Abstract

The Near Earth Asteroid Rendezvous (NEAR) mission is designed to place a spacecraft in orbit about the near-Earth asteroid Eros in January 1999. The February 17, 1996 launch was the first in the Discovery series of small planetary spacecraft missions. Designed in keeping with the intent of the Discovery program to reduce development and mission operations costs for planetary missions. The ground system command and control architecture consists of a single, flexible network, used commonly and simultaneously for Integration and Test (I&T) operations, launch operations, and Mission Operations. After a 27 month mission development program, NEAR Spacecraft Operations are conducted from the Mission Control Center at The Johns Hopkins University Applied Physics Laboratory. Radio contact with the spacecraft is via NASA's Deep Space Network, operated by the Jet Propulsion Laboratory.

NEAR MISSION BACKGROUND

The NEAR Mission

The NEAR mission is designed to place a science-based spacecraft into orbit around a near-Earth asteroid. The scientific yield will be extensive measurements of composition, density, and internal structure. This level of scrutiny can be achieved only by close-up study by orbiting the asteroid over a significant period of time, at varying altitudes. This information is of great interest scientifically because asteroids are believed to be primal universal material which can provide clues to early origins of solar system.

The February 17, 1996 launch of the NEAR spacecraft on a Delta-II rocket from the Cape Canaveral Air Force Station was the first in NASA's Discovery series of small planetary spacecraft missions. After a 27 month mission development program, the mission has successfully demonstrated the viability of spacecraft development of the cheaper, better, faster ilk. The spacecraft has already set records (for example NEAR now holds the record for the longest solar distance using solar panels). Along the way it has obtained impromptu images of the moon, and may image the asteroid Mathilde which it passes by in June 1997.

At the time of this presentation, the NEAR spacecraft is in the “cruise” phase and well on its way to a January 1999 rendezvous with the asteroid 433 Eros, discovered in 1898. This asteroid's orbit, which is inclined 10.8° to the ecliptic, lies between the orbits of Mars and the Earth, and can pass as close as 0.13 Astronomical Units, or 20 million kilometers, from the Earth. Figure 1 displays significant events in the three year trip to Eros, including a spacecraft close-
encounter Earth swingby in January 1998 for a combined energy boost and a change in orbital inclination to match that of the asteroid.

NEAR Spacecraft Operations are being conducted from the Mission Operations Center at The Johns Hopkins University Applied Physics Laboratory (JHU/APL). Radio contact with the spacecraft is via NASA’s Deep Space Network (DSN), operated by the Jet Propulsion Laboratory. Navigation analysis is provided by members of the Mission Navigation Center at Jet Propulsion Laboratory (JPL).

The NEAR Spacecraft

Weighing about 805 kilograms at launch, the NEAR spacecraft, shown in Figure 2, features hardware redundancy for most critical subsystems, with functional redundancy for some others. It is powered by solar cells, having on board only about an hour of nonredundant battery. The spacecraft will maintain a Sun-looking attitude in asteroid orbit. During ground contact periods, the body-fixed high gain antenna can be pointed toward the Earth and still keep the solar panels illuminated since the angle between the Sun and Earth as seen from the asteroid is generally less than 40°. Alternatively, communication with the Earth can be maintained at lower rates by using a lower gain fan beam antenna that can be pointed toward the Earth and still keep the panels pointed at the Sun. Attitude in orbit will be maintained by a combination of momentum wheels and small mono-propellant thrusters. In-route major trajectory changes and orbital insertion will be made using a single high-thrust bi-propellant engine.

NEAR carries five facility instruments. One of these is an eight color visible imager, with 95
$161 \times 161$ micro-radian resolution and a $2.25 \times 2.9^\circ$ field of view. An infrared spectrograph of 22 and 44 nanometer spectral resolution, and a combined X-ray/gamma-ray spectrometer are also on board. The instrument suite is rounded out by a magnetometer and a laser rangefinder. Radio science is planned using the telecommand subsystem.

The command and data handling system is based on redundant RTX2010 processors, and uses a redundant MIL-STD-1553 data interface bus for communication with all subsystems and instruments. Two 512 Mbit solid state recorders with separate read/write capability are the onboard storage medium for science and housekeeping data when out of contact with the Earth. Other RTX2010 processors control the science instruments and the guidance and control subsystems.

