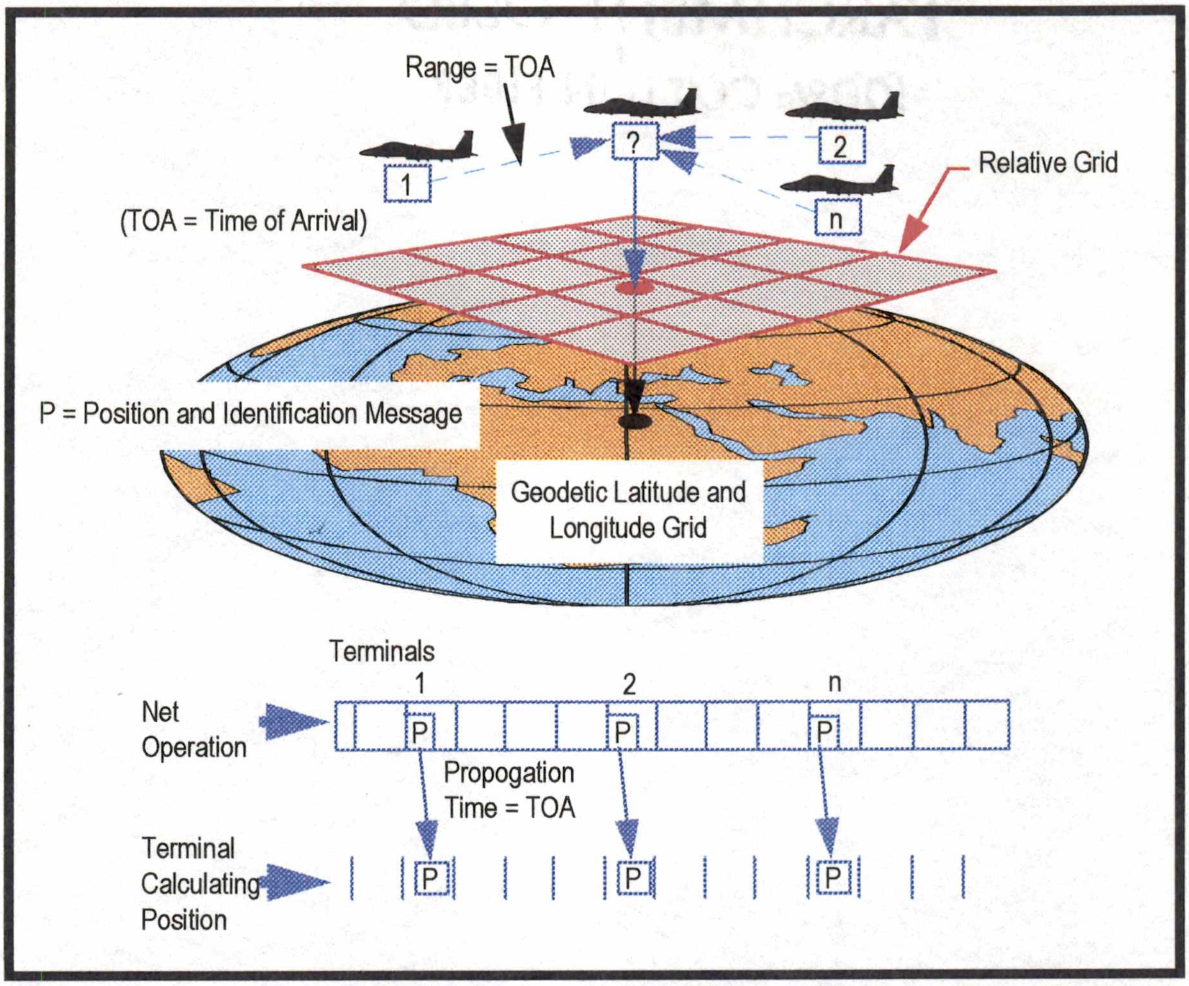


Figure 7. FDL User Position Computation

Source: Adapted from: Logicon, Inc. (1996). Understanding Link-16, A Guidebook for New Users. San Diego, CA.

controller. Like the Net Time Reference, the navigation controller function can be performed by any FDL user, and can be handed-off during network operations.

Regardless of the grid system used, once the user has calculated its position, it transmits periodic position reports for others to use (Figure 8).

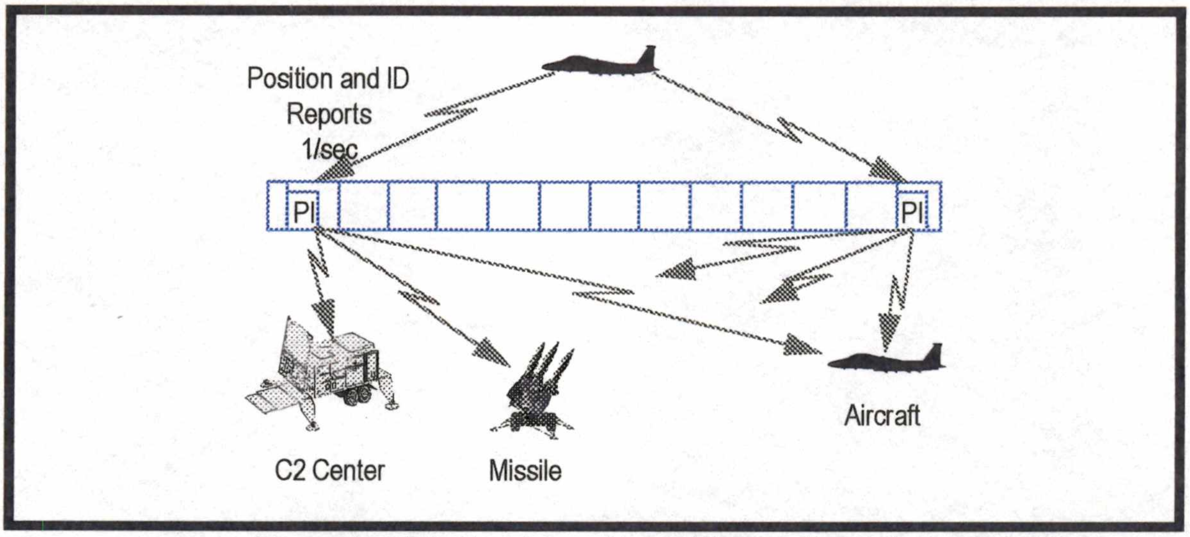


Figure 8. FDL Position and Identification Reporting

Source: Adapted from: MITRE JTIDS Project Staff. (1993). JTIDS Overview Description (MTR 8413R2). Bedford, MA.

4. IDENTIFICATION

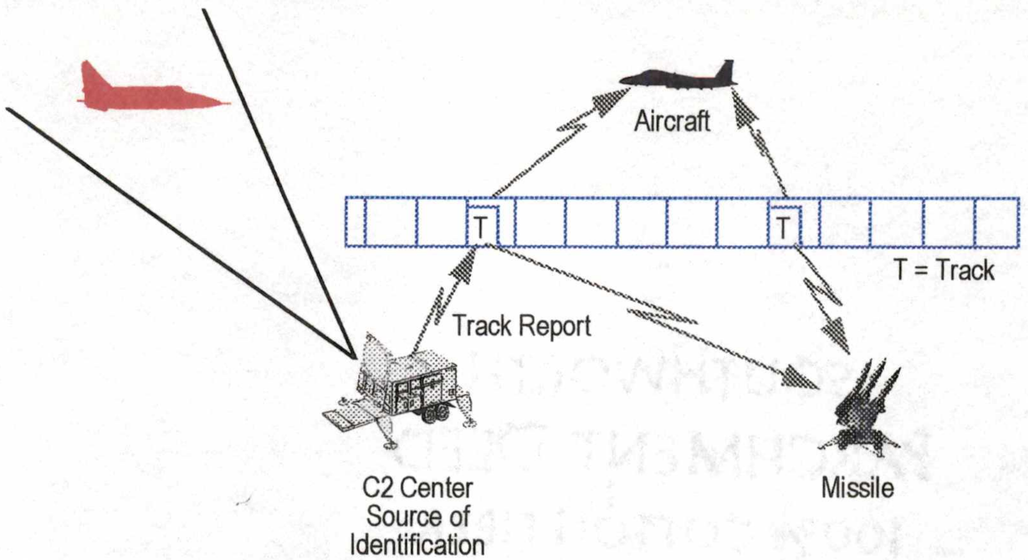
The final major requirement for JTIDS was that it provide identification of friendly, neutral, and hostile entities reported on the network. As illustrated by the friendly helicopter shoot-down described in Section 1, identification capability is vital to the F-15's mission. FDL identification is accomplished by direct reporting of Link-16-equipped entities and indirect reporting of non-participating entities.

