NASA Space Operations Mission Directorate
Grand Challenges

A. Background

The next subsections provide a short set of background facts to frame the Grand Challenges. In the President's January 2004 "A Renewed Spirit Of Discovery", the Space Shuttle and International Space Station focus was as follows:

Space Shuttle

- *Return the Space Shuttle to flight as soon as practical, based on the recommendations of the Columbia Accident Investigation Board;*
- *Focus use of the Space Shuttle to complete assembly of the International Space Station; and*
- *Retire the Space Shuttle as soon as assembly of the International Space Station is completed, planned for the end of this decade;*

International Space Station

- *Complete assembly of the International Space Station, including the U.S. components that support U.S. space exploration goals and those provided by foreign partners, planned for the end of this decade;*
- *Focus U.S. research and use of the International Space Station on supporting space exploration goals, with emphasis on understanding how the space environment affects astronaut health and capabilities and developing countermeasures; and*
- *Conduct International Space Station activities in a manner consistent with U.S. obligations contained in the agreements between the United States and other partners in the International Space Station.*

Towards these directions, the overriding goals and objectives were stated as:

- *Implement a sustained and affordable human and robotic program to explore the solar system and beyond;*
- *Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;*
- *Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and*
- *Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.*

As of September 2004, NASA articulated an integrated set of 13 Strategic Roadmaps, two of which are the focus of the Space Operations Mission Directorate, namely roadmaps which:

(6) Complete the assembly of the International Space Station, and focus on its use on supporting space exploration goals
(7) Safely transition from the Space Shuttle to a new exploration-focused launch capability utilizing new or existing launch systems.

To accomplish the above, sixteen teams were formed, and 3 Capability Roadmap teams (which represent the SOMD capabilities) will focus on:

(A) High capacity telecommunications and information transfer,
(B) Launch vehicles, and
(C) Spaceports / launch ranges.

B. **Grand Challenges** Specifics:

The following subsections focus on the **operational aspects** of new technology for the Grand Challenge. The overall objective is to make possible *the safe, affordable, effective, and **operationally effective** human/robotic missions and systems for the exploration and development of our solar system – and eventually space beyond our solar system*. In order to achieve this Grand Challenge in the 2015 to 2045 time frame, we must:

1. Create **operational** concepts, technologies, and capabilities for space transportation and communications that enable affordable future infrastructures.

2. Develop innovative **operational** concepts for systems, infrastructures and missions to extend the duration and boundaries of human space flight.

3. Create novel aerospace **operational** concepts and technology to support future sustainable human and robotic exploration and development of space.

Achieving these "grand challenges" requires the development of revolutionary new **operational** concepts and technologies that satisfy the following strategic technical challenges.

B.1 Nearer-Term Challenges (<2010):

- B.1.a **Self-Sufficient Space Systems**. **Operation** of diverse future space systems with increasing levels of self-sufficiency, including increasing autonomy vis-à-vis ground-based command and control, increasing independence vis-à-vis subsystem integration, check-out and test, and diminishing reliance on logistics provided from the Earth.

- Advanced Platform Systems. Exceptionally reliable, flexible and affordable modular Platform Systems for application in a wide range of future systems and missions to enable ambitious human/robotic research, discovery, exploration, and **operations** in space.
- Intelligent Operations. Exceptionally high levels of on-board intelligence (hardware and software) that can reduce dramatically the costs of future mission **operations,** while improving effectiveness and reliability.
- In Situ Manufacturing. Affordable and flexible local manufacture of robust, high-value components, systems elements, and systems (e.g., structural elements, tankage, solar arrays, spare parts for systems, etc.) in lunar and planetary venues using 'imported' and local materials.
- Surface Construction. Affordable, flexible and **operationally efficient** construction of robust local structures (e.g., radiation shielding, habitats, transportation infrastructures, etc.) in lunar and planetary venues using local (or 'imported') materials.
- In Situ Resource Extraction and Processing. Affordable, reliable, **operationally efficient**, and effective local production, using local materials of key mission/systems resources (including life support system consumables, propellants, etc.).
- Consumable and Volatiles Distribution. Affordable, reliable, **operationally efficient,** and effective local management, handling, transport and storage of key consumables and volatiles.

