Temporal, Spectral, and Spatial Threat Simulation Using a Towed Airborne Plume Simulator (TAPS)

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Abstract

Efforts are underway to develop Infrared countermeasure (IRCM) systems to defend aircraft against IR guided surface-to-air (SAM) and air-to-air (AAM) missiles. One such system is the Large Aircraft Infrared Counter Measure (LAIRCM) which employs temporal, spatial, and spectral missile warning techniques. There is no current technique however, for installed system flight testing of such countermeasures in a realistic temporal, spatial, and spectral environment. This paper is an introduction to the Towed Airborne Plume Simulator (TAPS), a system designed to address this test shortfall. The TAPS operational concept is described as well as techniques for simulating missile signatures.

Key Words

Infrared Countermeasures testing, missile simulator

Introduction

The TAPS system is an airborne towed body containing a specialized burner system capable of ejecting atomized pyrophoric fluid in a highly controlled manner. This material, which burns in the presence of air, is modulated in such a way as to mimic the infrared temporal characteristics of a threat missile approaching an aircraft. In addition to emulating the temporal signature, the TAPS system will approximate the spectral and spatial behavior of threat missiles. Specifically, the advanced capabilities of TAPS are as follows.

- Simulate the movement of a threat with respect to the background – a key spatial feature used for detection of a threat by a modern MWS

- Simulate threats moving against actual IR clutter backgrounds at low, moderate and high levels

- Simulate threats in close proximity to sources such as the sun, solar glint, industrial IR clutter, transitional boundaries such as the earth horizon, clouds, and potential false alarm sources

The overarching purpose of TAPS is to provide the test agency with a means to assess the operational functionality of MWS and IRCM systems through estimation of the probability of counter measure (P_{cm}) shown in equation 1.

$$P_{CM} = P_{detect} \times P_{handoff} \times P_{jam} \quad (1)$$

$where:$

$P_{detect} = probality\ of\ threat\ detection$

$P_{handoff} = probability\ of\ MWS\ handoff\ to\ tracking\ sensor$

$P_{jam} = probality\ of\ threat\ sensor\ jam$

The end result is increased confidence that these systems will work even under adverse conditions of severe IR background, increasing the survivability of countermeasure equipped aircraft.

TAPS Program Background

The TAPS development is sponsored by Central Test and Evaluation Investment Program (CTEIP) and is under the direction of the Center for Countermeasures (CCM) in White Sands NM. The prime contractor for TAPS is NewTec with subcontractor SAIC, serving as the technical lead.

The TAPS was born out of two major Test and Evaluation Studies sponsored by the Office of the Secretary of Defense (OSD); the OSD Test and Evaluation Capability End-to-End Study to identify shortfalls in EO/IR Missile Warning System (MWS) testing and the OSD Threat Plume Simulator Development Study which identified TAPS as a potential approach to addressing the test capability shortfalls.

A proof of principal effort was successfully completed in May 2005. Since that time, a series of flight tests have been completed demonstrating key system functionality in relating to P_{cm}. The latest of these efforts was the Flight Characterization Experiment number 2 (FCE II) occurring in March of 2009. During these tests, the TAPS system demonstrated the ability to replicate desired temporal IR signatures in an operationally relevant environment. Limited results from FCE II are presented herein.

Subsequent flight tests are scheduled during which measurements will be taken needed to develop control laws which capture the influence of airspeed, altitude and aspect angle on the output intensity of the TAPS plume. A final set of tests will accomplish verification and validation in advance of the scheduled LAIRCM Initial Operational Test & Evaluation.

TAPS System description & Concept of operations

The basic concept of the TAPS system is depicted in Figure 1. The TAPS Towed Vehicle (TTV) is carried aloft by a towing aircraft and is lowered via cable several hundred meters below. Since TAPS is airborne, it can be placed in the battle space at positions below, at, and above the local horizon of the system under test, simulating both SAM and AAM threats. TAPS can maintain a threat-like line of sight (LOS) to the System Under Test (SUT) while operating in an actual IR background. Another key attribute of TAPS is the ability to characterize the tracker/jammer performance of laser countermeasures installed on an operational aircraft. Radiometers on-board TAPS measure the received energy from the IRCM laser jammer. Upon declaration of TAPS as a threat, a laser-based countermeasure will direct its jam beam towards the radiometric Centroid of the TAPS plume. Radiometers placed at the aft end of the TTV will capture the laser energy needed to assess countermeasure effectiveness.