4.1. DIRECT IDENTIFICATION

The FDL provides direct identification among Link-16-equipped elements through periodic self-reporting of positive identification messages coincident with the position reports illustrated in Figure 8. These messages categorize the originator as a friendly or neutral entity and further identify the originator's aircraft or vehicle type. All network participants receive identification messages.

4.2. INDIRECT IDENTIFICATION

The FDL provides indirect identification through its information distribution function. Participants having identification information regarding non-participating entities broadcast this information on the network for all other participants to receive as appropriate. This information is normally obtained by radar, intelligence, or other sensors native to the message originator (Figure 9).



Indirect identification occurs when a Link-16 user, such as a command and control center, identifies a non-participating entity and transmits this identity information on the network for other Link-16 participants to use.

Figure 9. Indirect Identification of Hostile Aircraft

Source: Adapted from: MITRE JTIDS Project Staff. (1993). JTIDS Overview Description (MTR 8413R2). Bedford, MA.

5. F-15 FDL INTEGRATION

5.1. F-15 FUNCTIONAL EQUIPMENT

The FDL terminal was designed for 50 watt transmit power and two receiver synthesizers. It is comprised of four main components; Internal Power Supply (IPS), Modular Power Amplifier, Adaptable Front Panel Connector Plate, and SEM-E Modules. Seventy percent of the system is common with other MIDS terminals. The common MIDS modules are the Exciter/Interference Protection Feature (EXC/IPF), dual Receiver/Synthesizer (R/S), Receiver/Transmitter Interface (RTI), IPS, Signal Message Processor (SMP), and the Data Processor (DP). Other equipment in the F-15 (some with modification) used with FDL includes: FDL/JTIDS mode control panel, navigation antennas, the aircraft digital data bus, central computer, and Multi-Purpose Color Display (MPCD) (MITRE, 1993). Of greatest interest is the MPCD, because it displays JTIDS information in an easily understood presentation for the pilot, making the abundance of JTIDS data usable.

5.2. FDL DISPLAY

The FDL information is presented on the multi-purpose color display (MPCD) (Figure 10), a five-inch, sixteen color CRT display. The unit displays ownship radar targets, FDL data, armament data, and system test information, as selected by the pilot.

The display presents a graphic representation of the tactical situation. A display controller (much like a track-ball), mounted on the pilot's throttle control, allows the pilot to move a designation and interrogation (DI) symbol (much like a cursor) on the display to change display ranges, access other displays (pages), and obtain amplifying data on display symbols.

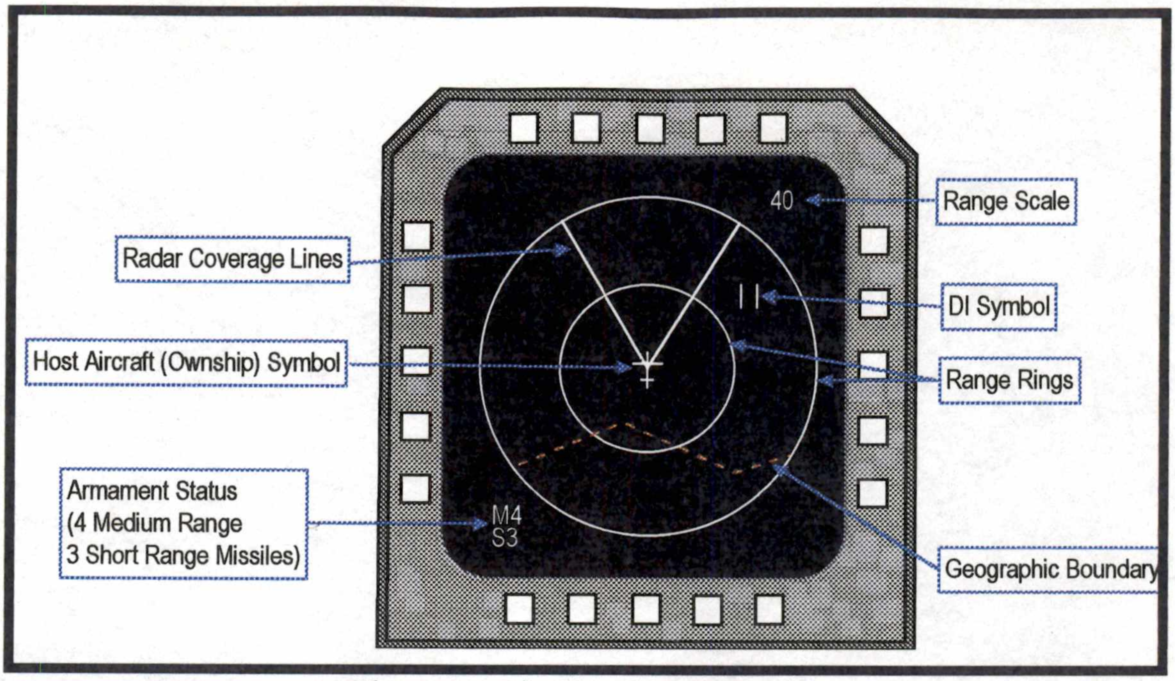


Figure 10. The F-15C FDL Display

The basic situation display shows range rings and a range scale value, which can be increased or decreased by placing the DI symbol against the top or bottom of the display. The range scale value can be selected from 5 to 320 nautical miles. The display center is normally located at the position of the host aircraft (i.e. self-centered). However, an option exists to center the display at a desired point beyond aircraft current position. These range and centering options allow the pilot to display available FDL information in any area of interest.

Selected FDL reported tracks (from surveillance assets or other fighters) may be transferred to the radar display to assist the pilot in acquiring targets. At the same time, radar targets detected by on-board radar are automatically shown on the FDL display and are correlated with other FDL information received from separate fighters and off-board sensors. This "other" information may include target type (e.g. MiG-29), target altitude, and number of aircraft within the target group.

5.3. FDL DISPLAY CONVENTIONS

The FDL display utilizes five of the MPCD's sixteen colors to distinguish types of data: green depicts friendly objects, white indicates pilot actions, red indicates hostile objects, blue indicates assignment and wingman symbols, and yellow indicates unknowns and routes (U.S. Atlantic Command, 1995). Common FDL display symbols are shown in Figure 11. Symbols are shape coded as well as color coded to allow compatibility with night vision goggles, which do not transmit color. Circles indicate friendly aircraft, squares neutral aircraft, and triangles hostile aircraft. Typical displays consist of hostile and friendly tracks with the range scale selected by the pilot. Additional information includes command messages in text form and engagement information from other aircraft, including which target their radar is locked to, whether or not they have shot a missile at that target, and their current weapons and fuel state. The pilot can select which types of data are displayed (e.g. surveillance tracks, ships, surface-to-air-missiles, and navigation lines) to show mission and situation-specific data without overcrowding the display.

