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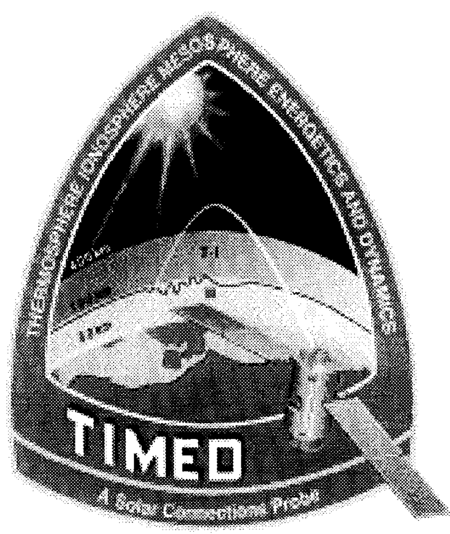
THERMOSPHERE • IONOSPHERE • MESOSPHERE ENERGETICS • DYNAMICS

(TIMED)

Concept of Operations



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1.0 GENERAL

This document defines, in a conceptual sense, the means and methods by which the TIMED spacecraft will be operated on-orbit by the APL-based Mission Operations Team (MOT) utilizing the TIMED Mission Operations System (MOS).

1.1 Purpose of Document

The purpose of this document is to define the operations concept, as it is envisioned at the date of preparation, of the manner in which the TIMED spacecraft, including the instruments and spacecraft bus, is to be operated on-orbit, utilizing the elements of the TIMED ground system. Functional interfaces as well as the allocation of functional responsibilities of the ground system elements are defined. The document should be reviewed from the standpoint of acquiring a conceptual understanding of how the entire ground system, collectively, works together to plan, conduct and evaluate operations of the TIMED spacecraft. Particular attention should be paid to the stated responsibilities of the various elements of the ground system and the operational teams which staff them. The concept documented herein is in full compliance of the TIMED Mission Requirements Document.

1.2 Scope of Document

This document focuses on those operations primarily related to the spacecraft bus; instruments are not comprehensively discussed. Regarding the ground system, the Mission Operations Center is emphasized while other components of the ground system (the Ground Stations, Mission Data Center, instrument Payload Operations Centers, for example) are not extensively documented; the interfaces between these and the Mission Operations Center, are however.

1.3 Mission Description

The entire spacecraft (instruments and bus) is supported by an extensive ground system which prepares and uploads the necessary spacecraft command messages required to support science operations and to maintain the spacecraft bus in its necessary support role, and ingests,

processes and analyzes the downlinked science and engineering data collected on-board the spacecraft. The Thermosphere, Ionosphere, Mesosphere, Energetics and Dynamics (TIMED) mission consists of a single spacecraft and four attached instruments flown in a 600 km (nominal) circular, 74.4 degree inclined orbit. The scientific objectives of the mission include the determination of temperature density and wind structure state parameters of the mesosphere, lower thermosphere and ionosphere (MLTI) region (60-180 km), including seasonal and latitudinal variations; and the determination of the relative importance of the various radiative, chemical, electrodynamic and dynamic sources (input) and sinks (output) of energy for the thermal structure of the MLTI. The instruments include the Global Ultraviolet Imager (GUVI), the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER), the Solar EUV Experiment (SEE), and the TIMED Doppler
Interferometer (TIDI).

The instrument suite is supported on-orbit by the spacecraft bus which provides power, thermal control, attitude control, current and predicted navigation (position, velocity, time) data, command control, data storage and science and engineering data downlink. The interface between the instrument suite and the ground system is via the spacecraft bus.

The spacecraft instruments will be operated to observe and collect data related to scientific phenomena in accordance with the requirements and objectives set forth by the Mission's Science Working Group (SWG). It is expected that the SWG will provide direct requirements to the instrument teams and instrument operational timelines will be derived from these. These procedures will be translated to instrument command sequences to control on-orbit instrument operational behavior. The spacecraft bus will be programmed to operate in support of these science orientated objectives.

The TIMED spacecraft will be placed into orbit by a Delta II launch vehicle in January, 2000. Two payloads will be launched; the JASON I spacecraft will also be deployed as part of this launch operation.

1.3.1 Mission Data Flow

Figure 1-1 illustrates flow of command and telemetry data between the ground-based spacecraft bus and instrument operations elements and the on-orbit spacecraft (comprising the spacecraft bus and instrument suite). The 'outer-loop' depicts instrument operations. Begin at the POC (POC Planning) where instrument commands are produced (there are four such POCs, one for each on-board instrument, so this outer-loop is actually repeated four times; there are four parallel paths). The command messages, in the form of packets (a standardized packaging format) along with some additional information needed by the MOC, are forwarded to the MOC (the Internet will be used to do this). At the MOC (MOC Authorize and Route) there is some checking performed, then these commands are queued for eventual uplink to the spacecraft instrument associated with the POC that generated the commands. Along with the command packets themselves, the POC appends timing information which indicates the time span (earliest and latest times) over which the command packet may be uplinked to the spacecraft instrument. These command packets, when uplinked to the spacecraft (by the MOC and via the ground station) are immediately routed, by the spacecraft bus command processor (the C&DH Routing Service), to the appropriate instrument. The command packet really goes 'directly' from the POC to the instrument, the MOC, ground station and spacecraft bus are merely the delivery system. This delivery system notifies the POC of the delivery status (when the delivery was attempted and how successful it was). This process can be imagined as a posting of a special delivery letter (to the instrument) with a delivery acknowledgment by the (postal) service.

Whereas the POCs produce instrument commands, the MOC produces spacecraft bus (S/C subsystem) commands. This is depicted in the 'inner-loop' on the diagram. This (MOC Planning) independent (of POC command generation) process prepares command messages to the spacecraft bus itself to operate it during the next day in space. These command messages are queued for uplink (MOC Authorize and Route) just like the instrument commands, only they go to a different destination (via the C&DH Routing Service). They are routed to spacecraft bus subsystems, once they arrive at the spacecraft. The MOC receives delivery status of these just as the POCs do.

Once these command messages have been received and acknowledged (Instrument Command Execution and C&DH Command Execution) on the spacecraft, they 'orchestrate' its operation. The on-board instruments produce science and engineering data (Instrument Data Collection) in response to the uplinked command messages (these messages tell the instruments how to operate; they select operating modes, instrument hardware and software configurations, determine when and where to collect data, and so on). The data produced by the instruments is sent to the spacecraft data system in the form of telemetry packets (like command packets, these are data formatted in a standard manner). Similarly, engineering data produced by the spacecraft bus, are also formatted into packets. The packets produced by the instruments and the spacecraft bus and conveyed to the spacecraft data system (C&DH Combine) may be sent immediately to a ground station, if the spacecraft happens to be flying over a ground station at that time (it hardly ever is, though), but usually they are stored in a data buffer (called a recorder) within the spacecraft data system (C&DH Recording). As the instruments and spacecraft bus collect data throughout the day the data are stored and the data buffer eventually fills up. This is supposed to happen about once a day. When this occurs, the entire contents of the data buffer are transmitted to a ground station (C&DH Frame Packaging). This empties the buffer and it begins to refill again.

On the ground (Ground System Telemetry Routing), real-time data are forwarded to the MOC and to the data archive, while all recorded data are stored at an archive facility (MDC Clean and Merge). The POCs will retrieve instrument data from this archive center and will process and analyze it. The cycle repeats, with the POCs preparing instrument commands for still another day in space. Spacecraft bus data is routed to the MOC (MOC Assessment) where an assessment function is performed. The MOC spacecraft bus planning process then repeats.

Of significance, here, is that the instruments and spacecraft bus are operated (almost) entirely independent of each other. The same can be said about the ground elements (the POCs and the MOC). This concept greatly simplifies the operations process, which traditionally requires these functions to be merged in a complicated manner.

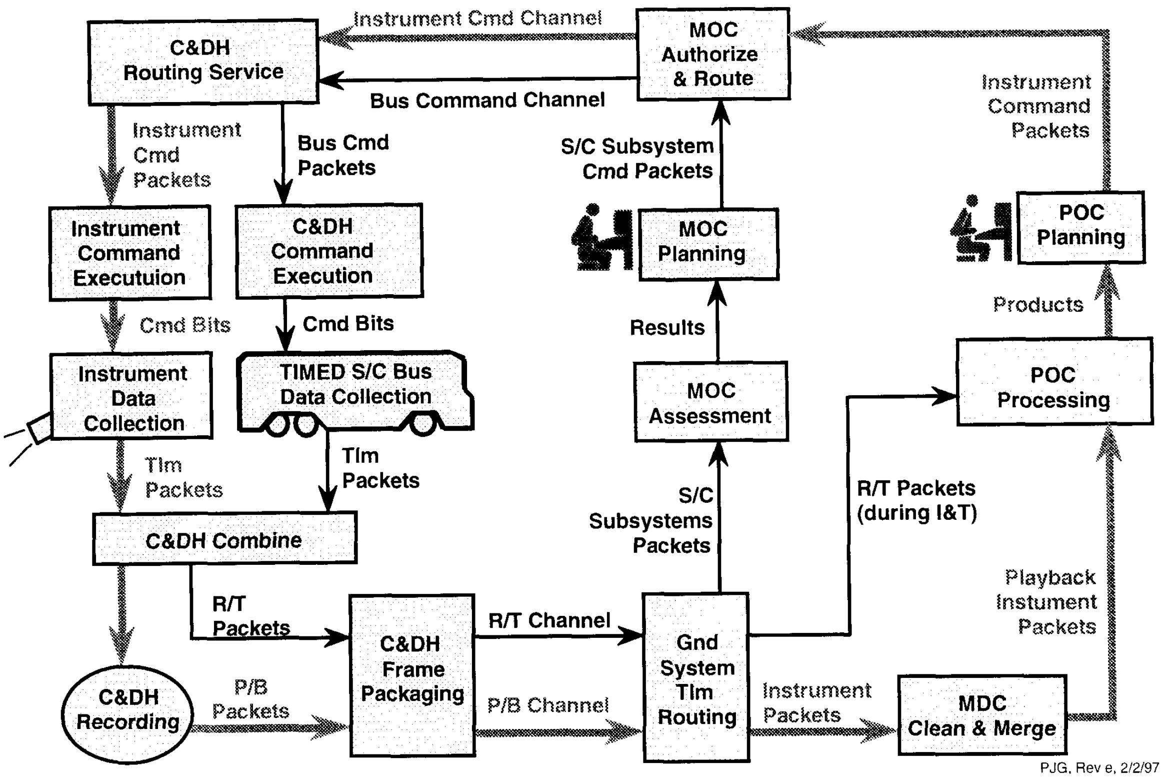


Figure 1-1
TIMED Mission Data Flow

1.4 TIMED Spacecraft

1.4.1 Spacecraft Description

Within this document, when the spacecraft is referenced, it refers to the spacecraft bus *and* the instrument suite *together*; otherwise the spacecraft bus (or bus) refers to the spacecraft *less* instruments.

A block diagram of the TIMED spacecraft data system is illustrated in Figure 1-2. The spacecraft bus subsystems are fully redundant; the instruments are single string and no one instrument is considered mission critical. The spacecraft bus is designed around an Integrated Electronics Module (IEM). The IEM is a card cage that contains the RF Communications, Global Positioning System Navigation System (GNS) and Command and Data Handling (C&DH) subsystem on plug-in cards. The cards within an IEM communicate over a PCI parallel data bus. Two identical modules are used. Both modules communicate to other spacecraft subsystems and the instruments over a redundant 1553 serial data bus.

The power subsystem employs solar panels that are positioned by a single axis drive. Power is managed by a Peak Power Tracker. A 50 Amphere-hour (A-h) Nickel Hydrogen Individual Pressure Vessel (NiH IPV) battery is used to support loads during eclipses. Battery charging and solar array power management are under control of the C&DH processor within the IEM.

The Guidance and Control (G&C) subsystem has a dedicated 1553 bus for communication between the attitude sensors (Star Cameras and Inertial Reference Unit) and the Flight (Attitude) Computers. The Attitude Interface Units (AIU) control other actuators, such as reaction wheels, torque rods and the solar array drive. The AIU also contains a processor for safing the spacecraft in the event of a loss of attitude control.

The G&C subsystem also uses a 32-bit RISC processor for processing data from the star cameras and Inertial Reference Unit (IRU) (a 3-axis gyro) and controlling, via the AIU, the reaction wheels and torque rods. Four reaction wheels are utilized, the operation of any three can provide the required 3-axis stability. Built-up momentum in the wheels will be dumped using three orthogonal torque rods. The two narrow field-of-view star cameras are mounted on the optical bench on the zenith (-z axis) end of the spacecraft. The output of any one star camera is sufficient to meet the attitude knowledge requirements to support most instrument operations (although two operational star cameras are required to support some TIDI operations). The G&C subsystem also controls the pointing of the solar array panels through the solar array drive. A Magnetometer supports dumping of momentum from the reaction wheels into the earth's magnetic field.

A dedicated 1553 bus is used by the attitude subsystem components to facilitate easy implementation of autonomy and safing algorithms. The loss of a single component within the attitude subsystem should not result in an immediate critical loss of attitude control.

The IEM utilizes two 32-bit RISC processors to control the GNS and C&DH subsystems.. The C&DH processor manages the traffic over the spacecraft 1553 bus by coordinating messages between C&DH, GNS, G&C and the instruments. The C&DH processor monitors the health of the AIU safing processors. When the C&DH receives a messages from the AIU that the spacecraft has lost attitude control, the C&DH can switch to the alternate AIU and begin the recovery process.

Redundant Solid State Recorders (SSR), each with a 2.5 Gbit capacity, can each store at least 24 hours of science and engineering data collected on-board the spacecraft. The recorders are interfaced to the 1553 bus and have high speed serial links to each IEM C&DH subsystem for downlinking the recorder contents.

The GPS Navigation System (GNS) subsystem consists of a single card within the IEM that functions as a GPS receiver, along with an embedded 32-bit RISC processor to provide on-board tracking and navigation solutions. Spacecraft position will be determined to within 300 meters (3 sigma), velocity to 25 cm/sec (3 sigma) and time to 100 usec using a single-frequency Standard Positioning Service GPS receiver. This information is made available to the on-board subsystems and instruments once per second via the 1553 bus (the once-per-second time tags provided to the instruments and are accurate to within 100 ms). The GNS will extrapolate the spacecraft orbit and will provide this information to on-board processors and for ground-based users via telemetry. The GNS will provide the basis for on-board event prediction, such as terminator crossings and ground station contacts.

Spacecraft antennae include transmitting and receiving antennae at both the (nominal) nadir (+z axis) and anti-nadir (-z axis) pointing axis on the spacecraft. Antennae/receivers are selected by commanding on-board relays.

Data interfaces between the spacecraft and the GS include a 2 kbps command uplink channel and 9 kbps low-rate and 4 Mbps normal downlink telemetry channels.

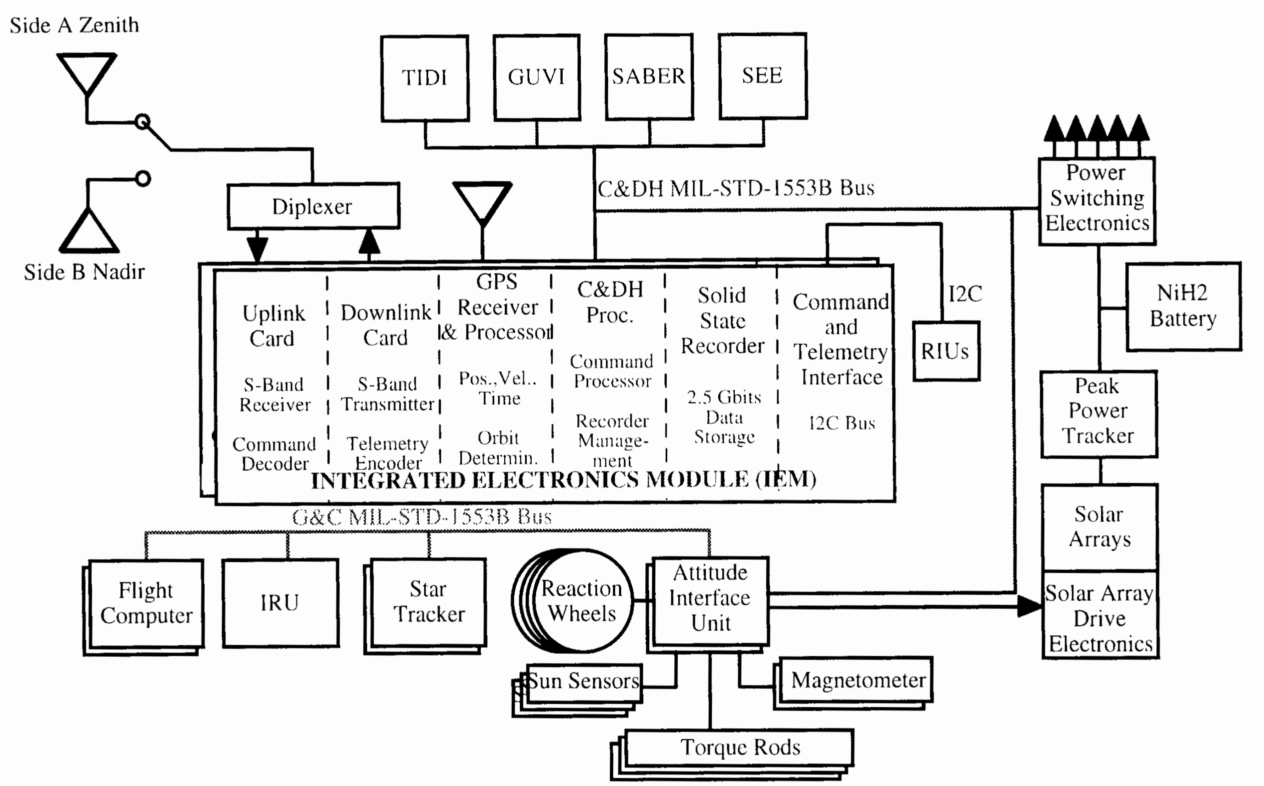


Figure 1-2
TIMED Spacecraft

1.4.2 Spacecraft Operations

The spacecraft will be operated to collect data as the on-board instrument suite observes regions of scientific interest. The spacecraft bus is operated to support this data collection by providing nominal attitude, power, navigation data, thermal control, data storage, rule-based autonomy as well as a conduit to a ground station network. It is expected that the spacecraft, in its entirety will operate mostly autonomously, requiring only minimal ground support to uplink occasional command messages and to recover science and engineering data on a daily basis. Ground-based contact with the spacecraft will be scheduled just once a day, usually for a period of about 10 minutes for a typical overhead pass of the spacecraft over a ground station. During the remainder of the day, the spacecraft will be 'on its own' collecting data, measuring its own health and responding, by itself, to any self-discovered anomalous operations. It will do this primarily by performing a continuous performance assessment function through observation of its own telemetry while evaluating pre-stored rules related to performance and operation. The goal of the MOT will always be to maintain a science data gathering capability but it is likely that some on-board anomalies cannot be autonomously handled in a manner so as to preserve normal operations. In these cases the spacecraft may transition itself to a safe-hold mode where science data collection is suspended and all non-essential instruments and subsystems, required to protect the spacecraft from catastrophic failure, are shut down.