- B.1.b **Space Utilities and Power**. Increasing dramatically the levels of affordable energy and/or power, **and operations** in space for a wide range of systems and mission applications and within diverse relevant environments—including power generation and transmission and energy storage.
  - Solar Power Generation. Highly-efficient, affordable generation of electrical power from sunlight, from very small arrays (watts) up to exceptionally high power levels (megawatts) for use in a wide range of **operatiions** in space, lunar and planetary environments.
  - Nuclear Power Generation. Safe, efficient, affordable, and **operationally efficient** generation of heat and/or electrical power from nuclear systems (radioisotopes and reactors), from very small arrays (watts) up to exceptionally high power levels (megawatts) for use in a wide range of in space, lunar and planetary environments.
  - Wireless Power Transmission. Safe, reliable and efficient wireless transport of substantial amounts of energy, as needed, for applications ranging from internal power (e.g., board level), to local

power (meters or less), to remote power (10s to 1000s of kilometers).

- Cryogenic Propellant Depots. Long-duration, low-loss transfer, management, **operations,** and storage of key cryogens, including hydrogen, for use in a wide variety of gravitational and other environments.
- Power Management and Distribution. Modular, intelligent, **operationally efficient** power management and distribution (PMAD) systems capable of local integration and reconfiguration that can autonomously synthesize power from multiple sources and distribute it with low losses to multiple 'users' as needed.
- Energy Storage. Long-duration/long-cycle life, **operationally efficient** Energy Storage for space applications ranging from exceptionally small systems (watts-electric or less, and watt-hours or less) up to very large systems (kilowatts or more, and kilowatt-hours or more).
- Structural Concepts and Materials. Robust, reliable, **operationally efficient**, and high strength-to-weight Structural Concepts and Materials for application within future systems—particularly involving high energy space systems—enabling ambitious future human/robotic systems and missions.

- B.1.c **Habitation, Bioastronautics, and EVA**. Safe, affordable and highly-effective humans-in-space systems, incorporating the concept of ambitious human/robotic team operations in a diverse range of appropriate environments, including low Earth orbit, the Earth's Neighborhood, and beyond.
  - Extravehicular Activity Systems. Safe, highly-effective and locally-maintainable Extravehicular Activity (EVA) systems for application in the context of capable human-robotic teams—in venues ranging from low Earth orbit to planetary surfaces.
  - Habitats, Habitability, and Human Factors. Safe, **operationally efficient,** and affordable provision of substantial habitable volume across a wide range of environments for human/robotic team operations in low Earth orbit, the Earth's Neighborhood and venues beyond (including the neighborhood and surface of Mars).
  - Life Support, Environmental Monitoring and Control. Low mass, highly efficient and reliable Life Support, Environmental Monitoring and Control technologies to enable safe and affordable human presence and activities in low Earth orbit, the Earth's Neighborhood (including the Moon) and venues beyond(including the neighborhood and surface of Mars).

- B.1.d **Space Assembly, Maintenance, Operations, and Servicing**. Enable the machine side of safe, affordable and effective human/robotic team **operations** in a diverse range of appropriate environments, including low Earth orbit, the Earth's Neighborhood, and beyond..
  - Robotic/Telerobotic Advanced Concepts. Timely identification, investigation and assessment of novel, high-value Robotic and Telerobotic Advanced Concepts of very high potential value to ambitious **operations** for future human/robotic research, discovery and exploration in space –including analytical and experimental validation.
  - In-Space Assembly and Construction. Affordable and **operationally** flexible In-Space Assembly and Construction of robust local structural systems (e.g., large arrays, observatories, habitats, transportation infrastructures, etc.) at various in-space venues using local (or 'imported') materials.
  - In-Space System Deployment. Fault-tolerant, reliable, **operationally efficient**, and affordable deployment of diverse future in-space systems, over a wide range of sizes and levels of complexity for future human/robotic missions and operations.
  - Self-Assembling Systems. Exceptionally flexible "systems of systems" capable of robust, reliable, affordable and largely autonomous Self- Assembly, Repair and Reconfiguration within increasingly-capable future systems and architectures for human and robotic research, exploration and discovery in space.
  - Inspection & Diagnostics. Safe, affordable, and informative Inspection and Diagnostics of the full suite of potential future systems (including instruments and observatories, platforms and habitats, transportation systems in supporting infrastructure, etc.) for a diverse suite of future human/robotic system and mission operations in venues ranging for low Earth orbit, throughout the Earth's Neighborhood (including the Moon) and to destinations beyond (including the neighborhood and surface of Mars).
  - Servicing, Maintenance & Repair. Reliable, affordable, timely and **operationally** **effective** Servicing, Maintenance & Repair of a broad range of future space systems, involving both human and robotic teams (in mixtures as appropriate to the challenge), and in venues including Earth orbit, the Earth Neighborhood (including the Moon), and beyond.