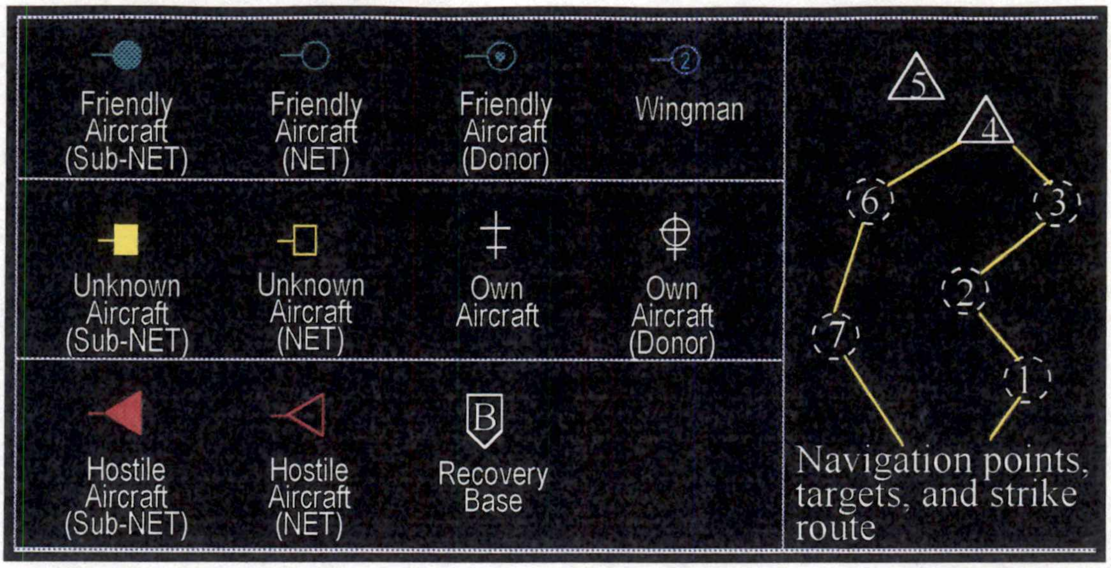


Figure 11. FDL Symbology

Source: Adapted from: MITRE JTIDS Project Staff. (1993). JTIDS Overview Description (MTR 8413R2). Bedford, MA.

6. FDL TESTING

6.1. TEST BACKGROUND

Multi-Functional Information Distribution System (MIDS) F-15 Fighter Data Link (FDL) testing was performed by the 46th Test Squadron, Eglin AFB, FL. Testing consisted of bench, ground, reliability, radio frequency absorber lined chamber, and flight testing from 25 March 1998 through 31 May 2000. USD(A&T) MIDS Production Transition Acquisition Decision Memorandum directed an accelerated testing approach for the acquisition of the FDL reduced function Link-16 terminals for the F-15. The underlying basis for an accelerated program was viable because the Joint Tactical Information Distribution System (JTIDS) Class 2 terminal had previously undergone comprehensive and exhaustive testing on the F-15 in the 1980s, proving the effectiveness and suitability of Link-16. The test team used the proven JTIDS Class 2 terminal as an interface baseline to validate FDL specification functionality and interoperability.

6.2. TEST OBJECTIVES

The overall objective of the test was to demonstrate that the FDL could communicate effectively in a Link-16 network. To do this, the FDL terminal had to be able to accept cryptographic (crypto) keying, successfully enter or establish a Link-16 network, operate in all modes, process messages, provide navigation information per Link-16 specifications, and be compatible with other systems on the F-15 aircraft. The FDL System Segment Specification/System Segment Specification Addendum (SSS/SSSA) and F-15 Interface Control Document/Interface Control Document Addendum (ICD/ICDA) established the technical parameters that had to be met. Specific objectives were:

OBJECTIVE 1: Demonstrate the F-15 FDL terminal initialization and crypto key fill (loading) meet SSS/SSSA and F-15 ICD/ICDA requirements.

OBJECTIVE 2: Demonstrate the F-15 FDL terminal timing and synchronization meet SSS/SSSA requirements.

OBJECTIVE 3: Demonstrate the F-15 FDL terminal modes of operation meet SSS/SSSA requirements.

OBJECTIVE 4: Demonstrate the F-15 FDL terminal message processing meets SSS/SSSA requirements.

OBJECTIVE 5: Demonstrate the F-15 FDL terminal navigation meets SSS/SSSA requirements.

OBJECTIVE 6: Demonstrate the F-15 FDL terminal communications performance meets SSS/SSSA requirements.

OBJECTIVE 7: Demonstrate the F-15 FDL terminal aircraft compatibility with other F-15 systems.

6.3. INSTRUMENTATION

6.3.1. Ground Instrumentation

Mux Analysis and Terminal Evaluation System (MATES). The MATES was a test device used to verify correct operation of the FDL terminal by monitoring the 1553 multiplex bus between the FDL terminal and its host aircraft. A bus transformer was used to couple the data on the bus with the MATES system computer. The system consisted of a Gateway Pentium 120 computer, a 17-inch monitor, a two-channel Excalibur 1553EP/MI bus card, four Northgate 1553 bus couplers, and special software.

Time Space Position Information (TSPI). Accurate TSPI data was provided from aircraft Global Positioning System (GPS) pods or range reference radars. Accuracy of GPS TSPI data were less than ±20 inches. As a backup to the reference radars, AN/FPS/16 radars were used to accurately track the FDL, JTIDS and target aircraft throughout the Eglin test range.

Real-time Link-16 Data Processor and Display (DPD). Real-time F-15 Multi-Purpose Color Display (MPCD) Video and 1553 Bus telemetry (TM) data were received, de-commutated and displayed in the Link-16 Support Facility (LSF).

Telemetry Video Display. The capability to view and display up to four cockpit video displays was possible through the use of Enterdyne video decoders and NTSC video boards in the Dell TM display personal computers located in the LSF.

JTIDS Test Device (JTD). The JTD was a command and control simulator. It had the capability to send and receive Link-16 messages to and from a Link-16 equipped aircraft. It could also be used to generate and playback pre-scripted scenarios and display all transmitted and received Link-16 messages.

Relative Navigation (RELNAV) Van. The RELNAV van was a mobile unit equipped with a Link-16 terminal and also has an on-board UHF radio for ground-to-air communications. The van was used during flight testing to provide a known ground reference point for Link-16 navigation testing.

Terminal Exerciser (TE). The TE was a contractor provided computer that could be connected to the FDL terminal to monitor the action within the FDL terminal. This test tool was used during bench tests to monitor the internal FDL terminal action and for troubleshooting purposes.

F-15 Operational Facility (OPFAC). The F-15 OPFAC was an F-15 simulator used to test the FDL terminal with the F-15 host in a laboratory environment. The OPFAC had real F-15 avionics with radar and navigation simulation.

6.3.2. Airborne Instrumentation

Two JTIDS Class 2 Terminal Equipped F-15C/D Aircraft. Two F-15C/D Multi-Stage Improvement Program (MSIP) aircraft were modified to accept the JTIDS Class 2 terminal and associated instrumentation. As a T-2 modification, the AN/ARN-118 TACAN system was removed and the JTIDS Class 2 terminal, with its embedded TACAN function, was installed in its place. A JTIDS Mode Control Panel (MCP) was installed to control JTIDS terminal power and other unique JTIDS functions. The Advanced Airborne Test Instrumentation System (AATIS) or the programmable Data Acquisition System (pDAS) was also installed to collect, and record JTIDS terminal and aircraft data of interest. An 8-millimeter recorder or VHS recorder system was installed to record the JTIDS MPCD, the Heads Up Display (HUD), and the Vertical Situation Display (VSD). The aircraft were also equipped with telemetry packages for data and video, a G-band radar tracking beacon, and a time code generator (TCG). The F-15 Class 2 terminal equipped aircraft served as an airborne Link-16 relative grid navigation source and as a baseline for F-15 FDL operations.

Two FDL Terminal Equipped F-15C/D Aircraft. Two F-15C MSIP aircraft were modified to accept the FDL terminal and associated instrumentation. As a T-2 modification, the FDL terminal was installed according to the Boeing FDL terminal installation documentation and drawings. A Link-16 MCP was installed to control Link-16 terminal power and other unique Link-16 functions. The AATIS was used to collect and record Link-16 terminal and aircraft data of interest. An 8-millimeter recorder system was used to record the Link-16 displays (HUD, MPCD, VSD). The aircraft was also equipped with telemetry packages for data and video, a G-band radar tracking beacon, and a time code generator (TCG).

One JTIDS Class 2 Terminal Equipped C-130 Aircraft. The Airborne Seeker Evaluation Test System (ASETS) C-130A aircraft was modified to accommodate the JTIDS Class 2 terminal. The C-130 acted as an F-15 host system and had F-15 avionics equipment installed. The Link-16 equipment was installed in 19" racks in the cargo area of the aircraft. The installation included a Stand-alone Control Panel (SACP) to monitor Class 2 terminal internal status and enable real-time parameter changes not possible on the F-15 aircraft. The C-130 acted as a relay terminal and a navigation participant. The instrumentation included pDAS, MARS 2000 tape recorder, and an MPCD video recorder. This test aircraft was also equipped with a G-Band radar tracking beacon and TCG.

