"DON'T LEAVE THE PAD WITHOUT IT" USING DEPLOYABLE ASSETS TO CONDUCT PRE-LAUNCH AND ON-ORBIT TESTING

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ABSTRACT

When hundreds of millions of dollars are invested in building, launching, and command/control of modern military space systems, the developers and operators need assurance that when their system achieves orbit, it will be able to "talk" with the ground network, exchanging commands, telemetry and ranging signals. Furthermore, prior to launch they need proof of compatibility with the ground data systems, showing that operational ground-based crypto keys, database parameters, and processing software are in-fact compatible with the spacecraft. This paper describes Air Force Materiel Command (AFMC), Space & Missile Center (SMC) Detachment 2's four classes of deployable test assets, emphasizing deployable's contribution to successful on-orbit performance. With not only the huge dollar investment, but even more important, the ability to execute a vital test or operational mission riding on compatibility, and launch vehicle and on-orbit test and evaluation operations the watchwords are "**Don't leave the pad without it**."

KEY WORDS

Deployable, Transportable, TT&C, Spacecraft Compatibility Test, Air Force Satellite Control Network (AFSCN), Space Ground Link System (SGLS)

INTRODUCTION

Air Force Materiel Command, Space & Missile Systems Center, Space Test and Evaluation Directorate (Det 2 SMC) deployable Telemetry, Tracking, and Commanding (TT&C) systems are on the cutting edge of field test and research for spacecraft and payload testing. Det 2 deploys and staffs these resources to support

Research, Development, Test and Evaluation (RDT&E) and Air Force Satellite Control Network operational missions. The test resources can and are deployed to factories, launch sites, or remote locations to transmit real-time commands, acquire and record telemetry and to interface with numerous communications systems. Space Ground Link System (SGLS) compatible, deployables are used for satellite compatibility testing at a laboratory or factory prior to satellite/payload shipment to the launch site, testing at the launch base prior to liftoff, additionally they may be used for launch booster or early orbit test and evaluation support for the satellite by deploying TT&C systems worldwide to meet user requirements. Finally, these assets can provide communications via S-band communications satellites between deployed test resources and the Test Support Complexes at Onizuka Air Force Base, Sunnyvale, California, or elsewhere, to complete end-to-end connectivity.

Often the first contact between the SMC Det 2 deployable assets and the satellite is in a laboratory or factory test environment. The Transportable Vehicle Checkout System (TVCS) usually performs this function. Worldwide on-orbit test and evaluation field deployments are made by the S-Band Transportable Ground Station (STGS). Transportable S-Band Terminals (TST) can perform mission communications or telemetry and commanding support for a early orbit mission or compatibility test. Another deployable asset, the Transportable Space Test and Evaluation Resource (TSTR) is available for compatibility and early orbit scenarios. Appendix I lists the top level characteristics for each of the transportable systems.

COMPATIBILITY TESTING

With hundreds of millions of dollars invested in the building, launching, and command/control of modern military space systems, pre-launch compatibility tests are crucial to ensure that the ground and space elements can communicate with each other. A typical compatibility test scenario begins when the control center (called Test Support Complex, Satellite Operations Center, or Mission Control Complex within the AFSCN) responsible for operating the orbiting spacecraft or booster requests the satellite sponsor to schedule the test. The goal is to run the trial as early as practical so that compatibility problems, if any, may be corrected with least cost and program impact. This does not need to be an exhaustive test. Its significance is to show that all major satellite TT&C paths are functioning in a system end-to-end test with the control center.

Prior to the scheduled test, Det 2 always conducts a site survey at the test location, evaluating such items as equipment space, power, communications, satellite access paths, and transportation requirements. This survey will uncover logistical and

technical items that must be resolved prior to the test date, thereby minimizing impact on scheduled activities.

