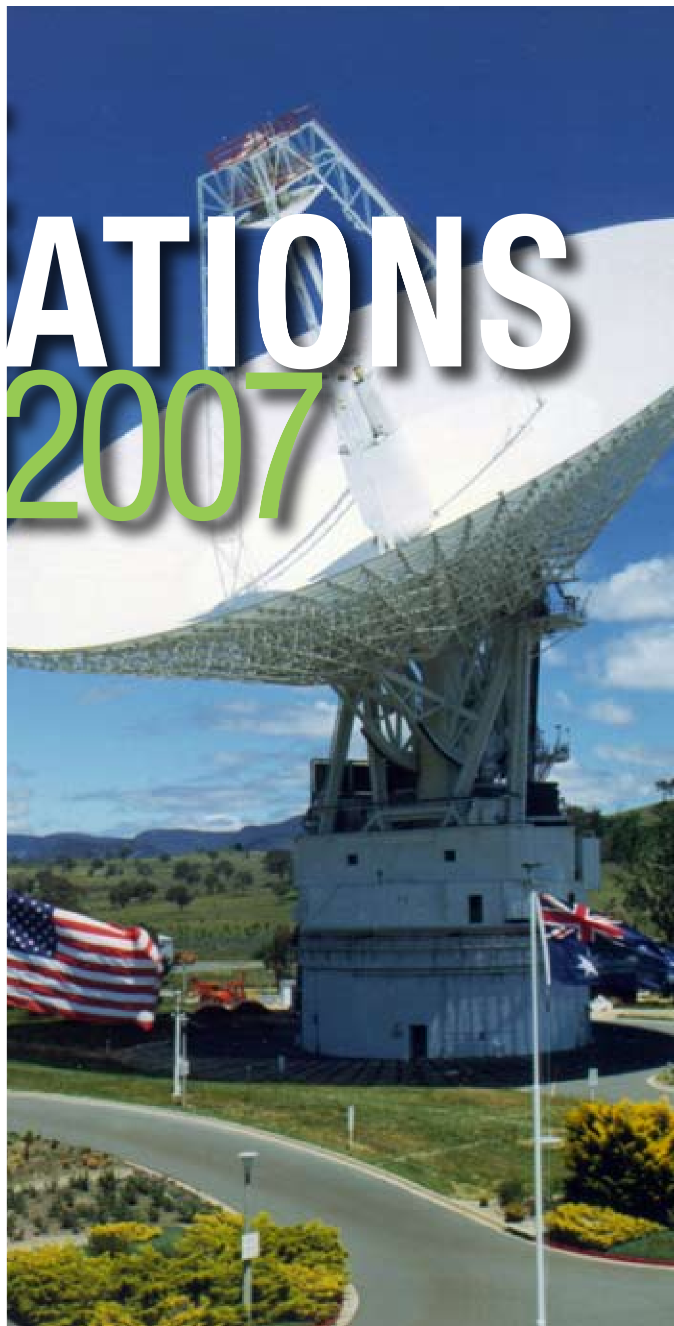
National Aeronautics and Space Administration

SPACE COMMUNICATIONS PLAN 2007



COVER PHOTO MONTAGE:

The Deep Space Network's 70-meter antenna in Australia (depicted lower right) communicates with missions beyond the Moon (upper right), while other SC Program resources supply communications to flight missions such as the International Space Station (top left) in the vicinity of the Earth (lower left).

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[Introduction] 1

The SC Program provides communications services for flight missions such as NASA's Spitzer Space Telescope, which collected the data used to generate this image of the Eagle Nebula. *Image credit: NASA/JPL-Caltech/Institut d'Astrophysique Spatia*

1.1 Purpose and Scope

Section 102(c) of the National Aeronautics and Space Administration (NASA) Authorization Act of 2005 (P.L. 109-155) directs the NASA Administrator to "develop a plan, in consultation with relevant Federal agencies, for updating NASA's space communications architecture for both low-Earth orbital operations and deep space exploration so that it is capable of meeting NASA's needs over the next 20 years." The Act also includes a request for cost estimates (including five-year funding profiles and life cycle costs), schedule information, and a description of estimated performance capabilities. (See Appendix A for detailed legislative language.)

This document addresses the Congressional direction within the framework of NASA's Space Communications (SC) Program, beginning with an overview of the Program and the current architecture. It outlines key Program goals based on the Agency's strategic plan, describes requirements and drivers that influence Program actions, and characterizes an evolving space communications architecture based on current goals and objectives. The plan addresses the sustaining engineering actions, proposed major upgrades, and potential development activities during the next 20 years to support the Vision for Space Exploration, as well as missions in near-Earth orbit. Supporting cost and schedule information regarding SC Program operations and development activities is also included, but due to the preliminary nature of this information, there is a large uncertainty associated with final cost estimates.

NASA envisions that its space communications architecture will gradually transform over the next 20 years from the current set of elements into a centralized architecture consisting of a "network of networks" to meet future mission needs. The Agency's plans for space communications development, therefore, are outlined in this document in the context of advancement toward that future architecture.

The schedule and cost estimates contained in this plan are based upon the best knowledge currently available to NASA. To compile this report, NASA considered numerous factors, including anticipated mission needs, technology development trends, benefits expected from technology incorporation (reduced costs, higher efficiency, etc.), the condition of current operating systems, investments by other Agencies, commercial service buys, and present National and Agency space initiatives. As these factors evolve, NASA will conduct additional analyses to refine Program schedule and cost estimates.

1.2 Space Communications Program Overview

NASA's SC Program is responsible for providing communications and navigation services to the Agency's flight missions and for supplying terrestrial communications needs. The SC Program is managed by the Space Communications and Navigation (SCaN) Office within the Space Operations Mission Directorate (SOMD) at NASA Headquarters.

The SC Program is comprised of the following elements:

1. **Deep Space Network (DSN):** globally distributed terrestrial communications stations predominantly supporting missions operating at significant distances from Earth orbit;
2. **Space Network (SN):** geosynchronous relay satellites predominantly supporting Low-Earth Orbit (LEO) missions with global coverage;
3. **Near Earth Network (NEN, formerly known as the Ground Network or GN):** globally distributed tracking stations supporting near-Earth spacecraft needing periodic contact;
4. **NASA Integrated Services Network (NISN):** commercial service backbones providing point to point terrestrial signal transport services and routing network services;
5. **SC Crosscutting Functions:** Spectrum, Standards, Technology, External Coordination, Resources, and Systems Planning functions that enable NASA's space communications networks; and,
6. **Exploration Communications and Navigation Systems (ECANS):** provides support to the Space Communications and Navigation (SCaN) Program regarding technical management and integration of new communications and navigation systems that will enable the President's Vision for Space Exploration.

These elements work in concert to satisfy the common goals of the Program. Figure 1-1 depicts the SC Program elements in the current SCaN architecture. Together, the Program elements provide a full complement of communications services to fulfill the requirements of NASA and the current set of flight missions. As the needs of the Agency and supported flight missions change, NASA will evolve the architecture to best achieve Program goals and satisfy flight mission communications needs.

1.3 Space Communications Program Goals

The centrally managed SC Program supports NASA Mission Directorates and external organizations by providing space communications and data systems services that are responsive to the mission needs within the allocated resources of the Program. This includes the utilization of commercial providers to the extent feasible and where cost effective. Additionally, the SC Program performs sustaining and replenishment efforts necessary to maintain the SC infrastructure so that service capacity and capability will meet the projected work load based upon the approved mission models. The SC Program includes infusion of communications and data systems technology and standards to provide mission enabling, efficient, and effective services.

The SC Program goals are derived from the 2006 NASA Strategic Plan and the subordinate tactical plans of the NASA Mission Directorates. SC Program goals are:

1. **Mission Safety:** Acquire, maintain, and operate SC systems to achieve NASA and flight program objectives in a safe and reliable manner;

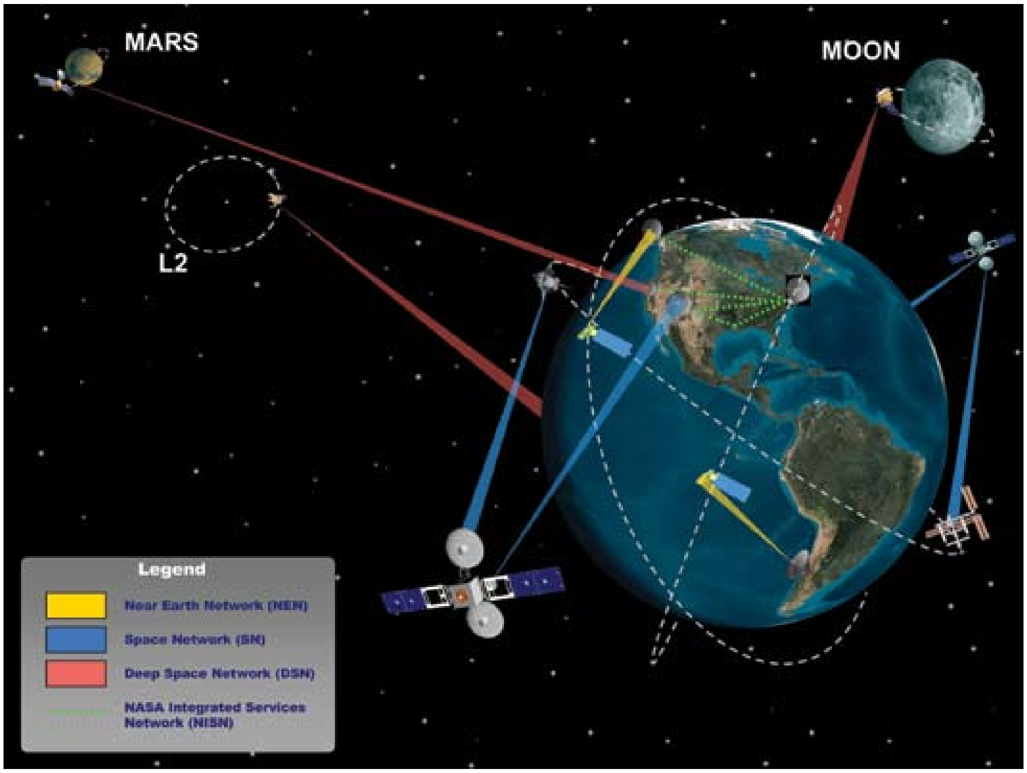


Figure 1-1: NASA Space Communications and Navigation Architecture–2006

2. **Mission Assurance:** Provide SC services to flight missions as agreed and documented in service agreements;
3. **Mission Commitment:** Work proactively to avoid or resolve service problems;
4. **Institutional Communications Assurance:** Acquire, operate and maintain NISN systems to meet Agency networking and video teleconferencing needs;
5. **SC Planning:** Evolve the SC services consistent with the architecture framework and mission requirements; and,
6. **Program Management:** Manage the SC Program to best value, consistent with the above goals.

These goals are the guiding principles by which the Program will conduct all of its activities, including planning, development, operations, and any associated crosscutting functions. SC Program goals will remain fairly static throughout the lifetime of the program; however, the activities the Program undertakes to support these goals will change over time.

There exist certain factors, or drivers, that influence the Program's actions in pursuit of its goals. These drivers fluctuate, and can originate internally or externally to the Program. The Program will need to respond to these drivers to successfully accomplish its goals. For example, SC Program assets and systems will age and degrade over time, perhaps becoming obsolete. This natural aging process is a driver that will cause the Program to conduct maintenance and sustaining activities or upgrade the affected equipment so that the organization can continue to attain its goals.