E-3 Airborne Warning and Control System (AWACS). An AWACS aircraft was used for command and control during three combined developmental test (DT)/ operational test (OT) flights flown on the F-15C/D aircraft in conjunction with the Air Force Operational Test and Evaluation Center (AFOTEC). The AWACS provided the air-to-air Link-16 picture during these missions.

6.4. TEST AND EVALUATION

6.4.1. OBJECTIVE 1: FDL Terminal Initialization and Crypto Key Fill

6.4.1.1. Test Procedures

Terminal initialization and crypto key fill was tested through bench tests, aircraft ground tests, and flight tests. Nine parameters were measured on the FDL terminal as listed in Table 3. For the bench test portion, the FDL terminal was installed in the F-15 OPFAC. The terminal was placed in NORMAL operation, initialized, and entered in a net operation with a Class 2 terminal in the JTIDS Test Device (JTD). For each bench test, the MATES examined the terminal input message (TIM) and terminal output message (TOM) bus data to confirm proper initialization and key fill.

For the F-15 aircraft ground tests (ground mount), the FDL terminal was installed in a modified F-15. The FDL terminal was keyed with crypto variables. The terminal was then placed in NORMAL operation, initialized, and entered in a net operation with a Class 2 terminal in the JTD. Terminal operation with the JTD and MPCD video telemetered from the aircraft to the LSF was monitored for proper terminal operation. Rollover (automatic switching from one crypto key to another at the start of a new day) was verified, as well as the ability of the terminal user to erase the crypto variables for security reasons. The different TIMs and TOMs, between the terminal and its host, were recorded from the 1553 mux bus in the aircraft on the AATIS.

During the flight test, the FDL terminal was installed in an F-15 aircraft. The MPCD video telemetry was examined for the proper display indications for initialization, time of day/date and crypto functions. The different TIMs and TOMs, between the terminal and its host, were recorded from the 1553 mux bus in the aircraft on the AATIS. Following each flight test, this data was reduced to confirm proper operation.

6.4.1.2. Criteria.

The ICD and SSS established criteria for each parameter. Results are listed in Table 3.

Table 3. FDL Terminal Initialization and Key Fill Test Summary

Objective 1: Initialization and Key Fill (10 Sub-objectives)			
Sub-Obj	**Description**	**Test Method**	**Rating**
1.1	Terminal/host information exchange	Bench/F-15 Gnd/Flight	Satisfactory
1.2	Initialization loading	Bench/F-15 Gnd/Flight	Satisfactory
1.3	Time of day and date	Bench/F-15 Gnd/Flight	Satisfactory
1.4	Deleted.		
1.5	Crypto loading in STANDBY	Bench/F-15 Gnd/Flight	Satisfactory
1.6	Maintenance of data through STANDBY	Bench	Satisfactory
1.7	Crypto zeroize	Bench/F-15 Gnd	Satisfactory
1.8	Midnight rollover	Bench/F-15 Gnd	Satisfactory
1.9	Missing cryptovariable detection	Bench	Satisfactory
1.10	Power interrupt	Bench	Satisfactory

6.4.1.3. Test Results and Discussions

All sub-objectives passed, although deficiencies remain open for sub-objectives 1.1, 1.2, 1.7, and 1.10. Testing in support of sub-objective 1.1 showed that the FDL terminal both received more messages than were transmitted, and received fewer messages than were transmitted, at different times during the normal mode of operation. Under test conditions, the terminal should have transmitted exactly as many messages as it received. This problem was intermittent, and had no noticeable impact on terminal performance. However, the data showed that message traffic was not operating at peak efficiency. The problem will be corrected during the next scheduled software change release for the FDL.

There was one small deficiency in sub-objective 1.2. FDL network parameters were loaded into the FDL system with a solid-state Data Transfer Module (DTM) after aircraft startup. These parameters include the network and network participation group(s) with which the user will exchange data and the frequencies and hopping pattern required to enter the network. When the DTM was inserted into the aircraft during testing, the FDL load date was not displayed on the MPCD until a master reset was performed. This was a known problem with the current integrated avionics software (Suite 3M) and had also been observed with JTIDS Class 2 terminals. The deficiency was converted to a deficiency report and will be corrected in the next scheduled avionics software change release.

One deficiency is unresolved for sub-objective 1.7. The crypto cue, which indicates that the crypto has been erased, was not displayed on the MPCD after the ZEROIZE (erase) switch was activated on the MCP when the FDL was in NORMAL, but not in the network. The crypto cue was displayed when net entry was started or after a master reset. This deficiency was converted to a deficiency report and will be resolved through the F-15 System Program Office (SPO) Material Improvement Program (MIP) process.

One deficiency was reported for sub-objective 1.10. The FDL terminal lost initialization data and dropped from the network during prime power interrupt that occurred within 10 seconds of midnight. This problem should be resolved in a future scheduled software change release.

Since none of the deficiencies for objective 1 adversely affected system performance, and since a master reset could clear two of the four, the deficiencies did not prevent the system from receiving a "Satisfactory" rating for objective 1.

6.4.2. OBJECTIVE 2: FDL Terminal Timing and Synchronization

6.4.2.1. Test Procedures.

Eleven timing and synchronization functions of the FDL terminal, as listed in Table 4, were tested in bench missions. Test data were also collected during flight test missions. For ground test missions, the FDL terminal was installed in the OPFAC and attempted a net entry with another terminal, which was a net time reference (NTR) or in sync with an NTR. The time from start net entry (SNE) to achieve Coarse Synchronization (Course Sync) and Fine Synchronization (Fine Sync) was recorded. TOM data on the 1553B mux bus contained information on the net entry status. The FDL terminal average time to achieve Fine Sync from Coarse Sync was computed, and compared with the specification requirements.

During the flight tests, the FDL terminal was installed in an F-15 aircraft, and every terminal mission synchronization attempt was monitored in real-time via MPCD video telemetry. MATES was used post-mission to compile appropriate TIM and TOM

Table 4. FDL Terminal Timing and Synchronization Test Summary

Objective 2: Timing and Synchronization (9 Sub-objectives)			
Sub-Obj	**Description**	**Test Method**	**Rating**
2.1	Synchronization (active - non NTR)	Bench/F-15 Gnd/Flight	Marginal
2.2	Synchronization (passive)	Bench/Flight	Satisfactory
2.3	NTR	Bench/Flight	Satisfactory
2.4	Deleted		Satisfactory
2.5	Time of arrival accuracy	Bench	Satisfactory
2.6	Initial net entry messages (INE)	Bench/F-15 Gnd/Flight	Satisfactory
2.6.1	INE generation	Bench/F-15 Gnd/Flight	Satisfactory
2.6.2	INE processing	Bench/F-15 Gnd/Flight	Satisfactory
2.7	Synchronization stability	Bench	Satisfactory
2.8	ETR	Flight	Satisfactory

data for analysis. For these tests, the aircraft was in a net with the JTD at Eglin and the RELNAV van at Test Site D1-B. The JTD was the NTR. During the flight, the FDL terminal equipped F-15 was directed to select SILENT operation (a receive-only mode of the FDL), do a Master Reset, and re-enter the net. MPCD video telemetered from the aircraft to the LSF was used to monitor the test. Successful net entry confirmed a successful test. TOM 1 data were also recorded for problem investigation. If Fine Sync was not achieved within a ten-minute time period, the attempt was considered a failure.

6.4.2.2. Criteria.

The criteria reference for each FDL terminal timing and synchronization measurement are provided in the SSS and ICD. Results are listed in Table 4.

6.4.2.3. Test Results and Discussions

All sub-objectives passed, however two deficiencies remain open for sub-objective 2.1. During reliability flight testing, the operator noticed no radio frequency (RF) activity from the FDL terminal. The time displayed on the MPCD was frozen on TOM 1. Fine Sync continued to be reported, but track symbols were frozen on the MPCD, and their positions were not updated. A master reset cleared the condition. This deficiency was also reported during bench testing in the LSF and at Boeing. This deficiency was deemed ***critical*** by the failure review board (FRB), but due to its low frequency of occurrence resulted in a "Marginal" rating. The problem is expected to be resolved and the solution fielded without waiting for the next scheduled software release.

