NASA’s Exploration Team:
Vision and Priorities

National Aeronautics and
Space Administration

June 12, 2002
“However our present interests may restrain us with our own limits, it is impossible not to look forward to distant times.”

-- Thomas Jefferson

The Corps of Discovery and America’s Future
THE OBJECT OF YOUR MISSION IS TO EXPLORE…

FROM THOMAS JEFFERSON’S ‘LETTER OF INSTRUCTION’ TO THE CORPS OF DISCOVERY [MAY 15, 1803]

JEFFERSON’S PILARS FOR THE COUNTRY’S GREAT ENTERPRISE OF EXPLORATION:

“INSTRUMENTS FOR ASCERTAINING, BY CELESTIAL OBSERVATIONS, THE GEOGRAPHY OF THE COUNTRY…”

=> Scientific exploration, enabled by technology.

“…[AND TO ASCERTAIN THE SUITABILITY OF THE FRONTIER] FOR THE PURPOSES OF COMMERCE.”

=> Economic opportunity, enabled by government investment.

“YOUR OBSERVATIONS ARE TO BE TAKEN WITH GREAT PAINS AND ACCURACY, TO BE ENTERED DISTINCTLY AND INTELLIGIBLY FOR OTHERS AS WELL AS YOURSELF….”

=> Public engagement, enabled by effective communication.

“You will therefore endeavor to make yourself acquainted, as far as diligent pursuit of your journey shall admit, of…the extent of…[life beyond the frontier].”

=> The adventure of new discoveries…the unanticipated.
Exploration of life in the Universe

... enabled by technology
first with robotic trailblazers,
and eventually humans,
going anywhere, anytime
Exploration of Life in the Universe

To *discover* scientific evidence and processes that *reveal* our place in the Universe, by *exploring* new places and phenomena, *leading* outward beyond the vicinity of the Earth, *enhancing* the quality of life and *sharing* the adventure of discovery with all humanity.

The imperative for space exploration can be articulated by three *Grand Challenges*:

**How did we get here?**
- How did life arise on Earth?
- How did intelligence evolve on Earth?

**Where are we going?**
- What is the fate of life on Earth?
- What is the interaction between life and the Earth’s environment?
- How do we optimize the role of humans in space? . . .

**Are we alone?**
- Are there other abodes for life in the Solar System?
- Are there other abodes for life in the Universe? . . .
More on What the Vision is

- Exploration of Life in the Universe
- Changing the pace of discoveries and enabling new ones
- Bringing new machines on site to facilitate faster and better science activities with higher and faster yields
- Ultimately bringing humans on site to radically alter the pace of discoveries
- All of this is catalyzed by cycles of innovation-driven investment
What is the NEXT Vision Difference?

**Where Are We Today?**
- Minimum Energy Transfers
- Launch cost indiscriminant of payload value
- Destination-Dependent (in series)
- Humans Only to LEO
- Low-Bandwidth Telecomm
- Infrequent Visits: *Hostage to Time*

**Where Do We Want to Go Tomorrow?**
- Non-minimum Energy transfers
- Launch cost determined by payload value
- Destination-Open (in parallel)
- Humans to L2, Mars .... Wherever
- Video Bandwidth Telecomm
- Frequent visits: *Sustained Operations*

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**Investing in technology makes the difference:**

*Increase value/lb - while decreasing cost/lb*
Traceable Thought Process and Current Progress

- NASA-wide Vision
- Science Questions and Pursuits
  - Activities
    - Measurements, experiments, etc.
  - Destinations
    - At which or from which questions are addressed
- Human & Robotic Integration
- Architecture Concepts
- Technology Investment Portfolios

- Exploration Vision - Codes S, Y, U and HEDS science
- Science and capabilities analysis - Metrics defining human enabling functions
- Exploration Capabilities - Enabling classes of destinations
- Destination/Technology-Specific Architecture Analysis
- Technology Breakthroughs - Roadmaps, Technology Assessments, Technology Investment Strategy
### Example Science Traceability

