TRANSPORTATION AND PLATFORMS PERSPECTIVE

Gary L. Bennett
National Aeronautics and Space Administration
Washington, DC

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Signed by Richard H. Truly
October 26, 1991
SPACE R&T MISSION STATEMENT

OAST SHALL PROVIDE TECHNOLOGY FOR FUTURE CIVIL SPACE MISSIONS AND PROVIDE A BASE OF RESEARCH AND TECHNOLOGY CAPABILITIES TO SERVE ALL NATIONAL SPACE GOALS

- **IDENTIFY, DEVELOP, VALIDATE AND TRANSFER TECHNOLOGY TO:**
  - INCREASE MISSION SAFETY AND RELIABILITY
  - REDUCE PROGRAM DEVELOPMENT AND OPERATIONS COST
  - ENHANCE MISSION PERFORMANCE
  - ENABLE NEW MISSIONS

- **PROVIDE THE CAPABILITY TO:**
  - ADVANCE TECHNOLOGY IN CRITICAL DISCIPLINES
  - RESPOND TO UNANTICIPATED MISSION NEEDS

INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

SPACE R&T PROGRAM DEVELOPMENT

20-YEAR VISION OF FUTURE FLIGHT PROGRAM STARTS

SPACE R&T PROGRAM STRATEGIES AND DECISION RULES

INTEGRATED TECHNOLOGY PLAN BASE R&T, FOCUSED R&T, FACILITIES, R&PM.
INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

RESEARCH & TECHNOLOGY STRATEGY

• 5-YEAR FORECAST INCLUDES
  '93 THRU '97:
  COMPLETION OF INITIAL SSF
  LIMITED SOME SHUTTLE IMPROVEMENTS
  NEW STARTS
  SELECTED SPACE SCIENCE STARTS
  NLS DEVELOPMENT
  INITIAL SEI ARCHITECTURE SELECTION
  EVOLVING GEO COMMERCIAL COMMSATS
  MINOR UPGRADES OF COMMERCIAL ELVS

• 10-YEAR FORECAST INCLUDES
  '98 THRU '93:
  MULTIPLE NEW STARTS
  TO BE LAUNCHED IN 2003 THRU 2010

• 20-YEAR FORECAST INCLUDES
  '04 THRU '11 OPTIONS FOR NEW
  STARTS TO BE LAUNCHED IN 2009 THRU 2020

SPACE RESEARCH & TECHNOLOGY PROGRAM

<table>
<thead>
<tr>
<th>Category</th>
<th>FY 1992</th>
<th>FY 1993</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;T BASE</td>
<td>$309.3M</td>
<td>$332.0M</td>
</tr>
<tr>
<td>SPACE PLATFORMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLANETARY SURFACE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPACE SCIENCE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRANSPORTATION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPERATIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXPERIMENTS</td>
<td>11%</td>
<td>10%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$309.3M</td>
<td>$332.0M</td>
</tr>
</tbody>
</table>
OSSA TECHNOLOGY NEEDS
Grouped According to Urgency & Commonality

Mission Performance Factors
- Specific Impulse (Isp): Determines propellant mass
- Power Level (P_e): Affects trip time
- System Specific Mass (α): Determines trip time limits
- Thruster Efficiency (η): Affects trip time, vehicle mass

Parameter: Desired Range Mission Impact
Isp High (>5000s) Low initial mass, Resupply mass
P_e High (MWe) Reduced trip time
α Low (<10 kg/kWe) Reduced Mass, trip time
η High (>50%) Improved mass, trip time

NASA
NUCLEAR ELECTRIC PERFORMANCE CHARACTERISTICS

Office of Exploration
TRANSPORTATION TECHNOLOGY

PROVIDE TECHNOLOGIES THAT SUBSTANTIALLY INCREASE OPERABILITY, IMPROVE RELIABILITY, PROVIDE NEW CAPABILITIES, WHILE REDUCING LIFE CYCLE COSTS

- ENHANCE SAFETY, RELIABILITY, AND SERVICEABILITY OF CURRENT SPACE SHUTTLE
- PROVIDE TECHNOLOGY OPTIONS FOR NEW MANNED SYSTEMS THAT COMPLEMENT THE SHUTTLE AND ENABLE NEXT GENERATION VEHICLES WITH RAPID TURNAROUND AND LOW OPERATIONAL COSTS
- SUPPORT DEVELOPMENT OF ROBUST, LOW-COST HEAVY LIFT LAUNCH VEHICLES
- DEVELOP AND TRANSFER LOW-COST TECHNOLOGY TO SUPPORT COMMERCIAL ELV's AND UPPER STAGES
- IDENTIFY AND DEVELOP HIGH LEVERAGE TECHNOLOGIES FOR IN-SPACE TRANSPORTATION, INCLUDING NUCLEAR PROPULSION, THAT WILL ENABLE NEW CLASSES OF SCIENCE AND EXPLORATION MISSIONS

