Revolutionary Aerospace Systems Concepts - Planning for the Future of Technology Investments

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Aerospace Systems Concepts and Analysis Competency
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ABSTRACT

In January, 2000, the NASA Administrator gave the following directions to Langley: "We will create a new role for Langley as a leader for the assessment of revolutionary aerospace system concepts and architectures, and provide resources needed to assure technology breakthroughs will be there to support these advanced concepts. This is critical in determining how NASA can best invest its resources to enable future missions."

The key objective of the RASC team is to look beyond current research and technology (R&T) programs and missions and evolutionary technology development approaches with a "top-down" perspective to explore possible new mission capabilities. The accomplishment of this objective will allow NASA to provide the ability to go anywhere, anytime - safely, and affordably- to meet its strategic goals for exploration, science, and commercialization. The RASC Team will seek to maximize the cross-Enterprise benefits of these revolutionary capabilities as it defines the revolutionary enabling technology areas and performance levels needed. The product of the RASC Team studies will be revolutionary systems concepts along with enabling technologies and payoffs in new mission capabilities, which these concepts can provide. These results will be delivered to the NASA Enterprises and the NASA Chief Technologist for use in planning revolutionary future NASA R&T program investments.

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The key objective of the Revolutionary Aerospace Systems Concepts (RASC) project is to look beyond current research and technology programs as well as ignore traditional evolutionary technology development approaches and, with a "top-down" perspective, explore concepts and architectures that represent a new paradigm in conducting the Agency's mission. Accomplishing this objective will allow NASA to go anywhere, at anytime, safely, reliably, and affordably. The RASC team seeks to maximize the benefits of revolutionary capabilities that span across Enterprises as it defines the technology areas and performance metrics needed.

The products of the RASC studies will be identified revolutionary systems concepts along with enabling technologies, the projected payoffs in new mission capabilities and projected technology development opportunities. These results are delivered to the NASA Enterprises and the NASA Chief Technologist for use in planning future NASA R&T program investments.

The Langley Research Center (LaRC) was chartered by the NASA Administrator to be the lead NASA Center for evaluating revolutionary aerospace system concepts and architectures to identify new mission approaches, and associated technologies that enable these missions to be implemented.

A "top-down" approach is used to address the following areas:

- Identify with at least a 25-year vision, desired new capabilities derived from NASA Enterprise strategic objectives and priorities;
- Define integrated systems approaches (architectures) and their required functional capabilities or engineering challenges;
- Explore revolutionary systems concepts to provide these capabilities;
- Conduct systems trade studies to define the enabling technologies and levels of performance needed to meet the challenges; and
- Recommend the most promising revolutionary concepts with their integrated system payoffs and key enabling technologies.

As the RASC teams carried out their studies, they follow the guidelines below:

- Use an integrated view of future aerospace technologies in examining aerospace systems concepts;
- Establish study objectives/focus through close coordination with NASA Enterprises and Centers to ensure relevance to NASA's strategic planning;
- Develop an integrated view of the Enterprise-desired capabilities such that resulting revolutionary systems concepts and enabling technologies have the maximum cross-Enterprise benefit;
- Study plans, approaches, and results will be regularly coordinated with the NASA Enterprises, and as appropriate, with peer reviews to verify quality;
- Carefully examine all approaches and concepts for credibility, consistency, and feasibility (check the physics and use best available proven methods);

LaRC leads the RASC team and reports the team results to the Enterprises and the Chief Technologist with participation by team members.

The Enterprises serve on the RASC Advisory Team. This team advises on the assessment of study plans and results as well as recommends participants to serve on RASC analysis teams. This team approach provides RASC with a sound Agency perspective in planning as well as access to NASA expertise for conducting the studies. Contributors from industry and universities will be involved through various mechanisms (task contracts, grants, cooperative agreements, etc.) to solicit ideas and expertise.

