We Must Take the Next Steps Towards Safe, Routine Space Travel

6 1/2 Generations of Airplanes in a Century

Wright Flyer (1903)

Boeing 777 (Today)

1st Generation Reusable Launch Vehicle (1981 – Today)
Enterprise Goals

GOALS: Earth-to-Orbit

- Within 10 years,
  - Increase the safety by two orders of magnitude
  - Reduce the cost to NASA transportation of placing payloads in orbit by one order of magnitude.

- Within 25 years,
  - Increase the safety by four orders of magnitude.
  - Reduce the cost of placing payloads in orbit by two orders of magnitude.

GOALS: In-Space Transportation

- Within 15 years,
  - A factor of ten reduction in the cost of Earth orbital transportation.
  - A factor of two to three reduction in propulsion system mass and travel time required for planetary missions.

- Within 25 Years,
  - Enable bold new missions to the edge of the solar system and beyond by reducing travel times by one to two orders of magnitude.
Generations of Reusable Launch Vehicles

Today: Space Shuttle
1st Generation RLV
- Orbital Scientific Platform
- Satellite Retrieval and Repair
- Satellite Deployment

2010: 2nd-Generation RLV
- Space Transportation
- Rendezvous, Docking, Crew Transfer
- Other on-orbit operations
- ISS Orbital Scientific Platform
- 10x Cheaper
- 100x Safer

2025: 3rd Generation RLV
- New Markets Enabled
- Multiple Platforms / Destinations
- 100x Cheaper
- 10,000x Safer

2040: 4th Generation RLV
- Routine Passenger Space Travel
- 1,000x Cheaper
- 20,000x Safer
Space Transportation Across NASA

Ames Research Center
- Non Metallic
- Thermal Protection Systems
- Computational Tools
- Information Systems

Sennis Space Center
- Rocket Propulsion Testbed

Kennedy Space Center
- Payload and Launch Operations
- Range Safety
- IVHM
- Cryo Testbed

Dryden Flight Research Center
- Atmospheric Flight Operations

Marshall Space Flight Center (Lead Center)
- System Integration
- Propulsion Systems
- Avionics Systems
- Combined-Cycle Propulsion

Langley Research Center
- Airframe Design
- Integrated Thermal Structures
- Materials Research
- Combined Cycle Propulsion

JPL
- In Space Propulsion Concepts
- Microelectronics/ Sensors

Glenn Research Center
- Power Systems
- Advanced Propellants
- Propulsion Materials
- Combined-Cycle Propulsion

Air Force Research Lab
- System Integration
- Propulsion Systems
- Avionics Systems
- Combined-Cycle Propulsion

Johnson Space Center
- Crew and Passenger Systems
- Vehicle Definition
- Structural and Mechanical Design and Integration
- Advance Manufacturing
Three Tiered Implementation Approach for Future Space Transportation Technology

Trailblazer Class Demonstrators
- Integrated system technology
- Flight demonstrators
- Responds to mission needs “pull”
- Verifies operability & programmatic viability
- May provide residual capability (science payloads)
- End users share in both decisions and cost

Pathfinder Class Demonstrators
- Narrow focus flight technology demonstrators
- Driven by technology
- Development similar to “Discovery” spacecraft series
- Less than ~ $100M each
- In test in less than ~ 3 years
- Allows for NASA and industry development
"We cannot foresee the ingenuity that companies, established or entrepreneurial, will bring to the building of new industries in the 21st century based upon the Highway to Space."
Develop a Comprehensive, Agency Level Space Transportation Plan That Will Enable NASA’s Strategic Plan

- Focus on Safety, Reliability, Cost and NASA mission requirements while making maximum use of US aerospace industry capabilities and commercial market leverage
- Enable a competition at an acceptable level of risk for a 2nd generation Reusable Launch Vehicle (RLV) by 2005 which could include Shuttle-derived and new design RLV concepts
- Secure NASA’s future through investments in 3rd generation RLV technologies for Earth-to-orbit and in-space applications
- Ensure Continued Safe Access to Space through Space Shuttle Safety Upgrades until a replacement alternative has been demonstrated
Timeline for Addressing NASA's Needs


