THE PHILLIPS LABORATORY'S MOBILE GROUND TRACKING STATION (MGTS)

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ABSTRACT

Phillips Laboratory's Space Experiments Directorate (PL/SX) is operating and upgrading the laboratory's premier transportable satellite tracking station, the Mobile Ground Tracking Station (MGTS) program. MGTS supports orbital, suborbital, and aircraft missions as a range system capable of processing and recording multiple data streams. MGTS receives, processes, displays, and records satellite state-of-health data, infrared images in a variety of wavelengths, video data, and state vector solutions based on IR returns from the Miniature Sensor Technology Integration (MSTI) satellite program.

The program has began in 1990 under BMDO sponsorship, with the intent to supplement existing test ranges with more flexibility in range operations. Wyle Laboratories and Systems Engineering and Management Company (SEMCO) provided the technical expertise necessary to create the first MGTS system. Autonomy and off-road capability were critical design factors, since some of the operations envisioned require deployment to remote or hostile field locations. Since inception, MGTS has supported the Lightweight Exo-Atmospheric Projectile (LEAP) sub-orbital missions, the MSTI satellite program, and Air Force wargame demonstrations. In pursuit of these missions, MGTS has deployed to White Sands Missile Range (WSMR), NM; Air Force Flight Test Center (AFFTC), Edwards AFB, CA; Vandenberg AFB, CA; Falcon AFB, CO; and NASA's Wallops Island Flight Facility, VA, to receive critical mission telemetry data conforming to both IRIG and SGLS standards. This paper will describe the evolution of the

MGTS program, current hardware configurations and past and future mission scenarios for the MGTS team.

KEY WORDS

Mobile Telemetry Processing, Satellite Ground Station, SGLS

INTRODUCTION

In the fall of 1990, the need for a dedicated mobile telemetry processing system became apparent as detailed planning for various missions began. Near-term telemetry requirements would have created scheduling conflicts with national range assets. They also required upgrading equipment to satisfy program needs. The solution was to develop a single program-dedicated system that could focus solely on mission telemetry. The system would also be easily relocateable and versatile enough to support many different testing scenarios. The additional requirement of handling secure data and sensitive equipment was a further consideration for the program planners, since the range selection process for the various missions was not yet complete. A certified secure system that could be directly controlled by the program office was the clear solution. In response to these issues facing the Phillips Laboratory's program office, the Mobile Ground Tracking Station (MGTS) was developed.

MGTS PROGRAM EVOLUTION

As the MGTS concept evolved in the winter of 1991, it was clear that some missions would require support from remote sites. The surplus Air Force Ground Launched Cruise Missile (GLCM) Launch Control Center (LCC) trailers and accompanying eight wheel drive tractors were chosen to meet the requirement. Since the now deactivated GLCM tractors and LCC trailers were designed for harsh field operations and were available free to the program as Government Furnished Equipment (GFE), two of the major issues facing the MGTS program office were solved - cost and durability/reliability of the proposed system. During the life of the GLCM program, the tractor/trailer combinations were deployed throughout the

European Theater and proved to be rugged and reliable on all terrain. The external dimensions of the LCC trailer which houses the MGTS unique equipment and operating stations for up to 3 people are 36 feet long by 8 feet wide by 12 feet high (see Figure 1). That the LCC trailers were also designed to meet secure data requirements allowed greater flexibility for mission support when sensitive telemetry data or equipment was to be handled. The decision was made for the Space Experiments Directorate of the Phillips Laboratory at Edwards AFB to obtain ten (10) tractors and six (6) LCC trailers as GFE and train operations personnel.

The first activities to be accomplished on the trailers were the conversion of the 400 Hz electrical systems to standard 110/208 VAC, 3 phase, 60 Hz and the upgrade of the Environmental Control Units to accommodate the higher heat loading expected from the MGTS-specific equipment. With these modifications complete on one of the trailers, hardware layout plans were developed to maximize the use of the limited space available in the racks. Internal modifications began on the trailer that would become the "prototype" system, referred to as MGTS #1. Existing Phillips Lab in-house telemetry components as well as some loaners from other programs were integrated into MGTS #1 for support of the first Ballistic Missile Defense Organization (BMDO) LEAP mission at White Sands Missile Range, NM.