1.4.2.1 Spacecraft Bus Operations

The C&DH computer will intercept ground-based command messages which provide initialization data, control instrument configurations, specify attitude configuration, allocate data storage reserves, and, in general, to 'orchestrate' the operation of the entire spacecraft as determined through the execution of stored command directives and imbedded rules of operation. Command messages not specifically addressed to the C&DH subsystem will be conveyed to addressed bus subsystem and instrument destinations via a data bus. The C&DH subsystem will report, via telemetry, the status of both the receipt (from the ground) and delivery (to the on-board instrument or subsystem) of these commands.

There are actually two command subsystems on-board the spacecraft (and each is completely redundant). A Critical Command Unit (CCU) is capable of handling relay (power switching) commands only and provides an 'emergency' capability to configure the spacecraft (that is to power on and off subsystems). The normal method of commanding is through the C&DH command processor (this processor may not always be powered on, hence the need for an alternate emergency command capability) that is capable of handling all commands.

State-of-health (housekeeping) data throughout the spacecraft are sampled by the C&DH subsystem and are stored on the Solid State Recorder (SSR). In addition, science and engineering data produced by the instrument suite are transferred to the SSR for storage. An SSR will hold about 2.5 Gbits of data, usually sufficient to store data collected on-board over a period of 24 hours. The SSR, containing all science and engineering data collected over a nominal 24 hour period is played back to the GS once per day. In addition to the stored data, real time spacecraft science and engineering data may be transmitted to the GS.

Spacecraft attitude will be nominally maintained in a nadir-pointing orientation (+z axis toward the earth) to an accuracy of one degree (3 sigma) continuously. This attitude will be controlled autonomously by the G&C subsystem. Attitude will be measured by star cameras, processed by the G&C processor (also called the flight computer) and adjusted by controlling spacecraft momentum using a reaction wheel assembly. Attitude data (quaternions) will be generated and will be provided to the C&DH subsystem for broadcast to on-board subsystems and instruments. Occasionally, the spacecraft will receive a commanded yaw adjustment to provide preferred sun orientation. The G&C subsystem produces, in addition to nominal engineering telemetry data (including attitude quaternions and state-of-health data), diagnostic data to be used for ground-based performance assessment. These diagnostic data are stored in circular data buffers holding both a single orbit sample and a 24 hour sample. The contents of these buffers are transmitted to the GS to support G&C subsystem performance assessment and possible anomaly investigations. If, for some reason, the spacecraft cannot maintain the preferred operational attitude, perhaps because of an on-board anomaly as detected by autonomy rule execution, the G&C subsystem will configure and maintain a 'life-saving' safe-hold attitude with solar panels directed toward the sun. Commands issued by the MOT may be required to transition out of this safe mode.

The G&C will control spacecraft attitude accurately enough to support instrument pointing requirements provided that both star cameras are functional (although most instrument data collection requires only a single star camera to be operational), an operational flight (G&C) computer and a knowledge of spacecraft orbital position. If the flight computer is turned off (it may be powered off in certain safing mode configurations), the AIU will be able to control spacecraft attitude to a nadir-pointing orientation, although not with sufficient accuracy to support instrument data collection (but instruments are off anyway in all safing configurations). This will provide the necessary spacecraft attitude control to support ground-to-spacecraft command and telemetry communications.

The GNS subsystem will produce navigation data spacecraft position, velocity, sun vector and time) as well as computed predictions thereof, for use by on-board subsystems and instruments as well as the ground system (i.e. tracking data will be provided by the spacecraft itself). The spacecraft needs orbital information and time provided by the GNS subsystem in order to operate. The GNS will also provide real-time indicators of ground station contact events, terminator crossing events and SAA events

The GNS subsystem, when commanded to the navigate mode, receives signals and messages broadcast by the on-orbit GPS space segment and processes these to produce position and velocity components of the spacecraft orbit as well as time. Prior to entering the navigate mode, the GPS receiver portion of the GNS must acquire and track four or more GPS satellites. A default sky search mode is provided to search for and acquire GPS signals that does not require knowledge of spacecraft position or time. Time to first fix (TTFF) for sky search is long, on tge order of one half hour. To acquire more rapidly, an aided search option is implemented. Aided search requires prior entry of a GPS almanac, TIMED spacecraft state vector and GNS coarse time set. Use of aided acquisition significantly speeds TTFF to about two minutes. Once TTFF has been accomplished, the GNS subsystem continuously updates these navigation data. Data are transferred to the C&DH subsystem where, in addition to being incorporated within the downlinked state-of-health data, are broadcast to on-board subsystems and instruments.

GNS data generated for on-board spacecraft use include spacecraft position and velocity coordinates (state vectors) and time. In addition, the GNS produces spacecraft ephemeris as 2-line (NORAD-format) element sets and augmented (15 element) Keplar elements which are, in addition to the state vectors and time, transmitted to the ground. The spacecraft orbit is extrapolated four days ahead and NORAD 2-line element sets, to be used for ground antenna pointing, are generated for each of the next 12 passes of the spacecraft over both the primary and the backup GSs. The augmented Keplar elements are provided for mission planning functions (as required to predict the orbit of the spacecraft). These are accurate over a four-day period (a cross-track accuracy of 8 km is maintained; this is the only established requirement regarding these elements). The augmented Keplar elements are updated every 12 hours and are output (to the SSR) every 12 hours. Generation and output occurs just prior to the start of an APL GS overhead cluster so as to produce the most accurate data possible for the ground-based mission planners.

The GNS subsystem has a commanded diagnostic mode where, in addition to the navigation and engineering data normally produced by this subsystem, raw measurement data are stored for ground-based navigation solution reconstruction and performance analysis (the raw measurement data are processed by ground-based navigation software and results are compared with the on-orbit products).

Spacecraft power is provided by solar panels augmented by a storage battery (when solar panel derived power itself is inadequate to support energy demands). The solar panels themselves are positioned along the x-axis (ram and anti-ram directions) and are optimally orientated (rotated) about this axis for maximum sun incidence upon the solar cells although the panels do not track the sun itself. Maximum power subsystem efficiency is maintained by a Peak Power Tracking feature controlled by a software algorithm resident in the C&DH subsystem computer.

The C&DH subsystem continuously monitors on-board telemetry measurands for violations of established operating rules (these rules are defined and uploaded by the ground-based MOT). Rule violations invoke command sequences which tend to overcome the cause of the violating condition. These autonomous operations attempt to maintain an operational spacecraft, but there are cases where the spacecraft itself is simply not smart enough to fix itself. In these instances, the spacecraft will transition to a safe-hold mode and await ground command response.

An RF watchdog timer is implemented within the CCU for the purpose of autonomously switching antenna configurations. With the antenna configuration, it is possible, should the spacecraft lose attitude control, or possibly in a sun-safe orientation, that the selected antenna (command and telemetry) will be pointing away from the earth and the GSs, so that telemetry may not be received and the spacecraft cannot be commanded. To avoid a perpetual communications void, the selected antenna will be switched to the opposite end (the alternate z axis) of the spacecraft. Then, a communications path to the GS will be provided. The watchdog timer interval is expected to be about 40 hours. It is reset whenever a command is accepted by the spacecraft.

In addition to the 'advertised' science and engineering data produced, the spacecraft also may accumulate diagnostic data that may not normally be downlinked. These data may be recovered when it is necessary to troubleshoot problems.

As part of the normally generated engineering telemetry, the spacecraft preserves a record of all commands executed on-board. Included are real-time, event scheduled and autonomous command execution. Such data are necessary in order to assess operational performance of the spacecraft system.

1.4.2.1.1 Command Uplink

The spacecraft C&DH subsystem receives telecommand uplinks (transmitted by the GS) which may either be addressed to the CCU or the C&DH command processor (in both cases, the actual redundant side must also be addressed. Telecommand packets are formatted into telecommand transfer frames (by the MOC). A packet may be imbedded within a single transfer frame or may span over several transfer frames. The packet, itself, is addressed to a particular spacecraft subsystem or instrument and all packets contained within a transfer frame must be addressed to the same subsystem or instrument. The C&DH subsystem command processor ingests and assembles the complete packet, then routes, via the PCI or 1553 bus (depending on the addressed subsystem or instrument), to its destination. If the received packet is incomplete or otherwise unacceptable (based on error detection criteria) the packet is rejected in its entirety and a status message is transmitted to the GS. The contents of the packet, itself, however, are not checked by the C&DH subsystem command processor. Once a packet has been received by the designated subsystem or instrument, it is the responsibility of that subsystem or instrument to evaluate the packet content for acceptability. The report of this evaluation must be conveyed via the engineering telemetry produced by that subsystem or instrument.

In addition to the direct delivery method of commanding described above, certain spacecraft configuration states may be commanded by the CCU. This subsystem, which 'parallels' the C&DH command processor, may issue only configuration commands which control the power switching relay states. These commands may be issued when the IEM, itself, is powered off (in the case, for example, when the spacecraft autonomy has powered the IEM off). These critical (relay) commands are formatted in packets, one command per packet, by the MOC, and then uplinked, via the GS, in real-time to the spacecraft CCU. CCU commands are executed as they are received (in real-time; there is no on-board storage of these commands).

1.4.2.1.2 Telemetry Downlinks

The spacecraft transmits real-time and stored (SSR) data to the GS in two modes (there actually are three possible, however).

1.4.2.1.2.1 Low-rate Telemetry Downlink Mode

This mode is designed to accommodate unfavorable spacecraft-to-ground station geometry, possibly caused by a tumbling (out-of-control attitude) spacecraft, which may compromise received signal strength. In this mode, which may be either explicitly commanded or may be invoked through autonomy, *only* spacecraft bus engineering telemetry is downlinked and at an increased sample rate (the telemetry measurands are sampled more frequently than normal). No instrument data, except the instrument status words contained within the spacecraft bus engineering data, are conveyed. In this mode, the telemetry transfer frame is formatted with three spacecraft bus state-of-health (C&DH) telemetry packets and one G&C subsystem diagnostic (stored orbital data) packet (normally only two of the four packets contain this state-of-health data) and is transmitted once per second. The downlink data rate is approximately 9 kbps.

1.4.2.1.2.2 High-rate Telemetry Downlink Mode

The high-rate telemetry downlink mode transmits real-time and playback science and engineering data at a data rate of approximately 4 Mbps. In this mode, real-time science and telemetry are multiplexed with stored (SSR) data as follows:

Real time science and engineering telemetry has priority. That is, if real-time science and engineering data are selected for downlink, then any data generated in real-time by either the spacecraft bus or instruments is formatted into transfer frames and downlinked immediately (after some processing by the C&DH processor). Spacecraft bus engineering telemetry data, consisting of the aforementioned state-of-health frames as well as other engineering data, are again formatted into transfer frames. Here the four packet transfer frame consists of two packets of state-of-health data and two packets of selectable engineering data (this could include such data as processor memory readouts, command history buffer readouts, or autonomy rule execution history). Instrument science and engineering data will be produced only when the instrument is powered on (engineering data) and only if the instrument has been commanded to a data collection mode (science data). The maximum total data rate for real-time science and engineering data produced and downlinked by the spacecraft is about 57 kbps.

Any data downlink channel bandwidth not occupied by real-time science and engineering data will be allocated to stored (SSR) data, provided this data playback has been commanded on. In the absence of SSR data, 'filler' packets are generated.

1.4.2.1.2.3 'Medium-rate' Telemetry Downlink Mode

The spacecraft data system is being designed to support a 2 Mbps downlink data rate, although this is not considered as an operational mode. This 'medium-rate' mode will provide the capability to playback the SSR data at a LEO-T GS (the 4 Mbps high data rate may be beyond the capability of a LEO-T data recovery bandwidth). Obviously, it will require twice as long to downlink a SSR playback in this mode.

1.4.2.2 Instrument Operations

As described above, the entire spacecraft is operated to collect science and engineering data by the instrument suite and essential engineering support data (such as orbital position, attitude and time) by the spacecraft bus. The operation of the spacecraft is programmed through ground-based command messages produced by the instrument POCs and the MOC. These command messages, when provided to instrument processors, define operational scenarios to be invoked based on recognized on-orbit events including time, orbital position, specific orbital milestones (terminator crossings, for instance), as broadcast, each second, by the C&DH computer via the 1553 bus. The instrument processors, themselves, are programmed to evaluate and respond to these broadcast event messages. The instruments, in general, will scan 'target' regions as referenced to the spacecraft attitude and will collect scientific data while storing these data on the spacecraft bulk data recorder (SSR) via a high-speed 1553 bus. In addition, instrument engineering (health and status) will also be collected and stored. It is expected that the instruments will operate in this manner orbit-after-orbit until interrupted by ground-based command messages.

1.4.2.3 Spacecraft Operating Modes

Spacecraft operating modes include the following:

Initialization mode where the GNS subsystem performs an initial navigation fix and begins to produce orbit data products and time. This mode is invoked, by on-board autonomy or ground command, when transitioning from the safe mode, or may be invoked autonomously when the on-board GNS subsystem loses track of the GPS satellite constellation.

Initialization is accomplished autonomously by the GNS subsystem performing a 'search the sky' for available GPS satellites, acquiring GPS constellation almanac data and approximate time from a single satellite and then performing an aided search (based on recovered GPS data) of additional GPS satellites until a navigation solution is computed. The autonomous initialization may require up to 30 minutes to accomplish, and is mostly dependent on the time it takes to acquire the initial GPS satellite. For a more rapid initialization, the GNS subsystem may be provided acquisition aiding data from the ground. Included here are estimates of time and the TIMED spacecraft orbital position as well as almanac data for the GPS constellation. The search time is then reduced and an initial navigation solution can be computed in about one minute. Once initialized, the spacecraft G&C subsystem, provided orbit position by the GNS subsystem, can compute and control the necessary precise nadir-pointing attitude required to support instrument data acquisition. Instruments then, if commanded on and to operational modes, will begin the collection and storage of science data.

Safe modes where non-vital loads are shed and the spacecraft is orientated to an attitude which maximizes solar energy incidence upon the solar array panels with the hot side of the spacecraft facing the sun. These modes are invoked whenever transitioning from an off mode (such as launch vehicle separation sequence), by ground command, or autonomously on-board when the spacecraft is unable to sustain normal operations. Several safe mode transition causes have been identified. These, and the impact upon the spacecraft operational configuration, include:

Loss of attitude control (as determined by the AIU)
- Instruments are turned off

Software low-voltage sensing switch activation (command processor software detects that the bus voltage has dropped below the current software low voltage sense (SLVS) level)

- Instruments are turned off
- One star camera is turned off
- Operational heaters, except battery heater, are turned off

Hardware low-voltage sensing switch activation (power subsystem detects in hardware that the bus voltage has dropped below the current hardware low voltage sense (HLVS) level)

-Instruments are turned off
-Both IEMs are turned off'
-G&C flight computer and star cameras are turned off
-Operational heaters, except battery heater, are turned off

In general, the safe mode is invoked whenever the spacecraft can no longer maintain nominal attitude control or if some other on-board malfunction has occurred and detected by the rule-based autonomy software. Once the safe mode is invoked, the ground-based MOT may be required to issue command messages to reenter the initialization and operational modes (autonomous recovery from some safe mode transitions may be permitted).

Operational mode where the spacecraft collects science data. In general, this mode is invoked upon completion of the initialization sequence. This is the normal spacecraft mode (the goal is to maintain this mode all of the time).

In addition, there are sub-modes, including a GNS idle mode when this subsystem is not searching for signals from the GPS constellation, and a diagnostic mode when the GNS is preserving raw measurement data for ground navigation algorithm performance assessment.

1.5 TIMED Ground System

Figure 1-2 illustrates the entire TIMED ground support system, including the TIMED Ground System (including the Ground Station, Mission Operations Center and Mission Data Center) and Science Data

System (which includes the POCs), ground-based observers and public users). All but the ground-based observers and the public users are described to, to some extent, within this document.

The POCs (SABER, SEE, TIDI and GUVI) are networked to science investigators, ground-based observers, public users as well as to the operations network connecting the MOC and MDC. Instrument commands flow to the MOC and command confirmation is returned. Instrument data (science and engineering) are provided to the POCs by the MDC. The MDC receives telemetry data from the spacecraft and planning data from the MOC for distribution to the POCs and other external users. The MOC (and the Ground Station) provides a command gateway to the spacecraft. Telemetry data recovered by the Ground Station are distributed to the MOC and MDC.

In general, the ground facilities are networked by communications circuits utilizing either Ethernet or Internet protocols. The actual MOC control of the spacecraft is protected from these general purpose networks (so that only authorized operational personnel may command the spacecraft).

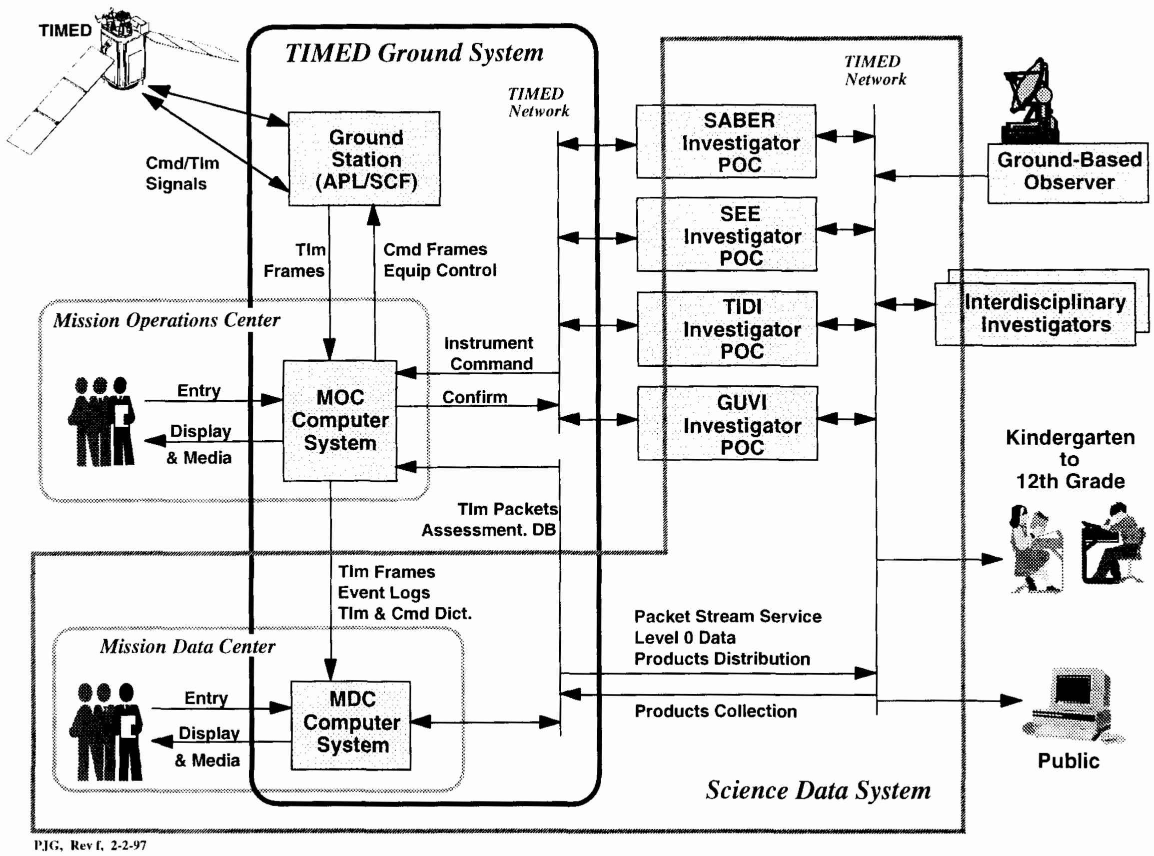


Figure 1. TIMED Ground System Composition and Context

Figure 1-3

TIMED Ground System Architecture

1.6 End-to-end Data System

The MOS is comprised of four instrument POCs, a MOC, a MDC and a network of GSs. These elements are interconnected by commercial grade communications circuits. Internet/Ethernet protocols are expected to be employed throughout. The instrument POCs will be located, developed and operated by the instrument teams. The MOC and MDC will be located at and developed by APL. The GS network will be procured or developed by APL and will be located strategically so as to provide adequate spacecraft to ground communications coverage to support mission requirements.

