

ENHANCED FLIGHT TERMINATION SYSTEM FLIGHT DEMONSTRATION AND RESULTS

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ABSTRACT

This paper discusses the methodology, requirements, tests, and implementation plan for the live demonstration of the Enhanced Flight Termination System (EFTS) using a missile program at two locations in Florida: Eglin Air Force Base (AFB) and Tyndall AFB. The demonstration included the integration of EFTS Flight Termination Receivers (FTRs) onto the missile and the integration of EFTS-program-developed transmitter assets with the mission control system at Eglin and Tyndall AFBs. The initial test stages included ground testing and captive-carry flights, followed by a launch in which EFTS was designated as the primary flight termination system for the launch.

KEY WORDS: Enhanced Flight Termination System, Flight termination, Flight Termination Receiver, EFTS, Range demonstration

INTRODUCTION

The purpose of the Enhanced Flight Termination System (EFTS) program is to develop the next-generation Flight Termination System (FTS) for Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) ranges. The EFTS program was created after an inadvertent activation that caused the termination and loss of a \$45-million Global Hawk (Northrop Grumman Corporation, Los Angeles, California) in 1999. Another inadvertent activation that caused termination and loss of a \$40-million Strategic Target System, launched by the United States Army, in Alaska in 2001 provided further incentive to develop the system.

A two-year (2000 – 2002) EFTS feasibility study preceded the development, beginning in 2004, of range and vehicle standards-compliant EFTS equipment. The development of EFTS airborne equipment, namely the EFTS Flight Termination Receiver (FTR), began in 2004. The EFTS ground equipment development began in 2005; the ground equipment consisted of the Encoder, Monitor, and Triple Data Encryption Standard (DES) Unit (TDU). The ground equipment was

developed to be the standard used on multiple ranges. The EFTS feasibility study revealed that most ranges have unique transmitter architectures. Thus, the development of the interface to generate the EFTS message (what is described as a command controller later in this paper) was left to each range to develop. A common range interface was not developed by the EFTS program.

The EFTS development was completed in 2007, when qualification testing concluded and was approved by the Government. To demonstrate the capabilities of the EFTS in operational scenarios, range testing using EFTS was performed in July 2007. The demonstration made use of two L-3 Cincinnati Electronics (L-3 CE) (Cincinnati, Ohio) EFTS FTRs, packaged inside a Raytheon Company (Waltham, Massachusetts) Non-Developmental Item-Airborne Instrumentation Unit (NDI-AIU) test and telemetry package. The EFTS FTRs replaced the existing Inter-Range Instrumentation Group (IRIG) FTRs without modifying the NDI-AIU telemetry package or the vehicle. The flight demonstrations included one captive-carry flight of an Advanced Medium Range Air-to-Air Missile (AMRAAM) (Raytheon Company) AIM-120-B Integrated Test Vehicle (ITV) on an F-15 airplane and a subsequent live-fire of the AMRAAM AIM-120-B Air-to-Air Vehicle (AAV). A future live-fire demonstration with the AAV is scheduled to occur in August 2007.

EFTS DEMONSTRATION AND RESULTS

This paper discusses the methodology, requirements, tests, and implementation plan for the EFTS demonstration. Demonstration scheduling necessitates presenting the final results and lessons learned at the 2007 International Telemetry Conference (ITC).

Demonstration Goals and Purpose

The function of an FTS is to protect the public from potentially hazardous test and launch vehicles that stray from nominal mission parameters and threaten the public's safety and property. As with most public safety communities, the flight termination community builds on existing designs and experience to provide a heritage of proven safety approaches, and has an excellent history of performance.

The EFTS program felt that, for the EFTS system to achieve wide adoption on United States ranges, operational experience should be gained by demonstrating the system at an operational range with an existing flight program. This resulting technical and operational experience is being documented in the EFTS Flight Demonstration Test Report, as well as in this paper. This legacy of experience will provide the EFTS with an operational heritage that will instill confidence in potential system users. The EFTS demonstration actively exercised standard FTS functions to validate the performance of the EFTS system in an operational environment.

