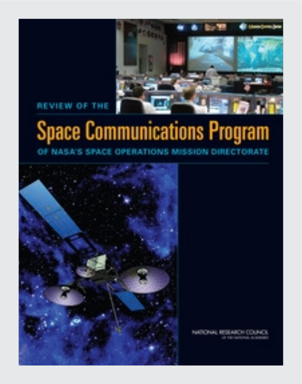


Review of the Space Communications Program of NASA's Space Operations Mission Directorate

DETAILS

98 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-10297-1 | DOI 10.17226/11718

AUTHORS

Committee to Review NASA's Space Communications Program; Aeronautics and Space Engineering Board; Division on Engineering and Physical Sciences; National Research Council

REVIEW OF THE
Space Communications Program
OF NASA'S SPACE OPERATIONS MISSION DIRECTORATE

Committee to Review NASA's Space Communications Program

Aeronautics and Space Engineering Board
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This study was supported by Contract No. NASW-03009 between the National Academy of Sciences and the National Aeronautics and Space Administration. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number-13: 978-0-309-10297-1
International Standard Book Number-10: 0-309-10297-9

Available in limited supply from the Aeronautics and Space Engineering Board, 500 Fifth Street, N.W., Washington, DC 20001; (202) 334-2858.

Additional copies of this report are available from The National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, www.nap.edu.

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Wm. A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Wm. A. Wulf are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

COMMITTEE TO REVIEW NASA'S SPACE COMMUNICATIONS PROGRAM

ROBERT E. DEEMER, *Chair*, Regis University School of Professional Studies, Denver, Colorado
HARVEY BERGER, Northrop Grumman Space Technology, Redondo Beach, California
THOMAS C. BETTERTON, United States Navy (retired), Warrenton, Virginia
ANTONIO L. ELIAS (NAE), Orbital Sciences Corporation, Dulles, Virginia
CHARLES T. FORCE, NASA (retired), Loogootee, Indiana
KEITH JARETT, Boeing Space and Intelligence Systems, Lafayette, California
MARJORY JOHNSON, RIACS/NASA (retired), Ashland, Missouri
YOGI Y. KRIKORIAN, The Aerospace Corporation, El Segundo, California
THOMAS MAULTSBY, Rubicon, LLC, Burke, Virginia
TODD J. MOSHER, Microsat Systems, Incorporated, Littleton, Colorado
PATRICK A. STADTER, Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland
PAUL G. STEFFES, Georgia Institute of Technology, Atlanta
MICHAEL W. TOMPKINS, KDM Systems, Centreville, Virginia
WILBUR TRAFTON, Will Trafton & Associates, Coronado, California
BARRY M. ZILIN, Practical Innovations International, Woodbridge, Virginia

Staff

SANDRA GRAHAM, Study Director (from December 2005)
ALAN ANGLEMAN, Study Director (through November 2005)
HEIDI MURRAY, Senior Program Assistant
ANNA FARRAR, Financial Associate
GEORGE LEVIN, Director, Aeronautics and Space Engineering Board

AERONAUTICS AND SPACE ENGINEERING BOARD

RAYMOND S. COLLADAY, *Chair*, Lockheed Martin Astronautics (retired), Golden, Colorado
WILLIAM L. BALLHAUS, BAE Systems National Security Solutions, Reston, Virginia
CHARLES F. BOLDEN, JR., Jack and Panther, LLC, Houston, Texas
EDWARD M. BOLEN, National Aviation Association, Washington, D.C.
ANTHONY J. BRODERICK, Aviation Safety Consultant, Catlett, Virginia
JOHN-PAUL CLARKE, Georgia Institute of Technology, Atlanta
PHILIP M. CONDIT (NAE), The Boeing Company, Redmond, Washington
ROBERT L. CRIPPEN, Thiokol Propulsion (retired), Palm Beach Gardens, Florida
RICHARD M. GOODY (NAS), Harvard University (emeritus), Falmouth, Massachusetts
PRESTON HENNE (NAE), Gulfstream Aerospace Corporation, Savannah, Georgia
WILLIAM W. HOOVER, U.S. Air Force (retired), Williamsburg, Virginia
SYDNEY MICHAEL HUDSON, Rolls-Royce North America (retired), Indianapolis, Indiana
JOHN M. KLINEBERG, Space Systems/Loral (retired), Redwood City, California
ILAN KROO (NAE), Stanford University, Stanford, California
MOLLY K. MACAULEY, Resources for the Future, Washington, D.C.
FORREST S. McCARTNEY, Lockheed Martin Astronautics (retired), Indian Harbour Beach, Florida
ELON MUSK, Space Exploration Development Corporation–SpaceX, El Segundo, California
AMY PRITCHETT, Georgia Institute of Technology, Atlanta
ROBERT R. RANKINE, JR., Hughes Space and Communications Company (retired), Clearwater, Florida
DEBRA L. RUB-ZENKO, The Boeing Company, Anaheim, California
CYNTHIA SAMUELSON, Logistics Management Institute, McLean, Virginia
PETER STAUDHAMMER (NAE), University of Southern California, La Quinta
HANSEL E. TOOKES II, Raytheon International, Inc. (retired), Palm Beach Gardens, Florida
RAY VALEIKA, Delta Airlines, Inc. (retired), Powder Springs, Georgia
ROBERT S. WALKER, Wexler & Walker Public Policy Associates, Washington, D.C.
ROBERT E. WHITEHEAD, National Institute of Aerospace, Henrico, North Carolina
THOMAS L. WILLIAMS, Northrop Grumman, El Segundo, California

Staff

GEORGE LEVIN, Director

Copyright National Academy of Sciences. All rights reserved.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Research Council (NRC). The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Sandy Bates, Topside Consulting, LLC,
Don Hard, Hard Enterprise,
Julie Miller, Lockheed Martin, and
Eytan Modiano, Massachusetts Institute of Technology,
Joseph Rothenberg, Universal Space Network.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Donald L. Cromer, United States Air Force (retired). Appointed by the NRC, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Assessment of Operational Networks

Assessment of Other Program Elements

General Issues

APPENDIXES[1]

---

[1] An appendix that appeared in the prepublication version of this report is not included here but is available in the public access files at the Academies.

This report is dedicated to the memory of

Major General Jimmey R. Morrell
(1946-2006)

Executive Summary

BACKGROUND

As currently organized, the Space Communications Office (SCO) within the Space Operations Mission Directorate (SOMD) at NASA has two primary roles within the agency, both of which are critical to the success and safety of human and robotic space missions. The SCO's first role is to directly manage two of the communication networks that enable spaceflight operations and research. These two operational program elements include the Space Network and the NASA Integrated Services Network. The SCO's second role is to integrate agency-wide telecommunications issues that influence policy formulation and to lead the effort to define NASA's future space communications and navigation architecture. Several program elements within the SCO address this role:

- Spectrum management,
- Standards management,
- Search and rescue,
- Communications and navigation architecture,
- Technology, and
- Operations integration.

In 2005, NASA requested that the National Research Council (NRC) perform a review of the effectiveness of the SCO in carrying out its program responsibilities. The NRC subsequently formed the Committee to Review NASA's Space Communications Program, which was tasked to assess the overall quality of the space communications program and offer findings and recommendations. In this study the committee has reviewed each of the program elements within the SCO, looking specifically at questions related to the formulation of each program element's plan, the methodology used to develop the plans, how each program element utilizes its connections to the broader community, and the overall capabilities that exist within each program element. While the primary purpose of the study was to provide a peer assessment rather than programmatic advice, the committee has in some cases commented on programmatic issues where they became apparent in the course of reviewing program effectiveness. Given below are the highlights of the committee's assessment of the overall SCO program and the individual program elements. Additional findings and recommendations are presented in the main text of the report. Significant portions of NASA's space communications work are managed outside the SCO, and those programs are not reviewed in this study.

OVERALL PROGRAM ASSESSMENT

After a careful review of each of the program elements in the SCO, it was the consensus of the committee that, despite what appeared to be marginal civil service staffing levels in some areas, the overall program was both well managed and highly effective in carrying out its critical functions. The committee did, however, note some areas of possible concern in the overall program and makes a number of suggestions for avoiding potential pitfalls as the program moves forward.

Prospective Centralized Space Communications Management

As this study was nearing completion, the committee learned that NASA was considering replacement of the fractionated space communications management structure at NASA headquarters with a more centralized approach. It was not within the committee's purview to review the advantages and disadvantages of consolidating NASA space communications management functions. However, the committee makes several observations on this issue, noting that:

- Centralized headquarters management and funding of space communications worked well for NASA for more than 30 years until 1996.
- The proposed reorganization apparently would centralize space communications requirements and architectures and realign the associated budgets, thus affecting visibility into and management of very large current and future NASA programs for generations to come.
- Changing management structures is not a panacea. Reorganizations are often disruptive, countering the expected benefits. For instance, the last shift in space communications management resulted in the loss of 90 percent of the space communications program management experience base that had previously existed at NASA headquarters. Most personnel either retired or were reassigned to unrelated programs.

Recommendation: Major changes in modus operandi, such as realigning top-level management and funding responsibilities, should be preceded by a transition plan that outlines the objectives of the changes and ensures that past corporate knowledge is considered by the new organization. The committee recommends a thorough review of the lessons learned from past reorganizations so that NASA can avoid repeating unsatisfactory consequences.

Limits of Review

Only the programs currently managed by the Space Communications Office at NASA were reviewed in this study. However, a significant portion of NASA's space communications work is managed within other parts of the agency, such as the operation of the Deep Space Network in the Science Mission Directorate. The committee believes that NASA would benefit from a comprehensive review of all of its space communications work and notes that NASA's proposed consolidation of all communications functions under a single management structure may offer a timely opportunity for such a review.

TDRSS Replenishment and Long-Term Communications Requirements

The Tracking and Data Relay Satellite System (TDRSS) is considered to be a national asset, and it supports, in addition to NASA, numerous users ranging from the Department of Defense to the National Science Foundation. A gap in TDRSS capability to support projected NASA user requirements will begin in 2015. NASA plans to include funding in the FY 2008 budget cycle for a preformulation phase 1 effort and expects to develop a compelling case for a FY 2008 start for TDRSS satellite replenishment[1] and thus avoid a gap in NASA user coverage. NASA is also working with non-NASA users that will have a gap in TDRSS support projected to start as early as 2010. Historically, when issues have arisen concerning prioritization of TDRSS support for NASA missions versus other missions, the resolution has often not been favorable to NASA.

The committee observes that the planned reorganization of space communications management could greatly alter the future approaches that will be available for supplying the near-Earth communications support that is currently provided by TDRSS.

Recommendation: A restructured space communications management organization should undertake a detailed analysis of alternative approaches for satisfying long-term terrestrial, near-Earth, and exploratory space communications requirements and select the most beneficial for implementation. This recommendation does not presuppose that the current approaches are wrong, but it does suggest that there may be attractive alternatives worthy of reconsideration that may have been eliminated due to organizational boundaries.

Recommendation: The committee believes it would be responsive and proactive for NASA to work with the broader TDRSS user community to examine programmatic alternatives that could accelerate TDRSS satellite replenishment in order to address the projected service gap for non-NASA users.

Centralized Space Communications Contracting

In 1996 NASA centralized its space communications contracting by having Johnson Space Center issue a single completion type contract to replace 18 contracts that had been awarded by the other NASA centers. This was the Consolidated Space Operations Contract (CSOC). NASA provided the committee with several documents on CSOC lessons learned revealing why the centralized contracting concept had failed. The committee observes that contracting strategies are critical to the success of the space communications program as it moves forward.

Recommendation: The planned reorganization of NASA space communications management at NASA headquarters provides an opportunity to benefit fully from the lessons learned from contracting approaches used under the Consolidated Space Operations Contract. The committee recommends an early and thorough examination and internal agency discussion of CSOC lessons learned to ensure that past errors are not repeated. NASA should also review approaches used prior to 1996 to take advantage of past successes.

Requirements Validation Process

While some program elements of the SCO (such as the NASA Integrated Services Network) have a requirements validation process, others do not formally vet or document user and operator needs. Possible problems that can arise as a result include disconnects between validated needs and the formal planning and budgeting process, added uncertainty in the acquisition process, confusion over key performance goals and threshold requirements, and an inability to establish metrics for measuring success in terms of user and operator needs. In turn, these problems could make it difficult to accurately establish and defend the levels of appropriated funding required by NASA and the reimbursable funding needed from outside the agency.

The committee notes that the projected reorganization of space communications management at NASA offers the opportunity for an end-to-end review of the requirements validation process across all space communications programs and the development of consistent best practices that can address these potential issues.

NASA Workforce

At NASA headquarters and at the centers, the committee found a highly experienced staff operating from an efficient matrix organization to support multiple programs. The committee also found strong working relationships with customers, contractors, and external organizations and judged that these relationships had been critical to the current success of the SOMD space communications program. The committee noted, however, that some elements of SCO have minimal civil service staffing and were relying heavily on contractors to accomplish the program's mission. The committee was unable to identify opportunities for further government personnel reductions in these elements.

The committee also noted that much of the civil service workforce for communications, and particularly its leadership, is nearing retirement. NASA has young, very talented professionals awaiting their turn to move up in the organization, but they are too junior to fill the vacuum that could well occur in the next few years as the current leaders retire. In addition, it is likely that as the agency's veterans of space communications retire, the interpersonal relationships that currently help facilitate their success will no longer exist, and higher staffing levels will be required in the future to accomplish the same tasks with more junior, less experienced replacements. Further, in presentations made to it the committee heard many comments on the difficulties caused by the manner in which funding for government staff is accounted for in budgets. The committee did not review this issue, but the comments indicate fairly widespread concern within the workforce.

Recommendation: One of the early reviews to be conducted by the newly centralized NASA headquarters space communications management should include a detailed analysis of the personnel needs of the space communications program. This review should consider the minimum civil service staffing levels needed, likely upcoming retirements, availability of comparable replacements, the impact of full-cost accounting on the ability to hire civil service replacements, and the proper mix of civil service and contractors required to perform the mission.

Program Plan

NASA spends a great deal of money on space communications in order to provide a capability that is critical to the success of human spaceflight and science missions. The committee found that formal planning documents exist for a number of individual elements, or aspects of elements, within the SOMD space communications program. However, there was no overarching plan for the conduct of that space communications program.

Recommendation: The committee recommends that NASA take the opportunity presented by the impending reorganization of space communications to develop a program plan and vet this plan with the participating centers and NASA headquarters elements to ensure that it is executable and fits within the vision expressed in the NASA strategic plan. In addition, those elements of space communications that currently do not have formal element-level planning documents should develop plans that are tailored to the size and complexity of the activity in that element.

PROGRAM ELEMENT ASSESSMENT

In reviewing the individual program elements within the Space Communications Office, the committee considered each of the questions in its statement of task (Appendix A) that was applicable to the given element. Although in some cases there was insufficient data to fully answer a particular question, the committee considered that it had adequate information to perform a quality review of all of the program elements. The committee made numerous observations and developed suggestions intended to provide guidance to NASA in the future conduct of these program elements, and a few of the key points are summarized here.

Space Network

Consisting of a constellation of tracking and data relay satellites and a series of ground tracking and relay stations, the Space Network provides global-coverage tracking and data acquisition services during launch, early orbit, and operations in low Earth orbit (LEO) to NASA, other government agencies, and commercial and international customers. The current TDRSS constellation consists of six first-generation (F1 and F3-F7) and three second-generation (F8-F10) satellites, with three of the nine satellites being stored on orbit.

The most significant issue associated with the Space

Network program element is the absence of a definitive plan and appropriate resources for ensuring continuity of service (TDRSS satellite replenishment) to both NASA and non-NASA users.

Finding: A NASA TDRSS satellite replenishment decision is needed not later than the FY 2008 budget cycle in order to ensure continuity of communications support for NASA missions.

Finding: There appears to be a "caveat emptor" mind-set when it comes to consideration of communications service continuity (TDRSS satellite replenishment and longer-term continuity of service) for the non-NASA user community.

Recommendation: If in fact TDRSS, plus its follow-on, is truly a national asset, NASA should take the lead in identifying the appropriate policy, the required resources, and the planning, implementation, and requirements validation process necessary to serve all TDRSS user communities' needs for communications services.

Finding: Commercial satellite communications systems may have limited ability to meet some of the mission needs currently being supported by the Space Network.

Finding: Reliance on reimbursable funds from non-NASA users as the major component of the funding needed for the operations and maintenance of the Space Network is an unhealthy basis for long-term planning and stability.

Recommendation: NASA, in conjunction with the user community, should examine alternatives for providing long-term, stable funding at the level required for operation and maintenance of the Space Network.

NASA Integrated Services Network

The NASA Integrated Services Network (NISN) project provides terrestrial networking for the agency. There are two separate networks: (1) a mission network for transmission of flight-mission data between NASA ground stations and mission operations control centers and (2) an institutional network to support more general NASA activities. The committee based its evaluation of NISN on discussions with NISN management, site visits to several NASA centers, customer assessments of NISN services, and documents governing project activities and responsibilities. Key findings and recommendations include:

Finding: Further outsourcing for the NASA Integrated Services Network appears to be infeasible, without negatively impacting the project, since network circuits are already provided commercially and the civil service staff is minimal.

Finding: The problem of having NISN equipment that is no longer serviceable is being resolved by replacing outdated equipment as funding allows.

Recommendation: NASA should structure future NISN support contracts to ensure that critical equipment is updated in an ongoing manner, with the minimum requirement being that equipment will be replaced before vendors cease maintenance.

Finding: NASA's mission network has more stringent requirements for reliability and availability than does its institutional network. However, given the improvements inherent in state-of-the-art network technologies, any network with such technology will satisfy the more stringent of the two sets of requirements, so that it is not necessary to differentiate between the two networks with respect to this issue.

Recommendation: NASA should reevaluate the possibilities for sharing a single network infrastructure for its mission network and institutional network.

Spectrum Management

NASA has extensive communications and remote sensing systems, and the availability of adequately protected electromagnetic spectrum[2] is essential to the implementation of NASA's overall mission and to its vision relating to space exploration, scientific discovery, and aeronautics research.

NASA's Spectrum Policy and Planning organization at NASA headquarters and at its field centers plays a key role in ensuring access to the electromagnetic spectrum, complying with U.S. and international spectrum regulations, and advocating for NASA's electromagnetic spectrum needs in national and international spectrum regulatory forums. In addition, it provides technical advocacy in support of U.S. commercial aerospace industries, facilitates private-sector use of spectrum, and encourages commercialization of space. All of these goals and objectives require an ongoing and long-term commitment of funding.

The committee found that NASA has been very effective in advocating for and protecting its spectrum management needs. The committee did note that there is continuing demand for access to spectrum for mobile voice, high-speed data, and Internet-accessible wireless services that subjects NASA crosslinks and downlinks to potential interference from other services. Two examples are the TDRSS Ku-band crosslinks and downlinks and the deep-space S-band uplinks. In this regard, the committee offers the following finding and recommendation:

Finding: NASA has been very effective in protecting its access to the radio frequency spectrum needed for space com-

munications. In addition, the potential interference from a proliferation of Ku-band non-geosynchronous orbit (NGSO) very-small-aperture terminals (VSATs) has not been realized because these systems have not, as yet, been deployed, and NASA is reducing its use of S-band uplinks from its Deep Space Network sites.

Recommendation: Although there is no compelling reason for NASA to vacate the Ku band, it would be prudent for NASA to consider relocating its future Ku-band downlinks to a band with a primary allocation and to encourage users to transition from the Ku band to the Ka band. This approach would provide insurance against unacceptable interference arising from the future proliferation of commercial very-small-aperture terminal uplinks and could offer the secondary benefit of a higher-capacity downlink.

Data Standards Management

The primary role of the data standards management program element is to represent NASA in a national and international collaborative activity, the Consultative Committee for Space Data Systems (CCSDS), which develops space-associated standards to facilitate more cost-effective missions by sharing common components, procedures, and infrastructure. Historically, NASA has played a leadership role in the CCSDS. The committee found that the standards management program makes especially valuable (though somewhat subtle) contributions to all space programs, as demonstrated by the increasing adoption of its products—standards. Given that adoption of standards is voluntary, both by NASA flight programs and by the other nine member agencies, this accomplishment is particularly meaningful. Another important metric of this program element's contribution is the value of adopted standards: in 2005, the CCSDS surveyed the dollar value and reached a consensus that it exceeded \$24 billion per annum[3]—an extremely impressive return given the quite modest level of resources devoted to this program element.

Finding: It appears that the expected services are being successfully provided by NASA's space data standards management program element, as evidenced by the continuing development of standards that are being adopted by space activities around the world. The relatively modest funding allocated seems stable, and no funding threats are foreseen.

Search and Rescue

The program element for search and rescue (SAR) provides distress alerting and location information to SAR authorities anywhere in the world for maritime, aviation, and land-based users. COSPAS-SARSAT (C-S), an international and multi-U.S.-agency system, is operational today. The Distress Alerting Satellite System (DASS), a U.S. program to upgrade C-S capabilities by improving timeliness and accuracy for locating users in distress, is in its proof-of-concept phase and is achieving technical expectations. NASA has been and continues to be the lead U.S. research and development agency for SAR programs. Next-generation international SAR programs are also in development and will be integrated with DASS as upgrades to the C-S system to provide worldwide life-saving search and rescue services. The proof of concept phase of DASS will be followed by a NOAA-managed demonstration and evaluation phase and subsequent incorporation of DASS into the C-S alerting system.

Finding: NASA has exceeded its agreed-to budget for DASS. Considerably more funds are needed to complete the proof-of-concept phase, and this additional budget may not be supported by NASA headquarters. If the FY 2008 budget cycle results in changes in NASA program funding, it is uncertain whether the DASS proof of concept can be completed in a form that reflects the plans and agency agreements the committee reviewed in this study. The impacts on the plans of participating agencies are also not known.

Recommendation: As chair of the DASS Management Working Group, NASA should assemble the interagency participants in the DASS proof of concept, review the program's progress toward meeting technical, operational, and programmatic requirements, review interagency and international commitments, and negotiate a plan for the future of DASS.

Communications and Navigation Architecture

The communications and navigation architecture program element is responsible for defining the space communications and navigation architecture to support NASA's science and exploration missions through 2030. This architecture must evolve through 2030 and beyond to keep pace with the needs of future science and exploration users, and, potentially, non-NASA users. The Communications and Navigation Architecture program element accomplishes its task through NASA's agency-wide Space Communications Architecture Working Group (SCAWG). SCAWG's membership includes representatives from the communication networks, the user community, NASA centers, and each NASA mission directorate.

Recommendation: NASA's top management should implement a management structure that involves the affected science and mission programs and other users and ensures support for, and compliance with, the long-term communications and navigation architecture.

Technology

The technology element of the Space Communications Office is chartered to identify NASA communications capability needs across the agencies' missions, track candidate enabling concepts and technologies, and develop those promising technologies through focused investment. The SCO uses a dedicated technology assessment team within its Space Communications Architecture Working Group to generate focus areas, direct technology development investments, and manage and track projects for infusion into future NASA systems.

The committee found a solid program management foundation that, if fully executed, would provide effective management of the technology development program. Several perceived limitations were identified in the execution of the overarching program, including a potential lack of uniformity in planning project executions and an occasional decoupling of top-down NASA mission needs and the bottom-up development of enabling technologies. The committee's conclusions for this element can be summarized as advising that a more formal, integrated management effort be undertaken across the technology element, to include peer review evaluations with stakeholders and partners and a uniform application of systems analysis to provide inputs for investment decisions, including selection, continuation, and termination of project efforts.

Operations Integration

The operations integration program element is charged with the task of managing communications activities for human spaceflight. This role requires the operations integration team to coordinate with the Space Shuttle program, the International Space Station program, and the contractors that serve them. The operations integration team oversees the combined efforts of a distributed set of contractors who must work together seamlessly to support a common mission, coordinates with a wide range of domestic and international entities, manages requirements between the Mission Control Center and the various components of the space communications infrastructure, and reviews and certifies the readiness of communications-related hardware, software, and personnel for human spaceflight. In reviewing this element, the committee's key findings included the following:

Finding: NASA missions that involve human spaceflight rely heavily on the skills and influence of several highly experienced individuals to manage their communications activities and provide readiness assurance.

Finding: NASA's center-based contract structure makes it critical for operations integration team members to be both highly experienced and widely respected across many organizations within NASA.

Finding: The individuals responsible for managing and executing the operations integrations program element do an excellent job in the eyes of their customers, the Space Shuttle and International Space Station programs.

NOTES

1. TDRSS replenishment as used in this report refers specifically to the next acquisition of replacement spacecraft needed to maintain some (currently unspecified) level of service to users as the on-orbit spacecraft reach the end of their useful life. Neither the planned capabilities/configuration of these replacement spacecraft, nor possible alternative approaches to provide comparable service, have been developed as yet and therefore were not assessed by the committee.
2. In spectral bands allocated for passive and active space research, space operations, passive and active Earth-exploration, and meteorological satellite, intersatellite, radionavigation, and deep-space research services.
3. Kelley, John D., NASA SOMD, personal communication, March 1, 2006.

1

Introduction

BACKGROUND AND GENERAL OVERVIEW

At the request of NASA, the Aeronautics and Space Engineering Board of the National Research Council (NRC) formed a committee to assess the overall quality of the space communications program of NASA's Space Operations Mission Directorate (SOMD) and offer findings and recommendations. This review included an examination of internal and collaborative activities and an overall peer assessment of SOMD's space communications program, which is carried out by the Space Communications Office (SCO). An overview showing the various program elements of the SCO is given in Figure 1.1.

The overall objective of SOMD is to "ensure the provision of space access and improve it by increasing safety, reliability and affordability."[1] Accordingly, SOMD provides services for launch, space communications, and rocket propulsion testing in support of NASA, other government, and commercial interests. Within SOMD, the SCO's primary objectives are to provide communications and data services for every flight mission, with each of the eight elements shown in Figure 1.1 contributing in diverse ways to meeting these objectives.

NASA asked the Committee to Review NASA's Space Communications Program to use specific criteria, where appropriate, as part of its assessment of the SCO program. The specific criteria were outlined in the following four key areas:

1. **Formulation of the program plan.** The focus of this criterion was to assess whether the space communications program had clearly defined goals and objectives. Does the program reflect a clear understanding of needs and has it articulated these needs to other organizations? Are the space communications program services accomplishing program activities, providing sufficient planning, and meeting customer needs?
2. **Connections to the broader community.** The focus of this criterion was to assess whether there is evidence that the program utilizes appropriate work already done by other agencies outside NASA; out-of-house work; and interoperability issues associated with other related agencies.
3. **Methodology.** The focus of this criterion was to assess how well the program plans are crafted, and the level of assessments, whether or not risk is properly being managed, and whether near- and longer-term studies are reasonable and justifiable.
4. **Overall capabilities.** The focus of this criterion is to assess the quality of the work compared to similar world-class efforts and if such work meets the requirements of the customers. The committee also explored the qualifications of NASA and contractor personnel, whether there were sufficient levels to meet program goals, and the overall state of program readiness.

NASA then asked the committee to use the criteria outlined above to evaluate the following operational networks and other program elements:

- **Operational networks**
  —Space Network
  —NASA Integrated Services Network (NISN)
- **Other program elements**
  —Spectrum management
  —Data standards management
  —Search and rescue
  —Communications and navigation architecture
  —Technology development
  —Operations integration

ELEMENTS OF SOMD'S SPACE COMMUNICATIONS PROGRAM

As previously stated, the primary objectives and out-

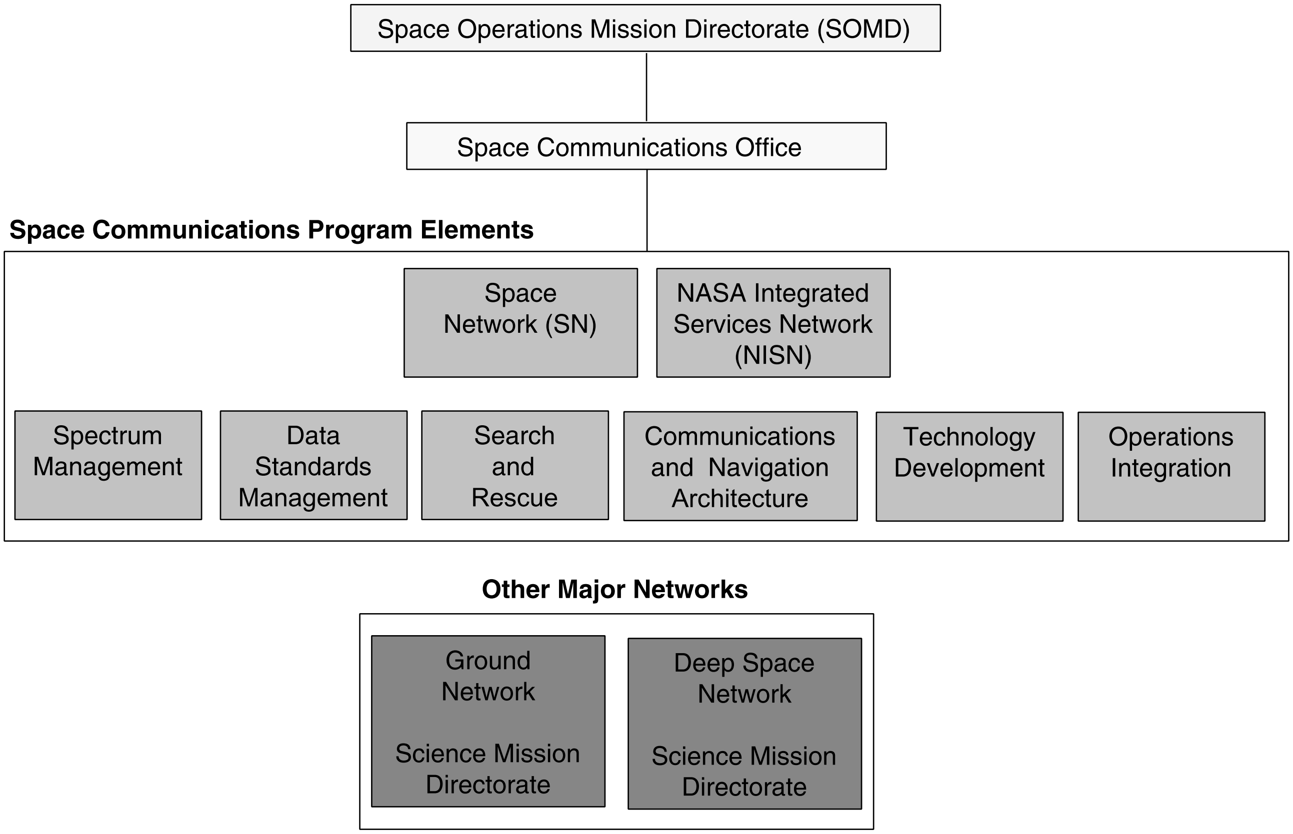


FIGURE 1.1 Space Communications Office (SCO) and its eight program elements. Also shown are two major communications networks that fall outside the SCO. SOURCE: Adapted from the NASA organizational chart, available at http://www.spacecomm.nasa.gov/spacecomm/about/orgchart.cfm, accessed May 12, 2006.

comes of the SCO are to help ensure the provision of space access by providing communications and data services for every flight mission. As illustrated in Figure 1.1, the SCO at NASA encompasses eight elements. For convenience, these elements are categorized here as either operational networks or other program elements. The **operational networks** include the Space Network and NASA Integrated Services Network, which are focused on providing continuous, near-global coverage for near-Earth missions, space-based relay for high-data-rate access, telecommunications services, and administrative communications. The **other program elements** support an array of near- and longer-term NASA needs for spectrum management, communications data standards, space-based distress and alerting and locating capabilities, and navigation and communications technologies, along with overall program management and operations integration.

Operational Networks

The operational networks are the elements of SOMD's space communications program that provide tracking, telemetry, command, and data acquisition in support of Space Shuttle, Space Station, space science, and Earth science missions. The **Space Network** consists of a constellation of communications satellites—the Tracking and Data Relay Satellite System (TDRSS) and a series of tracking stations to provide tracking and data relay services to NASA, non-NASA government, and commercial and international customers 24 hours per day, 7 days per week. The **NASA Integrated Services Network** provides telecommunications services among facilities such as NASA flight support networks, mission control centers, and science facilities, and it supplies administrative communications among NASA centers.