Simplified diagrams of the end-to-end data system, including the TIMED space-based and ground-based elements and a data flow diagram are illustrated in the figures 1-4 through 1-7 below. Figures 1-1 and 1-2 provide top-level diagrams of the interconnected MOS components.

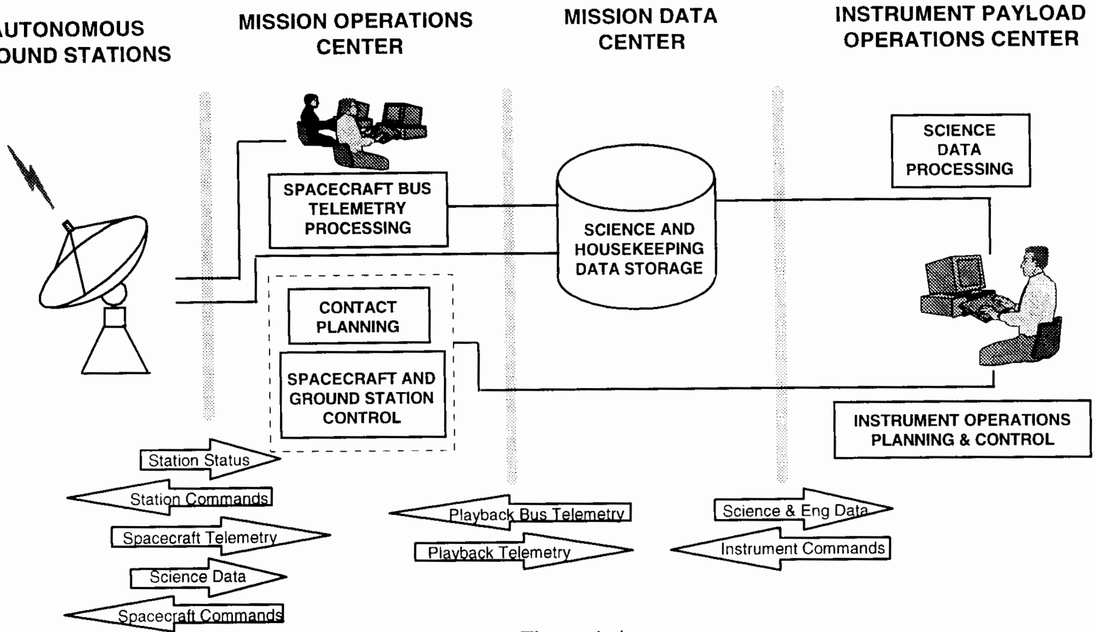


Figure 1-4
Mission Operations System

Figures 1-4 and 1-5 provide a top level perspective of the interconnections between the major elements of the MOS, the flow of data and the functions supported by each.

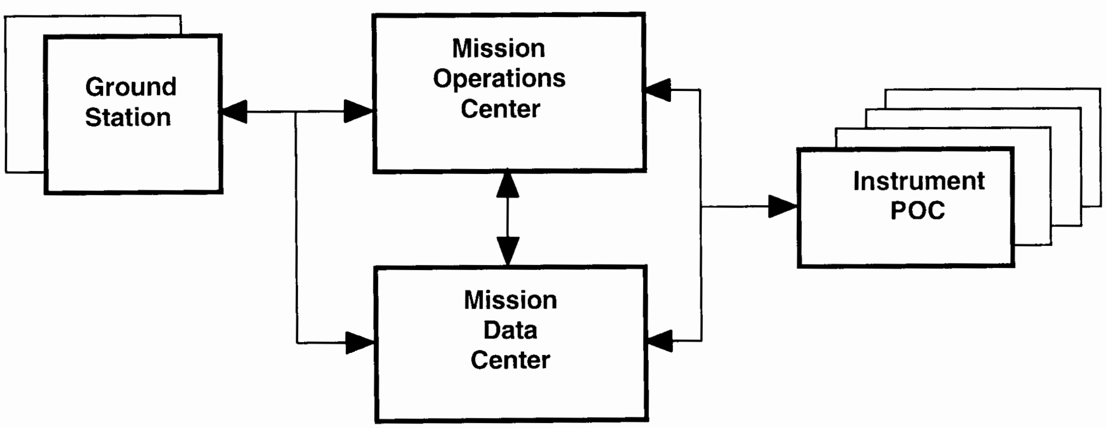


Figure 1-5
Mission Operations System

Figure 1-6 illustrates the 'conduits' between the POC, MOC, GS and the spacecraft bus and instruments. The 'outer-loop' defines the interconnection between the instrument POCs and the spacecraft instruments. Command messages prepared by the POCs flow to the on-board instruments and instrument telemetry flows to the POCs. The MOC produces spacecraft bus commands and receives bus telemetry. The MOC also interconnects with the GS to provide configuration and data flow control and to receive GS status messages.

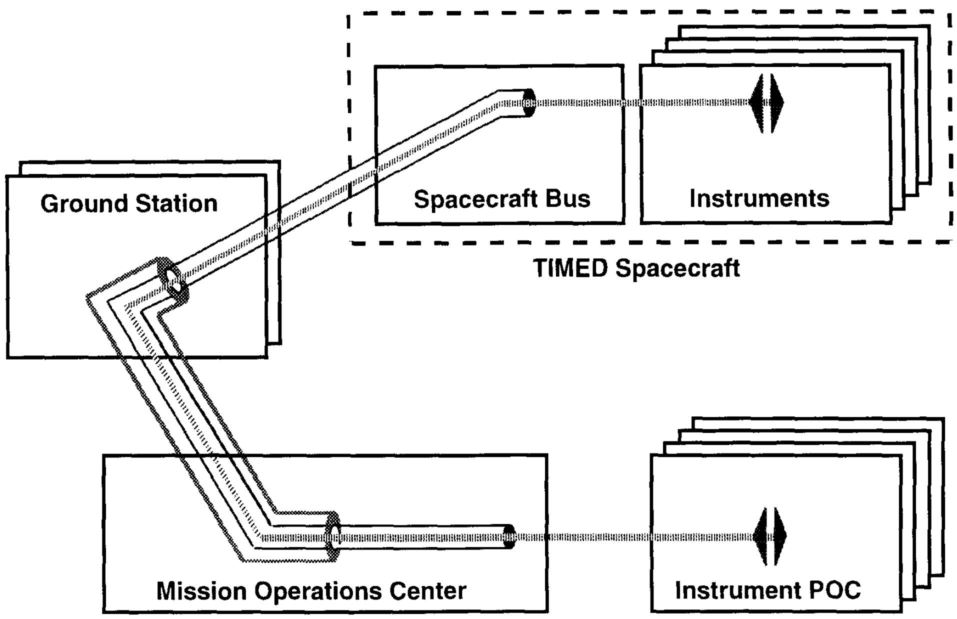


Figure 1-6
End-to-end Data System

All instrument operations will be planned, implemented and evaluated at the instrument POC. Each POC will prepare command messages, possibly daily, to configure and operate the corresponding spacecraft-based instrument. The command messages (packets) produced by the POCs will include headers which will be utilized to store information to be processed by the MOC in order to validate the command message and to establish a time of uplink to the spacecraft instruments. Included here will be the time of the earliest acceptable uplink to the instrument (start time) and the time of the latest time that the command packet can be uplinked. These command messages will be forwarded to the MOC where, after verification of proper instrument/POC pair (the POCs are commanding only their particular instrument), the messages are queued for uplink to the spacecraft to occur during a scheduled spacecraft-to-ground contact, based on the earliest and latest uplink times. During this contact, the prepared command messages will be routed to the spacecraft via a GS (the spacecraft bus will then route these to the addressed instrument via the 1553 bus). Data collected by the instruments will be stored within SSR and held there until the spacecraft passes over a GS. The contents of the SSR are then downloaded to the GS. At the GS, this playback data are stored and then forwarded to the MOC/MDC. Real-time telemetry data (science and engineering data), when downlinked by the spacecraft, will be forwarded immediately to the MOC (will be 'bent-piped' through the GS) and will be stored at the MDC. This data may be accessed in near-real-time from the MDC (the latency may only be a matter of seconds). The POCs then, may access this data as it is stored and so may view an actual spacecraft contact nearly as it happens. This near-real-time mode, however, is not considered to be the normal mode of operation. Normally, the POCs will access all data after the contact has occurred.

In addition to this, the normal mode of operation, there is a real-time mode whereby the POC prepared command messages are routed to the spacecraft in real-time (are not stored at the MOC) via the MOC and GS. At the same time, low bandwidth instrument engineering data are forwarded in real-time from the spacecraft to the POC via the GS and MOC/MDC.

All recovered (playback and real-time) data are stored at the MDC and acquired by the POC through data query database command directives. It is envisioned that even the real-time engineering data acquisition occur in this manner, so a slight delay in the path will likely occur (10 seconds, nominally).

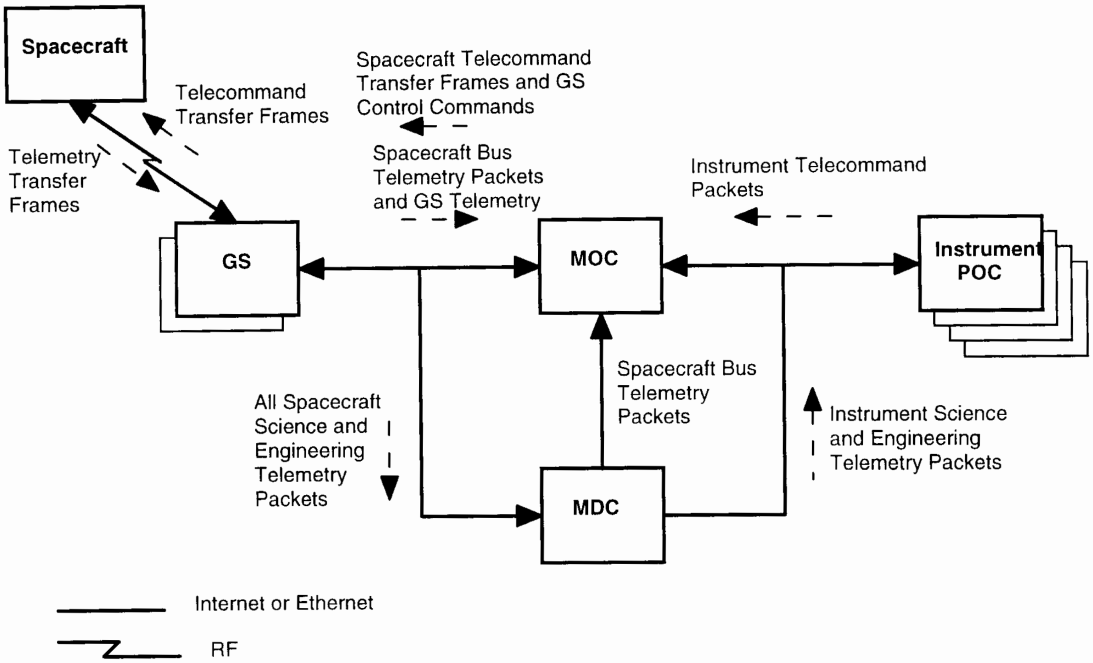


Figure 1-7
End-to-end Data Flow

The following are virtual channel assignments for both command and telemetry data:

Commands: Hardwired commands (CCU): Side #1: **VC0** Side #2: **VC1** Direct delivery commands (instruments and spacecraft bus): Side #1: **VC2** Side #2: **VC3**

Telemetry: Downlink filler: Side #1: **VC0** Side #2: **VC0** SSR playback (science and engineering data): Side #1: **VC6** Side #2: **VC6** Real-time (science and engineering data): Side #1: **VC7** Side #2: **VC7**

1.6.1 Command Data Flow Through the MOC

The MOC produces spacecraft bus commands, processes POC-generated instrument commands and provides a command gateway for all commands to the spacecraft, via the GS. Each POC (SABER, SEE, TIDI and GUVI) prepares command messages (packets) for the associated instrument and forwards these packets, along with some additional identifying and timing data, to the MOC (see Figure 1-8). At the MOC, the FTP Server and Authenticator validates the proper sender (POC)/receiver (instrument) pair [the POC provides an encrypted source identifier and an application telecommand packet (destination instrument) identifier]. An authentication receipt is returned to the POC.

Once a command has authenticated, it enters a Staging Queue (there is one such queue for each POC/instrument pair). Appended to the command message (the command packet and header) is a start and expiration time specification. These represent the earliest and latest times that the command packet may be uploaded to the instrument as specified by the POC. Once past the start time, the command packet is transferred to the Uplink Queue (again there is such a queue for each POC/instrument pair). Command packets in the Uplink Queue are ordered by expiration data, with those packets marked by the earliest expiration date ordered so as to be uplinked first. The MOT may examine the contents of the Uplink Queue to determine the number and size of the packets stored there. All stored commands will be uplinked beginning at the next ground station contact, as long as time permits (the contact is of sufficient duration) unless the MOT places a 'grocery belt bar' separating command packets within the queue. All commands to the left of the bar are uplinked, those to the right of the bar are prevented from being uplinked. This mechanism affords the MOT some degree of control of the uplink command packet traffic to the spacecraft.

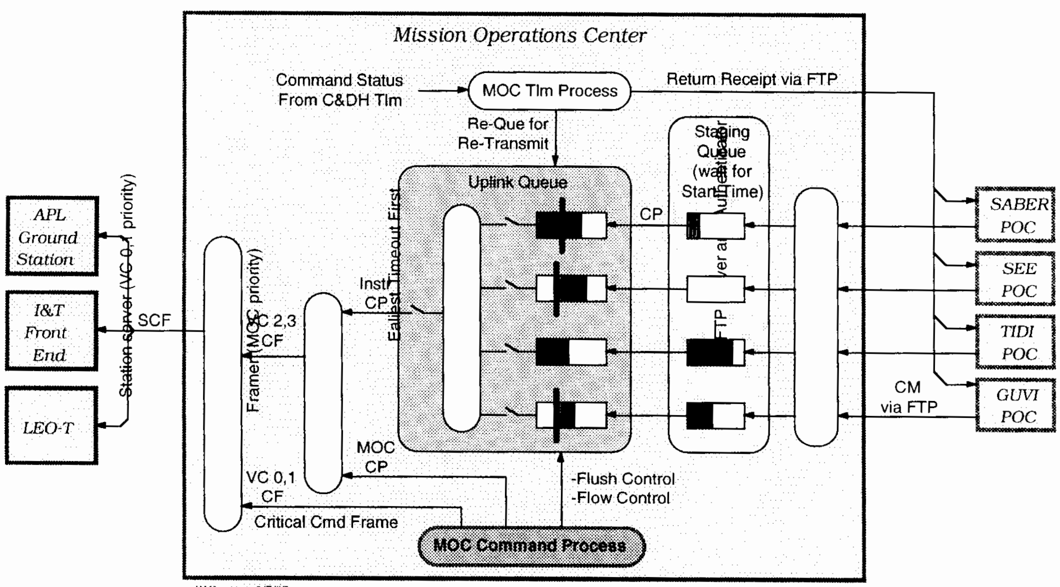
Notice the switch at the output (left side) of the queue. This will either enable (when closed) or disable (when opened) instrument packet command flow to the spacecraft. The queues can be flushed by MOT control, if deemed necessary (if the POC desires to replace the content of the queue, either entirely or in part, the entire queue is flushed and must be reloaded in its entirety. The MOC will issue notification (receipt) to the POC of either a forwarded (uplinked to the spacecraft) packed or a flushed queue.

Commands prepared for spacecraft bus consumption are merged with instrument commands. Normal C&DH command packets (command packets destined for the C&DH command processor) are merged at the Framer.

Here, spacecraft bus commands have priority (if any spacecraft bus commands have been prepared for uplink, these are uploaded first). Commands destined to the spacecraft bus CCU (Virtual Channel 0 or 1) are merged at the Station Server with CCU command packets assigned a higher priority than spacecraft bus command processor or instrument command packets (Virtual Channel 2 or 3).

The status of command packet delivery to the spacecraft command processor is provided via C&DH telemetry. Further, the status of command packet delivery to the on-board instrument and subsystems is provided via C&DH telemetry. This status is forwarded to the POCs for instrument command packet delivery as a return receipt. Thus the POCs are informed of the delivery, but not the verification of actual command content. This must be provided by instrument telemetry itself, which can be processed only by the POCs themselves.

The I&T (integration and test) front-end, which is only utilized during spacecraft ground-based testing, is shown in the figure. This may be utilized to provide MOC-generated command data to the spacecraft simulator during the on-orbit phase.



Command Message Types

- CM = [POC-MOC] Command Message
- SCF = Supplemented Cmd Frame
- CP = Command Packet
- CF = Command Frame

Figure 1-8
Command Data Flow

1.6.2 Telemetry Data Flow Through the MOC and MDC

Figure 1-9 illustrates the flow of real-time and SSR playback telemetry data between the GSs and the MOC and MDC. Real-time telemetry data (VC7) is flowed from the active GS to the MOC as supplemented telemetry frames (STF) (telemetry frames contain telemetry packets). Playback telemetry data (VC7) is flowed from the active GS to the MDC, again as supplemented telemetry frames. In both cases (real-time and playback) the received (by the MOC and MDC) packets are re-served to a packet-based server where telemetry packets are extracted and output as supplemented telemetry packets (STP) and as CCSDS telemetry source (as the data are generated by the spacecraft) packets (TP). In both cases packet streams (a flow of packets placed end-to-end in time order as they were received) are produced. The MOC provides the real-time telemetry it receives to the MDC for storage. Telemetry packets stored by the MDC, including the spacecraft playback bus engineering telemetry, is provided by the MDC to the MOC. From the GSs, real-time telemetry are 'streamed' while playback data are file transferred. The MDC archive and archiving services function is also shown in the diagram.

The I&T front-end, which is only utilized during spacecraft ground-based testing, is shown also. This may be utilized to provide spacecraft simulator generated data to the MOC and MDC during the on-orbit phase.