The NEAR telecommand subsystem operates at X-band. Besides the high-gain and fan-beam antennas, the spacecraft has a low gain antenna pair providing omni-directional coverage during near-Earth mission phases. The fan-beam antenna is used primarily as an adjunct and backup to the high gain antenna, and for emergency Earth acquisition. Uplink command rates are 125 bps normally with an emergency rate of 7 bps. There are eight different downlink telemetry rates ranging from 9 to 27000 bps. Rates between 2.9 kbps and 8.8 kbps will be used in orbit at Eros. The NEAR spacecraft is CCSDS compliant for both command and telemetry. Rate 1/2 and 1/6 convolutional encoding are used optionally as well as Reed-Solomon encoding.

The spacecraft has an autonomous safing system which operates in layers. Recoverable faults can generally be detected in the first layers, for which the spacecraft can autonomously clear the fault and resume operation. At the next layer, for serious faults which jeopardize the spacecraft health, the spacecraft suspends execution of any stored commands, places itself in a known configuration, and points toward the Sun. The fan-beam antenna is pointed toward Earth (knowledge of the Earth’s position is assumed) and an unmodulated carrier is transmitted. For critical faults, the position of the Earth is assumed lost. The spacecraft points itself toward the Sun, and rotates slowly about its central axis such that the unmodulated carrier from the fan beam is swept across the Earth periodically, permitting the ground station to inject stop rotation commands and recovery activities implemented.

**THE NEAR GROUND SYSTEM**

**Development Philosophy**

The NEAR Ground System has been designed in keeping with the intent of the Discovery program to reduce development and mission operations costs for planetary missions. the NEAR Ground System, this was carried out by adherence to a policy made up of the following elements:

- Use COTS (Commercial, Off-the-Shelf) resources where cost and schedule efficient
- Use a common architecture for both the Integration and Test (I&T) and Mission Operations (MOPs) activities to maximize efficiency
- Implement a system using open operating systems, networked workstations, and distributed processing
• Use existing supporting and operations infrastructure where cost efficient

In response to the first two of these policy directives, it was decided to procure a single COTS command and control system which could be used for both Integration and Test and Mission Operations. This provided obvious efficiency by eliminating duplicative system procurements, and permitted a great deal of "fly as you test" capability. However, the requirement for full concurrent engineering activities dictated by the 27-month development schedule meant that the common command and control architecture had to permit I&T activity and Mission Operations development on a non-interfering yet coordinated basis. This rendered using literally a single system somewhat difficult.

The solution was the separation of the command and control system into two identical segments. Since, in response to the third policy directive, the command and control system was based on networked workstations and distributed processing, the two segments could still be made equal parts of a common, fully integrated system. This approach permitted a full suite of cross-operations. For example, operators sitting at workstations in either segment could receive telemetry from, and send commands to, the spacecraft no matter which segment was in actual contact with the spacecraft. (The I&T segment is referred to as ITOGS (I&T Operations Ground Segment). The identical Mission Operations segment is referred to as MOGS (Mission Operations Ground Segment).

Another major advantage of this configuration came from the fact that the two segments were always joined by the common backbone network (a TCP/IP Ethernet network referred to as "NEARnet"). As the spacecraft development progressed, the I&T segment moved with the spacecraft from its integration site, to environmental test sites, and to the launch site. At every location however, members of the in-training Mission Operations team could have full access, including participation in and even conduct of, integration and test procedures from their workstations in the fledging Mission Operations Center. Further, Mission operations personnel training was enhanced by taking stints as online I&T team members, while training on precisely the system they would subsequently use to control the spacecraft after launch.

As a consequence of the NEAR ground system development policy of using an open systems architecture, the command and control system was required to be UNIX based, and populated initially with at least two currently available workstation platform families. This provided for the longevity of the system comfortably through the NEAR mission timeframe. After launch the ITOGS was combined with the MOGS to fill out a full and robust, and essentially redundant, Mission Operations computer system. Software developed in-house, such as non-command and control Mission Operations software for command planning, higher level telemetry analysis, and spacecraft performance and anomaly assessment, runs on these same workstations.

