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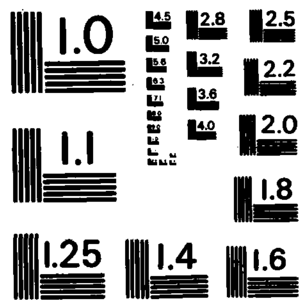

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Operational Applications of Military Test Ranges in Space Transportation System Programs

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Traditionally, military Ranges have existed to verify performance and aid in designed of weapons and weapons systems. Those Ranges which become involved in flight and exo-atmospheric applications have also developed an operational capablity used to support ongoing space and missile programs. This paper addresses military Range support capabilities and specific operational aspects of Range support to the Space Transportation System (STS). Its primary emphasis will be on C-band radar tracking and data flows rather than on the more familiar facets of range support.

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OPERATIONAL APPLICATIONS OF MILITARY RANGES TO THE SPACE TRANSPORTATION SYSTEM

Albert M. Thomas*
Colonel, United States Air Force

Abstract

Traditionally, military ranges have existed to verify performance and to aid in the design of weapons and weapons systems. Those ranges that became involved in flight and exo-atmospheric applications have also developed an operational capability to support ongoing space and missile programs. This paper addresses military range support capabilities and specific operational aspects of range support to the Space Transportation System. The primary emphasis is on C-band radar tracking and data flows rather than on the more familiar facets of range support.

I. Background

Cooperation between NASA and the military community has long been acknowledged. Both organizations have been involved in launch and orbital operations with an extensive exchange of information and even hardware. For example NASA has adopted military boosters like the Thor for commercial and scientific uses. Most people, however, have regarded individual operations as unique to a particular organization. This concept is rapidly changing with the advent of the Space Transportation System (STS). The STS is, in reality, a joint venture that is mutually supporting. This support extends to many areas so even some experts are confused about actual task performance, and, in particular, about the Department of Defense (DOD) support to STS flight operations.

II. Mission Control Process

To understand DOD C-band radar support it is necessary to briefly review the STS orbital control process and the organizations involved.

The Mission Control Center (MCC) at the Johnson Space Center in Houston, Texas is the NASA facility responsible for supporting the Orbiter vehicle during ascent, on-orbit, reentry, and landing phases. The MCC provides systems monitoring, flight data collection, and flight operations coordination. The MCC must have data to accomplish these functions, and gathering the data is the responsibility of Goddard Space Flight Center (GSFC) in Greenbelt, Maryland.

This Center operates a network of S-band telemetry, command and control, communications, and a few C-band radar sites around the world. This is the NASA Spaceflight Tracking and Data Network (STDN). The STDN is an extensive network of NASA stations and support facilities whose major functions include:

1. Providing ground track support to spacecraft and other designated space vehicles and transmitting resultant data to specified centers
2. Receiving and transmitting launch and trajectory data in realtime to specified centers
3. Relaying telemetry and television signals in realtime from spacecraft and other designated space vehicles to specified centers
4. Providing voice communications between ground stations and spacecraft and voice/data and teletype communications between stations and specified centers
5. Augmenting recovery communications

The DOD Space Shuttle Tracking Network (Fig. 1) supports the STDN and is composed of seven National Ranges all working under the operational control of a Lead Range. These ranges provide operational and technical support as part of the integrated NASA/DOD Space Shuttle Network under the NASA Network Director at GSFC. The national ranges supporting the DOD Space Shuttle Tracking Network are the

1. Eastern Test Range (ETR)
2. Western Test Range (WTR)
3. Air Force Flight Test Center (AFFTC)
4. Pacific Missile Test Center (PMTC)
5. Kwajalein Missile Range (KMR)
6. U.S. Army Electronic Proving Ground (USAEPG)
7. White Sands Missile Range (WSMR)

Each range commander is responsible for support to the Space Shuttle program consistent with his primary responsibilities for national defense. The support schedule is based on established priorities.