- “Design for SAMS” (Architectures, Standards and Infrastructures). Timely availability of novel design Architectures and Standards to enable the cost-effective development and validation of novel Infrastructures for Space Assembly, Maintenance and Servicing to support a range of ambitious future human/robotic system and mission **operations** in venues ranging for low Earth orbit, throughout the Earth’s Neighborhood (including the Moon) and to destinations beyond (including the neighborhood and surface of Mars).

- B.1.e **Surface Exploration and Expeditions**. Safe, affordable and effective research, discovery and exploration **operations** at a range of surface environments, including the Moon, Mars, and other relevant targets of interest (e.g., Near-Earth Objects).
  - Mobile Surface Systems. Highly robust, intelligent and long-range Mobile Systems to enable safe/reliable, affordable, **operationally sophisticated**, and effective human and robotic research, discovery and exploration in lunar, planetary and other venues.
  - Surface Laboratory Systems. Safe, affordable, **operationally sophisticated,** and effective Surface Laboratory Systems to enable increasingly valuable in situ research and discovery to be achieved by future human/robotic missions in lunar, planetary and other venues.
  - Flying and Swimming Systems. Highly effective and affordable Flying and Swimming systems to enable ambitious scientific (e.g., remotely operated sub-surface ‘swimmers’) and **operations** (e.g., regional over-flight) goals to be realized by future human/robotic missions in lunar, planetary and other venues.
  - Virtual Exploration. Acquisition (and ‘fusion’) of exceptionally large, multi-sensor data sets from localities—such as the Moon, Mars, or other destinations—and the creation of high fidelity “immersive” virtual reality to enable diverse **operationally effective**, scientific and outreach goals to be accomplished affordably and effectively.
  - Surface Environmental Effects. Understand the environmental effects to be experienced by humans and systems during future lunar, planetary or other target missions—and pursue mitigation of those effects to allow safe, affordable and effective research, discovery and exploration.
  - Sustained Surface Exploration & Expeditions Campaign Architectures. Novel and robust architectures that best enable Sustained Surface Expeditions and Exploration Campaigns to be undertaken to enable ambitious goals and **operationally effective** missions for future human/robotic research, discovery and exploration.

- B.1.f **Space Transportation**. Safe/reliable, affordable, **operationally effective** and effective transportation of equipment, logistics and crews for future missions in pursuit of high value future human/robotic research, discovery and exploration.
  - ETO Propulsion (On-Board). Safe/reliable, affordable and effective primary Earth-to-Orbit (ETO) Propulsion systems to enable low-cost, **operationally effective** highly reliable transport of systems, logistics and crews to low Earth orbit for future human/robotic space research, discovery and exploration.
  - Vehicle Airframe and Structures. Robust, reliable and high strength-to-weight Vehicle Airframe and Structures concepts and materials for application in diverse future vehicles supporting future human/robotic systems and missions.
  - Atmospheric Maneuver & Precision Landing. Global, highly reliable, exceptionally safe (where humans are involved) **operationally effective** and increasingly affordable Atmospheric Maneuver & Precision Landing for future human/robotic vehicles and missions—including robots, cargoes and crews—for missions in the Earth's Neighborhood and throughout the inner Solar System.
  - Vehicle Subsystems. Exceptionally reliable, flexible, **operationally effective,** and affordable modular Vehicle Subsystems Systems for application in a wide range of future vehicles and missions to enable ambitious human/robotic research, discovery and exploration in space.
  - In-Space Propulsion (Chemical/Thermal). Highly reliable, safe (where humans are involved), **operationally effective,** and affordable Chemical/Thermal propulsion systems for future human/robotic vehicles and missions—including both primary and secondary (e.g., maneuvering) propulsion needs—for missions in Earth orbit, the Earth's Neighborhood, and throughout the inner Solar System.
  - In-Space Propulsion (Electric/Electromagnetic). Highly reliable, safe (where humans are involved) **operationally effective,** and affordable Electric and Electromagnetic propulsion systems for future human/robotic vehicles and missions—including both primary and secondary (e.g., station-keeping) propulsion needs—for missions in Earth orbit, the Earth's Neighborhood, and throughout the inner Solar System.