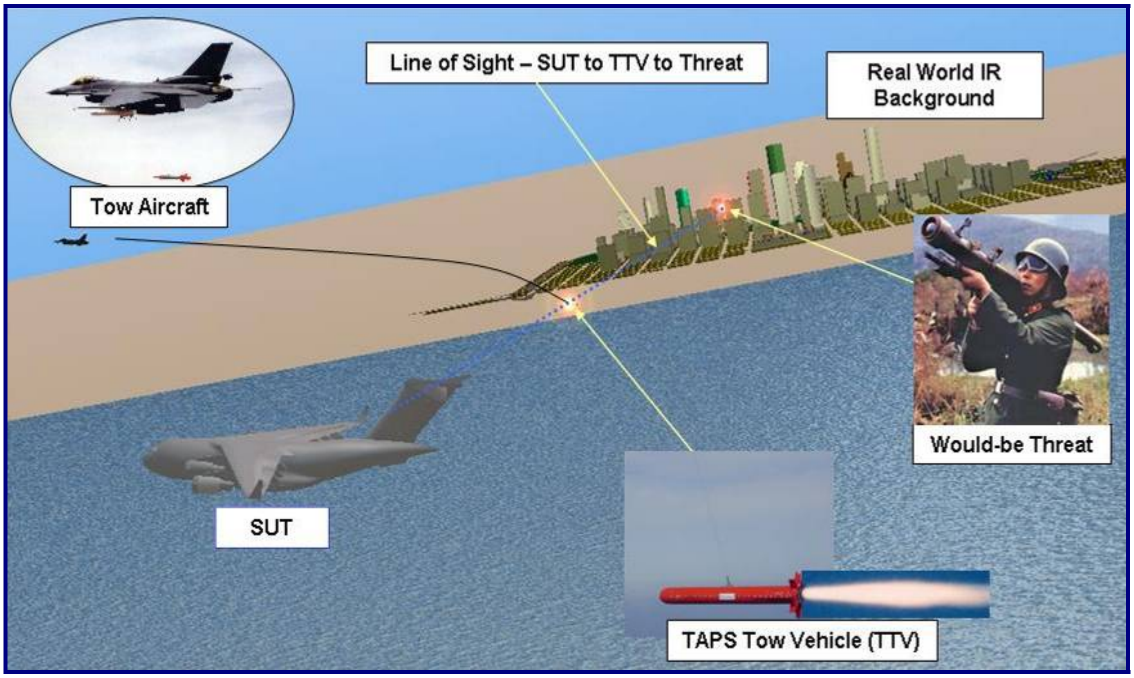

Figure 1. TAPS Operational Concept

The TAPS Towed Vehicle (TTV), the towing aircraft and an airborne radiometric witness aircraft (not shown) are integrated via C-band telemetry. This link provides control of the system from the towing aircraft or a chase aircraft as well as the means to transfer a wide range of real time or near real time measured data.

An illustration of the TAPS Towed Vehicle (TTV) is shown in Figure 2. The principal components are the Burner System, the Jam Beam Radiometers (JBR) and the electronics vessel.

The generation of a missile-like IR signature is accomplished with the TTV Burner system which includes fuel vessels containing a pyrophoric fluid which is pressurized with gaseous nitrogen.

This development is lead by Arnold Engineering Development Center (AEDC). The fuel used in all testing to date has been Tri-Ethyl Aluminum (TEA).