6.4.3. OBJECTIVE 3: FDL Terminal Modes of Operation

6.4.3.1. Test Procedures

Nine FDL terminal modes of operation (listed in Table 5) were tested on bench missions. Specific terminal modes of operation were loaded into the FDL terminal during initialization, and the mode was tested during Link-16 communication with JTIDS Class 2 terminals.

For the flight test of objective 3, the FDL terminal was installed in an F-15 aircraft. During these tests, the length of time the FDL terminal was in the NORMAL mode of operation versus other modes of operation, and how long it operated in the NORMAL mode while in Fine Sync, was monitored. Anomalies observed while in FDL terminal NORMAL operation mode were documented. During several flight tests, the FDL terminal was set to SILENT operation at the direction of the Test Engineer, and the

Table 5. FDL Terminal Modes of Operation Test Summary

Objective 3: Modes of Operation (9 Sub-objectives)			
Sub-Obj	**Description**	**Test Method**	**Rating**
3.1	Transmit modes		
3.1.1	Normal (Default Mode)	Bench/F-15 Gnd/Flight	Satisfactory
3.1.2	Conditional radio silence (normal to silent operation)	Bench/F-15 Gnd/Flight	Satisfactory
3.2	Range modes		
3.2.1	Normal range mode (Default Mode)	Bench/F-15 Gnd/Flight	Satisfactory
3.2.2	Extended range mode	Bench	Satisfactory
3.3	Test modes		
3.3.1	Test Mode 1	Bench	Satisfactory
3.3.2	Test Mode 2	Bench	Satisfactory
3.4	Communications modes		
3.4.1	Communications mode 1 (Default Mode)	Bench/F-15 Gnd/Flight	Satisfactory
3.4.2	Communications mode 2	Bench	Satisfactory
3.4.3	Security modes	Bench	Satisfactory

test aircraft's precise participant location and identification (PPLI) information was monitored in the OPFAC to ensure that it "went stale." This confirmed that the terminal was indeed SILENT, and was not reporting its position and identification in the direct identification mode of the system.

6.4.3.2. Criteria

The FDL terminal operation mode requirements are outlined in the SSS. Test results are listed in Table 5.

6.4.3.3. Test Results and Discussions

All sub-objectives except 3.4.3 in Table 5 were tested in bench, ground, and flight tests. All sub-objectives tested passed.

6.4.4. OBJECTIVE 4: FDL Terminal Message Processing

6.4.4.1. Test Procedures. Twenty-seven FDL terminal message processing functions (listed in Table 6) were tested during bench missions. Various Link-16 initializations that test specific terminal message processing functions were loaded in the FDL terminal. A Link-16 communication network was established between the FDL terminal and the JTD JTIDS Class 2 terminal. The MATES was used to monitor the 1553 bus between the FDL terminal and its host. The F-15 OPFAC display was recorded and monitored for correct message display.

During the flight test, all Link-16 messages transmitted and received were recorded on the AATIS system. The MPCD video telemetered to the LSF was monitored for correct message display and processing, and anomalies observed with FDL terminal message processing were documented.

Table 6. FDL Terminal Message Processing Test Summary

Objective 4: Message Processing (23 Sub-objectives)			
Sub-Obj	**Description**	**Test Method**	**Rating**
4.1	Fixed-format messages		
4.1.1	J2.2 Air PPLI	Bench/F-15 Gnd/Flight	Satisfactory
4.1.2	J2.3 Maritime PPLI	Bench/F-15 Gnd/Flight	Satisfactory
4.1.3	J3.0 Reference Point	Bench/F-15 Gnd/Flight	Satisfactory
4.1.4	J3.2 Air Track	Bench/F-15 Gnd/Flight	Satisfactory
4.1.5	J3.3 Maritime Track	Bench/F-15 Gnd/Flight	Satisfactory
4.1.6	J3.5 Land Track	Bench/F-15 Gnd/Flight	Satisfactory
4.1.7	J7.0 Track Management	Bench/F-15 Gnd/Flight	Satisfactory
4.1.8	J7.3 Pointer	Bench/F-15 Gnd/Flight	Satisfactory
4.1.9	J10.2 Engagement Status	Bench/F-15 Gnd/Flight	Satisfactory
4.1.10	J12.0 Mission Assignment	Bench/F-15 Gnd/Flight	Satisfactory
4.1.11	J12.1 Vector	Bench/F-15 Gnd/Flight	Satisfactory
4.1.12	J12.4 Control Unit Change	Bench/F-15 Gnd/Flight	Satisfactory
4.1.13	J12.6 Target Sorting	Bench/F-15 Gnd/Flight	Satisfactory
4.1.14	J13.2 Air Platform and System Status	Bench/F-15 Gnd/Flight	Satisfactory
4.1.15	J2.0 Indirect PPLI	Bench/F-15 Gnd/Flight	Satisfactory
4.1.16	J3.1 Emergency Point	Bench/F-15 Gnd/Flight	Satisfactory
4.1.17	J6.0 Intel	Bench/F-15 Gnd/Flight	Satisfactory
4.1.18	J7.7 Association	Bench/F-15 Gnd/Flight	Satisfactory
4.1.19	J15.0 Threat Warning	Bench/F-15 Gnd/Flight	Satisfactory
4.1.20	J28.2.8 ID	Bench/F-15 Gnd/Flight	Satisfactory
4.2	Deleted		
4.3	Deleted		
4.4	Receipt/compliance (R/C)	Bench/F-15 Gnd/Flight	Satisfactory
4.5	PPLI		
4.5.1	PPLI (processing)	Bench/F-15 Gnd/Flight	Satisfactory
4.5.2	PPLI (generation)	Bench/F-15 Gnd/Flight	Satisfactory
4.6	Message construction and generation (Link-16)	Bench/F-15 Gnd/Flight	Marginal
4.7	Message construction and generation (IJMS - limited)	Bench	Satisfactory
4.8	Limited IJMS translation	Bench/Flight	Satisfactory
4.9	Message Packing Limit	Bench	Satisfactory

6.4.4.2. Criteria.

The F-15 Link-16 message processing requirements were specified in the Joint Interoperability of Tactical Command and Control Systems Link-16 Technical Interface Design Plan (TIDP), Reissue 2, May 1988. FDL terminal message processing test results are summarized in Table 6.

6.4.4.3. Results and Discussions.

All sub-objectives passed, however a deficiency still exists for sub-objective 4.6, which involves some built-in-test (BIT) message cues (JAM, LAF, UAF, and BATTERY) that are not displayed when they should be. It appeared that this BIT information was available, but the FDL terminal did not send the information out via TOM 1 unless it was requested via TIM 7. This information should be sent out without request. This deficiency will be fixed and the correction fielded without waiting for the next scheduled software change release.

6.4.5. OBJECTIVE 5: FDL Terminal Navigation

6.4.5.1. Test Procedures

Five FDL terminal navigation functions (listed in Table 7) were tested in bench and flight test missions. In the geodetic missions, the ground-based Class 2 terminals reported accurate positions to serve as navigation sources for the aircraft, and the F-15 host platforms were initialized to use the geodetic corrections from the ground terminal. In the relative grid navigation missions, the F-15C/D host platforms were initialized to use the relative corrections from the terminal. The FDL used these corrections for target display, correlation, and target reporting purposes.

For target/track correlation, the pilots were asked to lock on to other Link-16

Table 7. FDL Terminal Relative Navigation Test Summary

Objective 5: Relative Navigation (3 Sub-objectives)			
Sub-Obj	**Description**	**Test Method**	**Rating**
5.1	Geodetic grid navigation	Flight	Marginal
5.2	Relative grid navigation	Flight	Marginal
5.3	Target/Track Correlation	Bench/Flight	Satisfactory
5.4	Range Separation	Flight	Satisfactory

equipped aircraft to determine whether the radar-reported target on the FDL display correlated with the target's self-reported PPLI data. When certain angle and range correlation criteria were met, the radar and PPLI targets would merge into one symbol, indicating that the FDL navigation solution of the test aircraft was accurate.