Siting for MGTS support of the LEAP-1 mission was established and a downrange remote location along the flight path of the Aries booster was chosen. With no range antenna assets available at this location, the team improvised by resurrecting an old AFFTC, Edwards AFB program track antenna pedestal, attached a 10 foot dish and mounted it on a trailer, thus creating the first of the MGTS mobile antennas. MGTS feasibility was further tested when range facility power wasn't guaranteed and a generator capable of running the whole set-up was required. Again constrained by cost limitations as well as schedule, an existing government 25 KVA generator was obtained and integrated into the power distribution system to allow MGTS #1 electrical autonomy. The processing systems were checked out prior to deployment by running mission test data tapes to verify the interconnections and accuracies of the data scaling factors. The antenna programming and capabilities were qualified during tracking engagements of targets of opportunity, which included satellite fly-bys.

With all functions checked out as 1990 came to a close, the MGTS #1 prototype system was deployed to WSMR, NM and its first true field test. As a prototype system, the MGTS program objectives for the LEAP-1 mission were to validate the concept and evaluate deployment feasibility to remote locations by means of the former GLCM assets. WSMR, with its numerous telemetry receiving and range safety sites and the LEAP contractors, had the mission data processing responsibilities covered. MGTS would be an alternate source of mission data if multiple, unforeseen failures were to occur at the existing sites. Upon MGTS #1 arrival at the operating location, the unpacking and setup efforts began. It immediately became apparent that advanced preparation was paying off as the facility power circuit breakers tripped under the load of the MGTS equipment and the generator was utilized to keep the systems functioning. The facility power problem was resolved and the MGTS #1 system was thoroughly checked out and ready to support the launch. In the early morning hours of February 18, 1992, LEAP-1 mission was launched and MGTS team completed its first field operational test. Because the Aries booster followed an off-nominal trajectory, the program track antenna could only maintain an intermittent lock on the telemetry streams. However, valuable lessons were learned during the operation including the utility and operational concept of a transportable system.

A few months later in June 1992, MGTS #1 was again deployed to WSMR to support the LEAP-2 mission. Because of the unpredictable nature of the trajectories involved in the LEAP missions, the program track antenna was not utilized for this effort. Instead, MGTS #1 was located at one of the range telemetry sites where an existing 10 foot autotrack antenna provided the mission telemetry. In this capacity MGTS successfully provided backup processing and recording capabilities for the mission. With this success and an increase in MGTS program requirements, efforts began to design and develop a more capable and robust system with its own autotrack antenna: MGTS #2.

THE MGTS #2 SYSTEM CONFIGURATION

The Phillips Laboratory's increased involvement in support of the Ballistic Missile Defense Organization's technology programs drove further MGTS requirements, including the need to:

(1) Ensure autonomy for extended periods of time at any operating location
(2) Accommodate both IRIG and SGLS standards
(3) Provide quick turn around processing and distribution of engineering data
(4) Provide realtime processing and enhancement of mission payload imagery
(5) Provide realtime data relay to remote support organizations
(6) Generate satellite commands and uplinks

To meet these increased requirements, a formal contract was established and an ambitious program began to develop MGTS #2. The resulting designs and equipment configurations are detailed in the following paragraphs. See Figure 2 for trailer specific interior equipment layout.

Antenna System

Conclusions from the first two LEAP missions indicated an easily transportable, autotracking antenna was a firm requirement. To meet the need, a customized parabolic 10 foot autotrack antenna and trailer were designed and integrated. For transportation the antenna is stowed with the feed pointed slightly down and to the rear of the trailer and the reflector's two detachable wings are removed. The pedestal is an elevation-over-azimuth design which automatically tracks at angular velocities from 0 to 40 degrees/sec and at angular accelerations and decelerations from 0 to 30 degrees/sec/sec, while maintaining an RF pointing axis accuracy of ±0.15 degrees of the electrical pointing axis. This level of dynamic antenna performance makes MGTS useful on a wide variety of missions, including satellite tracking, suborbital launches, aircraft flight testing, and missile testing.