In addition, not only must the SC Program serve its current set of flight missions, it must also prepare to serve future missions. The requirements of NASA-supported flight missions will evolve over time, driving the SC Program's resources and capabilities to mirror those changing requirements. Technology advancements and the Nation's and Agency's changing priorities are other drivers that will correspondingly affect SC Program evolution, either directly or indirectly, by altering the communications requirements of Program-supported flight missions. Additional drivers that may influence Program actions include the advent of National, Agency, or program-wide initiatives—such as the Vision for Space Exploration—which the Program will incorporate within the context of its governing goals.

This plan details how the SC Program will assure that the communications needs of current and future flight missions are fulfilled. Figure 1-2 shows how the future SCaN architecture may evolve into a "network of networks" to achieve SC Program goals. The SC Program will accomplish its goals via a balanced program of maintenance, upgrades, and development, deploying technology systems that provide best value to NASA. The SCaN Office will regularly evaluate the changing flight mission set, Agency priorities, and other drivers shaping the program's actions and update the SC Program Plan accordingly.

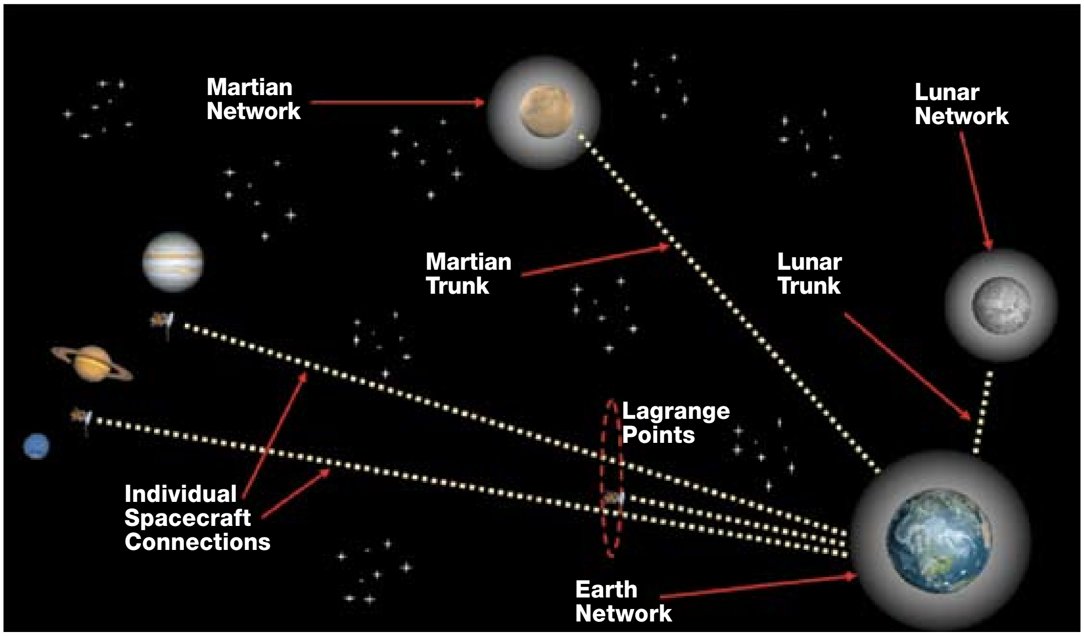


Figure 1-2: NASA Space Communications and Navigation Architecture–2030: A Network of Networks

[Flight Mission Communications Needs] 2

NASA's Mars Exploration Rover Opportunity—a mission supported by the Deep Space Network—acquired the data to produce this false color image of a rock exposure near the "Beagle Crater." *Image credit: NASA/JPL-Caltech/Cornell*

The SC Program's primary responsibilities are to provide communications and navigation services to flight missions and to supply NASA's terrestrial communications needs. To determine the needs of the flight missions, the SCaN Office maintains the Space Communications Mission Model (SCMM). The primary input to the SCMM is the Agency Mission Planning Model (AMPM) shown in Figure 2-1, which is controlled by the Office of Program Analysis and Evaluation (PA&E). The AMPM contains the baseline list of planned future launches, including missions at different levels of development and approval. In addition to missions identified in the AMPM, the SCMM includes currently operating missions (already launched), other mission support provided by SC Program elements (e.g., launch support and contingency support), and non-NASA missions (e.g., reimbursable missions, commercial missions, and cooperative missions with other agencies). The SCMM also includes data about each mission, such as mission duration, number of communication links required, data volume and rate information, and more.

The SC Program uses the SCMM to analyze long-term flight mission trends and identify upcoming communications needs. These analyses support the determination of Program requirements and drive decisions regarding development efforts and major modifications to the SCaN architecture. The SC Program also uses the SCMM as the basis for performing network loading studies and planning future operating budgets.

Furthermore, NASA performs trend analyses using historical data and future plans to identify upcoming flight mission communications needs. By extrapolating data about past and present missions, NASA can estimate the approaching demands for existing services, and deduce what types of new services or capacity might be required in the future.

The following paragraphs discuss current and future mission trends, as well as Agency plans for upcoming missions. Flight mission communications needs corresponding to those trends and plans are discussed, as well.

In the past, NASA primarily conducted science missions comprised of single spacecraft such as the Hubble Space Telescope (HST) and Cosmic Background Explorer (COBE). Current and future missions trend toward using constellations of spacecraft that work in concert as a science observatory. Recent examples include the Time History of Events and Macroscale Interactions during Substorms (THEMIS) and Solar Terrestrial Relations Observatory (STEREO) missions. The increasing number of constellation missions will require the SC Program to supply a greater number of communication links to spacecraft. If constellation mission data rates are not augmented by event-driven on-board capability, they may require data at greater volumes than present resources allow.

Examination of the mission models indicates that future missions are planning to use Ka-band for communications in an effort to relieve the congestion and interference occurring with X-band frequencies. Flight missions will need SC Program resources to provide sufficient support at Ka-band to satisfy user demand.

The Vision for Space Exploration entails long-term, sustained, human and robotic exploration of the Solar System and beyond. A key component is expanding our Nation's lunar exploration, including both robotic and human missions (e.g., Constellation Program). NASA will continue to conduct robotic exploration of Mars, and will eventually send human missions to explore that planet. At the same time, NASA will continue its broad space science program, including missions to the outer planets. These upcoming science and exploration missions to distant bodies in the Solar System will increase the requirements upon space communications. Before human exploration of the Moon resumes and that of Mars begins, NASA plans to send robotic missions to probe and study these remote regions. The first Exploration lunar robotic mission will gather data from orbit. Later robotic missions and human explorers will land on the Moon. Exploration of Mars continues with orbiting robotic missions providing information about the Mars environment and missions operating on the planet's surface for an extended period of time, including a Mars Sample Return mission, and culminating with human Mars exploration missions.

NASA will reinitiate lunar exploration in 2008 with the Lunar Reconnaissance Orbiter (LRO) and its secondary payload the Lunar Crater Observation and Sensing Satellite (LCROSS). Due to advances in technology, the instruments onboard these probes will possess increased capabilities, allowing them to provide multi-spectral or hyper-spectral images and detailed surveys. These orbiting missions will necessitate transport of very high volumes of data for extended periods of time, and will require communications support even when they are not in view of present SC resources.

NASA will begin transmitting even larger quantities of data once human missions to the Moon begin. NASA employs very strict safety measures for human missions. Communications must be provided via a diverse set of resources to provide redundancy and ensure availability.

When robotic and subsequent human missions to Mars are underway, it will be necessary to support a similar volume of data with greater coverage, at distances up to a thousand times further away introducing an even more difficult communications scenario. Analysis of present and future flight missions also indicates that there will continue to be a need for the types of

In this artist's concept of the future, an astronaut gathers samples on the surface of Mars, while a robotic explorer stands by to help. The Vision for Space Exploration calls for aggressive human and robotic missions that will return to the Moon and eventually explore Mars and beyond. *Image Credit: NASA*

communications support provided by existing elements of the SC Program. For example, many Earth science observation programs will take place in the future, such as the Ocean Surface Topography Mission, and the missions identified in the recent National Academy of Sciences report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, January 2007. Availability estimates for SC resources show that replenishment of aging assets will be necessary to meet anticipated flight mission communications needs.