The TVCS or TSTR is deployed and set up at the site-surveyed location near the spacecraft so that it interfaces at the radio frequency (RF) level. Typically, antenna hats or RF ports are used at the spacecraft end; Det 2 provides an RF coaxial cable and interface at the deployable equipment end. Figure 1 shows a top level block diagram for a typical compatibility test.

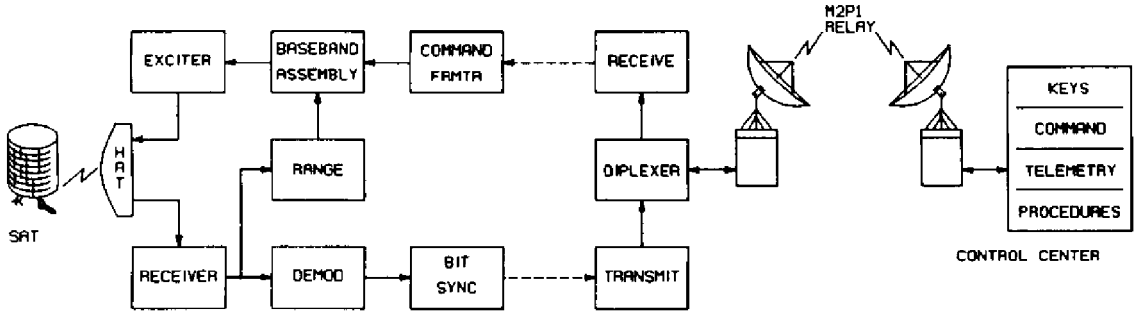

Figure 1. Compatibility Test Configuration

A signed-off Test Plan/Procedure is followed to demonstrate that the ground control center and spacecraft are compatible. The plan or script is usually jointly written by the spacecraft integrator and control center. The spacecraft sponsor is responsible for overseeing and approving the test objectives and methods.

To demonstrate compatibility, telemetry data is received by the Det 2 deployable equipment, downconverted and demodulated to baseband, recorded and relayed to the control center for evaluation. All RF carriers/channels and modulation schemes planned for on-orbit use are exercised and evaluated during this test. Commands are initiated at the control center and digitally transmitted to the deployables. There, the commands are converted to the spacecraft uplink waveform and sent to the vehicle. Command responses are verified by telemetry response or functional verification. The spacecraft ranging system is tested by uplinking a Pseudo-Random-Noise code and synchronizing to the returned code.

The following section describes several examples of Det 2 experience, illustrating vividly why the pre-launch compatibility testing is so important

COMPATIBILITY TEST PROBLEM EXAMPLES

Problem	Action	Potential Impact If Not Corrected Pre-launch
Cannot command the spacecraft and/or cannot process telemetry. Spacecraft crypto key changes were not passed on to the control center by the factory.	The correct keys were provided to control center.	Inability to contact spacecraft will delay crucial early-orbit initialization configuration procedures.
Spacecraft modulation scheme used for a payload transmitter exceeded the specification of ground station hardware.	Ground equipment was adjusted to extreme operating limits to accommodate the new vehicle and existing spacecraft.	Stored payload telemetry data would have been lost.
Telemetry data on QPSK I and Q channels were found to be reversed on a series of satellites.	Ground stations were directed to change configurations.	Valuable telemetry would have been lost during on-orbit initialization.
Spacecraft would not accept uplink RF commands because the manufacturer did not understand tracking station calibration procedures. The spacecraft responded only to a maximum command modulation index value.	Ground configuration databases were changed to select the modulation index required by the spacecraft.	Inability to command spacecraft during on-orbit initialization.
Inability to command spacecraft, traced to a control center database design problem caused by spacecraft factory documentation deficiencies.	Modified control center database structure.	Inability to command spacecraft on orbit.
No telemetry subcarrier from the spacecraft transponder.	Transponder wiring harness error, corrected during the test.	Mission failure

TVCS DESCRIPTION

The major downlink components of TVCS are two telemetry receivers, a ranging receiver, digital ranging system, subcarrier demodulators, bit synchronizers, low speed wireline modulator/demodulators, time code generator/reader, and an Inter Range Instrumentation Group (IRIG) Wideband Group II 7-Track recorder. For the uplink, a command formatter translates the incoming commands to satellite format, composes a modulation waveform and modulates a signal generator that provides the RF uplink. Other equipment such as convolutional decoders can be added to the basic suite for mission peculiar operations. With the exception of the ranging equipment and the command formatter software all other items are Commercial Off The Shelf (COTS) procurement.