Team Operations: Expected areas of expertise of team members from the various Centers is summarized below based on NASA Center roles:

Ames Research Center (ARC):
Astrobiology
Information Technology
Biotechnology
Airspace Improvement

Glenn Research Center (GRC):
Power
Propulsion
Communications

Goddard Space Flight Center (GSFC):
Earth Science and Space Science Instrumentation
unpiloted operations
Systems Engineering
Telescope Servicing Communications

Jet Propulsion Laboratory (JPL):
Planetary Missions
Interplanetary Trajectory Studies Operations
Technology Evaluations
Space Science
Surface Mobility
Sensors
Optics
Mission Planning
Mission Execution

Johnson Space Center (JSC):
Exploration Mission Architectures, Life Sciences
Crew Systems
ECLSS
Operations
Piloted systems
Life Support/EVA
Space Transportation
Robotic Systems, Sample Curation

Kennedy Space Center (KSC):
Launch Facilities and Operations
Ground Processing
Launch Processing

Marshall Space Flight Center (MSFC):
Space Transportation (In-space; Earth to Orbit)
Atmospheric Modeling

Langley Research Center (LaRC):
Airframe Systems and Aerospace Systems Concepts Analysis
Flight Simulations
Guidance Algorithms and Mission Design Systems Analysis
Aerospace vehicle systems Planetary Atmospheric Vehicle Flight
Structures & Materials
For the execution of specific studies, LaRC, participating NASA Centers and JPL will provide staff to address the expertise and subjects needed.

The LaRC RASC team will have responsibility for the definition and leadership of the studies as well as support through the ASCAC staff, study contracts and university grants as needed. Experience and insight of the Advisory Team will be used to guide the effort.

The typical study elements or tasks performed by the RASC team are described below. The principal purpose of this study approach is to maintain focus on supporting, “top-down” analysis of NASA’s goals and objectives. This approach will also focus on identifying new capabilities, new mission options, and identifying functional requirements for the missions. These requirements will establish the engineering challenges that must be met and the technologies that must be developed to enable the missions. The RASC studies will concentrate beyond existing research, technology and planning programs, as well as, near term missions. The scope and quantity of studies undertaken in a given time period will be consistent with Enterprise strategic plans and objectives and RASC team capabilities to complete the work on schedule.

The RASC teams examined Enterprise strategic goals and objectives and establish an understanding of the priorities and critical needs with each participating Enterprise. They establish an integrated set of desired capabilities that will provide the maximum cross-Enterprise benefits in reaching their respective goals. They develop candidate system architecture approaches to address these desired capabilities and review results with Enterprises to confirm relevance to needs.

Preferred system architectures and approaches will be selected based on discussions with the Enterprises and analysis and trade studies to determine the most effective, feasible approaches. The selected architectures will be further analyzed to identify the potential systems concepts needed to realize the desired capabilities. These concepts will be coordinated with the Advisory Team to identify the most promising concepts for further analysis and trades. In addition, such concepts will be coordinated with other key activities that are exploring revolutionary and advanced concepts, such as the NASA Institute for Advanced Concepts.

Candidate mission architectures and system concepts were modeled to allow systems analysis and trade studies to determine the effectiveness of the various system concepts in implementing the preferred system architectures and providing the desired functional capabilities. The key enabling technologies will be identified, as a product of the trade studies, including desired performance levels. Analyses conducted will address performance, cost, risk, and safety considerations.

The most promising system concepts and their enabling technology needs are documented and reviewed with the Enterprises. Included in the review is a comparison of enabling revolutionary technology needs to establish the nature of the technology gaps in the various discipline areas. Results of these analyses, Enterprise reviews, and Advisory Team coordination, will to be used to select the most promising revolutionary systems concepts and enabling technology needs. As appropriate, the RASC team sponsors peer reviews of each study to further refine the quality and value of the work. This information is provided to the NASA Enterprises and the technology portfolio managers for use in defining future NASA R&T needs. Key elements in the annual analysis cycle include: Theme determination, request for study topics, study formulation, review, downselect and Enterprise briefing, midterm reviews, final review and document results, and brief results to Enterprises.