<table>
<thead>
<tr>
<th>Vision</th>
<th>Science Question</th>
<th>Pursuits</th>
<th>Activities</th>
<th>Destinations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>How Did We Get Here?</strong></td>
<td>• Solar System evolution</td>
<td>• History of major Solar System events</td>
<td>• Planetary sample analysis: absolute age determination “calibrating the clocks”</td>
<td>• Moon&lt;br&gt;• Mars&lt;br&gt;• Asteroids</td>
</tr>
<tr>
<td><strong>Where Are We Going?</strong></td>
<td>• Humans adaptability to space</td>
<td>• Effects of deep space on cells</td>
<td>• Measurement of genomic responses to radiation</td>
<td>• Beyond Van-Allen belts</td>
</tr>
<tr>
<td></td>
<td>• Earth’s sustainability and habitability</td>
<td>• Impact of human and natural events upon Earth</td>
<td>• Measurement of Earth’s vital signs “taking the pulse”</td>
<td>• Earth orbits&lt;br&gt;• Libration points</td>
</tr>
<tr>
<td><strong>Are We Alone?</strong></td>
<td>• Life beyond the planet of origin</td>
<td>• Origin of life in the Solar System&lt;br&gt;• Origin of life in the Universe</td>
<td>• Detection of biomarkers and hospitable environments</td>
<td>• Mars&lt;br&gt;• Europa&lt;br&gt;• Titan&lt;br&gt;• Cometary nuclei&lt;br&gt;• Libration points</td>
</tr>
</tbody>
</table>
Why Use Humans?

To Accelerate Discovery & Innovation

**Discoveries**
- **Leadership:** Emerged as Cold War victor
- **Prosperity:** Catalyst for "information age"
- **Motivation:** Surge in education of scientists and engineers

**Ranger**
- **Surveyor**
- **Lunar orbiter**
- **Apollo 11**
- **Apollo 12 @ Surveyor 3 site**
- **Apollo 17 Rover**
- **Clementine**
- **Lunar Prospector**

**Discovery:**
- **Origin of the Earth - Moon system**
Why Use Humans?
Astronauts Enable Discoveries: HST

*1990-1999 data - most important stories per year
Source: Science News
The Places We Could Go

Earth and LEO

The Earth’s Neighborhood

Earth-Moon L1

The Moon

Sun-Earth L2

Accessible Planetary Surfaces

Mars

Asteroids or Other Targets...

Outer Planets

Discover pale blue dots with gigantic telescopes

Discover Solar System history

Discover traces of life

Discover valuable resources

Discover life in Europa’s oceans

Sun-Earth L2

LL1

LL2

Discover solar system history

Discover traces of life

Discover valuable resources

Discover life in Europa’s oceans
Sustainable Planetary Presence

Go anywhere, anytime

Accessible Planetary Surface

Earth’s Neighborhood

Earth and LEO

• Space Station experience
• Solar System learning
• Technology advancements

• Traveling up to 1.5 million km
• Enabling huge optical systems
• Operating in deep space
• Staying for 50-100 d

• Traveling out to 1.5 AU
• Enabling tactical investigations
• Visiting and operating on another planet
• Staying for 1-3 years

• Traveling out to ~1.5 AU, and beyond
• Enabling sustainable scientific research
• Sustaining operations on another planet
• Staying for indefinite periods
Overview
NEXT Approach

Current Concepts & Technologies

New Concepts and Current Technologies

New Concepts Using New Technologies

Revolutionary Concepts Using Breakthrough Technologies

Current Concepts and New Technologies

New Technologies
Earth’s Neighborhood
New Approach to Exploration Concepts

• Initial approach had separate scenarios, each requiring support infrastructures

• Discovered new approach for meeting trajectory requirements for vehicles in Earth’s Neighborhood with new benefits;
  – Low energy transfers between Lunar L1 and solar L2
  – Created efficient Gateway Concept
Evaluating Technology Investments

Example: Exploration in the Earth’s Neighborhood

Crew Transfer Vehicle

Gateway (Including Deployment)

Crew Transfer Vehicle (First Flight)

Normalized Mass

- Advanced Avionics (7%)
- Maintenance & Spares (18%)
- Advanced Materials (17%)
- Aerobraking (42%)
- Advanced Propulsion (EP) (45%)
- Closed Life Support (34%)
Example Architecture: Mars Mission
(SEP Option)

Habitat Lander and Ascent/Descent Vehicles delivered to Low Earth Orbit with “Shuttle Class” launcher. Solar Electric Propulsion stage spirals cargo to High Earth Orbit. Chemical injection used at perigee. SEP spirals back to LEO for reuse.