It is of interest to note that the ground system development approach taken on NEAR was a significant departure from the more familiar past approach of virtually independent I&T and Mission Operations development efforts. This almost cultural shift was jumpstarted at the beginning of the Program by defining both the I&T team and the Mission Operations team as the customers for the NEAR Ground System. As such, the essential requirements for the Ground System were levied from both I&T and Mission Operations as a coordinated effort. This coordination yielded requirements which were sufficiently melded to permit satisfaction of the often disparate needs of the two camps. Because spacecraft design was going on concurrently with the development of I&T, Mission Operations, and the Ground System, this was of necessity an on-going effort, and led to some
development beyond the COTS vendor's initial package. While the NEAR experience did not totally integrate the different viewpoints and goals of the two camps it did pave the way for much closer integration of the two arenas on future spacecraft.

Before leaving the policies which drove the final architecture of the NEAR Ground System, it is worth noting that the last policy statement listed above called for using existing infrastructure where possible. This of course was implemented fully by the use of the Deep Space Network for all space-to-spacecraft contacts, and the use of NASA Communications for all significant communications. This was the case during development and also for the post-launch operational system configuration, as we shall see in the next section.

Ground System Description

The essentials of the NEAR Ground System configurations during development and in final operational form are presented in Figure 3. This drawing has changed little since its first use at the NEAR Conceptual Review. As shown, the basic elements are a mix of existing entities, and components developed specifically for NEAR. The former include NASCOM (NASA Communications) and the Deep Space Network (DSN). The latter group includes the Mission Operations Center (MOC); the Integration and Test-oriented Ground Support System (GSS); the Science Data Center at JHU/APL; and the Mission Navigation Center at the Jet Propulsion Laboratory (JPL). Also among the latter is the Mission Design Team, which evolved to have no specific facility, since the team is potentially spread over a large geographic area, but has access to the secure NEARnet via a security router.

The development of the NEAR Ground System focused on properly incorporating the existing infrastructure, and providing the needed communications and data services to these NEAR-specific entities. The actual development of these various operational centers took place independently, coordinated by interface control.
agreements with the ground system. Likewise, the NEAR Ground System was also developed to interface agreements with NASCOM and the DSN. Therefore, this paper will briefly discuss those aspects of NASCOM and the DSN services that are significant to NEAR. Similarly, details of the organization and operation of the Science Data Center, the Mission Navigation Center, and the Mission Design Team, are beyond the scope of this paper, and only a quick description of their function will be given here.

The balance of this paper will then focus on two major components of the NEAR Ground System: the distributed and highly versatile command and control system, and the NEARnet. The command and control system provides all monitoring and control of the spacecraft. NEARnet provides at once the communications backbone for the command and control system, and also the integrated pathway for all operations-related spacecraft and ground system monitoring and control, science data collection, and both operational and mission oriented planning, analysis, and assessment.

**Mission Operations Center (MOC)**

The NEAR Mission Operations Center, located on the JHU/APL campus provides all operational control, detailed activity planning, and assessment of health, status and performance of the NEAR Spacecraft. A major part of the MOC is the EPOCH 2000 command and control system. Since launch, the full suite of equipment and software which comprise this system have been resident in the MOC. Prior to launch however, the MOC system constituted about half the complete command and control system, since the other half was being used in close proximity with the spacecraft for Integration and Test and subsequent launch. The MOC system was referred to as the Mission Operations Ground Segment (MOGS).

The term “segment” is literally intended to imply a part of the NEARnet structure. As the half of the command and control system used for spacecraft Mission Operations, it is identical to the I&T half, the Integration and Test Operations Segment (ITOGS), each segment having identical “frontends” for interfacing to the spacecraft for telemetry and commands. These interfaces are made through either umbilical or RF Ground Support Equipment (GSE) or through the DSN via NASCOM.

The MOGS remained essentially in place at JHU/APL during the entirety of spacecraft development, testing, and launch, and took up permanent residence in the MOC as soon as this facility was implemented several months prior to launch. As has been explained, the MOGS was a fully integrated part of the network, sharing a common command and telemetry database with ITOGS, and providing Mission Operations team members full command and telemetry access to the spacecraft during its development and launch phases.

**Ground Support System (GSS)**

This system comprises the suite of ground support equipment (GSE) that accompanied the spacecraft for the various phases of integration, testing and launch. The ITOGS provided all spacecraft command and control via the spacecraft umbilical and RF interfaces. Some of the supporting GSE was also controlled and monitored via NEARnet. In addition to the regular ITOGS workstations, several subsystem- or instrument-specific workstations and PCs were readily connected to NEARnet at various times.

