NASA Space Technology Draft
Roadmap Area 13:
Ground & Launch Systems Processing

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NASA Space Technology Roadmaps Process

**NASA Process**

1. START & Input from MDs & Center
   - Identified MD Goals, Missions, Architectures & Timelines;
   - MD Technology Roadmaps & Prioritizations;
   - Center Technology Focus Areas

2. Identify Technology Areas
   - Identified Technology Areas (TAs)

3. Establish TA Teams
   - OCT established NASA internal 6-member subject expert teams for each TA, with one or two chairs

4. Common Approach for TA Teams
   - Guidelines, assumptions, deliverables

5. Form Starting Point for TA Roadmaps
   - Assessed past roadmaps; MD & Center inputs

6. Roadmapping Process
   - Preliminary roadmaps for TA areas

7. Internal Reviews
   - Each TA Roadmap reviewed by OCT & extended teams of subject experts

8. DRAFT NASA STRs
   - OCT released draft Space Technology Roadmaps to the NRC & to the Public

**NRC Process**

A: Establish NRC Teams
   - NRC to appoint steering committee and 6 panels

B: Identify Common Assessment Approach
   - NRC to establish a set of criteria to enable prioritization within and among all TAs

C: Initial Community Feedback
   - NRC to solicit external input from industry & academia

D: Additional Community Feedback
   - NRC to conduct public workshops

E: Deliberations by NRC Panels
   - NRC panels meet individually to prioritize technologies and suggest improvements to roadmaps

F: Documentation by NRC Panels
   - NRC Panels to provide written summary to Steering Committee

G: NRC Interim Findings
   - NRC to release a brief interim report that addresses high-level issues associated with the roadmaps, such as the advisability of modifying the number or technical focus of the draft NASA roadmaps

H: FINAL NRC REPORT
   - NASA to release Roadmap Report
   - With decisional information, including: summary of findings and recommendations for each of the roadmaps; integrated outputs from the workshops and panels; identify key common threads and issues; priorities, by group (e.g., high, medium, low), of the highest priority technologies from the TAs

TA #13 Draft Roadmap briefing to the FAA/AIAA
Commercial Space Conference – Feb 2011
The Scope of TA #13 includes:

- Assembly, integration, and processing of the launch vehicle, spacecraft, and payload hardware
- Supply chain management
- Transportation of hardware to the launch site
- Transportation to and operations at the launch pad
- Launch processing infrastructure and its ability to support future operations
- Range, personnel, and facility safety capabilities
- Launch and landing weather
Technology Area Overview

The Scope of TA #13 also includes:

- Environmental impact mitigations for ground and launch operations
- Launch control center operations and infrastructure
- Mission integration and planning
- Mission training for both ground and flight crew personnel
- Mission control center operations and infrastructure
- Telemetry and command processing and archiving
- Recovery operations for flight crews, flight hardware, and returned samples
Technology Area Overview

• **HIGH RECURRING COSTS**. . . are the bane of our nation’s Space Program. . . and significantly and negatively impact our ability to fulfill NASA’s mission.
Technology Area Overview

• What are the challenges and cost drivers in our current Ground and Mission operations?
  – Dated, Vehicle-unique infrastructure
  – Labor intensive operations
  – Proliferation of duplicative systems
  – Lack of sufficient insight into system configuration/system performance margins
  – Low mission availability due to weather restrictions and significant maintenance/refurbishment required between missions
  – Conservative risk and safety postures
Technology Area Overview

- TA #13 identifies ground, launch and mission technologies that will:
  - Dramatically transform future space operations, with significant improvement in life-cycle costs
  - Improve the quality of life on earth, while exploring in co-existence with the environment
  - Increase reliability and mission availability using low/zero maintenance materials and systems, comprehensive capabilities to ascertain and forecast system health/configuration, data integration, and the use of advanced/expert software systems
  - Enhance methods to assess safety and mission risk posture, which would allow for timely and better decision making
Key Technologies Identified

- Low-loss cryogenic storage and transfer (TABS 13.1.1)
- Corrosion detection and prevention (TABS 13.2.1)
- Autonomous systems and integrated systems health management (ground systems and moving ground to onboard systems) (TABS 13.1.3.7)
- Intelligent, self-diagnosing/self-healing components and systems (TABS 13.3.5.4 and 13.3.6)
- Multipurpose models enabling distributed control and collaboration (TABS 13.1.3)
- Environmental protection and remediation (TABS 13.2.2 and 13.2.3)
- Weather effects detection and mitigation (TABS 13.4.3)
- Ground launch assist systems (TABS 13.3.1)
- Landing and recovery systems (TABS 13.4.2)
Corrosion Detection and Control