Other Program Elements

Spectrum management is crucial to the successful pursuit of all NASA missions. All agency flight programs require interference-free access to use of spectrum for communications to support launch, orbiting, navigation, telemetry, control, and sensor activities. **Data standards management** facilitates the interoperability of NASA space

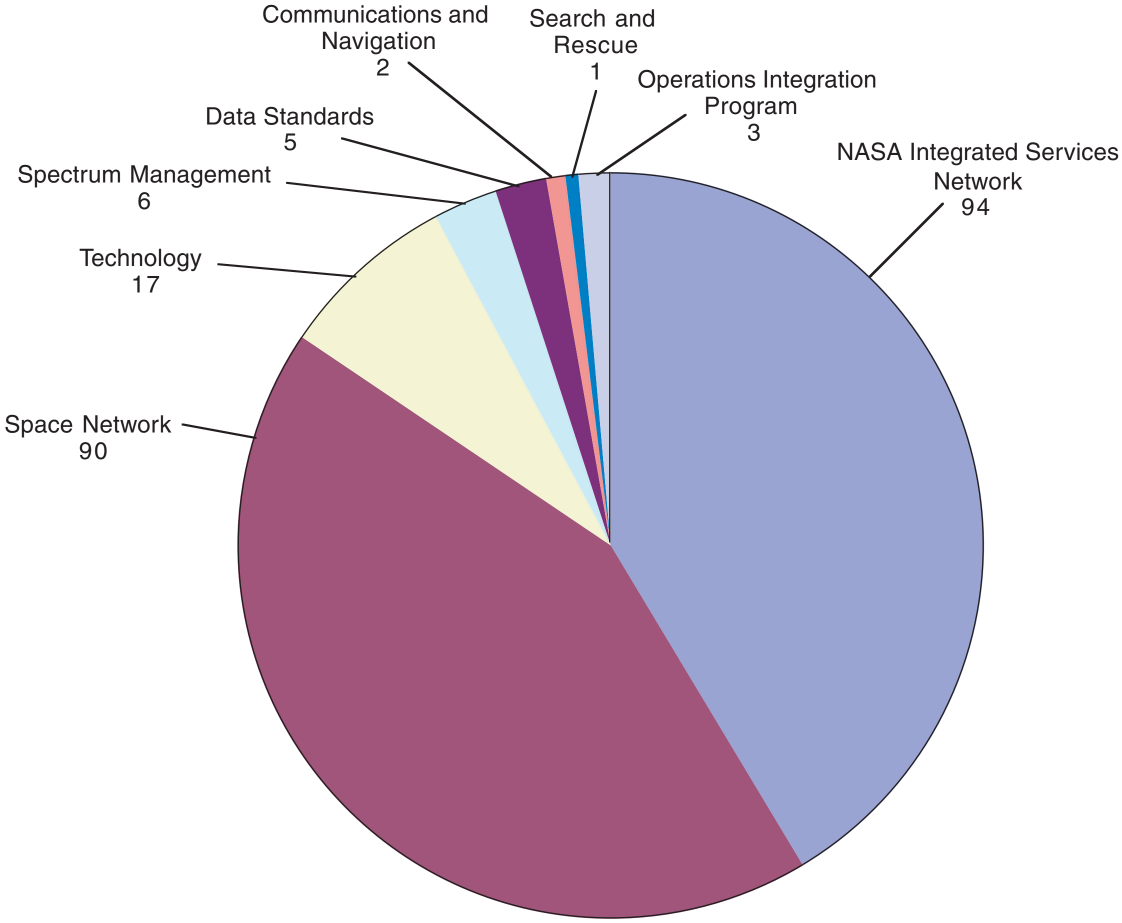


FIGURE 1.2 Annual budget for 2006 (in millions of dollars) for the eight elements of SOMD's space communications program. SOURCE: Budget data provided by NASA.

communications facilities through the use of common data standards. In addition, efforts to develop data standards play an important role internationally in fostering cooperation with other agencies and organizations. NASA is also responsible for research and development for a **search and rescue** capability. With existing emergency beacons in use worldwide on aircraft, ships, and individuals, and satellite-aided search and rescue contributing to the rescues of humans both nationally and internationally, search and rescue continues to be a critical element for NASA. Space **communications and navigation architecture** supports NASA's current science and exploration missions and is focused also on future exploration. **Technology development** also supports the current and future needs of NASA missions, investing in key communications and navigation technologies for NASA's future. The **operations integration** program element is charged with managing communications activities and assuring communications readiness for missions involving human spaceflight, focusing on support to the Space Shuttle and International Space Station programs.

Figure 1.2 provides an overview of the annual budget for each of the element areas associated with SOMD's space communications program.

STUDY APPROACH AND ORGANIZATION

Figure 1.3 provides an overview of the committee's study purview as it relates to the program elements and their various functions described above. The left-hand side of Figure 1.3 represents the primary focus of the committee's work in assessing the overall quality of the space communications program. To the right of the darkened line are those areas not examined by the committee's work, as those areas currently fall outside the direct responsibility of the SOMD space communications program.

The primary purpose of the committee's work was to provide peer assessments that would supply broad program and technical advice to the Space Communications Office and, in so doing, help to ensure that NASA continues "to provide and improve high-quality, reliable, cost-effective space communications networks and services" and to "develop breakthrough information and communication systems

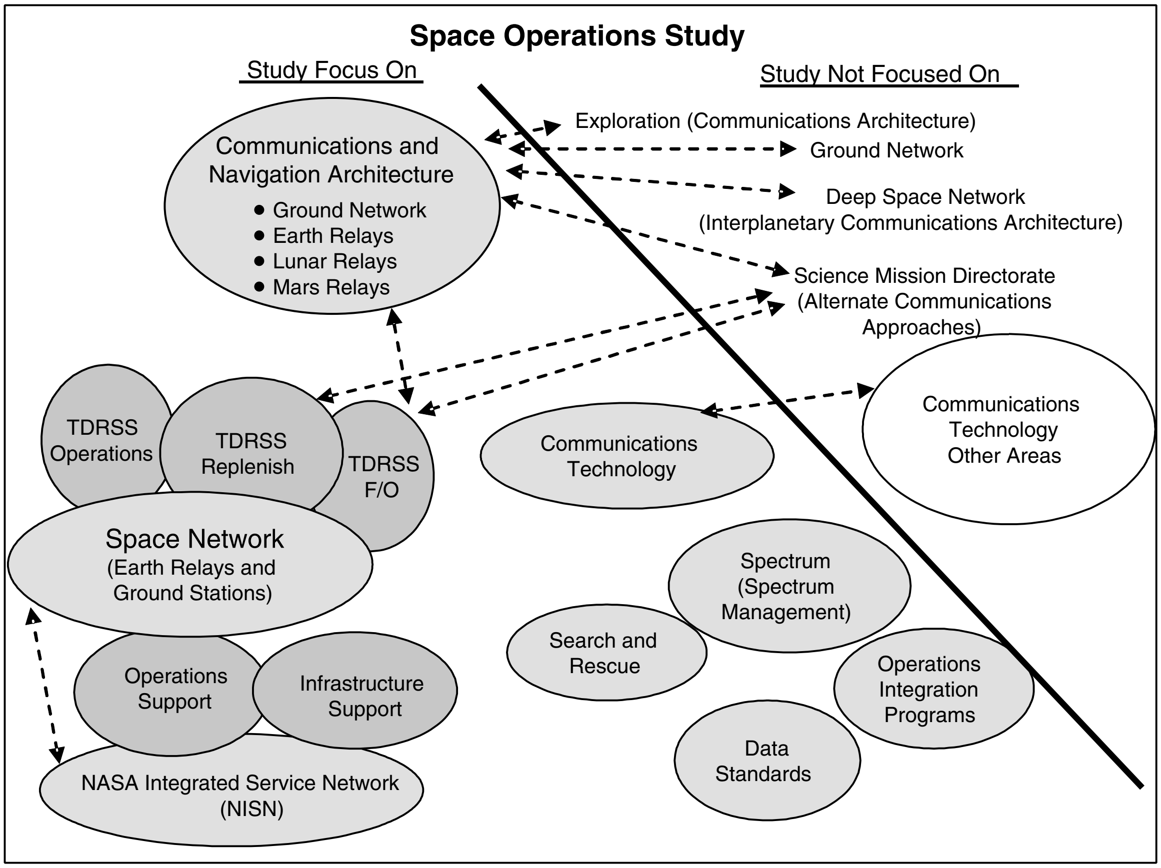


FIGURE 1.3 Study purview and element areas.

to increase NASA's understanding of scientific data and phenomena."[2] In discussions regarding this task, NASA indicated that it viewed the charge to the committee as posing the question, Is NASA doing things right?, rather than, Is NASA doing the right things? Thus the committee focused on determining the effectiveness of the current programs, rather than the exploration of alternate program designs.

Approach to the Assessment

The Committee to Review NASA's Space Communications Office was established by the NRC in December 2005. Its members included a cross section of senior executives, engineers, researchers, and other aerospace professionals (see Appendix B). As noted above, the committee was charged with independently assessing the overall programmatic and technical quality of the SOMD space communications program. These assessments included findings and recommendations on NASA's internal and collaborative research, development, and analysis regarding the Operations Network and element areas. While the primary objective was to conduct peer assessments, the committee did offer programmatic advice when such advice followed naturally from technical considerations.

The committee met at the National Academies' Constitution Avenue Building in Washington, D.C., on January 26-27, 2006, for an overview of the SOMD program and its various elements. Teleconferences and other information-gathering activities followed the first committee meeting. Subgroups of committee members subsequently participated in site visits to Goddard Space Flight Center in Greenbelt, Maryland, prior to the second committee meeting. The committee met again in Washington, D.C., on March 14-16, 2006. The March meeting was followed by additional site visits to NASA Johnson Space Center in Houston, Texas, and Marshall Space Flight Center in Huntsville, Alabama. In addition, numerous telephone conferences with key points of contact at NASA were completed, and a review of more than 95 related NASA publications, reports, and presentations was conducted.

During April 18-20, 2006, the committee held a third meeting at the National Academies' Beckman Center in Irvine, California. The focus of this meeting was to reach consensus on findings, recommendations, and overarching issues and to complete the writing of the final report.

Organization of This Report

This report focuses on two areas of assessment of SOMD's space communications program: (1) the operational networks and (2) other elements. Chapters 2 and 3 examine the overall quality of the operational networks and present a series of findings and recommendations (where appropriate) related to the Space Network and the NASA Integrated Services Network. Chapters 3 to 9 focus on the program's other elements, which include spectrum management, data standards management, search and rescue, communications and navigation architecture, technology development, and operations integration. In each of these chapters the committee attempts to address those questions in the statement of work that are applicable to that element. Chapter 10 looks at requirements, program management, and overlapping activities. Also presented in Chapter 10 are the committee's findings and recommendations on overarching issues. This report as a whole provides an overview, evaluation, and summary of the program elements outlined and assesses the overall quality of the space communications program of NASA's Space Operations Mission Directorate.

NOTES

1. Spearing, Robert, "Space Communications," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006.
2. National Aeronautics and Space Administration (NASA), NASA Strategic Plan, Washington, D.C., 2003.

Assessment of Operational Networks

2

Space Network Program Element Assessment

INTRODUCTION

The Space Network is a major element of the Space Operations Mission Directorate's (SOMD's) space communications program. It consists of a constellation of Tracking and Data Relay Satellite System (TDRSS) communications satellites and a series of ground tracking and relay stations to provide services to NASA, other government agencies, and commercial and international customers 24 hours per day, 7 days per week (Figure 2.1).

The Space Network's mission is to "provide global coverage tracking and data acquisition services during launch, early orbit, and operations in low Earth orbit, and satellite anomaly investigation via a constellation of geosynchronous satellites, and associated ground systems located in New Mexico and Guam."[1]

Since the 1980s, NASA has operated the TDRSS to provide communications links between Earth and low-Earth-orbiting satellites at S-, Ku-, and Ka-band frequencies. The TDRSS satellites are located in geosynchronous Earth orbit and are positioned in orbital locations that are in constant view either of the White Sands Complex (WSC) at NASA's White Sands Test Facility in New Mexico, or of NASA's Guam remote ground terminal (GRGT). The assigned orbital locations provide continuous or full-period telemetry, tracking, and command coverage for near-Earth-orbiting satellites.

The original TDRSS constellation was intended to provide three fully operational satellites, one in the East (or Atlantic region) at 041 degrees West longitude, one in the West (or Pacific region) at 171 degrees West longitude, and a fully functional spare at 079 degrees West longitude. The baseline configuration is depicted in Figure 2.2. Over the years the robust performance of the TDRSS satellites, as well as additional loading requirements, resulted in NASA's expansion of the system and the use of more spacecraft.

The current TDRSS constellation consists of six first-generation (F1 and F3-F7) and three second-generation (F8-F10) satellites, with three of the nine satellites being stored on orbit. The first-generation spacecraft support three categories of service: single access, multiple access, and tracking at the S and Ku bands. The second-generation spacecraft added Ka-band forward and return services in addition to the S- and Ku-band capabilities. Figure 2.3 depicts the current TDRSS constellation orbital placement, Table 2.1 gives the launch dates, and Figure 2.4 indicates the overall health of the TDRSS constellation. Figure 2.5 shows projected TDRSS constellation capacity based on failures experienced to date and long-term reliability models. The lower portion of Figure 2.5 shows anticipated user demand for service (hours per day), representing in excess of 60 different missions through 2017. The on-orbit health issues reflected in Figure 2.4 have had limited impact on tracking and data relay services at this time due to built-in redundancy and operational rescheduling. Specific failure trends are closely monitored and used in individual satellite as well as constellation end-of-useful life projections.

The TDRSS satellites are controlled through the WSC and the GRGT. The WSC consists of two functionally equivalent ground terminals that provide network scheduling and command and control of the TDRSS satellites, as well as serving as the relay points for customer data to the necessary control and data collection centers. The GRGT is used to support the TDRSS satellite located at 085 degrees East longitude (275 degrees West) and the customer satellites serviced through that relay. Major ground system upgrades were completed in 1994 (second TDRSS ground terminal) and 1996 (White Sands ground terminal upgrade). The GRGT became operational in 1998, expanding system capability to global coverage for near-Earth missions. A Space Network expansion project is under way to add up to two additional ground terminals to increase available TDRSS capacity. For more than 20 years, the Space Network has supported a wide variety of near-Earth missions, including

The Space Segment—9 Satellites
- 5 operational
- 3 in storage
- 1 residual (dedicated to the National Science Foundation)

The Ground Segment
- White Sands Complex
  - White Sands Ground Terminal
    - — 2 Space-Ground Link Terminals
  - Second TDRSS Ground Terminal
    - — 3 Space-Ground Link Terminals
  - Data Services Management Center
    - — Scheduling
    - — Monitor and control
- Guam Remote Ground Terminal
  - 1 Space-Ground Link Terminal

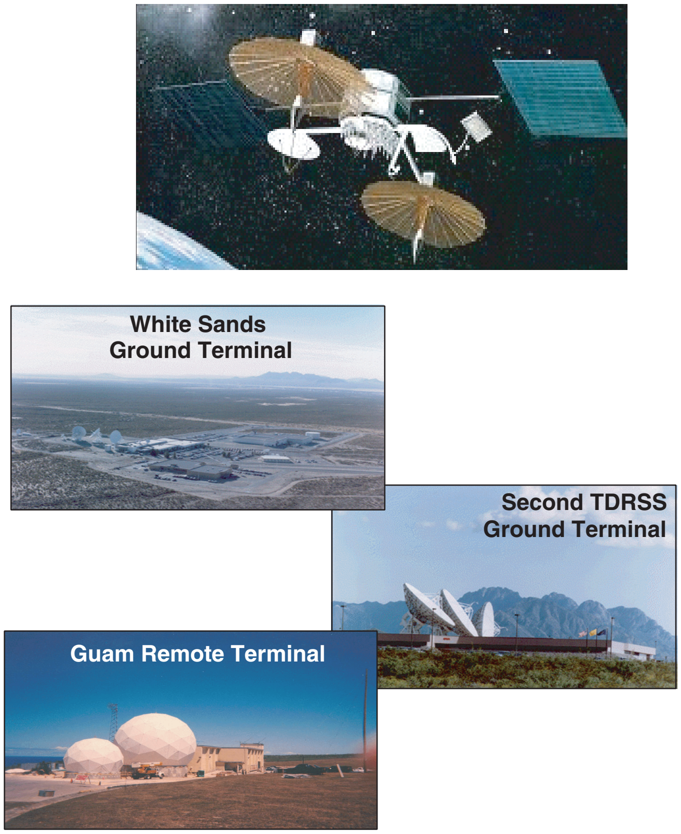


FIGURE 2.1 NASA's Space Network, comprising the TDRSS space segment and a ground segment. SOURCE: Ken Ford, NASA, "Space Network," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006, p. 6.

scientific, environmental, and human spaceflight missions, as well as launch vehicles and other non-NASA efforts. This capacity for global coverage and connectivity is expected to continue and expand as NASA defines future science and exploration missions. Planning for Space Network continuation apparently has started, but no details were available for assessment by this committee.

ASSESSMENT

Formulation of the Project Plan

Project Objectives

The Space Network's objectives are clearly articulated in the mission statement; they are aligned with the NASA Strategic Plan[2] and are traceable to the NASA Vision for Space Exploration.[3,4] The principal focus of the Space Network is day-to-day operation of the space and ground segments of the TDRSS to provide global tracking and data relay services. Continuity of these services represents a significant technical and budgetary challenge to the Space Network as the existing architecture ages and new demands for service are identified.

The agency-wide Space Communications Architecture Working Group (SCAWG) addresses the communications and navigation architecture needed to support future (25 years) NASA science and exploration missions. At this writing, specific details are pending on both the architectural roadmap and a realignment of management responsibility for space communications.

Project Deliverables

Current Space Network activities are well structured to provide documented services to a broad range of users.[5] The Space Network interacts daily with the user community, providing services within the network's established capacity and capability. Formal project service-level agreements or memoranda of agreement with both the NASA and non-NASA user communities document the specific Space Network services to be provided. The project service-level agreement is a formal agreement between the project office and the customer for services, at a specific cost, within a

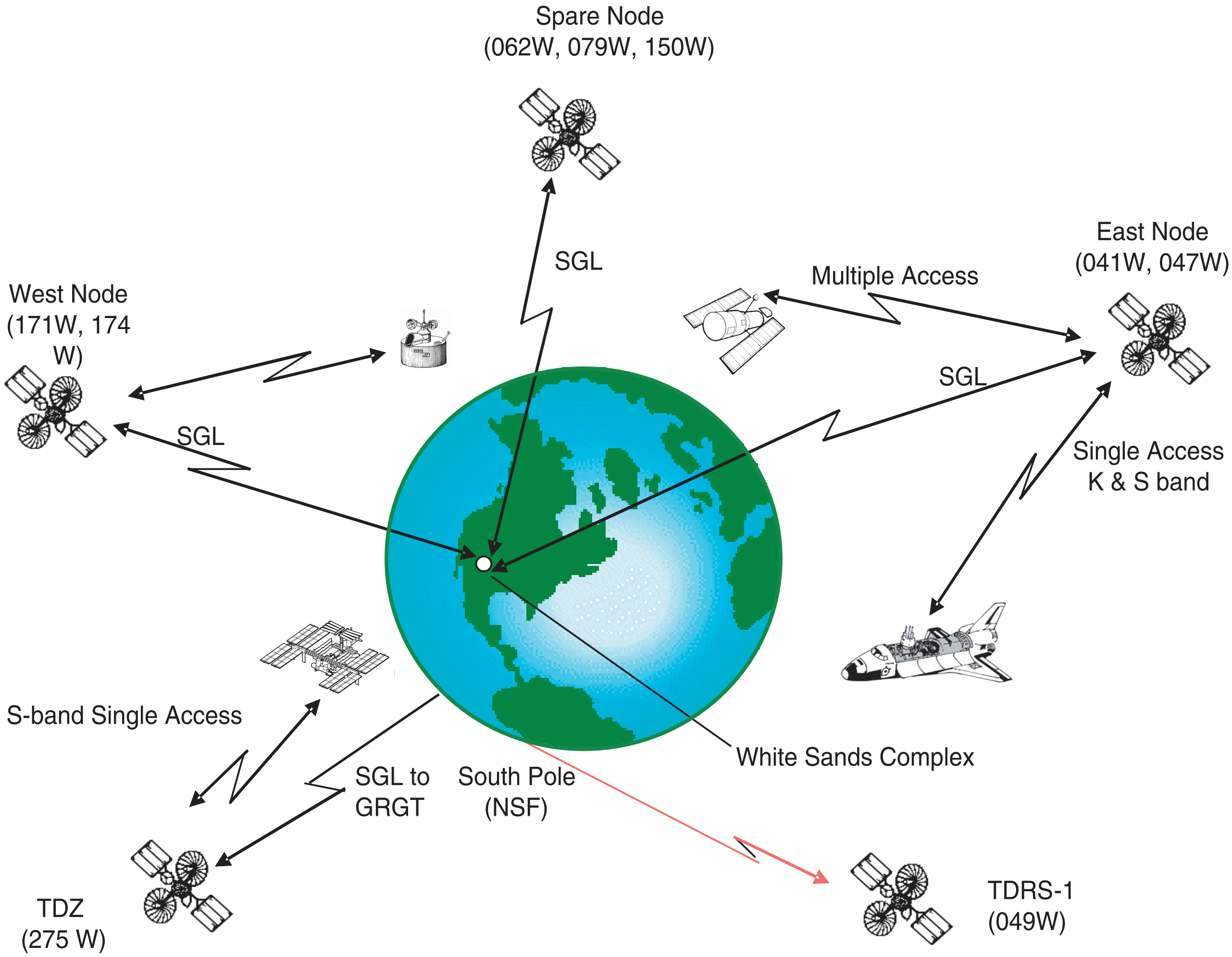


FIGURE 2.2 Tracking and Data Relay Satellite System baseline configuration. SOURCE: Ken Ford, NASA, "Space Network," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006, p. 5.

specified time frame. Committee discussions with a cross section of the customers indicated general satisfaction with the level and timeliness of the services provided. A number of metrics have been developed and are closely monitored to ensure satisfactory overall Space Network performance.

The day-to-day customer mission requirements are addressed through a formal customer commitment process and the Customer Commitment Office. This office provides tracking and data acquisition options, assistance with mission-unique communications needs, and assistance in defining those needs.

The total Space Network 2006 budget of $90 million represents approximately 50 percent of the budget that is actually appropriated for the SOMD space communications program.[6] That appropriated budget is currently augmented by reimbursable revenue from non-NASA users for Space Network services provided to them. However, as of January 2006 it was projected that the portion of the 2006 Space Network budget derived from these reimbursable sources would drop below the $70 million minimum level needed for operations and maintenance of the network. Such losses will be exacerbated as the constellation capacity for support to non-NASA missions degrades, as discussed in later sections.

Expected Services

The Space Network has a capacity/capabilities-driven architecture, rather than a requirements-driven architecture. There are continuing initiatives by the Space Network program element to interact with potential new users during the design phase of their missions. Documentation describing the Space Network's capability, capacity, and services is widely distributed and available for users considering use of the Space Network to satisfy their mission needs. As a result, there is not a formal process for reviewing and validat-

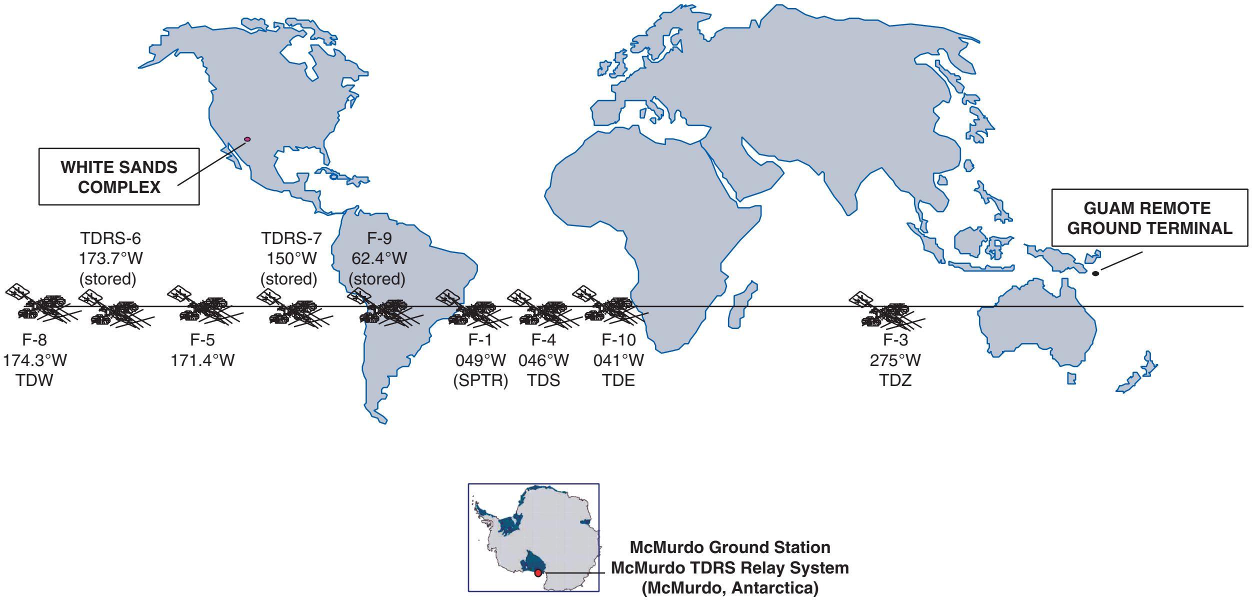
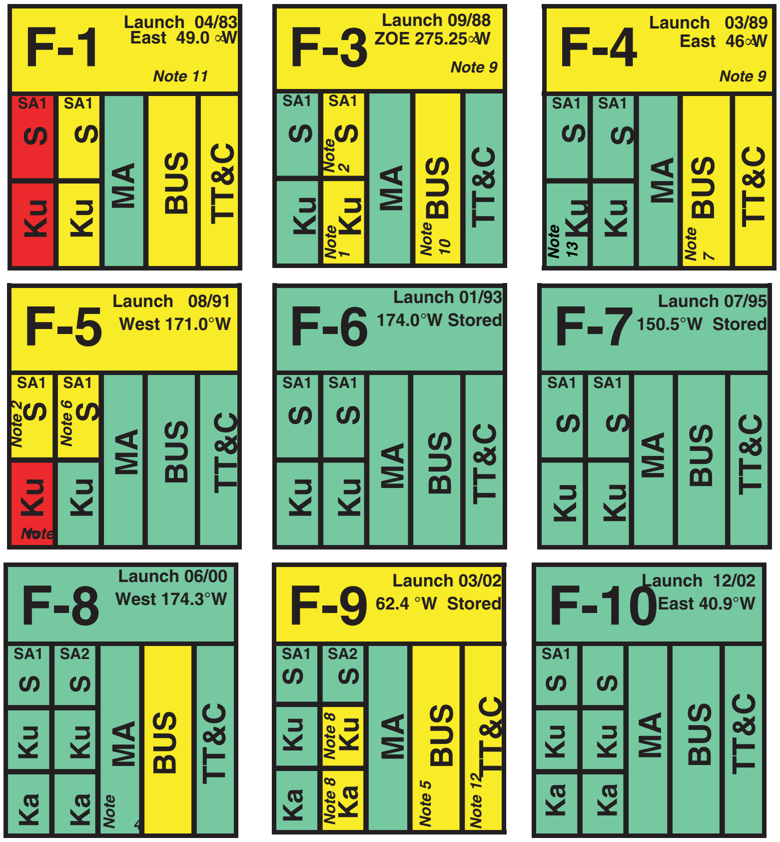


FIGURE 2.3 Space Network overview and current TDRSS constellation orbital placement. SOURCE: Ken Ford, “Space Network,” briefing to the NRC Committee to Review NASA’s Space Communications Program, Washington, D.C., January 26-27, 2006, p. 9.

TABLE 2.1 Current TDRSS Constellation

S/C	Launched	Geosynchronous Orbit	In-Orbit Checkout Complete	Utilization
TDRS-1	April 4, 1983 STS-6 (Challenger)	June 29, 1983	December 28, 1983 One Satellite System Acceptance April 1985	Operating at 49°W, providing South Pole Support
TDRS-3	September 29, 1988 STS-26 (Discovery)	September 30, 1988	January 15, 1989 Two Satellite System Acceptance July 1989	Operating at 275°W
TDRS-4	March 13, 1989 STS-29 (Discovery)	March 14, 1989	June 9, 1989	Operating at 46°W
TDRS-5	August 2, 1991 STS-43 (Atlantis)	August 3, 1991	October 7, 1991	Operating at 171°W
TDRS-6	January 13, 1993 STS-54 (Endeavor)	January 14, 1993	March 4, 1993	In storage 174°W
TDRS-7	July 13, 1995 STS-70 (Discovery)	July 14, 1995	August 22, 1995	In storage 150°W
TDRS-8	June 30, 2000 Atlas IIA	July 1, 2000	April 23, 2002	Operating at 174°W
TDRS-9	March 8, 2002 Atlas IIA	September 30, 2002	February 14, 2003	In storage 62°W
TDRS-10	December 5, 2002 Atlas IIA	December 6, 2002	May 9, 2003	Operating at 41°W

NOTE: TDRS-2 lost January 28, 1986, aboard STS-51-L (Challenger).
SOURCE: Ken Ford, NASA, “Space Network,” briefing to the NRC Committee to Review NASA’s Space Communications Program, Washington, D.C., January 26-27, 2006, p. 31.



🟩 **Indicates fully operational**

🟨 **Indicates backup unit(s) in use**

🟥 **Indicates failed subsystem**

General Notes:

- One spare SGL TWTA on F-3 and F-4
- Ten-year design life for F-1 - F-7, 11 years for F-8 - F-10, and 4 years for on-orbit storage

Notes:

- F-3 KSA2 polarization restricted to LCP, KSAR2 low performance; redundant Ku-band parametric amplifier selected to recover from switch anomaly
- S-band TWTA failed on F-3 (SSAF2), F-5 (SSAF1)
- Both Ku-band TWTA units on F-5 failed (KSAF1); return available
- F-8 MAR G/T shortfall
- F-9 propulsion anomaly: failure of A-3 and W-2 thrusters
- SSAR2 parametric amplifier failure on F-5
- F-4 ESA and MFG LO failures
- F-9 LO failure KSAR2
- KSA polarization services restricted on F-3 and F-4
- F-3 Primary coarse sun sensor failure
- F-1 SA2 SSAR and SSAF, KuSAR2 operational using WART
- F-9 primary central telemetry and Command Unit failure
- F-4 KSA1F TWTA failure

****Indicates updates and changes**

FIGURE 2.4 Health of the TDRSS constellation as of September 1, 2005. SOURCE: Ken Ford, NASA, "Space Network," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006, p. 32.

ing the totality of Space Network customer community requirements to establish a minimum acceptable, or threshold, level of Space Network capacity. The current process has worked well to date, but the need for infrastructure replenishment, upgrade, and transition to meet emerging exploration needs will demand an earlier and more formal interaction between the communications provider and the mission definition efforts.

Finding: The Space Network has a capacity/capabilities-driven architecture, rather than a requirements-driven architecture. Current Space Network activities are well structured to provide documented services to a broad range of users.

Long-Term Project Goals and Objectives

There is some indication of planning for near-term continuation of Space Network support for NASA missions, specifically TDRSS satellite replenishment,[7] but no commitment of resources as of this writing. There is no indication of planning for an orderly transition to the out-year architecture. TDRSS constellation reliability has been identified as the number-one Space Network risk, with the potential for a significant impact on NASA missions starting in the 2015 time frame.[8] See Figure 2.5. Moreover, a projection of capacity to support non-NASA missions shows a gap starting in the 2010 time frame. The committee noted that it is in NASA's best interest to continue to participate with the other organizations addressing this issue. Unless specific programmatic actions are taken to reverse the shortfall in capacity, significant competition for limited resources will require decisions about prioritization and/or degraded mission support. Space communications program management has stated that a TDRSS satellite replenishment initiative, to support only NASA mission needs, will be submitted for inclusion in the FY 2008 budget. The committee agrees with this approach and strongly supports the need for an FY 2008 acquisition start.

Finding: A NASA TDRSS satellite replenishment decision is needed not later than the FY 2008 budget cycle in order to ensure continuity of communications support for NASA missions.

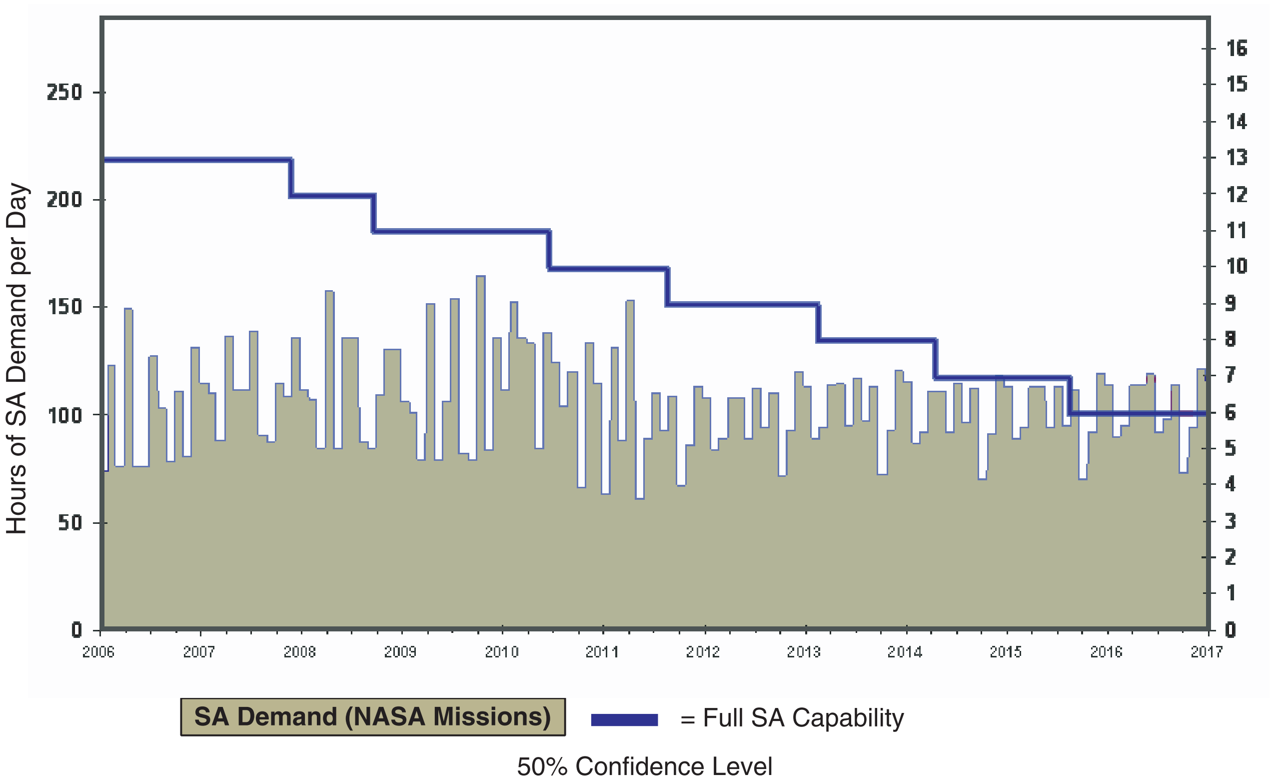


FIGURE 2.5 TDRSS capacity to support NASA missions, 2006 to 2017. Single access (SA) means provision of service to only one user at a given time. SOURCE: Ken Ford, NASA, “Space Network,” briefing to the NRC Committee to Review NASA’s Space Communications Program, Washington, D.C., January 26-27, 2006, p. 28.