- In-Space Propulsion (Nuclear). Exceptionally safe, reliable, **operationally effective,** and affordable Nuclear Propulsion Systems for future human/robotic vehicles and missions—for primary propulsion needs—for missions beyond the Earth's Neighborhood.

- In-Space "Propellantless" Transfer Systems. Highly reliable, safe (where humans are involved), **operationally effective,** and affordable "Propellantless" propulsion systems for future human/robotic vehicles and missions—including both primary and secondary (e.g., station-keeping) propulsion needs—for missions in Earth orbit, the Earth's Neighborhood, and throughout the inner Solar System.

- Launch Assist/Direct Launch Systems. Highly- efficient, **operationally effective,** and reliable ground-based Launch Assist and Direct Launch Systems capable of enabling exceptionally low cost access to space for a wide variety of vehicle and payload types.

- Launch Infrastructure and Operations. Affordable, safe, **operationally effective,** efficient and reliable Launch Infrastructure and Operations capable of supporting the full range of launch vehicles and payload processing in support of ambitious future human/robotic missions.

- Test Requirements and Instrumentation. Establish robust, high-confidence Test Requirements and Instrumentation for the validation of advanced space transportation technologies in order to assure readiness to begin systems developments; and for novel space transportation systems to assure readiness for deployment and operations..

- B.1.g **Information and Communications**. Affordable, exceptionally reliable, **operationally effective,** and highly capable Information and Communications systems to establish "terrestrial field laboratory" class (or better) computing and to deliver consistent high-bandwidth local, regional and remote communications services—in support of ambitious future human/robotic space systems and missions.

  - Radio Frequency Telecommunications Systems. Very high-data rate Radio Frequency Telecommunications Systems to enable transmission of operational, scientific and outreach data to-and-from, and among future human/robotic mission systems and crews.

  - Laser Telecommunications Systems. Exceptionally high-data rate Laser Frequency Telecommunications Systems to enable transmission of operational, scientific and outreach data to-and-from, and among future human/robotic mission systems and crews.

- Data Acquisition and End-to-End Management. Architectures, standards, devices and software to enable timely and cost-effective Data Acquisition and End-to-End Data Management for a diverse suite of future human/robotic system and mission operations in venues ranging for low Earth orbit, throughout the Earth's Neighborhood (including the Moon) and to destinations beyond (including the neighborhood and surface of Mars).
- Deep Space Navigation. Highly accurate navigation in deep space, including on-board techniques, integrated with Earth-to-space and space-to-space techniques for Deep Space Navigation technology.
- Command and Control Systems. Architectures, standards, systems and software to enable robust, timely, cost-effective and exceptionally high reliability Command and Control for a future human/robotic system and mission operations in venues ranging for low Earth orbit, throughout the Earth's Neighborhood (including the Moon) and to destinations beyond (including the neighborhood and surface of Mars).
- Mission Control Center Intelligence. Highly "intelligent" computing and software systems, including human-machine interfaces and displays to enable increasingly safe, affordable and effective Mission Control Center operations in support of future human/robotic systems and missions.
- Interplanetary and Planetary Networks. Architectures, standards, devices and software to enable cost-effective deployment and operation of robust, reconfigurable and largely self-reliant Interplanetary and Planetary Networks for a diverse suite of future human/robotic system and mission operations in venues ranging for low Earth orbit, throughout the Earth's Neighborhood (including the Moon) and to destinations beyond (including the neighborhood and surface of Mars).