The proposed annual budget for RASC is divided between LaRC and the Centers. The center budget allocations are based upon the studies selected and the anticipated participation by the appropriate NASA Centers and JPL. As the studies change and plans are adjusted, these allocations are revised.

The RASC resources are allocated through the Office of Advanced Technology (OAT). The resources are controlled through quarterly RASC team meetings and reviews for OAT, as required.

In FY 2001, there were 8 RASC studies. They were:

- Global/Orbital Transport
- Personal Aerospace Vehicle
- Rapid Package Delivery
- Quiet Green Transport
- Orbital Aggregation and Space Infrastructure Systems (OASIS)/ Hybrid Propellant Module
- Comet Asteroid Protection System (CAPS)
- Europa Search for Life
- Technology Decision Analysis Tools

In this paper only the last four bullets, those studies associated with space systems, are addressed.

The first study generated an architecture called the **Orbital Aggregation & Space Infrastructure Systems (OASIS)**. OASIS is a set of concepts that provide common infrastructure for enabling a large class of space missions. The concepts include communication, navigation and power systems, propellant modules, tank farms, habitats, and transfer systems using several propulsion technologies. OASIS features in-space aggregation of systems and resources in support of mission objectives.

The tasks associated with this study were:

- *Develop initial OASIS concepts in support of crewed Lunar, Mars & L_2 Design Reference Missions (DRMs) as well as commercialization scenarios*
- *Identify enabling technologies and/or requirements*
- *Perform a economic/benefit analysis*

Hybrid Propellant Module. The core component of OASIS is a reusable Hybrid Propellant Module (HPM) that combines both chemical and electrical propellant in conjunction with modular orbital transfer/engine stages. The HPM would provide chemical propellant for time critical transfers and utilize electrical propellant for pre-positioning or to return the HPM for reuse and refueling.

The study approach consisted of establishing a set of mission requirements and concept requirements that encompass the "sweet spot" for given set of exploration DRMs and future LEO commercialization scenarios. The concepts would feature a high level of reusability and are assumed to be supported by cheap launch of propellant and logistics payloads from the Earth.

The benefits of such an architecture features reduced future mission costs and increased mission robustness for future space exploration and commercialization initiatives by making cheap in-space transportation available in the form of modular transfer vehicles and propellant sources.

HPM History. The HPM was created as an answer to the need for a small, compact modular fuel depot capable of supporting a number of missions ranging from Low Earth Orbit to the planets. The initial HPM "Baseline" resulted from a focused L_2 mission concept analyses conducted in fall of 2000. The application of the HPM concept towards additional exploration missions (human Lunar/Mars) and future commercialization scenarios were the focus of the current activity. Issues identified by the Administrator will also be worked into the current efforts:

- *Determine configurations of HPM given various launch vehicle availabilities (other than Delta IV H, include STS).*
- *Review application of HPM to the HEO-based architectures.*
- *Take traffic model (2007-2015) of GEO and see how the HPM idea applies to commercial market.*

A logical path that evolves from where we are to a future infrastructure involving the HPM as well as economic and risk sensitivities is currently under identification.

A common HPM would facilitate the storage of LO_2, LH_2, and an electric propulsion propellant (at this point assumed to be Xenon – further study is needed to determine commercially compatible electric propulsion propellants.) HPM units could be aggregated together or positioned in various orbits to provide mission support.

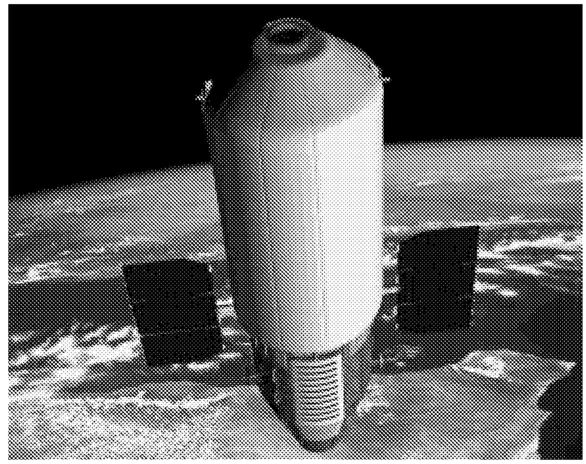

Figure 1. Hybrid Propellant Module

Multiple HPM/Depots would be used for missions to L_2, the Moon, Mars, asteroids, etc. as the basic propellant unit for the mission transfer vehicles. Such architecture would require smaller, modular vehicle concepts that would enable orbital positioning and transfer by both chemical and electric propulsion systems.

