Future Directions:
Strategy for Human and Robotic Exploration

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Space Architect
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Robust Exploration Strategy

Traditional Approach: A Giant Leap (Apollo)

- Cold War competition set goals, National Security justified the investment
- Singular focus on the Moon
- Humans in space an end unto itself
- Robotic exploration secondary to crewed missions
- Rigid timeframe for completion with unlimited resources
- Technologies are destination- and system-specific
- Inspirational outreach and education secondary to programs

New Strategy: Stepping Stones and Flexible Building Blocks

- NASA Vision and Mission drive goals and must justify investment
- Robust and flexible capability to visit several potential destinations
- Human presence is a means to enable scientific discovery
- Integrate/optimize human-robotic mix to maximize discovery
- Timeframe paced by capabilities and affordability
- Key technologies enable multiple, flexible capabilities
- Inspiration and educational outreach integral to programs

High-risk with limited vision beyond demonstrating a technology capability

Robust and flexible, driven by discovery, and firmly set in the context of national priorities
The NASA Vision
To improve life here,
To extend life to there,
To find life beyond.

The NASA Mission
To understand and protect our home planet,
To explore the universe and search for life,
To inspire the next generation of explorers
... as only NASA can.

www.nasa.gov
**Science Drivers Determine Destinations**
(Selected Examples)

<table>
<thead>
<tr>
<th>Science Questions</th>
<th>Pursuits</th>
<th>Activities</th>
<th>Destinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>How did we get here?</td>
<td>• History of major Solar System events</td>
<td>• Planetary sample analysis: absolute age determination “calibrating the clocks”</td>
<td>• Asteroids</td>
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<td>• Moon</td>
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<td>• Mars</td>
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<td></td>
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<td>• Venus</td>
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<tr>
<td>Where are we going?</td>
<td>• How do humans adapt to space?</td>
<td>• Measurement of genomic responses to radiation</td>
<td>• Beyond Van Allen belts</td>
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<tr>
<td>Are we alone?</td>
<td>• How did the Solar System evolve?</td>
<td>• Measurement of Earth’s vital signs “taking the pulse”</td>
<td>• Earth orbits</td>
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<td>• Libration points</td>
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<td>• What is Earth’s sustainability and habitability?</td>
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<td>• Is there Life beyond the planet of origin?</td>
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<td>• Cometary nuclei</td>
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<td>• Europa</td>
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<td>• Titan</td>
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Stepping Stone Strategy

1. Understand solar variability and the Sun-Earth connection.
2. Enhance security and the quality of life on Earth.
3. Improve how humans can live and work in space.

- Exploit unique viewpoints in space:
  - Build revolutionary telescopes to study planets around other stars.
  - Explore the universe and observe Earth.
  - Use as gateways for future human exploration.

- Follow the water on Mars and seek ancient or present life.

- Seek clues to the origins of the solar system and the building blocks of life.

- Seek the origins of the universe.
Stepping Stone Approach
Current Capabilities

Low Earth Orbit
- Crew Health and Performance
- Systems and Technology Performance
- Engineering Test bed
- Crew transportation

Earth Sensing
- Understand Earth as a system
- Develop predictive capabilities

EARTH’S NEIGHBORHOOD

Libration Points

Hubble Space Telescope
Space Infrared Telescope Facility
Mars Exploration Rovers

ACCESSIBLE PLANETARY SURFACES
Stepping Stone Approach
Near-term Next Steps for Human and Robotic Exploration

High Earth Orbit/High Inclination (above the Van Allen Belts)
- Assembly, Maintenance, and Servicing
- Initial Deep Space Crew Transfer

Low Earth Orbit
- Crew Health and Performance
- Systems and Technology Performance
- Engineering Test bed
- Crew transportation
- Heavy Lift

Earth Sensing
- Understand Earth as a system
- Develop predictive capabilities

Libration Points (60-100 day missions)
- Breakthrough Science Capabilities
- Deep Space Systems Development

Earth’s Neighborhood Accessible Planetary Surfaces

Moon (14 day + missions)
- Surface Systems
- Operations
- Resource Utilization
- High Power Systems

Mars

Potential Sites for Operations Above Low Earth Orbit
Stepping Stone Approach
Far-Term Next Steps for Human and Robotic Exploration

