Materials, Structures, Mechanical Systems & Manufacturing

OFFICE OF CHIEF TECHNOLOGIST
TECHNOLOGY ROADMAP

Technology Roadmap Briefing to NRC
January 27, 2011

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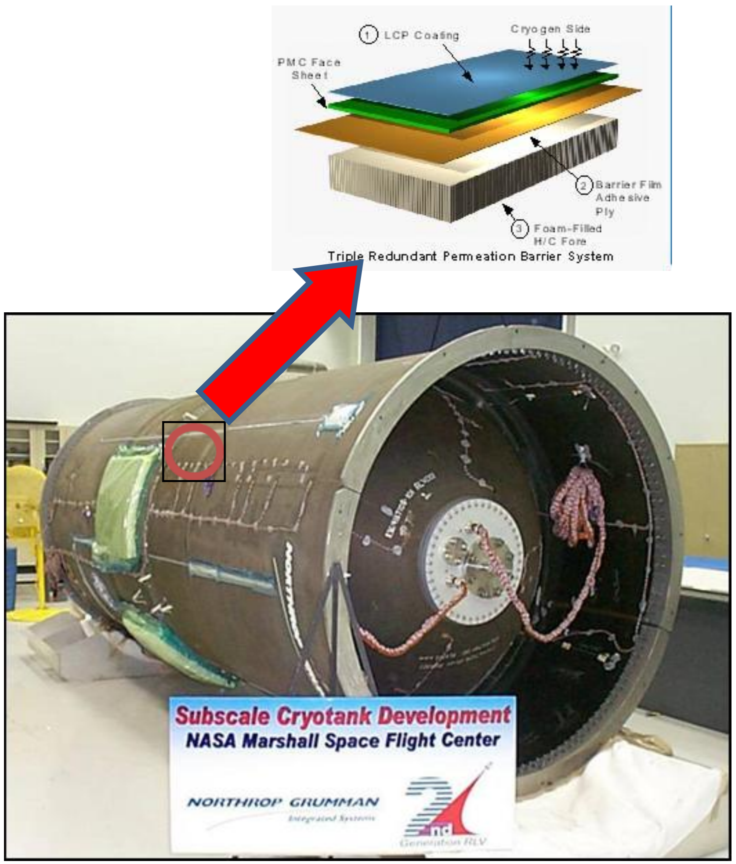
Presentation Outline

- Overview / Background
- Strategic Goals
- Materials/Structures/Mechanical Systems/Manufacturing Roadmap
- Virtual Digital Fleet Leader
- Top Technical Challenges
- Technology Area (TA) Interdependencies
- Benefits to other National Needs
- Summary

Martian Sunset

Technology Area Overview

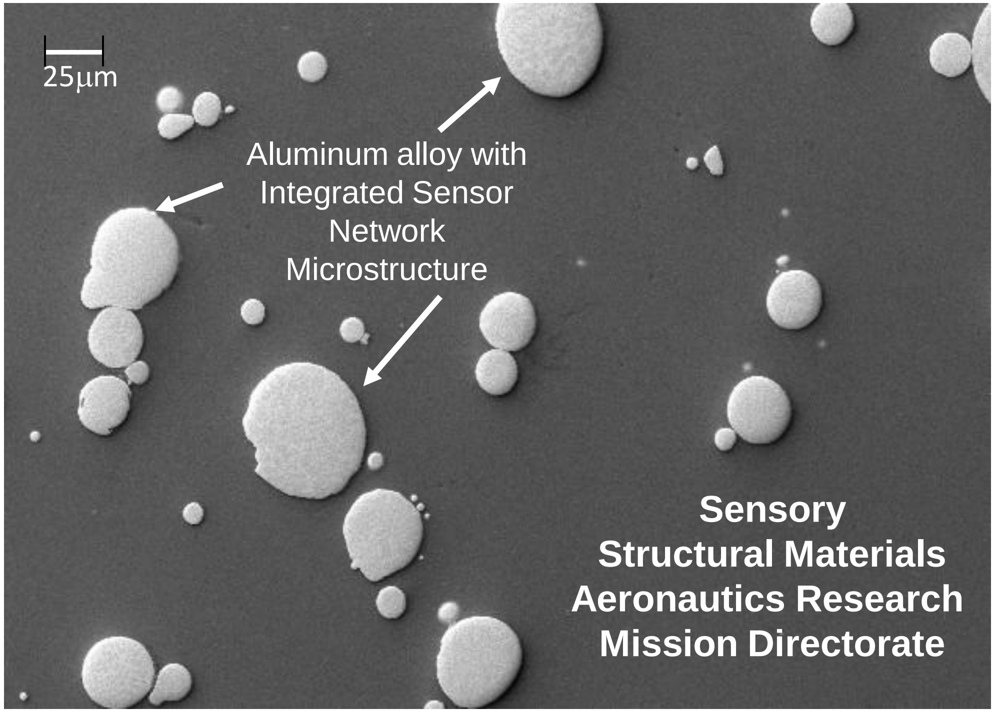
- **Technology Area (TA)**
  - Extremely broad discipline areas, technologies cross cutting into most other Technology Areas
  - Area is a high priority for all NASA missions
  - Addressing a broad NASA exploration architecture (robotic and human) and aeronautics – much of this architecture is conceptual
  - Focused on innovation and Game Changing new inventions or discoveries rather than incremental improvement
- **Roadmap Terminology**
  - Pull - Architecture: address known technology challenges – example: Micrometeoroids and Orbital Debris (MMOD) protection drives need for new materials/structure
  - Push - Technology: address technology gaps – example: new physics-based modeling capability drives robust structural certification
  - Strategic, long-term, and integrated investment strategy



