TRACKING AND DATA RELAY SATELLITE SYSTEM

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Summary As a result of three years of study, it has been determined that implementation of a Tracking and Data Relay Satellite System (TDRSS), using satellites in synchronous orbit to relay data between low altitude earth orbital spacecraft (both manned and automated) and the various mission control centers could improve the capabilities of the NASA tracking and data acquisition networks. Such a system, by providing nearly continuous, real time access to low altitude spacecraft, would improve mission reliability; contribute immeasureably to the safety and morale of the crews of manned spacecraft; permit real time command and control of automated spacecraft, making their operation more versatile; enable experimenters to monitor their experiments in real time, perhaps thereby reducing the workload on data processing facilities; and, in general, relieve constraints upon mission planning and operations that are imposed by the short duration, intermittent contacts characteristic of ground based T&DA facilities. Furthermore, studies indicate that this improved T&DA system will probably present networks that it could pay operation.

The benefits outlined above are an operational TDRSS consisting of ground stations. If initiation of commence in FY-1971, the launch of cost sufficiently less to operate than for itself within a few years of realizable upon the implementation of three satellites and their supporting the development of the system could the first two data relay satellites would be possible by CY-1974. Allowing for a thorough system checkout and evaluation, during which time the remaining satellites would be launched, a TDRSS could become operational by the end of CY-1975.

Background Tracking and data acquisition support for NASA space missions is currently provided principally by three specially configured networks of-ground stations, augmented by instrumented ships and aircraft. These are: (1) The Deep Space Network, (DSN) consisting of seven 85' antennas and one 210' antenna (with two more soon to be constructed) spaced approximately 120° apart in longitude, which provide full time support for planetary exploration missions; (2) The Space Tracking and Data Acquisition Network (STADAN), consisting of the Minitrack system and several Data Acquisition Facilities (DAF) which range from VHF Satan antenna systems to 85' parabolas, for support of low altitude, high altitude, and eccentric orbiting automated spacecraft; and (3) The Manned Space Flight Network (MSFN), which consists of two subnetworks, one subnet having one portable and ten permanent ground stations with 30' antennas primarily for support of earth orbital missions and the near earth phases of manned lunar missions, and one subnet having three ground stations with 85' antennas colocated with the primary DSN sites for support of the translunar and lunar phases of manned lunar missions. In addition, instrumented ships and aircraft supplement the MSFN during critical phases of manned missions that occur out of sight of the land based stations.

While these networks have thus far provided sufficient capability to support a vigorious program of space exploration, the limitations inherent in ground based T&DA facilities have in the past, and would in the future to a much more serious degree as missions become more sophisticated, impose extensive constraints on mission planning and operation. The limited visibility of spacecraft in near earth orbit results in sporadic, intermittent contact between the spacecraft and the mission control centers, with oftentimes excessively long periods between contacts. For automated missions, the result is a need to rely upon on-board data storage devices for the information accumulated by sensors when out of contact with ground stations, programmed command systems for exercising the spacecraft, and limitations in orbit determination resulting from short arc tracking.

The impact on manned flight includes all of the above factors and adds consideration of crew safety and morale. As an example of the coverage limitations, daily contact provided by the current MSFN for a typical space station orbit (260 nm altitude and 60° inclination) is approximately 275 minutes a day, or 19% of the time. During a lunar mission, when the 85' stations are not available for support of earth orbital missions, contact time is reduced to 205 minutes a day, or 14% of the time. In addition, there would be periods of up to 3 hours when there would be no contact at all. The longest period of continuous coverage would be 16 minutes.