EARTH’S NEIGHBORHOOD

High Earth Orbit/High Inclination
(above the Van Allen Belts)
- Assembly, Maintenance, and Servicing
- Initial Deep Space Crew Transfer

Low Earth Orbit
- Crew Health and Performance
- Systems and Technology Performance
- Engineering Test bed
- Crew transportation
- Heavy Lift

Earth Sensing
- Understand Earth as a system
- Develop predictive capabilities

Libration Points
(60-90 day missions)
- Breakthrough Science Capabilities
- Deep Space Systems Development

Asteroids

Mars
(365 day + missions)
- Explore a New World
- Search for Life
- Resource Utilization
- High Power Systems

Moon
(14 day + missions)
- Surface Systems
- Operations
- Resource Utilization
- High Power Systems

Earth Sensing
- Understand Earth as a system
- Develop predictive capabilities

Potential Sites for Operations Above Low Earth Orbit
<table>
<thead>
<tr>
<th>Human and Robotic Concepts</th>
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<tbody>
<tr>
<td><strong>LEO/GEO</strong></td>
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<tr>
<td>Earth-to-Orbit</td>
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<tr>
<td>40 mT</td>
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<td>100 mT</td>
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<tr>
<td>Transportation</td>
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<tr>
<td>Transfer Vehicle</td>
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<tr>
<td>Upper Stage</td>
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<tr>
<td>Lander</td>
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<tr>
<td>Space Power</td>
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<tr>
<td>Habitation</td>
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<td>EVA/Robotics</td>
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<td><strong>Moon</strong></td>
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<td><strong>Libration Points</strong></td>
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<td><strong>Mars</strong></td>
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Systematic Investment Strategy

Space Act & NASA Strategic Plan

Science: Questions, Pursuits, Activities

Requirements and Systems Engineering

Architectural Studies & Technology Trades

Programmatic and Technology Road Maps

Gap Analysis

Space Architect Focus

Products:
Integrated Space Plan, Technology Requirements, Priorities, and New Initiatives
Key Technology Challenges

• **Space Transportation**  
  – Safe, fast, and efficient

• **Affordable, Abundant Power**  
  – Solar and nuclear

• **Crew Health and Safety**  
  – Counter measures and medical autonomy

• **Optimized Robotic and Human Operations**  
  – Dramatically higher productivity; on-site intelligence

• **Space Systems Performance**  
  – Advanced materials, low-mass, self-healing, self-assembly, self-sufficiency…

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RLV  
NEP  
Invariant Manifolds  
Aerobraking

Space Solar Power  
M2P2  
L₁ Outpost  
Artificial Gravity

Robonaut  
Gossamer Telescopes  
Nanotube Space Elevator
## Strategic Building Block Investments

### FY 2003

<table>
<thead>
<tr>
<th>Technological Barriers</th>
<th>Nuclear Systems Initiative</th>
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<tbody>
<tr>
<td><strong>Power:</strong> Providing ample power for propulsion and science</td>
<td>Greatly increased power for space science and exploration</td>
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<thead>
<tr>
<th>Integrated Space Transportation Plan</th>
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<tbody>
<tr>
<td>Orbital Space Plane</td>
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<tr>
<td>Extended Shuttle Operations</td>
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<tr>
<td>Next Generation Launch Systems</td>
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<tr>
<th>In-Space Propulsion Program</th>
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<tr>
<td>Efficient Solar System Transportation</td>
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<th>Space Station Restructuring</th>
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<tr>
<td>Research Priority Focused</td>
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<td>Management Reforms</td>
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<tr>
<td>Sound Financial Base</td>
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<th>Bioastronautics Program</th>
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<tr>
<td>Roadmap to address human limitations</td>
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### FY 2004

<table>
<thead>
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<th>Project Prometheus</th>
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<tr>
<td>Nuclear power and propulsion for revolutionary science and orbital capabilities</td>
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<tr>
<td>First mission to Jupiter’s Moons</td>
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<th>Human Research Initiative</th>
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<td>Accelerate research to expand capabilities</td>
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<tr>
<td>Enable 100-plus day missions beyond low-Earth orbit</td>
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<th>Optical Communications</th>
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<tr>
<td>Vastly improve communication to transform science capability</td>
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<tr>
<td>First demonstration from Mars</td>
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Integrated Space Transportation Plan