Vehicle and Range Selection

From the inception of the EFTS, the EFTS program has been actively communicating the capabilities of the system to potential programs, ranges, and vendors by holding user community forums and Technical Interchange Meetings (TIMs), and by presenting at conferences. The

EFTS program has consistently presented its progress to the Range Commander's Council (RCC) Range Safety Group (RSG). The EFTS program has kept the FTS community decision makers informed during the EFTS development and has actively solicited their advice. In return, the EFTS program has received support from active test ranges that employ flight termination systems.

A potential user of the system, the AMRAAM System Program Office (SPO) was open to supporting the demonstration because of the potential long-term benefits of the EFTS to the war fighter. Some potential benefits to adoption of the EFTS are these: (1) the EFTS system provides a user feature that enables the telemetry transmitter power to be adjusted and may extend mission times and transmitter lifetimes; (2) the EFTS FTRs are field-programmable, minimizing required spares and increasing system availability times; (3) the EFTS data link has a dramatically increased FTR addressing space over RCC-compliant IRIG systems, resulting in the ability to communicate with more vehicles per mission than the current IRIG system; (4) designed hardware compatibility between the existing IRIG system and the EFTS system limits the required modifications to the vehicle, range, or mission operations; (5) digital receivers may require less retesting for shelf life than would IRIG tone-based receivers; and (6) the EFTS provides additional security against inadvertent activation.

Eglin AFB was selected as the host range for the EFTS demonstration because of the active participation of the Air Force Air Armament Command (AAC) at Eglin AFB in the EFTS program and because of the AAC support for AMRAAM missions. Eglin AFB also supports AMRAAM missions originating from Tyndall AFB, which is near Eglin AFB on the Florida panhandle.

During the first half of 2006, the EFTS program coordinated with various groups to develop the necessary interfaces between the range and the EFTS components. To accomplish this, the EFTS program relied heavily on Interface Control Documents (ICDs) and person-to-person communications.

To interface with the ground equipment, the EFTS program plan was to integrate the L-3 CE-developed components with the existing equipment at the transmit and monitor sites.

Technical Requirements and Implementation - Transmitter System

The EFTS system was inserted into the transmitter site at a point between tone control and tone generator, by rerouting at the baseband input to the range exciter, as shown in Figure 1. An EFTS encoder and TDU, developed by L-3 CE, would be used to generate the EFTS command message with an EFTS Command Controller (CC) to act as the interface between the range and the L-3 CE equipment.