TRANSPORTATION TECHNOLOGY

SHUTTLE ENHANCEMENT
- SSME Improvements
- Durable Thermal Protection Systems
- Improved Health Monitoring
- Light Structural Alloys
- Lidar-Based Adaptive Guidance & Control

NEXT GENERATION MANNED TRANSPORTS
- Configuration Assessment
- High Frequency, High Voltage Power Management/Distribution Systems
- LOX/LH2 Propellant for OMS/RCS
- Maintenance-free TPS
- Advanced Reusable Propulsion
- GPS-Based Autonomous GN&C
- Composites & Advanced Lightweight Metals
- Vehicle-Level Health Management For Autonomous Operations

HEAVY-LIFT CAPABILITY
- Advanced Fabrication (Forming & Joining)
- STME Improvements
- On-Vehicle Adaptive Guidance & Control
- Systems & Components for Electric Actuators
- Health Monitoring for Safe Operations
- AL-Li Cryo Tanks

LOW-COST COMMERCIAL
- Alternate Booster Concepts
- Advanced Cryogenic Upper Stage Engines
- Low-Cost Fab/Automated Processes/NDE
- Continuous Forging Processes for Cryogenic Tanks
- Fault-Tolerant, Redundant Avionics

IN-SPACE TRANSPORT
- High-Power Nuclear Thermal & Electric Propulsion
- High Performance, Multiple Use Cryogenic Chemical Engine
- Highly Reliable, Autonomous Avionics
- Low Mass, Space Durable Materials
- Long-Term, Low-Loss Management of Cryogenic Hydrogen
- Autonomous Rendezvous, Docking & Landing
- Aeroassist Technologies
### TRANSPORTATION TECHNOLOGY MISSION MODEL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SHUTTLE</strong></td>
<td><img src="image1" alt="Shuttle Evolution" /></td>
<td><img src="image2" alt="Shuttle Evolution" /></td>
<td><img src="image3" alt="Shuttle Evolution" /></td>
<td><img src="image4" alt="Shuttle Evolution" /></td>
<td><img src="image5" alt="Shuttle Evolution" /></td>
</tr>
<tr>
<td><strong>NEW MANNED SYSTEMS</strong></td>
<td><img src="image6" alt="Personnel Launch System" /></td>
<td><img src="image7" alt="Advanced Manneed Launch System" /></td>
<td><img src="image8" alt="Advanced Manneed Launch System" /></td>
<td><img src="image9" alt="Advanced Manneed Launch System" /></td>
<td><img src="image10" alt="Advanced Manneed Launch System" /></td>
</tr>
<tr>
<td><strong>HEAVY LIFT LAUNCH VEHICLES (HLLV)</strong></td>
<td><img src="image11" alt="Heavy Lift Evolution" /></td>
<td><img src="image12" alt="Heavy Lift Initial Capability" /></td>
<td><img src="image13" alt="Heavy Lift LUNAR Capability" /></td>
<td><img src="image14" alt="Heavy Lift LUNAR Capability" /></td>
<td><img src="image15" alt="Heavy Lift LUNAR Capability" /></td>
</tr>
<tr>
<td><strong>COMMERCIAL LAUNCH VEHICLES &amp; UPPER STAGES</strong></td>
<td><img src="image16" alt="Commercial Evolution" /></td>
<td><img src="image17" alt="Commercial Upgrades" /></td>
<td><img src="image18" alt="Commercial Upgrades" /></td>
<td><img src="image19" alt="Commercial Upgrades" /></td>
<td><img src="image20" alt="Commercial Upgrades" /></td>
</tr>
<tr>
<td><strong>SPACE TRANSFER VEHICLE/LANDERS</strong></td>
<td><img src="image21" alt="Space Transfer Chemical" /></td>
<td><img src="image22" alt="Space Transfer Nuclear Thermal" /></td>
<td><img src="image23" alt="Space Transfer Nuclear Thermal" /></td>
<td><img src="image24" alt="Space Transfer Nuclear Thermal" /></td>
<td><img src="image25" alt="Space Transfer Nuclear Thermal" /></td>
</tr>
</tbody>
</table>