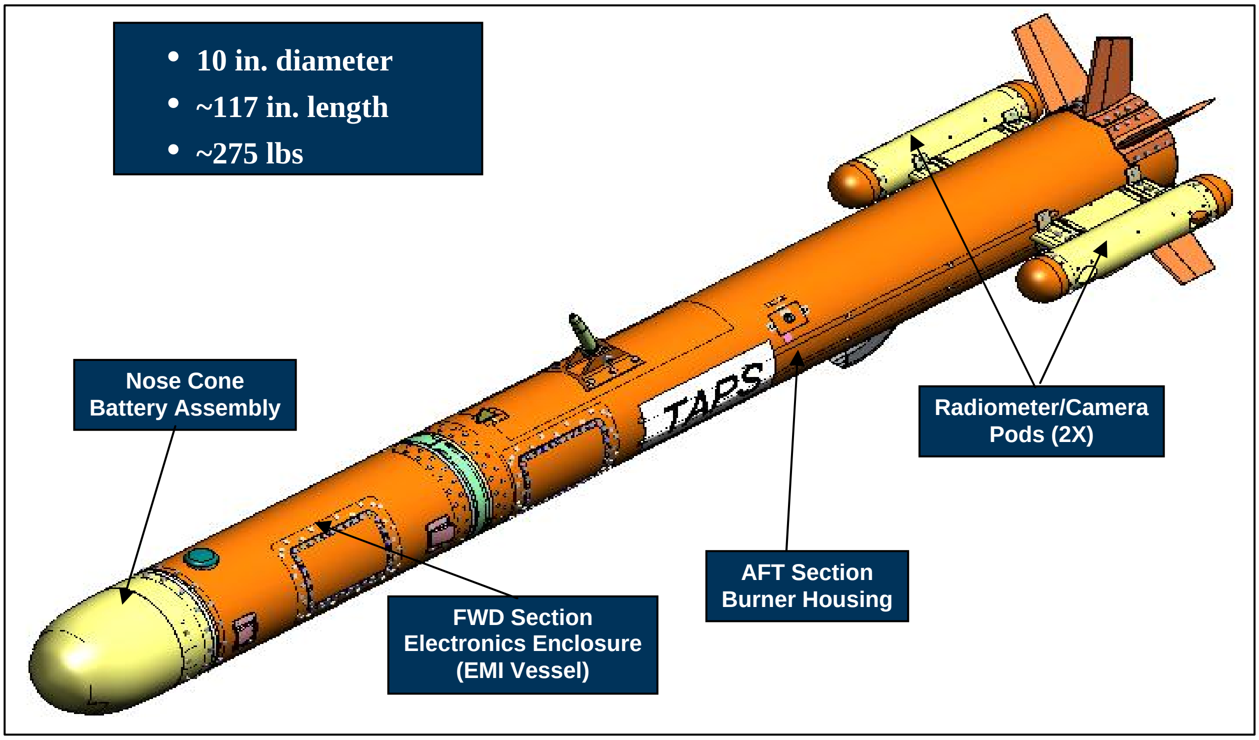

Figure 2 TAPS Towed Vehicle (TTV)

Infrared Temporal and Spectral Signature Emulation

Located at the base plate of the burner assembly are two valves (shown in Figure 3) from which the TEA is ejected under pressure, atomizing the material. These valves are each designed to produce different range of mass flow rates giving the TAPS TTV a radiometric range of approximately 20w/sr to 3000 w/sr. Figure 4 is a 2 dimensional snapshot of a plume produce in flight during the FCE II. This image is a side-view of the plume and was taken by the Airborne Radiometric Instrumentation System (ARIS) also developed by SAIC as a component of the TAPS system. The ARIS includes an external pod containing optical instruments, mounted on an aircraft which is flown in the vicinity of the TTV for plume characterization and independent witness during operational tests. The location of the plume centroid is an important measure as this represents the expected target point for the countermeasure's laser jam beam.

The time-varying (temporal) behavior of a threat missile's IR signal strength as seen by the SUT MWS has a number of characteristic features generated by the missile's motor event sequence. These include an eject spike (if shoulder launched), a boost motor onset, a sustain phase and a rapid growth in intensity as the threat missile approaches its target.