Presently, the antenna features a field replaceable, prime focus conical scanning autotracking feed. Efforts to upgrade the feed with S-band command capability are nearly complete. An RF housing contains band pass filters and low noise amplifiers for both right and left hand circular polarizations operating in two frequency ranges, 1750-1850 MHZ and 2200-2400 MHZ. The overall system performance of the antenna is a G/T of 6.0 dB/K and a gain of 30.5 dB in the 1750-1850 MHZ range and a G/T of 7.5 dB/K and a gain of 32 dB in the 2200-2400 MHZ range. The 3 dB beamwidths of the antenna far-field principle plane patterns are 4.1 degrees at 1775 MHZ, 3.2 degrees at 2250 MHZ, and 3.0 degrees at 2350 MHZ.

The antenna controller, located inside MGTS #2, is a microprocessor-based rack mounted chassis providing signal processing, operator functions and a system status display. In the autotrack mode, the controller receives data from the AGC and AM outputs of one of several telemetry receivers. The antenna system can operate in many other modes, including standby, manual, designate, slave, rate memory, position memory, sector/raster scan and program track.

Signal Processing

The downlink telemetry signals are split by a dual 1X6 multicoupler and sent to the RF patch panel. The signals are then distributed to a variety of narrowband and wideband telemetry receivers. Depending on the specific mission, MGTS #2 can be equipped with 6 receivers, including the dedicated SGLS receiver. Signal gains can be further increased with the diversity combiner. To accommodate the SGLS format, a subcarrier demodulator recovers the baseband telemetry data from the subcarrier. PCM data is then sent to the bit synchronizers for data reconstruction and clock generation. MGTS #2 presently has 3 bit synchronizers, including a 35 Mbps model.

Data Recording

Two 28-track wideband tape recorders provide recording of analog and digital data. The recorders are currently configured with direct record and digital data record/reproduce modules. The recorders use the standard 1 inch magnetic tape on a 15 inch reel. A formatting unit enables recording of high speed data (up to 35 Mbps) by spreading the data over multiple tracks of the recorder. A 6 channel FM multiplexer/demultiplexer is available to record multiple low frequency signals on a single wideband track. The mux/demux is typically configured to record mission timing, voice communications and receiver AGC. MGTS #2 also has a magnetic tape degausser to erase and recycle tapes.

Analog video signals are recorded on two Super VHS video recorders with edit capabilities, which enable mission video to be analyzed frame by frame. The two audio tracks are typically used to record mission time and voice. The audio tracks also provide a convenient way to record low speed PCM data and avoid the costly and cumbersome 1 inch magnetic tapes.

A 16 channel strip chart recorder is used to graphically record receiver AGC's and analog outputs from the telemetry decommutator.

<u>Video Processing</u>
Two high resolution 19 inch color monitors display analog video or digital video which has been converted to analog. The monitors can also be used to display the view from the antenna boresight camera. A video time inserter displays mission time on the monitor. MGTS #2 has a video processor which digitally removes random noise and enhances the video signal in either real time or during post mission processing. A video printer provides hard copies of the images displayed on the monitors.

<u>Mission Timing</u>
A GPS receiver and IRIG-B time code generator provides mission timing for the video time inserter, magnetic tape recorders, video recorders, telemetry decommutator, and the strip chart recorder. The GPS receiver also determines the exact MGTS #2 location, which is necessary for satellite tracking missions.

<u>Data Decommutation and Processing</u>
With a workstation-based decommutator, MGTS #2 is capable of simultaneously decommutating 3 PCM data streams. Two channels can accommodate data rates up to 10 Mpbs, and third is capable of 20 Mpbs. Multiple parallel processors in the decommutator allow a wide variety of

data manipulation. Almost all standard binary formats and data processing algorithms are supported with the default software from the manufacturer. Due to the unique telemetry formats MGTS supports, custom algorithms have been written to satisfy the program requirements. Using simple menu driven operations, processed data can be displayed in the form of graphs, bar charts, panel meters, strip charts and digital displays. Range limits can be programmed which notify the operators of "out of limits" conditions through color changes on the screen.