All of the GSS including the ITOGS moved with the spacecraft, which was located at JHU/APL for development and integration, at GSFC for environmental testing, and at Cape Canaveral for launch. At each location NEARnet remained intact, being carried by communications circuits of sufficient bandwidth to keep the Ethernet-based network running at the needed performance levels.
No longer needed in an I&T role after launch, the ITOGS has been physically integrated into the MOGS, essentially doubling the workstation and peripheral hardware base of the MOGS in addition to providing online frontend redundancy. This physical integration has necessitated little change in the prelaunch logical configuration since the two segments have always been integrated via the NEARnet.

**Science Data Center (SDC)**

Located on the JHU/APL campus, the SDC provides telemetry product (cleaned and merged) to the science community and subsystem engineering teams as needed. The SDC retrieves telemetry at the full CCSDS transfer frame level from the NEARnet by way of read-only file transfers.

**Mission Navigation Center**

Navigation analysis and processing are provided to the NEAR MOC by the navigation facility at JPL (JPL NAV). Information provided includes navigation analysis, time conversions, and spacecraft and asteroid ephemerides. JPL NAV is connected to the secure NEARnet via a dedicated NASCOM circuit.

**Mission Design Team**

The Mission Design team has the primary responsibility for planning propulsive maneuvers for NEAR throughout the cruise phase. They work with the Navigation Team at JPL, which plays a supporting role in verifying such maneuver planning. During the orbit phase, the roles of Mission Design and Navigation will be greatly heightened due to the intense activity associated with data gathering from orbit.

**Deep Space Network (DSN)**

Since launch, and throughout the complete mission, all communications with the NEAR spacecraft are via the three Deep Space Complexes of the DSN. These are located in Goldstone, California; Madrid, Spain; and Canberra, Australia. The primary support for NEAR during the three year cruise to Eros will be provided by the 34-meter systems at these sites, at approximately three 8-hour passes per week. For special events during cruise, such as major course maneuvers, and for operations at the asteroid, it is expected that continuous 34-meter coverage will be required, with an additional 8-hour pass per day using the 70-meter systems available at each location.

The DSN provides both store-and-forward and throughput spacecraft commanding. All commands are packaged into CCSDS standard protocol structures by the command and control system at the NEAR MOC prior to transmission to the DSN. For telemetry, the DSN provides convolutional decoding, frame synchronization, and time of receipt stamping, and sends telemetry realtime to the MOC in 4800 bit NASCOM blocks. (NASCOM service to the NEAR Program, as for all programs being served by NASCOM using the 4800 bit blocking protocol, will be moved to a TCP/IP service later this year as part of the NASCOM IP Transition Program.) All Reed-Solomon decoding, and virtual channel separation and depacketization, is done in the NEAR MOC by the command and control system.

During development and off-campus test and launch activities, two further services of the DSN were utilized. The DSN Compatibility Test Trailer (CTT) was used for testing with the spacecraft at JHU/APL and during environmental testing at Goddard Space Flight Center. In both locations the CTT, which emulates a DSN station, had a real RF interface with the spacecraft and provided the full and online DSN command and telemetry links during much of the testing. Additionally, the DSN compatibility testing and launch support facility known as MIL-71 was used extensively during launch operations. This fixed-antenna DSN station emulator also provided the full DSN linkup.
Goddard Space Flight Center (GSFC) and NASCOM

The essentials of the NEAR Ground System communications connectivity is shown in Figure 4. All significant NEAR data and voice communications with Ground system entities external to the JHU/APL campus are carried by NASCOM (NASA Communications). A node on the T1 digital frame-based NASCOM 2000 system exists at JHU/APL in the JHU/APL NASCOM Interface Facility (NIF). This node provides direct access to the switching center at Goddard Space Flight Center in Greenbelt, Maryland.

Of particular interest is that during off-campus I&T and launch operations, this NASCOM service provided the pipeline for the extensions of NEARnet to the roving ITOGS. Some of the ramifications of this extension of the 10 Mbps Ethernet-based NEARnet from a local area service to a wide area service mode are addressed in the following sections.