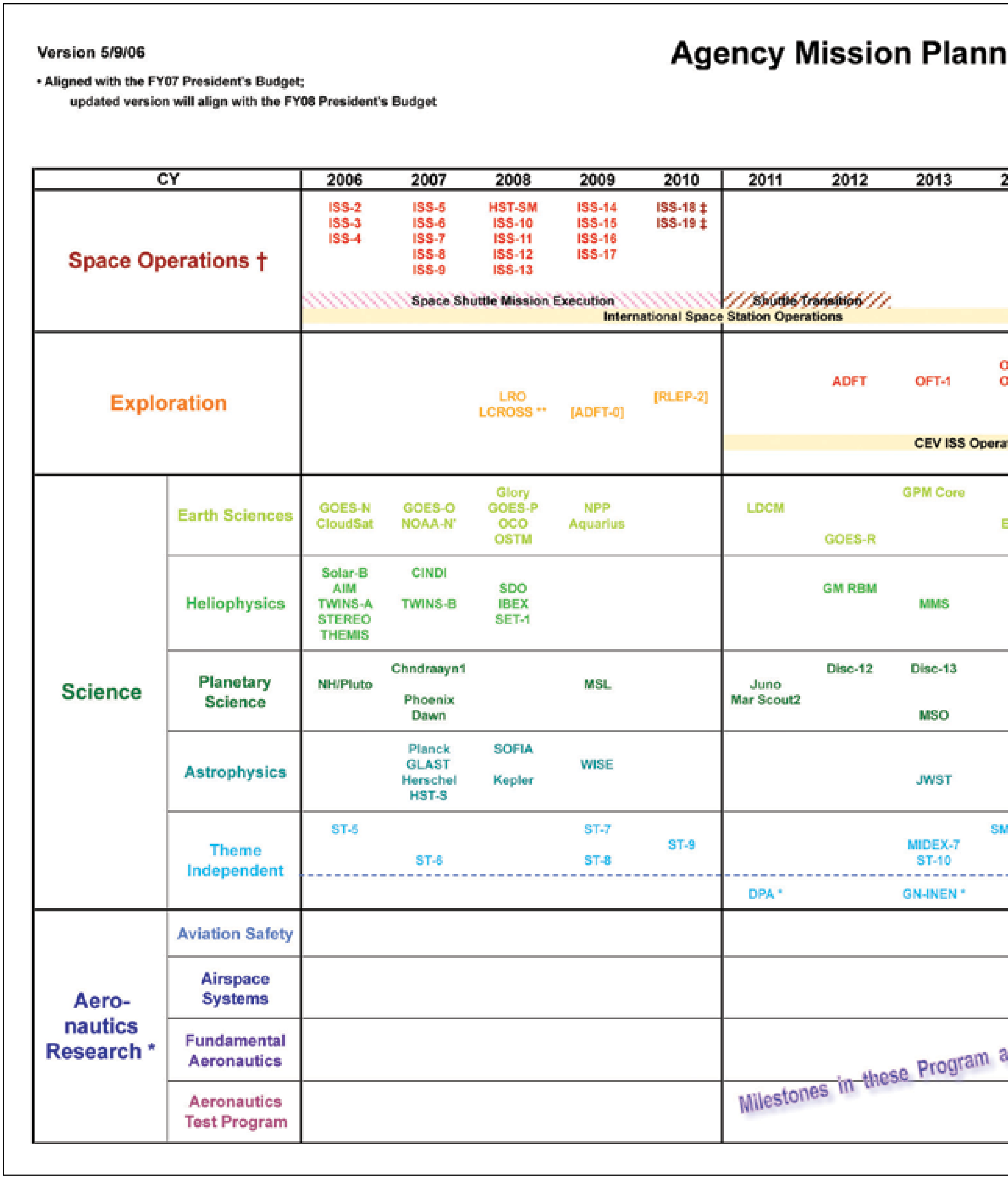
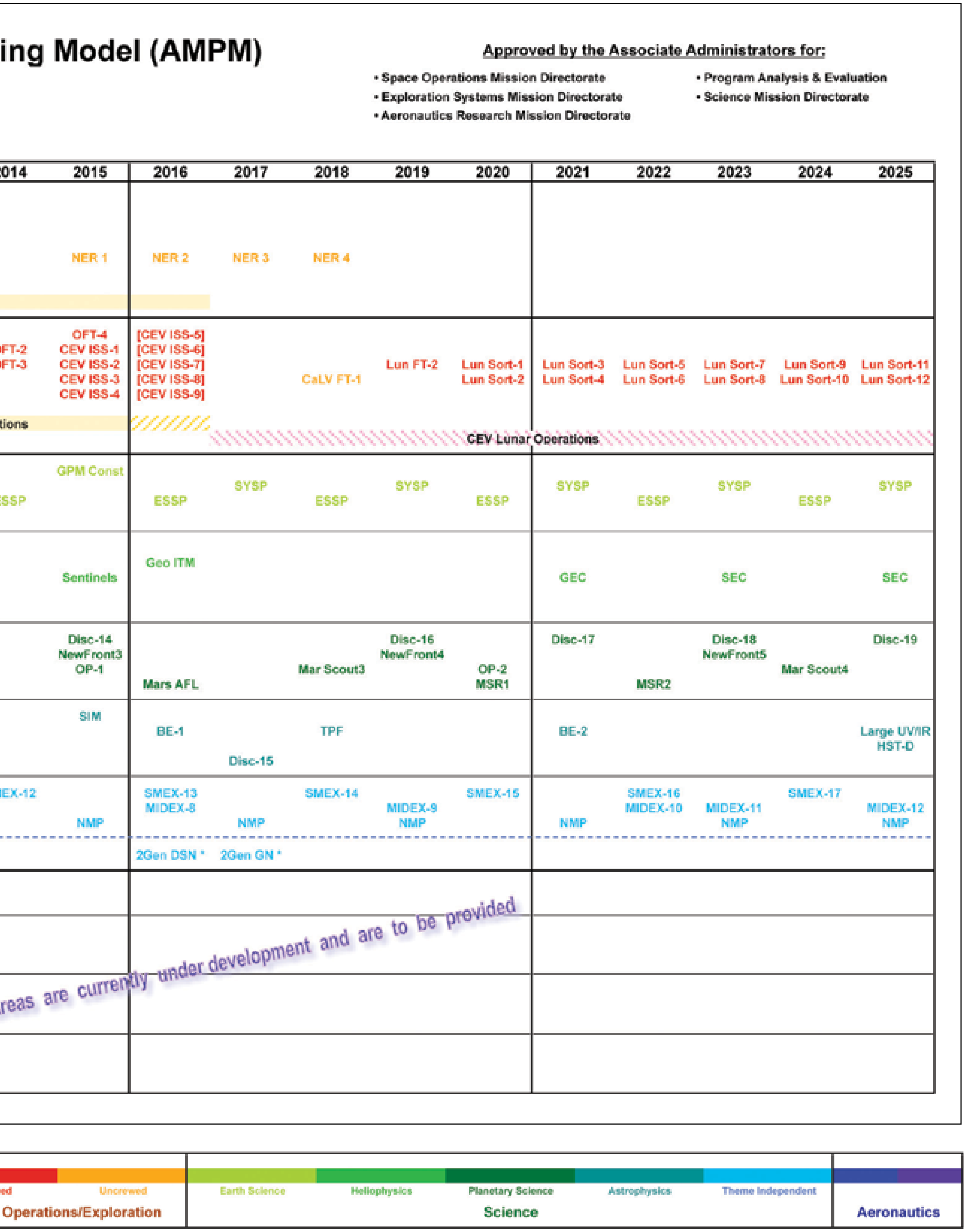


Figure 2-1: Agency Mission Planning Model (AMPM).

Notes:
* Ground-based Missions
† Shuttle Manifest is based upon the FY07 Presidents budget and does not reflect the slip in the schedule from May to June of ISS-2
‡ Contingency Shuttle flights
Lun Sort = 1 CEV flight and 1 CaLV flight
[ ] Brackets indicate flight is desired but is subject to budget constraints and/or future schedule decisions
** LCROSS is a secondary payload on LRO


ing Model (AMPM)
Approved by the Associate Administrators for:
• Space Operations Mission Directorate
• Exploration Systems Mission Directorate
• Aeronautics Research Mission Directorate
• Program Analysis & Evaluation
• Science Mission Directorate
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Operations/Exploration
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Heliophysics
Planetary Science
Astrophysics
Theme Independent
Science
Aeronautics

[Space Communications Program Requirements] 3

Radomes protect Near Earth Network antennas in Svalbard, Norway from the elements. *Image credit: NASA/KSAT*

SC Program requirements are developed to meet the communications needs of the flight missions contained in the SCMM. Program requirements are defined in terms of the services provided by the SC networks (NEN, SN, DSN, NISN) to flight missions. These services are defined by the following measurable characteristics:

1. **Capability: assets with attributes in place to perform network functions.** Capability is defined in terms of tracking, telemetry, and command services provided, as further described by the frequency bands in which the network operates, the bandwidth provided by the network, the peak data rate of equipment or the gain of antenna apertures that provide the connectivity. Capability may also encompass management of spectrum, standards and other space communications related competencies.
2. **Capacity: how much capability the network can provide.** Capacity is defined as the number of communications links or paths, the amount of bandwidth provided [in kilohertz (kHz) or megahertz (MHz)] and corresponding data rates of thousands, millions or billions of bits per second (kbps, Mbps or Gbps), or the number of services associated with each size and type of antenna.
3. **Service Quality: the reliability, performance, and availability of space communications services.** Service Quality is defined with metrics such as bit error rate, proficiency (a measure of meeting scheduled service commitments), availability (a measure of system down time) or reliability (a measure of system design robustness such as mean time between failures).

NASA Headquarters determines the capacity and capability provided by each network. The SC Program requirements are controlled by the SCaN Office, and flow down to the implementing and operating NASA Centers that develop the lower level requirements specific to each network.

As the communications needs of the missions in the SCMM change over time, NASA will correspondingly alter the SC Program requirements to reflect the mixture of needed capabilities and capacities. Future missions are anticipated to use higher data rates and generate greater volumes of data that must be transmitted over longer distances as exploration to the Moon and Mars occurs. NASA plans to upgrade and develop the SC Program elements so that the space communications architecture will accommodate the changing demand for communications and navigation services.

[Space Communications Program Architecture] 4

Antennas at NASA's Space Network ground terminals in White Sands, NM communicate with the Tracking and Data Relay Satellites in geostationary orbits.

The SC Program must maintain an adaptable architecture to realize program goals and requirements, meet mission communications needs, and address impacting drivers simultaneously. The SC Program has conducted studies (results currently under review) to address the current aging and fragile infrastructure and to identify attributes of a future integrated space communications architecture. The future SCaN architecture is envisioned as four physical elements with overlaying Networking, Security, Radio Frequency (RF) Spectrum, and Navigation architectures (see Figure 4-1). A thorough analysis of significant parameters including scalability, reliability, evolvability, adaptability, maintainability, availability, interoperability, and cost indicated that this architecture would best meet NASA's needs. This architecture approach serves as the basis for planning future NASA SCaN activities; however, as flight mission requirements and other drivers change, NASA will modify its architecture approach accordingly.

The SC Program has coordinated this architecture approach with stakeholders external to NASA. Program representatives consulted with the National Security Space Office's (NSSO) Transformational Communications Working Group about future activities pertaining to the SN and NISN. The Program discussed plans for interoperability and cross support involving NASA's McMurdo ground station and the National Polar-orbiting Operational

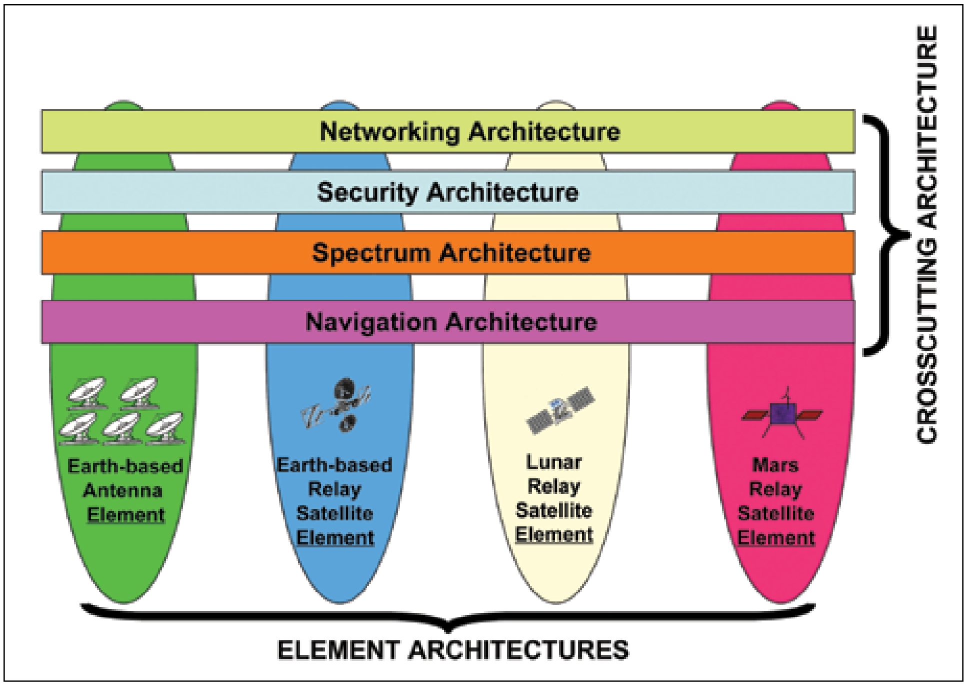


Figure 4-1: SCaN Architecture Consists of Element and Crosscutting Architectures

Environmental Satellite System's (NPOESS) Safety Net with the NPOESS Integrated Program Office (IPO). NASA also conducted preliminary studies with the National Science Foundation's National Radio Astronomy Observatory regarding use of the DSN's Very Long Baseline Array for precision spacecraft navigation. In addition, the National Research Council reviewed the SCaN architecture approach as part of an independent assessment of the SC Program (*Review of the Space Communications Program of NASA's Space Operations Mission Directorate*, January 2007).

The SCaN architecture is comprised of existing and future capabilities designed to serve different classes of missions with different service needs. There is intentional overlap in the element architectures' service domains to allow for the missions' need for service assurance and transition of mission spacecraft between domains. For example, human exploration missions to the Moon (or Mars) will use Earth-based Antenna Element support for launch, Earth-based Relay Satellite Element support while in low-Earth orbit, and Lunar (or Mars) Relay Satellite Element support in lunar (or Mars) orbit and on the surface; thus, these elements will require a degree of interoperability never needed before. The SCaN element and crosscutting architectures are described in further detail below.