Recommendation: NASA should develop a compelling case for a TDRSS satellite replenishment acquisition start for the FY 2008 budget cycle.

Connections to the Broader Community

Department of Defense

Various elements of the Department of Defense (DOD) are represented in the user base of TDRSS services. This relationship is expected to continue; however, NASA’s planning for the sizing and the schedule for replenishment of the TDRSS space segment is proceeding independently of these external user considerations.

There is no substantive interaction between SOMD’s space communications program and the ongoing DOD MilSatCom efforts.[9] NASA was involved with DOD in the original definition of the federal government’s Transformational Communications Architecture (TCA); however, there is little interaction at this time as elements of the TCA move into development and acquisition. NASA space communications are no longer an integral element of the TCA. At a minimum, some degree of interoperability between NASA’s Space Network as it evolves, and DOD MilSatCom would seem to be a worthwhile goal, but there is no indication of real movement in that direction.

Finding: The original objective of an appropriate level of interoperability between NASA/TDRSS and MilSatCom/TCA is still a worthwhile goal.

Recommendation: NASA should reestablish executive-level discussions with DOD MilSatCom to examine options for systems interoperability.

National Science Foundation

Since 1997 the oldest TDRSS satellite (F1, launched in 1983) has provided the bulk of the high-bandwidth data support for the National Science Foundation’s (NSF’s) advanced astronomy and astrophysics programs at South Pole Station.[10] Projected increases in needs for data transfer, and the apparent absence of cost-effective long-term alternatives for continuation of service, present a significant dilemma for the NSF. While informal discussions on future NSF needs have taken place between NASA and NSF personnel, the NSF has not been a formal participant or consideration in NASA’s planning for future communications architectures, and future support for the NSF astronomy program's increasing data communications needs is uncertain.

Finding: There appears to be a "caveat emptor" mind-set when it comes to consideration of communications service continuity (TDRSS satellite replenishment and longer-term continuity of service) for the non-NASA user community.

Recommendation: If in fact TDRSS, plus its follow-on, is truly a national asset, NASA should take the lead in identifying the appropriate policy, the required resources, and the planning, implementation, and requirements validation process necessary to serve all TDRSS user communities' needs for communication services.

Utilization of Commercial Space Systems

NASA conducted a comprehensive assessment of alternatives to TDRSS and in 2000 published a report that evaluated the technical feasibility as well as the business risk of using a commercial satellite system to support NASA low-Earth-orbit (LEO) missions.[11] The technical areas evaluated included the coverage and throughput available to NASA LEO users and the requirements that could be imposed on NASA LEO users to receive these necessary services. The business risk assessment identified characteristics of the commercial environment that affect the feasibility of relying on commercial satellite systems to support NASA LEO missions.

The assessment's principal conclusions included the following: commercial systems are designed for commercial users; NASA's high-volume traffic might be poorly supported; no commercial systems have the flexibility or the capacity of TDRSS; no commercial system can support NASA's real-time communications requirements for manned spaceflight or launch missions; coverage decreases with increased user altitude due to the conic shape of the antenna beams of commercial satellites; coverage is usually not available for polar regions at LEO altitudes, reducing coverage for missions with highly inclined orbits, such as Earth Observing System satellites and LandSat; and coverage is not continuous for most LEO missions, and typically is not guaranteed owing to business imperatives.

The committee noted that many of the assumptions about baseline availability and performance characteristics of the eight representative systems made in the NASA report have changed, and an update addressing those changes would be appropriate.

In addition, although the NASA report did a commendable job in assessing a total system alternative to TDRSS, it did not look at moving specific mission communications services to commercial providers. It might be prudent to consider such an approach, in order to partially offset the predicted shortfall in capacity mentioned above, as NASA looks at TDRSS satellite replenishment and transition to a new architecture.

Finding: Commercial satellite communications systems may have limited ability to meet some of the mission needs currently being supported by the Space Network.

Recommendation: NASA should update its 2000 study using information on the current state of commercial communications systems and focus on offloading mission support needs as appropriate.

Methodology

Project Plan Completeness

NASA has developed a draft Space Network Operations Project Plan that focuses primarily on customer interactions and the day-to-day operations of the Space Network.[12]

There is no SOMD Space Network element plan, nor is there an integrating program plan for the various elements of SOMD's space communications program.

The committee believes that program planning documentation is essential in order for the Space Communications Office to address its split management responsibilities; negotiate cross-program-element requirements, resources, and scheduling issues; and provide a more unified NASA space communications interface if future collaborative efforts are initiated with military and commercial communications systems.

Finding: There is no SOMD Space Network element plan that addresses requirements, a requirements validation process, resources, and schedule, nor is there an integrating plan for all of the various elements of SOMD's space communications program. There is a draft Space Network Operations Project Plan; however, it is focused primarily on customer interfaces and the day-to-day operation of the Space Network.

Recommendation: Given the opportunity offered by the impending reorganization of space communications work across NASA, NASA should develop a Space Network element plan as part of a space communications program planning documentation tree.

Risk Management

NASA has a formal risk identification and assessment process for the Space Network. Under this process, various risk scenarios are examined, and mitigation plans are identified. As of this writing, two high-risk items have been identified by NASA:[13] long-term TDRSS satellite reliability and inadequate funding to perform required sustaining engineering and upgrades.

Overall Capabilities

Quality of Work Performed

The Space Network has performed admirably for more than 20 years, providing for a wide range of customers services that are available from no other single source. In discussions with the committee, a variety of users indicated unanimous satisfaction with service provided by the Space Network in support of their missions. As the necessary backbone for any future NASA communications initiative, the Space Network not only must be provided sufficient resources, but also must be an integral part of the planning process. The current management structure of split responsibilities for the overall NASA space communications program is being reexamined in light of new exploration and science initiatives. The establishment of a SCAWG with widespread NASA representation to focus the development of a communications and navigation architecture is a step in the right direction, but additional management and budgetary alignments should be considered to implement a truly integrated space communications program.

Finding: The Space Network today sets a world-class standard for global coverage, tracking, and data acquisition services.

Adequacy of Resources

Space Network resources (people, facilities, and budget) are adequate to execute the current project scope. However, since currently more than one-half of the $90 million annual Space Network budget derives from non-NASA users (reimbursable funds), alternative approaches should be pursued by management to provide a more stable level of support for the operations and maintenance of the Space Network.

Finding: Reliance on reimbursable funds from non-NASA users as the major component of the funding needed for the operations and maintenance of the Space Network is an unhealthy basis for long-term planning and stability.

Recommendation: NASA, in conjunction with the user community, should examine alternatives for providing long-term, stable funding at the level required for operation and maintenance of the Space Network.

The committee notes that as NASA moves forward on the exploration path there will be expanded requirements placed on the space communications enterprise that will require significant management attention, particularly in the areas of personnel qualifications, motivation, and retention. The current leadership has done a good job in these areas, but the possible implementation of a new management structure with expanded responsibilities will impose even greater demands.

NOTES

1. Spearing, Robert, “Space Communications,” briefing to the NRC Committee to Review NASA’s Space Communications Program, Washington, D.C., January 26-27, 2006.
2. National Aeronautics and Space Administration (NASA), 2006 NASA Strategic Plan, NP-2006-02-423-HQ, available at http://www.nasa.gov/pdf/142302main_2006_NASA_Strategic_Plan.pdf.
3. NASA, The Vision for Space Exploration, February 2004, available at http://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf.
4. Spearing, Robert, “Space Communications,” briefing to the NRC Committee to Review NASA’s Space Communications Program, Washington, D.C., January 26-27, 2006.
5. NASA, Space Network Operations Project Plan, 452-PLAN-0003, NASA, Washington, D.C., February 22, 2006.
6. Spearing, Robert, “Space Communications,” briefing to the NRC Committee to Review NASA’s Space Communications Program, Washington, D.C., January 26-27, 2006.
7. TDRSS replenishment as used in this report refers specifically to the next acquisition of replacement spacecraft needed to maintain some (currently unspecified) level of service to users as the on-orbit spacecraft reach the end of their useful life. Neither the planned capabilities/configuration of these replacement spacecraft, nor possible alternative approaches to provide comparable service, have been developed as yet, and therefore were not assessed by the committee.
8. Ford, Ken, “Space Network,” briefing to the NRC Committee to Review NASA’s Space Communications Program, Washington, D.C., January 26-27, 2006.
9. Pawlikowski, Brigadier General Ellen M., MilSatCom SPD, personal communication, April 13, 2006.
10. Chiang, Erick, National Science Foundation Office of Polar Programs, “Data Communications Supporting Astronomy/Astrophysics at South Pole Station,” presentation to NASA-NSF Astronomy/Astrophysics Advisory Committee, Arlington, Virginia, May 11, 2006.
11. NASA, Assessment of Commercial Alternatives to TDRS Services, GSA-118, December 2000.
12. NASA, Space Network Operations Project Plan, 452-PLAN-0003, February 22, 2006.
13. Ford, Ken, “Space Network,” briefing to the NRC Committee to Review NASA’s Space Communications Program, Washington, D.C., January 26-27, 2006.

3

NASA Integrated Services Network

INTRODUCTION

The NASA Integrated Services Network (NISN) project provides terrestrial networking for the agency. There are two separate networks: a mission network, controlled out of NASA Goddard Space Flight Center (GSFC), and an institutional network, controlled out of NASA Marshall Space Flight Center (MSFC). NISN does not provide or manage the local on-site networks at the various NASA centers.

The budget for NISN is $94 million per year. This covers facility and circuit costs, as well as a workforce composed of 25 civil service employees and about 250 contractors. The primary NISN workforce is located at GSFC (13 civil service employees and about 40 contractors) and at MSFC (12 civil service employees and over 150 contractors) to operate the mission and institutional networks. NISN has a gateway at each of the other NASA centers, with a minimal staff typically consisting of a gateway technician and a customer service representative (CSR). A site's CSR serves as the interface between institutional network users at that site and NISN personnel at MSFC.

NISN Goals

The high-level mission of NISN, as stated in the 2005 NISN project plan, is as follows:

> Provide high-quality, reliable, secure, cost-effective telecommunications systems and services for mission control, science data handling, and program administration for NASA programs and facilities.[1]

An enterprise architecture (EA) is being established to ensure that information technology expenditures are aligned with agency strategic goals. NISN will use the EA structure to align NISN goals and services with those of its customers.

NISN Services

NISN provides wide-area network (WAN) services to support all the NASA mission directorates, all NASA centers and facilities, agency institutional activities, and individual projects and missions. According to the NISN project plan, standard services offered by NISN include video teleconferencing, voice teleconferencing, switched voice, mission voice, routed data, and intrusion detection.[2] NISN custom services include dedicated data links, high-rate data/video, integrated services digital network, international communications, security services, and various services to support NASA personnel in Russia. NISN also provides network integration and consulting services, including Domain Name System service for the agency, NASA directory service (X.500), communications management and information services, ad hoc communications service, and applications services.

The mission network is a closed network, used for transmission of flight-mission data between NASA ground stations and mission operations control centers. Accessibility to the mission network is tightly controlled, and the backbone consists primarily of dedicated circuits. In contrast, the institutional network is open, providing such services as e-mail and access to the Internet. The rationale for maintaining two separate networks is the criticality of real-time mission data. Consequently, the reliability and availability requirements are more stringent for the mission network than for the institutional network. For example, the amount of time targeted for problem resolution on the institutional network is 4 hours, whereas on the mission network it is 2 hours—and it is 20 minutes if a real-time mission is involved. However, the most significant difference in requirements for the two networks is the requirement that the mission network must be "frozen" for a period of time before and during a mission, meaning that the network configuration is not to be altered during that time (e.g., no network upgrades are allowed, and no changes can be made to any network services). This is done to ensure that users will have a stable network platform to support their missions.

NISN Customers

NISN customers include all NASA centers and NASA headquarters, most flight mission programs and projects, other networks for space communication (the Space Network, Ground Network, and Deep Space Network), NASA contractors, NASA international partners, academia, and other government agencies.

The mission and institutional networks serve different sets of customers. Customers of the mission network are NASA missions; key customers include the Space Shuttle, Space Station, and Earth and space science missions. Since the institutional network supports more general NASA activities, the customer base is much broader. Specific customers include NASA missions (transmitting data to the users once it has reached the ground), employees at the various NASA centers, and NASA's academic and international partners.

ASSESSMENT

NISN is fundamentally an operational organization, providing terrestrial networking services to the agency. Hence, any review of the NISN component of the SOMD space communications program must be based on customer assessment. In the conduct of this review the committee spoke with customers of the mission network and the institutional network, as well as NISN employees responsible for the operation of both networks. The committee also obtained copies of various documents that govern project activities and responsibilities, such as the NISN project plan[3] and various customer agreements.[4]

The committee spoke with several customers of the NISN networks during site visits to NASA's GSFC, MSFC, and Johnson Space Center (JSC). At GSFC the committee spoke with NISN personnel affiliated with the mission network control room, customers from the Science Mission Directorate, and space communications personnel who interface with mission personnel to develop evolving mission communications requirements. These discussions included representatives from two space science missions: the Hubble Space Telescope and GLAST (Gamma Ray Large Area Space Telescope) and two Earth observation missions: Aura and Aqua. The committee also spoke with the Earth Science Mission Operations network manager, who indicated to the committee that his group is responsible for about half of the NISN mission network requirements.[5] The discussions probed interactions between space communications representatives and science missions throughout the mission process, as Hubble, Aura, and Aqua are all operational missions, while GLAST has not yet been launched. At JSC the committee spoke with representatives from the Space Station Program and the Shuttle Program, two major users of SOMD space communications facilities. At MSFC the committee spoke with some institutional network customers, as well as NISN personnel in charge of various aspects of the institutional network, e.g., advanced technology, security, video-teleconferencing, and customer service. The committee spoke both with civil service employees and with contractors during all three of these site visits. At GSFC the committee toured the mission network control room, and at MSFC the committee toured the institutional network control facilities.

Formulation of the Project Plan

Project Objectives

The customer-focused nature of NISN is reflected in the project objectives stated above. According to the NISN project plan, the goals and objectives of NISN are consistent with NASA's strategic plan, as "the NISN network resource provides the means for the NASA Mission Directorates to fulfill the NASA agency strategic goals of Strategic Management, Delivery of Aerospace products and capabilities, and the generation and communication of knowledge between NASA and other agencies and institutes in the United States and International Partners."[6] In addition, NISN objectives clearly support the overall goals of the SOMD space communications program goals.

Project Deliverables

Customers of the mission network at GSFC indicated a high level of satisfaction with services provided by NISN, as well as the Space Network. Space communications personnel (including NISN personnel) work closely with mission personnel throughout the mission process, from mission inception through launch and operations, to ensure that mission communication requirements are met. The GSFC space communications personnel explained their procedure for interaction with mission personnel. Several agreements document the process. They include a detailed mission requirements document, a network operations support plan, and a project service-level agreement, which is the defining document that governs the relationship between NISN and the mission. Specified in these documents are the requirements NISN is to meet for both voice and routed data services, along with start and stop dates for each identified service. Once a mission becomes operational, daily discrepancy reports identify any problems. Each problem is assigned a discrepancy report number, and the problem is tracked to closure. Most discrepancy reports are closed within the day.

The process summarized above reflects close coordination between mission personnel and the communications team from the inception of a mission, so that communications requirements are well integrated into the planning process. All customers that the committee interviewed agreed that the process works well and that they are satisfied with the services delivered by NISN.

Requirements for the institutional network are more general, because of the open nature of the network. NISN maintains a memorandum of understanding with each NASA center, which specifies services to be provided to that center. As previously noted, the customer service representative at each site is the interface between institutional network users at that site and NISN personnel at MSFC.

Performance Metrics

The NISN project plan specifies key performance indicators that are used to evaluate NISN services. These indicators include standard performance parameters such as network reliability and availability, as well as management-oriented performance indicators such as percentage of time that security incidents are resolved within 2 hours. Quantitative goals are specified for each performance indicator; if satisfied, these goals would ensure excellent service to the customer and excellent value for the agency. The complete table is available in the NISN project plan.[7]

NISN personnel within the mission network control room at GSFC monitor the performance of the network on a 24-hours-per-day/7-days-per-week (24/7) basis and have direct access to the service providers. A circuit map provides the means for a quick visual check on the status of the links. When an operator sees that there is a degradation of service on the link, he calls the service provider and the problem is addressed immediately.

The institutional network is also monitored 24/7 at MSFC. There are redundant control facilities at MSFC. In case of severe weather, such as a tornado watch or warning, a bunker-like control facility will accommodate a reduced staff to ensure that the network remains operational. A further option for maintaining operation of the institutional network is off-site telephone capabilities, including the ability to manage the network from GSFC. This careful planning for contingencies heightens the availability of the institutional network, which is vital to the everyday functioning of the agency.

Review Mechanisms

Numerous reviews of NISN are conducted throughout the year. Some are internal to the NISN project or the SOMD space communications program, and others are conducted with customers. The NISN project plan provides a complete list;[8] a summary is included below. This National Research Council committee review is apparently the first external review of NISN.

Internal NISN reviews include daily meetings to discuss network outages, weekly staff meetings, monthly financial and contract reviews, monthly status reports to the SOMD space communications program, monthly reviews of requests for changes to policies and processes, and annual reviews to map NISN services to customer needs and to plan future directions.

Reviews with customers include annual reviews of requirements and budgets; quarterly video teleconferences to brief customers on ongoing NISN activities and on new and modified services, and to solicit customer feedback; and an annual customer forum. These customer forums, typically attracting about 250 attendees, provide a valuable opportunity for customers to interact with NISN and with each other. Customers of both the mission and the institutional networks can share their experiences, compare their networking requirements, listen to presentations of new technologies, meet in birds-of-a-feather sessions, learn about updates or changes to NISN policy and processes, or just meet with NISN team members.

Connections to the Broader Community

NISN leverages developments within the commercial networking community. The circuits for both the mission network and the institutional network are provided commercially via the U.S. General Services Administration’s Federal Technology Service contracting mechanism. This strategy of using the federal government contracting mechanism ensures the best possible price for NASA, since under Federal Technology Service regulations vendors cannot charge lower prices to any non-governmental entity than the prices quoted in their government bids. Currently AT&T provides the mission network, and Qwest recently won a contract to provide an upgraded institutional network (the WAN replacement network). The mission network is undergoing a technology upgrade this year, with AT&T replacing some obsolete equipment at no charge to NASA. This indicates a relationship that is beneficial to NISN.

NISN maintains a small civil service staff. Contractors perform the majority of the work, with the skeleton civil service staff retaining the management and decision-making responsibilities. The civil service staff sets policy, determines network requirements, architects the network, and monitors contractor activities; contractors operate the network. Although there are multiple contractor companies, both contractors and civil service employees at GSFC and MSFC assured the committee that all NISN employees work together as a unified team. NISN civil service and UNITeS (Unified NASA Information Technology Services is the name of the primary NISN contract) contractor personnel appear to work in close partnership, and the UNITeS performance rating for each 6-month period has consistently been “excellent.”[9] According to NISN management at MSFC, any issues that arise are resolved immediately, precluding the need to be included in the 3- or 6-month reporting structure.

Finding: Further outsourcing for the NASA Integrated Services Network appears to be infeasible, without negatively impacting the project, since network circuits are already provided commercially and the civil service staff is minimal.

Methodology

NISN project activities appear to be carefully planned and executed. There is a well-defined process for NISN personnel (as is true for space communications personnel in general) to work with mission personnel over the course of mission development and operation, to determine communication requirements and to ensure that these requirements are fulfilled after the mission is launched. The mission network is monitored on a continual basis. Trouble tickets are typically resolved within a single day. If mission requirements change, communication requirements are revised accordingly.

Due to continuing interactions throughout all phases of a mission, there appears to be an excellent relationship between space communications and mission staff. There are regularly scheduled opportunities for customers to provide input into NISN project planning. The annual NISN customer forum is a major such opportunity. Customer feedback during the forum is a critical element in establishing NISN priorities and enhancing service offerings.

Also, according to the NISN project plan, NISN annually reviews existing customer requirements and solicits future requirements from NASA centers, programs/projects, and mission directorates. Finally, NISN maintains a memorandum of agreement with each center outlining the management and negotiation of requirements levied from NISN to centers, and from centers to NISN.

Risk management is an important element of the NISN project. The following categories of risk are identified in the NISN project plan:[10]

- Cost,
- Schedule,
- Human capital, and
- Technical.

Risks to the NISN project are managed according to priority. The highest-priority activities are providing and maintaining network connectivity. Lower-priority activities include upgrading equipment and conducting evaluations of emerging technologies. In the event of a budget shortfall, the lower-priority activities will be affected first.

According to the NISN project plan, processes and tools used for identifying, tracking, controlling, and reporting NISN risks are specified in the MSFC Office of the Chief Information Officer Organizational Work Instruction ISO1-OWI-008 for Information Technology Risk Management.

NISN has a small advanced technology activity, staffed with approximately 2.5 employees. New technologies are evaluated and prototyped in the laboratory prior to possible deployment on the operational networks. The network testbed for this work includes laboratories at MSFC, GSFC, the Jet Propulsion Laboratory, Glenn Research Center, and Ames Research Center. Since only a few of these laboratories are funded by NISN, this activity is heavily dependent on the mutual interest of and cooperation from other groups.

As a further complication, in the past NISN focused on evaluation and prototyping of future technologies in the 3- to 4-year time frame, relying on the NASA Research and Education Network (NREN) group to investigate longer-range technology development. Over the past couple of years the NREN focus has shifted to supporting the Columbia supercomputing facility at NASA Ames Research Center. The resulting gap in technology evaluation within the agency might be problematic. A major customer of the mission network indicated his concern about this issue when he informed the committee of the "need to keep NREN or some cutting-edge, state-of-the-industry, group active and engaged with NISN."[11]

Finding: The advanced technology prototyping and evaluation activities within NISN are limited, in terms of both manpower and testing facilities.

Recommendation: NASA should reevaluate the role of the advanced technology effort within NISN, to determine whether activities in this area should be increased to alleviate the gap left by the NASA Research and Education Network's changing role. If so, additional funding would likely be required for more personnel and expanded testbed facilities.

NISN management indicated that NISN would conduct more technology studies, such as a study of Voice over Internet Protocol (VoIP), if funding were available. However, safety and mission success is the highest priority. High priority is also given to continuance of routine operations and data delivery, including provision of ongoing services and payment of circuit and maintenance costs. In the event of a budget reduction, lower priorities would include new initiatives, service improvements (e.g., replacement of obsolete equipment), and technology evaluation.

Overall Capabilities

Facilities and personnel seem adequate to accomplish NISN project objectives, as evidenced by the enthusiastic support for NISN on the part of the mission customers interviewed by the committee at all three NASA sites. The committee met with several of the NISN civil service employees; they all seemed competent in their areas of responsibility. In addition, the mix of civil service employees and contractors seems to work well.

NISN is able to attract candidates with experience when there are open positions, according to employees at GSFC. In addition, new NISN employees at GSFC must satisfactorily complete a certification process before they can conduct critical mission-network control-room functions by themselves, further ensuring quality service from NISN.

The customers that were interviewed by the committee uniformly expressed satisfaction with the services provided by space communications personnel, including NISN. For example, customers said that network reliability is good, that problems are relatively infrequent, and that when problems do arise they are identified immediately and are resolved rapidly. The committee heard no substantive customer complaints.

NISN is currently upgrading both the mission network and the institutional network. The mission network operates at a lower bandwidth than the institutional network and typically lags in technology. Currently the mission network backbone consists primarily of multiple T1 (1.5 megabits per second) links and some DS3 (45 megabits per second) links. The institutional network provided by Qwest, which is to be completed by the end of 2006, will be a fiber-optic network with gigabit capacity.

The committee did see a significant amount of obsolete equipment during the site visits, including a room full of over-30-year-old patch panels for voice distribution on the mission network. According to NISN management, other NISN equipment has gone beyond "end-of-life" designation to "end-of-service" designation, meaning that the vendors will no longer even service the equipment. This problem apparently is the result of a poorly structured contract under the former Consolidated Space Operations Contract. NISN is well aware of the criticality of this situation and is currently working to upgrade this equipment in a prioritized manner subject to funding constraints. For example, NISN is currently enhancing voice capabilities for the mission network under the Mission Operations Voice Enhancement project. In addition AT&T is upgrading switching equipment in the mission network at no charge to NASA (as mentioned above), because the current equipment is so obsolete that it is more cost-effective for AT&T to replace it rather than continue to maintain it.

Finding: The problem of having NISN equipment that is no longer serviceable is being resolved by replacing outdated equipment as funding allows.

Recommendation: NASA should structure future NISN support contracts to ensure that critical equipment is updated in an ongoing manner, with the minimum requirement being that equipment will be replaced before vendors cease maintenance.

The NISN mission network is also required to support some "legacy" protocols for handling data. In particular, 4800-bit NASCOM data blocks (devised as a proprietary protocol several decades ago to support NASA space missions) must be encapsulated in Internet Protocol packets for transmission. The ramifications of these requirements to support legacy protocols are unclear. During its site visit to Johnson Space Center, the committee was advised that JSC is in the process of eliminating all need for the 4800-bit NASCOM data blocks from their missions.

Finding: NISN continues to support legacy protocols instead of using only standard Internet protocols that would facilitate interoperability.

Recommendation: NASA should conduct an agency-wide study to determine trade-offs in continuing to support legacy protocols versus updating individual mission equipment to support Internet protocols.

The NISN institutional network serves the daily communications activities of everyone at all the NASA centers and hence operates in a less controlled environment than does the mission network. A result can be that unexpected requirements are suddenly imposed on the network. For example, a decision to locate all e-mail servers at MSFC led to a surge in traffic in and out of MSFC. This decision had not been coordinated with NISN, resulting in a degradation of network performance.

As indicated throughout this chapter, the mission network and institutional network are two separate networks, each provided by a different vendor. These networks are currently separate because of differing user requirements. However, according to NISN management, the differences in requirements for reliability and availability between the two are becoming less important, since state-of-the-art network technologies are inherently very reliable. Apparently, the only remaining real difference is the need to "freeze" the mission network around mission launch and operation. Using state-of-the-art technologies, it might be possible to combine the two networks and still offer separate services by providing separate channels on the same network infrastructure, e.g., using separate wavelengths on a fiber-optic network, using Virtual Private Network technology, or using router technology. Using a single network infrastructure for the two networks might provide a more cost-effective solution to satisfying user needs.

Finding: NASA's mission network has more stringent requirements for reliability and availability than does its institutional network. However, given the improvements inherent in state-of-the-art network technologies, any network with such technology will satisfy the more stringent of the two sets of requirements, so that it is not necessary to differentiate between the two networks with respect to this issue.

Recommendation: NASA should reevaluate the possibilities *for sharing a single network infrastructure for its mission network and institutional network.*

NOTES

1. National Aeronautics and Space Administration (NASA), NASA Integrated Services Network (NISN) Project Plan, December 2005, p. 7.

2. NASA, NASA Integrated Services Network (NISN) Project Plan, December 2005, p. 12.

3. NASA, NASA Integrated Services Network (NISN) Project Plan, December 2005.

4. Examples of customer agreements include memoranda of agreement at the NASA center level, and detailed mission requirements documents and project service-level agreements at the mission level.

5. Knoble, Gordon, NASA Goddard Space Flight Center (GSFC) Network Manager for Earth Science Mission Operations, discussion during the NRC Committee to Review NASA's Space Communications Program site visit to GSFC, March 13, 2006.

6. NASA, NASA Integrated Services Network (NISN) Project Plan, December 2005, p. 6.

7. NASA, NASA Integrated Services Network (NISN) Project Plan, December 2005, pp. 38-39.

8. NASA, NASA Integrated Services Network (NISN) Project Plan, December 2005, p. 45.

9. Paschall, Elizabeth, NISN Project Manager, personal communication, April 7, 2006.

10. NASA, NASA Integrated Services Network (NISN) Project Plan, December 2005, p. 42.

11. Knoble, Gordon, NASA GSFC Network Manager for Earth Science Mission Operations, presentation during NRC Committee to Review NASA's Space Communications Program site visit to GSFC, March 13, 2006.

Assessment of Other Program Elements

4

Spectrum Management

INTRODUCTION

NASA has extensive communications and remote sensing systems, and the availability of adequately protected electromagnetic (EM) spectrum enables the implementation of these systems. NASA headquarters and various field centers play key roles by ensuring that NASA has access to EM spectrum and that it complies with U.S. and international regulations regarding spectrum use.

There are approximately 150 spacecraft in NASA's purview that rely on access to various passive and active spectral bands to conduct space research, space operations, passive and active Earth exploration, meteorological monitoring, intersatellite communications, radionavigation, and deep-space research. Achieving NASA's mission and vision relating to space exploration, scientific discovery, and aeronautics research implicitly requires the involvement of the spectrum management element in the planning and implementation of these programs.

NASA's spectrum policy and planning organization at NASA headquarters and supporting centers represents and advocates for NASA's needs for electromagnetic spectrum in national and international spectrum regulatory forums, obtains operational authority for NASA programs, supports the federal government's four-stage review process, obtains domestic assignments and international registration, advances U.S. requirements globally, formulates spectrum policies in national and international regulatory bodies, provides technical advocacy in support of U.S. commercial aerospace industries, facilitates private-sector use of spectrum, and encourages commercialization of space.

Spectrum Management Organization

The spectrum management program element and critical personnel are defined in that element's policy directive[1] and management manual.[2] The NASA spectrum management organization is shown in Figure 4.1.

The associate administrator for the Space Operations Mission Directorate (AA/SOMD) is designated the NASA spectrum manager and is responsible for ensuring compliance with pertinent international and national rules and regulations affecting all NASA radio frequency spectrum users. The AA/SOMD has delegated authority for the overall planning, policy, and administration of the NASA Spectrum Management program to the director, Spectrum Policy and Planning (HQ/SOMD), who is also the NASA representative to the Interdepartment Radio Advisory Committee (IRAC), which assists the National Telecommunications and Information Administration (NTIA) in the allocation, management, and use of spectrum by the U.S. government. Other personnel include the deputy director, Spectrum Policy; national and international spectrum program executives; center spectrum managers; and various staff members.[3]

The director, Spectrum Policy and Planning (HQ/SOMD), establishes policies and procedures, and the national and international program executives implement them. The international program executive directs activities related to the electromagnetic spectrum that involve entities external to the United States, including the International Telecommunication Union (ITU), other non-NASA civilian space agencies (e.g., European Space Agency, Japan Aerospace Exploration Agency, and others), and the Space Frequency Coordination Group (SFCG). The national program executive directs domestic EM spectrum activities involving entities internal to the United States, including the NTIA and the Federal Communications Commission (FCC). The national program executive also ensures that the spectrum operational plan, 5-year plan, and long-range plan are updated and cooperates in assisting the NTIA in its federal spectrum strategic planning effort.

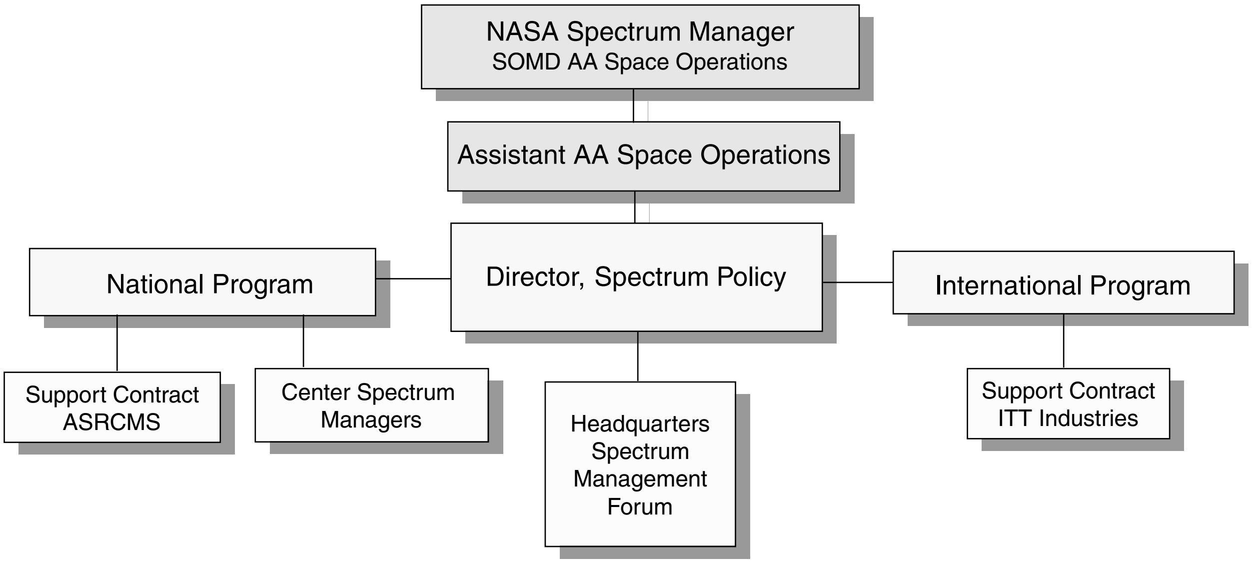


FIGURE 4.1 NASA spectrum management organization. SOURCE: David Struba, NASA, "NASA Spectrum Management," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006, p. 8.

Headquarters Spectrum Management Forum

The Headquarters Spectrum Management Forum (HSMF) was established to ensure NASA's compliance with Office of Management and Budget Circular A-11, Section 33.4, which provides that agencies should consider the economic value of radio spectrum used in major telecommunication, broadcast, radar, and similar systems when developing economic and budget justifications for procurement of these systems. In addition, the HSMF identifies and validates future spectrum requirements and ensures intra-NASA compatibility by coordinating spectrum requirements among the various mission directorates. Members of the HSMF include liaisons from the Space Operations Mission Directorate, Exploration Systems Mission Directorate, Science Mission Directorate, and Aeronautics Research Mission Directorate, and the external relations spectrum liaison, the legislative affairs spectrum liaison, and the general counsel spectrum liaison. The director, Spectrum Policy and Planning (HQ), chairs the HSMF with support from the national and international spectrum program executives. The HSMF meets at least once every 90 days.