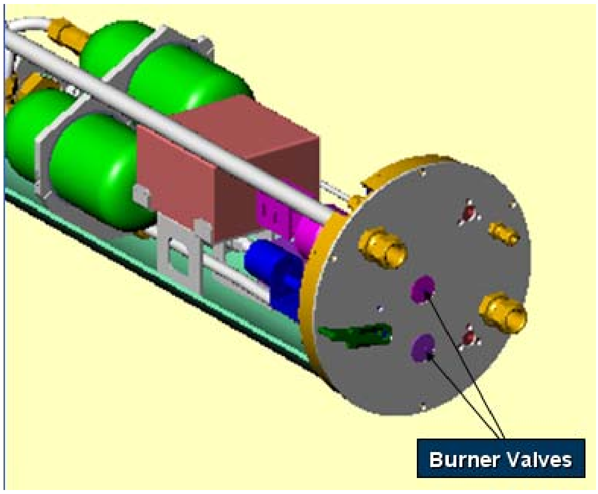

Figure 3 TTV Burner System

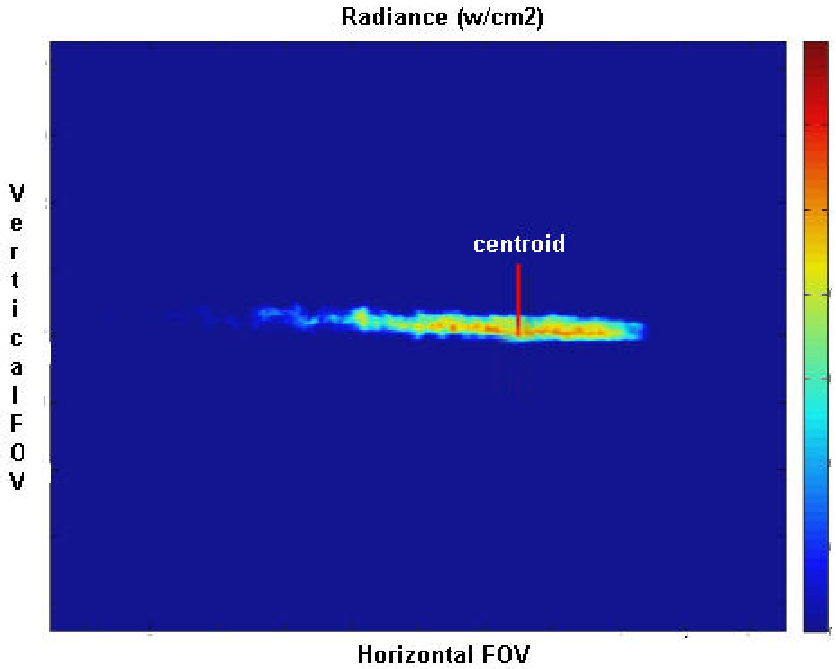

Figure 4 TAPS IR Plume Side View

The output of the TAPS TTV plume is programmed to emulate these temporal threat missile features. Figure 5 gives an example simulation executed during FCE II showing the intended (“desired”) radiant intensity along with the measured (“achieved”) radiant intensity.