4.1 Earth-based Antenna Element

The Earth-based Antenna Element currently includes the functionality of today's NEN and DSN. As the existing network assets reach their end of life, the SC Program plans to replace large antennas with arrays of smaller antennas to accomplish mission communications support, while maintaining equivalent service. To validate this approach, an independent analysis of alternatives is being conducted. The results of this analysis will be considered in making the final decision. The recommendation for near-Earth elements also indicates that several concepts will influence the future of the NEN: use of antenna arrays, a trend toward virtual networks, and a continuing shift away from NASA-owned assets toward commercial services.

4.2 Earth-based Relay Satellite Element

The Earth-based Relay Satellite Element consists of the SN's current Tracking and Data Relay Satellite System (TDRSS) and its supporting ground systems resources. As these assets age and become obsolete, they will be replaced with a set of new spacecraft and corresponding ground systems with enhanced capabilities to support the current and projected flight mission sets. These new assets will be functionally equivalent to the present TDRSS, and will continue the communications relay services currently provided to missions.

4.3 Lunar Relay Satellite Element

The Lunar Relay (LR) Satellite Element is a future concept that will benefit from NASA's experience with both the SN and the existing network of relay satellites providing communications to current Mars flight missions. The primary focus of the LR Satellite Element will be to provide flexible communications in support of NASA's Constellation Program. By the time the first lunar human mission is launched, this element will evolve into a series of incrementally deployed communications satellites, capable of relaying data to/from the Moon and intermediate points.

4.4 Mars Relay Satellite Element

The future concept for the Mars Relay (MR) Satellite Element will use technology and capabilities proven on both the existing Mars communication network and the future Lunar Relay element. Communications payloads are currently launched in conjunction with robotic science exploration missions to provide "store and forward" communications services for missions on the Mars surface or in Mars orbit. It is possible that by the time human missions to Mars occur, the Mars communications relay element will have evolved from today's communications co-payloads into a set of dedicated communications relay spacecraft.

4.5 Networking Architecture

The Networking Architecture addresses the standardized layered data services described in the work of the Consultative Committee for Space Data Standards (CCSDS) and other networking standardization organizations, and addresses how standards might be used to achieve interoperability and create virtual networks to meet mission objectives. A smooth spacecraft handover from Earth element ground antennas to near-Earth relay satellites has been an operational objective for some time. In fact, NASA intends to structure the Networking Architecture to provide flight missions with seamless transition between any SC Program components that provide communications services. A good example of transparent use of multiple networks is the integrated Shuttle mission network involving NASA ground and space based trackers along with Department of Defense (DOD) range trackers. In addition, the Networking Architecture should employ new techniques and standards to assure data delivery, which becomes particularly important as communications extend to interplanetary distances.

4.6 Security Architecture

The Security Architecture strives to ensure operational mission safety and data integrity, including confidentiality and authentication. Today the approaches involve closed communications networks, source encryption and personnel reliability programs. Aspects requiring additional study include new standards for automatic data processing, concerns about service denial, and how security will evolve in conjunction with changing Network architectures and international partners. As these requirements are further defined, study results will be incorporated into future developments.

4.7 Spectrum Architecture

The Spectrum Architecture will entail use of spectrum bands according to agreements forged by the International Telecommunications Union (ITU) and its supporting working groups. This architecture will be structured to minimize interference and maximize interoperability with other national and international agencies.

4.8 Navigation Architecture

The Navigation Architecture is a mix of radio and optical navigation including two-way and one-way Doppler and ranging for NASA network elements, on-board processing of Global Positioning System (GPS) satellite reference beacons, on-board star trackers and inertial references. For example, plane-of-the-sky navigation using Very Long Baseline Interferometry (VLBI) techniques is routinely used to help guide spacecraft to precise orbit insertion points. Time delay compensation, accuracy of time determination, and transfer or synchronization among satellite formations are anticipated to be important enabling capabilities for future science investigations.

[Performance Capabilities] 5

The Space Network provides communications services for flight missions such as NASA's Hubble Space Telescope, which captured this "true color" mosaic of a small portion of the Orion Nebula.
Image credit: NASA/C.R. O'Dell (Rice University)

The SC Program will evolve its elements to meet Agency goals and Program requirements, satisfying the communications needs of the anticipated flight mission set. In some instances, the predicted mission set requires the same performance capabilities that are provided by current Program resources. In other cases, new or changed performance capabilities are required. Changes to performance capabilities can be expressed in terms of the same measurable characteristics the Program uses to define its services—Capability, Capacity, and Service Quality (see Section 3.0 for a definition of these characteristics). The future SCaN architecture preserves certain existing capabilities through replenishment of resources, and adds new performance capabilities via development efforts.

5.1 Capability

Implementation of the SCaN Architecture described in this document will ensure that NASA's future space missions can operate anywhere in the solar system, with support from robust communication links providing Tracking, Telemetry, and Commanding (TT&C) and transfer of high rate mission data. The TT&C links will consist of S-band RF capability for near-Earth communication, and X-band capability for deep space mission support. The high rate transfer of data to support mission operations will move into the Ka-band RF spectrum and possibly optical bands as technologies mature. Future enhancements to the SCaN Earth-based Antenna and Earth-based Relay Satellite elements will seek to reduce the burden placed on spacecraft in terms of power, mass, and volume resources needed to use the SCaN infrastructure. In addition, NASA intends these future enhancements to achieve more efficient use of available RF spectrum. A key capability of the new architecture will be to enable a service-based structure that affords missions maximum flexibility. NASA is helping to define a set of network standards for providing services such as raw radiometric tracking, file transfer, and Internet Protocol (IP) network services from all elements of the future SCaN architecture. Through a focus on interoperability with other U.S. Government agency space communication assets, the SCaN infrastructure will be able to support other agencies' missions, as well as enable those agencies to support NASA missions with their space communication resources as appropriate.

5.2 Capacity

The SCaN element architectures provide for increasing data rate capacity on most RF links to spacecraft operating throughout the solar system. For example, moving the preferred spectrum band for the Earth-based Relay from Ku-band to Ka-band will allow future data rates up to 1.2 Gbps, well above the 300 Mbps currently available. Capacity increases are also planned for the links supporting spacecraft operating in deep space. In the past, many deep space missions used S-band links for TT&C and X-band links for high rate data transfer. To enable more productivity from future spacecraft and to relieve spectrum congestion, the preferred spectrum bands will shift to X-band for TT&C and to Ka-band for high rate links. Furthermore, technology development will make significantly higher data rates available to future missions. For example, data return rates on DSN 34-meter systems from spacecraft operating at Mars may increase from the 6 Mbps received today at X-band, to rates of 24 Mbps at Ka-band.

5.3 Service Quality

The SC Program must continue to provide its supported flight missions with reliable communications services that meet mission-driven performance and availability requirements. Independent reviews have indicated that many of NASA's SC systems are reaching or surpassing their planned lifetimes, and are becoming fragile and obsolete. Aging equipment poses a risk to successful provision of services since it may fail more frequently and is difficult to repair due to unavailability of legacy parts. To ensure service quality is maintained as the SCaN architecture evolves, the Program plans to replace these aging assets with new systems employing contemporary technology.

[Investment] 6

- Sustaining Engineering Activities
- Major Upgrades
- Development Efforts
- Technology Development

Artist's conception of a Tracking and Data Relay Satellite, the space-based segment of NASA's Space Network.

To ensure that the Program goals and requirements are achieved during the next 20 years in the framework of the evolving SCaN architecture, the Program will be required to undertake numerous activities beyond those necessary to support ongoing operations. These activities are categorized below as Sustaining Engineering Activities, Major Upgrades, Development Efforts, and Technology Development according to cost and scope. Each of these required activities can be traced to the mission model and one or more of the Program's goals. The NASA Center responsible for each network will accomplish these activities in accordance with Agency practices regarding competitively awarded work.

The SC Program considers Sustaining Engineering Activities for existing communications networks its highest investment priority—a position driven by the importance of ensuring mission success within the allocated resource constraints. SCaN Office objectives include allocation of approximately ten percent of the Program's annual operating budget for Sustaining Engineering Activities, and approximately eight percent of the budget for Technology Development.

6.1 Sustaining Engineering Activities

Sustaining Engineering Activities are intended to preserve, rather than change, system capability or capacity, and may include replacement of obsolete subsystems. Table 6-1 lists example Sustaining Engineering Activities planned by the SC Program, along with the reason or driver behind each activity, and the associated Program goal(s).

Sustaining Engineering Activities		
Activity (completion date)	**Reason/Driver**	**Associated SC Program Goal(s)**
DSN Antenna Controller Replacement (2007)	Obsolescence	Mission Commitment Mission Assurance
Refurbish DSN's Goldstone Solar System Radar (GSSR) High power tubes (2008)	Failed unique equipment	Program Management Mission Assurance
Consolidate NEN systems (2008)	Reduced capacity, retire labor intensive systems	Program Management
NEN Subsystems replacement (receivers, antenna gears, etc.) (2008)	Obsolescence and manufacturing defects	Mission Safety Mission Assurance Mission Commitment
Replace or refurbish supporting electronics for DSN (2011)	Aging equipment, obsolescence	Mission Commitment Mission Safety Mission Assurance
NISN Mission Operations Voice Enhancement (MOVE) (2011)	Obsolescence	Mission Assurance
Design and replace SN resources (2012) ■ High Data Rate Equipment ■ Automated Data Processing Equipment (ADPE) ■ Software Maintenance and Training Facility (SMTF)	Obsolescence	Mission Commitment Mission Assurance

Table 6-1: SC Program Sustaining Engineering Activities

6

investment

6.2 Major Upgrades

Major Upgrades result in an improvement of existing resources or equipment. New capabilities or changed capacity may be realized as a result of these activities. Table 6-2 lists examples of Major Upgrades planned by the SC Program, along with the reason or driver behind each action, and the associated Program goal(s).

Major Upgrades		
Activity (completion date)	**Reason/Driver**	**Associated SC Program Goal(s)**
200w DSN High Efficiency (HEF) uplink (2007)	Robustness, Availability	Mission Assurance Program Management
Ka-band on DSN 34-m Beam Waveguide (BWG) (2008)	Support Mars Reconnaissance Orbiter (MRO), Kepler, and other missions	Mission Commitment Mission Assurance
SN Ka-band enhancements (2010)	Support Advanced Land Observing Satellite (ALOS) and International Space Station (ISS)	Mission Commitment
Scheduling Tool [Service Scheduling Subsystem (SSS)] for SN and NEN (2010)	Efficiency, Automation	Program Management Mission Assurance
Internet Protocol on all networks (2014)	Support Constellation Program	Mission Commitment
Earth-based system upgrades on DSN and NEN (2014)	Support Constellation Program	Mission Commitment

Table 6-2: SC Program Major Upgrades

6.3 Development Efforts

Development Efforts are large-scale undertakings resulting in new systems, resources, or equipment that expand or change capability. All developments implement elements of the SCaN architecture consistent with the NASA AMPM (and correspondingly the SCMM).

Table 6-3 lists the Development Efforts being planned and considered by NASA, along with the reason or driver behind each action, and the associated Program goal(s). Development activities listed in Table 6-3 are organized according to the elements in the SCaN architecture. There are no planned NISN Development Efforts because NISN consists primarily of leased commercial resources. Development of new fiber networks is conducted by the resource owner, and is not directly funded by NASA.