Transit Habitat vehicle delivered to LEO with “Shuttle Class” launcher. SEP spirals Transit Habitat to High Earth Orbit. Crew delivered to vehicle via crew taxi. SEP spirals back to LEO for reuse.

Surface Habitat and exploration gear aerocaptures into Mars orbit.

Ascent/Descent Vehicle aerocaptures and remains in Mars orbit for the crew.

Crew travels to Mars in “fast transit” 180-206 day transfer. Aerobrakes into Mars orbit.

Crew rendezvous with Descent/Ascent Vehicle in Mars Orbit then lands in vicinity of Habitat Lander.

Habitat remains in Mars orbit.

Crew ascends and rendezvous with waiting Transit Habitat.

Crew returns to Earth on “fast transit” 180-206 day transfer. Direct entry at Earth.

30 days provided to satisfy “long-stay” criteria.

Surface Habitat lands and performs initial setup and checkout - Initial outpost established.

Mars Surface

Earth

Initial outpost established.
Evaluating Technology Investments
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
Launch Success
Cumulative Probability of Launch Success
• Nuclear Electric Propulsion can provide both IMLEO and trip time benefits for piloted and robotic missions
• Significant enhancements from advanced power and thruster technologies
• Lack of sunlight prevents use of SEP or Solar Sails for orbit rendezvous missions significantly beyond Mars
Evaluating Technology Investments
Example: Interplanetary Transportation Options

HEO Departure to Mars

- 3 - Tether / Chemical
- 4 - HPEP / NEP
- 5 - VaSIMR
- 6 - SEP / Chemical
- 7 - All SEP
* = One year total trip time

Typical pre-DPT reference mission duration

Trip time is for the crew departing from HEO.
In-Space Transportation Technologies

Application Missions
- Humans to LEO. Upper Stages for LEO-to-GEO and robotic missions
- Human mission capability for near-Earth space. Robotic missions anywhere in the solar system
- Safe, low-cost human and robotic exploration of the solar system

Safety & Reliability
- Mass: Chemical state-of-the-art
- Cost: ~1/200 failure probability
- Cost: $3000/kg LEO-to-GEO
- Mass: 100X safer
- Cost: $1000/kg - $300/kg
- Cost: $300 - $100/kg

Leading Candidate Technologies:
- High power electric propulsion (Isp: 3500 - 10,000 sec; power: 100 kW - 1 MW)
- Aeroassist and aerocapture (mid L/D aeroshells; ballutes)
- Plasma sails for efficient interplanetary transfer and inherent radiation protection
- Fission propulsion for reduced IMLEO and enhanced crew safety
- Momentum Transfer Tethers as a reusable in-space infrastructure for robotic and human exploration
- High energy density materials and advanced chemical fuels to increase Isp and reduce propulsion system mass

National Benefits:
- Lower cost and more reliable space transportation for commercial enterprises (e.g., communications, resource monitoring, tourism) and defense needs
## Evaluating Technology Investments