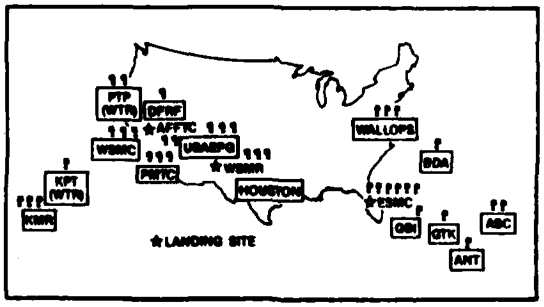

Fig. 1 DOD Space Shuttle Tracking Network.

III. DOD Range Support

The ranges are organized under a Lead Range concept. During mission operations, the DOD Lead Range responsibilities and functions are exercised from the Lead Range Control Center, which has operating positions for the Lead Range Control Officer and supporting military and Contractor staff. For all launches from KSC, the ETR is designated as Lead Range.

Support rendered to NASA by the DOD under the Lead Range concept can be segregated into several areas, most of which require the support of more than one range or test facility. For launches, the ETR provides the traditional support in premission

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payload processing, engineering and documentary photography, metric optical tracking, communications, timing, C-band radar and S-band telemetry tracking, and missile flight control (range safety). *In addition, the ETR provides nonstandard support* consisting of realtime television reception, ground support for contingency recovery forces, and chase aircraft vectoring for return-to-launch-site (RTLS) aborts. For support not normally supplied, the ETR has had to request the assistance of other organizations; e.g., the AF Technical Applications Center and PMTC augment ETR's support with airborne optical coverage of SRB reentry to supplement the Advanced Range Instrumentation Ship (ARIS/USNS Redstone); the US Coast Guard accomplishes launch area surveillance and security, and the Federal Aviation Administration (FAA) endeavors to control aircraft to forestall violation of the launch restricted airspace. Although the launch is normally associated with the ETR, all tasked DOD organizations must be ready to support if abort-once-around (AOA) or abort-to-orbit (ATO) occurs.

C-band radar tracking is made by a worldwide network of sites that span the globe from Kwajalein Atoll in the south Pacific to Ascension Island in the mid-Atlantic. These sites provide low-speed data to Johnson Space Center (JSC) via GSFC for orbit determination during the orbital phase, and provide high-speed data via the ETR central computer complex to JSC for launch and landing (Fig. 2). C-band radar tracking obtains precise metric data and can easily handle changing accelerations associated with maneuvers.

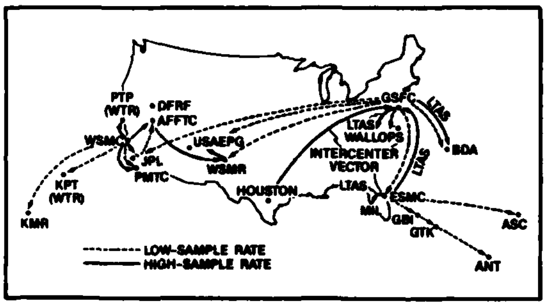

Fig. 2 Acquisition Data Flow.

For example, the accuracy tolerance limits of C-band radar at the ETR are

Angles:	±0.1 milliradian
Range:	±30 feet at 1 microsecond pulse width
	±45 feet at 5 microsecond pulse width
	±115 feet at 10 microsecond pulse width

Although the primary function of the C-band network is to provide tracking data during periods when no STDN data is available, some sites are used as a quality control and calibration standard. To better understand the way in which the acquired data is used, break the mission into its three phases:

Launch

The ETR Central Computer Complex (CCC) receives and processes all C-band radar tracking data and selects the best and second best sources, which are then tranmitted at 10 samples/second to JSC (Fig. 3). JSC uses this data together with STDN-supplied S-band data to monitor the performance of the launch vehicle. In addition, a determination is made by JSC regarding the need for a navigation update. If it is determined that the onboard navigation system requires an update, this update is computed from the C- and S-band data collected during the launch and is sent to the Orbiter computers via the NASA command system.