Sections 6.3.1 through 6.3.4 further describe the SC Program Development Efforts individually.

Development Efforts			
SCaN Arch. Element	**Activity (completion date)**	**Reason/Driver**	**Associated SC Program Goal(s)**
Earth-based Antenna Element	Ground stations for Solar Dynamics Observatory (SDO) and LRO (2007)*	Support lunar exploration and heliophysics endeavors	SC Planning Mission Assurance Mission Commitment
	Launch Head to support Constellation launch and ascent (2011)*	Support Constellation Program communication requirements	SC Planning Mission Commitment
	Earth-based network to support robotic Constellation lunar exploration (2012)*	Support Lunar Precursor and Robotics Program and Constellation Program communication requirements	Mission Commitment
	Earth-based network to support human Constellation lunar exploration (2018)	Support Constellation Program communication requirements	Mission Commitment
	Replace current DSN antennas ■ Retire 70-m antennas and replace with arrays of smaller diameter antennas (2015) ■ Retire or replace 34-m BWG antennas (2020)	End of life for large antenna systems; Support Mars exploration, outer planetary science missions	SC Planning Program Management Mission Commitment Mission Assurance
	Second Generation NEN (2016)	Aging systems and transition to Ka-band	Mission Assurance Mission Commitment
Earth-based Relay Satellite Element	SN Replenishment ■ TDRSS K (2011)* ■ TDRSS L (2012)* ■ TDRSS M, N (2015-2016)	Must meet mission commitments and maintain capacity	Mission Safety Mission Assurance Mission Commitment SC Planning
	Replace SN ground station system (2013)	Aging systems and need for standardization	Mission Assurance SC Planning
Lunar Relay Satellite Element	Lunar relay (co-payloads) to support exploration missions (TBD)	Support exploration communication requirements	SC Planning Mission Commitment
	Dedicated lunar relay to support human missions (2018)	Support Constellation Program communication requirements	Mission Commitment
Mars Relay Satellite Element	Mars standardized relay co-payload to support robotic missions (2016)	Support Constellation Program communication requirements	Mission Commitment

Table 6-3: SC Program Development Efforts

*Addressed in the FY 2008 President's budget request.

6.3.1 Earth-based Antenna Development

The SCaN architecture recognizes the need for an Earth-based antenna network. Individual development efforts for that network are addressed as follows:

6.3.1.1 Ground stations for SDO and LRO: The requirements for several upcoming science and lunar exploration missions call for new resources to support communications needs. In response to these needs, NASA is developing three 18-meter Ka-band antennas at the SN's White Sands Complex (WSC) as part of the NEN. Two of these antennas will support the upcoming Solar Dynamics Observatory (SDO) mission in geosynchronous orbit. The third antenna will support the LRO mission. Co-location of these 18-meter Ka-band terminals at WSC takes advantage of existing SN ground infrastructure, personnel, and wideband communications. These new Ka-band antenna systems at WSC will provide capabilities consistent with the SCaN architecture and will also be well positioned for future integrated SC operations.

6.3.1.2 Launch Head to support Constellation launch and ascent: NASA's upcoming Constellation spacecraft [Crew Exploration Vehicle (CEV) and Crew Launch Vehicle (CLV)] will entail communication requirements that differ from those of the Shuttle. Current launch head communications capabilities at the Merritt Island Launch Annex (MILA) and Ponce DeLeon (PDL) wing site provide the Space Shuttle with launch and early orbit communications and telemetry services. The Shuttle is slated for retirement in 2010; the Launch Head will be required to support command and telemetry during launch and early orbit for the upcoming CEV/CLV. NASA originally designed and implemented MILA/PDL in the 1960s/1970s to support the Apollo program, and has not upgraded the facilities and systems to take advantage of current state-of-the-art ground station equipment. Consequently, MILA/PDL operations are very labor-intensive and do not have the capability to support CEV/CLV communications requirements. The SC Program is presently conducting a number of trade studies to determine the implementation approach to meet the command and telemetry requirements for the launch and early orbit phase of the CEV/CLV. The Launch Head replacement will have an Operational Readiness Review (ORR) certifying facility readiness to support CEV/CLV orbital flight tests in late FY2012.

6.3.1.3 Earth-based network to support robotic Constellation lunar exploration: The SC Program will need to fulfill the Constellation Program's communication requirements throughout the program's life cycle. NASA will develop the ground based systems enabling communications for these missions incrementally, driven by mission needs. Initial Constellation lunar exploration will involve robotic missions. NASA will develop an Earth-based network of ground stations to support communications with these missions. Network locations outside of the United States may be selected so that infrastructure costs may be shared with international or commercial partners or other networks. In addition, the incremental, mission-driven growth of the network will allow for consideration of antenna arraying at a node to provide higher data rate communication with missions to Lagrange Points L1 and L2.

6.3.1.4 Earth-based network to support human Constellation lunar exploration: Subsequent to its initial robotic lunar exploration, the Constellation Program will conduct human exploration missions to the Moon. NASA will develop an Earth-based network of ground systems capable of supporting communications with these human lunar missions. Like the ground stations supporting robotic exploration of the Moon, these ground systems will be developed incrementally, based upon mission needs. The requirements for the Earth-based network providing communications support to human missions will differ from those of the network used to support lunar robotic missions. Additional antennas may be required at terrestrial sites to accommodate the increased load human missions will create and to provide the improved reliability needed to support human exploration.

6.3.1.5 Replace current DSN antennas: To meet mission requirements, NASA must provide communications support to the existing deep space mission set and ensure resources are in place to support future missions. The DSN's current 70-meter antennas cannot meet the requirements of these missions. The 70-meter antennas are functioning far beyond their designed lifetimes, and demand an increasing amount of maintenance time and resources to keep them operational to communicate and track the spacecraft flying today. Additionally, many of NASA's future missions will use Ka-band, a higher communication frequency, which allows more data to be captured from deep space missions—in essence providing a higher return on investment. The DSN's 70-meter antennas are not capable of providing the required performance at the Ka-band frequencies. Presently, the SC Program is conducting studies and analyses to examine replacement of the 40+ year old 70-meter diameter antennas at Goldstone, California; Madrid, Spain; and Canberra, Australia.

These studies focus on determining what should replace the 70-meter network. The leading candidate involves synthesis of large apertures using arrays of smaller diameter antennas that are sized for optimum performance and cost. Although the future architecture concept is to utilize arrayed antennas at X-band for uplink commanding of spacecraft, use of an array for uplink is a new technology. To mitigate uplink array technology risk, the plan is to utilize existing or new individual 34-meter antennas for uplink instead. The DSN currently arrays its 34-meter and 70-meter antennas as part of its standard support to flight missions. Arraying of smaller antennas has been performed by the radio astronomy community for over 50 years, and involves extremely low technical risk. In addition, arrays of smaller antennas have the following advantages:

1. Reduced risk for missions: If a 70-meter antenna is taken out of service for maintenance or repair, the DSN loses a substantial fraction of its capability and there is nothing to replace it. If a single antenna in an array is taken out of service, the impact to missions is less.
2. More efficient, cost effective system: The appropriate amount of aperture required to track any given spacecraft can be applied, leaving the remaining array antennas available to track other spacecraft.
3. Increase in data capture from spacecraft: By arraying a larger quantity of antennas, data can be captured at higher data rates and/or at greater distances than current single antennas to support future mission requirements. This flexibility prevents the SC capacity from becoming a constraint on defining future missions.
4. More precise navigational data (to enable precise landings of spacecraft on Mars, for example).
5. Reduced operations and maintenance costs.

Perhaps most importantly, the array can grow on an "as needed" basis so that the cost of implementation will be phased depending on the requirements of the mission set.

The arrays of antennas form the basis for the eventual phased replacement of the aging DSN 70-meter and 34-meter BWG, and enable expansion for more data to be captured from deep space missions. Furthermore, the DSN arrays will also be able to provide backup space communication capability for the NEN, as NASA moves into the era of higher frequency Ka-band space communications.

6.3.1.6 Second Generation NEN: To ensure that the communications needs of future missions are met, the NEN must be populated with new systems that are capable of supporting Ka-band missions and that make use of contemporary technology. NEN resources, however, consist of both government and commercial assets. NASA may be required to commit to long-term commercial service contracts to ensure that industry is willing to assume the cost of development efforts for commercially owned NEN assets.

The present NEN architecture consists of a global network of 11-meter antennas in several mid- and high-latitude locations. Due to age, these assets have become fragile and employ outdated technology. The NEN is primarily geared to support of customers using the X-band and S-band frequencies, while NASA's future flight missions are trending towards use of Ka-band.

A new set of flight missions is emerging, located up to two million kilometers from Earth and requiring communications support at hundreds of megabits per second. The conceptual architectural elements to provide complete communications coverage of this region include single and arrayed antennas at several locations around the world. The communications needs of Exploration and Space Science missions at Lunar and Earth-Sun Lagrange points (L1/L2) are somewhat complementary and warrant consideration of continuing the mixed-use human and robotic communications services provided by the current SN and NEN.

Three 18-meter Ka-band antennas are currently being developed at the WSC to support LRO and SDO. At the conclusion of the SDO mission, this three-antenna cluster may become the first element of a future three-node network of mid-latitude stations, equally spaced in longitude, and providing continuous Lunar and L1/L2 communications coverage. This ground-based portion of NEN may be grown incrementally, driven by mission needs. Second generation NEN locations outside of the United States may be selected in a manner to share infrastructure costs with international or commercial partners or other networks.

The Second Generation NEN implementation philosophy will:

1. Use existing infrastructure where it is cost effective to meet 2008–2020 lunar initiatives;
2. Implement near-term building blocks to meet requirements with focus on reuse (e.g., initial antennas at White Sands to service the LRO and other missions);
3. Integrate commercial service providers to provide routine support;
4. Permit downstream infrastructure decisions to allow:
    a. Exploration requirements to stabilize within the NASA Community
    b. Requirements to stabilize with other critical government programs [e.g. Global Earth Observation System of Systems (GEOSS)]
    c. Potential national and international partnerships to evolve
5. Integrate proven components to provide low-cost/low-risk solutions;
6. Invest in optical communications and tracking technologies for the longer term (2018-2030 timeframe); and,
7. Provide seamless network element integration for each customer mission.

6.3.2 Earth-based Relay Satellite Development

The ScaN architecture recognizes the continuing need for an Earth-based Relay Satellite network or SN. SCaN development efforts for this architecture element are discussed below.

6.3.2.1 SN Replenishment (TDRSS K, L): Demand for SN communications services is predicted to remain steady due to upcoming NASA and non-NASA space flight missions. Concurrently, the existing fleet of TDRS is aging, and reliability analyses predict a shortage of flight assets to support the user community by 2011. As a result, NASA will proceed in FY 2007 with acquisition of at least two TDRS Replenishment spacecraft (TDRS-K and TDRS-L).

The procurement will include launch, on-orbit delivery, and acceptance of two spacecraft (TDRS-K to be launched in 2012, followed by launch of TDRS-L in 2013) and modification of ground system equipment at the WSC in White Sands, NM. Contract options could potentially lead to the construction of two additional TDRS spacecraft in the 2015-2017 timeframe. Performance specifications of the new TDRS will be compatible with TDRS H,I,J, and will include two Single Access antennas capable of S-, Ku-, and Ka-band services, as well as a Multiple Access phased array.