NASA Spectrum Management Group

The NASA Spectrum Management Group (NSMG) provides a forum for the exchange of information on spectrum management requirements, actions, and issues. The NSMG is composed of spectrum managers from each center, the Jet Propulsion Laboratory (JPL), the Goldstone Deep Space Communications Complex (DSCC), and various test facilities. The NSMG meets annually under the leadership of the national spectrum program executive at NASA headquarters.

Field Centers

The Glenn Research Center (GRC) spectrum management organization, which reports to NASA headquarters but is located at GRC, is responsible for working all spectrum issues with the center spectrum managers on a shared, but complementary, basis with the national and international regulators.

Each field center, JPL, the Goldstone DSCC, and the various test facilities has a spectrum manager to ensure that all electromagnetic emissions comply with U.S. regulations and to ensure the electromagnetic integrity of their facility. The center spectrum managers provide national, international, on-center, and miscellaneous support. They are involved in the pre-acquisition and acquisition processes and provide briefings on spectrum management to new projects.

The Goddard Space Flight Center (GSFC) is responsible for the spectrum management of the Ground Network and the Space Network, and JPL is responsible for spectrum management of the Deep Space Network. Spectrum management for a mission is a shared and complementary responsibility: GSFC or JPL is responsible for network spectrum management, and the program center is responsible for spacecraft spectrum management.

Budget

The annual budget for the spectrum management program element is approximately $6 million per year and includes 17 full-time-equivalent civil service employees and 24 work-year-equivalent contractors.[4]

ASSESSMENT

Formulation of the Program Plan

While NASA's strategic plan[5] does not specifically address spectrum management, all of NASA's space communications programs rely on the availability of spectrum and NASA's ability to meet the complex national and international regulatory requirements.

NASA's Headquarters Spectrum Management Forum, chaired by the director, Spectrum Policy and Planning, identifies and validates future spectrum requirements and coordinates spectrum management across all of NASA's space communications programs.

The spectrum management program element has multiple short- and long-term goals and objectives:[6] (1) obtain adequate spectrum to support NASA programs, (2) ensure compliance with national and international rules and regulations, (3) ensure timely processing of spectrum allocations and frequency assignment requests and dissemination of regulatory changes, (4) provide guidance to NASA mission program managers, (5) identify and mitigate radio frequency interference, either from or to NASA programs, (6) plan and obtain new allocations or enhanced radio regulations through national and international organizations, (7) provide spectrum planning and support for NASA's technology transfer mission, and (8) advocate rules and rule changes that support the lowest-life-cycle-cost technical solutions to NASA programs for meeting their communications needs. These goals and objectives require an ongoing and long-term commitment of funding.

The spectrum management program element is different from typical NASA development programs in that there is no hardware development, and the program requires a long-term and ongoing commitment. NASA has made a significant commitment to spectrum management in both the national and international communities, and the committee expects that this commitment of agency resources will continue in the future. In addition, progress is dependent on the processes of external domestic and international agencies such as the NTIA and ITU. Although compliance with existing regulatory policies and procedures is generally straightforward, the allocation of new bands and services requires years of effort, given that World Radio Conferences (WRCs) meet infrequently. NASA has a long-term relationship with other space-faring nations and international organizations and has been successful in advocating its spectrum management goals. The committee expects these relationships to continue in the future.

The spectrum management program element is regularly involved in national and international meetings to advance its long-term spectrum management goals. NASA's success can be indirectly assessed in terms of the adoption of its positions through the frequent national WRC preparatory meetings, periodic international WRCs, annual SFCG meetings, and periodic Inter-American Telecommunication Commission (CITEL) meetings.

Connection to the Broader Community

NASA is a member of the NTIA Interdepartment Radio Advisory Committee, the International Telecommunication Union Radiocommunication Sector (ITU-R), SFCG, and CITEL, and it coordinates spectrum utilization with other government agencies, the commercial space industry, and international space-faring nations. NASA interfaces with multiple internal, national, and international venues in the area of spectrum management (Figure 4.2).[7] NASA chairs ITU-R U.S. Study Group 7 (Science Services) and two U.S. working parties on space science, and it contributes to various other ITU-R U.S. study groups and working parties.

Domestically, the national spectrum program executive is the NASA representative to the Spectrum Planning Subcommittee, Frequency Assignment Subcommittee, and Technical Subcommittee of the Interdepartment Radio Advisory Committee of the NTIA. These subcommittees independently review NASA's requests for frequency authorization and may request additional analysis to support requests for frequency authorization.

Internationally, the FCC International Telecommunication Advisory Committee (ITAC) General Guidance Document[8] governs U.S. participation in the ITU-R and in the CITEL PCC II (radio communication, including broadcasting) organizations. In particular, prior to submission of any U.S. document to an international meeting of the ITU-R, or to the Radio Regulations Board, or to meetings of CITEL PCC II, the document must be reviewed and approved by the U.S. Department of State in consultation with the FCC and NTIA. The U.S. ITAC-R review process ensures that U.S. government inputs are technically sound and comply with national policy.

NASA is one of the foremost leaders in spectrum management and is certainly on a par with the European Space Agency (ESA), Centre National d'Etudes Spatiales, Japanese Aerospace Exploration Agency, the Australian Commonwealth Scientific and Industrial Research Organisation, and the Indian Space Research Organisation. NASA generally operates in the space research and deep-space bands, which are different from the bands used by military and commercial space systems. In 2000, a NASA report evaluated whether commercial space systems could replace the Tracking and Data Relay Satellite System (TDRSS), and the report concluded that commercial systems cannot provide wide-range, continuous coverage of low-Earth-orbit satel-

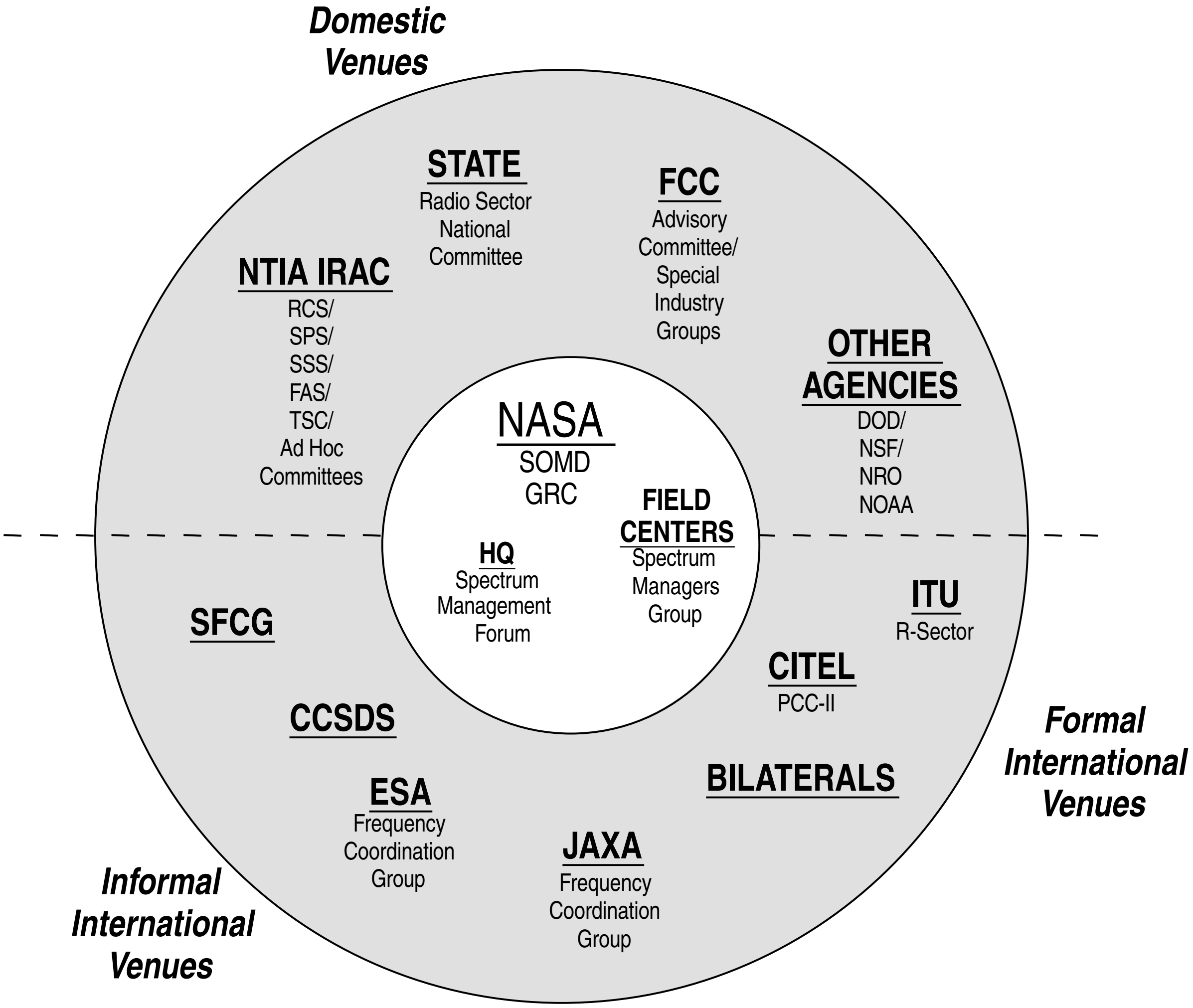


FIGURE 4.2 NASA spectrum management program element involvement with national and international groups. SOURCE: David Struba, NASA, "NASA Spectrum Management," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006, p. 10.

lites and support NASA's real-time communications requirements.[9] NASA's Space Network is, however, interoperable with satellites from other space agencies. NASA is a member of the SFGC, which provides a forum for multilateral discussion and coordination of spectrum matters concerning space research, space operations, and so on.

In anticipation of future missions, NASA has submitted to the ITU-R and SFCG several documents that address spectrum standards for missions to the Moon and Mars. These include:

- The definition of frequency bands for human and robotic exploration of the Moon compatible with deep-space missions as well as other guidance for spectrum management in the lunar region, and
- A proposed telecommunication relay network for Mars exploration and guidelines for the assignment of radio frequency spectrum for communications in the Mars region.

NASA is also coordinating its utilization of the radio frequency spectrum in the lunar region with the international community of space-faring nations at technical and intergovernmental meetings.

Methodology

NASA has extensive policies, procedures, and processes regarding spectrum management in order to provide the overall radio frequency spectrum implementation and administration policies necessary to support present and future programs. These include:

- NASA Electromagnetic (EM) Spectrum Management Policy Directive, NPD 2570.5D;[10]
- NASA Radio Frequency (RF) Spectrum Management Manual, NPD 2570.1;[11]
- NASA Long Range Electromagnetic Spectrum Forecast;[12]
- NASA EM Spectrum Operational Plan;[13] and
- Implementation plans unique to each NASA center.

The committee met with the Goddard spectrum manager to assess the spectrum management program at a representative field center. Goddard was selected because the TDRSS constellation and many Earth science programs are managed there. The committee's assessment is that the Goddard spectrum management program is well managed, and there is a clear and unambiguous understanding of roles and responsibilities and of how the center spectrum management program fits into the overall NASA spectrum management program. The Goddard spectrum manager is an integral part of the pre-acquisition and acquisition process for new missions; he briefs every new mission on national and international spectrum management requirements. The Goddard spectrum manager has 4.5 support personnel, and these personnel are used effectively and efficiently. They routinely perform intersystem interference analyses to assess the ability of NASA systems to share the frequency spectrum with other users and services.

There is continuing demand for spectrum for mobile voice, high-speed data, and Internet-accessible wireless services that subjects NASA crosslinks and downlinks to potential interference from other services. Two examples are (1) the TDRSS crosslink and downlink and (2) the Deep Space Network S-band uplinks.

- ***TDRSS crosslink and downlink.*** The TDRSS downlink band is shared with government spaceborne active sensors on low-Earth-orbiting satellites, commercial Earth-to-space very-small-aperture terminals (VSATs),[14] and airborne,[15] land-mobile satellite,[16] and shipboard[17] systems. NASA has not experienced unacceptable interference from government spaceborne active sensors, and the Goddard spectrum manager negotiates agreements with commercial systems to protect the TDRSS downlink. In addition, portions of the band are protected by U.S. footnotes. While nongeosynchronous orbit (NGSO) systems are allowed to operate uplinks in this band, which can potentially result in unacceptable interference to TDRSS, there are no operational or known planned NGSO systems in this band.

The TDRSS forward crosslink band is shared with commercial Earth-to-space uplinks; however, TDRSS is protected by both ITU-R[18] and U.S. footnotes.[19]

Although there has been some historical concern about increasing interference to the TDRSS forward crosslink[20] and downlink, this interference has not yet materialized.

- ***Deep Space Network S-band uplinks.*** NASA operates Deep Space Network uplinks from Madrid (Robledo), Spain; Goldstone, California; and Canberra (Tidbinbilla), Australia, in the 2110-2120 MHz band, and this band overlaps the IMT-2000/UMTS band; however, few existing NASA deep-space missions currently operate in this band, and no future missions will operate in it.[21] In Canberra, this band is not allocated for IMT-2000 spectrum licensing,[22,23] and, in a 2001 report,[24] the Australian Communications Authority concluded that 3G mobile services would be able to successfully operate in the Canberra area without any significant short-term interference. In Goldstone, the FCC[25] recognized that NASA will continue to operate in this band, and it directed that advanced wireless services licensees must accept any interference received from the Goldstone Deep Space Network facility. In Madrid, the use of this band is constrained because of certain actions taken by Spain in support of its national auctions; however, NASA will be able to access and use the band based on ongoing negotiations and agreements with the Spanish Ministry of Telecommunications.

Finding: NASA has been very effective in protecting its access to the radio frequency spectrum needed for space communications. In addition, the potential interference from a proliferation of Ku-band non-geosynchronous orbit (NGSO) very-small-aperture terminals (VSATs) has not been realized because these systems have not, as yet, been deployed, and NASA is reducing its use of S-band uplinks from its Deep Space Network sites.

Recommendation: Although there is no compelling reason for NASA to vacate the Ku band, it would be prudent for NASA to consider relocating its future Ku-band downlinks to a band with a primary allocation and to encourage users to transition from the Ku band to the Ka band. This approach would provide insurance against unacceptable interference arising from the future proliferation of commercial very-small-aperture terminal uplinks and could offer the secondary benefit of a higher-capacity downlink.

Spectrum management is a long-term effort and commitment, and NASA is diligently working through the NTIA, ITU, and SFCG to protect its interests and implement the President's Vision for Space Exploration.[26] NASA has identified three spectrum allocation deficiencies in forecasting its future requirements for radio frequency spectrum[27] that it would like to propose as WRC-2010 agenda items, and these goals and time spans are consistent with future program needs and the national and international regulatory processes.

Overall Capabilities

NASA's spectrum management work is comparable to that performed by other space-faring nations and organizations. NASA is a founding member of the SFCG. In comparison to the ITU Radiocommunication Bureau and Study Groups, the SFCG was established to provide a less formal and more flexible environment for the solution of frequency management problems encountered by member space agencies.

Through its many years of effort in the SFCG, U.S. ITU-R Study Group 7, and the NTIA, NASA has been successful in promoting and preserving the allocation of spectrum for its science missions. NASA has submitted several documents to the ITU-R and SFCG addressing spectrum management for missions to the Moon and Mars in anticipation of its future exploration requirements. These include the definition of frequency bands for human and robotic exploration of the Moon compatible with deep-space missions, other guidance for spectrum management in the lunar region, a proposed telecommunication relay network for Mars exploration and frequency assignment guidelines for communications in the Mars region, and the initiation of recommendations for optical communications.

NASA civil service employees have significant experience and expertise in spectrum management. As an example, a center spectrum manager worked in the Systems Review Branch (SRB)[28] of the NTIA for several years and was the chief of the SRB during this period. Prior to his tenure in the NTIA, he worked in spectrum management for the DOD including the DOD spectrum management policy office.

NASA employs the Arctic Slope Regional Corporation Management Services (ASRCMS) and ITT as support contractors. ASRCMS provides both national and international spectrum engineering support to NASA headquarters, and ITT provides international spectrum engineering support to NASA's Spectrum Engineering Office located at Glenn Research and other centers. Both contractors have significant spectrum management experience, and many of their employees were previously employed by the FCC, State Department, USAF, NASA, and the intelligence community. Their personnel appear to provide excellent support to NASA, skillfully representing NASA interests at SFCG meetings, for example, and complement government capabilities. Both support contractors provide technical support in the areas of frequency coordination, interference analysis, and preparation of documentation to support both national and international meetings. In addition, they monitor new national and international spectrum filings to determine if there is any potential impact on operational and future NASA systems.

The committee visited GSFC as a representative center and found the equipment, facilities, and working environment similar to those of other government laboratories and facilities.

NOTES

1. NASA (National Aeronautics and Space Administration), NASA Electromagnetic Spectrum Management Policy Directive, NPD 2570.5D, October 17, 2005, available at http://nodis3.gsfc.nasa.govdisplayDir.cfm?Internal_ID=N_PD_2570_005D_&page_name=main.
2. NASA, NASA Radio Frequency (RF) Spectrum Management Manual, NPD 2570.1, April 24, 2003, available at http://nodis3.gsfc.nasa.gov/npg_img/N_PR_2570_0001_/N_PR_2570_0001_.pdf.
3. NASA Spectrum Personnel, available at http://spectrum.nasa.gov/about/personnel.aspx.
4. Struba, David, "NASA Spectrum Management," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006.
5. NASA, 2006 NASA Strategic Plan, NP-2006-02-423-HQ, available at http://www.nasa.gov/pdf/142302main_2006_NASA_Strategic_Plan.pdf.
6. NASA, NASA Radio Frequency (RF) Spectrum Management Manual, NPD 2570.1, April 24, 2003, available at http://nodis3.gsfc.nasa.gov/npg_img/N_PR_2570_0001_/N_PR_2570_0001_.pdf.
7. Struba, David, "NASA Spectrum Management," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006.
8. Federal Communications Commission (FCC), General Guidance Document, U.S. Participation in the ITU Radiocommunication Sector and in CITEL PCC II (radio communication including broadcasting), November 18, 2003, available at http://www.fcc.gov/ib/sand/irb/guidance.html.
9. NASA, Assessment of Commercial Alternatives to TDRS Services, Version 2, NASA Goddard Space Flight Center, Greenbelt, Md., December 2000.
10. NASA, NASA Electromagnetic (EM) Spectrum Management Policy Directive, NPD 2570.5D, October 17, 2005, available at http://nodis3.gsfc.nasa.gov/npg_img/N_PD_2570_005D_/N_PD_ 2570_005D__main.pdf.
11. NASA, NASA Radio Frequency (RF) Spectrum Management Manual, NPD 2570.1, April 24, 2003, available at http://nodis3.gsfc.nasa.gov/npg_img/N_PR_2570_0001_/N_PR_2570_0001_.pdf.
12. NASA, NASA Long Range Electromagnetic Spectrum Forecast, Annex A, November 1, 2005.
13. NASA, NASA EM Spectrum Operational Plan, Draft, February 9, 2006.
14. In FCC 05-14, the FCC noted that its database indicated that 2,672 authorizations were issued for GSO FSS Earth stations in the 14.0-14.5 GHz band. The authorizations indicate the maximum number of Earth stations or antennas that a licensee may deploy. Since this is a very-small-aperture terminal (VSAT) band, a single GSO FSS authorization could cover several thousand VSAT Earth terminals.
15. In a 2005 Notice of Proposed Rulemaking, the FCC considered adding a footnote to protect TDRSS; however, the FCC has not yet issued a final report and order.
16. Land-mobile satellite system users in the 14.0-14.2 GHz band are coordinated on a case-by-case basis through the Frequency Assignment Subcommittee of IRAC.

17. Earth stations on vessels (ESVs) in the 14.0-14.2 GHz (Earth-to-space) frequency band within 125 km of the NASA TDRSS facilities on Guam or White Sands, New Mexico, are subject to coordination through NTIA IRAC per the Code of Federal Regulations, Title 47, Volume 2, Section 25.222, "Blanket Licensing Provisions for Earth Stations on Vessels," CFR Citation 47CFR25.222, revised October 1, 2005, available from the U.S. Government Printing Office via GPO Access at http://www.gpoaccess.gov/cfr.

18. International Telecommunications Union (ITU), Radio Regulations, Edition of 2004, Articles 5.502 and 5.503, ITU, Geneva, Switzerland, 2004.

19. U.S. Department of Commerce, National Telecommunications and Information Administration, Manual of Regulations and Procedures for Federal Radio Frequency Management, May 2003 Edition, January 2006 Revision, US Footnotes US337, US356, and US357, available at http://www.ntia.doc.gov/osmhome/redbook/redbook.html.

20. Wong, Yen, and Mark Burns, NASA/GSFC Ground Segment Upgrades for Ka-Band Support to Near-Earth Spacecraft, AIAA SpaceOps 2002 Conference, October 2002.

21. NASA, NASA Long Range Electromagnetic Spectrum Forecast, Appendix 3, NASA, Washington, D.C., November 1, 2005.

22. Australian Minister of Communications, Information and the Arts, Radiocommunications (Spectrum Re-allocation) Declaration No. 2 of 2000, October 7, 2000, available at www.dcita.gov.au/__data/assets/word_doc/9849/Radiocommunications_Spectrum_Re-allocation_Determination_2_2000.doc.

23. Australian Communications Authority, Radio-communications Spectrum Marketing Plan (2 GHz Band), Commonwealth of Australia, December 4, 2000, available at http://www. acma.gov.au/acmainterwr/radcomm/spectrum_auctions/pdf_files/marketing_plan.pdf.

24. Australian Communications Authority, Compatibility Assessment 2 GHz Deep Space Earth Stations with 3G Mobile Services, Spectrum Planning Report SP 09/01, Radiofrequency Planning Group, June 2001, available at http://www.acma.gov.au/acmainterwr/radcomm/frequency_planning/spps/0109spp.pdf.

25. Code of Federal Regulations, Title 47, Section 27.1134(d), "Protection of Federal Government Operations, Recognition of NASA Goldstone Facility Operations in the 2110–2120 MHz Band," CFR Citation 47CFR27.1134, revised October 1, 2005, available from the U.S. Government Printing Office via GPO Access at http://www.gpoaccess.gov/cfr.

26. NASA, The Vision for Space Exploration, February 2004, available at http://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf.

27. NASA, NASA Long Range Electromagnetic Spectrum Forecast, Annex A, November 1, 2005.

28. The SRB reviews the spectrum requirements and compatibility of all federal government systems that are submitted to the NTIA Spectrum Planning Subcommittee.

5

Data Standards Management

INTRODUCTION

There is agreement among the world's space agencies that the use of standardized techniques for handling space data is beneficial to all. Although data formats are generally standardized, the standards activity for space data is more complex, involving designing or adopting systems and procedures that can utilize these standardized data formats. In this context, the term "data standards" encompasses standards for the end-to-end transmission, handling, and storage of all data associated with space operations: scientific data originating on spacecraft, uplink and downlink data needed to conduct associated operations, tracking data, and even voice communications with astronauts. As with other uses of standards, the objective is to reduce costs and enable interoperability by adopting compatible systems and procedures.

The role of standards in space operations mirrors the history of standards in general, although accelerated by the extremely rapid development of the associated communications and computing technologies. Technology typically develops in many places simultaneously, with people doing similar things differently simply because there is little coordination. Space operations present a classic example of independently developed approaches to data handling. Experts were needed to build and operate each of various different data-handling systems performing essentially the same fundamental tasks. Most of the effort is spent on inventing (designing and developing), whereas the costs of producing and owning (maintaining) the products are relatively minor. Standardization minimizes reinventing.

Assuming agreement in principle that standardization is desirable, how can it be done right? The first step is to understand what it makes sense to standardize. Standardization generally focuses on interfaces: compatible form, fit, and function where components join. Standard components avoid the expense of reengineering and redesigning at the component level, of reinventing for each application. Yet these components can be combined in ways that make them unique and appropriate for a variety of purposes. To be effective, standards must be developed by users, rather than imposed from outside. Users must be motivated to look for commonalities, not differences.

What are some of the motivations to standardize? Generally, as technology develops and markets grow, pressures for standardization increase, primarily for economic reasons. Standards permit mass production, thereby reducing both production and ownership costs, and they facilitate expansion of markets, permitting products developed for one market to be sold elsewhere. There are also motivations beyond economic incentives for standardizing, such as safety. Countervailing factors that can inhibit standardization might also reflect economic interests, expressed, for example, in internecine battles to gain competitive advantages, or to maintain or expand contract bases. Often, simple inertia is also an impediment to standardization.

An international body, the Consultative Committee for Space Data Systems, commonly referred to as the CCSDS, is the primary organization that develops space-associated standards that facilitate and enable more cost-effective missions through the shared use of common components, procedures, and infrastructure (Box 5.1). SOMD's data standards program element is essentially synonymous with NASA's participation in the CCSDS.

NASA is a founding member of the CCSDS, which is supported by more than 30 space agencies (and their associated industrial bases) distributed across the world space community. Acting as a technical arm of the International Organization for Standardization (ISO), CCSDS generates the world body of standards in the field of space data and information transfer systems. The CCSDS is the undisputed world leader in space data standardization, and to date well over 300 space missions are able to interoperate using these standard capabilities. Within the United States, virtually all

NASA space missions—and a growing number operated by NOAA, the DOD, and U.S. industry—implement a significant complement of CCSDS standards. Specific missions are listed in Table 5.1.

CCSDS products are properly termed and treated as recommendations that space mission programs are free to accept or reject as they determine best for their individual programs. In this regard, neither the data standards management program element nor the broader SOMD program exercises any control over adoption of the standards. Establishment and approval of any "waivers" are totally outside the purview of SOMD. Thus, the degree to which spaceflight missions adopt recommended standards is a meaningful metric of the usefulness of SOMD's data standards management element, and the committee has accordingly attempted to determine the degree of adoption. Table 5.1 lists 78 new space missions that have adopted CCSDS standards recommendations in whole or in part.[1] In addition, other organizations frequently see compatibility with NASA space communications standards as a valuable means of enabling support or cross-support with NASA assets.

Although the evidence to date is not compelling that NASA's mission directorates have a clear understanding of the benefits of adopting standards, there are indications that the directorates are coming to recognize the value to their programs of adopting standards. One such observation focused on utilization by JPL and GSFC as discussed in Box 5.2.

ASSESSMENT

Formulation of the Program Plan

The standards management program element's goals and objectives are clearly defined. As explicitly stated in the charter of the CCSDS: "The major space agencies of the world recognize that there are benefits in using standard techniques for handling space data and that, by cooperatively developing these techniques, future data system interoperability will be enhanced."[2] *The Strategic Plan of the Consultative Committee for Space Data Systems* identifies and defines the goals and objectives of the international forum in which this NASA program element plays a leadership role. As stated in the plan's vision: "The NASA Communications & Data Standards Program provides the forum to advocate, coordinate, and recommend NASA, interagency, and international data communications standards required to carry out NASA missions, including NASA participation in international missions."[3]

By its basic nature, the scope of this program element extends beyond NASA. As noted above, standards development must be a broad-based effort, both to ensure full recognition of the needs of the broader user community and to obtain buy-in by those users. In this regard, NASA accomplishes associated objectives through participating in—and in this case, providing significant leadership to—the CCSDS.[4] All CCSDS member organizations are fully involved in the planning and review process.

The standards management program element's deliverables are also articulated in the CCSDS's strategic plan.[5] The expected services continue to be delivered by this program element's activities. The planning is well supported and documented in the strategic plan, and appropriate customer agreements are in place. The deliverables, which are coordinated and agreed to by the customers as indicated by their participation in the collaborative development, provide sufficient near-term standards and metrics according to which the standards management program element can be regularly assessed. There appears to be little value in developing off-ramps to enable reallocation of funding, given the continuing delivery of the agreed-to standards. The international scope of the activity would make an independent review of the CCSDS program complex, likely not adding significant value, given that the members continually review their individual participation in the activity. There is no evidence that NASA has previously had independent or external reviews of its participation in the CCSDS.

The program element's objectives, developing standards in coordination with and subscribed to by space activities around the world, are appropriate. Adequate personnel and resources are available, as evidenced by the continuing development and adoption of common standards.

Connections to the Broader Community

The data standards management program element focuses on national and international collaboration aimed at achieving consensus on space data standards, and thus it necessarily has forged extensive and effective connections with the broader community, which contributes to the development of standards and shares ownership in the process and products.

CCSDS standards find their way into the space-related communications and Internet Protocol marketplace. In calendar year 2005, the CCSDS surveyed the dollar value of the U.S. space communications protocol marketplace and concluded that the value exceeded $24 billion per annum.[6] If accurate, this would represent a very impressive return on investment, given the very modest NASA investments (see "Resources and Funding").

Participation by the Department of Defense, the U.S. commercial space industry, and others in developing space data standards is evidence that NASA's data standards work is appropriately recognized and is effective. This program element leverages other work done in the U.S. government and industry, as well as by international associates.

NASA appears to use out-of-house resources effectively to supplement its civil service team in providing leadership for the development of standards, with the latter managing and coordinating the program element and the former per-

BOX 5.1
Consultative Committee for Space Data Systems

The Consultative Committee for Space Data Systems (CCSDS) was formed in 1982 by the major space agencies of the world to provide a forum for discussion of common problems in the development and operation of space data systems.[1] It is currently composed of 10 member agencies, 22 observer agencies, and more than 100 industrial associates. Since its establishment, it has been actively developing recommendations for data- and information-systems standards to reduce the cost to the various agencies of performing common data functions by eliminating project-unique design and development, and to promote interoperability and cross-support[2] among cooperating space agencies to reduce operations costs by sharing facilities and other common resources.

In 1991, the CCSDS entered into a cooperative arrangement with the International Organization for Standardization (ISO). Under this arrangement, CCSDS recommendations are advanced to Subcommittee 13 within Technical Committee 20 (Aircraft and Space Vehicles), where they then advance via the normal ISO procedures of review and voting to become full international standards. A telling indicator of the broad understanding and appreciation of this effort is the degree of participation in developing the standards, and the degree to which they are subsequently adopted and used in space programs.

Although the growing acceptance of its recommendations is testimony to the quality of the CCSDS's work, much remains to be done. Not only must NASA continue to maintain the current recommendations, but it also must address new areas for standardization and incorporate new technologies. The challenges of capitalizing early on advancing technology while dealing with increasing budgetary pressures continue to confront the agency.

Within the CCSDS structure, a member agency is a governmental or quasi-governmental organization that fully participates in all CCSDS activities and provides a commensurate level of support. Unlike other participating entities, each member agency has CCSDS voting rights and thus the power to decide on CCSDS business. Member agencies name to the CCSDS Management Council individual representatives who exercise member agency voting rights to determine the overall direction of the organization. The CCSDS has over 100 active associate members. These associates are typically U.S. aerospace corporations that are consumers of CCSDS publications and products.

Objectives and goals are defined for six areas: systems engineering, mission operations and information management, cross-support services, spacecraft onboard interface services, space link services, and space internetworking services. Within each of these areas, specialized working groups are chartered to develop recommended standards. Recommended practices and experimental standards have also been added as additional categories to the specification hierarchy.

---

[1] Consultative Committee for Space Data Systems (CCSDS), About CCSDS, available at http://www.CCSDS.org.

[2] Cross-support is the cross-utilization of operational resources among agencies.

forming the detailed work. This balance seems quite appropriate to the endeavor, as evidenced by the demonstrated and continuing success in delivering coordinated standards.

The benefits and costs of increasing interoperability with military space systems, commercial space systems, and the systems of foreign space agencies seem properly considered, as evidenced by the direct involvement in ongoing standards development activities. The basic motivation for developing space data standards is to increase reliability and efficiencies with military, commercial, and foreign space operators, with the attendant benefits and cost savings achievable by enabling interoperability.

Methodology

The primary component of standards development is working groups that meet on a periodic and rotating basis.[7] Virtual collaboration is used effectively to minimize the need for the physical presence of working group members. The Collaborative Work Environment, a secure area in the CCSDS website, enables all working groups and area directors to have "net meetings" or to submit products, papers, or draft positions asynchronously for commentary and the formulation of draft positions. Often the give-and-take of the technical people as well as voting by the Engineering Steering Group and the Management Council occurs in this e-forum.

The committee judged the standards management program element planning to be quite well crafted, as evidenced by the program element's long history of demonstrated successes. Since its formation in 1982 the CCSDS has grown to 10 member agencies and 22 observer agencies. As noted, the CCSDS has a currently active suite of 78 standards, 29 of which have become ISO standards. Table 5.1 lists more than 70 new missions slated for launch in 2006 through 2008 that have adopted CCSDS standards in whole or in part. Such accomplishments would not have been possible without effective planning and execution, particularly when the limited authority of the CCSDS is taken into consideration.