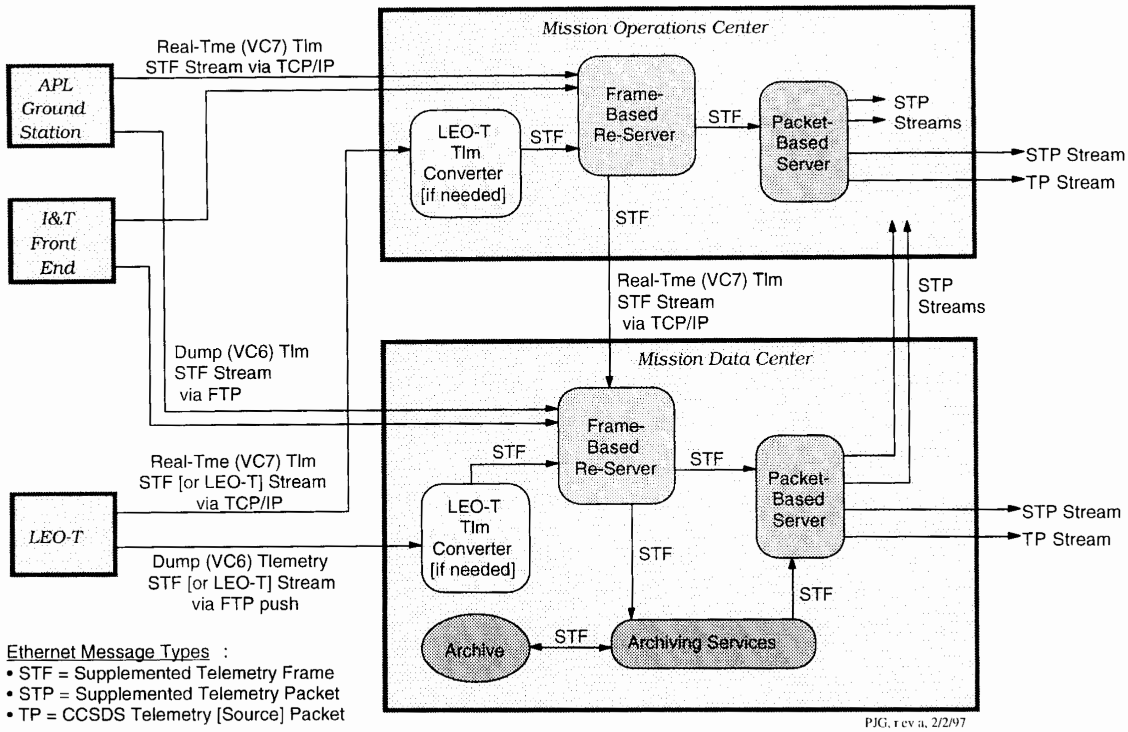


Figure 1-9
Telemetry Data Flow

1.7 Applicable Documents

1. TIMED System Requirements Document (APL Document Number 7363-9001, Revision A), January 1997

2. TIMED Mission Operations Requirements Document (APL Document Number 7363-9021), September 1996

3. TIMED Spacecraft General Instrument Interface Specification (APL Document Number 7363-9050), Undated

4. TIMED Software Quality Assurance Plan (APL Document Number 7363-9191), September, 1996

5. TIMED Spacecraft and Ground System Operational Contingency Plans and Procedures (TBS)

6. TIMED Early On-orbit Operations Plan (TBS)

7. TIMED Ground System Software Configuration Management Plan (TBS)

8. Interface Control Document; Spacecraft to Ground Station, (TBS)

9. Interface Control Document; Mission Operations Center to Ground Station, (TBS)

10. Interface Control Document, Mission Data Center to Ground Station, (TBS)

11. Interface Control Document, Mission Operations Center to Mission Data Center, (TBS)

12. Interface Control Document, Instrument Payload Operations Center to Mission Operations Center, (TBS)

13. Interface Control Document, Instrument Payload Operations Center to Mission Data Center, (TBS)

14. TIMED Program Data Management Plan, (TBS)

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2.0 MISSION OPERATIONS

2.1 Requirements

The TIMED System Requirements Document provides a description of mission requirements. Those requirements, or derivatives thereof, which pertain to the TIMED Mission Operations System include the following:

- The spacecraft will be placed into an orbit of 600 km altitude and inclined at 74.4 degrees. The mission operational lifetime is required to be two years. Orbital precession is designed so that the ground trace realized during the first year will repeat itself during the second year (the same viewing coverage is required).

- Science and engineering data collected on-board the spacecraft will be stored in a buffer which will be read out to ground stations at a data rate of approximately 4 Mbps. The spacecraft will collect about 2 Gb of data each day. Science data delivered to the POCs must include at least 99% of the data originally collected on-board the spacecraft. In addition to this stored (on-board) data, real-time science and engineering data will be downlinked, on command, at rates of either 9 kbps (low-rate mode) or a maximum of 57 kbps. (when multiplexed as part of the 4 Mbps high-rate mode transmission)

- A ground station network (primary and backup) will provide the interface between the spacecraft and the mission operations center.

- The spacecraft will be designed to be serviced only once per day by the MOT, operating the MOC. The single ground contact per day will nominally be scheduled during the day shift. During this contact, all state-of-health monitoring, command uplink and data playback must occur.

- Spacecraft science operations (instrument data collection) will be event driven. That is, the spacecraft bus will broadcast, over the 1553 bus, orbital status (position, time, sun angle, terminator crossings, etc.) to instrument processors. Instrument processors will be programmed to operate instruments at times corresponding to these orbit events.

- The instruments will be operated by the respective POC. The POC will generate command messages for uplink to the instrument processor and will process and analyze instrument science and state-of-health data. Instrument commands and telemetry will be passed through the MOC which, along with the ground station network, will provide a gateway between the spacecraft and the ground system.

2.2 The Mission Operations System

2.2.1 Overview

The spacecraft will be operated by a ground-based MOS which may extend world-wide and connected by communications circuits. The spacecraft bus and the instrument suite will be operated in a decoupled fashion; the APL MOC will provide all support of spacecraft bus operations, the four instrument POCs will individually operate the instrument suite although communication between the POCs and the spacecraft will necessarily flow through the MOC. All spacecraft servicing, including commanding and data recovery will occur during a single ground contact each day. This contact will extend over a nominal 10 minute window when the spacecraft is visible, communications-wise, to a GS as it 'flies' over that station. The GS will be connected to the MOC, to the MDC and possibly to the POCs in real-time. Spacecraft command messages will be uploaded and real-time engineering data will be received and evaluated to assess spacecraft health. Science and engineering data will be downlinked and stored at the GS, then flowed to the MDC at the completion of the real-time contact. Optionally, real-time instrument engineering data may be immediately forwarded to the respective POC for the purpose of evaluating instrument health in near-real-time.

2.2.2 Mission Phases

Insofar as the mission operations function is concerned, there are three distinct phases which encompass pre-launch and on-orbit segments of the mission:

2.2.2.1 Pre-launch development phase which begins with definition of requirements, design and development of the MOS and the testing thereof.

Also included here is the preparation of databases, procedures, timelines, operating rules, etc. to be utilized to eventually operate the spacecraft on-orbit. During this time, the MOT is identified, acquired and trained. This mission phase is culminated by operational demonstrations of the readiness of the MOS to support on-orbit operations, and of course, the launch of the spacecraft itself.

2.2.2.2 Launch phase which begins by loading all initial on-orbit command sequences, including the spacecraft separation (from the launch vehicle) sequence (a pre-planned sequence of events necessary to initialize the spacecraft after separation, including attitude stabilization and solar panel deployment).

2.2.2.3 Early on-orbit operations phase which begins with the separation of the spacecraft from the launch vehicle (the spacecraft is placed into its orbit) and includes all necessary operations required to turn-on and evaluate the performance of all spacecraft bus subsystems and instruments. Following successful turn-on, any necessary calibrations are performed to prepare the instrument and/or ground-based data system for the on-coming operational phase. This mission phase usually extends for a period of about one month.

2.2.2.4 Operational Phase which begins with the entire spacecraft has been declared operational. During this phase the experiments as identified by the objectives of the mission are performed and data are recovered, processed and analyzed. This phase typically concludes when all mission objectives have been met, the spacecraft becomes inoperative or the program runs out of funding. In the case of TIMED, this phase is expected to extend over a 2 year period.

2.2.3 Mission Operations System

2.2.3.1 Mission Operations Center (MOC)

The MOC has the primary responsibility of management of the spacecraft bus including the development of operational timelines and associated command sequences and the uplink of these to the spacecraft by way of the GS. Recovery of spacecraft bus engineering (state-of-health) telemetry and the performance analysis based on this telemetry is also performed at the MOC. In addition, the MOC receives spacecraft instrument command sequences (packets) from the instrument POCs and, after a cursory verification test to assure that a legitimate POC has prepared commands to only that instrument that is managed by that POC, queues these for uplink to the spacecraft based on start and expiration times appended attached to the command messages by the POCs.

During a spacecraft-to-GS contact, the MOC manages the flow of uplink commands (packets) to the entire spacecraft (via the GS) and control commands to the manage the operations of the GS itself. The flow of these commands is monitored to assure successful delivery to the destination. Automatically retransmission may be initiated if delivery is unsuccessful.

The downlink of real-time and stored (SSR playback) data are initiated under the control of the MOC. Real-time spacecraft bus engineering telemetry is ingested, processed (converted to engineering units and tested against prestored acceptable limits) and selectively displayed on visual media.

At the conclusion of a real-time contact, the MOC retrieves the stored spacecraft science and engineering telemetry from the MDC and processes the entire file (nominally 24 hours of data) of spacecraft bus engineering data in order to assess the performance of the spacecraft bus over the previous day of operations.

The MOC is operated by the MOT and is nominally staffed during the day shift, 7 days per week.

The MOC consists of a number of workstations and associated data processing and display equipment as well as the necessary interface equipment to connect to the GS, instrument POCs and MDC.

Figure 2-1 illustrates the MOC and includes interfaces to other MOS elements. Dedicated fiber lines connect the MOC to the ground stations The APL Ground Station (primary and backup) are connected via a 100 Mbps Ethernet link. The LEO-T Ground Station is interfaced via a NASCOM interface (a T-1 link). Communication to the POCs (GUVI, SABER, SEE and TIDI) are via the Internet, with access via modem/ISDN as a backup. Within the MOC itself are workstations to support spacecraft commanding, spacecraft bus monitoring and analysis and primary and backup databases and user files. The primary and backup command workstations (CMD WS) are isolated from the rest of the MOC by a router/firewall. Commands to the spacecraft may *only* be issued from these workstations. Real-time telemetry, received from the ground stations, is flowed through the firewall to the remaining workstations (MOC WS). Received telemetry (both real-time and SSR playback retrieved from the MDC) may be processed and displayed on these workstations. Main data paths are at least 100 Mbps Ethernet, with distribution within the MOC to some workstations and printers on 10 Mbps Ethernet. A total of 12 workstations (8 Sun Microsystems Ultra 1 Sparc Workstations and 4 X-terminals) are provided for MOT and SBET use.

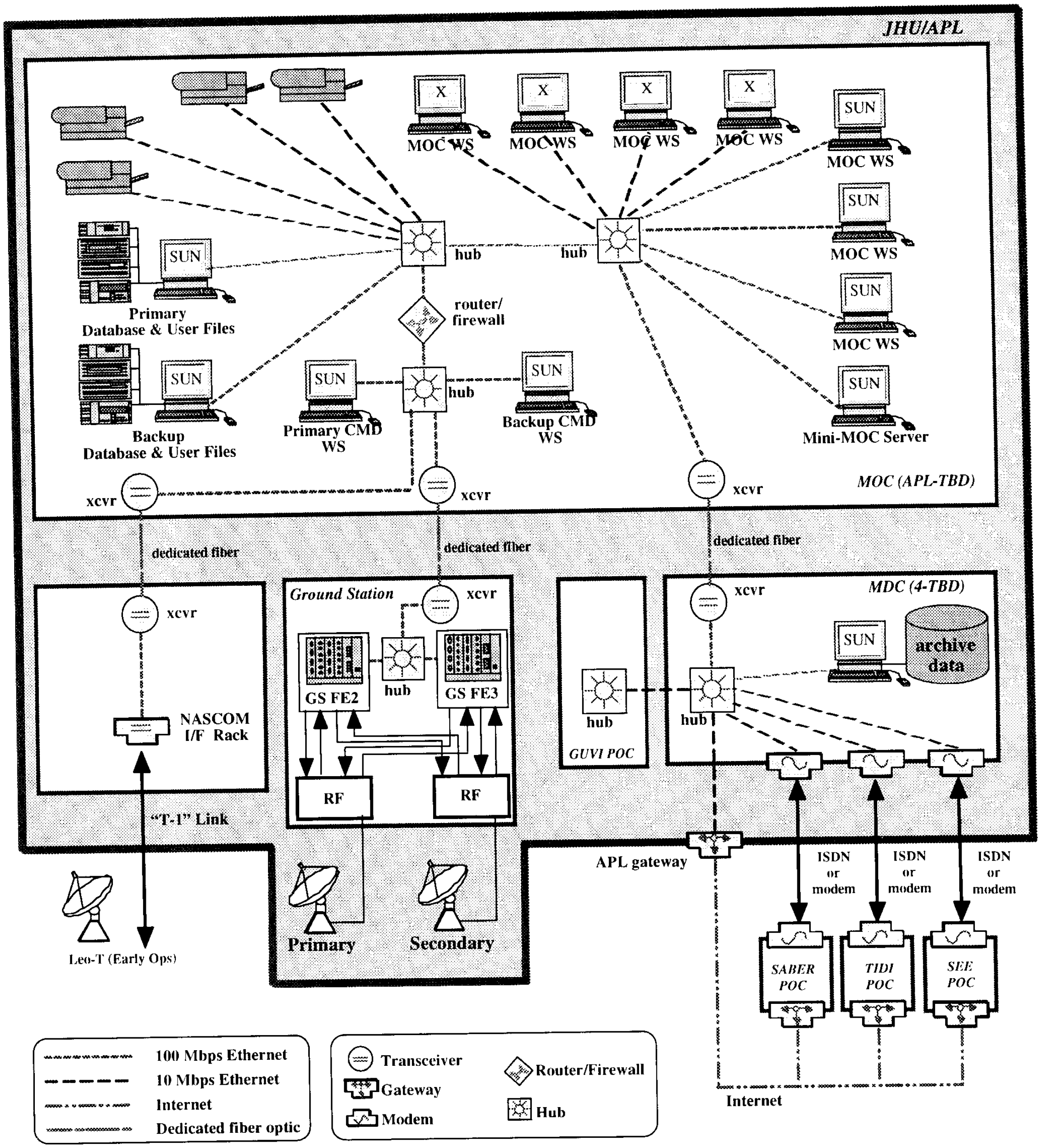

Figure 2-1
Mission Operations Center and Interfaces

2.2.3.2 Ground Station (GS)

The GS is assumed to be located remote of the MOC. The primary GS will be located at APL and will consist of both primary and backup systems. The GS interfaces are being designed to accommodate a Low Earth Orbiter Terminal (LEO-T) station currently being developed for the NASA. A LEO-T is expected to be deployed near Fairbanks, Alaska and may be utilized to support certain critical spacecraft operations as required during the conduct of the mission.

The GS receives antenna pointing data and data acquisition and storage equipment configuration data from the MOC so as to prepare (configure) the GS for impending communication with the TIMED spacecraft contact and to track the spacecraft as well.

The GS receives spacecraft command packets from the MOC in real time, then forwards these to the spacecraft in a 'bent-pipe' configuration (the packets are relayed to the spacecraft as they are received and after they are properly formatted for uplink). Command packet uplink is monitored for successful delivery and when delivery is unsuccessful, automatic retransmission is initiated. Status of the command uplink process is provided back to the MOC.

Dowlinked science and engineering data are received by the GS. Real-time science and engineering data may be immediately forwarded to the MOC and MDC for real-time evaluation. Spacecraft SSR playback data are temporarily stored at the GS and retrieved by the MOC upon completion of the real-time contact (GS to MOC/MDC data bandwidth may be insufficient to accommodate the playback data stream in real-time).

In addition to spacecraft telemetry, the GS transmits, to the MOC, telemetry representing the status of the GS itself.

2.2.3.2.1 APL Ground Station

The Satellite Control Facility (SCF), located at the Johns Hopkins University Applied Physics Laboratory (JHU/APL) will be utilized as the primary ground station. Both primary and a backup facilities will be available.

2.2.3.2.1.1 APL Primary Ground Station

The APL SCF assets for the primary downlink consist of the existing 60-ft antenna system and program-dedicated electronic components for the reception and demodulation of the TIMED downlink. The primary uplink antenna system is a 2-meter antenna system including the power amplifier and all associated transmit electronic components, including the modulators and exciter/driver for the uplink antenna system. The antenna systems are external to the control room and are located to provide maximum RF isolation between the several systems.

All RF and signal processing components electronics except for those that are mounted in or on the antenna system structures will be housed in the SCF control room. These components consist of redundant receivers, QPSK demodulators, and data drivers and receivers. These redundant receiver/demodulator strings are shared with the backup systems. Selection of antenna system to electronics connections are via patch panel.

The primary GS RF systems fully support the TIMED uplink and downlink parameters. The uplink system provides the full NASA standard uplink S-Band range (2025 to 2120 Mhz), and the downlink system provides the full NASA standard downlink S-band (2200 to 2300 Mhz). The 60-foot downlink antenna system tracks in either program or autotracking mode. The primary uplink antenna system operates in program or external input (slave) mode. It generally operates slaved to the 60-foot system. For slaved-tracking, the primary uplink antenna system may also be cross-connected to the 5-meter backup downlink antenna system.

The principal interface of the primary uplink and downlink systems interface to the MOC is via a Front-end Processor (FEP). This FEP is the interface for spacecraft commands and telemetry carried by the uplink and downlink. It is also the primary MOC interface for remote control and monitoring of the various equipments associated with the primary TIMED GS. (There are some monitor and control functions that can/do bypass the FEP.) The backup FEP is cross-connectable to the primary system for full redundancy.

The primary uplink system supports TIMED CCSDS commanding, ingesting telecommand transfer frames prepared and sent by the MOC, encapsulating these into CLTUs, and transmitting to the on-orbit spacecraft under the control of the MOC (command service). Both real-time and store-and forward commanding modes are supported, and COP-1 verification, based on pre-pass configuration input from the MOC. Some alteration of the pre-pass Command Service configuration during the pass by the MOC is possible.

The primary downlink system supports TIMED CCSDS telemetry, providing downlink demodulation, bit and frame synchronizing, decoding, and regeneration of spacecraft telemetry. The GS provides telemetry handling services, including separation of the telemetry into transfer frames by virtual channel (transfer frame service), and optionally, telemetry source packets separated by application identifier (APID) (source packet service). Real-time virtual channel data is supplied real-time to the MOC. All or selected (by virtual channel) transfer frames may be archived at reception, and retrieved during or post-pass by the MOC. Likewise, if packet service is being used, selected (by APID) source packets may be sent real-time to the MOC while all or selected others may be archived, for later during-pass or post-pass retrieval by the MOC. The choice of telemetry service options is established pre-pass as part of the pass configuration. Limited alteration of the telemetry service configuration during the pass is available.