B.2 Farther-Term Challenges (>2020):

- B.2.a **Earth-to-Orbit Transportation.** The challenge is to achieve Routine, reliable and increasingly low cost **operationally efficient** transportation of people, systems and consumables from Earth to orbit (and back). Meeting this challenge entails achieving the following objectives:

  - Continuing reductions in cost
    - Initially, less than $2000 per kilogram average recurring cost for transportation to low Earth orbit (LEO)
    - Later, less than $200 per kilogram average recurring cost for transportation to LEO

- Increasing reliability in transport of people and major systems
  - Initially, > 0.999 probability of nominal launch
  - Later, > 0.99999 probability of nominal launch
- The capacity to launch more than 1000t per year, average
- ETO transport of payloads of at least
  - Initially, > 40t per launch
  - Later, > 40-80t per launch

- B.2.b **In-Space Transportation.** The challenge is to achieve affordable, reliable, **operationally efficient,** and timely transport of people, machines and consumables across near-Earth and interplanetary space. Meeting this challenge depends upon achieving the following objectives:

  - Lower costs
    - Less than $500 per kilogram recurring cost from LEO to geostationary Earth orbit (GEO)
    - Less than $1000 per kilogram recurring cost from LEO to in-space destinations throughout the inner solar system
  - Increasing reliability in transport of people and major systems
    - Initially, > 0.995 probability of nominal transfer
    - Later, > 0.99995 probability of nominal transfer
  - With the capability of “fast” transits where needed (e.g., less than 4-6 months for transfer between the near-Earth space and near-Mars space)
  - Including the capacity to transport system “payloads” of at least 40-80t per “launch”
  - Including the capacity to transport more than 1000t per year, average

- B.2.c **Excursion Transportation.** The challenge is to achieve *Routine, flexible, **operationally efficient**, and affordable "excursions" of machines and people – locally in space and to planetary surfaces (and back to space).* Meeting this challenge involves achieving the following objectives:

  - Lower costs
    - Less than $200 per kilogram recurring cost to local in space "targets"
    - Less than $2000 per kilogram recurring cost to destinations on Mars, the Moon or small body surfaces
  - Increasing reliability in transport of people and major systems
    - Initially, > 0.995 probability of nominal excursion
    - Later, > 0.99995 probability of nominal excursion
  - Including systems of at least 10-20t per "excursion"
  - Including the capacity to transport more than 100t per year, average

- B.2.d **Human Habitats.** The challenge is to achieve Increasingly self-contained and **operationally efficient** human habitats (e.g., "miniature biospheres") at various scales (and over increasing time frames) in space and on planetary surfaces. Meeting this challenge depends upon achieving the following objectives:

  - Lower costs per cubic meter of habitable volume beyond low Earth orbit
    - Initially, less than $200,000 per cubic meter
    - Later, less than $40,000 per cubic meter
  - Larger total habitable volumes beyond low Earth orbit
    - Initially, habitable volumes of more than 100 cubic meters
    - Later, habitable volumes of more than 2,500 cubic meters
  - "Near complete" recycling of "waste products" – including gases, fluids and solids – using systems that are lower cost, and/or lower mass, and/or use less energy per kilogram of waste products processed
  - Detection and elimination of chemical and/or biological contaminants
  - Integrated systems including energy sources, thermal management systems, physical-chemical and bio-regenerative processors, living things (including floral and fauna), and integrated environmental monitoring and control

- B.2.e **Resources Development.** The challenge is to achieve Flexible and affordable, **operationally efficient**, physical and chemical translation, transformation and utilization of material solar system resources. Meeting this challenge involves achieving the following objectives:

- *In situ* production of propellants, life support and other consumables from local materials (including gases, ices, and mineral solids)
- Manufacture of end items (including components and eventually systems) for use in local and remote operations
- Increasingly complex self-replicating machines

- B.2.f **Human and Machine Operations.** The challenge is to achieve Effective, **operational efficient**, affordable and adaptive machine and human operations in the vacuum and accessible planetary environments. Meeting this challenge depends upon achieving the following objectives:

  - Increasingly capable robotic assembly, maintenance and repair of systems in near-Earth space
  - Safe and robust "shirt-sleeve" class human extravehicular activity (EVA) operations in the far-term
  - Including EVA systems capable of 100's of uses with only local servicing, maintenance and repair

- B.2.g **Human / Machine Communities.** The challenge is to achieve Sustained, evolvable, **operationally efficient,** and increasingly autonomous and self-sufficient machine and human operations in space and on planetary surfaces – leading to self-reliant "communities". Meeting this strategic technical challenge entails achieving the following objectives:

  - Initially, the capacity for ~10-100 distinct systems to inter-operate without intervention from Earth-based controllers
  - Later, the capacity for ~100-1000 distinct systems to inter-operate without intervention from Earth-based controllers
  - Bio-mimetic systems and architectures capable of collective learning and adaptive behaviors

- B.2.h **Surface Mobility and Access.** The challenge is to achieve Timely local, regional and global mobility, and **operational efficiency** in accessible planetary venues, with access at various depths below – and altitudes above – planetary surfaces. Meeting this challenge involves achieving the following objectives:

  - Mobility at increasing range across the surface of the Moon or Mars
    - Initially, at distances of > 100 km
    - Later, at distances from 1000 km up to circumnavigation of the body
  - Acquisition of samples that preserve physical, chemical and "location" information from below planetary and small body surfaces
    - Initially, at depths of 10-100 meters
    - Later, at depths of 100-1000 meters
  - Acquisition of samples from the Mars (and later other) atmosphere at various altitudes that preserve chemical and "location" information

- Appropriate forward- and back- contamination features – sufficient to meet both scientific requirements and key public concerns

- B.2.i **Networks & Communications.** The challenge is to achieve On-demand **operationally efficient** broadband computing and network communications locally and over interplanetary distances. Meeting this strategic technical challenge involves achieving the following objectives:

  - Open architectures for real-time and asynchronous communications
  - Increasing local data capacity
    - Initially, with local data capacity of 10-100 Mbps, with
      - 99.9% availability
      - Total daily capacity > 10 Tb
    - Later, with local capacity of greater than 100-1000 Mbps, with
      - 99.99% availability
      - Total daily capacity > 10 Tb
  - Increasing interplanetary data transfer capacity
    - Initially, interplanetary data rates greater than 1-10 Mbps, with
      - 99 % availability
      - Total daily capacity > 1 Tb
    - Later, interplanetary data rates greater than 10-100 Mbps, with
      - 99.9 % availability
      - 10 Tb total daily capacity

NASA Science Mission Directorate
Grand Challenges

Life is the common thread through NASA's Vision and Mission. While we seek to extend life to other places in the solar system and search for life beyond the Earth, we know that improving life here is our first and highest calling.

In the continuing quest for discovery, we seek clues from the past that can help us in the future and lessons from distant bodies that can teach us about our home planet. The future holds the promise of understanding the universe as a system of interacting matter and energy, radiation and particles, minerals and water. Imagine understanding completely how the Sun varies and how it interacts with Earth. Imagine deploying the most powerful exploration craft ever to uncover the mysteries of the outer planets. And imagine looking from the Sun to the comets —and beyond— for those markers that signify the presence of life. Beyond our own small community of planets and our familiar star, imagine finding the remnant ripples in gravity from the Big Bang, uncovering the secrets of the dark energy that pervades the universe, and taking pictures of a black hole. Imagine finally reading the whole story of how galaxies, stars, and planets came to be. The future of space science really consists of understanding the past. With ever-greater capabilities, we seek to connect with the elements, planets, and universe that brought us into being. How and when did the amazing events in the chain leading to our existence take place? Could they have happened elsewhere? Will they happen again? In seeking answers to these questions, humankind can reflect on its place and its destiny in the universe. These questions in the Earth and space sciences will be addressed by pursuing the following grand challenges:

Understand the Earth system and apply Earth system science to improve the prediction of climate, weather, and natural hazards.

Understand how Earth is changing, improve prediction for change, and understand the consequences for life on Earth.

• Develop and improve capabilities for prediction of climate variability and change.

• Develop and improve capabilities for prediction of how future changes in atmospheric composition will affect ozone, climate, and air quality.

• Develop and improve capabilities for prediction of carbon cycle dynamics and terrestrial and marine ecosystems will change in the future.

• Develop capabilities to probe the interior structure, distribution of mass, and variations beneath the surface of the Earth.

- Develop capabilities to remotely sense the ocean depths, including circulation, chemical composition, and bathymetry

<u>Expand and accelerate the realization of economic and societal benefits from Earth science, information, and technology.</u>

• Determine how water and energy cycle dynamics will change in the future.

• Significantly improve short term and long-term weather forecasting.

• Develop and improve capabilities for prediction of volcanic and earthquake activity.

• Develop capabilities for data mining, fusion, display, and synthesis into information products.