6.4.5.2. Criteria.

The criteria reference for each FDL terminal navigation tests are provided in the SSS, and the Operational Requirements Document (ORD) and the Midcourse Data Center F-15 Link-16 Display Correlation Parameters. Test results are summarized in Table 7.

6.4.5.3. Results and Discussions

All sub-objectives in Table 7 were tested. All sub-objectives passed, however three deficiencies still exist for sub-objective 5.1 and 5.2.

The first deficiency involved correlation. During some test flights, the test aircraft's PPLI information was sent out over the network, and then received later by the same FDL terminal. This PPLI information did not correlate with the FDL terminal's estimation of its own position (even though the test aircraft generated the initial PPLI message). Therefore, the FDL placed two symbols at the approximate location of the test aircraft. One of the symbols was the "ownship" symbol, and the other was a PPLI symbol. This deficiency was a nuisance that did not affect system performance and it will be corrected in the Suite 4 software release in November 2001.

The second deficiency was related to inertial navigation system (INS) updates via TACAN signals. TIM 8 (navigation inputs) mux data were analyzed during a TACAN navigation update. During the update, the navigation update flag was set at the wrong time, which caused the FDL to be updated with the old INS data, rather than the improved new data. This is a Suite 3M problem and will be corrected in the Suite 4 release.

The third deficiency involved the accuracy of PPLI data. During some missions, the altitude quality in the PPLI message, which was a geodetic parameter, intermittently rose to a high level in the absence of any geodetic processing. This value was too high to be accurate and will be corrected during a future scheduled software change release. The high value was transparent to the pilot and had no effect on system performance.

6.4.6. OBJECTIVE 6: FDL Terminal Communication Performance

6.4.6.1. Test Procedures.

Eight FDL terminal communication performance parameters (listed in Table 8) were tested on bench missions. A Link-16 communication network was established between the FDL terminal installed in the F-15 OPFAC and Class 2 terminal installed in the JTD. The RF line between the FDL terminal and the Class 2 terminal was hardwired with variable attenuation. Attenuation was increased and the MATES monitored the Link-16 messages received at the FDL terminal on the 1553 bus. As the signal was attenuated, a spectrum analyzer and peak power meter inserted in the RF line measured critical signal parameters.

Table 8. FDL Terminal Communications Performance Test Summary

Objective 6: Communications Performance (8 Sub-objectives)			
Sub-Obj	**Description**	**Test Method**	**Rating**
9.1	Message error rate		
6.1.1	Receiver sensitivity—standard messages	Bench	Satisfactory
6.1.2	Receiver sensitivity—packed-2 double pulsed messages	Bench	Satisfactory
6.1.3	Packed-2 single pulsed messages	Bench	Satisfactory
6.1.4	Packed-4 messages	Bench	Satisfactory
6.2	Antijam margin		
6.2.1	Standard messages	Bench	Satisfactory
6.2.2	Packed-2 double pulsed messages	Bench	Satisfactory
6.2.3	Packed-2 single pulsed messages	Bench	Satisfactory
6.2.4	Packed-4 messages	Bench	Satisfactory

6.4.6.2. Criteria. The criteria reference for each FDL terminal communication performance test are provided in the SSS. Test results are summarized in Table 8.

6.4.6.3. Results and Discussions. All sub-objectives in Table 8 were tested in the lab. All sub-objectives passed with no deficiencies reported.

6.4.7. OBJECTIVE 7: FDL Terminal Compatibility with Other F-15 Systems

6.4.7.1. Test Procedures

Radio Frequency Absorber Lined Chamber Testing: Ground missions were conducted on an F-15 suspended in the Preflight Integration of Munitions and Electronic systems (PRIMES) radio frequency absorber lined chamber. Selected aircraft avionics systems were operated during the test. Avionics systems included the FDL, both AN/ARC-164 UHF radios, the AN/ARN-118 TACAN system, the AN/ARN-101 Interrogation Friend or Foe (IFF) system, the AN/ALR-56C Radar Warning Receiver (RWR), the air-to-air interrogator (AAI), and the radar. The test was conducted in two stages. In the first stage, the FDL terminal was operated in a network with a Class 2 terminal in a RELNAV van located outside the chamber (cabled to an antenna in the chamber). Each of the avionics systems was activated individually to verify one-on-one compatibility. In stage 2, all avionics systems were operated simultaneously. Performance of all systems was thus baselined in a sterile RF environment. Performance of each avionics system during subsequent tests was compared to the baseline to identify anomalies.

Flight Testing. All F-15 systems, to include FDL, were exercised on all flight missions.

6.4.7.2.Criteria

The criteria for aircraft compatibility were provided by the SSS, ICD, and MIL-STD 291B. Results are summarized in Table 9.

6.4.7.3. Results and Discussions. All sub-objectives except 7.1 and 7.4 in Table 9 were tested in bench, ground, and flight tests. All sub-objectives passed, however deficiencies were reported for sub-objectives 7.2.1 and 7.2.2.

During FDL/Identification Friend or Foe (IFF) compatibility testing (sub-objective 7.2.1) in the PRIMES chamber, it was observed that transponder replies to IFF

Table 9. FDL Terminal Aircraft Compatibility Test Summary

Objective 7: Aircraft Compatibility (6 Sub-objectives)			
Sub-Obj	**Description**	**Test Method**	**Rating**
7.1	Contractor Test		
7.2	RF		
7.2.1	TACAN	Bench/Chamber/Flight	Satisfactory
7.2.2	IFF	Chamber/Flight	Satisfactory
7.2.3	RWR	Chamber/Flight	Satisfactory
7.3	EMC/EMI	Chamber/Flight	Satisfactory
7.4	Contractor Test		
7.5	Suppression Signals	Bench	Satisfactory

interrogations dropped in efficiency from 100 percent to 94 percent when TACAN was operating in channel 2X (1026 MHz). Reply efficiency dropped to 91 percent when TACAN was set to channel 6X (1030 MHz). Reply efficiency returned to 100 percent when TACAN was set to channel 30X (1054 MHz). Reply efficiencies with TACAN operating were not affected by FDL operating mode (off, hold, or normal) when TDMA was not transmitting. With TDMA and TACAN operating, reply efficiencies appeared to drop in a cumulative manner. This problem was converted to a deficiency report and will be resolved through the F-15 System Program Office (SPO) Material Improvement Program (MIP) process.

Two deficiencies were reported for sub-objective 7.2.2. First, during PRIMES chamber testing, the IFF generated false replies in any transponder mode (1, 2, 3A, or 3C) when the FDL was transmitting. Mode 1 of the IFF appeared to be the worst by observations made using a spectrum analyzer, but could not be quantified. This problem was added to a deficiency report. Second, when the IFF emergency discrete was active (Mode 3, 7700), the emergency indicator was set (emergency status) in the PPLI. The emergency indicator identifed the affected aircraft as being in distress to all users in the network. The problem occurred when the discrete was returned to normal (no emergency). The emergency indicator did not clear (no statement) in the PPLI. A master reset cleared the condition. This problem was converted to a deficiency report and will be resolved through the F-15 SPO MIP process.

The IFF response deficiencies did not adversely affect system performance in flight, but will be addressed to ensure optimum system performance is attained.

7. FDL TACTICAL APPLICATION

As an example of the FDL's ability to enhance the capabilities of the F-15, consider the following notional scenario. Two F-15s are flying an orbit about a fixed location searching for enemy fighters. Meanwhile, two different flights of two friendly F-16 fighters are ingressing into hostile territory to strike a target. Alerted to the F-16's presence, enemy fighters launch out of a hostile airfield to intercept them. At the same time, a group of enemy fighters begin an intercept on the F-15s. Further complicating the tactical picture, a United States Army helicopter is returning from a combat search and rescue mission. The scenario is diagrammed in Figure 12. The FDL-generated presentation the F-15 pilots would see in this scenario is shown in Figure 13.