### TRANSPORTATION MILESTONES

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SHUTTLE ENHANCEMENT</strong></td>
<td><img src="image26" alt="Flight Data" /></td>
<td><img src="image27" alt="Vacuum Plasma" /></td>
<td><img src="image28" alt="Identify Preferred" /></td>
<td><img src="image29" alt="Complete AER" /></td>
<td><img src="image30" alt="Select Candidate" /></td>
<td><img src="image31" alt="Integrated Health Monitoring" /></td>
<td><img src="image32" alt="Vacuum Plasma Spray" /></td>
<td><img src="image33" alt="Chamber Demo in TPS" /></td>
<td><img src="image34" alt="Vacuum Plasma" /></td>
<td><img src="image35" alt="Chamber Demo in TPS" /></td>
<td><img src="image36" alt="Vacuum Plasma" /></td>
</tr>
<tr>
<td><strong>NEXT GENERATION MANNED TRANSPORTS</strong></td>
<td><img src="image38" alt="Develop Optimized" /></td>
<td><img src="image39" alt="Identify Preferred" /></td>
<td><img src="image40" alt="Complete AER" /></td>
<td><img src="image41" alt="Select Candidate" /></td>
<td><img src="image42" alt="Integrated Health Monitoring" /></td>
<td><img src="image43" alt="Vacuum Plasma Spray" /></td>
<td><img src="image44" alt="Chamber Demo in TPS" /></td>
<td><img src="image45" alt="Vacuum Plasma" /></td>
<td><img src="image46" alt="Chamber Demo in TPS" /></td>
<td><img src="image47" alt="Vacuum Plasma" /></td>
<td><img src="image48" alt="Chamber Demo in TPS" /></td>
</tr>
<tr>
<td><strong>HEAVY LIFT CAPABILITY</strong></td>
<td><img src="image49" alt="Integrated AHAC, CASE, APS Demo" /></td>
<td><img src="image50" alt="Cryogenic Fluid Flow" /></td>
<td><img src="image51" alt="Bearing Tech." /></td>
<td><img src="image52" alt="Complete CFD Tools" /></td>
<td><img src="image53" alt="Verify System Monitoring" /></td>
<td><img src="image54" alt="Adv. Manufacturing" /></td>
<td><img src="image55" alt="Program Definition" /></td>
<td><img src="image56" alt="Input Flow" /></td>
<td><img src="image57" alt="Program Definition" /></td>
<td><img src="image58" alt="Input Flow" /></td>
<td><img src="image59" alt="Program Definition" /></td>
</tr>
<tr>
<td><strong>LOW-COST COMMERCIAL TRANSPORT</strong></td>
<td><img src="image60" alt="Cooperative Industry/Government Program" /></td>
<td><img src="image61" alt="Booster Engine" /></td>
<td><img src="image62" alt="Concept Verification" /></td>
<td><img src="image63" alt="Advanced VH-1" /></td>
<td><img src="image64" alt="Demonstrated" /></td>
<td><img src="image65" alt="Continuous Forged AL-Li" /></td>
<td><img src="image66" alt="Cryogenics Test Article" /></td>
<td><img src="image67" alt="Oxidizer Expander" /></td>
<td><img src="image68" alt="Cycle Verification" /></td>
<td><img src="image69" alt="Oxidizer Expander" /></td>
<td><img src="image70" alt="Cycle Verification" /></td>
</tr>
<tr>
<td><strong>SPACE TRANSFER VEHICLE/LANDERS</strong></td>
<td><img src="image71" alt="Aeroassisted Flight" /></td>
<td><img src="image72" alt="Cryogenics Engine" /></td>
<td><img src="image73" alt="Characterized" /></td>
<td><img src="image74" alt="Cryogenics Engine" /></td>
<td><img src="image75" alt="Characterized" /></td>
<td><img src="image76" alt="Cryogenics Engine" /></td>
<td><img src="image77" alt="Characterized" /></td>
<td><img src="image78" alt="Cryogenics Engine" /></td>
<td><img src="image79" alt="Characterized" /></td>
<td><img src="image80" alt="Cryogenics Engine" /></td>
<td><img src="image81" alt="Characterized" /></td>
</tr>
</tbody>
</table>
DEVELOP TECHNOLOGIES TO INCREASE ON-ORBIT MISSION EFFICIENCY AND DECREASE LIFE CYCLE COSTS FOR FUTURE MANNED AND UNMANNED SCIENCE, EXPLORATION & COMMERCIAL MISSIONS.

- DEVELOP TECHNOLOGIES THAT WILL DECREASE LAUNCH WEIGHT AND INCREASE THE EFFICIENCY OF SPACE PLATFORM FUNCTIONAL CAPABILITIES
- DEVELOP TECHNOLOGIES THAT WILL INCREASE HUMAN PRODUCTIVITY AND SAFETY OF MANNED MISSIONS
- DEVELOP TECHNOLOGIES THAT WILL INCREASE MAINTAINABILITY AND REDUCE LOGISTICS RESUPPLY OF LONG DURATION MISSIONS
- IDENTIFY AND DEVELOP FLIGHT EXPERIMENTS IN ALL TECHNOLOGY AND THRUST AREAS THAT WILL BENEFIT FROM THE UTILIZATION OF SSF FACILITIES