The TIMED Primary Ground Station is fully remotely configurable from the MOC. Configuration refers to the setting of uplink and downlink electronic equipment mode and functional parameters, and the selection of command service and telemetry service. Most station equipment is configured by directives issued from the FEP based on a configuration database. Particular stored configurations are selected by directive from the MOC.

All command, telemetry, and monitor/control communications between the MOC and the primary GS are via dedicated 100 Mbps Ethernet fiber optic circuits using TCP/IP and UDP/IP protocols. Socket protocols are used to establish the various command, telemetry, and configuration and monitor channels.

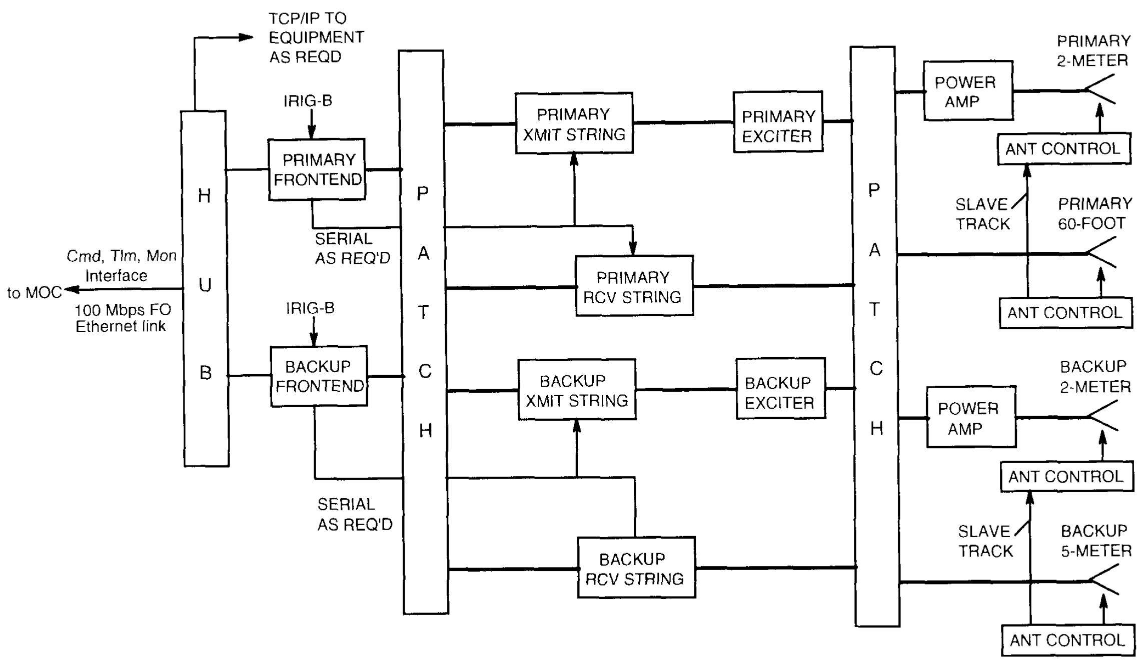

Figure 2-2
TIMED APL Primary and Backup Ground Station

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2.2.3.2.1.2 APL Backup Ground Station

The APL GS assets for the backup downlink consist of the existing 5-meter antenna system, some standard existing receiving equipment for the and program-dedicated electronic components for the reception and demodulation of the TIMED downlink. The backup uplink antenna system is a 2-meter antenna system identical to the primary uplink antenna system including the power amplifier and all associated transmit electronic components, including the modulators and exciter/driver for the uplink antenna system. The antenna systems are external to the control room and are located to provide maximum RF isolation between the several systems.

All RF and signal processing components electronics except for those that are mounted in or on the antenna system structures will be housed in the SCF control room. These components consist of redundant receivers, QPSK demodulators, and data drivers and receivers. These redundant receiver/demodulator strings are shared with the primary systems. Selection of antenna system to electronics connections are via patch panel.

The backup GS RF systems fully support the TIMED uplink and downlink parameters. The uplink system provides the full NASA standard uplink S-Band range (2025 to 2120 Mhz), and the downlink system provides the full NASA standard downlink S-band (2200 to 2300 Mhz). The 5-meter antenna system tracks in either program or autotracking mode. The backup uplink antenna system operates in program or external input (slave) mod. It generally operates slaved to the 5-meter system. For slaved tracking, the backup uplink antenna system may also be cross-connected to the 60-foot primary downlink antenna system.

The principal interface of the backup uplink and downlink systems to the MOC is via the backup Front-end Processor (FEP). This FEP is the interface for spacecraft commands and telemetry carried by the uplink and downlink. It is also the primary MOC interface for remote control and monitoring of the various equipments associated with the backup TIMED GS. (There are some monitor and control functions that can/do bypass the FEP.) The Backup FEP is cross-connectable to the primary system for full redundancy.

The uplink system supports TIMED CCSDS commanding, ingesting telecommand transfer frames prepared and sent by the MOC, encapsulating these into CLTUs, and transmitting to the on-orbit spacecraft under the control of the MOC (command service). Both real-time and store-and forward commanding modes are supported, and COP-1 verification, based on pre-pass configuration input from the MOC. Some alteration of the pre-pass command service configuration during the pass by the MOC is possible.

The backup downlink system supports TIMED CCSDS telemetry, providing downlink demodulation, bit and frame synchronizing, decoding, and regeneration of spacecraft telemetry. The ground station provides telemetry handling services, including separation of the telemetry into transfer frames by virtual channel (transfer frame service), and optionally, telemetry source packets separated by application identifier (APID) (source packet service). Real-time virtual channel data is supplied real-time to the MOC. All or selected (by virtual channel) transfer frames may be archived at reception, and retrieved during or post-pass by the MOC. Likewise, if packet service is being used, selected (by APID) source packets may be sent real-time to the MOC while all or selected others may be archived, for later during-pass or post-pass retrieval by the MOC. The choice of telemetry service options is established pre-pass as part of the pass configuration.

Limited alteration of the telemetry service configuration during the pass is available.

The TIMED backup GS is fully remotely configurable from the MOC. Configuration refers to the setting of uplink and downlink electronic equipment mode and functional parameters, and the selection of command service and telemetry service. Most station equipment is configured by directives issued from the FEP based on a configuration database. Particular stored configurations are selected by directive from the MOC. It is possible for the MOC to configure the backup systems for quick response during passes nominally supported by the primary GS since the primary and backup FEPs are addressed on different TCP sockets.

As with the primary GS, all command, telemetry, and monitor/control communications between the MOC and the backup GS are via dedicated 100 Mbps Ethernet fiber optic circuits using TCP/IP and UDP/IP protocols. Socket protocols are used to establish the various command, telemetry, and configuration and monitor channels.

2.2.3.2.2 LEO-T Ground Station

A Low Earth Orbiter Terminal (LEO-T), located in the vicinity of Fairbanks, Alaska, may be employed to support certain critical operations, provided this station is available. The relatively high latitude of this station provides far greater coverage of the spacecraft orbit then can be realized at APL. An additional LEO-T station is to be placed at the NASA facility at Wallops, Virginia. Following is a description of these assets.

The LEO-T GS assets consist of the NASA Wallops operated autonomous 5-meter antenna systems at Poker Flat, Alaska and Wallops, Virginia. These are fully autonomous stations that provide a maximum of five (5) uplink and downlink configurations which user programs can select pre-pass for the space-to-ground links to their respective spacecraft. Overall control of a LEO-T station is reserved for the LEO-T administrator. Except for a small set of specific items, the user has little or no real-time control of the selected configuration. The user is provided insight into the configuration and equipment status during a pass by way of periodic status messages.

The LEO-T RF system supports the TIMED uplink and downlink parameters. The uplink system provides the full NASA standard uplink S-

Band range (2025 to 2120 Mhz), and the downlink system provides the full NASA standard downlink S-band (2200 to 2300 Mhz). The LEO-T antenna system tracks solely in program track mode using NORAD or IIRV inputs from the user or elsewhere. A single antenna provides both uplink and downlink.

The principal interface of the LEO-T ground station to the TIMED MOC is via the LEO-T Front-end Processor (FEP). This FEP is the interface for spacecraft commands and telemetry carried by the uplink and downlink. It is also the primary MOC interface for station configuration and scheduling of the LEO-T ground station.

The LEO-T system supports TIMED CCSDS commanding, ingesting telecommand transfer frames prepared and sent by the MOC, encapsulating these into CLTUs, and transmitting to the on-orbit spacecraft. Both real-time and store-and forward commanding modes are supported, and COP-1 verification, based on pre-pass configuration input from the MOC is available for both store-and-forward and real-time modes. Mode selections are defined in the pre-pass configuration.

The LEO-T system supports TIMED CCSDS telemetry, providing downlink demodulation, bit and frame synchronizing, decoding, and regeneration of spacecraft telemetry. The ground station provides telemetry handling services, including separation of the telemetry into transfer frames by virtual channel (similar to the APL GS transfer frame service), and optionally, telemetry source packets separated by application identifier (APID) (similar to the GS source packet service). Real-time virtual channel data is supplied real-time to the MOC. All or selected (by virtual channel) transfer frames may be archived at reception, and retrieved during or post-pass by the MOC. Likewise, if packet service is being used, selected (by APID) source packets may be sent real-time to the MOC while all or selected others may be archived, for later during-pass or post-pass retrieval by the MOC. The choice of telemetry service options is established pre-pass as part of the pass configuration. Limited alteration of the telemetry service configuration during the pass is available.

The set of LEO-T configurations available to TIMED is established by arrangement with the LEO-T System Administrator. The details of this are TBD. Configuration refers to the setting of uplink and downlink electronic equipment mode and functional parameters, and the selection of various parameters for command and telemetry transfer between the MOC and the LEO-T ground station.

All command, telemetry, and monitor/control communications between the MOC and the LEO-T using TCP/IP and UDP/IP protocols. Socket protocols are used to establish the various command, telemetry, and configuration and monitor channels. Actual circuits and data throughput rates are TBD. NASCOM service and dedicated leased telephone lines are candidates.

2.2.3.2.3 Ground Station Scheduling

The APL SCF may provide dedicated support services (will depend on operational loading of this facility by other programs at the time of the TIMED mission). It is expected that the primary APL SCF GS will be dedicated to the TIMED mission and that facility may be assumed to be available to support any spacecraft overhead pass. The SCF backup GS may be a shared facility so its availability must be coordinated. In any event, the SCF Station Manager will be advised, by the MOT, of the support requirements by the TIMED program. In return, the Station Manager will verify availability of SCF support assets based on the support schedules provided.

The means by which a LEO-T station may be scheduled is TBD at this time. It is expected that a memorandum of agreement or equivalent will be drafted between the LEO-T provider and the TIMED program. This agreement will provide a scheduling timeline and protocol. There assuredly will be cases when a LEO-T station is required on a short timeline (in cases when the spacecraft is in trouble, for instance), so a means to quickly schedule support will be necessary. Mostly, however, these supports can be planned in advance (the early operations phase, for instance). The MOT must have the authority to schedule LEO-T supports, at any time, day or night.

2.2.3.2.4 Ground Station Support Summary

The table below illustrates typical spacecraft coverage by APL and LEO-T (Alaska) GSs. A minimum elevation of 5 degrees was used (that is, AOS and LOS are assumed at 5 degrees above the horizon). Further, the minimum usable pass interval (AOS to LOS) was specified to be 5 minutes. On most days, the APL station will 'see' four passes, two clusters each with two passes, with a cluster (center) separation of about 12 hours. This coverage offers a primary and a backup contact to be scheduled during each cluster. Normally, the cluster which occurs during the daytime will be scheduled. The night-time cluster will be used only for special operations such as contingency or early on-orbit operations. The LEO-T station provides extended coverage and provides capability for those operations requiring extensive real-time spacecraft operations, including the early on-orbit operations phase.

Station	Contacts/day		Data Bandwidth	
	Number	Total Time (min/day)	Uplink	Downlink
APL (Primary)	3 - 4	25 - 35	2 kbps	to 8 Mbps
APL (Backup)	3 - 4	25 - 35	2 kbps	to 4 Mbps
LEO-T (Alaska)	7 - 8	65 - 75	2 kbps	to 4 Mbps

2.2.3.3 Instrument Payload Operations Centers (POCs)

Each spacecraft on-board instrument will be supported by an instrument POC to be operated by a corresponding instrument operations team. These POCs will be located as follows:

GUVI	The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland
SABER	NASA, Langley Space Flight Center, Langley, Virginia
SEE	National Center for Atmospheric Research, University of Colorado Laboratory for Atmospheric and Space Physics, Boulder, Colorado

TIDI	Space Physics Research Laboratory, University of Michigan, Ann Arbor, Michigan

Each POC will be totally responsible for the operation of the respective instrument, including the planning of operations (generation of command loads), and the processing and analysis of instrument science and engineering data. Instrument command loads will be assembled as packets and transferred to the APL MOC prior to a scheduled spacecraft-to-ground contact. Included as part of the command packet transfer to the MOC will be certain identifying data to be used by the MOC to verify that an authorized source has generated and transferred the data and that the commands themselves as destined to the corresponding authorized instrument (i.e. that the POC/instrument pair are properly matched).In addition, the POC will attach data which specify both the earliest and latest times that the attached command packet may be uplinked to the instrument. The POC will be responsible for the verification and validation of instrument response based on the uplinked command load (the MOC will be responsible for the delivery of the content of the packet(s) to the addressed instrument but assumes no responsibility regarding the actual content -- the included data).

Similarly, the processing of science and engineering data pertaining to that particular instrument managed by that POC will be the responsibility of the POC. Telemetry data may be available both as real-time science and engineering data (actually, a short delay is expected as required to move the data from the spacecraft through the ground system). and as stored (playback) data. In both cases (real-time and playback) the data are retrieved from the MDC.

Real-time command and telemetry monitoring operations are expected to be available although such operations are considered only as contingency operations (including the possibility of initial early on-orbit operations).

The POCs will interface with the MOC and MDC via commercial communications circuits and will utilize standard TCP/IP protocols.

The POCs will be provided ground system planning information by the MOT. Included are the schedules for GS contacts, contact plans (if required), etc. All such information will be provided via the MDC.

2.2.3.4 Mission Data Center

The MDC is located at APL and is the central depository of all mission data, including spacecraft science and engineering telemetry and command files, mission planning data, ground system telemetry and status, external correlative measurement data , educational materials and level 1-4 data products. The MDC may be accessed, continuously (24 hours/day), via standard ethernet/Internet-type communication circuits. A simplified diagram of MDC functions and related data interfaces is depicted on Figure 2-3 below.

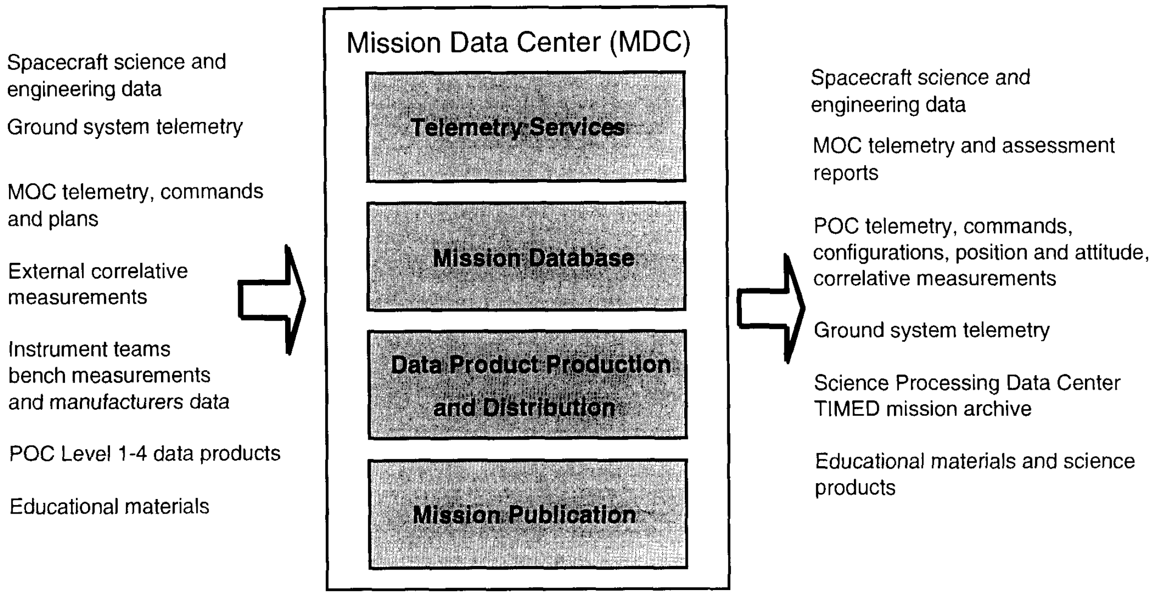

Figure 2-3
TIMED Mission Data Center

A more detailed diagram showing the data flow in and out of the MDC is illustrated in Figure 2-4. The MDC receives raw spacecraft data (SSR playback science and engineering) directly from a GS (or a simulator). In the figure both the APL SCF and LEO-T ground stations and a simulator (Sim) are depicted. In addition the MOC may transfer real-time telemetry and command data to the MDC. These enter the MDC at the TLM/CMD Ingest process. A tape backup is provided here. This process may serve real-time data (science and engineering telemetry) to users. Ingested data are cleaned and merged, then stored in the Telemetry/Command Archive database as packets. Both spacecraft science and engineering telemetry and command data as well as ground system (GSE) data are stored here. Some data are stored in a Mission Assessment database (DB). Included here are converted (to engineering units) spacecraft bus engineering telemetry and MOC summary tables (processed data produced by the MOC). The POCs supply a Science Catalog database, including a mission summary and a science product index for storage by the MDC. The data analysis facilities and correlative studies groups provide various data which comprise the Mission Data Archive database including correlative data, pointing and orbit data, timelines, processing logs, command history and documentation (this list is expected to grow). These are input and processed by the General DP (Data Processing) and Ingest function.

The databases maintain the data products required by the users. These products, as shown, include real-time science and engineering telemetry, playback science and engineering telemetry and command files, WWW access to all databases, files services to access archived data, database query services of the science catalog and the mission assessment database and archival and distribution services. The users will include the POCs, the MOC, spacecraft subsystem engineering teams, data analysis facilities and the external science community. Also, the Space Physics Data System (SPDS), a NASA data archive center is shown as a potential recipient of the MDC data.

On a daily basis, the MDC stores all command packets produced by the POCs and the MOC as well as all spacecraft science and engineering data and ground system engineering data. The real-time data acquired by the MOC is flowed to the MDC as it is received (the MOC also retains this data to support real-time operations and assessment). The POCs may access this real-time data from the MDC, with only a short time delay incurred. The SSR playback data which have been recovered by the GSs will be transferred to the MDC and will be distributed to both the MOC (spacecraft bus engineering data) and the POCs (instrument science and engineering data). Spacecraft telemetry data are reference (stored) by virtual channel number at the MDC and the data are accessed as 'streams' of data (that is the unprocessed telemetry are flowed in time order from the MDC to the user). The user must accept all data of the specified virtual channel and over the time interval specified. In the case of real-time data transfer, this 'spigot' is either open or closed. When open, all real-time data is flowed to the user as the data are ingested by the MDC.