6.3.2.2 Replace SN ground station system: Some elements of the SN ground station system have been in place for over 20 years. In addition, the Second TDRS Ground Terminal (STGT) was added at WSC in 1994. The original White Sands Ground Terminal (WSGT) was upgraded in 1996, and equipment was relocated in 1998 from WSC to implement the Guam Remote Ground Terminal (GRGT). As a result, the SN ground system now encompasses multiple configurations in multiple locations, making it increasingly difficult to operate and maintain. The current ground system is becoming an operational risk, and is cumbersome to maintain due to unavailability of spares, interfaces and subsystems that are no longer supported by vendors, and other hardware/software issues.

The SN ground system replacement will eliminate outdated equipment and ensure standardized systems are in place at all ground system locations. Ground system equipment at every SN ground station will be capable of supporting any spacecraft in the TDRS fleet. In addition, the modernization plan calls for replacement of outdated software responsible for setting up equipment chains, real-time monitoring control, scheduling, etc. Replacement of the switching system and upgrade of the Data Interface System are also included in this effort. NASA will ensure that SN users are provided with reliable, uninterrupted communications services throughout the replacement by continuing to sustain and upgrade existing elements of the ground system during the effort.

6.3.3 Lunar Relay Satellite Development

The SCaN architecture identified lunar relay satellites as a critical element required to meet the long term Vision for Space Exploration. NASA plans to implement the following development efforts regarding this architecture element.

6.3.3.1 Lunar relay (co-payloads) to support exploration missions: NASA's plans for space exploration involve missions to the Moon that may require communications while those missions are out of the line-of-sight of present Earth-based SC resources. Given this requirement, the SC Program will develop lunar relay satellites consistent with the Agency's lunar architecture. It is anticipated that robotic missions subsequent to the LRO will require a lunar relay satellite if the focus of those missions is at the lunar south polar region, thus posing a line-of-sight issue. The lunar relay to support exploration missions may consist of one or more small, mission-specific satellites, or may be comprised of satellites that are launched as secondary payloads on the lunar exploration launch vehicles.

6.3.3.2 Dedicated lunar relay to support human missions: NASA will require communications capability to support human lunar missions by 2018. To ensure the communications coverage, reliability, and robustness required to support human missions, NASA plans to develop a dedicated satellite relay in the vicinity of the Moon. The SC Program will need to develop a very capable and flexible lunar relay system to meet the stringent requirements associated with lunar sortie and lunar outpost missions. The lunar relay will have to support lunar-orbiting elements (CEV), elements traveling to and from the lunar surface (Lunar Surface Access Module or LSAM), a human outpost (the landed LSAM initially, with a permanent outpost established later), mobile surface elements (astronaut rover), and Extra Vehicular Activities (EVAs). Each of the lunar elements will have significantly different data connectivity, availability, and data rate requirements that the relay will have to accommodate. The SC Program will conduct a series of communications and navigation studies in concert with the Constellation Program to determine the optimum approach to meeting NASA's human lunar communications requirements. A constellation of one or two satellites in an elliptical orbit is sufficient if coverage is limited to the lunar south pole region, whereas a constellation of up to six satellites may be required to support a "go anywhere" on the Moon capability.

6.3.4 **Mars Relay Satellite Development**

The SCaN architecture identified Mars relay satellites as a critical element required to meet the long term Vision for Space Exploration. The SC Program will develop the Mars relay satellites required to implement the Agency's Mars architecture. These satellites will be extensions of the space communications co-payloads currently implemented on all Mars orbiting science satellites. These satellites have been highly successful—97% of all the data from the Mars Exploration Rovers has been returned via the communications relay packages on Mars Odyssey and the Mars Global Surveyor. The use of such relay packages has enabled NASA to capture approximately five times more data than had the Rovers transmitted data directly to Earth. The Mars relays also have enabled a significant reduction in energy consumption, freeing up energy for other rover science activities.

The capabilities and capacity required to support human Mars missions (which will take place outside the time frame of this study) are roughly 100 times greater than data rates transmitted by Mars orbiters today. The SC Program will conduct a series of communications and navigation studies in concert with the Mars Exploration Program to determine the optimum approach to meeting NASA's communications requirements for human Mars exploration.

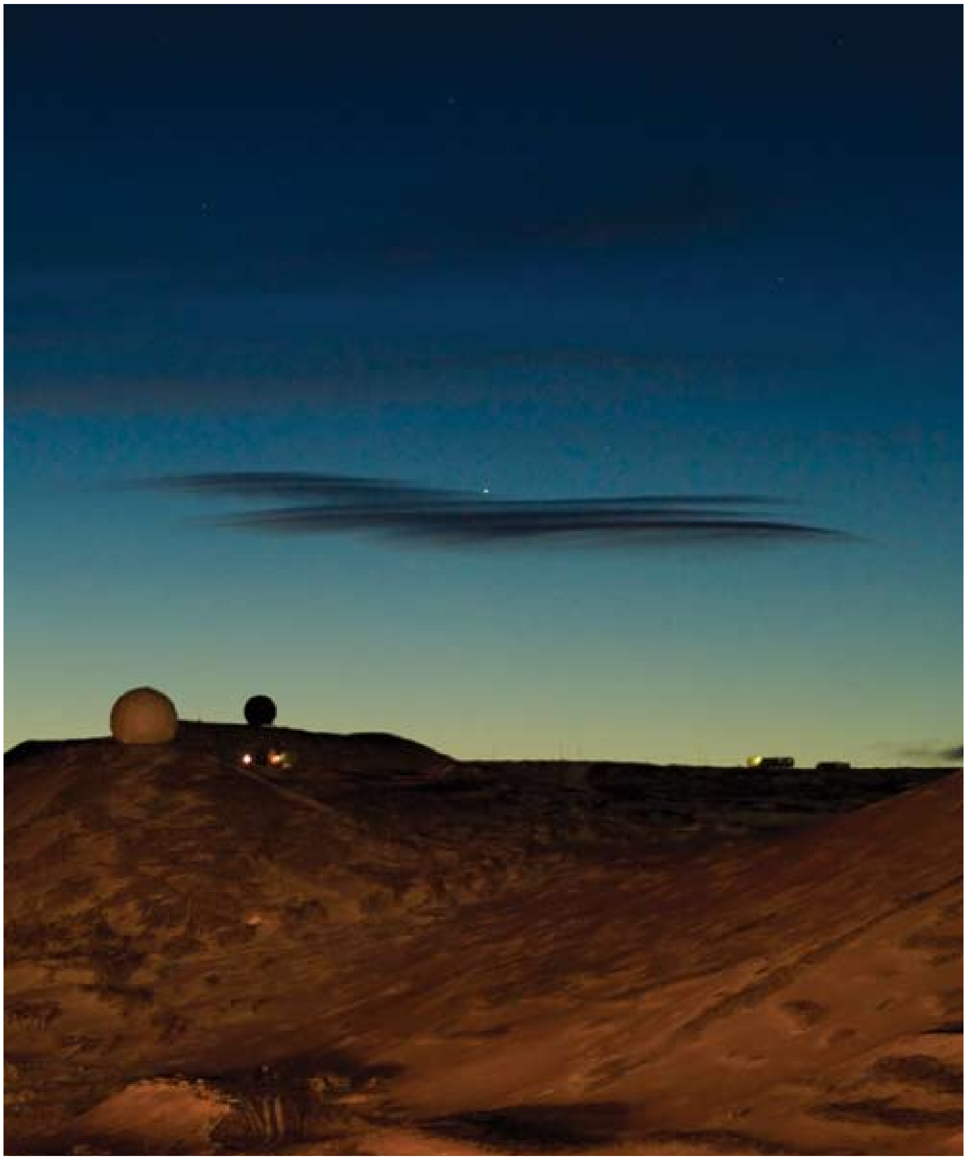
6.4 Technology Development

NASA's space communication technology development efforts in the past have supplied the fundamental technical capabilities that are now provided by our space communication networks. It is essential that this enabling process for long term evolution of our network capabilities continue. Current technology development efforts are focused in key areas for the future such as: deep space optical communication; software defined radios; new networking protocols; spectrum efficient modulation, coding, and data compression; command uplinking via small aperture arrayed antennas; relay satellite antenna arraying; advanced clocks; and demonstrations of potential capabilities of X-ray pulsar navigation techniques. Many of these areas are being pursued through joint funding efforts with other U.S. Government agencies that may also benefit from the SCaN technology work. Since technology development is the basis for continuing our ability to provide cutting edge space communication and navigation support to NASA's future missions, the SCaN management intends to invest approximately eight percent of the SC Program's future budget in this area.

[Schedule] 7

Artist's conception of the Ares I launch vehicle, topped by the Orion crew vehicle. The SC Program will supply these future systems with communications and navigation services. *Image credit: NASA/MSFC*

The SC Program determines its future activities based upon the needs of the missions contained in the SCMM, which is derived from the AMPM. As the AMPM and SCMM evolve, the SC Program will alter the schedule of its Development Efforts accordingly to ensure the needs of future space flight missions are fulfilled. Figure 7-1 shows the schedule of SC Program Development Efforts based upon the current AMPM and SCMM. Key flight missions that drive SC development efforts are depicted at the top of the figure.



NASA's Near Earth Network tracking station in McMurdo, Antarctica at mid-winter. *Image Credit: NSF*