<u>Understand the origins and societal impacts of variability in the Sun-Earth connection.</u>

• Develop the capability to predict solar activity and the evolution of solar disturbances as they propagate in the heliosphere and affect Earth.

• Specify and enable prediction of changes to Earth's radiation environment, ionosphere, and upper atmosphere.

• Understand the role of solar variability in driving space climate and global change in Earth's atmosphere.

<u>Catalog and understand potential impact hazards to Earth from space.</u>

• Determine the inventory and dynamics of bodies that may pose an impact hazard to Earth.

• Determine the physical characteristics of comets and asteroids relevant to any threat they may pose to Earth.

Explore the solar system and the universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere.

The following specific space science strategic goals are directly related to addressing these grand challenges.

Learn how the solar system originated and evolved to its current diverse state.

• Understand the initial stages of planet and satellite formation.

• Study the processes that determine the characteristics of bodies in our solar system and how these processes operate and interact.

• Understand why the terrestrial planets are so different from one another.

• Learn what our solar system can tell us about extra solar planetary systems.

Understand how life begins and evolves and determine the characteristics of the solar system that led to the origin of life.

• Determine the nature, history, and distribution of volatile and organic the characteristics of the solar system that led to the compounds in the solar system.

• Identify the habitable zones in the solar system.

• Identify the sources of simple chemicals that contribute to prebiotic evolution and the emergence of life.

• Study Earth's geologic and biologic records to determine the historical relationship between Earth and its biosphere.

Understand the current state and evolution of the atmosphere, surface, and interior of Mars.

• Characterize the present climate of Mars and determine how it has evolved over time.

• Investigate the history and behavior of water and other volatiles on Mars.

• Study the chemistry, mineralogy, and chronology of Martian materials.

• Determine the characteristics and dynamics of the interior of Mars.

Determine if life exists or has ever existed on Mars.

• Investigate the character and extent of prebiotic chemistry on Mars.

• Search for chemical and biological signatures of past and present life on Mars.

Develop an understanding of Mars in support of possible future human exploration.

• Identify and study the hazards that the Martian environment will present to human explorers.

• Inventory and characterize Martian resources of potential benefit to human exploration of Mars.

Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments.

• Understand the structure and dynamics of the Sun and solar wind and the origins of magnetic variability.

• Determine the evolution of the heliosphere and its interaction with the galaxy.

• Understand the response of magnetospheres and atmospheres to external and internal drivers.

Understand the fundamental physical processes of space plasma systems.

• Discover how magnetic fields are created and evolve and how charged particles are accelerated.

• Understand coupling across multiple scale lengths and its generality in plasma systems.

Learn how galaxies, stars, and planetary systems form and evolve.

• Learn how the cosmic web of matter organized into the first stars and galaxies and how these evolved into the stars and galaxies we see today.

• Understand how different galactic ecosystems of stars and gas formed and which ones might support the existence of planets and life.

• Learn how gas and dust become stars and planets.

• Observe planetary systems around other stars and compare their architectures and evolution with our own.

Understand the diversity of worlds beyond our solar system and search for those that might harbor life.

• Characterize the giant planets orbiting other stars

• Find out how common Earth-like planets are and see if any might be habitable.

• Trace the chemical pathways by which simple molecules and dust evolve into the organic molecules important for life.

• Develop the tools and techniques to search for life on planets beyond our solar system.

<u>Discover what powered the Big Bang and the nature of the mysterious dark energy that is pulling the universe apart.</u>

• Search for gravitational waves from the earliest moments of the Big Bang.

• Determine the size, shape, and matter-energy content of the universe.

• Measure the cosmic evolution of the dark energy, which controls the destiny of the universe.

<u>Learn what happens to space, time, and matter at the edge of a black hole.</u>

• Determine how black holes are formed, where they are, and how they evolve.

• Test Einstein's theory of gravity and map space-time near event horizons of black holes.

• Observe stars and other material plunging into black holes.

<u>Understand the development of structure and the cycles of matter and energy in the evolving universe.</u>

• Determine how, where, and when the chemical elements were made, and trace the flows of energy and magnetic fields that exchange them between stars, dust, and gas.

• Explore the behavior of matter in extreme astrophysical environments, including disks, cosmic jets, and the sources of gamma-ray bursts and cosmic rays.