**Example: ETO Cargo Trade Space**

<table>
<thead>
<tr>
<th>Candidates</th>
<th>Launch Frequency @ 400 mt/yr</th>
<th>Scale @ 8 km/s Shot</th>
<th>ROM Cost</th>
<th>Strength/Weakness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slingatron</td>
<td>800 Launches @1-25/day</td>
<td>Gyration = 9 Hz</td>
<td>Non-recurring: $2.2B</td>
<td><strong>Strength</strong> - High Frequency launch</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D = 300 m</td>
<td>Recurring: $650 - $2,540/kg payload</td>
<td><strong>Weakness</strong> - Engineering complexity</td>
</tr>
<tr>
<td>Blast Wave Accelerator</td>
<td>800 Launches @ 1 - 2/ day</td>
<td>Number of explosive rings = 2,800 L = 860 m</td>
<td>Non-recurring: $1+B</td>
<td><strong>Strength</strong> - High energy density explosive</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Recurring: $1,238 - $3,122/kg payload</td>
<td><strong>Weakness</strong> - Controlled detonation</td>
</tr>
<tr>
<td>Electromagnetic Coil Gun</td>
<td>800 Launches @ 1-3/day</td>
<td>L = Several hundred meters</td>
<td>Non-recurring: $2.7B</td>
<td><strong>Strength</strong> - Higher technical maturity</td>
</tr>
<tr>
<td>Rail Gun</td>
<td></td>
<td></td>
<td>Recurring: $3,000-$5000/kg</td>
<td><strong>Weakness</strong> - Massive electric energy storage</td>
</tr>
<tr>
<td>ELVs</td>
<td></td>
<td>Payload mass to LEO: 5000 kg</td>
<td>$9,700 - $11,100/kg payload</td>
<td></td>
</tr>
<tr>
<td>Delta 7920</td>
<td>78 Launches</td>
<td></td>
<td>$26,700 - $33,300/kg payload</td>
<td></td>
</tr>
<tr>
<td>Pegasus</td>
<td>888 Launches</td>
<td>Payload mass to LEO: 450 kg</td>
<td>$26,700 - $33,300/kg payload</td>
<td></td>
</tr>
</tbody>
</table>
Power System Technologies

Application Missions

Now

- LEO/GEO satellites
- Earth & planetary science missions
- International Space Station
- Short duration/low power Mars surface PV
- 100w class RTGs
- 10-100kW near-Earth PV

10 Years

- Mars long-stay robotic labs
- Libration point observatories
- Electric propulsion
- kW class Mars surface PV
- 10+kW surface nuclear
- Higher efficiency/low mass PV for in-space

20 Years

- Human missions far from Earth
- High power electric propulsion
- Multi-MW PV and nuclear dynamic systems for in-space
- 100+kW surface nuclear
- Robust, high power surface systems

Leading Candidate Technologies:

- Thin-film and high-efficiency photovoltaic cells to reduce the array area and stowed volume
- Advanced dynamic and static conversion to reduce both thermal input and radiator size
- High density energy storage to increase the duration of mobile systems
- High efficiency power management and distribution to reduce losses and save system mass

National Benefits:

- Increased reliability and reduced cost of NASA, military and commercial satellites and spacecraft.
- More compact power systems for remote terrestrial applications, hybrid/electric vehicles and hand-held devices.
Evaluating Technology Investments

**Example:** Power Trade Space

<table>
<thead>
<tr>
<th>Applications</th>
<th>Nuclear</th>
<th>Isotope</th>
<th>PV only</th>
<th>PV/ RFC</th>
<th>PV/ Batt</th>
<th>FC/ RFC</th>
<th>Batt.</th>
<th>Beam</th>
<th>Power Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEO Fuel Depot</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>~3 MW</td>
</tr>
<tr>
<td>BNTR</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>30-50kW</td>
</tr>
<tr>
<td>NEP</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>30-50kW/100kW-MMW</td>
</tr>
<tr>
<td>SEP/Chem</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>20-30kW/1-2MW</td>
</tr>
<tr>
<td>Ascent/Descent/Re</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>3-5kW</td>
</tr>
<tr>
<td>30 day Mars</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>10-20kW</td>
</tr>
<tr>
<td>500 day Mars</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>60-100kW</td>
</tr>
<tr>
<td>10 hour rover</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>crewed, 1-3 kW</td>
</tr>
<tr>
<td>Multi-day rover</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>crewed, 5-10 kW</td>
</tr>
<tr>
<td>Mars mobile drill</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>1-5 kW</td>
</tr>
<tr>
<td>14 day lunar</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>2-100kW</td>
</tr>
<tr>
<td>45 day Lunar</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>10-100kW</td>
</tr>
<tr>
<td>Lunar S. pole</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>2-100kW</td>
</tr>
<tr>
<td>L2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>2-10kW</td>
</tr>
</tbody>
</table>