MGTS #2 has an Ethernet network which links two workstations with the decommutator so that two operators can monitor the data and control the decommutator at the same time. Also on the Ethernet, is a 386 PC which is used for post-mission data reduction. A customized data gather program stores selected telemetry data in a text file on a workstation 1.2 Gb hard drive. The PC then reads data files from the workstation hard drive as drive D. Using standard spreadsheet programs such as Excel, customized data plots are produced on a color plotter, laser printer or a dot matrix printer. The workstations accommodate multiple data storage formats, including: a CD-ROM drive, a 150 Mb tape drive, and a standard 3.5 inch high density disk drive.

Uplink Commanding

The telemetry processor also provides the command and telemetry processing for satellites equipped with SGLS transponders. The telemetry processor generates and transmits SGLS commands as well as processing SGLS telemetry data. Since encryption of the uplink and downlink data is normally required, the system also provides the necessary cryptographical hardware interfaces to process the telemetry data. The baseband commands are then modulated onto the carrier, then a TWT amplifier increases the signal power up to 250 Watts. SGLS command validation is provided by demodulating the FSK/AM modulated uplink command and comparing it to the intended transmitted command. SGLS command verification is accomplished by comparing commands that are sent to the satellite with telemetry information that is received back from the satellite via the telemetry downlink.

External Communications and Data Relay

MGTS #2 is equipped with a STU III phone/fax for secure voice and data transmission. MGTS has also relayed data via local RF link to terminals within a few miles.

Test Equipment

MGTS #2 has as extensive suite of test equipment which provides for complete pre-mission checkouts, complete loop tests (including the antenna), mission simulation, and fault isolation. Test equipment is mounted in the racks. This test suite includes a digital oscilloscope, spectrum analyzer, telemetry signal simulator, function generator, power meter, digital multimeter, PCM link analyzer, digital counter, video test pattern generator, video waveform monitor, wideband level meter, noise source generator, and a microwave hazard meter.

Secure Equipment

MGTS #2 is certified to process secure data. A separate rack holds units which satisfy all requirements for red/black signal isolation. The secure equipment is locked-out or de-installed when not in use.

Patch Panel Assembly

Multiple patch panel assemblies provides the interconnection scheme which allows virtually any signal to be routed to any appropriate piece of equipment. The flexibility of the patch panel allows for quick and easy system reconfiguration.

MGTS APPLICATIONS

Three applications were developed specifically to serve the warfighters and space operators by demonstrating new capabilities in transportable space operations.

- Target State Vector Determination (TSVD). This software feature provides realtime, 'once per second' updates of target position, velocity, acceleration, and latitude/longitude. The TSVD program accomodates inputs from MSTI (for IR subjects) and/or radar assets (for suborbital or aircraft missions). The TSVD program then generates solutions based on MSTI mission returns, radar coordinates, or both. Integrated Systems, Inc (ISI) developed the TSVD application.

- Advanced Satellite Control. The software for satellite control features automated satellite commanding, where packages of commands are triggered by selecting a general satellite activity. The system also interprets telemetry and recommends/executes operator actions. The objective of this tool is to minimize the expertise required to operate MGTS for satellite control, and to demonstrate simplified space operations in general.

- In-the-Field Observer (IFO). This feature demonstrates the ability of a warfighter to task a remote-sensing satellite payload realtime, while in the field. Though the software is a limited demonstration version, it allows the operator to bring up a map (treated as the local theater of battle) and graphically select a portion of the map to image. The demonstration indicates how commands are then automatically generated and uplinked, followed by realtime recovery and display of an IR or visible image. The whole process occurs during one pass of an overhead satellite. Storm Integration is the company behind this tool's development.

MGTS MISSIONS

The first part of this paper focused on the development and capabilities of MGTS. To deliver a complete understanding of the system, and understand how the configuration of the system evolves from new mission requirements, a further look at how MGTS is used on missions follows.

Recently, the MGTS team has sought opportunites to bring MGTS technology, resources, and experience to the operational commands of the Air Force, and to the commercial sector. This effort is in keeping with the lab's mission of technology transfer to industry, and efficient use of government resources.