• Discover how the interplay of baryons, dark matter, and gravity shapes galaxies and systems of galaxies.

NASA Aeronautics Mission Directorate
Grand Challenges

The Aeronautics Mission Directorate represents the first “A” in NASA and carries on the Agency’s 80+ year legacy of exploring ways to make future air travel safer, faster, more convenient, more economical and environmentally benign. Many of the technological achievements embodied in today’s aviation systems are a product of advanced concepts inspired or developed by NASA. The NASA Institute of Advanced Concepts (NIAC) is an important means to continue that legacy.

The NIAC can serve NASA’s long-term goals by seeking advanced concepts in four key areas:

(1) Concepts to greatly increase the capacity of our nation’s – and the world’s – air space systems though new ways to manage vastly more aircraft carrying many more passengers and much more cargo than we do today. The vision for the future is that aircraft of all kinds will travel more freely through the air space, planning and adjusting their route of travel to meet the demand for service and dictates of weather. They will travel between major metropolitan areas as today, but also, and maybe more so, among smaller cities and towns to bring the benefits of safe convenient air travel to everyone. Today NASA is working to move our means of air space management towards this vision, but its full potential is still decades away with ample opportunity to be influenced by truly innovative advanced concepts

(2) Safety, across all aspects of air travel and airspace operations is of critical importance to NASA and is one of the cornerstones of the Aeronautics Directorate’s research and technology program. Our nation’s aircraft and airspace are the safest in the world and air travel has become the safest form of personal transportation. Nonetheless, NASA is always striving to find innovative ways to make aviation even safer. Key areas of opportunity for advanced concepts include ways to provide the pilot with full situational awareness of everything around him: other aircraft, weather and terrain; concepts to determine the complete “health” of a vehicle so we will always know of an impending problem before it occurs; and concepts to enable “intelligent vehicles” that provide unprecedented levels of control under the worst of conditions.

(3) Truly advanced and innovative vehicle concepts to provide an unlimited range of services are at the core any revolution in aeronautics. This includes long-range transports, regional aircraft, small “personal aircraft, rotorcraft and UAVs (uninhabited air vehicles). Fifty years after the first commercial jet transports came into service, the basic concept, layout and construction is

largely the same. The aircraft are far better, safer and more efficient, but there is a need to explore new vehicle concepts that are as different from today's aircraft as the first jet transport was from the wood and cloth bi-planes that preceded them 50 years earlier. NASA's vision for the future includes a far broader mix of aircraft than is in service today. Today, air travel is dominated by transports that carry 100 to 500 passengers (or large amounts of cargo) from one major metropolitan area to another. In the future, we will still need such aircraft, but the will have to be much more efficient, quieter and environmentally benign. Technology is emerging to reduce the weight of vehicles by as much as half and new propulsion concepts may lead to aircraft that essentially have no harmful emissions. Add to that, revolutionary vehicle architectures and it may be possible for efficient, affordable overland supersonic flight. Fifty years ago visionaries foresaw private aircraft "in every driveway". This is still a vision but today it is much more possible. Today we are also exploring a new class of aircraft, not envisioned 50 years ago. High altitude UAVs that can stay aloft for indefinitely servings as outposts in the sky for monitoring the environment, relaying communions, exploring space from the upper fringes of the atmosphere, and other things yet to be thought of. It will not be enough to build on the legacy of the past 50 years. NASA's vision is to begin a new legacy with vehicle concepts that are faster, safer, more efficient, more environmentally benign and which meet the demands for air travel, any time, from anywhere to anywhere. Emerging technology can enable this vision and the NIAC can help define the vehicles that will use it.

(4) Finally, a totally new frontier of aeronautics is emerging from NASA's space exploration activities in the potential of robotic aero-vehicles as critical components of campaigns to explore other planets, in particular Mars. The total land area of Mars is about equal to the total land area of Earth and atmospheric vehicles may offer the greatest opportunity for long-range and long-term exploration from a point of view unavailable by satellites or surface rovers. Clearly, there are major challenges to overcome: the very low density of the atmosphere and a composition that is 90% non-combustible carbon-dioxide. However, NASA can envision a time when new concepts enable atmospheric travel in Mars and other planetary atmospheres as a routine part of space exploration.