Resources and Funding

NASA's funding and level of effort for the total CCSDS program are as follows:[8] SOMD (Space Operations), $5 million annually and SMD, $1.5 million annually. Neither ESMD (Exploration) nor PAE (Chief Engineer) contribute

TABLE 5.1 Missions That Implement Consultative Committee for Space Data Systems Standards

Mission	Description	Launch Date	Related Organizations
NPP	National Polar Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project	2006 (Dec.)	NASA/GSFC
AIM	Aeronomy of Ice in the Mesosphere	2006 (Sept.)	NASA/GSFC
SBIRS-High	Space Base Infrared System	2006	DOD
New Horizon	Pluto-Kuiper belt mission	2006	NASA/APL
Dawn	Meteorite Explorer	2006	JPL, UCLA
THEMIS 5	Time History of Events and Macroscale Interactions during Substorms	2006	NASA/SSL
THEMIS 4	Time History of Events and Macroscale Interactions during Substorms	2006	NASA/SSL
THEMIS 3	Time History of Events and Macroscale Interactions during Substorms	2006	NASA/SSL
THEMIS 2	Time History of Events and Macroscale Interactions during Substorms	2006	NASA/SSL
THEMIS 1	Time History of Events and Macroscale Interactions during Substorms	2006	NASA/SSL
Solar-B		2006	ISAS
GLAST	Gamma-ray Large Area Space Telescope	2006	NASA
COROT	Convection Rotation a Transits planetaires (Convection Rotation and Planetary Transits)	2006	CNES
INMARSAT 4F 3	International Maritime Satellite 4F3	2006	INMARSAT
GOCE	Gravity Field and Steady State Ocean Circulation Explorer	2006	ESA
ATV-3	Automated Transfer Vehicle 3	2006	ESA
CRM	Coral Reef Mission	2006	PCRF, MIT/CSR
RascomStar-Qaf 1	Telecommunications	2006 (June)	RascomStar-QAF
ARABSAT4B		2006	ARABSAT
ARABSAT4A		2006	ARABSAT
SKYNET 5B		2006	British Ministry of Defence
SKYNET 5A		2006	British Ministry of Defence
HOTBIRD 8	Telecommunications	2006	Eutelsat
Anik F3	Telecommunications	2006	Telesat Canada/ESA
Galaxy 17	Telecommunications	2006	PanAmSat/ESA
COSMO-Skymed3	Mediterranean Basin Observation	2006	ASI
COSMO-Skymed2	Mediterranean Basin Observation	2006	ASI
Rømer	After the Danish astronomer Ole Rømer	2006	DSRI
Formosat3/ ROCSAT-3/ COSMIC 6	Republic of China Satellite-3/ Constellation Observing System	2006 (Mar.)	NSPO
Formosat3/ ROCSAT-3/ COSMIC 5	Republic of China	2006 (Mar.)	NSPO
Formosat3/ ROCSAT-3/ COSMIC 4	Republic of China	2006 (Mar.)	NSPO
Formosat3/ ROCSAT-3/ COSMIC 3	Republic of China	2006 (Mar.)	NSPO
Formosat3/ ROCSAT-3/ COSMIC 2	Republic of China	2006 (Mar.)	NSPO
Formosat3/ ROCSAT-3/ COSMIC 1	Republic of China	2006 (Mar.)	NSPO
ST5 3	Space Technology 5	2006 (Mar.)	NASA
ST5 2	Space Technology 5	2006 (Mar.)	NASA
Cassiope	ePOP probe meteorological satellite	2007	CSA
SBSS	Space-Based Space Surveillance	2007	NASA/GSFC
ADM-Aelous	Atmospheric Dynamic Mission	2007 (Oct.)	ESA
OCO	Orbiting Carbon Observatory	2007 (Oct.)	NASA/GSFC
GOSAT	Global Climate Observation System	2007	JAXA
COF	Columbus Orbital Facility	2007	DLR
Aeolus-S Sim		2007	ESA
Aeolus-X		2007	ESA

continued

TABLE 5.1 Continued

Mission	Description	Launch Date	Related Organizations
Orbview 5	Commercial Imaging Satellite	2007	GSFC
Star-One C-2		2007	ESA
Planck	Satellite for the imaging of the anisotropies of the cosmic background radiation	2007	ESA
Herschel Space Observatory	Formerly Far Infrared and Submillimetre Telescope (FIRST)—ESA Horizon 2000 cornerstone 4 (CS4)	2007	ESA
SDO	Solar Dynamic Observatory	2007	NASA/GSFC
Kepler	Satellite for the search of Earth-size and smaller planets	2007	NASA Ames
SMOS	Soil Moisture and Ocean Salinity	2007	ESA/CNES/SNP
Megha-Tropiques	Convective systems, water cycle, and energy budget in the tropical atmosphere	2007	CNES/ISRO
Solar Probe		2007	NASA/JPL
Mars Premier Orbiter		2007	CNES
ACCESS	Advance Cosmic Ray Composition Experiment for the Space Station	2007	NASA/GSFC
ATV-4	Automated Transfer Vehicle 4	2007	ESA
HTV-01	H-II Transfer Vehicle	2007	JAXA
HTV-DM	H-II Transfer Vehicle Demonstration Flight Model	2007	JAXA
Phoenix	Study Mars Polar Region	2007	NASA
COSMO-SkyMed4	Constellation of Small Satellites for Mediterranean Basin Observation	2007	ASI
THEOS	Thai Earth Observation System	2007	GISTDA
Orbview-5	Commercial remote sensing satellite	2007	ORBIMAGE
Astra-1M	Telecommunication Satellite	2008	ESA
LRO	Lunar Reconnaissance Orbiter	2008	NASA GSFC
ZX 9 (Chinasat)	Telecommunications Satellite	2008	
Spirale 2	Early Detection System	2008	CNES
Spirale 1	Early Detection System	2008	CNES
Eddington	L2 Astroseismology Mission	2008 (June)	ESA
Chandrayaan-1	Lunar Mission	2008	ISRO
Skynet 5C		2008	British Ministry of Defence
GLORY	The GLORY satellite is an Earth science mission that uses the refurbished bus of the cancelled VCL satellite	2008	NASA/GSFC
MSG-3	Meteosat Second Generetion-3	2008	ESA
ATV-5	Automated Transfer Vehicle 5	2008	ESA
SST	Space Solar Telescope	2008	CNSA
HTV-03	H-II Transfer Vehicle	2008	JAXA
HTV-02	H-II Transfer Vehicle	2008	JAXA
Picard		2008	CNES
Pleiades HR 1	Pleiades High Resolution 1	2008	CNES, ASI

SOURCE: John D. Kelley, NASA, "NASA Communications and Data Standards Program," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006, pp. 13-14, 16-18.

any funding. (Recall the point above that the total value of CCSDS standards was said to exceed $24 billion per annum.)

The corresponding figures for CCSDS activity outside NASA are not readily available. A way of estimating the level of effort is to consider that the CCSDS has 130 active associate members, typically U.S. aerospace corporations that are consumers of CCSDS publications and products. These companies adopt or adapt the CCSDS line of products to their own applications. The USAF and other agencies are also consumers of CCSDS products, which usually come to them via the associate members. There is an indirect economic relationship between corporate/U.S. government consumers and the private-sector producers and vendors of private-sector communication applications with CCSDS standards integrated into them.

CCSDS member agencies of other countries contribute to CCSDS in the form of full-time-equivalent (FTE) personnel. Typically the European Space Agency (ESA) matches NASA's contribution, and the Japanese Aerospace Exploration Agency plus a number of other agencies such as INPE (Brazil) contribute roughly one-fourth of the total contributed by NASA plus ESA.

The CCSDS Operating Plan for Standards Development,[9] which is subordinate to the CCSDS strategic plan, is updated yearly and defines near-term products in detail. Sys-

BOX 5.2
Examples of CCSDS Usage by NASA Centers

Jet Propulsion Laboratory

As described by NASA, JPL tends to strictly enforce compliance with use of CCSDS standards mainly because much of the CCSDS's work addresses the challenges of deep-space links such as poor quality of service and other problems associated with sending radio frequency (RF) waves across the solar system. All JPL missions since Mars Observer have complied at the link layer and below, meaning that they are using standard TC and TM at the link layer, or Advanced Orbiting Systems (AOS) for high-data-rate missions, for direct to Earth (DTE) or direct from Earth (DFE) links. The Command Operation Procedure (COP-1) with the Frame Acceptance and Reporting Method (FARM) is typically used for uplink reliability. Because two-way recall times are very long in deep-space applications, downlink data are typically sent in "unreliable" modes, although various nonstandard retransmission schemes are in use for critical frame or packet data.

The rover and lander missions are configured similarly for their DTE/DFE links, but they also use Proximity-1 in reliable mode for their orbiter-to-landed element links. The bulk of data being transferred from the very successful MER Rovers has come down over Proximity-1 relays to Odyssey and other orbiters. Odyssey and the other orbiters that support relaying also implement Proximity-1 for these local links. Some of the hardware implementations of Proximity-1 have known problems (CE-505 radio), but there are well-understood work-arounds for these. The missions using this radio tend to be compliant with the Proximity-1 standard at the undifferentiated byte stream (rather than packet stream) level. The more recent radio implementation—Electra—does not have this problem; it is a software defined radio that can be reconfigured as needed to support a fully compliant Proximity-1 link protocol. NASA expects that future missions using Electra will be fully compliant at the packet transfer level to better support relay operations.

Below the link layer, other CCSDS and Space Frequency Coordination Group (SFCG) standards are used for coding, modulation, and appropriate selection of frequencies. A variety of different frequencies and coding approaches are used, depending on the operating environment and characteristics of the mission links. Reed-Solomon, Convolutional, and now Turbo codes are used. High-data-rate missions are expected to use Deep Space LDPC codes as these are stabilized in the future.

Above the link layer a variety of different approaches are used for file delivery. Some missions have fully embraced the CCSDS File Delivery Protocol (CFDP) and used it successfully for uplink and downlink file transfers. Where missions are flying on-board file systems this is easier to accomplish, but even some missions that do not fly file systems have found it useful to adopt CFDP protocol elements and use the standard CFDP ground implementation. This provides lower-risk and lower-cost ground system implementation. One mission, Deep Impact, used JPL-developed CFDP software for both its flight and ground implementations. Other missions, like Messenger, used CFDP on-board in a fully automated approach, with no human in the loop.

Most of the Mars rover missions have adopted a file management and retransmission method that was first used on Mars Pathfinder. This has been driven by a desire to be able to more closely manage downlink prioritization, on-board data handling, and uplink bandwidth. It also provides support for handling compressed data in a way that recognizes the need to handle compression block boundaries to support error containment. Discussions are in progress to identify ways to accommodate all of these needs within the CFDP specification, or in some simple extensions to the specification that NASA will propose to CCSDS.

Many of the higher-level CCSDS protocols either are not appropriate for use in deep space or are not yet mature enough to be adopted. These include Space Link Extension (SLE) Service Management, and Spacecraft On-board Interface Services (SOIS). The command/uplink SLE data transfer protocols (SLE-FCLTU) are effectively in use by all missions that use the Deep Space Network (DSN) since they are part of the command subsystem. The SLE downlink protocols (SLE-RAF, SLE-RCF) are being used widely by the DSN to provide cross-support to external missions. CCSDS standards for exchange of navigation data (orbits) are just coming into use. Other navigation data exchange standards (tracking, attitude) are expected to be adopted as they become finalized.

Future JPL missions are expected to adopt the existing space link protocols and to also adopt more fully the use of CFDP. As support is provided for more networked sets of missions NASA expects to see use of the standard relay operations in CFDP, and eventually to see use of the newly developed Delay Tolerant Networking (DTN) protocols. These protocols, and the SCPS, Internet tuned for space, protocols are more likely to see first use in the lunar environment in support of Constellation.

Goddard Space Flight Center

Nearly every Goddard mission in the past 10 years has used the CCSDS telecommand protocols (including COP-1) for commanding and the TM/AOS protocols for telemetry. (TM was used for telemetry until AOS replaced it.) The rare exceptions to the general rule are typically very small missions, for example, a balloon experiment out of Wallops.

Goddard missions that use CCSDS telecommand and telemetry protocols include FAST, SWAS, WIRE, SAMPEX, HESSI, TRACE, SWIFT, GLAST, XTE, TRMM, MAP, IMAGE, EO-1, ST5, SDO, and LRO. (Some of these missions are still in development.)

The GPM mission started on a non-CCSDS track but returned to CCSDS when the designers discovered that spacecraft vendors had considerable knowledge, experience, and a reliable track record with CCSDS protocols—qualities not evident with the alternative that was being considered.

Although CFDP is not universally used, it is gaining acceptance, with planned use by JWST, LRO, GPM, and (possibly) MMS. Reasons given for not using CFDP include "it didn't exist when we designed our mission" and "it doesn't have Goddard flight heritage."

SOURCE: John D. Kelley, NASA SOMD, March 1, 2006.

tem-level assessments are conducted routinely as an integral aspect of developing the operating plan. The CCSDS strategic plan is updated as necessitated by changing events, and at least every 3 years. The strategic plan redefines goals, the organization's current objectives, and domains for standardization as appropriate. Development of the operating and strategic plans evidences planning that is thoroughly considered, projecting future activities that are both reasonable and justifiable.

Managers executing plans for the data standards program have both an understanding of the objectives and processes for space data handling, and an acceptable ability for risk[10] management, as demonstrated by their continuing success in delivering standards in a timely manner and within available resources.

Overall Capabilities

The quality of the work of NASA's data standards management program element is clearly comparable with that of other world-class efforts, as demonstrated by the fact that the products—data standards—have been adopted as ISO standards as appropriate. As noted above, there are currently 78 active publications (standards), of which 29 have become ISO standards. Also, as witnessed by their adoption and use, the standards meet the requirements of both internal and external customers.

The qualifications of the NASA/contractor staff are clearly sufficient to achieve the goals of the data standards management program element, as demonstrated by its continuing success in playing a leading role in CCSDS activities. In addition, the capabilities, quantity, and state of readiness of the equipment and facilities used to achieve program element goals appear to be quite satisfactory, again given the continuing delivery and acceptance of the program element's data standards.

Personnel, equipment, and facilities appear to be used efficiently, with support contractors effectively complementing government personnel. There are no laboratories or other facilities dedicated specifically to standards development. Although testbeds are utilized to advance standards development, existing mission testbeds are normally used as appropriate to develop prototype standards.[11]

As NASA has noted,[12] the majority of the resources applied to standards development are people with unique expertise, and thus overlap in personnel resources is usually minimal. Assimilation of the common threads that contribute to standards development usually occurs via agency-wide and international working groups; therefore standards development work tends not to be tied to geographic locations, such as specific NASA centers.

Finding: It appears that the expected services are being successfully provided by NASA's space data standards management program element, as evidenced by the continuing development of standards that are being adopted by space activities around the world. The relatively modest funding allocated seems stable, and no funding threats are foreseen.

NOTES

1. Kelley, John D., "NASA Communications and Data Standards," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006.
2. Consultative Committee for Space Data Systems (CCSDS), About CCSDS, available at http://www.CCSDS.org.
3. CCSDS Secretariat, Strategic Plan of the Consultative Committee for Space Data Systems, CCSDS A01.1-Y-2, Draft 4, Version 3, March 8, 2005.
4. CCSDS, available at http://www.ccsds.org.
5. CCSDS Secretariat, Strategic Plan of the Consultative Committee for Space Data Systems, CCSDS A01.1-Y-2, Draft 4, Version 3, March 8, 2005.
6. Kelley, John D., NASA SOMD, personal communication, March 1, 2006.
7. Kelley, John D., NASA SOMD, personal communication, April 24, 2006.
8. Kelley, John D., NASA SOMD, personal communication, March 1, 2006.
9. CCSDS, CCSDS Operating Plan for Standards Development, CCSDS Record A01.2-Y-4 Yellow Book, July 2005.
10. Both the technical risks associated with capitalizing on technologies that are leading edge, yet sufficiently mature to be viable, and the risks from working within limited resources.
11. Kelley, John D., NASA SOMD, personal communication, April 26, 2006.
12. Kelley, John D., NASA SOMD, personal communication, April 24, 2006.

6

Search and Rescue

INTRODUCTION

NASA participation in search and rescue efforts is clearly defined in a series of international and national understandings, agreements, and interagency plans. The United States is a signatory to the 1988 International COSPAS-SARSAT[1] (C-S) Program Agreement.[2] C-S is an operational satellite-based program, and the National Oceanic and Atmospheric Administration (NOAA) is the lead U.S. agency for C-S operations.[3] NASA participation in search and rescue (SAR) efforts is governed by a series of memoranda of agreement (MOA). NASA is a member of the National Search and Rescue Committee (NSARC), a standing interagency committee that oversees the National Search and Rescue Plan (NSP).[4] The NSARC assigns and coordinates SAR responsibilities, develops and implements SAR requirements and standards, outlines joint SAR tasking, fosters international cooperation, and promotes close cooperation between military and civil authorities for the provision of SAR services.[5] The NSP provides guidance to federal agencies for development of SAR-related systems, including cooperation for the development, coordination, and improvement of SAR services, and states that NASA supports C-S objectives through research and development (R&D) or application of technology[6] and is the primary R&D agency for the follow-on to the C-S program, called the Distress Alerting Satellite System (DASS).[7] The draft DASS implementation plan clearly defines the program goals and objectives in the context of the numerous international and U.S. interagency memoranda of agreement that govern search and rescue. However, this plan is not a binding document and does not yet represent the approved positions of the participating agencies.

The C-S system has user, space, and ground segments. The user segment is composed of radio beacons for aviation, maritime, and personal use that transmit signals during distress situations. The space segment consists of instruments aboard satellites that are used to detect the distress signals. C-S-equipped satellites are in low Earth orbit (LEO) and in geostationary Earth orbit (GEO)—the LEOSAR and GEOSAR systems, respectively. The ground segment consists of several components. Ground receiving stations or local users terminals (LUTs) receive and process the satellite downlink signal to generate distress alerts. Mission control centers (MCCs) receive alerts produced by LUTs and forward them to rescue coordination centers, search and rescue points of contacts, or other MCCs.[8]

Because of their high altitude and fixed position with respect to Earth, GEOSAR satellites cannot independently locate a beacon, and can provide location information only if the beacon contains a navigation receiver and transmits its position. However, the GEOSAR system can provide almost immediate alerting in the footprint of the GEOSAR satellite. The LEOSAR system provides coverage of the polar regions (which are beyond the coverage of geostationary satellites), can calculate the location of distress events using Doppler processing techniques, and is less susceptible to obstructions that may block a beacon signal in a given direction because the satellite is continuously moving with respect to the beacon. However, LEOSAR satellite orbit patterns result in noncontinuous Earth coverage, and so delays are possible between beacon activation and the generation of an alert message.[9]

In September 1997, a Canadian study revealed that a constellation of mid-Earth-orbiting (MEO) satellites could be used to augment the existing C-S system by providing a vastly improved space-based distress alerting and locating capability.[10] In 2000, the United States, the European Commission, and Russia began consultations with C-S regarding the feasibility of installing SAR instruments on their MEO navigation satellite systems—Global Positioning System (GPS), Galileo, and GLONASS. These MEOSAR constellations could eventually become components of an international C-S MEOSAR system.[11] NASA, in coordination with the U.S. Air Force Global Positioning System Program Office and Sandia National Laboratories, determined that the GPS constellation would be the best and most cost-effective MEO constellation to host the SAR instruments. This project is called DASS.[12]

NASA has committed funds and personnel for the development of a proof-of-concept (POC) system for DASS. The DASS POC project is designed to confirm the feasibility of the MEOSAR concept, evaluate the operational impact to C-S of adding a MEOSAR component, determine what modifications will be required prior to the beginning of the demonstration and evaluation (D&E) phase, and establish the scope and content of the D&E phase.

NASA POC funding paid for integration of a DASS-modified payload on nine GPS Block II satellites.[13] The Air Force intends to incorporate the DASS payload on all remaining Block IIR/IIF satellites.[14] The POC space segment will receive 406-MHz beacon signals through an extant UHF antenna. Signals, without any onboard processing, will be relayed to the MEOLUT through an existing S-band antenna. The downlink frequency differs from the internationally recognized 1544-1545 MHz distress and safety communications frequency used by C-S, but its use in no way inhibits the ability of POC DASS to demonstrate SAR repeater capability.

NASA is funding the installation of a POC ground station at GSFC.[15] The four-antenna POC and demonstration DASS ground station will be capable of tracking signals at both the S-band and the L-band to allow visibility both of POC DASS signals and of C-S L-band signals from operational LEOSAR and GEOSAR satellites. The ground station will be used to verify and characterize the DASS concept after sufficient POC payloads are on orbit to allow simultaneous four-satellite visibility. In the United States, distress alert data will not be distributed to operational SAR services during the proof-of-concept phase, but will be transmitted during the demonstration and evaluation phase so that an assessment of DASS's operational capabilities can be performed.[16]

If resources allow, an assessment of system performance when using data combined from MEOSAR, LEOSAR, and GEOSAR systems will also be accomplished.[17] The program achieved a significant cost savings by making slight modifications to existing DOE payloads and using them as SAR instruments.[18] There are six of these modified GPS IIR satellites in orbit.[19]

The operational DASS will function as a secondary mission aboard GPS III satellites and, when fully deployed, will consist of 24 to 27 MEO payloads with no less than four DASS payloads visible from anywhere on Earth at any time. The DASS system will be completely compatible with C-S distress beacons. It will receive, decode, and locate distress beacons throughout the world and will support near-instantaneous distress alerting.[20] The operational DASS satellite payload will continue to function as a transparent repeater for 406-MHz beacon signals, but the system will up-convert all incoming signals to the band at 1544.8-1545.0 MHz for rebroadcast.[21]

The DASS ground segment will be composed of MEOLUTs and the existing C-S MCC network. The MEOLUT will receive and process satellite downlinks, calculate beacon locations, and forward this information to the MCC. The MCC network will perform the same basic functions for MEOSAR alerts as it currently provides for LEOSAR and GEOSAR alerts.[22]

NASA chairs the DASS Management Working Group (DMWG), which consists of NASA, NOAA, the U.S. Coast Guard, the USAF, the DOE, and other agencies as appropriate. The DMWG provides interagency planning and direction during the development, POC, and D&E of DASS.[23]

The Goddard Space Flight Center SAR Mission Office is the NASA lead for SAR R&D. This office performs C-S R&D and provides technical support to NOAA and other federal agencies in their operation and use of C-S.[24] It is also responsible for developing the DASS system performance requirements for the design, procurement, and operation of the DASS prototype ground segment; for defining and conducting the POC phase testing; and for supporting DOE on DASS POC implementation using the existing DOE payload on the GPS space segment. NASA will fund the POC ground segment until POC completion.[25]

NASA maintains a multi-function laboratory called the SARLab at GSFC for C-S support and to perform DASS POC R&D. The SARLab consolidates all R&D functions of the SAR Mission Office into one unit, including a search planning station and two combined ground stations: the System Evaluation and Development Laboratory (SEDL) and the new DASS POC ground station.[26] NASA uses the SEDL to support C-S operations. The SEDL also addresses emergency beacon failures as a result of damage and false alarms and develops new classes of beacons. One is a self-locating beacon with a built in GPS receiver. Another is a portable prototype personal locator beacon.[27]

NASA also performs R&D on beaconless SAR, including using synthetic aperture side-looking radars on search aircraft[28] and also using laser systems on search aircraft to transmit and receive signals that enable discrimination between background objects and reflections from inexpensive reflective tape on the person or vehicle in distress.[29]

GSFC is expecting to release a POC test plan in April 2006 to define the criteria for completing the POC, including testing requirements and requirements for internal and external review. The DASS POC will be complete when the goals in the POC test plan have been achieved.

ASSESSMENT

Progress Toward Achieving Program Plan

The DASS implementation plan is the overarching interagency program plan for DASS.[30] Developed by the DMWG, which is chaired by NASA, the implementation plan clearly sets forth each agency's roles, responsibilities, milestones, requirements, metrics for requirements satisfaction, funding, international participation, how international MEOSAR programs work with DASS and C-S, and the vision for the future of SAR implementation. At meetings of the DMWG, each participating agency provides a report of its DASS implementation status and a schedule of its planned activities. Other meetings and technical reviews concerning DASS design and performance capabilities will be scheduled as needed.[31] The DMWG assigns action items to each stakeholder and these are documented in the implementation plan, which is updated after each DMWG meeting. A review of these action items reveals that there are no critical near-term issues and that participating agencies are working on issues well in advance of the date for program implementation.[32] In addition, the document contains multiyear funding profiles for each agency.

Finding: The committee's review of the action items from the DASS Management Working Group (DMWG) meetings indicates that the DMWG believes that the program has proceeded as planned and that NASA has allocated the appropriate personnel, facilities, and funds and is progressing toward completing the DASS proof of concept without any major issue.

Successful completion of the POC phase will initiate the transition to the D&E phase. D&E builds on work completed during the POC. NOAA will assume program management responsibility for DASS implementation at the conclusion of the POC phase and will guide the system transition through D&E to an operational status.[33] The current plan is for NASA to provide funding as necessary for the prototype ground station to support the D&E test activities and for analytical support of the technical test results. Plans also call for NASA to continue its evaluation of the prototype ground station to refine the requirements and specifications for operational MEOLUTs.[34] The Air Force will continue to launch GPS IIR and IIF satellites with DASS payloads.[35]

D&E will evaluate the operational effectiveness of DASS and provide the basis for a recommendation on its operational use in order to ensure that national and international organizations accept DASS as an alerting source. During this phase all minimum DASS performance parameters required for compatibility with C-S will be evaluated, with the possible exception of global coverage. Sufficient space and ground segment capability will be required to adequately characterize the system and to confirm its benefits.[36] Proof of success is measured against the set of international and national documents that are the source of program requirements. These documents define the C-S interfaces and implementation plan, the SARSAT operational requirements, required DASS capabilities, the interfaces to GPS III, other GPS III design requirements, and performance requirements for the LUTs.[37]

The DASS IP indicates that the international MEOSAR programs, particularly Galileo, are proceeding years ahead of the DASS schedule. This provides the potential for the United States to be able to use SAR/Galileo transmissions to conduct POC and D&E activities on a system-wide basis before GPS Block III satellites are launched.[38] If Galileo proceeds as initially planned, a major DASS cost avoidance could result. However, NOAA representatives were skeptical that this benefit would materialize, given early indications that Galileo funding decisions could greatly reduce the number of SAR payloads included in the constellation. They also expressed concern that the United States would have no control over the testing of SAR/Galileo, which could very well be outsourced to a nation less well versed than the major nations contributing to the core navigation program.[39] The committee observed, too, that the United States may not want to rely solely on a non-U.S. system for SAR functionality.

Finding: The DASS implementation plan allows NASA to take maximum advantage of work that is being done by partner agencies (e.g., Air Force satellites, DOE payload) and international C-S partners (e.g., Russian and European MEOSAR constellations). In addition, the DASS program architecture retains much of the existing C-S ground segment, all the international interfaces to the C-S system, and the POC ground segment developed by NASA.

Methodology

The DASS implementation plan is a detailed interagency program plan that describes the implementation of agency responsibilities as outlined in the document *Memorandum of Agreement between NASA, NOAA, USAF, USCG, and DOE Regarding the Development and Demonstration of the Global Positioning System-Based Distress Alerting Satellite System*, dated February 2003. The agreement sets forth the roles and responsibilities of the participating agencies during the development and demonstration phases of the DASS program implementation.[40] The DMWG provides interagency planning and direction during the development, proof-of-concept, and demonstration and evaluation of DASS. It is chaired by NASA through the POC phase and NOAA during D&E. Participants meet quarterly, as necessary, to coordinate requirements, long-range planning, and acquisition strategies.[41]

Finding: The U.S. agency participants in the DASS program meet regularly under the umbrella of the DASS Management Working Group and clearly agree on roles and responsibilities for the DASS proof-of-concept development. The DMWG is chaired by NASA, the lead development agency.

A successful DASS POC is a key step leading to eventual incorporation of DASS into the international C-S architecture. The DASS program places particular emphasis on correct processing of rescue signals. That function is performed in the ground segment. SAR is an operational lifesaving system, and so the agencies have embarked on a well-defined risk reduction program for DASS POC ground segment activities.[42] Two support contractors in the United States are capable of performing POC ground segment development activities. NASA selected one of these as its support contractor. NOAA selected the other to verify and validate the work of the NASA development contractor, providing risk mitigation for a critical system element.[43]

Upon successful completion of D&E, the DASS program will transition to an operational system funded and managed by the agencies responsible for search and rescue operations and C-S administration, functions for which NOAA is the lead U.S. agency today. At that time a new MOA that governs the management of the operational DASS will be required.[44]

Overall Capabilities

The committee's interviews were very positive with the lead U.S. SAR agency, NOAA, at the Suitland facility regarding the quality of NASA's participation in search and rescue R&D.[45] NOAA's representatives stated that NASA is meeting requirements, has been a good shepherd of search and rescue R&D efforts since program inception, and has identified no budget issues.

The committee observed that GSFC personnel, equipment, and facilities are appropriate to the DASS POC task and that support contractors are used efficiently to fill gaps in NASA capabilities without duplication.

An interview with the GPS Joint Program Office revealed that the Air Force is not participating in the DASS ground system development. The Air Force role in the POC DASS is as the space segment host for the DASS payload. That work is essentially complete, and all block IIR/IIF satellites will be equipped with the R&D DASS configuration to support NASA's DASS POC testing. The Air Force plans to procure GPS III in blocks, and based on the current state of requirements validation within the Air Force, DASS might not be included on the first block of GPS III satellites unless there is strong advocacy by the civil agencies participating in the program.[46]

In preparing its FY 2008 budget, NASA headquarters is now assuming that the DASS POC phase will be complete in FY 2007 and will no longer be funded in FY 2008.[47] Conversations with NASA headquarters, and confirmation by e-mail, indicate that the DASS POC has accomplished the vast majority of its objectives but has already exceeded its original $20 million agreed-to budget by $3.5 million, with an estimated cost to complete of $11.5 million. NASA headquarters is prepared to make DASS a budget and programmatic issue in the upcoming budget cycle and expects to review alternatives, including rephasing the program to match the GPS III schedule, reducing NASA funding to slow the pace, or obtaining additional funding from other agencies.[48,49]

Finding: NASA has exceeded its agreed-to budget for DASS. Considerably more funds are needed to complete the proof-of-concept phase, and this additional budget may not be supported by NASA headquarters. If the FY 2008 budget cycle results in changes in NASA program funding, it is uncertain whether the DASS proof of concept can be completed in a form that reflects the plans and agency agreements the committee reviewed in this study. The impacts on the plans of participating agencies are also not known.

SUMMARY AND CONCLUSIONS

NASA has performed well as the lead agency for search and rescue R&D and will continue in that role until the completion of the DASS POC. NASA has successfully planned and managed the multiagency SAR development programs and has integrated the POC DASS system with the existing COSPAS-SARSAT, an international program that has performed a daily critical mission since it was declared operational in 1985. The programs have achieved cost and schedule leverage by piggybacking on existing systems and avoiding unnecessary development and risk. Even the completion of the future parts of the SAR program will continue to depend on this leveraging of systems funded by other U.S. agencies and international partners

Unfortunately, the DASS program has significantly overrun its allocated funding. Although the program has been well supported by NASA and contractor personnel, a restructuring of the DASS POC is likely during the upcoming budget cycle.

Recommendation: As chair of the DASS Management Working Group, NASA should assemble the interagency participants in the DASS proof of concept, review the program's progress toward meeting technical, operational, and programmatic requirements, review interagency and international commitments, and negotiate a plan for the future of DASS.

NOTES

1. COSPAS (Cosmicheskaya Sistyema Poiska Avariynich Sudov), Space System for the Search of Vessels in Distress; SARSAT, Search and Rescue Satellite-Aided Tracking.
2. International COSPAS-SARSAT Programme Agreement [ICSPA] between the United States, Canada, the Union of Soviet Socialist Republics, and the Republic of France, Paris, France, July 1, 1988.
3. Memorandum of Understanding among the National Oceanic and Atmospheric Administration, United States Coast Guard,

United States Air Force, and the National Aeronautics and Space Administration Regarding U.S. Responsibilities for the COSPAS-SARSAT System, Issue 1, Revision 1, January 1998, p. 2.

4. NASA, United States National Search and Rescue Supplement to the International Aeronautical and Maritime Search and Rescue Manual, National Search and Rescue Committee, including Appendix A, the National Search and Rescue Plan—1999 [NSP], Washington, D.C., May 2000, p. 2-1.

5. NASA, United States National Search and Rescue Committee [NSARC] Agreement among the Department of Transportation, Department of Commerce, Department of Defense, Department of Interior, Federal Communications Commission, and the National Aeronautics and Space Administration, March 3, 1999, paragraph 4.

6. NASA, United States National Search and Rescue Supplement to the International Aeronautical and Maritime Search and Rescue Manual, National Search and Rescue Committee, including Appendix A, the National Search and Rescue Plan—1999 [NSP], Washington, D.C., May 2000, pp. A-2–A-3.

7. Memorandum of Agreement between the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the United States Air Force including the Space and Air Combat Commands, the United States Coast Guard, and the Department of Energy National Nuclear Security Administration Regarding the Development and Demonstration of the Global Positioning System-Based Distress Alerting Satellite System (DASS), February 2, 2003, p. 3.

8. COSPAS-SARSAT, International Satellite System for Search and Rescue, available at http://www.cospas-sarsat.org/Description/concept.htm.

9. COSPAS-SARSAT, International Satellite System for Search and Rescue, available at http://www.cospas-sarsat.org/Description/concept.htm.

10. NASA Goddard Space Flight Center Search and Rescue Mission Office, Distress Alerting Satellite System (DASS), available at http://searchandrescue.gsfc.nasa.gov/dass/index.htm.

11. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, pp. 1-2–1-3.

12. NASA Goddard Space Flight Center Search and Rescue Mission Office, Distress Alerting Satellite System (DASS), available at http://searchandrescue.gsfc.nasa.gov/dass/index.htm.

13. Kelly, John D., NASA SOMD, personal communication, April 19, 2006.

14. Reaser, Colonel Richard, GPS Deputy Joint Program Director, personal communication, April 19, 2006.

15. NASA Goddard Space Flight Center Search and Rescue Mission Office, Distress Alerting Satellite System (DASS), available at http://searchandrescue.gsfc.nasa.gov/dass/index.htm.

16. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 2-5.

17. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, pp. 7-3–7-4.

18. NASA Goddard Space Flight Center Search and Rescue Mission Office, Distress Alerting Satellite System (DASS), available at http://searchandrescue.gsfc.nasa.gov/dass/index.htm.

19. Memorandum of Agreement between the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the United States Air Force including the Space and Air Combat Commands, the United States Coast Guard, and the Department of Energy National Nuclear Security Administration Regarding the Development and Demonstration of the Global Positioning System-Based Distress Alerting Satellite System (DASS), February 2, 2003, pp. 3-4.

20. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 2-1.

21. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 2-4.

22. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 2-4.

23. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 4-4.

24. Memorandum of Understanding among the National Oceanic and Atmospheric Administration, United States Coast Guard, United States Air Force, and the National Aeronautics and Space Administration Regarding U.S. Responsibilities for the COSPAS-SARSAT System, Issue 1, Revision 1, January 1998.

25. Memorandum of Agreement between the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the United States Air Force including the Space and Air Combat Commands, the United States Coast Guard, and the Department of Energy National Nuclear Security Administration Regarding the Development and Demonstration of the Global Positioning System-Based Distress Alerting Satellite System (DASS), February 2, 2003, pp. 6-7.

26. NASA Goddard Space Flight Center Search and Rescue Mission Office, Search and Rescue Laboratory (SARLab), available at http://searchandrescue.gsfc.nasa.gov/sedl/sarlab.htm.

27. NASA Goddard Space Flight Center Search and Rescue Mission Office, Emergency Beacon Development Web Page, available at http://searchandrescue.gsfc.nasa.gov/techdevelopment/beacons.htm.

28. NASA Goddard Space Flight Center Search and Rescue Mission Office Search and Rescue Synthetic Aperture Radar (SAR2), available at http://searchandrescue.gsfc.nasa.gov/techdevelopment/sar2.htm.

29. NASA Goddard Space Flight Center Search and Rescue Mission Office Laser Search and Rescue (L-SAR), available at http://searchandrescue.gsfc.nasa.gov/techdevelopment/l_sar.htm.

30. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006.

31. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 4-5.

32. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006.

33. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 4-3.

34. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 7-9.

35. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006 p. 2-4.

36. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 7-6.

37. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, pp. 3-4–3-5.

38. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 7-13

39. Button, Tom, and A.J. Mehta, meeting with NOAA, March 30, 2006.

40. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 1-1.

41. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 4-5.

42. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, pp. 6-2–6-5.

43. Button, Tom, and Ajay Mehta, SARSAT Program Manager, meeting with NOAA, March 30, 2006.

44. DASS Management Working Group, Distress Alerting Satellite System Implementation Plan [DASS IP], Issue 1, January 12, 2006, p. 4-5.

45. Button, Tom, and Ajay Mehta, meeting with NOAA, Suitland, Md., March 30, 2006.

46. Reaser, Coloniel Richard, GPS Deputy Joint Program Director, personal communication, April 19, 2006.

47. Kelly, John D., NASA SOMD, personal communication, April 13, 2006.

48. Kelly, John D., NASA SOMD, personal communication, April 11, 2006.

49. According to the International COSPAS-SARSAT Programme Agreement (ICSPA), p. 5, Article 6, Financial Matters, “Each party, in conformity with its domestic funding procedures, and subject to the availability of appropriated funds, shall be fully responsible for financing all costs associated with its contribution to the Space Segment as determined pursuant to Article 5, and the common costs arising from the obligations of this Agreement.”

7

Communications and Navigation Architecture

INTRODUCTION

The communications and navigation architecture program element is responsible for defining the space communications and navigation architecture to support NASA's science and exploration missions through 2030. This architecture must evolve through 2030 and beyond to keep pace with the needs of future science and exploration users and, potentially, non-NASA users. The communications and navigation architecture necessarily encompasses components such as the Deep Space Network and the Ground Network that are managed outside the Space Operations Mission Directorate (SOMD). As per its charge, in this chapter the committee examines NASA's approach to developing the architecture, and the resources and capabilities that will support that development.

The communications and navigation architecture program element accomplishes its task through NASA's agency-wide Space Communications Architecture Working Group (SCAWG), whose purpose is to develop a future space communications architecture and identify associated technology investments necessary to support all future NASA exploration, science, and human-tended missions.[1] SCAWG'S scope is shown in Figure 7.1.

The purpose of NASA's space communications architecture is "to concurrently architect the Space Communications Network to enable NASA's changing mission of Exploration."[2] To do this, NASA is developing 5-year "snapshots" of the space communications architecture that must evolve from the present Deep Space Network, Space Network, and Ground Network in order to provide the necessary communication capabilities to support NASA exploration and science programs. Figure 7.2 shows the elements that will be associated with NASA's space communications architecture by approximately 2030.

Regarding the navigation portion of the communications and navigation architecture, NASA believes that navigation requirements will continue to heavily influence modulation formats and other details of the physical layer (layer 1 of the OSI model) for communication, including the need for accurate and synchronized time sources. For example, a fraction of a spacecraft's transmitter power can be dedicated to an unmodulated radio frequency beacon that is included strictly for the purpose of computing the range and range rate from Earth to the spacecraft. If a user spacecraft needs to find its position by comparing beacons from different sources, as in the Global Positioning System, those sources must synchronize their transmissions. Navigation requirements can influence the selection of a particular constellation of communication relay satellites orbiting a planet, but these requirements are not expected to significantly influence the choice of whether or not to link specific nodes in the space network. Therefore, it is not unreasonable that navigation is mentioned only occasionally in SCAWG documents. The remainder of this chapter focuses on communications.

ASSESSMENT

Formulation of the Program Plan

Project Objectives

NASA's SCAWG encompasses members that carry out both technical and programmatic/authoritative functions, and that represent each NASA mission directorate, the Strategic Investment Division of the chief financial officer, and communication networks and the user community, including NASA centers. Evidence of the breadth of SCAWG's membership was confirmed by the committee through its review of documentation[3] and in presentations to the committee by the SCAWG's chair. Structurally, SCAWG's membership allows for inviting subject-matter experts from government, academia, and industry to participate in specific studies on an as-needed basis.

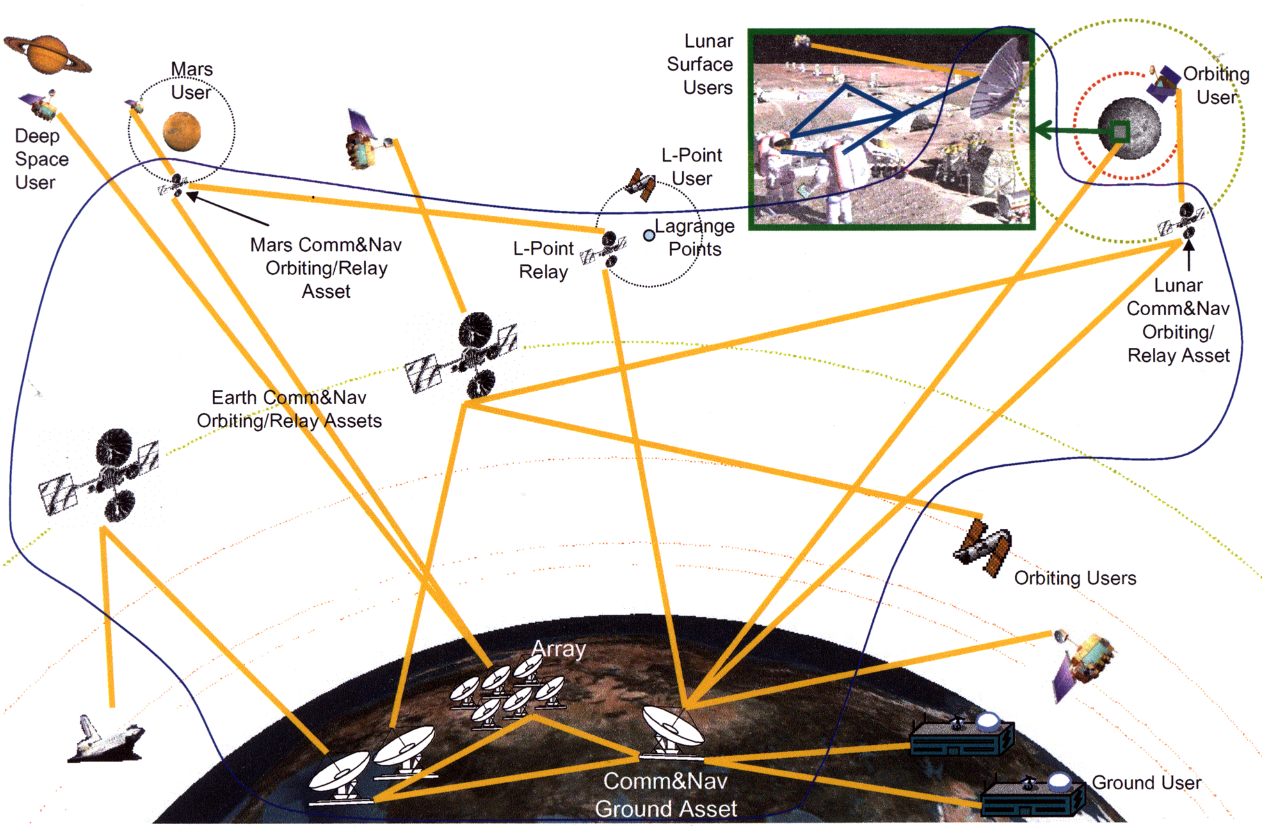


FIGURE 7.1 Scope of NASA's Space Communications Architecture Working Group, as indicated by the continuous thin blue line encompassing capabilities such as Earth, lunar, and Mars communication and navigation relays. SOURCE: John Rush, NASA, "NASA Navigation and Communications Architecture," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006, p. 7.

Because all interests are represented in the SCAWG, the recommendations are likely to flow both to and from organizations represented in the SCAWG and to flow both from work in process and any formal reports by the SCAWG. Given this high degree of continuing interaction, the committee believes that the objective of involving mission directorates in planning and review is adequately addressed.

Finding: NASA's Space Communications Architecture Working Group appears to have all the necessary qualifications, capabilities, and facilities to perform its work, and its output is of high quality.

Project Deliverables

One example of SCAWG activities is a recent lunar relay architecture study[4] that produced a preliminary evaluation of the options shown in Figure 7.3. Further refinement of the elliptical orbit option is now beginning at GSFC, as lunar relay becomes a project rather than a concept. The SCAWG will have one or more members from GSFC's lunar relay project team, keeping the architecture team up to date on the capabilities that lunar relay is expected to provide. Eventually, lunar relay will be one more existing infrastructure capability forming a basis for future space communications architectures.

As it was explained to the committee, the 2006 SCAWG activity is a one-time effort to defragment NASA's vision for space communications infrastructure. Now that the SCAWG has established its vision for a 2030 communications architecture and has conducted a lunar relay architecture study, its level of activity is expected to decrease within the next 2 years. The nature of that activity could also change as today's proposed architectures become tomorrow's projects. For example, the SCAWG is responsible for keeping track of GSFC's preliminary design work on a lunar relay project and any other near-term design efforts.

Recommendation: NASA's Space Communications Architecture Working Group should continue as planned to carefully evaluate near-term and intermediate-term architecture options while promoting development of components such as relay satellites and ground stations consistent with the long-term communications architecture.

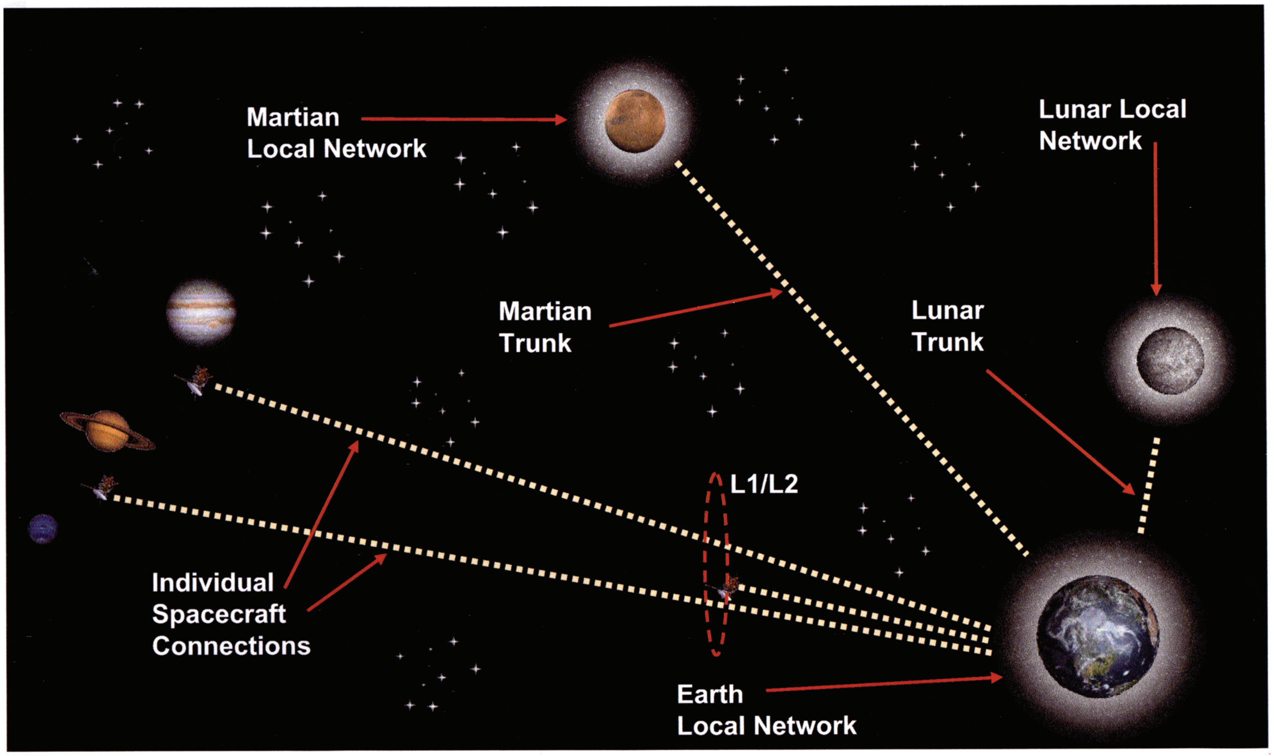


FIGURE 7.2 Top-level view of NASA's space communications architecture circa 2030. SOURCE: John Rush, NASA, "NASA Navigation and Communications Architecture," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006, p. 10.

Expected Services

The development path to the SCAWG's long-term communications architecture vision will be determined by programmatic decisions yet to be made, namely the definition and scheduling of specific missions. As long as the intermediate steps provide proper software layering and allow for some software upgradability, the path to the long-term vision is quite flexible. This is one of the greatest technical strengths of the SCAWG's recommended communications architecture.

The SCAWG will produce occasional updates on the long-term architecture plus individual studies of how to satisfy the communication and navigation needs of specific missions. These updates should enable NASA to assess progress, should prompt feedback from internal customers (the designers for each mission), and should ultimately make the case for reallocating funding as needed. Adequacy of staffing to support this level of activity depends on active support from other mission directorates.

The SCAWG has not yet attempted to define whether or how the existing near-Earth network (Tracking and Data Relay Satellite System; TDRSS) could evolve to support the long-term communications architecture. One of the elements of that long-term vision is a next-generation Earth relay satellite, but the features of this satellite are unspecified. NASA needs to have a working concept (or concepts) of the next-generation Earth relay satellite, if only to allow for an orderly transition of service from the current TDRSS and its planned replenishment.

The committee does not presume to define an evolutionary path from today's TDRSS forward, but only to point out that some baseline definition, however imperfect, should be undertaken before NASA issues requests for proposals for future Earth relay satellites. This suggestion is not inconsistent with NASA's present plan to include acquisition in the FY 2008 budget of "clone" TDRSS satellite replacements for launch in 2015.

Finding: A critical near-term task for NASA's Space Communications Architecture Working Group (SCAWG) will be to define one or more potential evolutionary paths from today's TDRSS to an Earth relay system consistent with the SCAWG's vision for a long-term communications architecture.

Technologies that might be worth further study as components of some of the evolutionary paths include those for augmentation of the ground network (more sites, fiber interconnection) to provide better coverage in low Earth orbit;

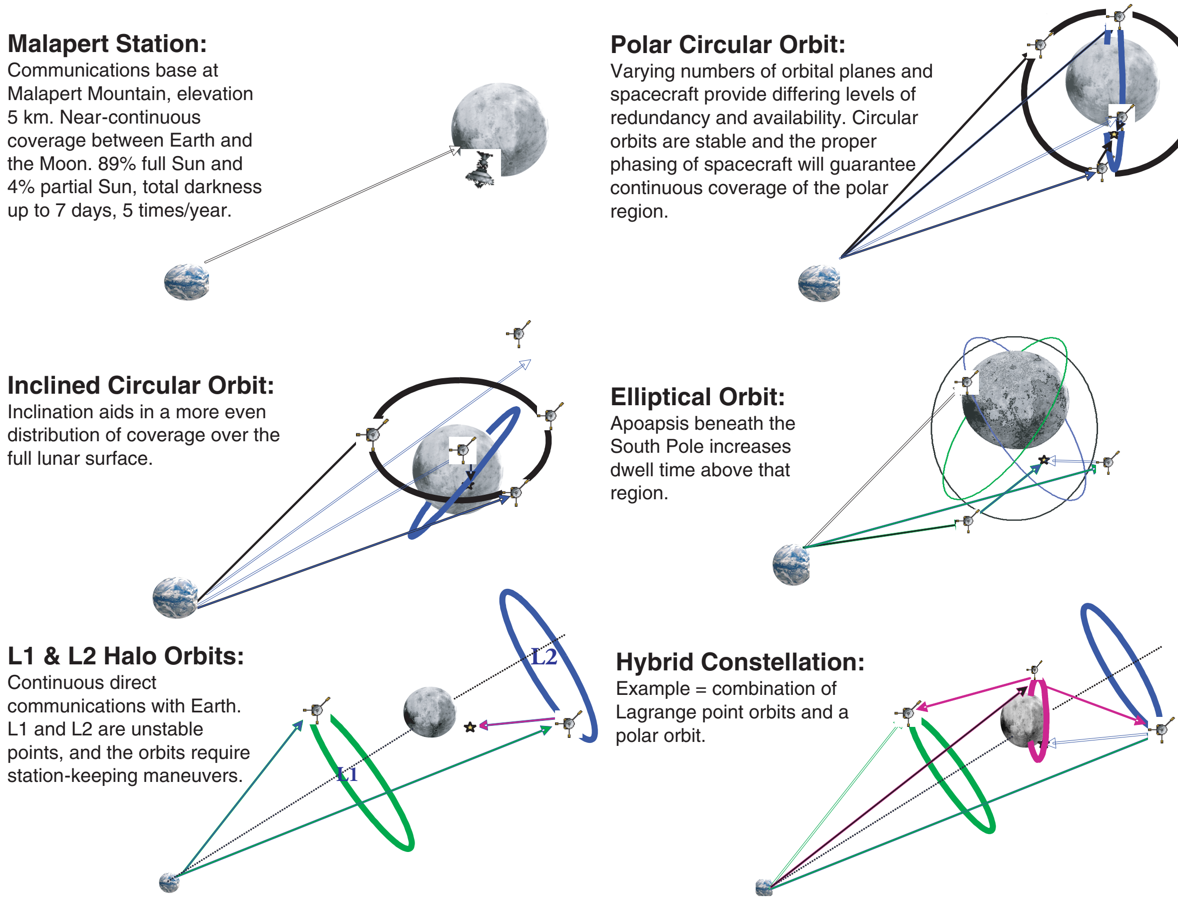


FIGURE 7.3 Lunar relay constellation options considered by the SCAWG. SOURCE: John Rush, "NASA Navigation and Communications Architecture," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006, p. 14.

technologies for improved performance of the multiple access service (higher transmitted signal levels and greater receiving sensitivity) to allow some current S-band single-access users to move to multiple access; near-Earth relay crosslinks into the DOD's transformational satellite (TSAT) network (in order to share TSAT's communications backbone); technologies for packet switching (with or without a router); optical links to user satellites; and combined DOD/NASA satellite payloads.

In addition to working on the evolution of Earth relay capabilities, the SCAWG will need to work closely with Goddard's Exploration, Operations, Communications, and Navigation Systems organization to maximize the long-term utility of the technologies and components of the lunar relay project.

The SCAWG did not present to the committee any results on protocol stack software for space networks, but the requirements for this software are largely independent of the constellation design. This problem can therefore be addressed separately. JPL is currently taking the most prominent role in design of protocol software for space networks.

The committee is aware of the differences of opinion regarding space communications protocols. (See "The Interplanetary Internet," *IEEE Spectrum* magazine, August 2005.) However, that conflict is not primarily a technical one: everyone agrees that IP (Internet Protocol, the basic packet data communication standard) will work fine at short ranges and that UDP (User Datagram Protocol for one-way transport of data packets) will be the foundation for longer-range communication. The SCAWG should promote the development of long-term protocol stack solutions consistent with the ongoing use of IP in networks on the Moon and Mars. This should include consideration of any applicable delay-handling and QoS[5] techniques currently being pioneering in DOD's TSAT effort.

As these protocol solutions progress from concept to implementation, they will move under the control of the Data Standards program element. This process is analogous to the movement of the architecture concepts from the SCAWG to individual programs as the elements (such as lunar relay) become real projects.

Finding: Protocol stack solutions for space communications networks beyond Earth orbit are an important foundational element for the long-term communications system architecture.

Recommendation: NASA's Space Communications Architecture Working Group should promote cooperation between the Jet Propulsion Laboratory and other groups, both within NASA and in DOD and academia, that are doing significant work to design the protocol stack software necessary to operate packet networks in deep space.

Long-Term Project Goals and Objectives

The primary challenge to implementing the architecture developed by the SCAWG will be ensuring support and compliance by the component projects and user entities. The agency-wide representation in the SCAWG is most appropriate for the current effort, and an extension of that approach that includes all users should be considered as the communications and navigation architecture moves along the path to fruition.

Recommendation: NASA's top management should implement a management structure that involves the affected science and mission programs and other users and ensures support for, and compliance with, the long-term communications and navigation architecture.

Connections to the Broader Community

Department of Defense

An advantage of having the SCAWG take the lead in defining the path to the next-generation Earth relay satellite is the need to fully explore possible future cooperation with DOD. Although the committee is aware of the occasional conflicts over resource allocation between DOD and NASA users today, the potential overall benefit from combining networks is too attractive to ignore.

Additionally, some portion of NASA's communications backbone could be provided by DOD systems, including TSAT and the Global Information Grid, which could relieve some of NASA's budget pressure while still providing vital communications capability.

Other Space Agencies

In his presentations to the committee the SCAWG's chair did not mention cooperation with foreign space agencies. Cooperation on specific missions for common relay capabilities and sharing of ground network resources is probably best handled by the project managers for the specific missions. Nevertheless, it would be useful for the SCAWG to establish a mechanism for periodic identification of opportunities for international cooperation.

NOTES

1. National Aeronautics and Space Administration (NASA), SCAWG Charter, date unknown.
2. NASA, Space Communications Architecture Vision, available at https://www.spacecomm.nasa.gov/spacecomm/programs/architecture.cfm.
3. NASA, SCAWG Charter, date unknown.
4. NASA, NASA Space Communications and Navigation Architecture Recommendations for 2005-2030, available at https://www.spacecomm.nasa.gov/spacecomm/programs/architecture.cfm.
5. QoS (quality of service) refers to a system by which some packets receive improved handling (greater precedence, for example) according to the requirements of the application.

8

Technology

INTRODUCTION

It is the mission of the technology program element of the Space Communications Office (SCO) to constantly look to the future in order to find and develop new technologies that will enhance NASA space communications and navigation capabilities, or enable new capabilities that will improve service to NASA exploration and science mission users. The Technology element is funded at $17 million per year and is managed by NASA headquarters. This budget supports a civil service workforce of 32 full-time equivalents and 15 work-year equivalents of contractor support. The Technology element has contracts with Spectrolab Inc., Intevac Inc., OEC Inc., Princeton Lightwave Inc., and General Dynamics.[1] Owing to proprietary concerns, details on these contracts were not provided to the committee, which thus did not have further insight into the size of each of these contracts, the work being done, the schedule and tasks planned, the contract length, or how the contractors were selected.

NASA uses the output of the Space Communications Architecture Working Group (SCAWG) and its Technology Assessment Team, described in Chapter 7, to select the technologies on which it will focus its resources. Technologies that serve all of NASA's mission directorates are included in the SCO's technology element portfolio.

The unifying challenge in space communications is the need to transport data with higher quality, efficiency, flexibility, and interoperability than is currently possible. This need creates architectural challenges that vary depending on where a NASA mission is going, when it is going, and what it will be doing when it gets there. Table 8.1 shows notional data rates for various communications services.[2]

NASA has chosen to divide the Technology element into six areas: optical communications, uplink arraying, spacecraft radio frequency technology, programmable communications systems (software defined radio), navigation, and plug-and-play interoperability.[3] NASA's communications and navigation architecture is a service-based infrastructure providing command, telemetry, data return and forwarding, emergency services, and astronaut communications between each other and to mission control. These activities are performed during all phases of a space mission, including launch and transit, as well as for all possible final destinations, including Earth orbit, the Moon, Mars, and anywhere else in the solar system and beyond its boundaries. Table 8.2 shows how these various technology areas relate to these mission phases and destinations.[4]

For each of these technology areas, NASA identified a key capability that was selected to meet evolving NASA mission needs. The capability is based on assumed data rates, link availability, and quality of service expected. NASA also identified the current state of practice for each capability as well as the estimated development time needed to achieve the capability. Each of the key capabilities with its associated data is shown in Table 8.3.[5]

ASSESSMENT

Space communications is a critical service that enables NASA to perform its missions; therefore it follows that technology developed for space communications also should be of critical importance. This report's focus was limited to the Space Operations Mission Directorate's (SOMD's) space communications program. However, this program provides only a portion of the overall NASA space communications work, and also, only a portion of the spending for communications technology development. Since space communications is in fact a critical function for *any* space mission, NASA's investment is further only a portion of the overall technology investment in this area, with the Department of Defense (DOD) and commercial entities also investing in space communication technologies. Where possible, the committee's review of the space communications program's technology development is placed in this larger context.

TABLE 8.1 Notional Data Requirements

	User	Channel Content	Latency	No. of Channels	Channel Rate	Total Rate
Operational						
	Base	Speech	NRT	2	10 kbps	20 kbps
		Engineering	NRT	1	100 kbps	100 kbps
	Astronauts	Speech	NRT	4	10 kbps	40 kbps
		Helmet camera	NRT	4	100 kbps	400 kbps
		Engineering	NRT	4	20 kbps	80 kbps
	Human transports	Video	NRT	2	1.5 Mbps	3 Mbps
		Engineering	NRT	2	20 kbps	40 kbps
	Robotic rovers	Video	NRT	8	1.5 Mbps	12 Mbps
		Engineering	NRT	8	20 kbps	160 kbps
	Science orbiters	Quick look	NRT	4	1 Mbps	4 Mbps
		Engineering	NRT	4	20 kbps	80 kbps
High Rate						
	Base	HDTV	1 day	1	20 Mbps	20 Mbps
	Human transports	HDTV (medical and PIO)	NRT	2	20 Mbps	40 Mbps
		Hyperspectral imaging	1 day	1	150 Mbps	150 Mbps
	Robotic rovers	Surface radar	1 day	1	100 Mbps	100 Mbps
		Hyperspectral imaging	1 day	1	150 Mbps	150 Mbps
	Science orbiters	Orbiting radar	1 day	2	100 Mbps	200 Mbps
		Hyperspectral imaging	1 day	2	150 Mbps	300 Mbps

SOURCE: John Rush and Dan Williams, NASA, NASA Communication and Navigation Technology Capability Portfolio, August 19, 2005.

TABLE 8.2 Technology Area Relationship to Destinations

	Technology Areas					
Capability Support Areas	Optical Communications	Uplink Arraying	Spacecraft Radio Frequency	Programmable Communications Systems	Navigation	Plug-and-Play Interoperability
Launch			X	X	X	
Earth orbit			X	X	X	X
Transit	X	X	X	X	X	X
Lunar	X		X	X	X	X
Mars	X	X	X	X	X	X
Solar system and beyond	X	X	X	X	X	X

SOURCE: John Rush and Dan Williams, NASA, NASA Communication and Navigation Technology Capability Portfolio, August 19, 2005.

However, understanding this larger context and how it affects the technology portfolio has proven challenging for NASA, as was confirmed by the Space Communications and Navigation Architecture presentation to the Strategic Management Council (SMC) on March 17, 2006, that called for the initiation of an integrated strategic communication technology program.[6] In that briefing, the need for a multicenter campaign that would involve other government agency participation was identified.

Recommendation: As stated in the NASA Space Communications and Navigation Architecture presentation to the Strategic Management Council on March 17, 2006, a strategic communication technology program should be initiated to improve coordinated technology investment in this critical mission function.

To review the SCO technology element, the committee requested several presentations and supporting documents. Personnel involved with this review included experts previ-

TABLE 8.3 Status of Key Capabilities

Capability/Subcapability	Mission or Roadmap Enabled	Current State of Practice	Minimum Estimated Development Time
High-data-rate optical technology (1 Gbps from Mars maximum distance)	High data rate from Mars, solar system, and beyond; lower mass, power, volume for lunar mission spacecraft	None	4 years (demo 1 Mbps) 16 years (operational 1 Gbps) 2012 demo lunar capability
Uplink antenna array—initial 12-m antenna array and extended	Deep space, Mars, and transit to both	Single-dish antennas	5-8 years
High-data-rate radio frequency technology (1 Gbps from Mars maximum distance)	High data rate from Mars, solar system, and beyond	Example: Mars Global Surveyor 33 kbps, Mars Odyssey 14 kbps	10 years
Programmable communications systems (software-defined radio)	All missions	Starlight, Electra, and LPT	15 years (25 Mbps landers, 500 Mbps orbiters, full autonomous independent platform software)
Navigation	All missions	Radiometric techniques	5 years (x-ray pulsar navigation)
Plug-and-play interoperability	All missions	Limited protocols for large delays	Delay-tolerant protocols demonstrated on simulation and emulation testbed
Downlink antenna array—initial 12-m antenna array and extended	Decommissioning of large Deep Space Network antennas	Single-dish antennas	3 years

SOURCE: John Rush and Dan Williams, NASA, NASA Communication and Navigation Technology Capability Portfolio, August 19, 2005.

ously tapped for the NRC review of the communications and navigation roadmap conducted in March 2005,[7] therefore providing some continuity with that effort. Even after the cancellation of that NRC effort, within NASA an effort continued to create the NASA Communication and Navigation Technology Capability Portfolio report,[8] which was an important source of information in this assessment.

Formulation of the Program Plan

NASA presented to the committee a top-level overview of the process for determining technology needs in space communications. That process begins with the exploration and science missions (with their associated roadmaps), identifying needed capabilities and the time period in which they will be needed. That information is incorporated into the design of the communications and navigation architecture by the SCAWG as discussed in Chapter 7. The SCAWG in turn determines the technologies needed to support the architecture. This process ensures that the goals and objectives of the technology program are consistent with the NASA strategic plan and lower-level plans of the Science Mission and Exploration Systems Mission Directorates. However, as NASA itself has acknowledged,[9] the technology element managed by the SCO has little insight into the overall NASA funding of communications technology efforts, creating a disconnect in this technology portfolio determination process. The technology program element is executed in a collegial fashion with many efforts receiving funds independently from the Space Operations Mission Directorate as well as from the Science Mission Directorate. Presumably, if things were allowed to continue in this manner, the Exploration Systems Mission Directorate would become a third uncoordinated funding source.

The Space Communications Coordination and Integration Board (SCCIB) technology working group that spans directorates is officially supposed to coordinate technology efforts, but unofficially NASA stated that the process is fairly ad hoc and informal. Since the SCCIB lacks “control,” it cannot prevent the mission directorates from acting only in their own best interests, and there is the risk that an integrated, efficient approach may not result. This includes the risk of duplicating and misdirecting efforts. For example, NASA cited the fact that optical communications technology efforts have focused on multiple wavelengths rather than concentrating efforts on a single one. NASA remarked that the technology program was more focused when there was a consolidated organization.[10] As indicated above in connection with the March 2006 presentation to the Strategic Management Council, NASA has acknowledged the need for its space communications technology development to become a coordinated multicenter effort that spans all of NASA.

A specific program plan document has not been written for the technology element. As a surrogate, the *NASA Com-*

munication and Navigation Technology Capability Portfolio report contains some of what one would expect in a program plan. It discusses the portfolio and the process for determining it without including specific information on allocation of resources and schedule. It also lacks lower-level plans for each of the technology areas. Examples of lower-level plans separate from this portfolio document were given to the committee regarding how different specific technology projects within the technology areas are executed, but there is not a complete set of plans for all of the technology projects, and there was little evidence of a uniform process to plan and assess these efforts. This lack of detail made a complete evaluation of the technology element's goals and objectives difficult, including whether appropriate time horizons are identified for technology advancement, how risk is managed, and the availability of critical personnel and facilities.

To address questions regarding the adequacy of facilities and personnel, NASA did supply a document[11] that stated the following list of facilities and personnel issues needed to support NASA's communications and navigations capabilities:

Facilities and Assets

- Deep Space Network ground stations at Canberra, Goldstone, and Madrid
- Ground stations including White Sands Complex, MILA, KSC, WFF, GRGT
- Research and test facilities at JPL, GSFC, and GRC
- Tracking and Data Relay Satellite System (TDRSS)

Critical Workforce Competencies

- RF and optical communications technologists
- NASA: GSFC, JPL, GRC, JSC, KSC and associated contractors
- Laboratories: MIT Lincoln Labs, JHU Applied Physics Lab, Naval Research Lab, Sandia National Lab, Air Force Research Lab
- Universities

Human Capital Considerations

- Critical competencies must be maintained
- Improved workforce competency in new and emerging technology areas such as optical communications and programmable communication systems

Although the level of information provided did not allow the committee to assess whether the facilities and personnel to support the technology element are adequate or if and how the personnel issues are being addressed, the committee agrees that this is a comprehensive top-level list. However, it is difficult to see how the leadership of the SCO can influence this large list beyond its organizational boundaries without more formal interagency relationships and increased resources to meet the need for all of these critical workforce competencies.