= Preferred concept
Crew Health & Safety: Radiation Protection

Application Missions

Uncertainty in cancer risk

Radiobiological database

Solar flare strategies

Model Validation

Leading Candidates Technologies:

- Biomolecular risk prediction; molecular surveillance; genetic screening
- New structural materials with optimal shielding properties with significant improvement over aluminum
- Electromagnetic shields, including electrostatic, magnetic, and plasma shields from innovative propulsive techniques
- Pharmacology: antioxidants, antisense drug discovery, ribozymes; cell cycle modifiers
- Biomolecular intervention, such as stem cell replacement and gene therapy

Flight rules

Optimal shielding materials

Biomolecular Intervention

Now

10 years

20 years

Short duration missions in low Earth orbit
600%
10% complete
40% complete
Ground facilities

Extended missions in Earth's Neighborhood
120%
50% complete
75% complete
ISS; free flyers; balloons

Long-duration missions to more distant destinations
50%
100% complete
100% complete
Beyond Van Allen Belts

October 1989 SPE

EVA Dose, Sv

Daytime, hr

Kρ = 7

Magnetic Disturbance Index, Kρ

EVA Safe Window

Kρ = 5

Kρ = 1

Daytime, hr

Flight rules

Optimal shielding materials

Biomolecular Intervention
Attacking the Radiation Challenge

LEO+
500-1000 Days

As Low As Reasonably Achievable

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

Risk/Uncertainty

* NEXT funded Activities

3% lifetime limit
Evaluating Technology Investments

Example: Shielding Effects on Radiation

Lens Dose Equivalent from GCR at Solar Minimum behind Candidate Shielding Materials

Proposed ISS sleeping quarters shield for 35% reduction
Materials Technologies

Strength-to-Mass Ratio
Deployment.
Embedded Elements

Application Missions

Leading Candidate Technologies:
- Carbon Nanotubes with up to 1000 times greater strength/mass
- Carbon nanotube microfibers with 40x stiffness/mass
- Thin-film materials with 1% nanotube whisker reinforced polymers results in dramatic improvement in thin film properties
- Wide bandgap semiconductors for high temperature environments, high-power circuitry, and high-strength MEMS devices
- Silicon carbide & elastomeric foams for self deploying & complex space structures
- Zeolites, carbon molecular sieves, etc. for in situ propellant production and air/water revitalization

National Benefits:
Benefits all facets of standard of living and national defense, such as medical, all forms of transportation, computing, energy generation and distribution, military vehicles, etc.
NEXT / THREADS R&T Approach:
Progressive Exploration Capabilities

Earth’s Neighborhood Capability
- In-space propulsion, Isp>1000 sec
- Power systems, >200 w/kg
- Integrated Human/robotic capabilities
- Crew countermeasures for 100 days
- Closed water/air systems
- Materials, factor of 9
- IVHM - Integrated vehicle health monitoring
- Current launch systems

Accessible Planetary Surface Capability
- In-space propulsion, Isp>3000 sec
- Power systems, >500 w/kg
- Robotic aggregation/assembly
- Crew countermeasures for 1-3 years
- Closed life support
- Materials, factor of 20
- Micro-/Nano- avionics
- ETO @ ~$2000/kg

Sustainable Planetary Surface Capability
- In-space propulsion, Isp>3000 sec
- Sustainable power systems
- Intelligent systems, orbital and planetary
- Crew countermeasures for indefinite duration
- ISRU for consumables & spares
- Materials, factor of 40
- Automated reasoning and smart sensing
- ETO @ <$2000/kg
“As for the future, your task is not to foresee it, but to enable it.”

A. de Saint-Exupery