The HPM was designed to be completely self-sufficient utilizing zero boil-off (ZBO) cryogenic fluid management technology (CFM) with a common Fluid Transfer Interface (FTI). The HPM would be designed to be reusable many times - HPMs with spent H_2/O_2 would be ferried back to LEO via electric propulsion for refueling. HPM/Depot would be refilled via low cost launches and an Orbital Maneuvering and Transfer Vehicle. Both expendable vehicles and reusable vehicles can be accommodated.

Comet and Asteroid Protection System (CAPS)

There exists a significant hazard to life and property due to Earth impacting asteroids and comets. Earth approaching asteroids and comets are collectively termed NEOs (near-Earth objects). Current efforts, funded by NASA and other sources, have the goal of cataloging and characterizing the orbits of 90% of all near-Earth asteroids with diameters larger than 1 km by 2008. Although the probability of an actual impact is extremely small (1 impact every 500,000+ years), objects of this size are generally considered the greatest risk since they are capable of disturbing the Earth's climate on a global scale. Smaller asteroids (less than 100 m) are estimated to be much more numerous and the probability of impact is much higher (1 impact every several hundred years). Although damage would be more localized, impact from a small NEO near an urban area or coastline could result in considerable loss of life, extensive damage, and economic disruption. The limiting size of NEO that would actually survive entry into the Earth's atmosphere and reach the ground is estimated to be approximately 50 m. Even objects of this size would release approximately 10 megatons of energy upon impact (approximately 800 Hiroshima-size bombs).

The primary task - Detection: The CAPS team examined the feasibility of system concepts that can expand the range (size and/or distance from Earth) of detectable NEOs, including long period comets (LPCs), smaller near-Earth asteroids, and short period comets, and provide a permanent warning system with continuous NEO monitoring. LPCs do not regularly enter near-Earth space (200-14 million year periods) and represent a potential threat with potentially little or no warning time using conventional ground-based telescopes. The detectable size of an object on a perceived collision course should be such that warning time provided is proportional to the destructive energy of the impact. Detection of LPCs would permit at least a reasonable mitigation effort to be organized against a confirmed threat. Detection of smaller NEOs may not provide enough warning time to deflect the confirmed impactor, but would allow some level of action against the threat (international notification, evacuation, etc.). The fundamental difference between the current detection strategies and the RASC goal is to develop a concept that maximizes the range of detectable objects, and provides a high probability that the objects will be detected with significant warning time, *even upon the first observed near-Earth approach.*

The secondary task - Mitigation: The CAPS team assessed innovative chemical/electric propulsive mitigation concepts that would have the capability to successfully alter the orbit of a confirmed Earth impacting NEO.

The study groundrules and requirements

Discover, catalog, and characterize the orbits of:

- LPCs larger than 1 km at a distance of 5 AU. This would provide at least 1 *year* of warning time.
- NEOs larger than 50 meters at a distance of 0.2 AU, providing approximately 30 *days* of warning time.
- Be able to scan the entire sky within 30 days. Search patterns would potentially be optimized to concentrate near the ecliptic, but LPCs can approach from any inclination relative to the ecliptic.

- Quantitatively characterize the ability of innovative chemical/electric propulsive concepts to rendezvous with and deflect potential impactors, and estimate the bounds on NEO size and time required for mitigation. Provide initial assessment of the feasibility of pre-positioning assets to provide maximum mitigation capability.
- Identify enabling technologies and/or requirements for detection and mitigation concepts studied.