It was difficult to assess from the data provided whether the technology plans can be accomplished, and whether the planning is adequate and has sufficient decision points, down selects, customer agreements, and/or unallocated out-year funding. Quarterly reviews with each of the centers supported by the SCO technology program are identified, but NASA acknowledged that maintaining the quarterly schedule has been challenging and that the reviews were not always consistent.[12] Again without detailed data about each of the technology areas and the projects supported under those technology areas (examples were provided, but not a complete set), it was difficult for the committee to assess specifics regarding deliverables, progress, off-ramps, and sunsets. Risks and risk management were not discussed for the various technologies, and this is a deficiency that should be addressed. A lack of information made it difficult for the committee to completely assess the adequacy of the planning and the process used to complete this planning.

In general NASA's technology assessment process is described as consisting of four steps: (1) identify system-level issues, (2) identify performance requirements, (3) determine technology and possible performance, and (4) identify transformational technologies and track performance. Out of this process is to emerge the recommendations that determine the technology portfolio composition, schedules, and resource allocation. In determining this portfolio of investments, options are selected by NASA as a function of potential "return on investment," stated more specifically as an identification of the potential benefit of a technology in terms of reduction of user burden. NASA also tries to avoid duplication of investments made by other U.S. government agencies through dialogue within the large national space communications community as well as by looking for opportunities for partnerships with other agencies and industry. This portfolio is also integrated with NASA Small Business Innovation Research (SBIR) program investments, which appears to be one of NASA's primary methods to obtain industry involvement.[13]

NASA measures progress primarily by using technology readiness levels (TRLs) with each plan and providing a technology maturation plan with TRL milestones aligned with cost estimates for achievement. Technology program performance is measured as a function of planned versus actual TRL advancement.[14] Examples of technology plans were provided to the committee, and it appears that the approach is sound if applied uniformly.

Finding: Examples of specific technology development plans provided by NASA to the committee exhibited the characteristics of a sound technology planning process; however, there was evidence suggesting that such a process was not applied uniformly to all of the projects, with the most obvious being the inability of NASA to provide this data for all of the projects in the SCO technology element portfolio.

Connections to the Broader Community

The space communications community is quite vast, spanning not only NASA's needs, but also those of the DOD and other agencies. It is also a segment of the space market with extensive commercial success and assets that NASA can take advantage of to leverage its efforts. Without details on all of the technology areas it was difficult to assess whether the technology element utilized appropriate technology work already done by the DOD, the U.S. commercial space industry, and others. Knowledge of work done outside the SCO program within NASA as well as in the larger community is gathered informally. Without further detailed review it is difficult to assess the quality of the SCO technology element relative to leaders in the field. A past review by the National Research Council ranked several of NASA's space communications technology projects as world-class efforts;[15] however, a review of this depth was not performed for this report. NASA does have unique technological requirements that need to be addressed, and its track record in communications supports its position as a leader in addressing these unique challenges.

Also, it was difficult to assess, from the details available, whether the strategy for out-of-house work (competitions, partnerships, and so on) was well chosen and well managed. There was evidence that there is out-of-house competition, with the SBIR process appearing to be the primary mechanism. Examples were given of partnerships with other agencies, but a complete overview was not provided. Again, because of the lack of complete information, the benefits (and costs) of increasing interoperability with military space systems, commercial space systems, and the systems of foreign space agencies were not assessed.

It was difficult to assess the role of external peer review in the SCO technology element, as information on how internal and external projects were selected was available only for isolated examples. The committee suggests that the SCO institutionalize a process for external peer review of all of its technology projects, both internal and external. External peer review should serve a role in task selection, ongoing reviews of progress, and a final assessment of results. It is important for this process to be credible, and so a number of non-advocate reviewers should be included. External peer review has proven beneficial in other government technology programs within NASA as well as in other government agencies. If executed properly it can provide a relatively unbiased review that creates defensible results to justify selections. The following recommendation is not new to NASA, having been suggested by the NRC in a previous report.[16]

Recommendation: The Space Communications Office should establish a formal external peer review process that would assess all aspects of the technology program element, including task selection, progress toward goals, and assessment of final results. This process should be applied to external and internal technology projects.

Methodology

The lack of a complete technology element plan and the challenge of providing the committee with requested information made assessment difficult. Those examples seen by the committee appeared well crafted, but integration seemed to be lacking. The examples shown to the committee of how the SCAWG performed system-level assessments appeared to indicate a sound process (more completely described in Chapter 7). Again, whether system-level assessments were done for all of the technologies considered and how this influenced the selection of the complete portfolio was unclear.

Finding: The connection between the top-down mission-driven technology needs of the NASA missions and NASA's bottom-up technology planning must be tighter and must be applied uniformly. The process is in place and simply needs to be completely executed.

In an ideal technology planning process, plans (including tasks, priorities, schedules, and resources) are created and accepted by all stakeholders. Periodic reviews are used to assess progress and make project adjustments based on this progress. There is likely no single right answer for portfolio composition, and the optimal composition will certainly change over time, but it is important to try to maintain some stability so that adjustments are minor and done mainly to improve the technology portfolio as a whole. The importance of stability and continuity in technology development should not be underestimated.

Systems analysis is a crucial part of technology portfolio management, enabling competitive task selection and ongoing refinement and redirection as technical progress is made. Systems analysis also leads to an awareness of the system-level impact of individual technologies under development, allowing for a more holistic judgment. The committee observed gaps in system-level analysis in the technology element. It suggests that, for every one of the projects within the technology element, some form of systems analysis capability be applied. The methods can range from low-fidelity, back-of-the-envelope approaches to methods of increased fidelity, including parametric analysis and specific point designs. Encouraging this system-level awareness down to the lowest levels of individual technology projects will serve as a mechanism to ensure that research goals retain their relevance. The fidelity of the method can be appropriate to the level of the project, but even performing a low-fidelity analysis for the lowest-level project is important as opposed to conducting no analysis at all. A recommendation for improving NASA's systems analysis capability as a tool for technology portfolio management is not new, having been offered before.[17]

Recommendation: To support technology investment decisions, systems analysis should be strengthened and made *more uniform across the SCO technology element as a crucial part of the portfolio management and project selection process. The outlined general process of linking technology decisions back up to architectures that are designed to meet mission requirements—which in turn are determined by the missions selected as a part of NASA's strategic plan—is a good approach, but it needs to be applied uniformly so that all technology projects have this top-to-bottom linkage. This linkage will allow the lowest-level projects to retain their relevance. However, the process must be flexible enough to accommodate changing needs and new technology discoveries.*

CONCLUDING COMMENTS

Through its excellence in mission execution, NASA has demonstrated that many of its efforts in space communications technology are world-class and enabling for the science discoveries it has made. Space communications will continue to be an essential aspect of mission success and will always pose critical challenges that have to be met to enhance missions of the future.

To achieve this success has required critical workforce capabilities and unique facilities. To continue to achieve mission success in the future, NASA must maintain and enhance its workforce and facilities to keep pace. Insufficient detail was available to enable the committee to assess the current state of the workforce and facilities supporting the technology element or to assess whether plans will sufficiently support this critical NASA capability in the future. Further review is merited to ensure that the capability to create world-class technologies to support NASA's critical space communications function is maintained and enhanced. If the recommendation to the NASA Strategic Management Council to create an integrated NASA communications technology program across all of NASA is executed, then a review of the integrated program will be merited to see if goals are being met and the recommendations provided here have been incorporated. With sufficient information and time for analysis, such a review could explore more deeply the development of the technologies on an individual project level so that the overall NASA space communications technology portfolio can be properly weighed. Unfortunately, the schedule for and the data available during this review were not adequate for exploring NASA's space communications technology development to the depth that it deserves.

If NASA creates an integrated technology development program, this integration of efforts should go a long way toward addressing shortfalls of the technology element, which appear to involve primarily a lack of coordination. Processes are in place at NASA that, if applied uniformly, could result in a technology program that strives for the ideal technology planning process, whereby plans (including tasks, priorities, schedules, and resources) are created and accepted by all stakeholders. If so, the result could be improved stability and continuity in space communications technology development, the importance of which should not be underestimated. As has been recommended by the NRC to NASA previously,[18] performing systems analysis at all levels of the technology portfolio, uniformly executing the strategic management process outlined, and effectively using external peer review can all be methods to ensure successful technology development.

NOTES

1. Rush, John, "NASA Communications Technology," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006.
2. Rush, John, and Dan Williams, NASA Communication and Navigation Technology Capability Portfolio, August 19, 2005.
3. Rush, John, and Dan Williams, NASA Communication and Navigation Technology Capability Portfolio, August 19, 2005.
4. Rush, John, and Dan Williams, NASA Communication and Navigation Technology Capability Portfolio, August 19, 2005.
5. Rush, John, and Dan Williams, NASA Communication and Navigation Technology Capability Portfolio, August 19, 2005.
6. Rush, John, "Space Communication and Navigation Architecture," briefing to the NASA Strategic Management Council, March 17, 2006.
7. The final stage of this study was cancelled as a result of administrative changes at NASA.
8. Rush, John, and Dan Williams, NASA Communication and Navigation Technology Capability Portfolio, August 19, 2005.
9. Rush, John, and Dan Williams, personal communication, March 27, 2006.
10. Spearing, Robert, comment during briefing to NRC Committee to Review NASA's Space Communication Program, Washington, D.C., March 14, 2006.
11. Spearing, Robert, and M. Regan, NASA Communication and Navigation Capability Roadmap, May 2005.
12. Rush, John, and Dan Williams, personal communication, March 27, 2006.
13. Rush, John, "NASA Communications Technology," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006.
14. Rush, John, "NASA Communications Technology," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26-27, 2006.
15. National Research Council (NRC). 2003. *Review of NASA's Aerospace Technology Enterprise: An Assessment of NASA's Pioneering Revolutionary Technology Program*. The National Academies Press, Washington, D.C.
16. NRC. 2003. *Review of NASA's Aerospace Technology Enterprise: An Assessment of NASA's Pioneering Revolutionary Technology Program*. The National Academies Press, Washington, D.C.
17. NRC. 2003. *Review of NASA's Aerospace Technology Enterprise: An Assessment of NASA's Pioneering Revolutionary Technology Program*. The National Academies Press, Washington, D.C.
18. NRC. 2003. *Review of NASA's Aerospace Technology Enterprise: An Assessment of NASA's Pioneering Revolutionary Technology Program*. The National Academies Press, Washington, D.C.

9

Operations Integration Program Element

INTRODUCTION

The operations integration program element is charged with the task of managing communications activities for human spaceflight. This role requires the operations integration team to coordinate with the Space Shuttle program, the International Space Station program, and the contractors that serve them. Assets engaged in providing these communications services include the Space Network, Ground Network, the Air Force Satellite Control Network (AFSCN), NASA Integrated Services Network (NISN), and the Eastern Range. The primary end users reside at Johnson Space Center and Kennedy Space Center; however, voice, television, and other data are disseminated to other users through NISN. A budget of $3 million is dedicated to operations integration. Support is included in this budget for four full-time-equivalent civil service employees and four work-year-equivalent contractors.

The larger mission of managing communications activities for human spaceflight is broken down into the following distinct subtasks:[1]

- Overseeing the combined efforts of a distributed set of contractors who must work together seamlessly to support a common mission;
- Coordinating with, and planning among, a wide range of entities, including domestic and international, distributed and center-based, and government and contractor;
- Managing requirements between the Mission Control Center and the various components of the space communications infrastructure; and
- Reviewing and certifying the readiness of communications-related hardware, software, and personnel for human spaceflight.

The operations integration element also leads development activities to enhance or create capabilities relevant to human spaceflight.

FORMULATION OF THE PROGRAM PLAN

The goals, objectives, and deliverables of the operations integration program element are integral to and dependent on several other programs, projects, and centers. The Space Communications Office (SCO) does not currently have a formal program plan in place—although one is planned for release in the future—and the committee has based its assessment on relevant global NASA documents as well as less formal documentation. The following subsections first discuss the activities for which the operations integration program element is responsible. The assessment regarding the formulation of the program then follows.

Contractor Oversight Activities

Many of the resources that facilitate the communications capabilities required for human spaceflight are managed as contracted services. The total budget associated with these contracts is in excess of $2 billion over 5 years. The execution of these large contracts is managed by four NASA centers: Goddard Space Flight Center, Johnson Space Center, Kennedy Space Center, and Marshall Space Flight Center. Operations integration dedicates a portion of its budget—which is in totality $15 million over the same 5-year period—to overseeing specific aspects of these contracts that impact communications for human spaceflight. Prior to 2003, NASA managed these resources through a centralized contract, the Consolidated Space Operations Contract (CSOC). In 2003, this single contract was replaced by the current set of distributed contracts. This change occurred because NASA administration felt that the centralized structure provided by CSOC was too inflexible to accommodate necessary changes, was "not consistent with the dynamic characteristics of NASA's mission requirements," and was "inefficient due to an overly centralized process resulting in non-optimal customer response."[2]

Goddard Space Flight Center manages the Near Earth Network Services (NENS) contract, valued at roughly $785 million over 5 years. Through this contract, Honeywell Technology Solutions, Incorporated, provides administration, operations, and technical support to NASA's Space Network and Ground Network. Honeywell also manages eight major subcontractors and provides technical and management services in support of tracking and data-acquisition operations at several facilities.[3] It also manages the Flight Dynamics Facility at GSFC.

Kennedy Space Center (KSC) manages the Kennedy Information and Communications Services (KICS) contract, through which the Central Data and Switching Center is funded. The prime contractor, InDyne, Inc., has a contract valued at approximately $190 million over 5 years. InDyne provides communications services at KSC in support of the Space Shuttle and the International Space Station Programs. InDyne also provides business engineering logistics, facilities management, and hardware and software integration and development for voice, video, and data communications for KSC.[4]

Johnson Space Center (JSC) manages the Mission Support Operations Contract (MSOC), which funds Lockheed Martin Space Operations Company to provide supporting elements of the Space Shuttle and International Space Station Mission Control Centers. This includes support for the JSC Space Operations Mission and Data Services. MSOC provides ground system services for JSC's Emergency Operations Center and the Electronic System Test Laboratory, which includes space communications integration. The total contract, extending from October 2003 through September 2006, is valued at approximately $246 million.[5,6]

Finally, the Marshall Space Flight Center manages the Unified NASA Information Technology Services (UNITeS) contract that funds the NASA Integrated Services Network. Science Applications International Corporation, the prime contractor, is responsible for the Integrated Financial Management Program and NASA's wide area network, information technology (IT) security, and digital television. The total value of the contract is approximately $826 million over 5 years.[7]

At the highest level, the success of Operations Integration in effectively overseeing relevant aspects of these contracts is demonstrated by the successful maintenance of communications capabilities required to support human spaceflight. Lower-level performance metrics are also generated by each prime contractor for the assets they manage. For example, under the NENS contract, Honeywell reports availability and reliability metrics for the Space and Ground Networks. This feedback is then reported up the NASA management structure through monthly status reports and to the NASA headquarters management through program status reports. Deviation from standards of excellence in these metrics alerts senior management to potential risk, and additional scrutiny is applied when it is deemed necessary.[8]

Coordinator and Planning Activities

The Network Operations Integration Team (NOIT) is responsible for coordinating with and planning between international partners, communications assets (the Space Network, Ground Network, and NASA Integrated Services Network) and the Space Shuttle and International Space Station Control Centers. The MSOC (Lockheed Martin) covers supporting elements of the Space Shuttle and International Space Station Control Centers at JSC. The Space Flight Operations Contract (United Space Alliance) covers vehicle processing and flight control elements that occur at JSC and KSC. The NOIT interacts with both contracts, interfacing on a technical level with Space Flight Operations Contract mission managers, MSOC support elements, and resources from other NASA centers (GSFC and MSFC, in particular) to "ensure common awareness of pending development activity as well as Integrated Networks and Communications mission support readiness issues across these contracts."[9] These interactions are shown notionally in Figure 9.1.

The NOIT is composed of senior-level staff members with extensive experience in mission operations, integration, and requirements management. The Manager of Space Communications Operations Integration heads the NOIT. The individual currently filling this role has 40 years of experience at NASA, dating back to the Apollo/Lunar Module program. Although most NOIT members are highly experienced, the team also draws on expertise from the NASA centers and strives to maintain a team with the variety of skills and experience levels needed to ensure that the vital coordination and planning capabilities that they provide will continue to be available in the future.

Requirements Management Activities

Missions involving human spaceflight demand that more stringent communications requirements be levied on the supporting elements than do unmanned programs. Operations Integration plays a critical role in defining these requirements for the Space Shuttle and International Space Station programs through their respective program requirements documents. The requirements-definition process is also currently underway for Exploration programs. These include an array of requirements levied on the Crew Exploration Vehicle, Crew Launch Vehicle, cargo elements, and Lunar Surface Access Module.

Readiness Assurance Activities

Engineering and operations reviews by SCO personnel are an essential component of the system NASA uses to

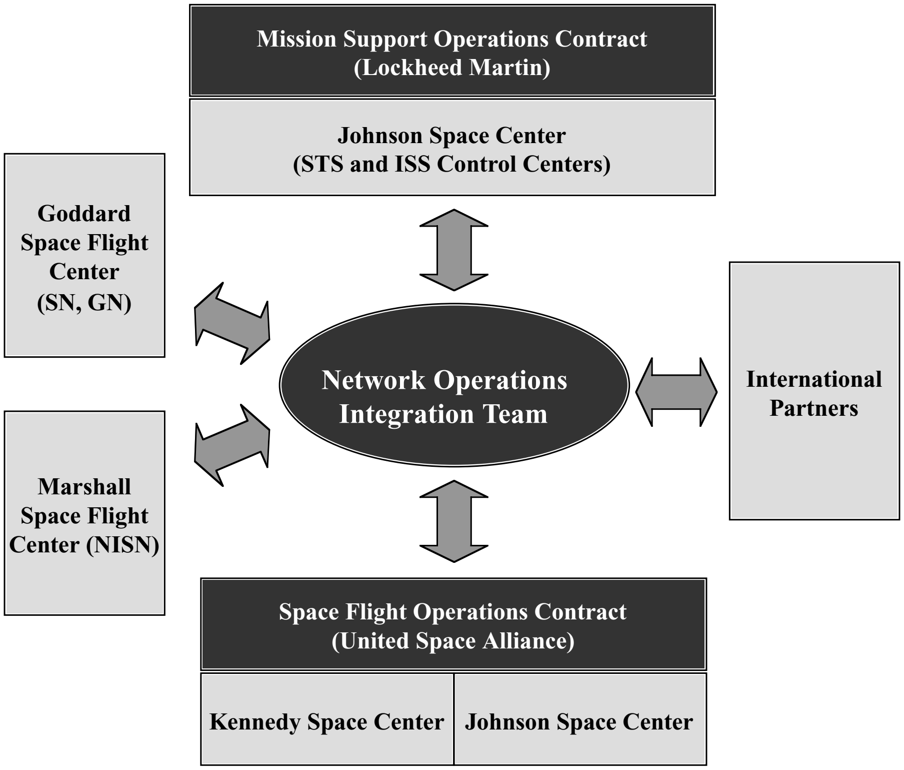


FIGURE 9.1 The Network Operations Integration Team interfaces between program elements, mission managers, and NASA centers.

maintain the communications capabilities necessary for human spaceflight. These reviews include daily and weekly Integrated Operations teleconferences between centers as well as preliminary and critical design reviews for newly developed or updated pieces of the communications infrastructure. The Automated Support Requirements System management team and Network Support Group also provide oversight and readiness assurance reviews. NISN's readiness is verified in both forums and quarterly reviews. The space communications program is also evaluated as a whole through status reports and status reviews. Finally, the NASA chief engineer uses a system of independent technical authority to provide an unbiased assessment of project, program, and mission readiness. These experts, designated as technical warrant holders for their areas of expertise, also address disputed engineering issues.

In preparation for launch and mission support, SCO personnel conduct a series of structured readiness reviews. These reviews include an operations readiness review, a stage operations readiness review, a flight readiness review at JSC, a launch readiness review at KSC, and an agency-wide flight readiness review. This process culminates in submission of a certificate of flight projects directorate networks readiness, indicating that all of the communications network elements are ready to support the mission. Figure 9.2 illustrates how many different assets must be brought to bear to support a mission involving human spaceflight.[10] The formal readiness review process is designed to make sure that each of these network elements will fulfill its role in the mission at hand.

Development Activities

Although the operations integration program element's primary role involves coordinating and managing specific activities related to human spaceflight, the program sometimes uses its unique position to sponsor development activities when a significant agency-wide benefit is apparent. The intercenter nature of operations integration gives it the perspective and the means to implement changes to the communications infrastructure for the greater good of all users.

An example of such a development activity is an effort currently underway to develop a command generation capability for KSC and implement it in KSC's Launch Control Center. Historically, KSC has relied on JSC's Mission Control Center and legacy command equipment at the Merritt Island Launch Annex (MILA) tracking station. It is in NASA's interest to reduce the complexity of the MILA hardware. If this can be accomplished, it may be possible to commercialize the facility in the future, resulting in long-term cost savings. This command capability is also projected to be of benefit to several future Exploration programs. Finally,

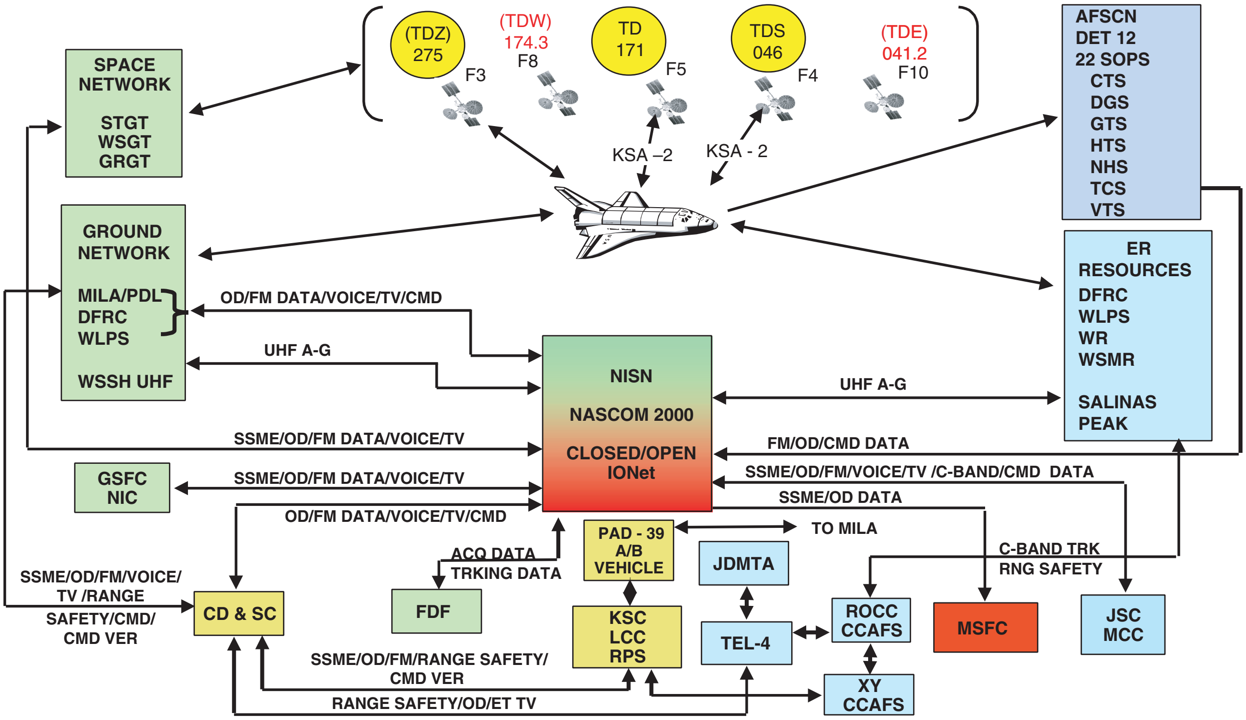


FIGURE 9.2 Interaction among the elements involved in NASA's operations integration support. SOURCE: Gary Morse, NASA, "Operations Integration," briefing to the NRC Committee to Review NASA's Space Communications Committee, Washington, D.C., January 26, 2006, p. 4.

incorporation at the Launch Control Center provides KSC with a more robust, stand-alone prelaunch test capability. This project is being implemented through the KICS contract at KSC and is slated for completion in FY 2006.

RELATED ASSESSMENT

The goals and objectives of the operations integration program element are well understood, but they are not documented in a formal program plan. NASA Procedures and Guidelines document NPG 7120.5[11] refers to several of the types of activities that operations integration is responsible for, such as requirements and risk management (e.g., flight readiness certification). However, NPG 7120.5 discusses program-related activities only in general terms; it does not assign objectives and goals specifically to operations integration. The Support Requirements System Management Plan[12] (JSC 27379) and the Automated Support Requirements Handbook[13] (GP-60-3) include details on the processes and procedures governing requirements management. Highly qualified and experienced individuals make up the operations integration team, and they are tightly coupled to the senior management of the space communications program. Despite the fact that goals and objectives are not logged in a single, formal document, these senior participants clearly understand their mission and know how to manage available resources to accomplish it.

Senior NASA leadership understands the critical importance of maintaining communications for human spaceflight. This is evident in the assignment of such senior staff to this program element. The authority granted to the operations integration team to intervene on behalf of flight readiness is another indication of the confidence that NASA has in the team. Lives depend on the activities that they oversee and the decisions that they make.

Some of the deliverables that operations integration provides are concrete and well documented, but others are less so. Examples of the former include the team's contributions to the Space Shuttle program and International Space Station program requirements documents. Other deliverables such as contract oversight generally contribute to the overall mission of communications for human spaceflight, but they are necessarily delivered as a single, concrete product. Senior NASA leadership reviews the performance of the operations integration team, and, in the end, successful maintenance of communications for missions involving human spaceflight is the ultimate indicator that operations integration is delivering.

The senior staff members involved in operations integration have demonstrated that they know how to provide the expected services using the resources available to them.

To a large extent, they also dictate the program activities that they will use to meet those end goals. Decision points and down-selects have little relevance to the mission that operations integration is designed to perform.

The mission that operations integration performs is difficult to break down into specific short-term deliverables and metrics. Each mission that is successfully prepared for, certified, and executed serves as further acknowledgment that the operations integration program element continues to succeed in meeting its customers' needs. Development activities have traditional schedules and metrics associated with them. However, it is more difficult to apply similar standards to the requirements development, contract oversight, and coordination activities that make up the vast majority of the operations integrations mission.

Operations integration's overarching responsibilities are ongoing as long as human spaceflight continues. The primary goal, maintaining communications for those missions, is not only appropriate but also essential. As noted previously, the personnel assigned to operations integration have a tremendous amount of expertise and experience. They represent an irreplaceable resource. To plan for the future, operations integration recruits talented individuals from within the NASA centers and grooms them for increasingly responsible roles. The skills that these personnel need are well understood by SCO management. The facilities and equipment used to enable the communications capabilities that operations integration oversees are funded through center-managed contracts. The subsets of related facilities and equipment that fall under the SCO are discussed in Chapters 2 and 3 of this report.

Connections to the Broader Community

Operations integration's mission is unique to NASA, in part because the program element's role is required owing to the distributed, center-based management of SCO assets. Another aspect that is specific to NASA is the driver for the program element: human spaceflight. The work of others in the field (e.g., high-reliability terrestrial communications network design) bears little relevance to operations integration due to stark differences in the operational environments and the consequences associated with a service outage. The vast majority of the associated resources are contracted, not provided in-house. It is impressive that operations integration is able to coordinate and oversee such expansive contractual activities with the limited resources available to it.

Methodology

As mentioned at the outset of this chapter, there is not a formal program plan in place for the SCO. Operations integration's mission requires it to perform system-level assessments every time it certifies readiness for human spaceflight. The sterling track record that operations integration has in terms of communications reliability serves as validation for its risk management approach. Its mission is centered on risk mitigation. The activities described above all contribute—some directly and some indirectly—to the program's effort to reduce the risk of human spaceflight.

Overall Capabilities

The operations integration program element team members do a remarkable job in both defining and meeting the requirements related to communications assurance for human spaceflight, especially given the limited resources at their disposal. Their responsibilities are extremely broad in scope. The success that NASA has enjoyed in terms of maintaining communications on missions involving human spaceflight can be credited to the efforts of a select team of individuals who are exceedingly well qualified and capable of exerting their influence across a broad range of functional organizations. Their influence is particularly critical in light of the fact that the contractors who perform the tasks required for communications for human spaceflight report to their respective NASA centers, not to operations integration. Despite a rather complex contractor-management scheme and an indirect reporting structure for the contractors it oversees, operations integration has been extremely successful in meeting the needs of its customers and maintaining an outstanding record of accomplishment.

FINDINGS

Reliance on Individuals' Skills and Expertise

Finding: NASA missions that involve human spaceflight rely heavily on the skills and influence of several highly experienced individuals to manage their communications activities and provide readiness assurance.

The possible unavailability of a few key personnel represents a significant risk to NASA's ability to maintain an outstanding record in terms of communications for human spaceflight. It is doubtful that a less experienced team could meet the current high level of performance without dedication of significant additional resources. Operations integration actively recruits and trains new team members. Unfortunately, no amount of training can make up for the decades of experience that will be lost if a few key individuals depart.

Complex Reporting Structure

Finding: NASA's center-based contract structure makes it critical for operations integration team members to be both highly experienced and widely respected across many organizations within NASA.

The personnel responsible for the assets and activities engaged to facilitate communications for human spaceflight do not report directly to operations integration. The efficacy of the operations integration team therefore depends on their ability to identify and motivate key personnel across a wide range of functional organizations. Regardless of the specific reporting structure, critical activities such as flight readiness assurance will always require the involvement of highly skilled and experienced team members.

Outstanding Level of Customer Satisfaction Achieved

Finding: The individuals responsible for managing and executing the operations integrations program element do an excellent job in the eyes of their customers, the Space Shuttle and International Space Station programs.

This finding is based on a site visit made by panel members to JSC. During that visit, the International Space Station and Space Shuttle program managers both gave resoundingly positive reviews of the work performed by the members of the operations integration program element. Interaction with these customer representatives at JSC convinced panel members that an outstanding level of customer satisfaction is achieved.

NOTES

1. Morse, Gary, "Operations Integration," briefing to the NRC Committee to Review NASA's Space Communications Program, Washington, D.C., January 26, 2006.
2. Costrell, James, NASA Deputy Assistant Associate Administrator, personal communication, February 23, 2006.
3. Feinberg, A., and E. Thompson, NASA Awards NENS Contract to Honeywell Technology Solutions, NASA Press Release, October 9, 2003, available at http://www.nasa.gov/home/hqnews/2003/oct/HQ_c03jj_near_earth_network.html.
4. Feinberg, A., First Contract in SMCDS Solicitation Awarded to InDyne, Inc., NASA Press Release, September 17, 2003, available at http://www.nasa.gov/home/hqnews/2003/sep/HQ_ c03ff_indyne_contract.html.
5. Beutel, A., and K. Humphries, NASA Awards Mission Support Operations Contract, NASA Press Release, September 29, 2003, available at http://www.nasa.gov/home/hqnews/2003/sep/HQ_ c03hh_mission_ops_cntrt.html.
6. Beutel, A., and K. Humphries, NASA Exercises Lockheed Martin Mission Support Contract Option, NASA Press Release, July 3, 2006, available at http://www.nasa.gov/home/hqnews/2004/jul/HQ_c04c_lockheed_contract.html.
7. Mathews, M., NASA Awards Technology Services Contract to SAIC, NASA Press Release, December 23, 2003, available at http://www.nasa.gov/home/hqnews/2003/dec/HQ_c03ww_saic_tech_services.html.
8. Morse, Gary, NASA Johnson Space Center Space Operations Services Manager, personal communication, February 22, 2006.
9. Morse, Gary, NASA Johnson Space Center Space Operations Services Manager, personal communication, February 22, 2006.
10. Morse, Gary, "Operations Integration," briefing to the NRC Committee to Review NASA's Space Communications Committee, Washington, D.C., January 26, 2006.
11. National Aeronautics and Space Administration (NASA), NASA Procedures and Guidelines NPG7120.5B, November 21, 2002.
12. NASA, Support Requirements System Management Plan, document number JSC-27379, December 1997.
13. NASA, Automated Support Requirements System Handbook, Kennedy Space Center General Procedures, Document Number GP-60-3, December 9, 2004.

General Issues

10

Overarching Issues and Recommendations

In the course of reviewing the overall quality of the space communications program of NASA's Space Operations Mission Directorate (SOMD), the committee made observations on a number of issues that seemed to be significant to the overall program.

LIMITS OF REVIEW

The statement of task for this study called for the committee to assess the quality and effectiveness of the SOMD space communications program, and the report has thus necessarily focused on the various elements that fall within the Space Communications Office (SCO). However, as noted elsewhere, much of the space communications work at NASA takes place in directorates other than SOMD and therefore was outside the purview of this study. As a result, the committee did not review the Exploration Communications Architecture, Deep Space Network Interplanetary Communications Architecture, Alternate Communications Approaches under the Science Mission Directorate, and several communications technologies managed by other directorates. This limited scope of work eliminated significant communications programs that the committee believes would have benefited from a review, and also prevented the committee from providing a comprehensive review of the overall architecture of NASA's work in space communications. As discussed further below, NASA has recently begun making plans to consolidate all of its communications functions within a single office or directorate. Once this consolidation is accomplished, NASA might wish to consider carrying out a more complete review that covers all of the agency's space communications programs.