Update: 10/24/02

- Space Shuttle
- Orbital Space Plane
- Next Generation Launch Technology

International Space Station
- US Core Complete
- ISS Crew Return Capable
- ISS Extend?
- ISS Crew Transferred on Human-Rated EELV
- ISS Crew Transfer on Human-Rated EELV
- ISS Extend? International Space Station
- ISS Crew Return Capable
- ISS Extend?
- ISS Extend Until 2020+
- ISS Extend? International Space Station
- ISS Crew Return Capable
- ISS Extend?
- ISS Extend Until 2020+
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The Orbital Space Plane (OSP) will:

• Support NASA’s strategic goals and science objectives by achieving assured access to the International Space Station (ISS) and Low Earth Orbit (LEO)
  – Crew return capability from the International Space Station as soon as practical but no later than 2010 (Goal is now 2008)
  – Crew transfer to and from the ISS as soon as practical but no later than 2012 (Goal is now 2010)

• Provide the basis for future exploration beyond Low Earth Orbit
OSP Primary Earth-to-LEO Transportation

High Earth Orbit / Low Lunar Orbit

Low Earth Orbit

Propellant Lunar Lander (wet)

LEO Tanker

Crew Transfer from OSP to XTV*

XTV Fuels in LEO

XTV Refuels

Propulsive Capture

Crew Transfer to OSP

LEO Tanker and OSP

OSF Crew Landing

Contingency Return

Earth Surface
Project Prometheus

• Revolutionary capabilities for nuclear propulsion and power
  – Much greater ability to power instruments, change speed, and transmit science data
  – No launch constraint to use gravity assists
  – Can orbit multiple objects or moons with vastly greater, persistent observation time
  – Can change target mid-mission (to support change in priorities)

• First use: Jupiter Icy Moon Orbiter
  – Search for evidence of global subsurface oceans on Jupiter’s three icy Galilean moons: Europa, Ganymede, and Callisto. These oceans may harbor organic material.
  – Nuclear technology will enable unprecedented science data return through high power science instruments and advanced communications tech
• **Mission Needs**
  – 1-g, 4 rpm system – consistent with human centrifugation tests
  – Minimize AG vehicle mass “penalties” & complexity
  – 18-month Mars roundtrip, nuclear electric propulsion

• **Assessments**
  – AG crew hab module design assessment
  – Power/propulsion/trajectory trades
  – Angular momentum management/vehicle steering strategies
  – Preliminary assessment of structural, power system designs

• **Results**
  – Only small dry mass AG penalties identified (<5%)
  – Good synergy among power system and propulsive performance
  – Propellant-efficient steering strategies identified
Crew Health and Safety

Attacking the Radiation Challenge

**CURRENT MITIGATION**
- Safe Havens
- Career/Mission Time Constraints
- Dosimetry
- Historical Data/Modeling
- Earth’s Magnetic Field

**ADVANCED APPROACHES**
- Fast Transit
- Personnel Screening
- Active Shielding
- Pharmaceuticals
- Integ. Design of Passive Shields
- Materials
- Tissue Testing/Modeling

**Exploration Location/Duration**
- LEO
  - 180 Days
- LEO+
  - 500-1000 Days

**Risk/Uncertainty**
Optimizing the Human/Robotic Equation

Example Science Activities

- Creating science instruments and observing platforms to search for life sustaining planets
- Search for evidence of life on planetary surfaces

Optimal Human and Robotic Combinations

- Technology Projections
- Experience and Lessons Learned
- Mission Performance Assessments
Large Space Telescope Construction and Maintenance

Complexity/Capability

- Suit Advances
- Human Interface Development
- Robotic Development
- Electrical Development
- Fluid Development
- Structural Development

Telepresence

Multi-Agent Planning

EVA/Robotic Optimization

Dexterity

Path Planning

State of the Art (2002)

2002

Studies

2005

Demonstrations

2010

Flight Demonstrations

Complex Systems

20m Parabolic Telescope

300m Linear Phased Array

Geosync Synthetic Aperture Radar (code Y)

Time
Example: Mars Human Mission

- Advanced Avionics (7%)
- Maintenance & Spares (18%)
- Advanced Materials (17%)
- Closed life Support (34%)
- Advanced Propulsion (EP or Nuclear) (45%)
- Aerobraking (42%)

Mass Savings Normalized to ISS Mass
"As for the future, your task is not to foresee it, but to enable it."

Antoine de-Saint-Exupery