TVCS is packaged in 10 road cases that are stacked in a 3 X 3 configuration at the test site. The recorder has its own case and is placed adjacent to or behind the stack.

External interfaces are limited to power/ground and the RF cable to the spacecraft. All internal TVCS connections are via patch panels at the rear of the cases.

TSTR DESCRIPTION

The TSTR is a full scale tracking station packaged to fit in a pair of semitrailer shelters. One 45-foot long semitrailer contains an erectable, remotely pointed, or full autotracking 23-foot dish antenna and a 2.25 KW High Power Amplifier (HPA). The other semitrailer, the 40-foot long core van, contains the uplink and downlink equipment that either interfaces to the antenna/HPA van or to a satellite via a hardline. The core van is capable of supporting multiple simultaneous downlinks, up to 5 MBps each and recording the telemetry data. Normally the core van is connected to the control center via a 9.6 KBps data link that provides considerable remote control capability and status collection by the control center. In this scenario the control center may direct antenna position, switch a transmitter from dummy load to radiate, or send command data for uplinking to a spacecraft. Other internal configuration parameters are controlled by a preplanned database build. A capability exists to exercise, or override, all control functions locally. This feature allows responding to unplanned events quickly and efficiently.

Addition of the antenna/HPA to the core van provides a solution for early orbit test and evaluation scenarios that require a relatively high EIRP and a sensitive receive system. Although large, the total TSTR system provides industrial strength solutions for difficult applications.

STGS/TST DESCRIPTION

The STGS and TST each have a parabolic dish antenna that provides an RF interface between the ground and space element. STGS uses the larger 12-foot diameter antenna versus the 8-foot diameter antenna for the TST. Like the TVCS all hardware is COTS and is modular packaged for shipping. STGS/TST do not have a PRN ranging capability but each has an antenna controller and 250 watt HPA for orbital support.

STGS is designed to provide RDT&E support for low to medium altitude satellites. Higher altitude, lower-powered satellites such as DSCS and FLTSATCOM cannot be reliably supported because of poor link margins. The TST can also support mission satellites if the link margins are satisfactory. Note that STGS/TST can also support compatibility testing via hardline, by just deploying with the subset of the equipment needed.

The STGS and TST antenna positions can be controlled several different ways:

1. Azimuth and elevation position can be manually controlled to the angle/time position by an operator.

2. Azimuth and elevation position can be updated automatically, once-per-minute. A ±1 degree scan in both axes is initiated by the antenna controller. The controller then returns the antenna to the strongest signal point.

3. Azimuth and elevation position can be automatically moved to angles calculated from a NORAD 2-Line Mean Element set. This process is iterative and extremely useful for satellites with significant orbital movement with respect to the antenna.

A subset of this method employs two separate NORAD 2-Line Mean Element Sets with a bridging technique to transition from the first to the second. This technique is useful when a booster performs high energy burns during a contact.

4. Azimuth and elevation position for the STGS antenna can be controlled by an optional autotrack receive only feed and electronics assembly. This system is available for missions that do not require commanding. The TST does not have this capability.

5. Azimuth and elevation position can be controlled by processing Earth Fixed Geocentric (EFG) messages from an outside resource in near realtime such as a range RADAR. The EFG measurands are transformed into local antenna look angles and the antenna follows the target's position. This enhancement was recently tested during a deployment to Newfoundland in support of STS-53.