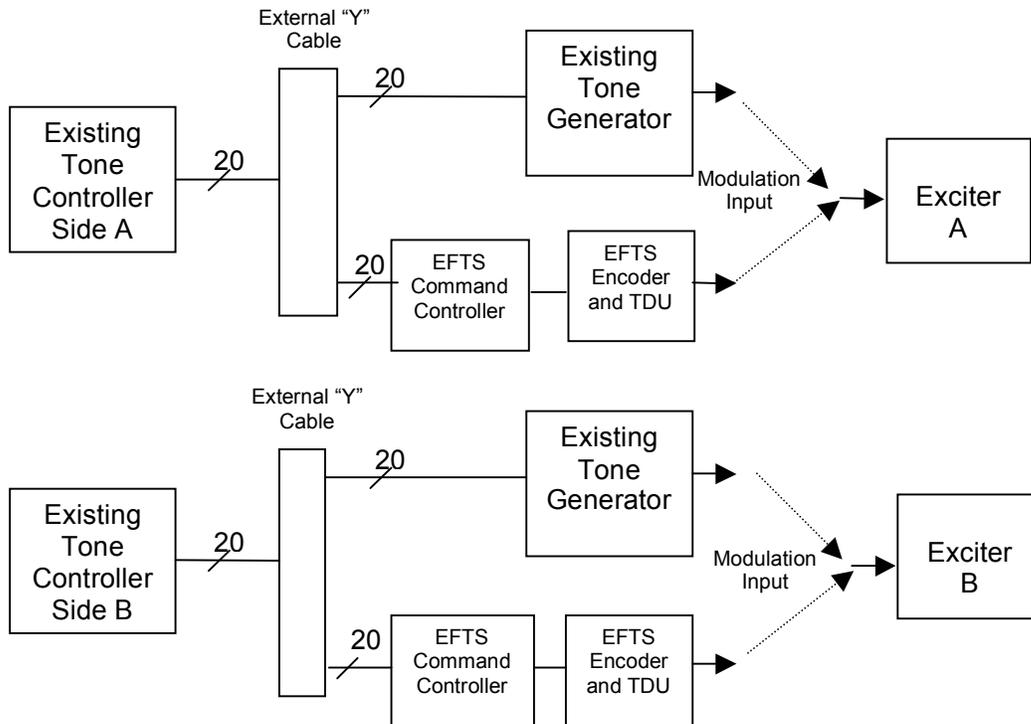


Figure 1. Integrating the Enhanced Flight Termination System into existing range infrastructure.

The CC was developed by the EFTS program for the EFTS demonstration and is not an operational system. As described in the “Introduction” section above, operational CCs were left to each individual range to develop. The purpose of the CC is to translate the tones at the output of the tone-control interface and map the tones to the required interface of the EFTS encoder. The CC was developed to interface with the 20 control-tone signals, in which each EFTS command was mapped to the presence of certain tones and the absence of certain tones at the interface. A command priority scheme was developed to arbitrate multiple commands to the same vehicle; only the highest priority command is sent. Up to 10 vehicles can be concurrently supported by the CC. Figure 2 shows the EFTS CC.



Figure 2. The Enhanced Flight Termination System Command Controller.

In order to provide flexibility during the demonstration, the CC was field-programmable to allow tone selection to be performed at the test site. Because the 20 control lines in the existing system

use an opto-isolated interface, the CC also implemented an opto-isolated interface. This allowed the CC and the existing system to be connected with a “Y” cable without interference between the two systems. The chassis of the CC was developed to house two independent CCs in a 1 Rack Unit (RU) (1.75”) 19” rack mount configuration.

The development of the CC required the development of several other test devices. A range interface test box was developed to emulate the range control interface at Eglin AFB, because no spare interfaces would be available for the development. The test box was essentially 10 switches, each of which was tied to two tone commands of the 10-command output from the tone controller. Configuration software was also developed for this system.

The development of the EFTS equipment by L-3 CE was not complete at this time; L-3 CE had passed the Critical Design Review (CDR) phase of development but had not yet passed qualification and acceptance testing, and the CC interface was neither stabilized nor complete. Because the EFTS program had a short schedule within which to implement the EFTS system for the EFTS demonstration, an encoder simulator was developed to accurately represent the documented EFTS encoder-to-CC interface. This concurrent development had the added benefit of an independent developer from L-3 CE’s staff who began actively reviewing and using the interface. This independent development method resulted in several key changes to the interface prior to formal testing of the unit by L-3 CE. In June 2006, the CC and L-3 CE Encoder with TDU communicated with each other on the first attempt during an integration test. No modifications were required to the interface as a result of the testing, and L-3 CE was able to proceed immediately to acceptance testing. Figure 3 shows the EFTS encoder.



Figure 3. The L-3 Cincinnati Electronics Enhanced Flight Termination System Encoder with the Triple Data Encryption Standard Unit inserted.

Technical Requirements and Implementation - Monitor System

The EFTS demonstration would require independent monitoring and archiving of the transmitted signal. L-3 CE developed an EFTS radio frequency (RF) Monitor capable of decoding the RF signal, but no system was developed to archive or display the signals. This was because the EFTS monitor provided a standard serial interface, thus the EFTS program would be able to borrow and use a standard telemetry decommutator and display system to view the data, and a standard serial recorder to archive it. The EFTS program could not acquire the resources,

however, so L-3 CE developed a Monitor/Recorder for the demonstration. The application interfaces to the Monitor with an RS-422 card and cable. Figure 4 shows the EFTS monitor.



Figure 4. The L-3 Cincinnati Electronics Enhanced Flight Termination System Monitor with the Triple Data Encryption Standard Unit inserted.