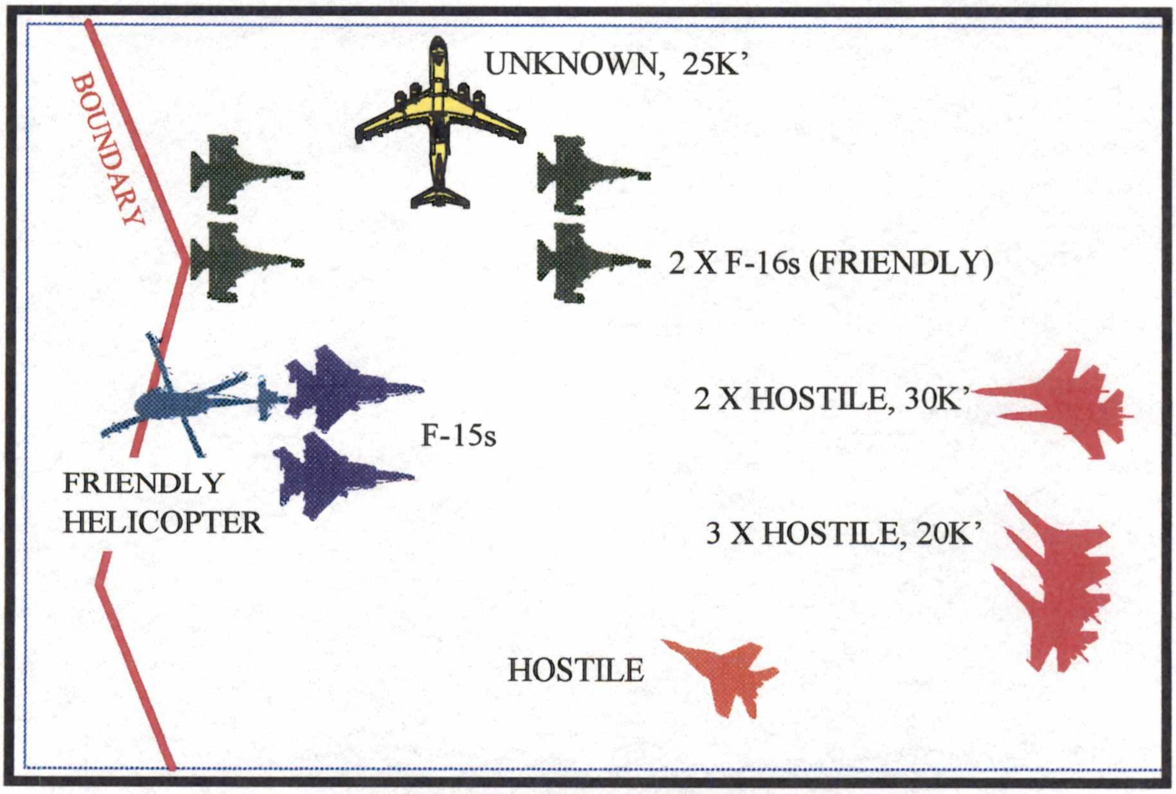


Figure 12. A Tactical Scenario

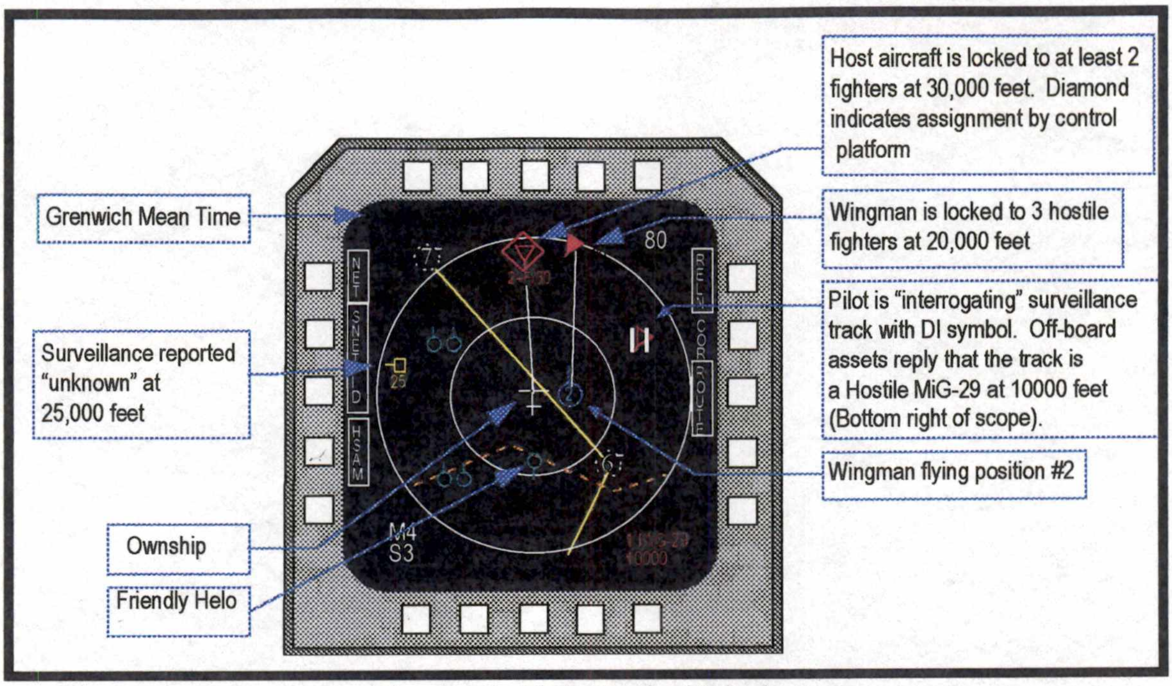


Figure 13. FDL Tactical Display

With a quick glance at the display, the F-15 pilots have an accurate picture of the situation. They know the location and identification of all friendly and hostile entities and have amplifying intelligence information regarding the threat platforms. They know what type of aircraft are threatening them, the altitude of those threats, and the number of aircraft in each threat group.

Open symbols (not filled in) represent data linked to the fighters from an outside source. The solid symbols, on the other hand, represent tracks obtained from on-board F-15 systems.

Targeting information is also provided to the F-15 pilots. The red diamond surrounding the corresponding threat symbol represents a command from a controlling agency for the F-15s to target the approaching fighters at 30,000 feet. Inter-flight targeting information is shown by the white "lock lines" emanating from the ownship and wingman symbols on the display. The lead aircraft (ownship) is locked to the approaching fighters at 30,000 feet, while the wingman is locked to the fighters at 20,000 feet, which are targeting the F-16s. With this information, the flight lead can either redirect his wingman to lock into the 30,000 foot group, or direct him to continue his intercept on the 20,000 foot group to protect the F-16s.

Additional symbols on the display include the geographic boundary line, which delineates the boundary between friendly and hostile territory, and the navigation line which shows a pre-planned navigation route for the F-15s. Both of these lines are programmed before the mission and are loaded in the F-15 FDL system with the initialization instructions prior to takeoff.

This tactical picture is critical to the F-15 pilot. Instead of having to imagine the situation, he can view it directly. His mind is now free to make the best tactical decisions possible. Notice for example, that the location and identity of the Army helicopter is immediately obvious, even though it is part of a large, complicated scenario.

8. COMMERCIAL APPLICATION

The Multi-Functional Information Distribution System has potential to increase aircrew situational awareness and enhance safety in the commercial aviation environment. The system's nodeless time division multiple-access multiple-net architecture and spread spectrum frequency hopping technique is ideally suited to handle a high number of users in a dense signal environment. Furthermore, the large number of commercial users with integrated Global Positioning System (GPS) navigation systems would allow the system to function on a geodetic grid (as opposed to a relative grid) which would enable multiple users to share a network without pre-coordination and without having to designate a navigation controller. Likewise, GPS system time could be used as the net time reference, further reducing system complexity. Similar to the Fighter Data Link implementation of MIDS, a commercial application would involve both direct and indirect reporting entities, providing vast system flexibility and coverage. Direct reporting entities would be those equipped with automatic dependent surveillance-broadcast (ADS-B), a GPS-based self-reporting position system. Non-reporting entities would be tracked by surveillance radar and displayed on the net for all users to observe, just as they are in FDL.