NEARnet

From a networking viewpoint the NEAR command and control system which supported both spacecraft I&T and provides post launch operations is comprised of a group of UNIX computer systems. These computers are interconnected by the NEARnet network as shown in Figure 5. The ground system contains two autonomous subsystems - the ITOGS and the MOGS which are detailed in Figure 6. Each subsystem is further divided into two Ethernet subnets. The so-called UDP subnet contains the subsystem front end processor (FEP), and mission critical operations workstations. The X11 subnet contains additional telemetry viewing workstations.

Figure 4. NEAR Ground System Communications
Multi-port LAN (local area network) and WAN (wide area network) routers were used to implement NEARnet’s local and remote communications. Note that the NEARnet network provides a communications channel for both UNIX system network traffic (i.e., remote file system mounting, remote workstation login) and spacecraft commanding and telemetry receipt. Partitioning each subsystem network into two subnets assures critical spacecraft commanding and telemetry receipt activities can occur with no interference by other UNIX network workstation activities.

Industry standard network hardware and software is used in the design and implementation of NEARnet. Previous spacecraft ground systems developed at JHU/APL had used proprietary network communications protocols. This resulted in long development cycles and soaring maintenance and operations post launch costs. The multi-vendor TCP/IP communications protocol is extensively used, both for spacecraft command and control, and for workstation network activities. For example, the built-in UNIX network file system (NFS) file sharing capability is used to share the ground system database file between the FEP and the client workstations. Two different computer systems vendors are used to reduce single system supplier dependencies. Interoperability was easily achieved between the two vendor’s systems.

The NEAR FEP provides satellite telemetry to client workstations. Network configuration options provide for both point-to-point and broadcast methods. By utilizing the built-in TCP/IP network communications, no application level software needed changing to support telemetry delivery over the LAN link or the WAN configuration network link.

The development of the NEAR ground system occurred in distinct phases. The early
phases supported the NEAR spacecraft bench testing while the later phases (and final phase) focused on mission operations of the satellite. The architecture of the NEARnet was designed to support and facilitate each of the development phases. For example, spacecraft telemetry flowed between the ITOGS FEP and a MOGS workstation using 10 Mbps Ethernet in the I&T development phase. To support spacecraft launch, the same telemetry flowed over a 224 Kbps WAN. No application software (or user interface operations) were changed.

Detailed TCP/IP network design occurred before any implementation phase. Numeric network and subnet assignments (for the four subnets) were developed, and WAN IP network routing (including propagation of broadcast packets) was fully analyzed. Below is a summary of the NEAR command and control system development phases:

**Phase I**, initial network systems integration: single FEP and single workstation ITOGS; direct connection of spacecraft via ground support equipment (GSE) and ITOGS FEP; single FEP and single MOGS workstation.

**Phase II**, spacecraft integration at JHU/APL: ITOGS fully populated with client workstations; multiple MOGS workstations; dual WAN/LAN ITOGS/MOGS network connectivity;

**Phase III**, spacecraft environmental testing at GSFC: MOGS fully populated with client workstations; ITOGS moved from JHU/APL to GSFC; NEARnet WAN communications using 224 Kbps NASCOM channel on T1 JHU/APL to GSFC circuit.

**Phase IV**, launch phase: ITOGS moved to KSC for launch; NEARnet WAN communications as in Phase III; Full spacecraft command and control redundantly provided by local ITOGS or remote MOGS.

**Phase V**, spacecraft operations: ITOGS and MOGS merged into the NEAR MOC

The I&T phases of the NEAR command and control system are shown in Figure 6. The MOGS and the ITOGS were interconnected by both an Ethernet local area network (LAN) and a 224 Kbps wide area network (WAN). During phase II, the WAN was used to exercise the Phase IV launch network configuration. The higher speed Ethernet communications channel was
used at other times for full speed ITOGS/MOGS data transfers. The MOGS and ITOGS routers were programmed to enable IP packet routing over the higher speed LAN connection, if available. If no LAN connection was present (as in Phases III and IV), the router directed network packets over the WAN communications channel. Using this fail-over technique, no router re-programming was needed when the ITOGS was moved from the local JHU/APL integration site to the environmental testing site.

Figure 7 shows the post-launch NEARnet Mission Operations Center (MOC) configuration. After launch, the suite of ITOGS system components were merged with the MOGS. To ease the post-launch network re-configuration, the ITOGS TCP/IP network addresses assigned during Phase II were retained. This allowed rapid integration of the ITOGS systems into the MOC. Note that since identical FEPs were employed for both MOGS and ITOGS, the MOGS FEP can back up the ITOGS FEP during critical spacecraft commanding sequences.