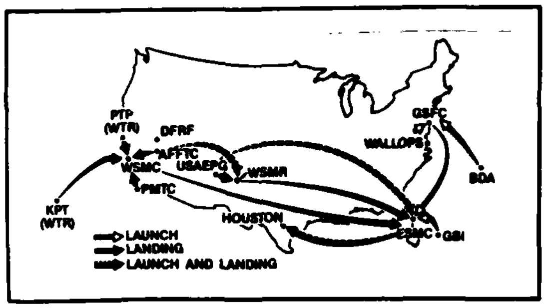

Fig. 3 Launch and Landing Data Flow.

On-orbit

JSC maintains the Orbiter's ephemeris using C-band tracking data from the DOD and S-band data from NASA facilities, both of which have sources located around the world (Fig. 4). Navigation updates are sent to the Orbiter as needed; hourly acquisition messages are computed and transmitted to tracking sites with view periods in the next two hours. Because the quality of acquisition messages (interrange vectors or internet predictions, etc.) depends on the quality of data already processed, a lack of tracking data would degrade the acquisition messages and trackers could experience difficulty in acquiring track.

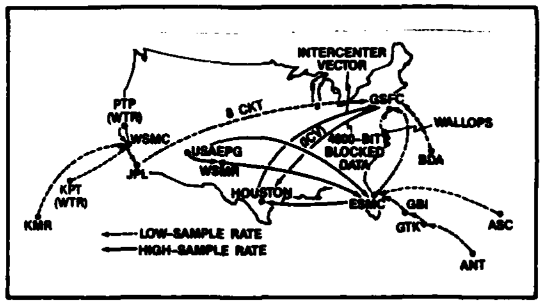

Fig. 4 On-Orbit Tracking Data Flow.

DOD tracking data is transmitted from the radars in a 46-character teletype format to GSFC. At GSFC, data from several trackers is combined into 4800-bit blocks and transmitted to JSC via a 1.544-megabit system. During this phase, JSC actual data requirements vary, depending on the criticality of the mission events. During orbital maneuvering and payload deployment, ephemeris maintenance and navigation update require constant track data updates, while during nonevent periods only occasional updates are needed.

Landing

Data from C-band trackers in the landing area is transmitted to the ETR/CCC. As on launch, the best and second best data sources are selected and sent to JSC at 10 samples/second. This data is used by JSC to monitor performance and to provide navigation updates when required.

Each site in the network receives GSFC-generated acquisition data and uses it to acquire the Orbiter during the mission. The resulting data must be manipulated before JSC personnel can make any use of it. This manipulation can consist of a simple reformatting (performed by GSFC on-orbit or by the DOD for launch and landing) or can consist of a complicated source selection to send JSC the best available sources. In addition to the operational manipulation, all ranges make use of the data during analysis to determine system problems, confirm system accuracy, and ensure system readiness.

Although the primary end-of-mission (EOM) landing site has been Edwards AFB in the past and will be KSC or Vandenberg AFB in the future, sometimes weather constraints or mission problems can force the landing to occur elsewhere; e.g., White Sands Missile Range on STS-3. All DOD organizations can be called up to support landings, just as for launches. This callup is made as conditions dictate in order to support non-nominal missions without need for frantic preparation. Much of the support rendered by the EOM site is as extensive and, for some items, even more complex than that encountered by the launch range. Radar and optical tracking, photography, communications, and ground support for recovery operations and postlanding Orbiter processing are the major support services given by the EOM site. Chase aircraft vectoring is also provided, sometimes by a range that is not even at the landing site, although the landing site agency maintains a capability as a backup. (WTR vectors landings at Edwards AFB; when KSC landings begin, ETR will provide vector.)