Besides the benefits of the primary mission, the detection and mitigation concepts studied under RASC could provide extensive secondary benefits to NASA Enterprises and the scientific community. Having a set of space-based telescopes constantly scanning the celestial sky is of immense value on the astronomical community. Mitigation concepts could have in-space transportation applications for both crewed and robotic missions.

The team approached the study by establishing a set of detection concept requirements that provide a "revolutionary" advancement in the detection of NEOs. Several potential concept options will be studied to varying levels of definition. For the detection system concept, various options may be combined to create a hybrid system solution. The concepts studied would be developed with an effort to minimize overall system costs, but only rough order cost estimates would be produced during this study phase. Finally, a preliminary assessment of chemical/electric propulsive mitigation of NEOs was performed.

Detection Concept

Functionality: The three major functions of the detection system are as follows (Note that these functions may be collocated or performed in a distributed manner):

- Discover that a NEO is present in the observed area of sky.
- The discovered NEO is then compared to a catalog of existing objects to determine if the NEO is a newly discovered object and if so, is added to the catalog.
- The orbital elements of the NEO are then calculated. If the object is a potential Earth crosser, the orbit is propagated forward in time to determine the probability of impact.

Candidate Options:

- Space based optical systems utilizing ultra-lightweight and/or low cost telescopes with sufficient sensitivity and resolution to meet detection requirements.
- Potential use of alternate wavelength systems to provide coarse resolution for the discovery of candidate objects.
- Active "illumination" search techniques (e.g., active laser system combined with lower resolution optical system).
- Investigate the potential benefits of using the Moon as a base for detection system (NASA Cross-Enterprise mission compatibility).

Optical Concepts. A space based optical/CCD (Charge-coupled device) system consisting of many optical telescopes or a smaller number of telescopes with sufficient field-of-view. These telescopes could be combined into a single semi-autonomous detection platform or form a distributed system.

Optical telescopes would have the resolution and sensitivity to discover, catalog, and characterize the required range of NEOs. The system configuration would provide appropriate sky revisit intervals and subsystem capabilities.

Lunar-based telescoped could also be employed to provide similar sky survey capabilities. Such telescopes, used in concert with each other could employ optical Interferometry techniques to obtain precision orbit determination when required. Increase the effective diameter of the telescope by using multiple telescopes (100+ meter baseline).

Active laser ranging is also employed to augment and/or enable precision orbit determination.

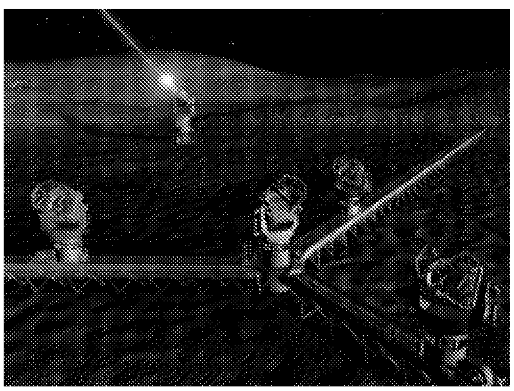

Figure 2. Comet Asteroid Protection System

Mitigation Concepts. Although one may argue that mitigation of the collision threat is the responsibility of other governmental entities, but the entire detection/mitigation systems must be studied in its entirety. To that end the CAPS team is investigating mitigation concepts. One concept is laser ablation. This technique employs a spacecraft-based laser that intercepts the body and "ablates" is surface in such a way that the body's inertia is altered thus its trajectory is altered.