As might be expected, MGTS is well-suited to military applications. First, the system is developed and operated by a joint government-military-contractor team. Second, the option to use an all-military crew in combat conditions (or to simulate such use) exists. Third, the GLCM shell that houses the system was designed with survivability in mind. Fourth, efforts to minimize the necessary operator expertise are compatible with military turnover due to frequent reassignment. MGTS is also deployable by land, air, or sea to any area, and may support all classes of satellite. Finally, MGTS can provide the link from the warfighter directly to the space system, sought by space planners and warfighters in recent years.

MISSION HISTORY

o LEAP ½/3, White Sands, NM. Processed health & status data from LEAP, the payload module bus, and the target vehicle. Also processed infrared seeker video and payload module bus camera video

o Navy LEAP 2, Pacific Missile Test Center, CA. Processed LEAP vehicle health and status, mission video, and launch vehicle health & status

o MSTI ½, Edwards AFB, CA. MGTS processed MSTI health and status data, and payload infrared video both on-orbit and during integration and testing

o MSTI-2/Sergeant (Joint Task Force 95), NASA Wallops Flight Facility (WFF), VA. MGTS processed MSTI-2 health & status and payload IR video. Fused WFF range radar data with MSTI tracking data, resulting in enhanced vector of the Sergeant's trajectory. The Navy ship RK Turner received MSTI target data via MGTS software.

o U.S. Space Command Support to the Warfighter Demo, Falcon AFB, CO. MGTS tracked DSMP and exhibited Target State Vector, In-the-Field Observer, and Advanced Satellite Control software packages.

o Navy LEAP 3/4, NASA Wallops Flight Facility (WFF), VA. MGTS processed raw radar data into state vector format, then used a local RF link to introduce the data into the Wallops Range Control Center. In addition, Long- Wave Infrared and video cameras were field-integrated into the MGTS antenna system and used to track the two launches. Both infrared and standard video products were made available on the N ASA video net.

FUTURE MISSIONS

As of June 1995, the MGTS program is pursuing several possible missions:

o Center for Research Support (CERES) backup. MGTS and the CERES satellite facility at Falcon AFB were developed to be highly compatible. Plans are in work for MGTS to provide backup when CERES goes into planned downtime several months from now. This interval may last for several weeks, during which MGTS will demonstrate advanced satellite control features, experiment with test and checkout satellites, and possibly participate in wargaming scenarios.

o Geophysical rocket experiment. MGTS may support an international venture to analyze telemetry from a small launch vehicle. This scientific mission proposes to view plasma cloud data from onboard cameras and remote observers.

o MSTI-3. MGTS is currently coding the software necessary to support MSTI-3 ground operations, including recovery of engineering and mission data.

o CLARK satellite. In a cooperative effort with the small satellite company CTA, MGTS will host CLARK MUE for support of demonstrations and military exercises.

o Other. Several other missions are in work, but are of a sensitive nature and cannot be presented in this paper.

CONCLUSION

MGTS continues to accomplish and expand its mission. The system's application has broadened from strictly BMDO missions to other military and commercial programs, which adds to the dynamic nature of upgrading and operating MGTS. Flexibility, operability, low operating cost, and military applicability remain the cornerstones of the program. Configuration of the current system continues to evolve as new mission needs arise.

REFERENCES

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NOMENCLATURE

AFB. Air Force Base.

AGC. Automatic Gain Control.

BMDO. Ballistic Missile Defense Organization.

COMSEC. Communication Security.

GFE. Government Furnished Equipment.

GLCM. Ground Launched Cruise Missile; a phased-out military program.

LCC. Launch Control Center; refers to the mobile vans used in the GLCM program.

LEAP. Lightweight Exo-Atmospheric Projectile; a kinetic-kill vehicle program.

MGTS. Mobile Ground Tracking Station.

MSTI. Miniature Satellite Technology Integration; a low-earth orbit experimental satellite with a variety of infrared instruments onboard.

MUE. Mission Unique Equipment.

PL. Phillips Laboratory (in this paper, PL generally refers to the operating location at Edwards AFB)

SGLS. Space-Ground Link System. Satellite communication protocols and frequencies used by the Air Force Satellite Control Network.

WSMR. White Sands Missile Range.