CENTRALIZED SPACE COMMUNICATIONS MANAGEMENT WITHIN NASA HEADQUARTERS

In March 2006 the SOMD presented a decision briefing to the Senior Management Council (SMC) recommending that the fractionated space communications management structure within NASA headquarters be replaced with a more centralized approach. The resulting SMC decisions have not been finalized; however, the SOMD recommendations seem to have been accepted. Final SMC decisions are expected to be in place in late spring 2006. It was not within the committee's purview to review the advantages and disadvantages of consolidating NASA space communications management functions. However, the committee made several observations in this area, noting that:

- Centralized NASA headquarters management and funding of space communications worked well for NASA for more than 30 years until 1996.
- The planned reorganization apparently will centralize space communications requirements and architectures and realign the associated budgets, thus affecting visibility into and management of very large current and future NASA programs for generations to come.
- Changing management structures is not a panacea. Reorganizations are often disruptive, countering the expected benefits. For instance, the last shift in space communications management resulted in the loss of 90 percent of the space communications program management experience base that had previously existed at NASA headquarters. Most personnel either retired or were reassigned to unrelated programs.

Recommendation: Major changes in modus operandi, such as realigning top-level management and funding responsibilities, should be preceded by a transition plan that outlines the objectives of the changes and ensures that past corporate knowledge is considered by the new organization. The committee recommends a thorough review of the lessons learned from past reorganizations so that NASA can avoid repeating unsatisfactory consequences.

CENTRALIZED SPACE COMMUNICATIONS CONTRACTING

NASA centralized its space communications contracting in 1996 by having Johnson Space Center issue a single completion-type contract to replace 18 contracts that had been awarded by the other NASA centers. This was the Consolidated Space Operations Contract (CSOC). NASA provided the committee with several previously compiled CSOC "lessons-learned" presentations indicating why, according to NASA, the centralized contracting concept had failed:

- A completion contract was inappropriate. The NASA mission model was far more dynamic than the new managers at JSC had expected, resulting in a high volume and cost of changes to the contract. Causes of changing requirements included launch delays and spacecraft operating beyond stated lifetimes. Also, operating degraded spacecraft placed increased demands on the space communications infrastructure to recover data.
- Space operations activities at each NASA center were more distinct than had been appreciated, and the centralized management of CSOC proved unwieldy.
- There was deep-seated internecine rivalry among centers, which resulted in most users of space communications services becoming very unhappy customers.
- The contract structure resulted in a lack of local decision making, slow response times, and lack of cost visibility.
- Even though CSOC combined 18 contracts under one, the contract did not save money, was too inflexible to support users' needs, overwhelmed the contracting system with changes, and caused a groundswell of opposition from the using community. All this contributed to its failure.

The committee observes that contracting strategies are critical to the success of the new space communications program as it moves forward.

Recommendation: The planned reorganization of NASA space communications management at NASA headquarters provides an opportunity to benefit fully from the lessons learned from contracting approaches used under the Consolidated Space Operations Contract. The committee recommends an early and thorough examination and internal agency discussion of CSOC lessons learned to ensure that past errors are not repeated. NASA should also review approaches used prior to 1996 to take advantage of past successes.

TDRSS REPLENISHMENT AND LONG-TERM COMMUNICATIONS REQUIREMENTS

The Tracking and Data Relay Satellite System (TDRSS) is considered to be a national resource because it supports many NASA and non-NASA users. A gap in system capability to support projected NASA user requirements will begin in about 2015. NASA plans to include funding in the FY 2008 budget cycle for a preformulation phase 1 effort and expects to develop a compelling case for a FY 2008 start for TDRSS replenishment and thus avoid a gap in NASA user coverage. NASA is also working with non-NASA users that will have a gap in TDRSS support projected to start as early as 2010. Historically, when priority issues have arisen between TDRSS support of NASA versus other missions, the resolution often has not been favorable to NASA.

The committee observes that the planned reorganization of space communications management could have major ramifications for alternatives to supplying the near-Earth communications support that is currently provided by TDRSS. For instance, a single management organization might consider the requirements of exploratory space as well as terrestrial and near-Earth communications to develop a series of alternatives that could provide greater benefit at lower overall cost and risk to NASA. Such a radically different review could result in very different alternatives and could completely change the current approach to maintaining low-Earth-orbit communications service.

Recommendation: A restructured space communications management organization should undertake a detailed analysis of alternative approaches for satisfying long- term terrestrial, near-Earth, and exploratory space communications requirements and select the most beneficial for implementation. This recommendation does not presuppose that the current approaches are wrong, but it does suggest that there may be attractive alternatives worthy of reconsideration that may have been eliminated due to organizational boundaries.

Recommendation: The committee believes it would be responsive and proactive for NASA to work with the broader TDRSS user community to examine programmatic alternatives that could accelerate TDRSS replenishment in order to address the projected service gap for non-NASA users.

REQUIREMENTS VALIDATION PROCESS

The committee observed that while some elements of the SOMD space communications program, such as NISN, have a requirements validation process, others do not formally vet or document user and operator community needs. This can create disconnects between validated needs and the formal planning and budgeting process. It can also inject uncertainty into the acquisition process, create confusion over key performance goals and threshold requirements, and can bring into question the ability to establish metrics for measuring success in terms of user and operator needs. These problems could make it difficult to accurately establish and defend the levels of appropriated funding required by NASA and the reimbursable funding needed from outside the agency.

The committee notes that the projected reorganization of space communications management at NASA offers the opportunity for an end-to-end review of the requirements validation process across all space communications programs at the agency and the development of consistent best practices that can address the potential issues cited above.

NASA WORKFORCE

The committee's review revealed an overarching concern regarding the NASA workforce. At NASA headquarters and at the centers, the committee found a highly experienced staff that was efficiently supporting multiple programs from an efficient matrix organization. The committee also found strong working relationships with customers, contractors, and external organizations and judged that these relationships had been critical to the current success of the SOMD space communications program. The committee noted, however, that some elements within the SCO had minimal civil service staffing and were relying heavily on contractors to accomplish the program's mission. The committee was unable to identify opportunities for further government personnel reductions in these elements.

To the contrary, the committee noted that much of the communications workforce, and particularly its leadership, is nearing retirement. NASA has young, very talented professionals awaiting their turn to move up in the organization, but they are too junior to fill the vacuum that could well occur in the next few years as the current leaders retire. In addition, it is likely that as the agency's veterans of space communications retire, the interpersonal relationships that currently facilitate their success will no longer exist, and higher staffing levels will be required in the future to accomplish the same tasks with more junior, less experienced replacements. This problem is not unique to NASA space communications work, but it is one that must be dealt with if the agency is going to continue to provide the superior level of performance that the public has come to expect.

In presentations made to it the committee heard many comments on the difficulties caused by the manner in which funding for government staff is accounted for in budgets. The committee did not review this issue, but the comments indicate fairly widespread concerns within the workforce.

Recommendation: One of the early reviews to be conducted by the newly centralized NASA headquarters space communications management should include a detailed analysis of the personnel needs of the space communications program. This review should consider the minimum civil service staffing levels needed, likely upcoming retirements, availability of comparable replacements, the impact of full-cost accounting on the ability to hire civil service replacements, and the proper mix of civil service and contractors required to perform the mission.

PROGRAM PLAN

NASA spends a great deal of money on space communications in order to provide a capability that is critical to the success of human spaceflight and science missions. The committee found that formal planning documents exist for a number of individual elements, or aspects of elements, within the SOMD space communications program. However, there was no overarching plan for the conduct of that space communications program.

Recommendation: The committee recommends that NASA take the opportunity presented by the impending reorganization of space communications to develop a program plan and vet this plan with the participating centers and NASA headquarters elements to ensure that it is executable and fits within the vision expressed in the NASA strategic plan. In addition, those elements of space communications that currently do not have formal element-level planning documents should develop plans that are tailored to the size and complexity of the activity in that element.

Appendixes

A

Statement of Task

The Aeronautics and Space Engineering Board of the National Research Council (NRC) will form a committee to assess the overall quality of the space communications program of NASA's Space Operations Mission Directorate and offer findings and recommendations thereto. This task includes internal and collaborative activities. The primary objective is to conduct peer assessments rather than provide programmatic advice.

The committee will meet as required during the study to receive technical presentations about the projects under review by their group and formulate final findings and recommendations. Members will also make site visits as deemed necessary in formulating the assessment. Portions of each meeting will be highly interactive with NASA personnel. The committee will develop a final report based upon inputs and discussions at the committee meetings and site visits.

The committee's observations will follow broad themes concerning program quality. The committee will not make explicit budget recommendations to NASA, but will instead comment on program effectiveness.

Where appropriate, the committee assessment should use specific criteria, such as the following:

Formulation of the Program Plan

— Are the program's goals and objectives clearly defined and consistent with relevant document such as NASA's Strategic Plan?

— Is there evidence of a clear understanding of the need by NASA's mission directorates, other organizations or the aerospace community at large for the space communications services? Are the program's deliverables to those organizations clearly articulated and are those organizations adequately involved in the planning and review process?

— Can the expected services be accomplished by the program activities? If not, is the path to adequately providing the services clear? Is this planning well supported by sufficient decision points, down selects, customer agreements, and/or unallocated out year funding?

— Are there sufficient near-term deliverables or progress metrics from which the program can be regularly assessed? Are there sufficient off-ramps or sunsets to ensure that funding is reallocated within the program or to other programs if the program does not make adequate progress towards one or more of its goals and objectives? Are the program's plans for independent and/or external reviews adequate and appropriate?

— Are appropriate objectives being posed, taking into consideration program goals, NASA's strengths, and the time horizon for the project? Are critical personnel and facilities required to support the program well defined?

Connections to the Broader Community

— Is there evidence that the program utilizes appropriate work already done by the Department of Defense, the U.S. commercial space industry, and others? Does it leverage the work of leaders in the field?

— Is the strategy for out-of-house work (competitions, partnerships, etc.) well chosen and managed?

— Are the benefits (and costs) of increasing interoperability with military space systems, commercial space systems, and the systems of foreign space agencies properly considered?

Methodology

— How well crafted are the program plans for the areas under review?

— Have the appropriate supporting system level assessments been conducted?

— Do the managers understand and manage the risks involved to an appropriate level?

— Are the plans for further study reasonable and justifiable?

Overall Capabilities

— Is the quality of the work comparable to similar world-class efforts in other organizations, and does it meet the requirements of its customers (both internal and external).

— Are the qualifications of the NASA/contractor staff sufficient to achieve program goals?

— Are the capabilities, quantity, and state of readiness of equipment and facilities sufficient to achieve program goals?

— Are personnel, equipment, and facilities supplied by support contractors used efficiently; do they fill gaps in government capabilities without duplication?

The selection of criteria for each assessment and the relative weights given to each criterion are within the committee's discretion and can vary from program to program. The NRC will evaluate the following program elements using the criteria above.

Space Communications Program Elements

Space Network
NASA Integrated Services Network (NISN)
Tracking and Data Relay Satellite System (TDRSS)
Systems Engineering
Technology
Spectrum Management
Standards Management
Communications and Navigation Architecture
Search and Rescue
Program Integration

B

Committee Member Biographies

ROBERT E. DEEMER, *Chair*, has 29 years of industry experience in the fields of spacecraft systems design, simulation modeling, virtual prototyping, network design, operations and project management, systems engineering, spacecraft communications, and executive management. He has master's degrees in computer science, management science, business administration, project management, and the humanities from California State University, Northridge, Colorado Technical College, Pepperdine University, Villanova University, and Redlands University. He also has undergraduate degrees in engineering, software design, economics, philosophy, and English literature. Mr. Deemer is attending the University of Colorado, working toward a doctorate in philosophy and advanced technology. Currently, Mr. Deemer is a graduate professor for Regis University, teaching classes in operations, advanced technologies, technical management, and project management. Prior to teaching, he was vice president of technology for Catalina Research and worked for 23 years for Lockheed Martin Astronautics and Litton Industries as a design and systems engineer and as the manager of the Spacecraft Technology Center. He has served on two other NRC study groups in the capacity of chair and committee member.

HARVEY BERGER is a technical fellow for Data Links at Northrop Grumman Space Technology. He received a B.S. in electrical engineering and an M.S. in information and algebraic coding theory from Cornell University. He has 35 years' experience as a communication systems engineer in the areas of bandwidth efficient modulation, error correction coding, RF propagation, and RF and optical link design. He is currently supporting the NPOESS program in the design of its L-band, X-band, and Ka-band communications links. Previously he was a payload architect for the Astrolink satellite program, and he definitized architectures for future advanced high-data-rate one- and two-hop satellite communication systems that realize bandwidth efficiencies of 3 to 5 bps/Hz; he developed predistortion algorithms for two-hop communications links. He also developed a bandwidth-efficient coded 8PSK modulation technique utilizing predistortion that achieves a bandwidth efficiency of 2 bps/Hz in a highly distorted nonlinear multi-hop communications channel as well as a ROM-based decoding technique for triple-error correcting BCH codes. He also system-engineered an end-to-end very-high-data-rate satellite communications system that included all components from the spacecraft modulator to the ground data demultiplexer output and defined all specifications, performed all analysis, integrated units on the spacecraft and in the ground station, and verified end-to-end performance after deployment. He is a member of ITU-R Study Group 3 (Radiowave Propagation), Working Party 3J (Propagation Fundamentals), and Working Party 3M (Point-to-point and Earth-space Propagation). He has been awarded nine patents and is the co-recipient of the 2004 NGST President's Award for Innovation for "Simulation of Weather Conditions and Their Impact on Satellite Data Transmission" and the co-recipient of the 1999 TRW Chairman's Award for Innovation for "Gigabit-Per-Second Bandwidth Efficient Modulation."

THOMAS C. BETTERTON, a retired rear admiral in the United States Navy, is currently a visiting professor for space technology at the Naval Postgraduate School and has been retained as a management and technical consultant by a number of aerospace-related corporations. He holds a master's degree and an engineer's degree from the Massachusetts Institute of Technology. As a naval aviator and designated acquisition professional, he served as a major program manager and the senior Navy official, Director Program C, in the National Reconnaissance Office for over 16 years. He has participated in several study efforts for the Defense Science Board and the Air Force Scientific Advisory Board and was a member of the NASA Advisory Committee for the International Space Station. He is a fellow of the American Institute of Aeronautics and Astronautics. Admiral Betterton retired from active duty in January 1992.

ANTONIO L. ELIAS is executive vice president and general manager for advanced programs at Orbital Sciences Corporation. Previously, he served as Orbital's chief technical officer from 1996 to 1997, corporate senior vice president from 1992 to 1996, and first vice president for engineering from 1989 to 1992. From 1987 to 1997, he led the technical team that designed and built the Pagasus air-launched booster, flying as a launch vehicle operator on the carrier aircraft for the rocket's first and fourth flights. He also led the design teams of Orbital's APEX and Sea Star satellites and the X-34 hypersonic research vehicle. Dr. Elias came to Orbital from the Massachusetts Institute of Technology (MIT), where he held various teaching and research positions, including the Boeing Chair in the Department of Aeronautics and Astronautics. A member of the National Academy of Engineering (NAE) and a fellow of the American Institute of Aeronautics and Astronautics (AIAA), his awards include the 1991 AIAA Engineer of the Year, the AIAA Aircraft Design Award, and the American Astronautical Society (AAS) Brouwer Award. He is also a co-recipient of the National Medal of Technology and the National Air and Space Museum Trophy.

CHARLES T. FORCE has a 42-year professional career spanning both government and industry. He served almost 30 years with what is now NASA's space communications program, beginning as an overseas station director and retiring as an associate administrator. As associate administrator for Space Operations (later renamed Space Communications), he provided capabilities to meet the rapidly increasing communications and information needs essential to all NASA programs, doing so within a flat budget by continually capitalizing on technology. He has testified before Congress on both policy and program matters. His responsibilities included planning, procuring, launching, and operating the Tracking and Data Relay Satellite System (TDRSS), which provides communications with the Space Shuttle as well as with most of NASA's low-Earth-orbiting (LEO) scientific satellites. He was also responsible for the Deep Space Network, ground communications networks, unmanned satellite control centers, and orbital tracking facilities. He has represented NASA in national and international radio regulatory processes, and actively participated in the 1992 WARC that obtained allocations for the LEO satellites. Mr. Force has also served as president of Vtex International, deputy program manager at Computer Sciences Technology Associates, and co-founder and vice president of Space Data Corporation. He received a BSAE from Purdue University in 1957.

KEITH JARETT is an associate technical fellow with Boeing Space and Intelligence Systems (formerly known as Boeing Satellite Systems) in El Segundo, California. He is currently managing an internal research and development (IRAD) project focusing on critical technologies and capabilities for NASA's long-term Communication and Navigation System Architecture. Dr. Jarett has a technical background in information theory and communication theory. He recently designed portions of the communication system for TSAT, the Defense Department's Transformational Satellite program. TSAT will provide a common high-bandwidth space-based communication backbone available to all DOD systems. Starting in 1999, Dr. Jarett led Boeing's design effort for a proposed satellite system to deliver Internet service to vehicles, including a novel Ka-band payload architecture using beam-hopping switch networks. In 2002 he worked extensively on a satellite system design for the FAA's Air Traffic Management, and in a related effort he established the feasibility of ad hoc data networking of aircraft over the Atlantic Ocean using VHF radios. He has also worked on advanced beam-forming antenna concepts, including ground-based beam forming.

Prior to rejoining Boeing in 1999, Dr. Jarett spent 12 years at TCSI, helping it grow from 3 to over 300 employees. He led systems engineering projects ranging from a smartcard system for MasterCard to a digital cellular personal base station for AT&T Wireless (then McCaw). He jointly architected large software systems for UPS (package tracing) and FedEx (airplane/truck scheduling and weight and balance). Dr. Jarett began his engineering career at Boeing (then Hughes Aircraft Company) as a Howard Hughes Doctoral Fellow. He received his M.S. and Ph.D. in electrical engineering from Stanford University and his B.S. in electrical engineering from Cornell University. In the early 1980s, Dr. Jarett worked extensively on the Space Shuttle's Ku-band Communications System, and he designed deep-space communication links for a proposed Galileo probe carrier spacecraft. Dr. Jarett holds 14 U.S. patents, with several more pending. He is a licensed professional engineer in the state of California.

MARJORY JOHNSON was a senior scientist at the Research Institute for Advanced Computer Science (RIACS) at NASA Ames Research Center for almost 21 years. During that time she contributed to several networking research projects, including development of the data network system for the Space Station, development and analysis of the FDDI protocol, and analysis of space data-communications protocols in support of the international Consultative Committee for Space Data Systems (CCSDS) organization, and she was involved with the Bay Area Gigabit Network Testbed as part of the next-generation Internet initiative. In 1998 Dr. Johnson joined the NREN (NASA Research and Education Network) project and became associate manager in 2000, a position she held until she retired in 2004. During her tenure, the NREN project conducted research to enable the infusion of emerging network technologies into NASA mission applications, thereby enabling new methodologies for achieving NASA science, engineering, and education objectives. The NREN testbed (which included both ground and satellite components) paired with high-performance testbeds sponsored by other federal agencies and with the university-led Internet2 testbed to provide a nationwide platform for conducting network research and for prototyping and demonstrating revolutionary applications. Dr. Johnson worked closely with representatives of other federal agencies to coordinate networking research activities across the agencies. She has participated in several review panels, both to review projects within NASA and to review activities of other federal agencies. Dr. Johnson received a Ph.D. from the University of Iowa and taught mathematics at the University of South Carolina and computer science at the University of Missouri-St. Louis prior to joining RIACS.

YOGI Y. KRIKORIAN is manager, System Design and Simulation Section, at the Aerospace Corporation. He has 17 years' experience in communications engineering, including 5 years in commercial industry including Hughes Space and Communication Company. He has been active in several NASA/JPL projects. He provided communication dynamic link analysis for the Mars Rovers, Spirit and Opportunity, and the Mars Telecommunications Orbiter; Mars Scout evaluations, including the Phoenix mission; and New Frontiers proposal evaluations. While at Hughes, Mr. Krikorian worked as a payload system engineer on the ICO Global Communication Satellite program. He helped design and develop the LO distribution network, communication processors, payload control processor (PCP), payload layout, and gain distribution of IF, RF, and LO signals. Mr. Krikorian also served as the manager of applications engineering at Elanix, Inc. in Westlake Village, California, where he provided technical expertise and support on the SystemView, a PC-based software simulation for designing DSP algorithms, communications systems, and RF/analog systems. Other commercial experience includes serving as senior technical engineer and director of engineering at RJS, Inc. in Santa Fe Springs, California. Mr. Krikorian rejoined the Aerospace Corporation in August 2000 after spending 8 years at Aerospace (1987-1995), during which he earned his master's degree in electrical engineering from the California Institute of Technology. In addition to participating in several NASA projects, Mr. Krikorian also analyzed, simulated, and presented information on the susceptibility of the ICO commercial satellite to pulsed radar frequency Interference for GMSK and QPSK modems.

THOMAS MAULTSBY retired from the U.S. Air Force in 1989 with the rank of lt. colonel. His Air Force assignments spanned satellite design, production, testing, launch operations, satellite ground systems acquisition, and program management. His specific positions within the government included senior Air Force representative to NASA headquarters for DOD Shuttle operations, assistant for space policy in the Office of the Secretary of Defense, and special assistant to the secretary of the Air Force for advanced technology insertion. In addition to the positions held within the government, Mr. Maultsby has filled a range of positions in the commercial aerospace industry. These included Director of Advanced Concepts at MacDonnell Douglas Electronics Systems Company, Senior Vice President and Director of the Decisions Technology Division of GRC International, and founder and President of Rubicon LLC, a specialized aerospace consulting firm. Mr. Maultsby has also served on numerous independent review committees and has held a variety of additional related positions. From 1998 to 1999, he was a member of the Defense Science Board Task Force on Space Superiority. From 1992 to 1995, he served on the Board of Directors (and as chair in 1994) of the Security Affairs Support Association.

TODD J. MOSHER is the director of Advanced Systems at Microsat Systems Inc., a company that specializes in small satellites. Dr. Mosher joined MSI after serving as senior manager of Advanced Exploration Systems for Lockheed Martin Space Systems Company, where he was a part of the group that recently was awarded the Orion Crew Exploration Vehicle from NASA. At Lockheed Martin, Dr. Mosher served as the principal investigator for an internal research and development project in autonomous rendezvous and docking, a critical technology for space exploration missions. Prior to working at Lockheed Martin, Dr. Mosher was an assistant professor at Utah State University (USU) where he was the director of the Center for Advanced Satellite Manufacturing, a state-sponsored center of excellence. While at USU, his research was sponsored by the Air Force Research Laboratory, the Office of Naval Research, the National Reconnaissance Office, the Air Force Office of Scientific Research, Lockheed Martin, The Aerospace Corporation, and the Space Dynamics Laboratory. He also served as the program chair for the annual American Institute of Aeronautics and Astronautics (AIAA)/USU Conference on Small Satellites, which celebrated its 20th anniversary in August 2006.

Prior to serving at Utah State University, Dr. Mosher was the associate director of the Space Architecture Department at the Aerospace Corporation, was an instructor at the University of California Los Angeles, and worked at General Dynamics Space Systems on a variety of launch systems ranging from future concepts to the contemporary Space Shuttle and Atlas. Dr. Mosher earned his Ph.D. in aerospace engineering from the University of Colorado, has two master's degrees in aerospace engineering and systems engineering from the University of Colorado and the University of Alabama in Huntsville, respectively, and received his bachelor's degree in aerospace engineering from San Diego State University. Dr. Mosher previously served the National Research Council as chair of the NASA Communications and Navigation Capability Committee in 2005 and as a member of the Committee for the Review of NASA's Pioneering Revolutionary Technology Program and its supporting Panel on Enabling Concepts and Technologies from 2001 to 2003. Additional distinctions include two patents pending in small satellite design, nearly 50 professional publications, serving as the current chair of the AIAA Space Systems Technical Committee, and being named an Associate Fellow of the AIAA in 2004. He has received several awards from NASA and the AIAA for his work mentoring students.

PATRICK A. STADTER is a principal professional staff engineer at the Johns Hopkins University Applied Physics Laboratory, where he serves as an assistant supervisor for military systems in the Space Systems Applications Group. Dr. Stadter earned a B.S.E.E. from the University of Notre Dame (1991), an M.S.E.E. from the Johns Hopkins University (1993), and a Ph.D. in electrical engineering from Pennsylvania State University (1997). Dr. Stadter was the principal investigator of the NASA Explorer's program to develop the cross-link transceiver for interspacecraft communications and navigation among multiple spacecraft, and the PI of the NASA-funded distributed spacecraft modeling and simulation testbed. He currently leads several Department of Defense research programs for small spacecraft applications. Dr. Stadter's research includes distributed command and control methods for autonomous vehicles, integrated navigation and communication systems, and information-theoretic classification techniques. Dr. Stadter has numerous technical publications and holds two patents related to communication and navigation systems.

PAUL G. STEFFES received his Ph.D. in electrical engineering from Stanford University, and his primary research area is microwave and millimeter-wave remote sensing of planetary atmospheres, microwave and millimeter-wave satellite communications systems, radio and radar astronomy systems and techniques, radio science, and non-invasive monitoring of glucose levels in the human body. He worked as a graduate research assistant at the Massachusetts Institute of Technology's Research Laboratory of Electronics, Radio Astronomy, and Remote Sensing Group while pursuing his master's degree (1976-1977). From 1977 to 1982, he was a member of the technical staff at Watkins-Johnson Company Sensor Development in San Jose. He was a graduate research assistant at Stanford University's Center for Radar Astronomy while pursuing his Ph.D. (1979-1982). Dr. Steffes has worked at the Georgia Institute of Technology since 1982, as assistant professor (1982-1988), associate professor (1988-1994), professor (1994-present), and associate chair (2004-present). He has been involved with several space missions, including Pioneer-Venus, Magellan, the Advanced Communications Technology Satellite, Cassini, and Juno. He was a member of NASA's SETI Microwave Observing Team and was involved with the Project Phoenix microwave search conducted by the SETI Institute. Dr. Steffes' honors include the Metro Atlanta Young Engineer of the Year Award, presented by the Society of Professional Engineers (1985); the Sigma Xi Young Faculty Research Award (1988); elected membership to the Electomagnetics Academy (1990); the Sigma Xi Best Faculty Paper Award (1991); NASA Group Achievement Award for the High Resolution Microwave Survey Project, for which he was a principal investigator (1993); and the Institute of Electrical and Electronics Engineers Judith A. Resnik Award (1996). He was named a fellow of the IEEE in 2004. He has served on two other NRC study groups, and he chaired the Committee on Radio Frequencies (BPA/CORF) from 1998 to 2001. He was named a lifetime national associate of the National Academies in 2001.

MICHAEL W. TOMPKINS is a senior project engineer with KDM Systems, Incorporated, a firm specializing in technical consulting to the National Reconnaissance Office. He is a member of a team that spans multiple program offices and focuses on demonstrating and fielding advanced satellite payloads. He earned a B.S.E.E. from the University of Texas at Austin in 1993 and M.S. and Ph.D. degrees in electrical engineering from the University of Illinois at Urbana-Champaign in 1995 and 1997, respectively. Prior to joining KDM Systems in 2006, Dr. Tompkins was an engineering specialist for the Aerospace Corporation (1997 to 2003) and an assistant professor of electrical and computer engineering at Utah State University (2003 to 2005). He has led or participated in a wide range of research and development activities that combine the disciplines of electromagnetics, microwave electronics, digital signal processing, and communications theory.

WILBUR TRAFTON is president of Will Trafton & Associates, an aerospace consulting firm. Previously he was president and chief operating officer of Kistler Aerospace Corporation. Prior to joining Kistler, Mr. Trafton was vice president/general manager of Boeing Expendable Launch Systems and president of Boeing Launch Services. He served as chairman of the board and president of Sea Launch Company, LLC. He was also president of International Launch Services. Mr. Trafton is a former associate administrator for spaceflight at NASA headquarters in Washington, D.C., where he was responsible for planning, budgeting, and execution of the Space Shuttle program, the International Space Station program, the Expendable Launch Vehicles program, and the Deep Space Network. He was also responsible for four NASA centers: Johnson Space Center in Houston, Texas; Kennedy Space Center, in Florida; Marshall Space Flight Center in Huntsville, Alabama; and Stennis Space Center in Mississippi. In 1997 Mr. Trafton was selected for the Presidential Rank of Meritorious Executive. He was also awarded two NASA Outstanding Leadership medals.

Mr. Trafton retired from the United States Navy as a captain after 26 years of service. He is a decorated combat veteran, having flown 85 combat missions from the aircraft carrier Shangri-la in the Vietnam War. He also served as commanding officer of the fast combat support ship Seattle in Desert Storm. He was awarded the Bronze Star for his duty in Desert Storm. He held a number of high-level positions in the areas of operations, acquisition of weapons systems, and international affairs, including commanding officer of Attack Squadron 113 and executive officer of the aircraft carrier Forrestal. He has over 3000 flight hours and 700 carrier landings.

A graduate of the U.S. Naval Academy, he received a master's degree in operations research and systems analysis from the U.S. Naval Postgraduate School in Monterey, California. He is also a graduate of the Defense Systems Management College in Ft. Belvoir, Virginia.

BARRY M. ZILIN is the president and CEO of Practical Innovations International, a small business corporation that focuses on the key disciplines required to perform research, development, test, evaluation, production, operation, and maintenance of aerospace systems. Mr. Zilin retired from the Air Force in 1989 after 20 years of distinguished service during which he held a variety of system acquisition positions, including buyer, procuring contracting officer, program control chief of plans and advanced requirements, project engineer, program manager, and system program director. Mr. Zilin now consults for industry and government agencies, providing support for strategic planning; in depth research, studies, and analyses; program execution and management; systems engineering and analysis; business process reengineering; and proposal planning, preparation, and review. He has supported industry on U.S. and European space launch programs; ISR, communications, and experimental space vehicle programs; launch range upgrade, sustainment, and O&M programs; attack, strike fighter, and training aircraft programs; and restricted programs. He has participated on launch accident review boards. He has been an ad hoc member of the Air Force Scientific Advisory Board; an advisor to the Air Force PEO (Space), the Air Force vice chief of staff, and the commanders of the Air Force Materiel Command and Air Force Space Command; and a consultant to the DARPA director. Mr. Zilin earned a B.S. in aerospace engineering from the Polytechnic Institute of Brooklyn in 1968, and an M.S. in aerospace engineering from the University of Arizona in 1972. He holds a top-secret SCI clearance.

C

Acronyms

24/7	24 hours per day/7 days per week
AA	associate administrator
AFSCN	Air Force Satellite Control Network
AOS	Advanced Orbiting Systems
ASRCMS	Artic Slope Regional Corporation Management Services
ASRS	Automated Support Requirements System
AWS	advanced wireless services
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS File Delivery Protocol
CITEL	Inter-American Telecommunication Commission
COP-1	Command Operation Procedure
CSOC	Consolidated Space Operations Contract
CSR	customer service representative
CWE	collaborative work environment
D&E	demonstration and evaluation
DASS	Distress Alerting Satellite System
DFE	direct from Earth
DMR	detailed mission requirements
DMWG	DASS Management Working Group
DOD	Department of Defense
DSCC	Deep Space Communications Complex
DSN	Deep Space Network
DTE	direct to Earth
DTN	Delay Tolerant Networking
EA	enterprise architecture
EM	electromagnetic
ESA	European Space Agency
ESMD	Exploration Systems Mission Directorate
ESV	Earth station on board vessel
FARM	Frame Acceptance and Reporting Method
FCC	Federal Communications Commission

FTE	full-time equivalent
GEO	geosynchronous Earth orbit
GLAST	Gamma Ray Large Area Space Telescope
GN	Ground Network
GPS	Global Positioning System
GRC	Glenn Research Center
GRGT	Guam Remote Ground Terminal
GSA FTS	U.S. General Services Administration Federal Technology Service
GSFC	Goddard Space Flight Center
HSMF	Headquarters Spectrum Management Forum
ICSPA	International COSPAS-SARSAT Program Agreement
IP	Internet Protocol
IRAC	Interdepartment Radio Advisory Committee
ISDN	Integrated Services Digital Network
ISO	International Organization for Standardization
IT	information technology
ITAC	International Telecommunication Advisory Committee
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union Radiocommunication
JHU	Johns Hopkins University
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KICS	Kennedy Information and Communications Services
KSC	Kennedy Space Center
LEO	low Earth orbit
LSAM	Lunar Surface Access Module
LUT	local users terminal
MCC	mission control center
MEO	mid-Earth-orbiting
MILA	Merritt Island Launch Annex
MilSatCom	Military Satellite Communications
MIT	Massachusetts Institute of Technology
MOA	memoranda of agreement
MSFC	Marshall Space Flight Center
MSOC	Mission Support Operations Contract
NASA	National Aeronautics and Space Administration
NENS	Near Earth Network Services
NGSO	non-geosynchronous orbit
NISN	NASA Integrated Services Network
NOAA	National Oceanic and Atmospheric Administration
NOIT	Network Operations Integration Team
NRC	National Research Council
NREN	NASA Research and Education Network
NRT	near-real time
NSARC	National Search and Rescue Committee
NSF	National Science Foundation
NSMG	NASA Spectrum Management Group

NSP	National Search and Rescue Plan
NTIA	National Telecommunications and Information Administration
POC	proof of concept
PSLA	project service-level agreement
QoS	Quality of Service
RF	radio frequency
SAR	synthetic aperture radar; search and rescue
SBIR	Small Business Innovation Research
SCAWG	Space Communications Architecture Working Group
SCCIB	Space Communications Coordination and Integration Board Sector
SCO	Space Communications Office
SEDL	System Evaluation and Development Laboratory
SFCG	Space Frequency Coordination Group
SFOC	space flight operations contract
SLE	Space Link Extension
SMC	Senior Management Council
SMD	Science Mission Directorate
SN	Space Network
SNE	Space Network Expansion
SOIS	Spacecraft On-board Interface Services
SOMD	Space Operations Mission Directorate
SRB	Systems Review Branch
SRS	space research service
SSA	S-band single access
TCA	Transformational Communications Architecture
TDRSS	Tracking and Data Relay Satellite System
TRL	technology readiness level
TSAT	Transformational Satellite System
UNITeS	Unified NASA Information Technology Services
VoIP	Voice over Internet Protocol
VSAT	very-small-aperture terminal
WAN	wide-area network
WFF	Wallops Flight Facility
WRC	World Radio Conference
WSC	White Sands Complex