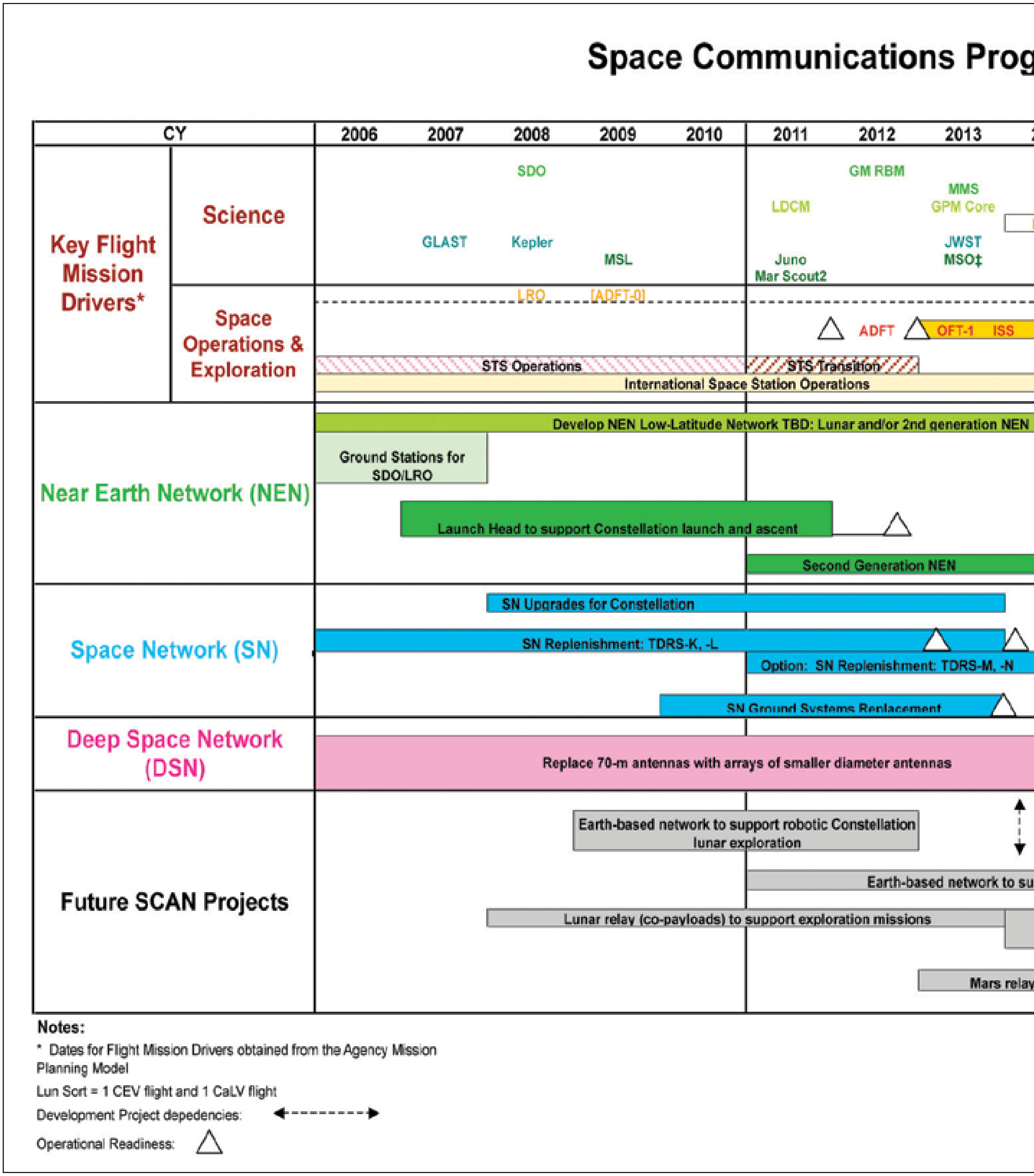
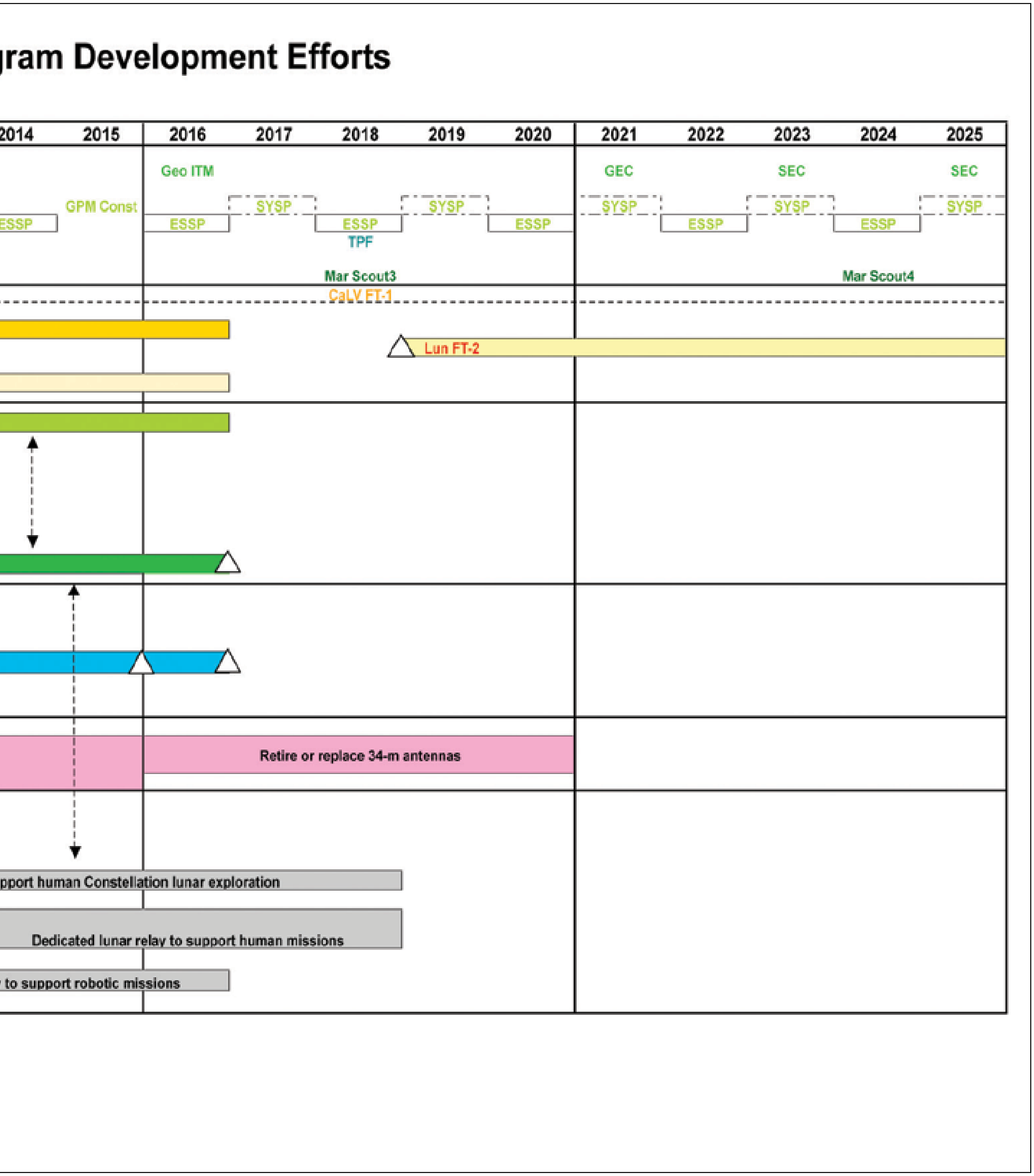


Figure 7-1: Schedule of Space Communication Program Development Efforts


gram Development Efforts
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
Geo ITM
GEC
SEC
SEC
GPM Const
ESSP
SYSP
TPF
Mar Scout3
Mar Scout4
CaLV FT-1
Lun FT-2
Retire or replace 34-m antennas
pport human Constellation lunar exploration
Dedicated lunar relay to support human missions
to support robotic missions

[Resources] 8

Artist's conception of the Space Shuttle and the International Space Station—two flight missions supported by the SC Program. The illustration also depicts the Moon and Mars, regions where other flight missions supported by the SC Program operate.

8.1 Budget and Life Cycle Costs

Table 8-1 contains a summary of the SC Program's five-year funding profile, which is derived from the President's FY 2008 budget request.

NASA Space Communications Budget ($ Millions)	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012
Deep Space Network	234	242	246	245	250
Near Earth Network	50	48	52	51	52
Space Network/Tracking & Data Relay Satellite	202	206	50	41	46
NASA Integrated Services	108	109	108	99	99
Exploration Communications and Navigation Systems	22	27	42	146	214
Space Communications Crosscutting Functions	61	58	57	66	65
Total NASA Space Communications Budget	**677**	**690**	**555**	**648**	**726**
Space Network (Estimated Reimbursable)	80	80	80	80	80
Grand Total Space Communications Budget	**757**	**770**	**635**	**728**	**806**

Table 8-1: SC Program Five-Year Funding Profile

Table 8-2 lists the total estimated Life Cycle Costs (LCC) for all of NASA's Space Communications. The LCC of a project or system can be defined as the total cost of ownership over the project or system's life cycle from formulation through implementation. It includes all design, development, deployment, operation and maintenance, and disposal costs. The SC LCC in Table 8-2 is followed by a breakdown of LCC for the DSN and SN respectively in Tables 8-3 and 8-4, per Congressional direction in the NASA Authorization Act of 2005. The LCC figures in Tables 8-2 and 8-4 include reimbursable funds received by the SC Program. It is important to note that these are estimates based on several assumptions. The actual costs could change significantly due to changes in NASA requirements as well as potentially due to advances in technology, use of commercial services, the extent of reimbursable demand from other agencies, international cooperative efforts, and other factors.

Estimated 20-year costs for Space Communications ($ Millions)	FY 2006–FY 2026
Operations and Maintenance:	
Deep Space Network	6,000
Near Earth Network	1,300
Space Network/Tracking and Data Relay Satellite System (TDRSS)	2,000*
NASA Integrated Service Network	2,500
Space Communications Crosscutting Functions	1,500
	13,300
Potential Major Upgrades	**300**
Potential Development Efforts:	
Earth-based Antenna Element (NEN and DSN)	2,300
Earth-based Relay Satellite Element (Satellite and Ground Segments)	2,400**
Lunar Relay Satellite Element	2,300
Mars Relay Satellite Element	1,000
	8,000

* Includes estimated reimbursable of $400 M
** Includes $1,200 M from non-NASA sources; excludes TDRS M&N options of $1,600 M ($500 M NASA and $1,100 M non-NASA)

Table 8-2: Estimated LCC for NASA Space Communications (2006–2026)

NASA Deep Space Network 20-Year Cost estimate ($ Millions)	FY 2006–FY 2026
Operations and Maintenance	6,000
Development	2,800*
	8,800

* Includes Mars Relay Satellite Element of $1,000 M

Table 8-3: Estimated LCC for NASA Deep Space Network (2006–2026)

NASA Space Network 20-Year Cost estimate ($ Millions)	FY 2006–FY 2026
Operations and Maintenance	2,000*
Ground Station Development	600
TDRS Development	1,800**
	4,400

* Includes estimated reimbursable of $400 M
** Includes $1,200 M from non-NASA sources; excludes TDRS M&N options of $1,600 M ($500 M NASA and $1,100 M non-NASA)

Table 8-4: Estimated LCC for NASA Space Network (2006–2026)

8.2 Reimbursable Services

The SC Program provides services to non-NASA customers as well as NASA missions. Services may be provided to other U.S. Government agencies [Department of Defense (DoD), National Oceanic and Atmospheric Administration (NOAA)], commercial enterprises (launch vehicles), and other space agencies [Japan Aerospace Exploration Agency (JAXA)]. Services range from flight vehicle communications for command and telemetry, to data transport via ground communications networks. Provision of services is arranged through a Memorandum of Agreement (MOA) between NASA and the customer, which sets forth the service requirements and the respective responsibilities of the parties.

Generally, services are provided to non-NASA customers on a "best efforts," non-interference basis (i.e., the SC Program's primary mission of providing for NASA flight mission and terrestrial communications requirements is not disrupted). Costs to the service recipient reflect the full cost of providing the service.

In some cases, however, service provision commitments are made to non-NASA customers on an equal footing with service provision to NASA customers, creating partnerships with customer entities. In these instances, the revenue generated by non-NASA use is used to offset (discount to the NASA SC Program appropriated budget) the cost of service provision. This is the case with SN operations, maintenance, and systems engineering. Similarly, the acquisition, development, and deployment of TDRSS K,L is a partnered U.S. Government arrangement, including joint funding.

NASA continually assesses future reimbursable customer service consumption and the attendant reimbursable revenue. However, these revenue estimates can be affected by customer circumstances beyond the control of NASA management, and as such, insert an element of risk to these crucial flight mission services not normally encountered.

8.3 External Resources and Services

NASA uses the space communications resources of other agencies and organizations to both complement and supplement its own capabilities. The organizations employed by NASA include other U.S. Government agencies, international space agencies, commercial entities, and universities.

The means by which NASA obtains these services varies by mission, but in general three methods are used:

1. Collaborative, mission-specific venture with another agency, where there is mutual interest in the mission science [e.g., the Solar and Heliospheric Observatory mission (SOHO) with the European Space Agency (ESA)]
2. Barter arrangement with another agency, where there is no mutual science interest in the missions at hand; the agencies provide similar space communications services to each other's selected missions (e.g., NASA and NOAA provide mutual backup at ground stations in Alaska and Wallops Island, Virginia)
3. Reimbursement via a formal arrangement [e.g., Universal Space Network for the Geostationary Operational Environmental Satellite (GOES) Program]

Collaborative and barter arrangements are accomplished via formalized, agency-to-agency governing agreements.