- Corrosion is a “silent killer” of the world’s critical infrastructure and costs the world economy over $2 trillion annually
  - The total annual estimated direct cost of corrosion in the U.S. in 2010 was $578 billion—approximately 4.2% of the nation’s Gross Domestic Product
- For NASA, the severe degradation of structures from corrosion (caused by exposure to high temperature, humidity, salinity, sunlight, or highly acidic launch exhaust, use of dissimilar metals, standing/trapped water, etc.) has resulted in significant ground operations corrosion-related costs.
- NASA can achieve significant cost savings, for the space program and for the nation as a whole, by developing and implementing new corrosion prevention, detection, and mitigation technologies that provide environmentally friendly (no toxic materials) corrosion resistant/protective materials, coatings, and systems
  - longer lasting and fewer reapplications required
  - lower maintenance/inspection costs
  - reduced corrosion related damage/structural failures
  - less environmental contamination
Corrosion Detection and Control Technologies

- **Enhancing current capabilities:** Smart, multifunctional, environmentally friendly paint system that detects and signals corrosion, mitigates corrosion, and self heals mechanical damage.
- Proactive corrosion control technologies will replace the current reactive state-of-the-art practice of repair and refurbishment after a failure or problem occurs.
- **Enabling new, game-changing capabilities:** Autonomous, self-healing structures using corrosion-hardened materials that perform without degradation or the need for coatings or repairs; corrosion resistant structures.
- Providing benefits for improving and protecting national infrastructure
  - Military weapon systems. (CC Tech and NACE Int. in cooperation with DoT and FAA, Sept 2001)
  - Army ground vehicles and Navy ships
  - U.S. oil and gas industry ageing infrastructure (rusting, corroded assets)
  - Other potential spinoffs/collaborators include the automotive, building, manufacturing, and housing industries, the Paint industry, and degrading transportation infrastructure.
Need for Additional "Higher TRL" Investment

Continuous Improvement

Technology Integration
System Development
Risk Reduction

Investment Level, %

- TRL 1 to 2
- TRL 2 to 3
- TRL 3 to 4
- TRL 4 to 5
- TRL 5 to 6
- TRL 6 to 7
- TRL 7 to 8
- TRL 8 to 9
- Veh & Gnd Sys Upgrades

Percent of Current Investment
Technology Integration Shortfall

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Ground and Launch Technologies Demonstrations

• In our existing Spaceflight Programs, sets of existing “Domain” Technologies have been integrated and validated for Ground and Launch operations.

• Without comprehensive capabilities for full scale test and demonstration, new, individual technologies are overly constrained to be “one for one”, drop-in replacements for an existing capability, without the ability to re-engineer HOW operations are conducted.
  - This has severely restricted the ability for meaningful technology insertion.

• To address this issue, a series of Ground and Launch Technology Demonstrations (GLTDs) are identified in TA #13 to integrate and test a bundled set of technology capabilities into an operationally relevant environment (TRL 6/7 and IRL 6/7).
Ground and Launch Technologies Demonstrations

• Regularly scheduled technology demonstrations (approximately every 18 months) provide a deterministic and consistent ability for technologists, engineering and operations experts to collaborate for fielding demonstrations for advancing Technology and Integration Readiness of component technologies.

• GLTDs would showcase a distributed Ground Demonstration “Network” to utilize multiple locations (e.g., vehicle providers, commercial data centers, test stands and control rooms distributed across the country) collaborating for conducting distributed demonstration.

• Promising and emerging technologies that are proven via GLTD could then be incorporated into upcoming test flights, referenced for the planning and development of future missions, and/or retrofitted into upgrades to existing operational capabilities.
### Technology Area Strategic Roadmap

#### Technology Roadmap: Ground and Launch Systems Processing

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<th>NASA Space Missions and Milestones</th>
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#### Key Investments and New Capabilities

**13.1 Technologies to Optimize the Operational Life-Cycle**  
- Details: Densification, rapid transit, zero loss storage, virtual reality, and information technology
- Key Assumptions: Intelligent devices, for autonomous cryo ops...
- Milestones: Draft Roadmap briefing to the Ground-Launch Systems...

**13.2 Environmental and Green Technologies**  
- Details: Air, water, and soil remediation, self-healing materials...
- Key Assumptions: Autonomous detection, coatings...
- Milestones: Roadmap briefing to the FAA/AIAA...