As shown in Figure 7, NEARnet is connected to the JHU/APL campus network via the NEARnet firewall. This firewall performs IP packet filtering of incoming and outgoing TCP/IP network packets. Internal NEAR computers are on the closed-side of NEARnet. A single computer is designated as the gateway host. This system resides within the NEAR physical security perimeter, but is logically connected to the JHU/APL campus network. TCP/IP communications to and from campus systems are expressly prohibited by the NEARnet routers packet filtering tables. The gateway host is allowed limited communications access to NEARnet systems. For example, an authorized gateway system user is allowed telnet remote login into the MOGS FEP. The gateway host is also used as a drop box for file exchange between the closed-side of NEARnet and the campus network.

The use of industry standard network communications protocols running on UNIX-based workstations allowed for a shortened development cycle for a complex multiple frontend/workstation WAN and LAN distributed satellite ground system. It further provides a convenient infrastructure for the NEAR command and control system, which is now described.

**NEAR COMMAND AND CONTROL (C&C) SYSTEM**

The NEAR C&C system, illustrated in Figure 8, consists of four major components:

- Workstations
- Front end computers
- Network hardware
- Satellite control center software

These components are all COTS, and follow industry standards. This minimizes initial system cost and allows easy upgrade and/or replacement of individual components as necessary during the extended NEAR mission.
The workstations provide a high-performance, graphical user interface for each operator. Through this interface, an operator can control and monitor all aspects of the spacecraft and the C&C system. Each workstation runs the UNIX operating system with its usual complement of user interface and networking software:

- X.11/Motif user interface toolkits
- CDE desktop
- TCP/IP network protocol
- NFS distributed file system
- ONC RPC remote procedure calls

Most vendors provide these tools on their workstations at no additional cost, providing a powerful, inexpensive foundation for the satellite control center software.

The front end processors (FEPs) perform the real-time telemetry and command processing. They are based on the VMEbus standard, making it easy to integrate the COTS hardware needed for NEAR communications. Specific cards used are:

- NASCOM interface
- Rate 1/2 Viterbi bit synchronizer
- Rate 1/6 convolutional decoder (custom - not COTS)
- Frame synchronizer
- Serializer
- IEEE-488 interface to signal generator
- Time code reader

The front ends run commercial real-time UNIX and the standard networking software listed above. UNIX is a time-share operating system, so commercial real-time extensions to UNIX are used on the front ends to ensure that the throughput and timing requirements of the NEAR mission are met.

The NEAR C&C system is based on Ethernet, the industry standard for low cost, reliable, local and wide area networks. The C&C system includes the following network components:
• X.11 terminals
• Laser printers
• Routers
• Hubs

X.11 terminals provide additional, inexpensive workstation interfaces during periods of high activity, e.g., launch and Eros rendezvous. As explained previously, routers are used to isolate laser printer and X.11 communications from real-time telemetry and command network traffic, while hubs implement low cost network segments.

The COTS command and control software integrates the workstations, front ends, and network into a unified system for NEAR operations. By using a COTS package, new software development is limited to NEAR-specific requirements. Most of the NEAR mission requirements have been met just by populating the database.

The NEAR command and control software is made up of the following major components:

- System Database
- User Interface
- Telemetry and Command (T&C) Processing
- Ground Equipment Processing
- Off-Line Utilities

These components are described in more detail in the following sections.

**System Database**

The system database stores the spacecraft and ground system data that configures the commercial satellite control center software for the NEAR mission. It is built on a COTS relational data base platform, which provides lots of tools for loading and maintaining the data. An easy-to-use, forms interface facilitates data entry, validation, display, and reporting. Figure 9 shows an example of these forms.

The spacecraft portion of the system database stores all the information necessary for processing telemetry and generating commands. The telemetry database defines the CCSDS packet formats produced by NEAR, as well as conversion coefficients, limits bands, and state ranges for each telemetry point. The command database defines the CCSDS command frame formats and validation sequences for each NEAR command.

The ground portion of the system database contains configuration and monitoring data definitions for the front end VMEbus hardware. It also includes data definitions for the DSN station equipment used by the C&C system for NEAR communications.