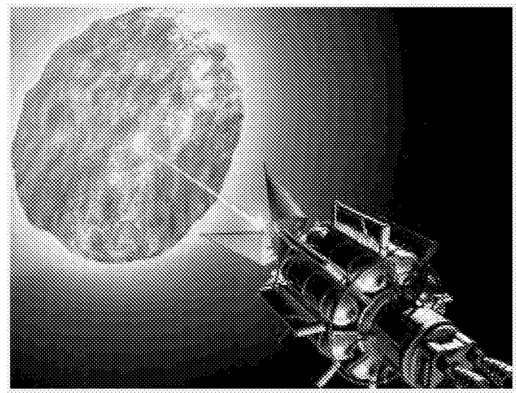

Figure 3. Mitigation of Collision Threat

Exo-Biological Exploration of Europa (E^3)

E^3's mission is to determine if Jupiter's Moon, Europa, contains the basic elements found in frozen surface or sub-surface samples that constitute the evidence of biological life outside of Earth. By sending a suite of instruments to analyze the frozen surface, sub-surface, and potential sub-surface liquids, the question of finding life outside Earth's boundaries can be further expanded to prove the existence of exobiological processes.

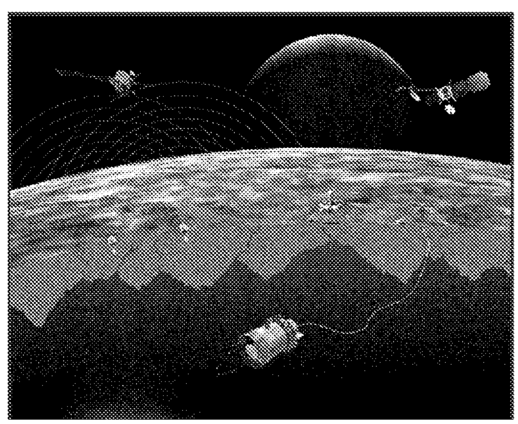

Figure 4. Exobiological Exploration of Europa

In performing such a mission a suite of vehicles and instruments are required. The team investigated concept(s) to launch a Spacecraft (Science Mapper & Relay & Lander) or series of spacecraft to deliver a Lander (Surface Science Facility) to penetrate the frozen surface and analyze the liquid flows for biological existence and /or processes.

E^3's goal was to indicate, incorporate, and evaluate both breakthrough and enabling technologies.

Key requirements for the study were:

- Locate a Mapper/ Lander at any longitude or latitude on the surface of Europa:
- The mapper/landing phase would be to conduct surface mapping and characterization for approximately 1-2 months, refine surface depth location targeting; and then descend to the surface for Lander operations
- Once landed, a robotic ice-boring instrument/vehicle would be deployed to penetrate through the frozen surface to explore the surface and liquid subsurface. The proposed lifetime; lifetime of ~2 years
- The proposed system should provide a surface/subsurface infrastructure & capability for science
- data and video communications back to Earth (DTE or Relay)

Figure 5. E3 Swimmer Concept

The Surface Relay Orbiter (SRO) survives for up to 2 years, its function being to Provide relay communications between the landed systems and the Earth.

In this study, a new decision analysis tool was created, utilized and validated. This tool aids the analyst and technology development managers in deciding which technologies are of higher priority for development with respect to the analyst/manager's strategic objectives. The tool indicates concept option paths; categorizes risks, mission success criteria and cumulative costs associated with various path options and concept options.

Two levels of technologies are identified: Breakthrough and enabling. Breakthrough technologies are technologies that changes the way one defines the status quo, have been known to be a problem, and have had continuous improvement efforts for years. Now, latest developments and activities have opened up possibilities to make these technologies accomplishable in the mission timeframe.

The breakthrough technologies are:

- Radiation Tolerant Electronics, Components, and Instruments
- In-situ (In Ice & Water) Sensing Components for Physical Science & Life Science Measurements
- In-situ(From Ice & Ocean) Resource Extraction, Sampling & Processing Hardware
- Reliable Components for Severe Environments. (Extremely cold and High Radiation)
- System-on-a-chip (e.g. inclusive of power management and distribution;

(>4Mrad))for Life Detection & Communications
- Miniaturized Communication components for data transfer through Ice, & , water
- Miniaturized, Integrated, and highly reliable Life Detection Instruments, System on a Chip.
- Deep Ice Penetration: Low-mass, Power-efficient, & Reliable Cryobot/Hydrobot/Tethered Submarine Assemblies
- Miniaturized, Integrated, and highly Reliable, & Autonomous Navigation Hardware for the Cryobot/Hydrobot & Tethered Submarine
- Smart and reconfigurable transponders

Enabling technologies are technologies in which areas of performance are necessary in the mission timeframe. Although technology acceptance and readiness levels may be low, funding and scheduling will provide these technologies for the mission.