**13.3 Technologies to Increase Reliability and Mission Availability**  
- Details: On-demand dynamic frequency allocation,...  
- Key Assumptions: Integrated prognostics and FDR pathfinder for autonomous cryo ops...
- Milestones: Draft Roadmap briefing to the Ground-Launch Systems...

**13.4 Technologies to Improve Mission Safety/Mission Risk**  
- Details: Virtual reality, tele-operated inspection and servicing robots...
- Key Assumptions: Autonomous inspection and servicing robot...
- Milestones: Draft Roadmap briefing to the Ground-Launch Systems...

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**Milestones:**  
Summary

- Ground and Launch Processing Technologies enhance life on earth AND have a major impact on how we access space
  - GLPT are also directly applicable to building and manufacturing industries, weather forecasting, defense/homeland security, oil and gas industries, energy, hazardous operations
  - Can feasibly provide the cost breakthroughs to help realize routine, commercial space access
- The inter-relationships between Technology Readiness, Integration Readiness, and System Readiness drive the maturation of Ground and Launch Processing Technologies
  - “Ground and Launch Technology Demonstrations”, which integrate promising technologies into an operationally relevant environment, can maximize the benefits of our Agency’s technology programs
- For more information on this Roadmap, and to provide input and public comment, please visit the National Research Council Site or support the public workshop in March:
  - http://sites.nationalacademies.org/DEPS/ASEB/DEPS_059552
Technology Area Breakdown Structure

13.1 Technologies to Optimize the Operational Life-Cycle

13.1.1 Storage, Distribution and Conservation of Fluids
1. High efficiency/zero loss storage
2. High efficiency fluid transfer
3. High efficiency recovery, purification, and liquefaction systems
4. Limited resource conservation (e.g., Helium)
5. Fluids system components
6. Low-cost commodity production
7. Fluid servicing

13.1.2 Automated Alignment, Coupling, and Assembly Systems
1. Positioning and alignment systems
2. Automated control systems (self positioning, self-configuring)
3. Automated ground-to-vehicle and ground-to-payload umbilicals and interfaces
4. Leak free quick disconnects with self sealing capability
5. Latching, actuation, mating and release mechanisms (shape memory alloys)
6. Automated handling and assembly (robotics)

13.1.3 Autonomous Command and Control for Ground Systems and Integrated Vehicle/Ground System
1. Next-generation modeling capabilities for life-cycle
2. Mission preparedness technologies
3. Advanced space-borne computing
4. Open, ground system service-oriented architecture (common multi-mission infrastructure)
5. Automated planning and scheduling tools
6. Automated/autonomous information systems
7. Transferring mission operations ground planning and scheduling software to the flight element
13.2 Environmental and Green Technologies

13.2.1 Corrosion Prevention, Detection and Mitigation
1. Prevention: environmentally friendly corrosion resistant materials and systems
2. Detection of hidden corrosion (i.e. under paint)
3. Control and mitigation

13.2.2 Environmental Remediation and Site Restoration
1. Groundwater and soil contamination detection and mitigation (pollution/contaminant removal)
2. Airborne release detection and mitigation (emission control)
3. Spill/damage prevention and response technologies
4. Environmentally friendly remediation of waste and materials

13.2.3 Preservation of Natural Ecosystems
1. Carbon sequestration technologies
2. Reduction of nutrient runoff into Estuaries and Waterways (bio-reactors for wastewater treatment)
3. Nitrocision for coating removal - eliminates contaminated sand blast media and water
4. Laser based surface prep technologies - to replace chemicals used to etch/activate substrate surfaces reducing hazardous streams

13.2.4 Alternate Energy Prototypes
1. Alternative fuels (non-toxic propellants)
2. Green products, materials, and processes
3. Alternate energy sources
13.3 Technologies to Increase Reliability and Mission Availability

13.3.1 Advanced Launch Technologies
1. Multi-vehicle launch capabilities (e.g. universal launch pad)
2. Vertical launch capabilities
3. Horizontal launch capabilities
4. Air launch capabilities

13.3.2 Environment-hardened materials and structures
1. Low flammability materials
2. Puncture/abrasion resistant materials
3. Thermal protection/insulating materials
4. Blast/explosion abatement technologies
5. Lightning/Radar hardening of vehicle and components
6. ESD resistant materials/coatings - increase decay-rate of charged materials
7. Weather hardening of structures

13.3.3 Inspection, Anomaly Detection and Identification
1. Non-destructive, minimally intrusive inspection and evaluation electronics
2. Automated anomaly detection capabilities for ground and launch systems and processes