Because commercial relational database packages are notoriously slow, the run-time software doesn’t access the database directly. Instead, ASCII reports containing all configuration data from the database are generated off-line. The run-time software parses the ASCII reports at start-up and stores the parsed reports on disk. Subsequent runs only parse an ASCII report file if it has been updated.

**User Interface**

A NEAR operator monitors and controls the spacecraft and the C&C system using COTS user interface software running on each workstation. Operators use tiled and overlapping window layouts specified in EPOCH Display Language (EDL) for monitoring, and the System Test and Operations Language (STOL) for control. Standalone pass playbacks and simulations are also supported.

EDL is a proprietary screen and page layout definition language supported by the COTS user interface software. It is designed for the control center environment and hides as many of the details of X.11 and Motif as possible from the end users. The NEAR mission operations center users have developed an extensive library of window layouts using both the user interface’s built-in display editing capabilities and EDL...
Figure 9. System Database

directly. Figure 10 depicts a typical NEAR user interface layout, designed and implemented by the NEAR mission operations team.

STOL is a procedural language for spacecraft command and control applications. The COTS user interface supports both STOL directives (one-line STOL commands) and STOL procedures (files of STOL commands, including argument passing and flow control). STOL procedures can be nested, supporting structured, modular automation of all NEAR operations. STOL is easy to use — a library of STOL procedures has been developed by the NEAR spacecraft engineers, I&T team, and operators for their specific needs. The library continues to evolve with the mission.

The COTS user interface supports stand-alone pass playbacks, so an operator can review spacecraft and C&C system activity on their workstation without affecting on-going NEAR support. This capability has been very useful already in evaluating NEAR subsystem performance.

The user interface also includes a spacecraft data simulator, used primarily for checking out new database ASCII report files and STOL procedures before they are put on line.

Telemetry and Command (T&C)Processing

Real-time spacecraft T&C processing is performed on the front end. T&C processing functions include:
• Telemetry packet decommutation, point-and subsystem-level status checking, dump collection
• Command frame generation
• STOL schedule execution
• Data archival
• T&C data service

The COTS command and control software supports multiple T&C communications streams in parallel. This capability has been exploited in NEAR testing (simultaneous spacecraft communications via NASCOM and GSE interfaces) and in NEAR operations (simultaneous spacecraft communications through two DSN stations during station hand-off).

The telemetry and command processing is performed in software. NEAR has quite complex T&C formats, so the flexibility of software T&C processing is a benefit — most of the NEAR requirements are met without code changes.

Processing in each T&C communications stream is controlled by a schedule. A schedule is just a STOL procedure which runs on the front end and is visible at all workstations. Planned NEAR control activities are coded in STOL and executed as schedules so that all operators can see what's going on. An example schedule, as seen at a C&C workstation, is presented in Figure 11.

Each active T&C communications stream performs its own data archival to hard disk, where the data are available for post-pass analysis. Archived data includes all telemetry, relevant ground equipment parameters, and system events. Each stream also provides data service to client programs. This capability has been used in NEAR to drive a 3-D spacecraft display program and a real-time Internet site.
**Ground Equipment Processing**

The COTS ground equipment processing software provides the connection between the T&C processing and the VMEbus hardware for the configured NEAR communications path (DSN station 1, DSN station 2, or baseband hardware). Functions performed by this software include:

- Drivers for the VMEbus hardware
- DSN protocol and simulation
- Reed-Solomon decoding software
- CLTU encoding software
- Embedded transfer frame synchronization
- NASCOM block and transfer frame archival
- Ground equipment data service
- Science data center interface

The major benefit of this software is that it encapsulates NEAR-specific processing so that the commercial control center software can be used without modification. For example, the display of DSN station equipment data shown in Figure 12 is generated by the standard user interface software.

Figure 11. T&C Schedule
Off-Line Utilities

Lastly, off-line processing software is provided for:

- Command load generation
- Archive data processing

The command load generation program allows an operator to generate a binary load file of spacecraft commands from an ASCII specification. Archive data processing includes extraction of selected telemetry points and conversions between various file formats.

SUMMARY

The NEAR ground system provides an efficient command and control for the NEAR spacecraft. It achieves this by maximizing the use of a commercial, off the shelf command and control system, and of existing communications infrastructure. Additionally, it uses an open and networked computer system architecture, which is used jointly for both spacecraft integration and test and for mission operations. This system will remain flexible and effective for the four-year life of the NEAR mission.
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