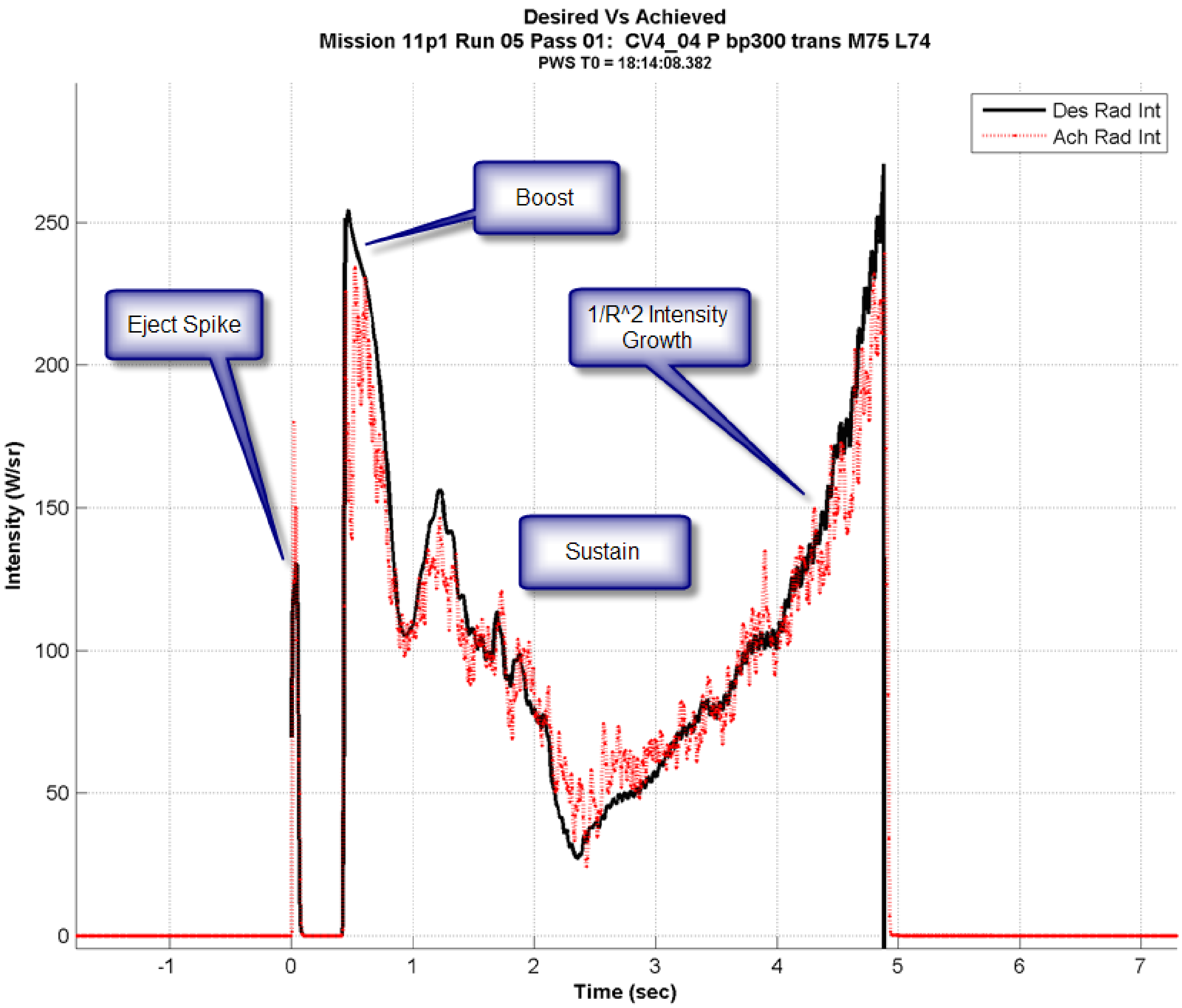

Figure 5 Temporal Signature Emulation by the TAPS System

The "desired" output radiant intensity of the TAPS plume is specified through modeling of a specific threat scenario. The flight path of a notional target aircraft is first specified along with a threat missile type and shot geometry (azimuth and range). The flight path of the missile is modeled using the Threat Modeling and Analysis Program (TMAP). Using this information, the resulting irradiance at the SUT's MWS is then modeled by the Infrared Missile Signature Model (IRMSig) and Moderate Transmission (ModTran) atmospheric propagation model. This basic relationship is shown in equation 2.

$$I_{TAPS} = (E_{threat} \times R^2)/\tau \quad (2)$$

$where:$

$I_{TAPS} = desired\ TAPS\ plume\ source\ Radiant\ Intensity$

$E_{threat} = modeled\ irradiance\ at\ MWS$

$R = slant\ range$

$\tau = atmospheric\ transmission$

The spectral content of the pyrophoric TAPS plume is comparable to a missile plume in the infrared. Figure 6 shows the spectral content of a typical aluminized solid propellant tactical missile.