Technical Requirements and Implementation - Flight Termination Receiver

The EFTS program coordinated with Raytheon Company, the manufacturer of the AMRAAM missile and the NDI-AIU, which is the test package that contained the FTR. After a review of the technical compatibility of the two systems, the determination was made that only a slight modification to the interface connector of the FTR would be required to integrate it into the test package. After a detailed analysis by the EFTS program and L-3 CE, it was determined that the required changes to the FTR would be permanent, and would have no impact on the program schedule. The FTR was then physically inserted into an existing test package to ensure fit and connector compatibility.

In order to test the FTR without an encoder, the program provided Raytheon Company with an EFTS Baseband Output Signal Simulator (BOSS). The BOSS was developed to provide an EFTS source to vendors for FTRs. For the demonstration, a status display was developed to view the information from the serial configuration port of the FTR and all of the signals on the inputs and outputs of the FTR. Figure 5 shows the EFTS FTR.



Figure 5. The L-3 Cincinnati Electronics Enhanced Flight Termination System Flight Termination Receiver.

Security Key Requirements and the National Security Agency

The TDUs and FTRs were loaded using Data Transfer Devices (DTDs); the DTDs used keys obtained from the National Security Agency (NSA) using standard channels for key distribution. This provided EFTS program members with experience in obtaining and handling keys at both Eglin and Edwards AFBs.

Initial System Integration and Testing

The EFTS program integrated and tested all available equipment at Edwards AFB in the autumn of 2006. This integration included testing of the complete transmitter system with NSA-generated keys on both the transmitter and receiver side. The system was tested closed-loop and the results of this integration testing were positive.

The test setup was as follows: the CC was connected to the encoder, with a TDU in the encoder. From the encoder, the baseband went to an exciter, which modulated the signal to the desired levels (frequency and power). The output of the exciter, instead of being transmitted, went directly into the monitor and the EFTS Flight Termination Receiver (EFTR). Using laptop computers connected to the encoder, CC, monitor, and EFTR, the EFTS program was able to verify the functionality of EFTS commands in a closed-loop laboratory environment. As well, the tests were able to validate the requirements for sensitivity and frequency ranges.

L-3 CE provided configuration applications for use during the EFTS demonstration. The applications are engineering support applications and are not meant for widespread distribution or operational use. They are engineering tools to aid development that L-3 CE provided as unsupported. Therefore, while functionally capable, these engineering tools led the EFTS program to determine the need for a potential long-term “enterprise-wide” application capable of configuring and monitoring all components in the system.

During the testing at Edwards AFB, the EFTS program successfully tested each EFTS command. The encoder, monitor, EFTR, and CC, all functioned as expected. There was only one anomaly during the testing: the TDU failed on one occasion because of hot-swapping TDUs. The analysis by L-3 CE of the failed TDU showed that there was a resistor problem, which has since been corrected. The resistor problem caused the TDU to fail upon excessive hot-swapping. With the resistor problem fixed, the TDUs can be hot-swapped without any concern.

The testing resolved several integration issues and provided the EFTS program with confidence in the system. After documenting the connection and interfaces, the system was shipped to Eglin AFB for integration with the Eglin AFB transmitter system.

Flight Termination Receiver System Integration Testing at Raytheon Company

The EFTS program and L-3 CE visited Raytheon Company in the autumn of 2006 and supported integration testing between the FTR and the NDI-AIU. This testing was a success, and the EFTS program provided EFTS training to the Raytheon Company team.

After this testing and training was complete, and several EFTS FTRs were available for testing, the combined NDI-AIU EFTS FTR functional performance validation tests were conducted. The tests were conducted at Raytheon Company and the unit passed with success.

Transmitter System Integration at Eglin Air Force Base - A3 Site

Eglin AFB has two sites with the same system setup for FTS transmission: the A3 site in Fort Walton Beach and the D3 site in a remote location near Fort San Blas. The D3 site is a busy operational site that conducts missions on a daily basis. Because the A3 site was closer to the Eglin AFB main base, the initial integration tests were conducted at the A3 site. These tests integrated the EFTS system into the range exactly as determined during the requirement phase. The EFTS program provided EFTS training to the A3 site staff.