<table>
<thead>
<tr>
<th>Evolved Shuttle (Upgrades, Obsolescence and Performance)</th>
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Mandatory Safety Upgrades to Current Shuttle

Decadal Plan

| Criteria for 2nd Generation RLV Decision |

Mission Model

| 2nd Generation RLV Competition |

Baseline Req'ts Update

| 2nd Generation RLV IOC |

- Human Rating Update
  - CTV/CRV
  - Shuttle Upgrades
  - Architecture Study

Shuttle Derived Design

2nd Generation RLV Development and Operations

Current Shuttle Transition

- 2nd Generation RLV Certification

New RLV Design

2nd Generation RLV Development and Operations

CTV / CRV

Technology for 3rd Generation RLV

Programmatic Planning
Significant 2nd Generation Technology Drivers

- Crew Escape and Survival
  - Detection, separation, ascent/descent

- Operable, Long-life $\text{H}_2/O_2$ and RP/O$_2$ Engines
  - 200 mission life, 100 missions to overhaul

- Long life, lightweight integrated airframe
  - Critical integrated cycle testing (500 missions)

- Advanced TPS, IVHM, and Operations
  - Quick turn vehicle with intelligent data analysis

- Ejector Ramjet
  - Improved performance margin

- SHARP Leading Edges
  - Global crossrange from orbit

Significant Commonality Between Shuttle Derived and New Design RLV Needs
Example Large Scale Ground Demonstrations

LOx/LH₂ Engine Prototypes
LOx/Hydrocarbon Engine Prototype
Ejector Ramjet Testbed
Crew Escape Demonstrations
Integrated Airframe Life Cycle Testing
Large Scale Advanced Mfg
Example Pathfinder Demonstrations

- Additional X-34 and X-37 Experiments and Demonstrations
- Space Shuttle Experiments
- Reusable First Stage
- Rocket Based Combined Cycle Experiments

- SHARP Materials / High Lift/Drag Experiments
- Crew Escape Demonstrations (Narrow Envelope / Subscale)
- Rapid Operations Demonstrations
3rd Generation Technology Drivers

- Dramatic Propulsion Performance Improvement
  - RBCC/TBCC - Dual Mode Ramjet/Scramjet
  - PDE - Pulse Detonation Rocket Engine / Combined Cycle Engine
  - 500 mission propulsion component life
  - Magnetic Launch Assist

- Low Drag aerodynamic structures
  - SHARP ultra-high temperature ceramics
  - Integrated smart/adaptive thermal-structures
  - Morphing structures
  - Drag modulation through electromagnetics and flow physics

- Adaptive Intelligent Systems
  - Adaptive, self-diagnosis, self-healing thermal protection systems
  - Structurally integrated, wireless, micro/nano sensors and avionics
  - Regenerative sensors and system healing
  - Autonomous, adaptive control

- Spaceport Range Operations
Systems Approach to Safety, Reliability and Cost

10,000x Safer

Cost

100x Cheaper

Move Operating Range/De-rate
Add Material Capability/Weight

Requires Increased Margin
Reduce Variability
Requires Increased Testing

Safety
Crew
Escape
Inherently Reliable
Repairable
IHM
Robust Design
Operating Margin
### ASTP Organization is Driven By Goals

#### Pillar 3

<table>
<thead>
<tr>
<th>Goal</th>
<th>2nd Generation RLV</th>
<th>In-Space</th>
<th>Spaceliner 100 (3rd Generation RLV)</th>
<th>Space Transportation Research</th>
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Composite Tank and Structures (LaRC)
- Materials and Manufacturing Processes

Propellant Densification (GRC)
- Reduced GLOW

Propulsion (MSFC)
- Light weight, High-performance, Increased Safety Margins and Manufacturing

Power (GRC)
- High Power Density and Reliability

TPS and Hot Structures (ARC/LaRC)
- Materials, Waterproofing, and Manufacturing
National Center for Advanced Manufacturing
Manufacturing Technology Development