IV. Specific Range Functions

Each range with the necessary instrumentation sends updated metric data to NASA. In addition, the ranges respond to other STS requirements including meteorological data, telemetry downlinks, and optical support. To better demonstrate the instrumentation involved throughout the network, the support for each range will be discussed singly and in detail.

As the Lead Range for Eastern Launch Site launches, the ETR supplies the bulk of the instrumentation support because it is located at the primary launch facility and because the Central Computer Complex (CCC) is associated with that facility. During the launch countdown, the CCC is performing double duty. As it is supporting all launch critical instrumentation and range safety requirements, it is also processing data flow tests from instrumentation at the other ranges and test centers. This off-range data is then retransmitted to JSC. In addition to radar and data processing, the ETR is providing range safety, meteorological, and optical support for launch and any possible contingencies. ESMC's Range Safety group coordinates a joint Air Force/NASA command and control network with stations at Cape Canaveral AFS, Grand Bahama Island, Wallops Island, and Bermuda. Meteorological support is provided throughout the entire mission by the Cape Canaveral Forecast Facility.

ETR support for on-orbit and non-KSC landing is also quite extensive. As on launch, the bulk of the landing support comes from the CCC. The CCC receives and processes C-band radar data from all C-band radars and outputs the data to JSC. ETR on-orbit track is provided by radars at Merritt Island, Patrick AFB, Antigua, and Ascension Island. For a KSC landing, additional support includes a C-band radar for tracking and vector control of the Shuttle chase aircraft, and optics to cover approach and landing of the Orbiter.

The Western Test Range (WTR), at Vandenberg AFB California, provides continuous support throughout the total Space Shuttle mission. The primary instrumentation supporting the mission are the C-band radars, communications, and optical devices for landings at Edwards AFB. C-band radars at Vandenberg AFB, Pillar Point AFS, and Kaena Point, Hawaii are used early to support certain abort modes immediately after the launch phase, during on-orbit for support, and at landing, to back up Edwards AFB and White Sands Space Harbor (WSSH). The WTR communications center is a centralized junction for all data and communications transmitted from the WTR, PMTC, AFFTC, and KMR. For landings at Edwards AFB, the long-range optics at Tranquillian Peak and Santa Ynez Peak obtain exceptional optical tracking data from the Orbiter prior to landing. Both Vandenberg and Pillar Point are also providing telemetry support at this time.

The Air Force Flight Test Center (AFFTC) also furnishes extensive support. Prior to launch, the C-band radars at Edwards AFB and the NASA Dryden Flight Research Facility (DFRF) transmit high-sample-rate data through the WTR to the ETR/CCC. After nominal launch and orbital insertion, the AFFTC is placed in standby for possible early EOM landing should problems develop with the Orbiter. For landing, the AFFTC and DFRF radars transmit high-sample-rate C-band radar data through the WTR and, over a direct data circuit, to the ETR/CCC. This data is transmitted for nominal landings at Edwards AFB and the WSSH. One C-band radar provides beacon track of the Orbiter chase plane.

The U.S. Navy Pacific Missile Test Center is on operational standby for launch and on-orbit support. For landing, the C-band radars at San Nicolas Island transmit high-sample-rate data to the ETR/CCC via WTR. PMTC also sends meteorological data from Point Mugu and Barking Sands for landings at Edwards AFB or WSSH.

The primary support from the Kwajalein Missile Range (KMR) is on-orbit tracking. Prior to launch, the KMR radars at Kwajalein and Roi-Namur Islands transmit low-speed tracking data through the WTR communications center to the ETR/CCC for system validation. Upon launch, KMR is placed on operational standby for scheduled on-orbit skin tracking support. KMR normally provides initial track of the Orbiter after orbital maneuvering system 1 and 2 burns on orbit 1. The data obtained is processed to provide acquisition data for C-band radars at Kaena Point and the other west coast radars.