SPACE PLATFORMS TECHNOLOGY

EARTH ORBITING PLATFORMS

- Structural Dynamics
- On-Orbit Non-Destructive Evaluation Techniques
- Space Environmental Effects
- Power Systems
- Thermal Management
- Advanced Information Systems

SPACE STATIONS

- Regenerative Life Support
- Integrated Propulsion and Fluid Systems Architecture
- Extravehicular Mobility
- Telerobotics
- Artificial Intelligence

SPACE BASED LABORATORY AND TESTBED

- Exploit Microgravity and Crew Interactive Capability to Advance and Validate Selected Technologies

DEEP SPACE MISSIONS

- Power and Thermal Management
- Propulsion
- Guidance, Navigation and Control
SPACE PLATFORMS TECHNOLOGY MISSION MODEL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EARTH OBSERVING SYSTEM</td>
<td>E OSSAR</td>
<td>EOS POLAR</td>
<td>EOS GEO</td>
<td></td>
</tr>
<tr>
<td>SPACE STATION FREEDOM</td>
<td></td>
<td>MTC</td>
<td>FOLLOW-ON PHASES USER OPERATIONS</td>
<td>PMC</td>
</tr>
<tr>
<td>SPACE SCIENCE</td>
<td>LUNAR OBSERVER</td>
<td>MARS NETWORK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMMUNICATIONS</td>
<td>ADRSS</td>
<td>GEO PLATFORMS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SPACE PLATFORMS MILESTONES

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EARTH ORBITING PLATFORMS</td>
<td>Complete Testing &amp; e-0 Evolutionary Model</td>
<td>CSI Ground Testbed Operational</td>
<td>Launch Mid-deck Attitude Control (MACS) Experiment</td>
<td>Demo 100-W thruster Control Array</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPACE STATION</td>
<td>Conduct CSI Beretta Studies for Multi-Ply Plasmas &amp; Attached P/L</td>
<td>Laboratory Test &amp; Selection of On-Orbit NDI Technologies</td>
<td>Complete Advanced LEO Materials &amp; Debris Model</td>
<td>Demo Advanced Control Technologies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEEP SPACE PLATFORMS</td>
<td>Acquire Hybrid-Scale Model of SS Freedom M-15 (AC) Configuration</td>
<td>Advanced Portable Life Support Methodology Selected</td>
<td>Begin ECLS Hardware Testing in Ground Based Testbed</td>
<td>On-Orbit Demo of MultiPropellant Rocket</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Complete Assessment of SDA Contaminant Sensors</td>
<td>Advanced Displays Tested</td>
<td>Complete AdvancedEMU Prototype</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SPACE TECHNOLOGY PLANNING CYCLE

Winter

Integrated NASA Space Technology Plan - Baseline

R&T Base & Focused R&T Program Revisions

SSTAG Preliminary Review of Planning

Spring

Integrated NASA Space Technology Plan - Revised

Spring Preview Technology Budget To Code A

Summer

Final Integrated Annual Plan and Budget To Code A

INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

TECHNOLOGY READINESS LEVELS

LEVEL 1
BASIC PRINCIPLES OBSERVED AND REPORTED

LEVEL 2
TECHNOLOGY CONCEPT AND/OR APPLICATION FORMULATED

LEVEL 3
ANALYTICAL & EXPERIMENTAL CRITICAL FUNCTION AND/OR CHARACTERISTIC PROOF-OF-CONCEPT

LEVEL 4
COMPONENT AND/OR BREADBOARD VALIDATION IN LABORATORY ENVIRONMENT

LEVEL 5
COMPONENT AND/OR BREADBOARD VALIDATION IN RELEVANT ENVIRONMENT

LEVEL 6
SYSTEM/SUBSYSTEM MODEL OR PROTOTYPE DEMONSTRATION IN A RELEVANT ENVIRONMENT (Ground or Space)

LEVEL 7
SYSTEM PROTOTYPE DEMONSTRATION IN A SPACE ENVIRONMENT

LEVEL 8
ACTUAL SYSTEM COMPLETED AND "FLIGHT QUALIFIED" THROUGH TEST AND DEMONSTRATION (Ground or Flight)

LEVEL 9
ACTUAL SYSTEM "FLIGHT PROVEN" THROUGH SUCCESSFUL MISSION OPERATIONS
INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

TECHNOLOGY MATURATION STRATEGY

Technology Readiness Level

OAST R&T Responsibility

Potential Joint Responsibility

Flight Program Office Responsibility

Flight Project Office Responsibility

System Test, Launch and Operations

System/Subsystem Development

Technology Demonstration

Technology Development

Research To Prove Feasibility

Basic Technology Research

Flight Project Full-Scale Development, Launch & Operations