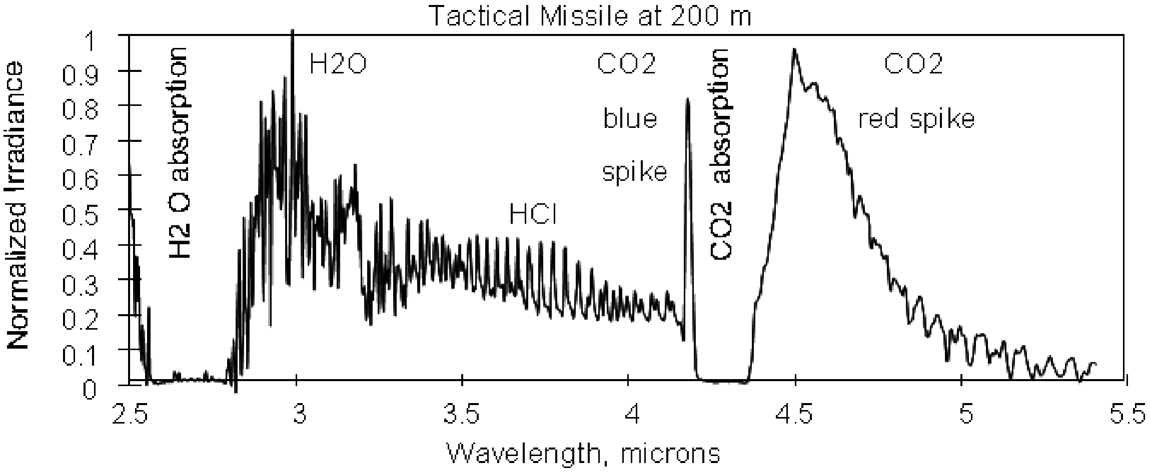

Figure 6 Tactical Missile Spectrum

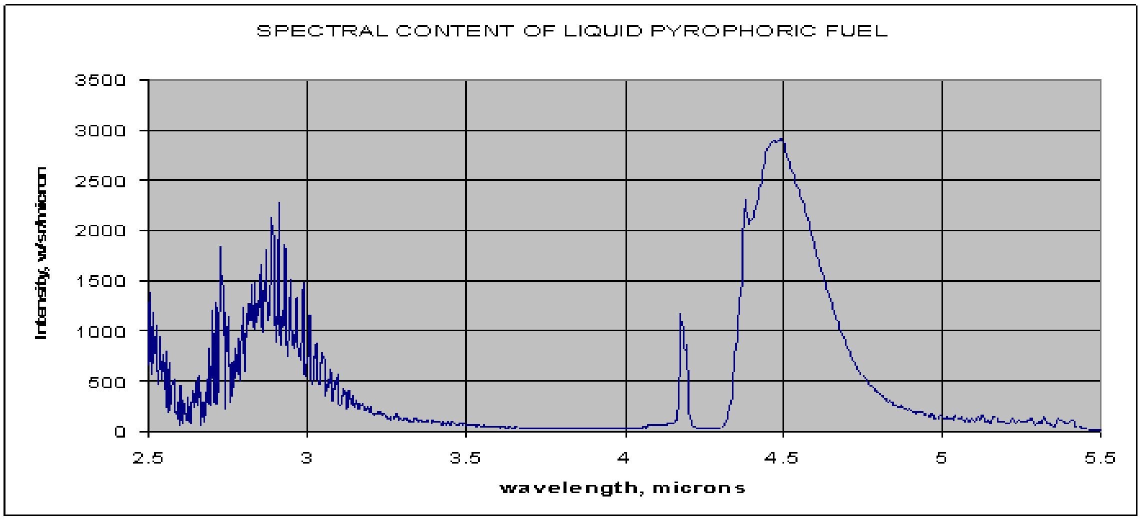

Figure 7 TAPS Tri-Ethyl Aluminum Spectrum

Figure 7 shows the spectrum of the TAPS plume. Note the strong resemblance with the exception of the reduced intensity of the blue spike. During the initial development (to date), TAPS focused on the Red spectral band. Since this time, an elevated importance has been placed on the ratio of red band to blue band signal. The fuel used to present (TEA) is deficient in color ratio. Efforts are underway at the time of this report to modify the pyrophoric fuel to overcome this issue. Ground test results indicate that a specific blend of TEA and Tri-methyl Aluminum will achieve the appropriate ratio.

Spatial (Line of Sight) Signature Emulation

Along with the Temporal and Spectral simulation of a threat missile, the TAPS system can estimate the line of sight behavior of a threat. The towing aircraft will fly in a parallel path to the SUT and emulate the elevation and azimuth angles of a missile in proportional navigation mode. This typically manifests in a near constant azimuth angle and an increase in elevation angle. Figure 8 shows the elevation angle time-history modeled by TMAP for a typical missile engagement. Figure 9 shows the same for a measurement made during FCE II.