13.3.4 Fault Isolation and Diagnostics
1. Minimally-intrusive, non-intrusive monitoring technologies
2. Wireless interconnects
3. Wiring, harnesses, cables
4. Electronics, connectors, switches
5. Materials (coatings/polymers, adhesives, composites, insulation)
6. Components and systems (test equipment, structures)
7. Automated fault isolation capabilities for ground and launch systems and processes

13.3.5 Prognostics Technologies
1. Wiring, harnesses, cables
2. Electronics, connectors, switches
3. Materials (coatings/polymers, adhesives, composites, insulation)
4. Components and systems (test equipment, structures)
5. Automated prognostics capabilities for ground and launch systems and processes

13.3.6 Repair, Mitigation, and Recovery technologies
1. Wiring, harnesses, cables
2. Electronics, connectors, switches
3. Materials (coatings/polymers, adhesives, composites, insulation)
4. Components and systems (test equipment, structures)
5. Automated repair and recovery capabilities

13.3.7 Communications, Networking, Timing, and Telemetry
1. Launch vehicle telemetry systems
2. Remote telemetry systems
3. Communication/Telemetry systems based on new spectrum (e.g. millimeter wave and optical)
4. On-demand dynamic frequency allocation
5. On demand communications
6. Universal comm beacon
7. Highly secure, access controlled flexible data networking (terrestrial and airborne)
8. Intelligent network topologies
9. Self-planning inter-spacecraft communications
10. Anomaly/Fault detection, isolation and recovery architectures
11. Adaptive data compression

TA #13 Draft Roadmap briefing to the FAA/AIAA Commercial Space Conference – Feb 2011
13.4 Technologies to Improve Mission Safety/Mission Risk

13.4.1 Range Tracking, Surveillance, and Flight Safety Technologies

1. Range tracking technologies
2. Range surveillance technologies
3. Range flight safety systems

13.4.2 Landing and Recovery Systems and Components

1. Vertical landing in an Energy Absorption Foam Filled Pit
2. Precision landing systems
3. High lift to drag re-entry vehicles with deployable inflatable aero-surfaces
4. Autonomous landing systems
5. Short runway vehicle arresting systems
6. Advanced air bag landing systems
7. Advanced vertical landing gear - variable density damping
8. Ground based power beam assisted vertical landings

13.4.3 Weather Prediction and Mitigation

1. Single Authorative Source for weather data assimilation and prediction
2. 3D atmospheric electrical field measurement
3. Direct probing of the electric field in the clouds
4. 4D weather information integration for pilot and autopilot use

13.4.4 Robotics/Telerobotics

1. Machine vision
2. Remote repair capability
3. Remote hazardous operations
4. Autonomous robotic operations - interface and check-out systems

13.4.5 Safety Systems

1. Advanced algorithms to predict failures
2. Advanced tools to assess risk posture
3. Autonomous "Safety Sentinels"
4. Human performance modeling
5. Advanced systems for Protection of Equipment
6. Advanced systems for protection of personnel
Backup – TASR - 13.1 Technologies to Optimize the Operational Life-Cycle

Key NASA Missions and Milestones

- Key Investments and New Capabilities
  - 13.1.1 Storage, Distribution and Conservation of Fluids
    - Zero loss storage: NBP cryo
    - High efficiency valve coupling
    - Leak-free valveless pumps
  - 13.1.2 Automated Alignment, Coupling, and Assembly Systems
    - Rapid mate umbilicals
    - Contactless umbilicals
  - 13.1.3 Autonomous C&C for Ground and Integrated Vehicle/Integrated Systems
    - Planning systems standards
    - Comprehensive data archive and retrieval

Technology Legend:
- Needed for planned missions
- Enhances planned missions
- Enables new mission types ("push" technologies)

Timeline:
- 2010
- 2015
- 2020
- 2025
- 2030
Backup – TASR - 13.3 Technologies to Increase Reliability and Mission Availability (1 of 2)

**Key Assumptions**

- NASA Space Missions and Milestones

**Key Investments and New Capabilities**

- **13.3.5 Prognostics Technologies**
  - Integrated prognostics and FDIR pathfinder for autonomous cryo ops
  - Wiring harnesses & cables failure predict algorithms
  - Prognostics enabled intelligent devices
  - Materials & structures failure predict algorithms

- **13.3.6 Repair, Mitigation, and Recovery Technologies**
  - Recovery algorithms for intelligent devices
  - Recovery pathfinder for autonomous cryo ops

- **13.3.7 Communications, Networking, Timing, and Telemetry**
  - Beacons
  - Software defined radios
  - Millimeter wave communication
  - Optical beam coupling & alignment