After connecting the EFTS equipment to the A3 site range infrastructure, the EFTS program was able to successfully test the EFTS commands by sending them from the CC into the encoder; and, the EFTS program viewed and verified that the commands were displayed correctly on the monitor. Unlike the testing that was performed at Edwards AFB, these commands were sent via open loop and were successfully captured and verified by the EFTS monitor.

Captive-Carry Integrated Test Vehicle Flight Termination Receiver NDI-AIU Build-Up

While the EFTS program conducted tests with the equipment L-3 CE had already delivered to Edwards AFB, L-3 CE continued with qualification testing on the EFTR. The qualification testing included but was not limited to the following: environmental tests (such as storage temperature, bench handling shock), random/transportation vibration test, fungus resistance, salt fog test, fine sand test, temperature cycling tests, temperature/humidity test, temperature/altitude test, operating random vibration test (captive-carry buffet and non-buffet), operating acceleration test, operating pyrotechnic shock test, operating random vibration (free-flight) test, explosive atmosphere test, electromagnetic interference tests, and many more. Three EFTR test units underwent qualification testing. Qualification testing was completed successfully with minimal failures. All failures were analyzed, all problems were fixed, and each failed FTR was retested to ensure each unit passed qualification testing.

Near the end of the qualification testing, in preparation for the range testing and live-fire demonstration, the EFTS program was gearing up to test the EFTR on the AMRAAM. With the support of Raytheon Company, the EFTS program was able to build up the AMRAAM with two EFTRs. Because the EFTRs were developed with the same form and fit as the existing IRIG FTRs, Raytheon Company was able to use the EFTRs as drop-in replacements in the AMRAAM for the IRIG FTRs, in the AMRAAM NDI-AIU. This allowed for a relatively quick integration of EFTS into the AMRAAM.

Ground Mount Testing with Integrated Test Vehicle NDI-AIU

When the built-up NDI-AIU with the EFTS FTR arrived at Eglin AFB, it was tested on 13 June 2007 with the Eglin AFB-developed Portable EFTS Test System (PETS). The PETS is a portable EFTS signal generator. The PETS uses an L-3 CE-provided TDU for encryption, and

an external function generator for modulation. The PETS allows all EFTS functions to be exercised in the FTR, which demonstrated its adherence to the specification. During this testing, there were several anomalies in the FTR wireless configuration function. The anomalies have been recorded; they will be fixed in future versions of the unit.

Once the NDI-AIU was tested with the PETS, it was tested receiving a signal from the EFTS ground transmitter at the A3 site. This was open-loop testing that validated the performance of the system end-to-end.

Ground System Integration at Eglin Air Force Base - D3 Site

After the system was successfully tested with the NDI-AIU from the A3 site, the final integration of the components into two portable transit cases was completed on 20 June 2007. The transmit equipment (CCs, Encoders, TDUs, and controlling PC) were put into one case, and the monitor equipment (Monitors and controlling PCs) were put into the other. The equipment was then transferred to the D3 site.

The D3 site ground infrastructure was identical to the A3 site ground infrastructure; thus, integrating the EFTS equipment into the D3 site infrastructure was accomplished in one day. Testing the equipment at the D3 site was similar to the A3 site testing. The EFTS program provided EFTS training to the D3 site staff.

Captive-Carry Integrated Test Vehicle Demonstration

The EFTS testing with the captive-carry ITV was a success. The EFTS program was able to successfully transmit EFTS commands, open-loop, using the EFTS-developed equipment in conjunction with the transmitter systems at Tyndall AFB. While flying, the ITV successfully received and acted upon each of the EFTS commands correctly.

On Monday, 25 June 2007, the system was successfully Ground Mount tested with a Captive-Carry AMRAAM ITV on the flight line at Tyndall AFB using the PETS with an EFTS-developed TDU. This test involved powering up the ITV missile using ground power, placing the PETS approximately 24 inches away from the ITV test article, transmitting encrypted EFTS commands, and verifying that the commands were received correctly by checking with the Tyndall AFB telemetry (TM) personnel. The TM parameters were viewed on strip charts that were used for recording the TM data received from the ITV. The operator, who was transmitting encrypted EFTS commands, validated in real-time that the TM being received was what was being transmitted.