- *Advanced Power:* Safe radioisotope power sources, high-specific energy batteries (e.g. Li polymer),
- *Advanced Propulsion* (Lightweight engine, thrusters, lightweight tanks, warm gas pressurization) for descent
- Real-time autonomous descent, guidance and precision safe landing.
- Planetary Protection & Contamination: Sterilization of terrestrial contaminants (cleaning and measuring microbes.
- *Thermal:* Emphasis is thermal control on the surface ice; keep electronics warm, but do not melt through ice; thermal heat sources must be cooled during cruise; waste heat utilization
- *Structures:* multi-functional structures; electronic cabling modules integrated with structure
- *Telecom:* Spacecraft transponding modem, as well as solid state power for Ka band

Summary

From each of these studies, lists of technologies and their associated performance targets are generated and supplied to the technology development managers for possible implementation into their technology programs.

In FY02, a change in the overall conduct of the program was realized in such a way as to integrate the study efforts into some uniform theme. Four themes were developed:

- Human/Robotic Space Exploration
- Humans to the Outer Planets
- Airspace Mobility
- Remote Sensing from Space

These studies are currently ongoing until the end of calendar year 2002.

Human/Robotic Space Exploration encompasses the studies associated in defining the degree in which humans and their robotic counterparts collaborate and cooperate with each other in the performance of tasks to gather scientific information. Identify revolutionary architectures, concepts, and key technology requirements for Human and Robotic systems which have the potential, when synergistically combined, to reduce the time, distance and safety barriers associated with scientific exploration beyond Low Earth Orbit (LEO).

The Humans to the Outer Planets Study, or HOPE- Human Outer Planet Exploration, is functioning to develop revolutionary aerospace systems concepts for human space exploration of the solar system beyond Mars orbit and to identify critical technology requirements for the realization of these systems concepts. The investigation encompasses the in-space transportation, in-space infrastructure, surface infrastructure, and all other aspects of a human reference mission, excluding concepts related directly to human/ robotic activities. This investigation also includes the identification of precursor science mission activities setting the stage for human exploration.

Remote Sensing form space encompasses the remote sensing of phenomena from space looking back at the Earth or looking outward to the stars.

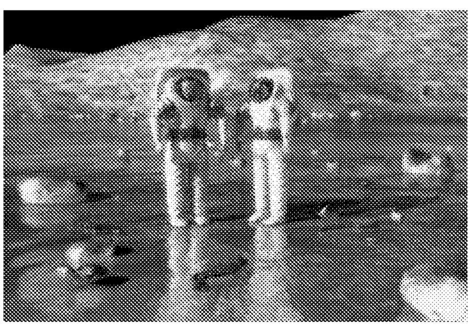

Figure 6. Human Outer Planet Exploration

The overarching mission is to use the revolutionary aerospace mission architectures and systems concepts as the foundation for identification of common technology and infrastructure requirements for in-space remote sensing.

• Common technology areas exist between the current set of mission studies. Key technology areas will be assessed through additional focused assessments (when resources are available):
– Formation flying
– Inter- vehicle communications
–Metrology
– Autonomous operations

Infrastructure requirements will be fed to the other RASC groups to provide input to their concept definitions as well as to leverage their analysis results.

Fiscal Year 2003 brings another round of studies designed to provide the technology development portfolio managers with the expected performance enhancements due to technologies infused into aerospace systems concepts. From these studies, we can now link the Agency's strategic goals to strategic measurements or scientific questions that lead to missions to answer such questions and also define the infrastructure and technologies necessary to leave Low Earth orbit.