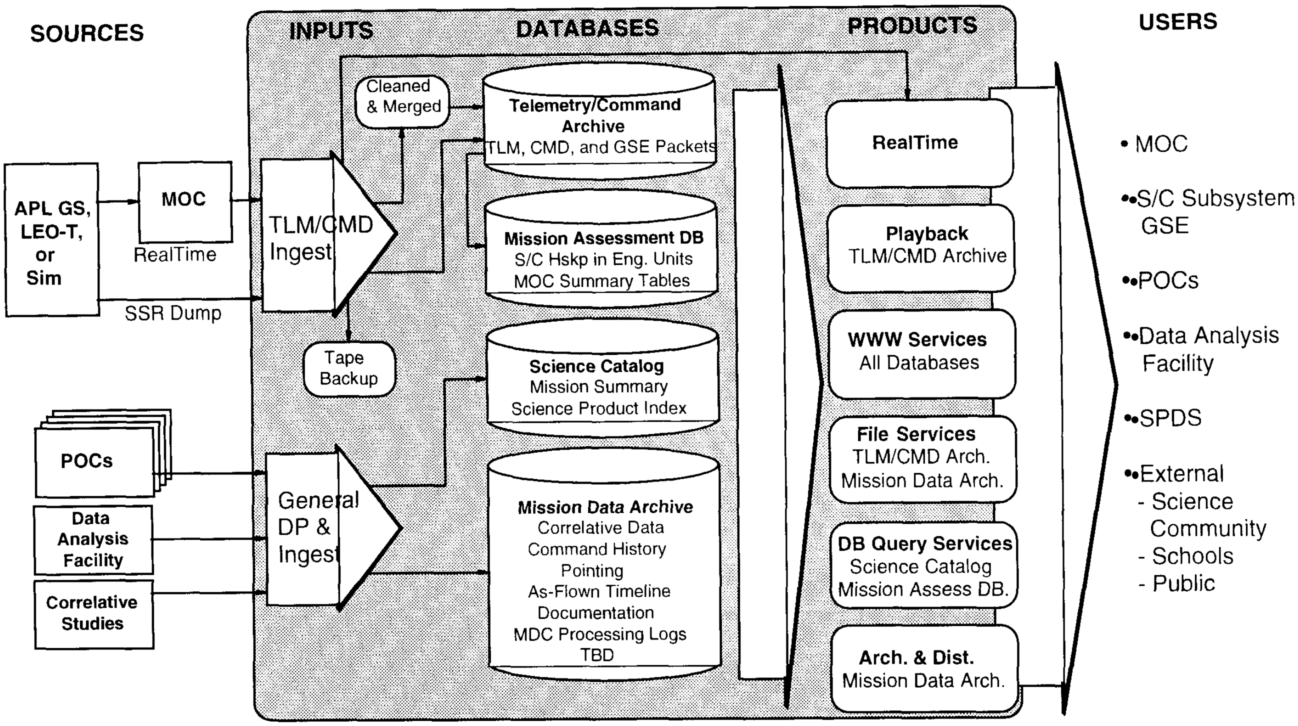

Figure 2-4
Mission Data Center and Interfaces

2.2.3.5 Spacecraft Test Bed

The Spacecraft Test Bed (STB) consists of the TIMED Operations Simulator (TOPS) and associated subsystems necessary to support the following activities:

- Validate prepared spacecraft operations command sequences prior to uplink to spacecraft.
- Support anomaly investigations by ‘recreating’ problems detected on the on-orbit spacecraft on the ground.
- Test new software modules prior to uplink to the spacecraft.
- Contact timing estimation
- MOC operational verification
- Spacecraft performance prediction.
- MOT training

The TOPS consists of a collection of spacecraft bus engineering model hardware (that is expected to perform like the flight equivalent components), associated flight software and stimulators and simulators (of the on-orbit spacecraft environment), all configured to 'act and operate' as a spacecraft-on-the-ground. Simulations must be run in real-time since the spacecraft simulator, itself, if comprised of actual hardware and software components (the simulator cannot be run in an accelerated fashion, say, to 'operate' the spacecraft over a full day on orbit in only a few minutes. Therefore the STB will only be used to validate newly developed operational scenarios which operate over short periods of time or any planned critical operations.

A diagram of the spacecraft simulator (TOPS) is illustrated in Figure 2-5 below. Shown here are the ground spacecraft components consisting of the EM (engineering model) IEM, the EM AIU and the EM FC (the G&C Flight Computer). Interfaced the these spacecraft components are the IEM GSE (ground support equipment necessary to interface between the MOC and the spacecraft IEM), the GPS GSE [principally, the GPS signal simulator use to drive the GNS (within the IEM)] and the TASTIE [the TIMED Attitude System Test and Integration Equipment (which simulates the environment of the G&C sensors)]. Also illustrated is a IRIG-B (Time Code) Reader/Generator for test time entry and the MOC (the controlling function).

The MOC will define test time and will initialize the spacecraft and ground support equipments via the IRIG-B Reader/Generator and will command the spacecraft to initialize its clock accordingly. The spacecraft ground support equipments will operate in 'unison' to provide a coordinated signal and sensor stimulation environment to the spacecraft components. The MOC will operate the spacecraft just (almost) as it does in flight by issuing commands and recovering engineering telemetry data.

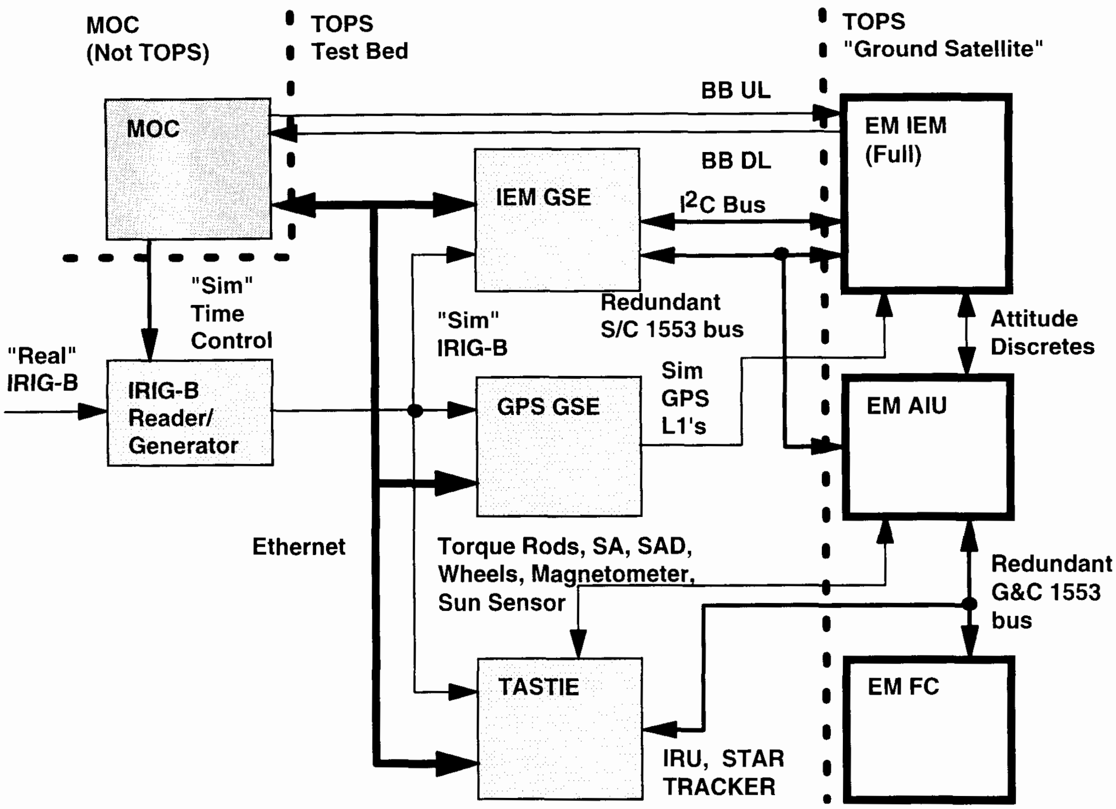

Figure 2-5
TIMED Operations Simulator

2.2.3.6 Flight Software Development Facilities

The upgrade and maintenance of all spacecraft on-board processor software is the responsibility of the respective software development teams. It is expected that development facilities utilized to support the development of this software will be maintained by these development teams. Any required software modifications or upgrades will be prepared at these facilities and software load modules, prepared for uplink to the spacecraft, will be provided to the MOT for final testing (on the STB) and uplink to the spacecraft.

2.2.3.7 Mission Operations Center Interfaces

The figure below illustrates data interfaces between the MOC and interconnected facilities. All interfaces have been previously discussed.

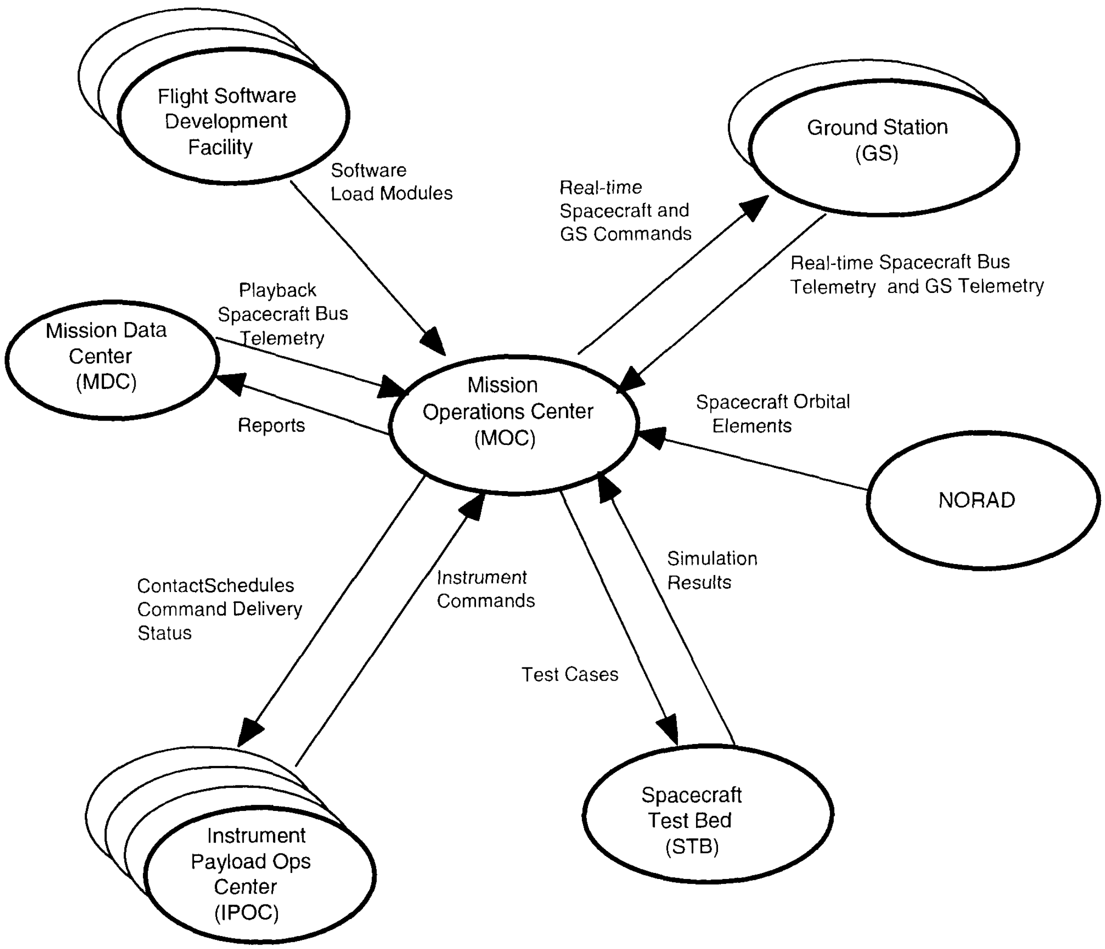

Figure 2-6
Mission Operations Center (MOC) Interfaces

2.2.3.8 Mission Operations Center Voice Communications

The MOT will communicate with the interconnected facilities via commercial voice circuits. It is expected that these will be standard dial-up services. Headsets will be required by the MOT and MOC-resident spacecraft operations support teams during contact operations. A means of communicating within the MOC (between workstations) will be required. It is advisable to accomplish this via communications circuits rather than an intercom or 'squawk-box' to assure two-way point-to-point communication among the resident team members.

Communication between the MOC and external facilities is expected to be minimal. No critical real-time coordinated operations are expected with external teams.

Voice circuits to the GSs will be required to support occasional calibration, maintenance or troubleshooting activities.

2.3 The Mission Operations Teams

The components of the total TIMED MOS will be managed and operated by respective operational teams located at the site of the system component(s).

2.3.1 Mission Operations Center

The MOC will be managed and operated by the APL MOT. The MOT will be comprised of two operational teams necessary to support a day shift operation, seven days per week, continuously.

2.3.2 Ground Stations

The ground stations are expected to operate autonomously, so will not require on-line operational support during normal operations. Operation of the ground stations will be controlled by the MOC through the utilization of command directives which will configure the ground station as necessary to support a spacecraft contact, will direct the tracking of the ground station antennae and will control the flow of command and telemetry data. Occasional maintenance will be required and will be performed by a resident (or on-call) maintenance team.

2.3.3 Instrument Payload Operations Centers

The instrument POCs will be managed and operated by respective instrument operations teams. The make-up and scheduling of these teams is the responsibility of the respective instrument teams.

2.3.4 Mission Data Center

The MDC will be managed by an APL data management team and the facility itself will operate autonomously; an on-site operational team will not be required. Software and hardware support teams will be available on-call.

2.3.5 Software Development Facilities

The respective flight processor development facilities will be staffed by the software development teams, managed by spacecraft subsystem development technical centers.

2.4 The APL Mission Operations Team

As stated previously, this document focuses on the operation of the spacecraft as performed by the APL MOT. Associated operations, facilities, interfaces, and teams are described to the extent that the relationships between these and the operations related to the MOT can be placed in perspective. The remainder of the document will primarily address spacecraft operations as performed by the APL MOT.

An operations concept can be described in terms of facilities, teams and procedures; all are required to operate a spacecraft.

2.4.1 Facility

The facilities necessary to support spacecraft operations, including the instrument POCs, MOC, GSs and MDC and the interfaces thereof, have been described previously, albeit briefly. Since the MOC is staffed and operated by the APL MOT, this facility will be discussed in additional detail.

2.4.1.1 The APL Mission Operations Center

Section 2.2.3.1 provides an overview of the MOC.

2.4.1.1.1 MOC Workstation Assignments

A total of 12 workstations will comprise the MOC (some of these workstations will be used by the spacecraft Integration and Test Team and will only be available after the launch of the spacecraft). It is anticipated that, for normal (nominal) operations, only two workstations will be required by the MOT to support spacecraft commanding operations and spacecraft health monitoring. The remaining workstations will be available for special operations including early on-orbit turn-on, checkout and evaluation operations and possible high profile or contingency operations. It is not clear at this time if the instrument teams will require a MOC presence and, if so, what workstation requirements these teams may have. It is probable, however, that these teams will support the early operations phase of the mission. A preliminary listing of workstation assignments is provided below.

Mission Operations Center (MOC) Workstation Assignments

Mission Operations Team (MOT)		
1	Contact Control	continuous use
2	Health Monitor	continuous use
Spacecraft Bus Engineering Team (SBET)		
3	Power subsystem	early operations and troubleshooting
4	Thermal subsystem	early operations and troubleshooting
5	C&DH subsystem	early operations and troubleshooting
6	G&C subsystem	early operations and troubleshooting
7	GNS subsystem	early operations and troubleshooting
8	RF subsystem	early operations and troubleshooting
9		
10		
11		
12		
Instrument Teams		
	GUVI	early operations
	SABER	early operations
	SEE	early operations
	TIDI	early operations

Only workstations 1 and 2 (MOT workstations) are capable of commanding the spacecraft and are located (networked) within a protective security firewall. All workstations have access to the spacecraft bus telemetry, both real-time and SSR playback data.

2.4.2 The Mission Operations Team (MOT)

The MOC is staffed and operated principally by the MOT. The SBET and instrument teams (when the Test POCs are installed) will provide staffing to support specific operations.

2.4.2.1 Responsibilities, Staffing and Schedules

The MOT is responsible for all spacecraft and commanding, the recovery of all spacecraft telemetry, the assessment of spacecraft bus performance and the control, monitor and performance assessment of all ground components necessary to support these functions. The MOT will be staffed by two teams each comprised of the following:

Team Leader
Spacecraft Specialists (2)
System Maintenance Engineer

The Team Leader is responsible for the following functions:

- Overall conduct of operations that occur during a particular shift
- Providing a central point of contact between the MOT and the external MOS
- Lead spacecraft and ground system troubleshooting activities
- Manage any adjustment to the operational schedules
- Occupy the position of a Spacecraft Specialist, when necessary

The Spacecraft Specialists are responsible for the following functions:

- Spacecraft bus operational planning and command generation
- Ground station scheduling and antennae control data generation
- On-line spacecraft control and readiness tests thereof
- Spacecraft bus and ground system performance assessment
- Operation of the Spacecraft Test Bed

The System Maintenance Engineer is responsible for the following:

- Normal maintenance, and calibration of the MOC components
- Evaluation of GS operations (diagnostic testing, etc.)
- MOC software upgrades

Specific work schedules have not been determined yet but will be arranged to 'cover' the daytime spacecraft overhead (of the GS) passes. These schedules will support the one contact per day operational concept dictated by the System Requirements Document. Occasional off-nominal hours scheduling is likely to occur during some special operations including the early on-orbit phase and during contingency activities. Such 'double-shift' operations can be sustained over brief periods with the MOT composition as described above.

2.4.2.1.1 The Extended Mission Operations Team

Although the MOT will be entirely capable of operating the spacecraft bus and will also be capable of detecting and responding to anomalies, the Spacecraft Bus Engineering Team (SBET) are considered an essential and integral adjunct. The SBET consists of the spacecraft bus subsystem development teams who, collectively, and along with the MOT, maintain the complete technical knowledge base regarding the operation and performance of the spacecraft bus. During the subsystem level testing and the follow-on spacecraft bus integration and test phase, the MOT, working side-by-side the SBET, will acquire the knowledge necessary to operate the spacecraft bus on-orbit. When operational anomalies are uncovered by the MOT during evaluation of the engineering telemetry, an immediate assessment will be made to ascertain the ability of the MOT, with the accrued knowledge and existing contingency procedures, to correct the anomalous operation within a reasonable time frame. If the anomaly is not clearly understood or if the recovery action is uncertain, the appropriate SBET (associated with the subsystem(s) under investigation) will be notified and will be expected to support the MOT during the recovery process.

To maintain the SBET in a continuous state of readiness, the MOT will provide periodic performance reports to the SBET (the form and content of these must be negotiated). In addition, the SBET will have access to all engineering telemetry stored at the MDC and should be able to access this from standard office personal computers.

MOC workstations will be available to the SBET when direct support of on-orbit operations is necessary. Certainly this will occur during the early on-orbit turn-on, evaluation and calibration phase of the mission and most probably during period of anomaly investigations.