Like the TVCS, equipment can be added or deleted from the basic complement to tailor the system for a particular mission. Equipment packaging is similar to TVCS with all equipment mounted in transportable cases for ease of movement. All the TST or STGS equipment must be sheltered except for the antenna which must be located outside. The STGS requires the same amount of floor space as TVCS.

LAUNCH VEHICLE & EARLY ORBIT TEST EVALUATION

Transportable equipment is frequently deployed to support early orbit test and evaluation activities. Usually these deployments take place because critical events take place outside of view of fixed ground stations. Another reason for deploying TT&C equipment is that during early orbit test and evaluation the satellite sponsor

may require far more support than the AFSCN fixed antenna schedule loading will allow. Shifting large amounts of RDT&E satellite support to a Det 2 transportable frees the network to perform its operational commitments.

A site survey is one of the first items completed for a LEO deployment, just as in compatibility testing. Again, the reason is to make sure the mission can be supported on time and as economically as possible. Site survey topics are the same as for compatibility testing with several important additions. Local obscura is plotted and compared to predicted orbit paths to ensure minimum interference in the RF line of sight path. Weather conditions are extremely important and play a major role in site selection. Coordination with authorities, local or foreign, is always required. Again, the objective is to find problems early, work them out, or to suggest acceptable solutions.

The most common scenario is to deploy STGS/TST terminals to the desired location. For more demanding orbital deployments, the TSTR may be preferred. In addition to the ARTS core van mentioned earlier, there is a companion semitrailer which contains a 23-foot parabolic dish antenna and a 2.5 KW HPA. The tradeoff is that TSTR is large - and relatively expensive to move.

Past deployments have been staged to receive telemetry from TITAN IV boosters. Other deployments include receiving and relaying telemetry data for the Inertial Upper Stage (IUS)/Defense Support Program (DSP), IUS/NASA, and Shuttle/Magellan. Commanding and telemetry support was provided for RME, Shuttle/DSP, and other national programs. To date, over 85 deployments have been accomplished.

COMMUNICATIONS

In the ideal world the deployable's customer provides communications from the deployable location back to the control center. Rarely is this the case. Det 2 has developed the TST to provide this capability. M2P1 satellites are used to transfer command date outbound to the deployed location and to receive low rate telemetry in return. The TST and STGS differ only in antenna sizes with the TST utilizing a smaller 8-foot diameter dish, the rest of the equipment is the same.

The TST typically receives data at rates up to 64 KBps NRZ and transmits at a maximum of 128 KBps NRZ. Alternately, the 12-foot STGS may be used in case higher data rates are needed. Alternately the smaller TST antenna may support the mission satellite while the higher gain/EIRP STGS provides the communications function - each mission dictates how the equipment is configured to meet requirements.

Det 2 also has MUX/DEMUX equipment that is used to support multiple data and/or communications streams. Both the field and home nodes are provided by Det 2. A STU-III and compatible facsimile machine are also available.

Transportable generators capable of powering the TST and STGS are available if local power is not suitable. Radomes to protect the antennas and equipment shelters are available for challenging weather areas.

PLANNED ENHANCEMENTS

Residing on the leading edge of testing and LEO support requires continual equipment upgrades. Systems must evolve to meet the projected Research and Development requirements. These are some of the near term changes that are planned for the deployables that will be visible to the users:

1. Modernization of hardware is undergoing review. The objective is to update equipment to a modern configuration representative of today's technology. Particular attention is focused on the RF segments of TVCS, such as receivers, ranging, and demodulation equipment. Computerized control of equipment is a goal to decrease set up time, reduce the probability of configuration error, and to ensure test repeatability.

2. Small generators are available for STGS/TST/TVCS deployments. An internally derived requirement is to provide the same capability for the TSTR. There will be sufficient generation capacity to power both the ARTS core and the antenna and HPA units. Planned fuel capacity is 2 or 3 days of continuous operation before refueling.