- Provide World Class Manufacturing Capability Enabling Future Space Transportation Systems
- Strengthen U.S. Competitiveness in Aerospace/Commercial Markets
- Create Federal, State, University and Industry Mfg. Partnerships
- Enhance Educational Development
- Effect a cultural change in Manufacturing to Intelligent-Collaborative Environment
Large Scale Propulsion Testbeds/Demonstrations

Major demonstrations will use the Sst ACT.
Two Focused Investments

♦ Peroxide/RP Propulsion
AR2-3 Test Program
Boeing Rocketdyne SAA

Advanced Catalysts,
Igniters, & Turbopumps
Boeing Rocketdyne CA
Aerojet CA
TRW/GK/Purdue FFPC
FMC FFPC

♦ Peroxide/Hybrid Propulsion

Hybrid Sounding
Rocket (HYSR)
LMMSS-SAA

LMA/Thiokol/Boeing-IFCC

Upper Stage
Flight Experiment
• Pressure fed engine
• Common bulkhead
composite structures
Orbital Sciences-IFCC
Scope of Space Transfer Technology Project

Orbital Transfer Vehicles

Sample return

In-Situ Prop/Ascent Chem Prop Stage
Interstellar Precursor Technologies

Solar Sails

Nuclear Electric Propulsion
Technical Challenges

- Improved propulsion performance to specific impulse (Isp) > 500 sec using combined cycle air-breathing rocket propulsion

- Increased all propulsion system thrust-to-weight ratio through the use of metal matrix composites, ceramics, and other advanced materials

- Increased propulsion life cycle capability to 500 missions through advanced design techniques and materials

- Decrease development cost through advanced design techniques and robust testing
Accomplishments

♦ Aerojet & Rocketdyne Flowpath Tested
  • Test Conducted From M0 to Mach 8
  • Total Of 253 Test Conducted
  • Good Overall Performance

♦ Several First In Testing
  • Dynamic Trajectory Simulation (AAR -> RAM and RAM-> SCRAM))
  • SCRAM Testing @ High Dynamic Pressure (M8 @ 1,200 Psf)

♦ Parametric Test Performed By Pennsylvania State University

♦ Trailblazer Concept Development
  • Lead By Glenn Research Center
  • Currently Testing @ GASL

♦ System Studies
  • Various Vehicle/Engine Combinations Being Studied
    - RBCC
    - TBCC
    - PDE
  • Sensitivity Trades Being Made
    - Trajectories
    - Fineness ratio
    - Payload capability
Airframe Technology Elements

Integrated Airframe Design (LaRC Lead)

Integrated Thermal Structures and Materials (LaRC Lead)

Thermal Protection Systems (ARC Lead)

Aero/Aerothermo Enhancement (LaRC Lead)
No FY00 Funding
Launch Technologies Elements

Avionics and Flight Control
Lead Center - MSFC

Power
Lead Center - GRC

Integrated Design and Analysis tools
Lead Center - MSFC

Crew Systems
(No FY00 Funding)
IVHM Elements

Core Technologies (ARC)
- Information Technologies
- Sensors
- Communications

Power IVHM
- GRC

Systems Engineering and Integration IVHM
- ARC

Avionics IVHM
- MSFC

Structures IVHM
- LaRC

Ground IVHM
- KSC

Thermal Protection Systems IVHM
- ARC

Propulsion IVHM
- GRC and MSFC
Project Elements

Operations and Range Technology Project

MagLev Launch Assist

Spaceport Range and Operations

Automated Umbilical
Objectives - Space Transportation Research Investment Area

- The Space Transportation Research Investment Area is responsible for developing the technologies to enable bold new missions.
- Research will pursue proof-of-concept research in revolutionary technology areas that may lead to
  - Dramatic reductions in the cost of access to space or
  - Enable new interplanetary or interstellar space missions by reducing travel times by one to two orders of magnitude.
- This investment area consists of the
  - Advanced Propulsion Research Project
  - Breakthrough Propulsion Physics Project.

Areas

- Advanced Chemical
- Electromagnetic
- Advanced Nuclear
- Fusion / Antimatter
- Interstellar Research
- Breakthrough Propulsion Physics