**Technology Legend**

- △ Needed for planned missions
- ⬤ Enhances planned missions
- ▶ Enables new mission types ("push" technologies)
### Key Assumptions

**NASA Space Missions and Milestones**

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### Key Investments and New Capabilities

#### 13.4.1 Range Tracking, Surveillance, and Flight Safety Technologies

- Anti-jamming, anti-spoofing system
- Collision avoidance system
- Ground tracking
- Autonomous on-board FTS
- Space-based laser FTS
- Autonomous range center
- Self-correcting flight trajectory
- Autonomous precision landing pathfinder
- Power beam landing assist

#### 13.4.2 Landing and Recovery Systems and Components

- Remote vehicle sensing at landing
- Automated vehicle/payload landing/reconfiguration
- Airbag landing systems
- Energy absorption foamfilled landing pit
- AGV "Seek and Grab" pathfinder

#### 13.4.3 Weather Prediction and Mitigation

- NextGen atmospheric flight database
- NextGen launch, landing, recovery database
- Onboard 4D pilot displays
- Onboard 4D autopilot capability
- 3D R/T lightning measurements
- Remote measurement of lightning potential

### Technology Legend

- Needed for planned missions
- Enhances planned missions
- Enables new missions/types ("push" technologies)
## Key Assumptions

### NASA Space Missions and Milestones

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## Key Investments and New Capabilities

### 13.4.4 Robotics/Telerobotics

- Virtual instruments
- 3D materials and structures visualization and planning
- 3D launch pad visualization and planning
- 3D landing env and vehicle visualization and planning
- Tele-operated inspection and servicing robot
- Tele-operated maintenance and repair robot pathfinder
- Machine vision and object recognition
- Autonomous inspection and servicing robot
- Smart cameras
- Autonomous "Safety Sentinel"
- Hazardous ops pathfinder
- Remote control safety sentinel pathfinder
- Human performance modeling
- Advanced flame retardant pathfinder
- Advanced SCAPE/cryo-breathers

### 13.4.5 Safety Systems

- Microgravity safety sentinel
- Advanced crack detection
- Risk/hazard automated assessment
- Autonomous inspection and servicing robot
- Remote control safety sentinel pathfinder
- Human performance modeling
- Advanced flame retardant pathfinder
- Advanced SCAPE/cryo-breathers

## Technology Legend

- ▲ Needed for planned missions
- △ Enhances planned missions
- □ Enables new mission types ("push" technologies)
What is Integration Readiness Level?

**Definition [9]**

1. **Compatibility** (i.e. common language) between technologies to orderly and efficiently integrate and interact.
2. There is some level of specificity to characterize the interaction (i.e. ability to influence) between technologies through their interface.
3. There is sufficient detail in the quality and assurance of the integration between technologies.
4. There is sufficient control between technologies necessary to establish, manage, and terminate the integration.
5. The integrating technologies can accept, translate, and structure information for its intended application.
6. The integration of technologies has been verified and validated with sufficient detail to be actionable.

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**Integration** – the combining and coordinating of separate components into a seamless unit – interfacing the compatible interactions of various technologies together.

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"Technologies are not only getting more complex, they are getting more integrated."

- Murray Cantor, Distinguished Engineer, IBM Rational Group

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**Technology Readiness Levels**

The TRL Continuum (does it take 4 years, or 15?)

New Systems Deployed Today would begin development two to five years ago, with technologies proven one or more years before that. After several years of technology development - we need integrated and strategic alignment of research and development for the future.

**System Readiness Level Model**

The SRL Model is a function of the individual Technology Readiness Levels (TRLs) in a system and their subsequent integration points with other technologies, the Integration Readiness Level (IRL).

**What is Integration Readiness Level?**

A systematic measurement of the interfacing of compatible interactions for various technologies and the consistent comparison of the maturity between integration points.

**System Readiness Level**

The System [Diagram]

**Integration Readiness**

Definition:
1. The integration of technologies has been verified and validated with sufficient detail to be actionable.
2. The integrating technologies can accept, translate, and structure information for its intended application.
3. There is sufficient control between technologies necessary to establish, manage, and terminate the integration.
4. There is sufficient detail in the quality and assurance of the integration between technologies.
5. There is compatibility (i.e., common language) between technologies to orderly and efficiently integrate and interface.
6. There is some level of specificity to characterize the interaction (i.e., ability to influence) between technologies through their interface.
7. An interface (i.e., physical connection) between technologies has been identified with sufficient detail to allow characterization of the relationship.

**System Readiness**

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