The most severe limitations in coverage occur, of course, at low altitude. As the spacecraft altitude increases, so does the visibility from a point on the earth’s surface, until by the time a spacecraft reaches some 8000 nautical miles, three ground stations (such as in the DSN configuration) are sufficient to provide nearly 100% coverage for near-equatorial orbits (up to 30° inclination). Coverage of low altitude orbits can be increased in either of two ways: (1) by increasing the number of ground stations, the cost of which makes any substantial increase in coverage impractical; or (2) by changing the vantage point of the tracking station from the ground to a point above the earth, i.e. to put the tracking station in high altitude orbit, from where it will look down upon the spacecraft which it is supporting. A most convenient orbit for such a Tracking and Data Relay Satellite is at synchronous altitude, where it can be tied back to the ground through a single supporting ground station, and from where it can see any spacecraft beneath it for approximately half an orbit. A series of three such TDRS provides complete, and in fact partially overlapping, coverage of spacecraft at any altitude up to the limit of the TDRS antenna beamwidth and/or scan capability.

There is a cost tradeoff in determining the maximum altitude that a TDRS should cover. As the altitude increases, the TDRS antenna beamwidth or scan capability must increase, which reduces system gain, putting a greater burden on the user spacecraft to supply transmitter power. A suitable compromise seems to be above 1600 nautical miles (3000 kilometers).

Most spacecraft that fly in circular orbits are either below that altitude or sufficiently far above it that ground station support is far superior to that which could be provided by a TDRS system. Also, the spacecraft of major concern that operate in the area between 1600 nautical miles (below which they have full support from a TDRSS) and 8000 nautical miles (above which the DSN type network gives full coverage) are usually in a highly elliptical orbit or are in a transfer trajectory to some other orbit, are are therefore not in the zone of limited coverage for any length of time.

Requirements for a TDRSS The TDRSS under study at NASA is intended to augment, and to the extent feasible, to replace existing facilities of the present T&DA'networks. Current studies are considering TDRSS configurations that would provide support for all low altitude spacecrafts from the small, spin-stabilized, low data rate, automated spacecraft of the explorer class to the large, 3-axis stabilized, super high data rate spacecraft such as the manned Space Station and Earth Resources Survey spacecraft. The latter two missions represent the greatest demand upon the TDRSS.

Requirements for communications support for the Space Station are currently projected as follows:

<u>Earth to Space Station</u>

Mission Operations - Continuously available voice and low-rate data (a few kilobits per second)

Experiment Support - Multiple voice, low-rate data, and video

Entertainment and Personal Communications - Multiple voice and video

Space Station to Earth

Mission Operations - Continuously available voice and low-rate data

Experiment Support - Multiple voice, high rate data, and video

Personal Communications - Multiple voice

Mission operations communications are to be provided via an “omnidirectional” antenna on the Space Station to insure maintenance of contact at those times when a high gain antenna cannot be deployed, such as during emergency conditions and during the initial establishment of the station. Experiment support, which provides for transmission of experiment data to the ground and for coordination between on-board and ground based experimentors, will be provided via a high gain antenna on the Space Station, as will the crew entertainment and personal communications circuits.

Replenishment of expendables and rotation of the Space Station crew will be accomplished by periodic launch of logistics spacecraft. Communications requirements for the logistics spacecraft will be limited to two-way voice and low-rate data and will most likely be accomplished via an “omni-directional” antenna.

Current Agency planning for the Space Station is predicated upon data relay support capability, since requirements for continuous voice and long duration video transmissions cannot be met with the present Manned Space Flight Network or any reasonable extension thereof.

Another flight program for which TDRSS support will eventually be required is the Earth Resources Survey. During the early stages of development of multispectral imaging of the earth’s surface, using the Earth Resources Technology Satellite (ERTS), all activities can be accomplished while the ERTS is over the Continental United States, which permits the use of existing ground stations to collect the data. For an operational Earth Resources Survey system, however, it is planned to take data world wide. Projected data rates for such a system (up to 100 million bits per second) far exceed on-board bulk data storage capabilities. The data must therefore be collected in real time, requiring either the fulltime contact capabilities of a TDRSS or the implementation of a ground station in each geographic area of interest. If all data is to be relayed to a central data processing facility in the United States in real time or near real time, the cost of transmitting the data from such a large number of remote ground stations via common carrier would be prohibitive. Therefore a TDRSS appears to be the only economically practical means of providing the required service.