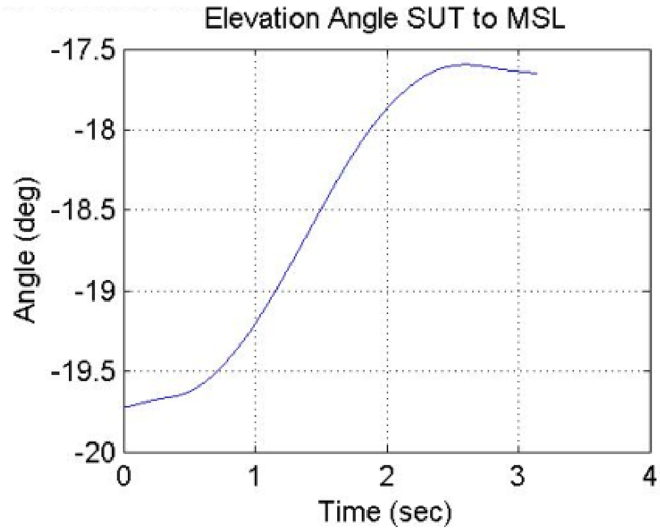

Figure 8 Example Time-Dependent Threat Elevation Angle from TMAP

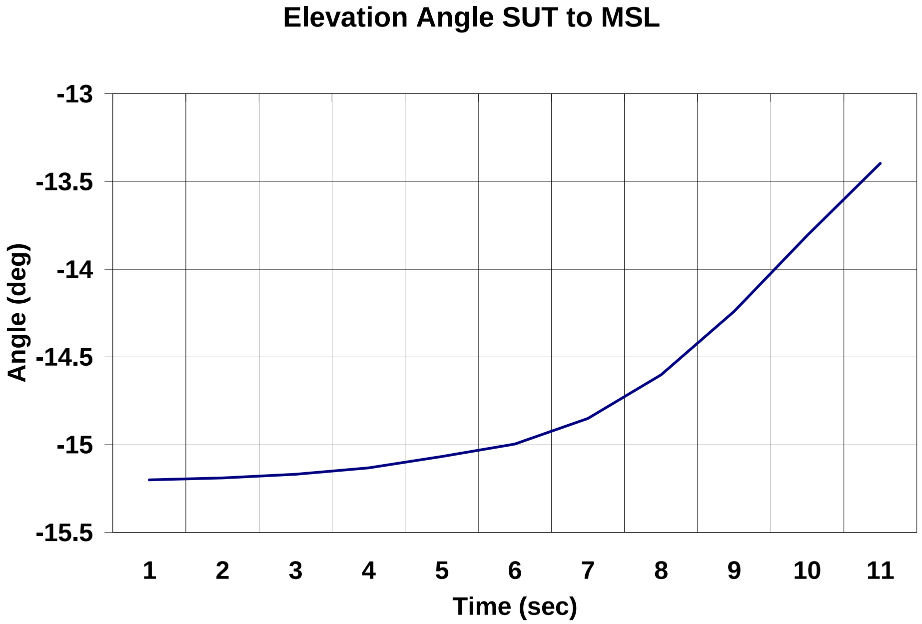

Figure 9 Measured Time-Dependent TTV Elevation Angle during FCE II

TAPS Control and Data Acquisition Systems

The operation of the TAPS system requires active control of the TTV, the tow aircraft, the chase aircraft, and the SUT. Control and diagnostics of these elements is accomplished with the Mission Control Computer (MCC) located on either/or tow and chase aircrafts shown in figure 10. Currently, both aircraft host MCCs for redundancy. The option exists for a ground station as well. The RF communication subsystem consists of the C-Band wireless local area network (WLAN) radio telemetry (TM) system, a UHF TM and an emergency control (EC) element. The C-Band TM element is the primary communication link between the TTV and operates in the 4.447 gigahertz (GHz) range; the UHF TM element operates in the 298.8288 megahertz (MHz) range. The UHF TM element is the secondary path for recovery and recording TAPS mission results (in the event of a C-Band TM element failure). More importantly, the UHF TM element is the backup link for commanding a fuel dump in case of emergency.