2.4.2.2 Operations Planning

Operations planning will consist of those activities necessary to support a scheduled contact and will consist of:

- Scheduling of GS contacts
- Preparation of spacecraft bus commands
- Preparation of GS commands
- Validation and assimilation of instrument commands (as received from the instrument POCs)
- Generating a contact plan to include necessary MOC, GS and spacecraft bus commands to support:
    - Real-time engineering data assessment requirements
    - Command uplink requirements
    - Science and engineering data downlink requirements
    - Recovery of any on-board diagnostic data buffers such as:
        - Command history buffers
        - Autonomy rule execution buffers

The spacecraft will usually 'fly over' the APL GS four times each day, two clusters of passes spaced about 12 hours apart with each pass in the cluster separated by about 100 minutes (the orbital period of the spacecraft). Since the MOT will consist of only a day shift operation, the pass cluster that occurs during the day time hours will be selected and scheduled as potential contacts. Since there will usually be two passes in each cluster, the first pass will be scheduled as the primary contact and the second pass of the cluster will be available as the backup contact support. Only the primary contact will be required on a regular basis; the backup contact support will provide for recovery of any non-nominal primary contact operations should the MOT fail to complete all planned activities as defined in the contact plan. The spacecraft SSR storage is being managed so that sufficient storage will be available to sustain spacecraft science data collection over the period of an additional orbit in case the SSR is not played back to the ground during the scheduled daily contact.

Operations planning includes the scheduling of GS contacts, preparation of antenna pointing data and the preparation of spacecraft state vector contingency uploads (in case the spacecraft is not navigating from GPS). Spacecraft ephemeris necessary to produce these products normally is provided by the spacecraft itself and downlinked as part of engineering telemetry. In addition, NORAD 2-line element sets will be received from the USSPACECOM, probably daily. The NORAD data will not be as accurate as the spacecraft provided data, so will only be used as a contingency.

2.4.2.2.1 Definition of a Spacecraft Planning Day

The concept of a planning 'day' must be understood. That is, over what period of time in the life of the spacecraft are operations to be planned and executed? A daily spacecraft/ground system contact has been proposed. During this contact all commanding and data recovery are accomplished. Commands are uplinked for the next 24 hours of operations and the data recorded during the previous day on orbit are retrieved. Perhaps the concept of a 'spacecraft planning day' needs to be introduced. Such a 'day' might start at the same time each day so that the operations plans are produced over fixed time intervals. Alternately, time 'day' might be defined as the period between scheduled primary contacts. Of course, if this definition were used, the planning period would not really be the same every day, since primary contacts will not occur at the same time every day. The concept of TIMED spacecraft operations, however, where instruments are operated based on orbital events (time, orbital position, terminator crossings, etc.) a fixed-length planning day may be unnecessary. It will be assumed that the latter is the case, that the planning day or the operational day in the life of the spacecraft, will be defined as the period of time between the primary contacts of today and tomorrow.

2.4.2.2.2 Contact Scheduling

As specified in the System Requirements Document only a single contact per day will be required to support spacecraft ground operations.

Although it is possible to support routine operations with only a single contact, there are reasons why such a concept may not be prudent. In particular, 'waiting' for a full 10 minute contact, which will be required to service the spacecraft each day may preclude a backup contact of sufficient duration to be scheduled. It is always prudent to have a full backup contact available. For instance, the entire primary contact may be canceled because of a ground system failure. In that case, a backup contact will be required to provide the full daily support previously scheduled for the (canceled) primary contact. If all data is not recovered from the SSR, data will most likely be lost before the next contact (which will occur tomorrow) is available.

Given the case where the primary only contact is scheduled (for routine operations) and that contact either partially or entirely fails to recover the SSR data and reprogram the spacecraft for the next 24 hours of operation, and the backup contact is of insufficient length of complete the daily support requirements, it is possible to schedule a second shift to complete the support. This assumes that onboard SSR data will not be lost (that sufficient SSR data has been recovered during the daytime contacts to provide storage for the new data generated prior to the next pass cluster), or that the necessary commands have been loaded during the daytime contacts to program the instruments to collect the new data. But second shift operations are intended only to support planned special operations (such as processor loads, for instance) or potential spacecraft health damaging contingencies (emergencies). Primary ground contact partial or complete failures are to be expected and will occur occasionally, although probably rarely. Nonetheless, if there is a procedure that may be employed to circumvent a second MOT shift that ought to be pursued.

Such a procedure might be to always utilize the *first* pass in the daytime cluster provided it is of some minimal duration, as a scheduled contact. Since, quite often, this first pass will be of relatively low elevation, it usually will not, by itself, provide the necessary coverage to satisfy the daily spacecraft service requirement. The first pass, along with the second (and most always longer duration) contact will fulfill the daily support requirement.

2.4.2.2.3 Spacecraft Command Preparation

The MOT will determine the operational requirements of the spacecraft bus over the next 24 hours of operation after the scheduled primary and will prepare the necessary command message units (packets) to satisfy these requirements. Typically these commands will be event-drive, probably time-tagged commands required to operate the spacecraft in support of science data collection operations. Real-time commands, to be executed immediately upon receipt by the spacecraft bus, will also be produced. These possibly will control the SSR playback, will recover on-board diagnostic data buffers, perhaps the occasional spacecraft yaw adjustment, and so on. Together these command messages (stored and real-time) will be formatted into packets to be uplinked, under MOT control, during the next contact.

In additional to these spacecraft bus commands, instrument command packets will also be uplinked during the contact. These instrument command packets will be prepared, in advance by the instrument POCs and will arrive at the MOC no later than two hours prior to the scheduled primary contact (the POCs will receive contact schedules in advance so they will know when command packets must be provided to the MOC). In general, however, instrument command packets will arrive well in advance of this deadline. Many instrument teams intend to forward command packets only once a week with included packets designated for uplink to the on-board instruments each day of the week. Scheduling data, to accompany the command packets, will indicate when to actually uplink these packets. Until then, they will be stored at the MOC. The means by which these command packets are scheduled has been described previously (see section 1.6.1). Briefly, the command packets will be augmented with two time tags. One time tag will specify the earliest time that the command packet can be uplinked to the on-board instrument and the other will indicate the latest time that this can happen (the expiration time). Those command packets that have a start time that has been exceeded by the next contact (uplink) time will be queued for uplink at that contact. Each instrument will have its own set of storage buffers (pending and active queues) at the MOC.

The MOT has the responsibility of managing the command uplink for all spacecraft commands, to the bus and to the instruments. Accordingly, the MOT must have some knowledge of just what is contained in the instrument active queues. The actual instrument commands, themselves, is unimportant, but the quantity of data to be uplinked is. The scheduled contact will offer limited uplink capacity. Commands will be uplinked at a rate of 2 kbps for a duration which is dependent on the contact period itself. In general, a contact period will not exceed 10 minutes and the portion of a contact when commanding will be permitted is at least two minutes less than this. Commanding during this interval is not continuous, either. Rather, the command packets, packed into transfer frames, are uplinked and verified, transfer frame by transfer frame. The verification process can slow the uplink down some. Also, any retransmissions will add additional delays.

The MOT will examine the instrument active command queues in order to assess the transmission time necessary to uplink the content. MOC software will provide status of the content of the queue including expiration time (the queues will be sorted in order of increasing expiration time so that packets needed first are uplinked first). The status provided will also indicate estimated transmission time of all queued commands. Further, the time to transmit all the commands in the active queues of all instruments will be provided. In section 1.6.1 the concept of a 'grocery bar' was introduced. The purpose of this is to separate, in the active command queue, those packets which will be uploaded during the upcoming contact and those which are being purposely held back. The manipulation of this 'grocery bar' by the MOT will provide the necessary traffic control of instrument commands so that the uplink time of the instrument command packets to be transmitted, along with the queued and real-time spacecraft bus command packets, will all fit snugly into the contact duration allocated for commanding.

Manipulation of this 'grocery bar' is the only control of the queued instrument command packets, except flushing (removing all command packets from) the queue altogether. No editing control is available to the MOT. Flushing will only be permitted when authorized by the instrument team associated with that particular queue.

As stated previously, spacecraft bus commands will receive priority during uplink operations and these can interrupt instrument command uploads (but only at times so assure the entire instrument command frames have been transferred; that is these transfer frames will not be interrupted in the middle of transmission, the frame being currently uploaded will be permitted to complete). The MOT will actually have control over this process and can withhold spacecraft bus command uplink when necessary. In general, it is expected that the scheduled command uplink duration will not exceed the available uplink time during the contact. On occasion, however, it may be necessary to utilize the backup contact to complete the upload of the entire command packet ensemble. The contract plan, prepared by the MOT, will specify precisely what command packets, instrument and spacecraft bus, real-time and stored, are to be uplinked during a given contact period.

2.4.2.2.4 Types of Contacts

Contact planning will satisfy the requirements and produce contact plans for the following contact types:

Health monitor only (type a) when only the downlinked spacecraft bus engineering data are recovered, in real-time, and an evaluation of spacecraft health is performed.

Health monitor and SSR playback (type b) when, in addition to health monitoring, the stored science and engineering data are recovered from the SSR.

Health monitor and command uplink (type c) when, in addition to health monitoring, spacecraft commands are uploaded (stored and/or real-time)

Health monitor command uplink and SSR playback (type d) when, in addition to health monitoring and spacecraft command uploads, the stored science and engineering data are recovered from the SSR.

Normally, when only a single support contact per day is scheduled, the latter contact (type d) will be required. If the SSR playback is programmed, on the spacecraft, to occur autonomously then no command uplink at all may be necessary (type b). If the daily required command upload and SSR recovery have been successfully performed, other available contacts may be scheduled for the purpose of simply obtaining additional real-time performance data (type a). In cases where spacecraft anomalous behavior has been detected, contingency command uploads may be required (type c). It may be necessary to upload processor software or data files. Also real-time command uplinks may be required to maintain spacecraft subsystems such as watchdog timer resets, (type c).

2.4.2.3 Operations Control

Operations control will consist of those activities immediately prior to and following a scheduled contact and will include:

2.4.2.3.1 Pre-pass Readiness Testing and Contact Preparations

A pre-pass test of the ground facilities scheduled to be utilized during the contact and including:

- GS
- MOC (elements required to support real-time contact)
- MDC (if any MDC real-time operations are required)
- POC(s) (if real-time POC operations are scheduled)
- Voice circuits
- Data circuits

Testing will include:

- GS antenna control tests
- Data flow tests
    - MOC to/from GS
    - MOC to/from POC(s) (as required)
    - MOC to/from MDC (as required)
- Diagnostic tests (as required)

This testing will assure that the necessary elements of the ground system are functional and properly interconnected as required to support the prepared contact plan. The MOC and GS will be configured, under MOC control, as defined in configuration files. The POCs, and MDC, if required, will be configured by their respective operating staff.

At the conclusion of pre-pass testing, any final configuration adjustments necessary to support the upcoming contact will be made by the respective operating teams. At this time MOC workstation data display files will be loaded to prepare screen displays (screen display formats will often be dictated by the contact plan). In addition, the contingency command file will be accessed and a menu prepared for rapid display on the command workstation in case contingency command uplink is required.

2.4.2.3.2 Contact Operations

Contact operations follow pre-pass testing and generally encompass the period between the acquisition of the spacecraft telemetry signals as the spacecraft initially appears at the horizon of the GS to the final loss of these signals when the spacecraft falls below the horizon of the GS. The spacecraft will be programmed to autonomously control the operation of the transmitter so as to begin the flow of downlink real-time telemetry when the spacecraft enters the acquisition zone of the GS and will then be turned off when the spacecraft departs this zone. During the actual contact, the MOT will control spacecraft bus operations from the MOC. These operations will encompass:

- Initial acquisition and monitoring of the real-time engineering telemetry to assess the state of health of the spacecraft bus.

- Assuming a healthy spacecraft bus, initiate the downlink of the stored (in the SSR) science and engineering data (to be routed to the MDC) while continuously monitoring the real-time engineering data.

- Initiate and monitor the delivery process of any queued command messages (packets) to be uplinked.

Any anomalies detected will require an immediate assessment of spacecraft health and performance impact by the MOT and may possibly invoke contingency procedures. In any case, the on-going contact operation (and the plan thereof) may require revision (possibly cancellation).

The playback of SSR data, when this occurs manually (that is, under MOT direct control) will be initiated by MOT generated playback control commands, to be issued in real-time. These commands will specify which portion of an SSR to be recovered (played back). In general, if the contact is of sufficient duration, the entire SSR will be played back. But is will also be possible to recover only part of the stored contents. The selection of the data to be recovered, all or a portion thereof, will be determined by the MOT, and generally will be determined by both the need and the available downlink time within the contact. During evaluation and troubleshooting operations it may be desirable to only recover diagnostic buffers, for instance. Or, when the total SSR playback is spread over multiple contacts, the MOT may specify the range of SSR storage locations to be recovered during each contact. The playback control commands will be produced during the daily contact planning period and will be incorporated into the contact plan.

Prior to the end of the contact, it will be necessary to make an assessment of the quality and quantity of the SSR playback data (if a SSR playback occurred during the contact) so that a decision can be made regarding the release of SSR storage space on the spacecraft. It is assumed that the spacecraft will retain stored data, even after downlink, until the MOT 'releases' this storage, allowing new data to be recorded to replace the old. This decision will usually have to be made prior to the completion of the contact since the next opportunity may not come until the next day. But, the retrieval of the actual playback data will not happen until after the contact is over. Status of the quantity of data received and stored at the GS should be available from GS status. Further, since real-time data packets will be intermixed with the playback data, the quality of the real-time data ought to be a measure of the quality of the playback data. So, given this information, a sensible decision can be regarding the release of spacecraft SSR data storage. Typically, a real-time command will be issued by the MOT releasing this storage are so as to enable the recording of new data.

When both IEMs are powered, and hence both SSRs may be utilized to store data on-board the spacecraft, the urgency to release SSR storage diminishes since the alternate SSR may be programmed to store new data once the primary SSR is filled to capacity. The recently downlinked SSR playback data will have been processed and the quality of data assessed prior to tomorrow's scheduled contact. The decision to release that SSR storage or to playback that data again, can be deferred until tomorrow's contact.

Spacecraft commanding may only be initiated at the MOT command workstation (two MOC workstations, protected by the security firewall, will be designated as command workstations, one of these will be activated to support commanding during the contact, the other will be ready as a 'hot' backup in case the active workstation fails). All MOC workstations may display processed telemetry data from both the spacecraft and the ground system. In general, the active command workstation will be dedicated to only commanding and the verification thereof, and to assure that the contact plan is properly executed. The remaining workstations, as staffed, will monitor spacecraft and ground system performance via processed telemetry.

2.4.2.3.3 Post-contact Operations

The downlinked science and engineering data that has been stored at the GS during the real-time contact must be recovered and stored at the MDC. The MOT will initiate the necessary GS directives to accomplish this. Included will be:

- Assess the operational status of the GS.

- Initiate the recovery of stored spacecraft science and engineering data and monitor the transfer of this data.

- Initiate the recovery of any stored GS engineering telemetry.

- Evaluate the quality of recovered data and if acceptable, release GS buffer storage. Otherwise attempt data recovery again.

2.4.2.4 Performance Assessment

An assessment of the performance of the spacecraft bus over the previous 24 hour period will be performed by the MOT after the spacecraft playback (SSR-stored) data are recovered by the MDC. The MOT will access the entire file of spacecraft bus engineering telemetry, ingest this into the MOC and using a software toolkit, will scan, process and evaluate the entire data set as follows:

2.4.2.4.1 Quick-look Performance Assessment

The real-time and playback spacecraft bus engineering telemetry will be evaluated (both during the contact in the case of real-time data and after recovery of the playback data) for anomalies and other non-nominal behavior in a cursory fashion. Such an evaluation will quickly scan the data in order to identify problems that may need immediate attention by the MOT. A quick-look scan of this sort needs to be completed in time so as to be able to utilize the scheduled back-up contact to perform any contingency operations. This backup contact will occur about 100 minutes after the previous contact, so the quick-look must occur well within this 100 minute window. A goal would be to have completed the cursory review of the data within a hour of the completion of the primary contact. This would allow nearly 40 minutes to prepare a contingency plan to execute during the backup contact.

The playback data quality, itself, may be evaluated based on the quality of the spacecraft bus engineering data processed and analyzed; the quality of this portion of the entire playback data set may be equated to the quality of the entire set. Based on this assessment, it may be possible to playback this, or at least some of this playback data set during the backup contact, if it is determined that the originally recovered data are not of good quality. Or if a portion of the data are simply missing, that portion only may be played back during the backup contact. Even if the SSR had been released to store new data, it is assumed that the old data will remain until overwritten, so an orbit later (when the backup contact occurs) only a small part of the originally stored data will be overwritten.

2.4.2.4.2 Comprehensive Performance Assessment

If no anomalous behavior is uncovered during the quick-look evaluation of the recovered data, the performance assessment function can continue toward a full process. Included herein:

Verify the operational 'as-flown' timeline by analysis of the on-board command history buffers recovery and a comparison of this with the planned timeline.

- Identify any out-of-limits (based on pre-stored parameters) and assess performance impact. Initiate investigative actions when necessary.

- Plot and trend selected measurands.

- Prepare reports for SBET and other designated recipients.

- Transfer assessment reports and related data to the MDC for general query.

- Determine impact of any anomalous behavior on future operations and adjust these activities accordingly.

The MOT performance assessment function will be augmented by in-depth analysis of subsystem performance as performed by the SBET. The SBET, in addition to received performance reports as prepared by the MOT, will have direct access to the engineering telemetry database stored at the

MDC, so any data, past or present, may be accessed and processed to the satisfaction of the responsible engineer. Also, some subsystems, the G&C and GNS for instance, will maintain separate facilities to support performance assessment and other engineering functions. These data processing and analysis centers will receive data from the MDC. In the case of both the G&C and GNS, the data processed and analyzed will include the diagnostic and raw measurement data acquired on-board and downlinked to the ground system.

2.4.2.5 Daily MOT Tasks Timeline

The following represents a proposed daily timeline of spacecraft operations as conducted by the MOT (all times are referenced to the beginning (AOS) of the scheduled primary contact) and assumes a 10 minute contact period.

Start Time	Duration	Activity
-135 minutes	120 minutes	Contact planning
-15 minutes	15 minutes	Pre-contact tests
0 minutes	10 minutes	Contact period
+10 minutes	20 minutes	Playback data retrieval
+30 minutes	30 minutes	Cursory telemetry view
+60 minutes	120 minutes	Performance assessment

The cursory telemetry view is a 'quick-look' of the retrieved spacecraft bus engineering data. If any problems are encountered that may require priority attention, the back-up contact will be utilized to provide this attention.

The 10 minute contact period, itself, may be further segmented as follows:

Start Time	Duration	Activity
0 minutes	10 minutes	State of health assessment
1 minute	8 minutes	SSR playback
1 minute	<8 minutes	Uplink spacecraft commands

It will require about 8 minutes to recover a full 2 Gb SSR playback. The command transmission period depends on the quantity of the uplink data. The command transmission may extend throughout the contact period provided that sufficient time has been allocated for command transmission status (has the command data been successfully delivered?). Here, an allowance on one minute has been included for final verification (no commands are issued during the final minute of the contact).

2.5 Special Operations

Described herein are spacecraft and ground system operations which will occur during the life of the on-orbit mission but which are either one-time events or events and activities which occasionally throughout the life of the mission. They represent departures from those previously described operations.