While the Space Station and/or the Earth Resources Survey satellites are expected to be the major users of the TDRSS, the system would also be used to support other low altitude automated spacecraft. These may be conveniently divided into two categories, 3-axis stabilized spacecraft, such as the Orbiting Astronomical Observatories (OAO), the Orbiting Solar Observatories (OSO), NIMBUS, etc., and the small, spin stabilized spacecraft of the explorer class.

Exactly what kinds of missions will be flown in the post 1975 time period are, of course, purely speculative at this early date. On the assumption that they will at least be similar to the OAO, OSO, and NIMBUS missions, however, the data-rate requirements have been projected as a few tens of kilobits per second. Being 3-axis stabilized, these spacecraft can carry and point a steerable antenna.

The small spin-stabilized spacecraft, on the other hand, cannot be expected to carry a directional antenna. Furthermore, their small size limits the electrical power available to a few watts. The result is a low effective radiated power (ERP), which in turn translates into a data rate capability through any realistic data relay satellite limited to a few kilobits/second. Fortunately, current explorer class satellites (and therefore, presumably, future spacecraft of that class) commonly have data rates of one kilobit/second or less.

While the data rates of the small satellites are low, the impact of these satellites on the design of the TDRSS is, nevertheless, quite significant. The prediction of the number of such spacecraft that may be in orbit in the late 1970’s (around forth, on the average) indicates that a relay satellite must either have a very large number of antennas, or, more likely, that it must have earth coverage from a single antenna, Also, the small ERP available from these small spacecraft requires the use of a large aperture antenna on the TDRS. The combination of large aperture and earth coverage implies a low operating frequency. A most fortuitous coincidence is that at 136-138 MHz, the frequency band currently used for telemetry by the Explorer satellites, a 25 foot aperture has a beamwidth just sufficient to cover the earth plus a couple of thousand miles. Current thinking calls for each relay satellite to be capable of supporting a number of spacecraft simultaneously. At present this would appear to be two manned spacecraft (the Space Station and a logistics spacecraft), up to three observatory class automated spacecraft, and up to 15 of the small, Explorer class spacecraft.

There is another aspect to the requirements upon which the design of the TDRSS is predicated, that part related to the ‘T’, for “tracking”. If the TDRSS is really to perform all of the functions of the existing networks, then the orbit of the mission spacecraft being supported must be determinable via the TDRSS. Requirements for tracking range from that which is sufficient for a “go, no-go” decision at insertion for manned flight, to post flight precision orbit determination for some of the automated spacecraft.

A summary of the communications and tracking requirements is shown in the enclosed Table 1 Summary of TDRS Requirements.

TDRS System Description The TDRSS under consideration would consist of a minimum of three data relay satellites in synchronous (but notnecessarily geostationary) orbit, two or three (probably co-located) supporting ground stations in the Continental United States, and possibly one overseas ground station in the western Pacific area. The exact location of these ground stations will be such as to minimize the total cost to the agency of providing the required data to the ultimate users, and will include such factors as the cost of transmitting data from the supporting ground stations to the control centers and data management centers via terrestrial communication lines.

Several optional relay satellite configurations are currently under study, ranging from dual-spinning spacecraft of the Intelsat III and IV and the military TACSATCOM type, to multiple antenna 3-axis stabilized spacecraft of about the same degree of sophistication as the ATS-F. All options, however, have a.number of communications subsystem characteristics in common.

1. Housekeeping data and command and control functions for all automated spacecraft, full support of the large numbkbr of small, spinstabilized automated scientific satellites, and voice and low-rate data support of manned spacecraft would be provided at VHF (136-138 MHz from the user spacecraft and 149-151 MHz to the user spacecraft).