The support from the White Sands Missile Range and the U.S. Army Electronic Proving Ground can be grouped together due to their geographic proximity and similar support requirements. The WSMR and USAEPG perform system validation of their C-band radars. The high-sample-rate data from these radars is routed from the WSMR computer to the ETR/CCC. In addition to the C-band radars, WSMR and USAEPG telemetry stations at Alamo Peak, North Oscurra Peak, and Mount Lemmon are used as acquisition aids during landing phases. The WSMR also provides extensive meteorological support for data reduction to support the Orbiter landing, as well as various ground support services for WSSH landings.

V. Future of DOD Support

The STDN network supports other spacecraft in addition to the STS, however the network can monitor only a small fraction of the orbital period. Some stations can monitor only one vehicle at a time. Plans to overcome this limitation involve using a new network employing geostationary satellites to track and communicate with user spacecraft. This network is the Tracking and Data Relay Satellite System (TDRSS).

As NASA began to conceptualize its new satellite system, plans were formed to eliminate the orbital tracking support from STDN and DOD. The TDRSS consists of identical satellites in geosynchronous orbits plus a dedicated ground station at White Sands, New Mexico. The first two satellites (TDRSS-East and TDRSS-West) will form the operational TDRSS service providing near-global realtime user satellite coverage. The third satellite will be an in-orbit spare. These satellites will, in fact, be interchangeable. NASA has planned to provide TDRSS services for an initial 10-year period. Using the tracking, telemetry, and command capability of the system, NASA envisioned a system wherein radar and conventional telemetry tracking were to become obsolete.

Remarkably, the development of a system designed to reduce NASA's dependence on the ground radar has increased DOD support requirements instead. Two examples illustrate these increased requirements. First, there is the quantity of support rendered. NASA, coincident with the implementation of TDRSS, planned to eliminate a majority of their own STDN—not just elimination of requirements on the STDN, but elimination of the network itself. The original phasedown plan, which was to begin in late 1983 or early 1984, called for the transfer of a large portion of STDN equipment to other organizations; i.e., the DOD, Deep Space Network, academic institutions, and foreign governments. Although the phasedown schedule has slipped at least six months due to operational problems with TDRSS, some portions of the schedule have already received a final NASA commitment. Thus, the DOD can expect an increase in orbital tracking support to fill any gaps created by the phasedown.

Second, there is the type of support required. Once TDRSS is operational and the SDTN has been phased down, GSFC will control only a very small number of ground stations. Along with the change from ground to space network operations, GSFC has begun to examine the other types of support they give the ground network. One step was to ask the ETR to examine the possibility of providing mission acquisition data to all ground stations. The ETR is currently making provisions to achieve this capability so it is quite possible that it will provide this acquisition support to the remaining STDN stations as well as to all the C-band sites.

Other enhancements to orbital navigation will have an impact on DOD support requirements. Those impacts are not expected for some time, however, and will most likely be felt only in the orbital tracking area. Demonstration and acceptance of the TDRSS and orbital TACAN systems are firm prerequisites to any significant changes in DOD C-band orbital support requirements. Even then, cases where C-band radar support is desired are expected. Examples include non-TDRSS cooperative spacecraft and the maintenance of orbital ephemeris during maneuvering. Problems encountered during TDRS-1 deployment on STS-6 and during the subsequent satellite checkout have forced a delay in the reduction of C-band network requirements.

Originally conceived as a backup to the NASA STDN to obtain information for updating orbital ephemeris, the DOD C-band network has become a vital part of the STS program. Experience gained during the past seven missions has led NASA/JSC personnel to conclude that the DOD network is an invaluable and highly reliable source of critical tracking data. Recent NASA discussions toward formalizing a new baseline have affirmed that C-band network support will continue to be required for launch and landing phases, and, most probably, at some level during the orbital phase. As the STS continues to prove that routine space operations are both feasible and desirable, the instrumentation and facilities associated with national military ranges will continue to provide support and may eventually become a permanent part of the operational Space Transportation System.

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