3. There is a need for rapid, economical, worldwide communications between transportable assets on deployment to the home base and control center. To provide this capability a portable suitcase sized commercial INMARSAT terminal is now in the procurement process. Addition of this device will allow secure voice and low to medium speed data communications between most deployed locations and the control centers.

4. Some users prefer secure communications. A cellular STU-III has been requisitioned for these type of missions. The ability to communicate securely from deployed locations, on demand, and at a reasonable cost, will immensely enhance operations.

5. Some potential Det 2 customers may extend their uplink frequencies to the Unified S-Band range of 2025-2120 MHz; some contemplate shifting to the 2300-2400 MHz downlink band. Det 2 is studying the changes necessary if these changes become requirements.

Other modifications to support future operations will be considered by Det 2.

CONCLUSION

Total system testing between the spacecraft using representative ground station equipment and a supporting control center makes sense. The potential failures due to misunderstandings or failure to communicate can be catastrophic or lead to delays in initializing a new satellite or payload on orbit. Transportable TT&C resources can and should be used to verify this ability to communicate if fixed ground resources are not available. After launch, important events occur out of view of the normal ground resources. The requirements for capturing critical data, or providing command support at the correct time and place are being met by deployment of Det 2 hardware resources and personnel. "**Don't Leave the pad without it**".

APPENDIX I

TOP LEVEL CHARACTERISTICS

TOP LEVEL CHARACTERISTICS	TRANSPORTABLE S-BAND TERMINAL	S-BAND TRANSPORTABLE GROUND STATION	TRANSPORTABLE SPACE TEST EVALUATION RESOURCE	TRANSPORTABLE VEHICLE CHECKOUT SYSTEM
Antenna Size	8-foot	12-foot	23-foot	N/A
Uplink Frequency (MHz)	1750-1850	1750-1850	1750-1850	1750-1850
Polarization	RHCP	RHCP	RHCP	N/A
Transmit Power (Watts)	250	250	2250	.001
EIRP (dBm)	80.6	84.0	101.6	W/A
Downlink Frequency (MHz)	2200-2300	2200-2300	2200-2300	2200-2300
Beamwidth (Deg)	3.7	2.8	0.6	N/A
G/T (dB/^{0} K min)	9.0	11.0	21.5	N/A
Slew Rate (Deg/Sec)	Az 8.0/EL 5.0	Az 8.0/EL 5.0	15	N/A
Antenna Gain (dB)	32	36	46	N/A
Remote Control	None	None	Extensive	None
SGLS Compatible	Yes	Yes	Yes	Yes
Power	20A, 2 Ph of 120/208V 2 x 20A @120V	20A, Ph of 120/208V 2 x 20A @120V	175 KVA of 208V, Both Vans	15A @120V
Telemetry Data Rate	Up to 5 MBps	Up to 5 MBps	Up to 5 MBps	Up to 5 MBps
Telemetry Recording	7 Track, 0.5 inch	7 Track, 0.5 inch	14 Track, 1 inch	7 Track, 0.5 inch
Simultaneous Receive/Transmit	Yes	Yes	Yes	Yes
Digital Ranging	Optional	Optional	Yes	Yes
GPS Receiver (Time/Location)	Yes	Yes	Yes	Yes
Test Equipment	Yes	Yes	Yes	Yes
Spares	Yes	Yes	Yes	Yes
Shipping Weight, With Spares & Documentation	3500 Lbs	5,000 Lbs	61,000 Lbs ANT/HPA 50,000 Lbs, Core	2,100 Lbs
Shipping Size, With Spares & Documentation	370 Cubic Feet	520 Cubic Feet	10,500 Cubic Feet	240 Cubic Feet
Auxiliary Equipment				
Portable Power	Yes	Yes	Yes	Yes
Multiplex & Other Comm	Yes	Yes	Yes	Yes
STU-III/Facsimile	Yes	Yes	Yes	Yes