2. Wide band data (including video) from manned spacecraft and the larger, three-axis stabilized, automated spacecraft would be relayed at microwave frequencies, probably S-band or X-band, with some consideration being given to Ku-band. This service would require a high gain antenna on the user spacecraft.

3. X-band is considered the likely choice for the TDRS-to-ground and ground-to-TDRS links.

4. Provisions for range and/or range rate tracking of the user spacecraft via the TDRS are included.

Studies to further define all system parameters, including the characteristics of user spacecraft terminals and supporting ground station terminals, are continuing.

Conclusion A Tracking and Data Relay Satellite System represents the most logical approach to the next generation of tracking and data acquisition facilities for support of low altitude spacecraft. The marriage of communications technology and space technology can provide nearly full time, real time coverage of both manned and automated spacecraft. It produces a system having several times the capability of present day ground based tracking facilities at a cost that compares favorably with current network costs. Among the benefits that would accrue from the implementation of the TDRSS are:

- Reduction in data acquisition costs by reducing operation or closing present tracking and data acquisition stations.
- Reduction in future augmentation of present ground stations and/or construction and operation of new ground stations to meet future Tracking and Data Acquisition MDA) requirements.
- Enhancement of mission operations and astronaut safety and morale.
- Increased reliability and lifetime of satellite systems by reducing dependence upon on-board data storage equipment, a frequent source of failure in today's spacecraft.
- Increased data acquisition capability due to greatly increased contact time.

TABLE 1

SUMMARY OF TDRS REQUIREMENTS

A. COVERAGE:	REQ.
(a) Orbital Altitude	< 3000 Km
(b) Inclination Angle	All angles
B. SUPPORT:	
(a) Manned Missions	Two missions simultaneously desirable Three duplex channels each (3 up & 3 down) per s/c Emergency service available instantaneously or at least 60 seconds after demand
(b) Planetary Missions	Parking orbit support during launch phase of mission
(c) Automated (Includes all programs stated before and all s/c classes such as Explorers and Observatories.)	15 Low data rate spacecraft simultaneously from any one sync DRS 3 High data rate spacecraft simultaneously.
C. SYSTEM REQUIREMENTS:	
(a) Manned Spacecraft	Up-link voice and low-rate data via omnidirectional antenna; television via directional antenna Down-link voice and low-rate data via omnidirectional antenna; multiple voice, television, and high-rate data via directional antenna
(b) Automated Spacecraft	Up-link 10 bps to 2000 bps Standardized Address Command System Down-link Explorers - 10 bps to 20,000 bps Observatories - 20,000 bps to 500,000 bps Observatories W.B. Sensors – 200,000 bps up to 10's of megahertz

D. TRACKING REQUIREMENTS:	
(a) Manned Requirements: Parking Orbit.	Insertion, go no-go requirement (mandatory for astronaut safety). One sigma values. One minute after burnout must know perigee height within five (5) kilometers. Five minutes after burnout must know perigee height within two (2) kilometers. Minimum perigee height is 130 km.
Earth orbit rendezvous.	One sigma values after 10 min. tracking. (mandatory) Velocity within 0.3 meter per second (scalar) and 2 meters per second (vector) Position within 300 meters
Injection from Parking Orbit	Go no-go requirement: (mandatory) Covered by rendezvous requirement.
Reentry on return from Lunar or AAP Missions:	(mandatory) Reentry starts at 75 km altitude. After 20 minutes of tracking 4 meter per second (scalar) and flight path angle 0.1°.
Tracking for 100 seconds between blackouts:	(desirable) Position to 10 kilometers and velocity (vector) 2 meters per second.
(b) Automated	No real-time tracking requirements exist except for orbit or parking orbit injection. These are very desirable to be less than one sigma of the vehicle injection errors. Typically for a Centaur (most accurate): Position 3 km Velocity (vector) 2m per sec. Final orbit determination requirements: best possible, limited by knowledge of earth geometry and gravity field. Limits to be determined by ATS-F, AAP, Nimbus Experiment. Time limits are determined by Operational convenience.