2.5.1 Early On-orbit Turn-on, Checkout and Evaluation

Early operations encompasses from pre-launch through on-orbit checkout and evaluation. Pre-launch operations will include software loads which update time values for time-tagged commands to be executed during launch vehicle ascent. Such commands are necessary for TIMED to spin up reaction wheels and turn on gyros prior to separation from the vehicle, allowing the spacecraft to stabilize more quickly from possible tip-off rates. In addition, the spacecraft will be programmed with a PROM-based separation sequence that will be triggered by activation of a separation switch upon physical separation of the spacecraft from the launch vehicle. This command sequence will control, in time order, critical spacecraft bus operations necessary to deploy stowed components and to initiate operations to establish an initial safe orientation. This sequence may include (but not necessarily limited to):

- Deployment of solar panels
- Rotation/orientation of solar panels
- Attitude stabilization
- Initiation of safe-hold mode attitude capture (Sun safe mode)
- Turning on the flight computer and star camera(s)
- Orientation to a Nadir pointing sun exposure mode

- Initiation of first contact, downlink at expected station position

This separation sequence triggers a command sequence pre-stored in the C&DH subsystem. This sequence, usually referred to as the launch command load, will sustain spacecraft operations until the first scheduled GS contact occurs. The MOT, upon evaluation of the performance of the spacecraft bus at that time, may choose to alter the planned operational sequence or may elect to continue with the stored launch load sequence until the next scheduled contact. The MOT may elect to store additional commands to extend past (in time) the pre-stored launch sequence.

The early operations phase extends from launch vehicle separation to the declaration, by the operations teams that the spacecraft, in its entirely, is capable of supporting mission objectives, or the decision to begin the operational phase with an impaired spacecraft (the problems cannot be resolved by hardware or software configuration adjustments, perhaps ground-based procedures may be invoked to compensate for on-board anomalies).

In general, the sequence of events that will occur during this phase includes:

- Spacecraft bus turn-on, checkout and evaluation, including
    - Power subsystem
    - G&C subsystem
    - C&DH subsystem
    - GPS subsystem
    - Thermal design validation

- Spacecraft instruments turn-on, checkout, evaluation and calibration, including:
    - GUVI
    - SABER
    - SEE
    - TIDI

During the early operations phase, especially during the very early (perhaps first week) of operations, the TIMED MOS and associated teams will depart from the nominal steady-state staffing plans in order to provide a more or less continuous 24-hour/day support effort utilizing all available APL GS contacts and augmented by selected LEO-T contacts. This very early on-orbit phase will most likely be supported by combined MOT, SBET and instrument teams all located at the APL MOC. Any ground support components, along with the field operations teams deployed at the launch site, may also be utilized (provided these can provide value-added).

The spacecraft coverage as viewed by the APL and LEO-T GSs over the first 24 hours on-orbit after launch vehicle separation is provided in Appendix A-2.

2.5.2 Flight Processor Software Uploads

Replacement of flight processor software is to be expected since all on-board processors are designed to accommodate software reloads. Prior to any actual replacement of flight processor software, the configuration changes must be proposed to and endorsed by the Configuration Control Board (CCB) and must be properly tested on the ground prior to authorized (again, by the CCB) upload to the spacecraft. Any such replacement software will, when possible, be loaded into a redundant (backup) processor which is not operational (on-line) at the time.

Software development teams will prepare software load modules for upload in an acceptable format (to be negotiated) and will provide these to the MOT. The MOT will ascertain the GS support coverage necessary to effect the upload (and validation/verification), then schedule GS support contacts. The load module to be uploaded will be segmented as necessary to fit the GS contact schedule. The priority of the software upload must be considered along with all other proposed or scheduled operations and the actual software upload schedule may be impacted by necessary and higher priority activities. A contact plan will be generated for each upload segment and these contacts may (and probably will) include some operations necessary to sustain science operations (assuming the spacecraft can functionally operate in a science collection mode at this time).

As each segment of flight software is uploaded (consider here that a segment is uploaded during a GS contact), it then must be validated and verified to assure a successful load into the target processor memory. In general, the delivery of this software is handled no differently than any other command packet upload in that the end-to-end data system will guarantee delivery or will report otherwise. The actual software upload content (the contents of the uploaded packets) can only be completely verified by a read-back of the loaded memory addresses to the ground and a verification of conformance to the planned upload file.

Upon successful completion of the entire upload, the new software must be tested, and this testing must be verified utilizing procedures developed by the software development team and the MOT. Once the new software is declared operational (again as endorsed and approved by the CCB) the processor containing this software may be switched into operation. The redundant (backup) processor software then may be similarly replaced.

The replacement of flight software is a very deliberate process requiring a joint and cooperative effort between the software development facilities and associated teams and the MOT.

2.5.3 Spacecraft Bus and Ground System Contingency Operations

Non-nominal performance of both the spacecraft and the ground support system is to be expected. While problems and anomalies will likely happen infrequently, provisions must be formulated to account for and adjust to these occurrences. The spacecraft will be designed to operate autonomously, to ‘correct’, when it possibly can, self-detected problems or deviations from a normal timeline. But such self-control is limited to those situations where built-in recovery can be expressed in straightforward simple logical expressions and those of which recovery procedures are not extensive and not overly time consuming.

Anomalous behavior which can be pre-supposed and considered as likely to occur, but which cannot be dealt with by on-board autonomy, must be resolved and managed by the MOT utilizing MOC-based processes and procedures. For those conditions which are so identified, recovery command sequences will be prepared and stored for use by the MOT as the need presents itself. Out-of ordinary behavior of the spacecraft system will be identified by the MOT through observation of displayed telemetry and telemetry monitoring tools (limit checking processes, for instance). Once such an anomaly is identified, documented procedures will be referenced to determine the course of action to follow, and the existing stored contingency command directory will be accessed. Normally the course of action will specify particular recovery command sequences, stored within this directory, to execute.

In addition to spacecraft problems and anomalies, the ground system must be examined in the same manner and, where necessary, documented procedures to identity and recovery from these situations must be prepared.

The establishment of 'causes and cures', and the documentation thereof, will be a task performed by the MOT during the development phase.

2.5.4 Attitude Maneuvers

In its operational mode, the spacecraft will maintain a continuous nadir pointing (+z axis pointed toward the center of the earth) orientation. The instrument suite demands a control accuracy to within one degree (3 sigma) about each axis, and control knowledge to within 0.03 degrees about each axis. This attitude will be controlled autonomously on-board by the G&C subsystem and utilizing spacecraft on-orbit position and time as provided by the GNS subsystem (via the C&DH subsystem). Attitude performance derived from on-board data continuously stored in the SSR will be closely monitored by the MOT and the SBET.

The only planned departure from this steady-state attitude will be the occasional yaw maneuvers necessary to maintain a favorable sun-to-spacecraft orientation. This yaw maneuver, a 180 degree rotation about the z axis, will be scheduled at approximately 60 day intervals and will be performed by the MOT-controlled special operation (a spacecraft maintenance operation). During the execution of the maneuver on-board the spacecraft, on-board subsystems and instruments will be notified by a status message. This on-orbit attitude maneuver is expected to require less than 10 minutes and will generally be scheduled at a time so as to minimize interruption of instrument data collection.

2.5.5 Spacecraft Bus Initialization

At times, following a safe-hold mode transition, for instance, it may be necessary to provide initialization aiding data to the spacecraft bus to improve the recovery timeline to the operational mode. Initialization, here, encompasses those operations necessary to perform an initial navigation fix by the GNS subsystem. Though is generally true that the GNS subsystem can initialize autonomously, the time period expended to accomplish this may exceed 30 minutes. By providing certain acquisition aiding data, this timeline may be reduced to about two minutes. The aiding data include the following:

- Estimate of GPS time
- Estimate of the TIMED spacecraft orbit
- GPS constellation almanac data

2.5.6 Unattended MOC Operations Demonstrations

In general, it is a goal of future space program ground operations to conduct spacecraft-ground operations autonomously, that is, without an operations team 'at the helm'. So-called 'lights-out' operations will certainly save on operating expenses if they can be reliably accomplished without presenting an inordinate risk factor.

On the TIMED mission, such unattended operations will be attempted, if approved by the program office. Demonstrations of 'operator-less' MOC spacecraft support contacts will be prepared and attempted. Initially, the emphasis will be on very simple risk-free activities. Such a beginning might be a scenario where the spacecraft autonomously downlinks real-time engineering data (which is always stored on-board the spacecraft SSR, so there is no danger of actually losing any data) and this data are recovered by the GS and passed onto the MOC in real-time. The unattended MOC then simply stores the data and awaits the daily arrival of the MOT for a review of this data. Initially, this operation (and all such autonomous MOC operations) will be accomplished with a MOT standing-by in case something goes wrong.

As time goes on, and depending on the success of previous autonomous MOC operations, more complex operational processes may be attempted. Included here might be a autonomous real-time data recovery and process (monitor the performance by limit-checking, etc.) and to then, if necessary notify the MOT (again autonomously) of any abnormal data. The MOT then could interrogate the stored data, possibly remotely, and be mentally prepared to address the problem 'in the morning'. Another scenario might recover SSR playback data during the nighttime passes. It should be emphasized that such 'lights-out' demonstrations are just that --. they are only *demonstrations*, and are not considered as a requirement of any kind. And again, they will only be attempted after careful risk mitigation, and with the proper approval.

2.6 Quality Assurance and Control

2.6.1 Configuration Management

Management of the configuration of the ground system hardware and software, the MOT operating procedures, and the spacecraft software configuration will conform to the directives imposed by the Program Office and by the MOS development team and the associated oversight engineering staff.

2.6.1.1 Change Control Process

The change control process will be defined and documented by the MOS software development oversight staff and will be managed by the CCB, appointed by the Program Office..

2.6.1.2 Configuration Controlled Items

The following are to be placed under configuration control and managed by the CCB:

- MOC hardware and software
- MDC hardware and software
- GS hardware and software
- MOC operating procedures
- Spacecraft bus command scripts, including
    - Contingency procedures and scripts
    - Autonomy rules and related recovery procedures and scripts

2.7 Mission Operations Team (MOT) Training

Staffing of the MOT will begin early during the development phase of the program. MOT Spacecraft Specialists will be assigned functional responsibilities necessary to provide both an 'education' and essential and meaningful tasks in support of the SBET as well as the Integration and Test Team. These MOT Spacecraft Specialists will support the spacecraft subsystem engineering teams during the testing of these subsystems prior to delivery to the Integration and Test Team. Components (hardware and software) of the actual MOC, called a Mini-MOC, will be employed to support subsystem testing, development of databases, display formats, data processing and command scripts and so on, produced (by the MOT Spacecraft Specialists) to support subsystem tests may all be brought forward to the spacecraft system level support effort.

The MOT will develop procedures and will support the conduct of acceptance testing of the MOC hardware/software system.

During the integration and test phase, the MOT Spacecraft Specialists will define and produce the necessary system-level tests to support the conduct of mission simulation tests (to test the spacecraft in the same manner as it will eventually be operated on orbit). During the conduct of tests, the MOT Spacecraft Specialists will provide direct support, as members of the Integration and Test Team, to the Test Conductor. The function of the MOT Spacecraft Specialist here to provide an assessment of the performance of the spacecraft system under test. During certain times within the Integration and Test phase, MOT Spacecraft Specialists will assume the role of the Test Conductor. (Three Integration and Test Teams will be assembled to support around-the-clock test operations. Each team will be staffed by a Test Conductor and a Spacecraft Specialist in addition to supporting test personnel. Of the six Test Conductor/Spacecraft Specialist positions, five will be filled by MOT Spacecraft Specialists).

Of particular significance are the spacecraft on-orbit simulations, where the spacecraft, on the ground, is operated as if it were on-orbit. These tests will be conducted by the MOT just as they will during the actual on-orbit phase of the mission. All external operations supporting organizations and facilities (POCs, MDC, etc.) will support these tests. These will become the rehearsals of the MOT and the entire MOS..

2.8 Mission Operations Working Groups

As the development phase progresses, and at appropriate times, working groups will be organized by the mission operations function for the purposes of joint-preparation of essential procedures and related documentation that will establish the basis of the spacecraft and ground systems operating procedures as required by the MOT. It is the intent of the MOT to actually prepare the necessary documentation, the content however will require a collaborative effort with the spacecraft and ground system development teams. Working groups will be formed to address the following:

2.8.1 Early Operations Plan

This working group, comprised of the MOT and SBET will establish the operational procedures necessary to conduct spacecraft operations between launch vehicle separation and until the spacecraft is declared operational.

2.8.2 Spacecraft Operating Rules and Constraints

This working group, comprised of the MOT and SBET, will identify rules and constraints to be imposed upon the spacecraft users and the MOT.

2.8.3 Spacecraft Autonomy Rules and Procedures

This working group, comprised of the MOT and SBET, will specify autonomy rules and the on-board command scripts to be employed upon rule violations.

2.8.4 Spacecraft and Ground System Contingency Plans and Procedures

This working group, comprised of the MOT, SBET and ground system development teams, will identify potential contingency situations as MOT managed recovery procedures.

2.8.5 Mission Operations System Processes and Interfaces

This working group, comprised of representatives of all elements of the total TIMED on-orbit operations support system (MOC, GSs, MDC, instrument POCs) will address issues related to the overall ground system, hardware, software, teams, and procedures.

APPENDICES

A-1 Abbreviations and Acronyms

1553	MIL-STD 1553-B Bus
AIU	Attitude Interface Unit
Amp	Amplifier
Ant	Antenna
AOS	Acquisition of Signal
APID	Application Packet Identifier
APL	(The Johns Hopkins University) Applied Physics Laboratory
BB	Baseband
C&DH	Command and Data Handling
CCSDS	Consultative Committee for Space Data Systems
CCB	Configuration Control Board
CCU	Critical Command Unit
CLTU	Command Link Transmission Unit
cm	Centimeter (meter x 10E-2)
COP-1	Command Operation Procedure
CF	Command Frame
CM	Command Message
Cmd	Command
CP	Command Packet
DB	Database
DL	Downlink
DP	Data Processing
EM	Engineering Model
FEP	Front-end Processor
FO	Fiber Optics
FTP	File Transfer Protocol
G&C	Guidance and Control
Gbit	Giga-bit (bits x 10E9)
Gbps	Giga-bits/second (bits/second x 10E9)
GNS	GPS Navigation System
GPS	Global Positioning System
GS	Ground Station
GSE	Ground Support Equipment
GUVI	Global Ultraviolet Imager
HLVS	Hardware Low Voltage Sensing (Switch)

I&T	Integration and Test
I2C	Inter-IC Control (Bus)
IEM	Integrated Electronics Module
IIRV	Improved Interrange Vector
IRIG-B	Interrange Instrumentation Group (Code Standard)-B
IRU	Inertial Reference Unit
JHU/APL	The Johns Hopkins University Applied Physics Laboratory
kbps	Kilo-bits/second (bits/second x 10E3)
km	Kilo-meter (meters x 10E3)
L1	GPS Primary Navigation Signal
LEO-T	Low Earth Orbiter Terminal
LOS	Loss of Signal
Mbit	Mega-bit (bits x 10E6)
Mbps	Mega-bits/second
MDC	Mission Data Center
Mhz	Mega-Hertz (Hertz x 10E6)
Min	Minutes
MOC	Mission Operations Center
MOS	Mission Operations System
MOT	Mission Operations Team
ms	Milli-seconds (seconds x 10E-3)
LOS	Loss of Signal
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NORAD	North American Air Defense Command
P/B	Playback
PCI	Peripheral Component Interconnect (bus)
POC	(Instrument) Payload Operations Center
PROM	Programmable Read-only Memory
QPSK	Quadrature Phase Shift Keying
R/T	Real-time
Rcv	Receive
RF	Radio Frequency
RISC	Reduced Instruction Set Computer
RIU	Remote Interface Unit
SA	Solar Array
SAA	South Atlantic Anomaly
SABER	Sounding of the Atmosphere using Broadband Emission Radiometry
SAD	Solar Array Drive

SBET	Spacecraft Bus Engineering Team
SCF	(APL) Satellite Control Facility
SCF	Supplemented Command Frame
sec	Second
SEE	Solar EUV Experiment
Sim	Simulate/Simulation
SLVS	Software Low Voltage Sensing (Switch)
SPDS	Space Physics Data Center
SSR	Solid State Recorder
STF	Supplemented Telemetry Frame
STB	Spacecraft Test Bed
STP	Supplemented Telemetry Packet
SWG	Science Working Group
TBD	To Be Determined
TBS	To Be Supplied
TCP/IP	Transfer Control Protocol/Internet Protocol
TIDI	TIMED Doppler Interferometer
TIMED	Thermionic, Ionosphere, Mesosphere, Energetics and Dynamics (Spacecraft)
TLM	Telemetry
TOPS	TIMED Operations Simulator
TP	(CCSDS) Telemetry Packet
TTFF	Time to First Fix
UDP/IP	User Datagram Protocol/Internet Protocol
UL	Uplink
us	Microsecond (second x 10E-6)
USSPACECOM	United States Space Command
UT	Universal Time
UTC	Universal Time Coordinated
VC	Virtual Channel
WWW	World-wide Web
XMIT	Transmit

A-2 Ground Station Coverage

Ground traces over a the initial 24 hour period of the spacecraft orbit after separation from the launch vehicle are illustrated in Figure A-2-1. This figure is representative of what may be expected during a typical day on-orbit throughout the mission. The APL SCF and the Alaska LEO-T ground stations coverage 'circles' are also shown. These are 5 degree minimum elevation circles (that is the depict the coverage when the spacecraft is at least 5 degrees in elevation with respect to the horizon).

The table below lists potential ground contacts for the initial 24 period on orbit. The left column lists elapsed time, from launch-vehicle/spacecraft separation, to the start (AOS) of a contact (the first contact occurs one hour and 15 minutes after separation, the second begins 7 hours and 22 minutes after separation, and so on). The contact duration is that part of a overhead pass when the spacecraft is at least 5 degrees above the horizon (sufficient signal link margins which occur during this fraction of an overhead pass will provide reliable command and telemetry data communications). Included GSs are located at Poker Flat, Alaska (LEO-T) and at APL (SCF).

TIMED Spacecraft Ground Coverage
(first 24 hours after separation)

AOS (hh:mm) from Separation	Maximum Elevation (degrees)	Duration (minutes)	Station
1:15	8	5	LEO-T
7:22	6	4	APL SCF
8:56	86	11	APL SCF
10:38	9	6	APL SCF
12:18	10	6	LEO-T
13:53	37	11	LEO-T
15:31	63	11	LEO-T
17:11	30	10	LEO-T
17:26	8	6	APL SCF
18:51	24	11	LEO-T
19:03	80	11	APL SCF
20:30	35	10	LEO-T
20:44	7	4	APL SCF
22:09	82	11	LEO-T
23:47	24	10	LEO-T

Minimum elevation above horizon = 5 degrees

Figure A-2-1
TIMED Spacecraft Early On-orbit Ground Traces
(first 24 hours after launch vehicle separation)

Figure A-2-1
TIMED Spacecraft Early On-orbit Ground Traces
(first 24 hours after launch vehicle separation)