[Appendices]

The Space Network supports the Terra spacecraft, whose Advanced Spaceborne Thermal Emission and Reflection Radiometer instrument acquired the data to produce this image of the Grand Canyon in Arizona. *Image credit: NASA/GSFC/MITI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team*

APPENDIX A: **Excerpt from the National Aeronautics and Space Administration Authorization Act of 2005**

SEC. 102 REPORTS

(c) SPACE COMMUNICATIONS PLAN—

(1) PLAN—The Administrator shall develop a plan, in consultation with relevant Federal agencies, for updating NASA's space communications architecture for both low-Earth orbital operations and deep space exploration so that it is capable of meeting NASA's needs over the next 20 years. The plan shall include life-cycle cost estimates, milestones, estimated performance capabilities, and 5-year funding profiles. The plan S. 1281—12 shall also include an estimate of the amounts of any reimbursements NASA is likely to receive from other Federal agencies during the expected life of the upgrades described in the plan. At a minimum, the plan shall include a description of the following:

(A) Projected Deep Space Network requirements for the next 20 years, including those in support of human space exploration missions.

(B) Upgrades needed to support Deep Space Network requirements.

(C) Cost estimates for the maintenance of existing Deep Space Network capabilities.

(D) Cost estimates and schedules for the upgrades described in subparagraph (B).

(E) Projected Tracking and Data Relay Satellite System requirements for the next 20 years, including those in support of other relevant Federal agencies.

(F) Cost and schedule estimates to maintain and upgrade the Tracking and Data Relay Satellite System to meet projected requirements.

(2) CONSULTATIONS—The Administrator shall consult with other relevant Federal agencies in developing the plan under this subsection.

(3) SCHEDULE—The Administrator shall transmit the plan under this subsection to the Committee on Science of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate not later than February 17, 2007.

APPENDIX B: **List of Acronyms**

2Gen DSN	Second Generation DSN
2Gen GN	Second Generation GN (NEN)
ADFT	Ascent Development Flight Test
ADPE	Automated Data Processing Equipment
AIM	Aeronomy of Ice in the Mesosphere (SMEX-9)
ALOS	Advanced Land Observing Satellite
AMPM	Agency Mission Planning Model
BWG	Beam Waveguide
CaLV FT-x	Cargo Launch Vehicle Flight Test (x- mission #)
CCSDS	Consultative Committee for Space Data Standards
CEV	Crew Exploration Vehicle
CEV ISS-x	Crew Exploration Vehicle to International Space Station (x- mission #)
Chndraayn1	Chandraayan instrument to be flown on Indian satellite
CINDI	Coupled Ion Neutral Dynamics Investigation
CLV	Crew Launch Vehicle
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Dawn	Mission to Vesta and Ceres asteroids
Disc-xx	Discovery Mission (xx- mission #)
DOD	Department of Defense
DPA	DSN Prototype Array
DSN	Deep Space Network
ECANS	Exploration, Communication, and Navigation Systems
ESA	European Space Agency
ESMD	Exploration Systems Mission Directorate

ESSP	Earth System Science Pathfinder
EVA	Extra Vehicular Activity
Gbps	gigabits per second
GEC	Global Electrodynamnic Constellation
GEO	Geosynchronous Earth orbit
GEOSS	Global Earth Observation System of Systems
GLAST	Gamma-ray Large Area Space Telescope
Glory	An advanced polarimeter mission to measure aerosols as causes of climate change
GM ITM	Geospace Ionosphere-Thermosphere Mapper
GM RBM	Geospace Radiation Belt Mapper
GN	Ground Network (NEN)
GN-INEN	Ground Network-Intermediate Near Earth Network
GOES	Geostationary Operational Environmental Satellite
GOES-x	Geostationary Operational Environmental Satellite (x- mission #)
GPM Const	Global Precipitation Monitor Constellation
GPM Core	Global Precipitation Mission Core
GPS	Global Positioning System
GRGT	Guam Remote Ground Terminal
GSSR	Goldstone Solar System Radar
HEF	High Efficiency
Herschel	Herschel Space Observatory (Far Infra-Red/submillimetric Space Telescope)
HST-D	Hubble Space Telescope Deorbit
HST-S	Hubble Space Telescope Servicing Mission
IBEX	Interstellar Boundary EXplorer (SMEX-10)

IMP	Interplanetary Monitoring Platform
IP	Internet Protocol
IPO	Integrated Program Office
IR	Infrared
ISS	International Space Station
ISS-x	Space Shuttle flight to the International Space Station (x- mission #)
ITU	International Telecommunications Union
JAXA	Japan Aerospace Exploration Agency
JUNO	JUpiter Near-polar Orbiter (New Frontiers #2)
JWST	James Webb Space Telescope
kbps	kilobits per second
Kepler	Kepler Observatory
kHz	kilohertz
L1	Lagrange Point 1
L2	Lagrange Point 2
Large UV/IR	Large UV/IR Optical Imager (concepts include SUVO and Stellar Imager)
LCC	Life Cycle Costs
LCROSS	Lunar CRater Observation and Sensing Satellite
LDCM	Landsat Data Continuity Mission
LEO	Low-Earth Orbit
LR	Lunar Relay
LRO	Lunar Reconnaissance Orbiter
LSAM	Lunar Surface Access Module
Lun Sort-x	Lunar Sortie mission (x- mission #)
Lunar FT-x	Lunar Flight Test (x- mission #)

MagCON	Magnetospheric Constellation
Mars Scout-x	Mars Scout flight (x- mission #)
Mars AFL	Mars Astrobiology Field Laboratory
Mbps	megabits per second
MEO	Medium Earth Orbit
MHz	megahertz
MIDEX-xx	Medium-class Explorer (xx- mission #)
MILA	Merritt Island Launch Annex
MMS	Magnetospheric MultiScale
MOA	Memorandum of Agreement
MOVE	Mission Operations Voice Enhancement
MR	Mars Relay
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
MSO	Mars Science Orbiter
MSR-x	Mars Sample Return (x- mission #)
NASA	National Aeronautics and Space Administration
NEN	Near Earth Network
NER-x	Near Earth Relay (x- mission #)
NewFront-x	New Frontiers flight (x- mission #)
NH/Pluto	New Horizons Pluto mission (New Frontiers #1)
NISN	NASA Integrated Services Network
NMP	New Millennium Program of Space Technology (ST) missions
NOAA	National Oceanic and Atmospheric Administration
NOAA-N’	National Oceanographic and Atmospheric Administration satellite

NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NSSO	National Security Space Office
O&M	Operations & Maintenance
OFT-x	Operational Flight Test (x- mission #)
OP-x	Outer Planets mission x
ORR	Operational Readiness Review
OSTM	Ocean Surface Topography Mission
PA&E	Program Analysis and Evaluation
PC-x	Pressurized Cargo mission to ISS (x- mission #)
PDL	Ponce DeLeon
Phoenix	Mars Scout #1
Planck	Planck Surveyor
POP	Program Operating Plan
QuikSCAT	Quick Scatterometer
RF	Radio Frequency
RLEP-x	Robotic Lunar Exploration Program (x- mission #)
SC	Space Communications
SCaN	Space Communications and Navigation
SCMM	Space Communications Mission Model
SDO	Solar Dynamics Observatory
SEC	Sun Earth Connection
Sentinels	Solar Sentinel missions
SIM	Space Interferometry Mission
SMD	Science Mission Directorate

SMEX-xx	SMall-class Explorer (xx- mission #)
SMTF	Software Maintenance and Training Facility
SN	Space Network
SOFIA	Stratospheric Observatory For Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
Solar-B	Second Solar physics mission
SOMD	Space Operations Mission Directorate
SSS	Service Scheduling Subsystem
STEREO	Solar-TErrestrial RElations Observatory
STGT	Second TDRS Ground Terminal
ST-x	Space Technology Mission #5 (x- mission #)
SUVO	Space Ultraviolet-Visible Observatory
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
THEMIS	Time History of Events and Macroscale Interactions during Substorms (MIDEX-5)
TT&C	Tracking, Telemetry, and Commanding
TWINS-A/B	Two Wide-angle Imaging Neutral-atom Spectrometers
UV	Ultraviolet
VLBI	Very Long Baseline Interferometry
WAN	Wide Area Network
WISE	Wide-field Infrared Spectroscopic Explorer (MIDEX-6)
WSC	White Sands Complex
WSGT	White Sands Ground Terminal

C

appendix c

APPENDIX C: **Compliance Checklist**

Section 102(c) of the National Aeronautics and Space Administration Authorization Act of 2005 is replicated below. Bold text in parentheses indicates the locations in this document where information requested in the Act is found.

SEC. 102 REPORTS

(c) SPACE COMMUNICATIONS PLAN—

(1) PLAN—The Administrator shall develop a plan, in consultation with relevant Federal agencies (**Section 4.0**), for updating NASA's space communications architecture for both low-Earth orbital operations and deep space exploration so that it is capable of meeting NASA's needs over the next 20 years (**Section 4.0**). The plan shall include life-cycle cost estimates (**Section 8.1, Tables 8-2, 8-3, 8-4**), milestones (**Section 7.0, Figure 7-1**), estimated performance capabilities (**Sections 5.0–5.3**), and 5-year funding profiles (**Section 8.1, Table 8-1**). The plan S. 1281—12 shall also include an estimate of the amounts of any reimbursements NASA is likely to receive from other Federal agencies during the expected life of the upgrades described in the plan. (**amount specified in Table 8-1, amount included in Table 8-2 and Table 8-4, and reimbursable services explained in Section 8.2**) At a minimum, the plan shall include a description of the following:

(A) Projected Deep Space Network requirements for the next 20 years, including those in support of human space exploration missions. (**mission needs discussed in Section 2.0**)

(B) Upgrades needed to support Deep Space Network requirements. (**DSN Upgrades listed in Table 6-2; DSN Development Effort listed Table 6-3, DSN Development effort explained in Section 6.3.1.5**)

(C) Cost estimates for the maintenance of existing Deep Space Network capabilities. (**DSN O&M costs included in Table 8-1; DSN O&M costs listed in Table 8-2 and Table 8-3**)

(D) Cost estimates and schedules for the upgrades described in subparagraph (B). (**included in Table 8-2, DSN Development cost listed in Table 8-3; schedule included in Figure 7-1**)

(E) Projected Tracking and Data Relay Satellite System requirements for the next 20 years, including those in support of other relevant Federal agencies. (**SN Upgrades listed in Table 6-2; SN Development Efforts listed in Table 6-3, SN Development efforts explained individually in Section 6.3.2.1 and Section 6.3.2.2**)

(F) Cost and schedule estimates to maintain and upgrade the Tracking and Data Relay Satellite System to meet projected requirements. (**SN O&M costs included in Table 8-1; SN O&M costs listed in Table 8-2 and Table 8-4; costs of SN Development efforts included in Table 8-2 and listed in Table 8-4; SN Development Efforts schedule included in Figure 7-1**)

(2) CONSULTATIONS—The Administrator shall consult with other relevant Federal agencies in developing the plan under this subsection. (**Section 4.0**)

(3) SCHEDULE—The Administrator shall transmit the plan under this subsection to the Committee on Science of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate not later than February 17, 2007.

National Aeronautics and Space Administration

NASA Headquarters
300 E Street SW
Washington, DC 20546

www.nasa.gov

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