During the Ground Mount testing, the PETS generated the encrypted EFTS commands, which were sent to a function generator connected to an antenna to transmit to the ITV. The following are commands that were sent: Check Channel; Monitor; Arm; Terminate; Command Counter Clear; Wireless Configuration Enable to Configuration 1; and Wireless Configuration Commit to Configuration 1.

On Tuesday, 26 June 2007, the program successfully pretested the captive-carry ITV on an airborne F-15 airplane, with the Tyndall AFB transmitter systems. On Wednesday, 27 June 2007, the captive-carry ITV was successfully tested on the airborne F-15 airplane.

The encrypted EFTS commands sent on Tuesday and Wednesday were identical. Wednesday's commands included two additional command messages at the beginning, to ensure that the EFTS receivers on the captive-carry ITV were in the proper configuration. On both days, all EFTS commands that were sent from the CC appeared correctly on the EFTS monitoring software.

The commands that were sent to the captive-carry ITV were the following: Carrier ON (not a command); Check Channel; Wireless Enable to Configuration 1; Wireless Commit to Configuration 1; Monitor; Arm; Terminate (Fire); Arm + Terminate Sequence (Auto-destruct sequence); Default; Test; Wireless Enable to Configuration 0; and Wireless Commit to Configuration 0. Parentheses include other terminology that is used for the listed command.

As stated previously, all commands were sent via the encrypted EFTS format. All commands were seen correctly on both the EFTS monitor software and the Tyndall AFB TM strip charts.

The TM parameters that were recorded on the strip charts showed the following signals coming down from the captive-carry ITV: Failsafe Monitor; Automatic Gain Control (AGC) Signal Strength; Pulsed Command; Receiver Status Telemetry Output (RSTO); Check Channel; Monitor; Arm; and Terminate (Fire). The signals seen were recorded for both receivers that were on the captive-carry ITV.

Captive-Carry and Live-Fire Demonstration

At the time of the writing of this paper, the EFTS live-fire demonstration had not yet occurred. The live-fire is scheduled for August 2007, and the results will be reported at the 2007 International Telemetry Conference in October 2007.

CONCLUSION

Testing of the EFTS to date has been very successful. The EFTS program has successfully tested each EFTS developed component in a laboratory environment. After the laboratory testing, the EFTS program was able to successfully test each EFTS developed component in a real-time mission environment.

The final results and lessons learned from all testing involving the live-fire demonstration will be documented and reported at the 2007 International Telemetry Conference in October 2007.

ACKNOWLEDGMENTS

The Enhanced Flight Termination System demonstration required the cooperation of many groups to be successful, including: the Advanced Medium Range Air-to-Air Missile

(AMRAAM) program; Edwards Air Force Base; the Enhanced Flight Termination System (EFTS) program; Eglin Air Force Base; L-3 Cincinnati Electronics; the NASA Dryden Flight Research Center; the National Security Agency (NSA); Raytheon Company (Tucson, AZ, for the NDI-AIU); and Tyndall Air Force Base.

NOMENCLATURE

AFB	Air Force Base
AMRAAM	Advanced Medium Range Air-to-Air Missile
CC	Command Controller
DFRC	Dryden Flight Research Center
EFTR	Enhanced Flight Termination System Receiver
EFTS	Enhanced Flight Termination System
FL	Florida
Ft.	Fort
FTR	Flight Termination Receiver
FTS	Flight Termination System
ICD	Interface Control Document
IRIG	Inter-Range Instrumentation Group
ITV	Integrated Test Vehicle
L-3 CE	L-3 Cincinnati Electronics
NASA	National Aeronautics and Space Administration
NDI-AIU	Non-Developmental Item-Airborne Instrumentation Unit
NSA	National Security Agency
PETS	Portable EFTS Test System
RCC	Range Commander's Council
RSO	Range Safety Officer
TDU	Triple DES Unit
TM	Telemetry
U.S.	United States