The benefits of a commercial MIDS system would be vast. Users would enjoy: enhanced visual acquisition for "see & avoid," enhanced visual approaches, enhanced airport surface awareness, station keeping capability, enhanced in-trail climb/descent, reduced departure spacing, and improved final approach spacing. The system could also be programmed to include an advanced Traffic Alert/Collision Avoidance System (TCAS). Since the MIDS system is able to compute the flight path vectors of participating and non-participating aircraft, accurate predictions of conflict potential could be made with a reduced false alarm rate as compared to the current TCAS system, which uses only range and range rate in calculations. The MIDS display could also color code aircraft in terms of their conflict potential, which, coupled with the two dimensional plus altitude MIDS display, would help aircrew visually acquire conflicting traffic in time to react appropriately. On the ground, the system could be used to prevent runway incursion incidents by underlaying an airport diagram on the display, which would show when an aircraft has cleared a given runway, and which aircraft are moving on the airfield surface. The MIDS could also be integrated with a Head-Up display (HUD) to facilitate visual acquisition of MIDS-reported targets by presenting a cue in the HUD indicating line-of-sight to the target.

Another advantage of the MIDS system for commercial aviation is that it provides data on reported contacts through the designation/interrogation function. By placing a cursor over a given track, the system could be mechanized to display information such as aircraft callsign, ground speed, destination, and next fix on route of flight. Such data would greatly increase SA and allow aircrew to make intelligent decisions and requests to controlling agencies, which would speed traffic flow.

The Multi-Functional Data Distribution System has a final feature that would contribute to commercial aviation safety and efficiency, and that is the capability to send and receive text messages. With this capability, controlling agencies could send text message commands for the aircrew to either accept "WILCO," or reject "NO GO." This would reduce voice communications in a congested environment and provide pilots a reference after the message is sent. In addition, it would be possible to implement a push button that would translate the text message into speed, heading, and altitude commands for the aircraft's flight management system. The result would be reduced errors. An example MIDS presentation of a notional commercial scenario is provided in Figure 14.

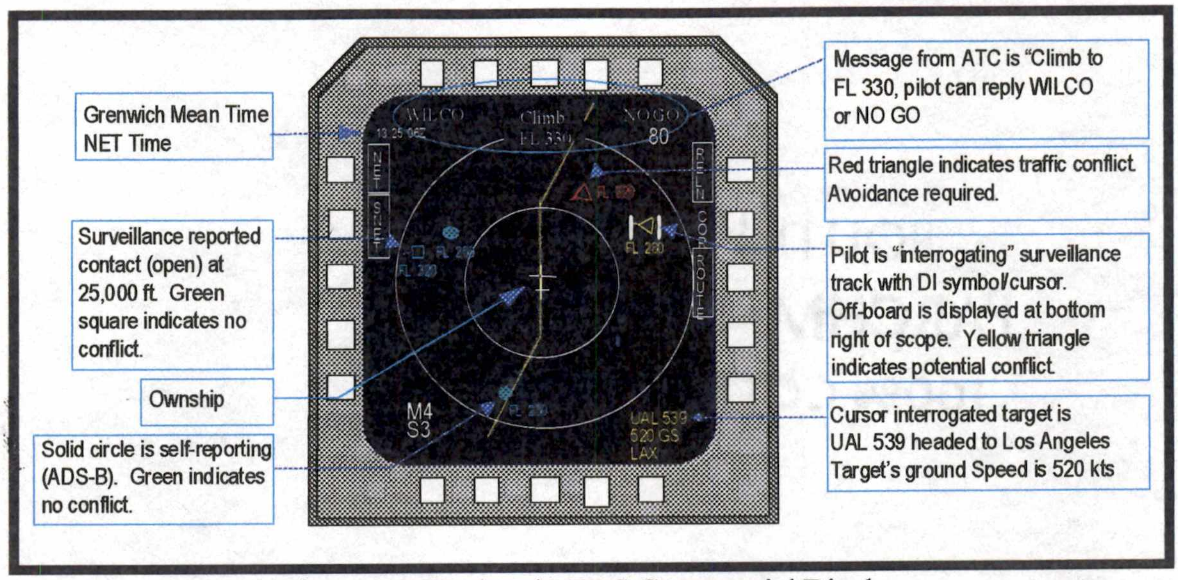


Figure 14. Notional MIDS Commercial Display

9. CONCLUSION

By installing MIDS F-15 FDL, situational awareness is increased in the F-15, which improves mission effectiveness and aircraft survivability. Mission effectiveness is improved because the FDL provides F-15 pilots with real-time information about the present and near term disposition of friendly and hostile aircraft. This information is crucial to the pilot's decision process and allows him to prosecute hostile subjects while protecting friendly assets. Mission effectiveness is also improved through the use of fighter-to-fighter shared sensor data which builds a common picture of the opposition force among F-15s and allows them to effectively employ air-to-air missiles in beyond visual range scenarios.

The system improves survivability by providing threat intelligence data that was unavailable prior to the advent of the FDL. For example, a FDL-equipped flight of F-15s may choose not to engage a group of hostile fighters based on data indicating that the F-15s are outnumbered and outgunned. Survivability is also improved because FDL provides threat warning advisories to F-15s concerning specific FDL tracks (e.g. surface-to-air missiles, hostile aircraft, etc.).

Testing of the Fighter Data Link System proved that it effectively communicates on a Link-16 network. However, 12 deficiencies were brought out that should be corrected to improve system performance. Only one of the deficiencies had a significant effect on system performance from the operator's point of view. This critical deficiency involved occasional system lock-ups, which froze symbols on the display. This deficiency is under study and a software correction will be fielded as soon as possible.

The FDL is an example of an information distribution and management system that improves military mission effectiveness. At the same time, the system has potential to improve traffic efficiency and improve aviation safety in the civil sector. As the world moves forward in the Information Age, it will be systems like FDL that will determine the ultimate effectiveness of airborne operations.

10. RECOMMENDATION

Based on its proven capability to improve pilot situational awareness and its potential to enhance safety and efficiency, the military-developed technology of Fighter Data Link should be evaluated for civil applications.

REFERENCES

REFERENCES

Hill, K. & Ulrich, R. (1991). A Case Study of the Joint Tactical Information Distribution System (JTIDS) (Report AD-B159494). Navy Postgraduate School, Monterey, CA.

Joint Chiefs of Staff. (1989). Multiple Required Operational Capability for the Joint Tactical Information Distribution System (MJCS-193-89). Joint Staff, Pentagon, Washington, DC. Classified Document.

Joint Chiefs of Staff. (1989). Tactical Digital Information Link (TADIL) Message Standards (JCS Pub 6-01.1). Joint Staff, Pentagon, Washington, DC. Classified Document.

Logicon, Inc. (1996). Understanding Link-16, A Guidebook for New Users. San Diego, CA.

MITRE JTIDS Project Staff. (1996). Cooperative Engagement Capability through CEC/JTIDS Integration. Bedford, MA.

MITRE JTIDS Project Staff. (1993). JTIDS Overview Description (MTR 8413R2). Bedford, MA.

U.S. Atlantic Command Combat Identification Working Group. (1995). Final Report. (Office of the CNO N62). 2000 Navy Pentagon, Washington, DC.

U.S. Atlantic Command Combat Identification Working Group. (1995). Final Report Unclassified Appendices. (Office of the CNO N62). 2000 Navy Pentagon, Washington, DC.

VITA

Colin R. Miller was born in Buffalo, New York on 26 January 1966. He graduated from Bishop Dennis J. O'Connell High School in June 1984. In the fall of 1984 he began undergraduate studies under the cooperative work-study program at Virginia Tech, which led to a Bachelor of Science degree in Mechanical Engineering in 1989. In January 1990, he enlisted in the United States Air Force as an Officer Candidate. He was commissioned a second lieutenant in April 1990 and immediately began undergraduate pilot training at Laughlin AFB, Texas. After 52 weeks of pilot training he was assigned to Tyndall AFB, FL for F-15 training, with a follow-on assignment to Kadena Air Base, Japan. During a brief tour at the Pentagon he earned a Master of Arts degree in Business Administration at The George Washington University. He then flew the F-117A Stealth Fighter before selection to the United States Air Force Test Pilot School.

He is presently an experimental test pilot flying all models of the F-15 aircraft at Eglin Air Force Base, Florida.