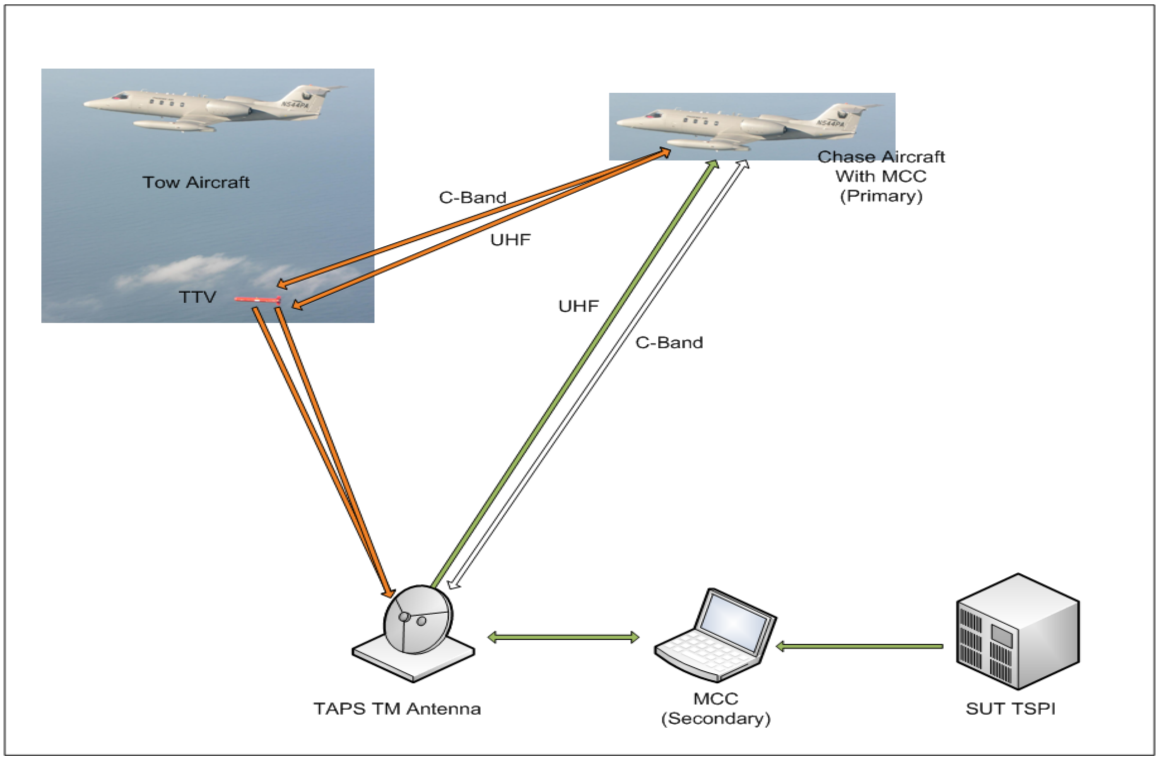

Figure 10 TAPS Telemetry

The airborne and ground station TM hardware are the same except for the ground tracking station antennas and the prime power source. Both UHF and C-Band links use a bidirectional packet format and operate in one direction at a time on the same frequency. Figure 11 gives a block diagram depiction of the TAPS telemetry subsystem. Figure 11 provides a block diagram of the C-Band TM element showing the path to communications with the TTV Onboard Computer System (OCS).

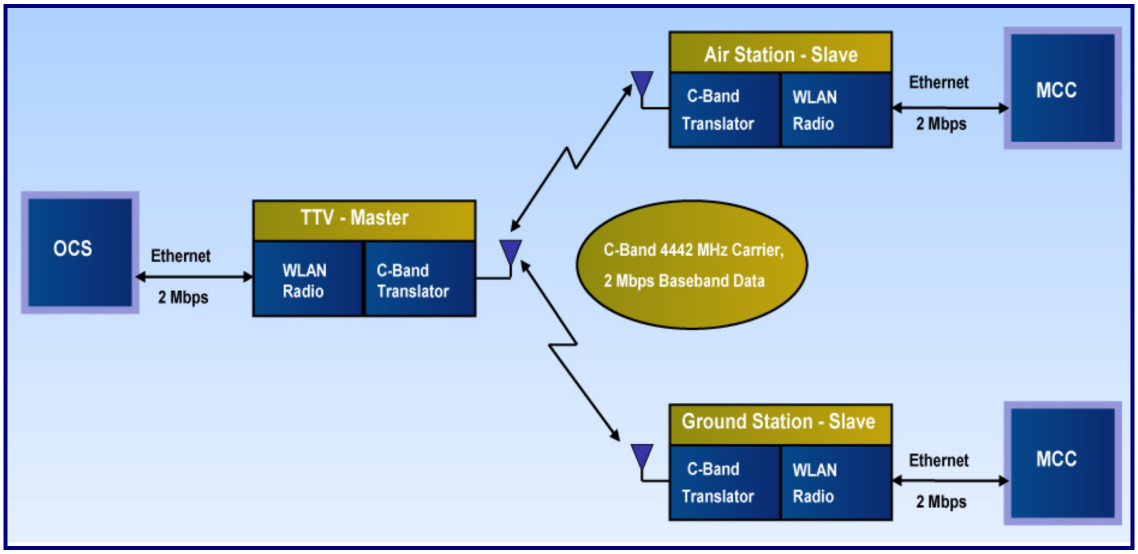

Figure 11 TAPS Telemetry Systems

Conclusions

This paper provides an introduction to the TAPS concept and limited measurements from recent flight tests. The TAPS system has demonstrated initial successes in key areas indicating it's viability as an important test asset with as yet, unattainable characteristics. Development has been essentially completed for the primary sub-systems with continued flight testing ongoing. The continuing efforts will focus on refining control of the burner system and refining operational procedures.

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