Permeation Resistant Integrated Composite Tank
Pre -Exploration Systems Mission Directorate

Technology Area Overview

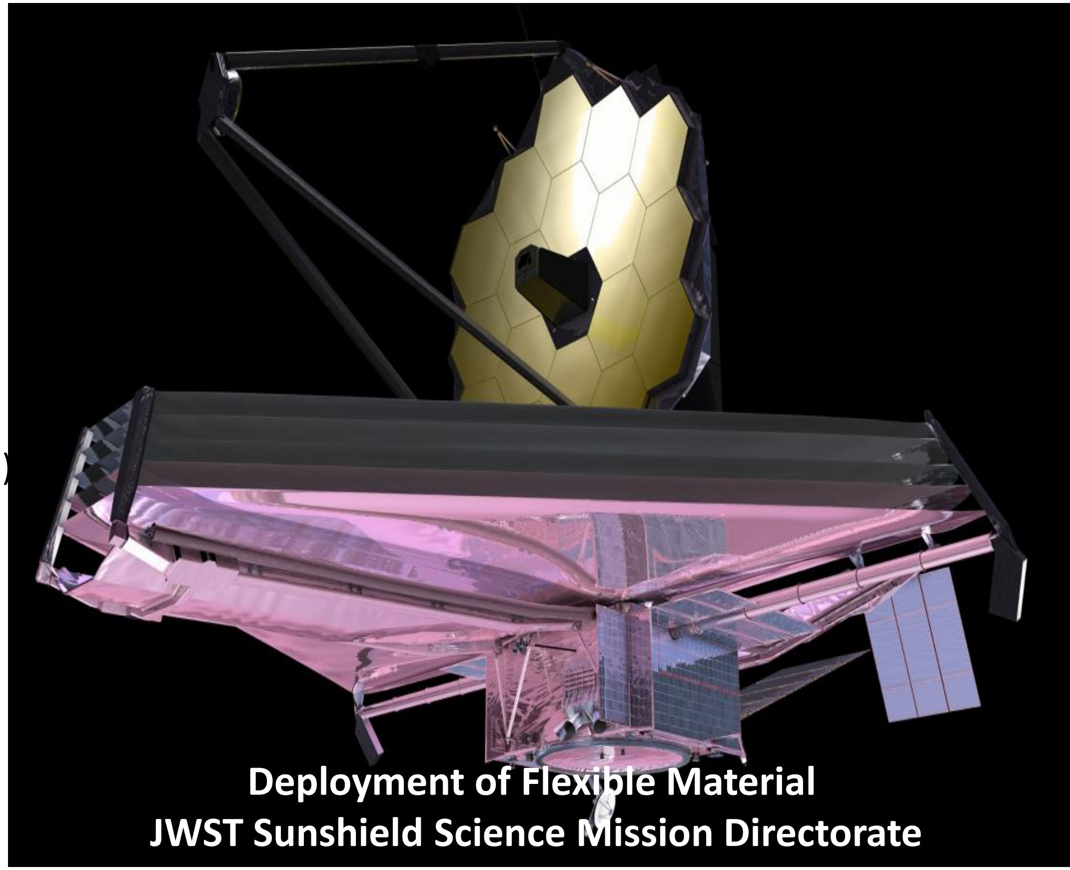
- **Technology Direction**
  - Roadmap identifies a technology path (a direction). It should give long term guidance. It identifies obvious technology needs and it stimulates a thought process that should identify new technologies and approaches
  - It is NOT a how-to (cook book) document
- **Process (Agency-wide)**
  - Team developed strawman roadmap
  - Input from > 100 senior scientists/engineers
  - Independently vetted by key senior Agency experts



Technology Area Overview

- **Key Roadmap Avenues (themes)**
  - Pull Technologies
    - Affordability
    - Multifunctional
    - Lightweight
    - Environmentally Friendly
  - Push Technologies
    - Physics-based methods
    - Materials (computational, tailored , etc.)
    - Intelligent Manufacturing
    - Sustainment
    - Reliability

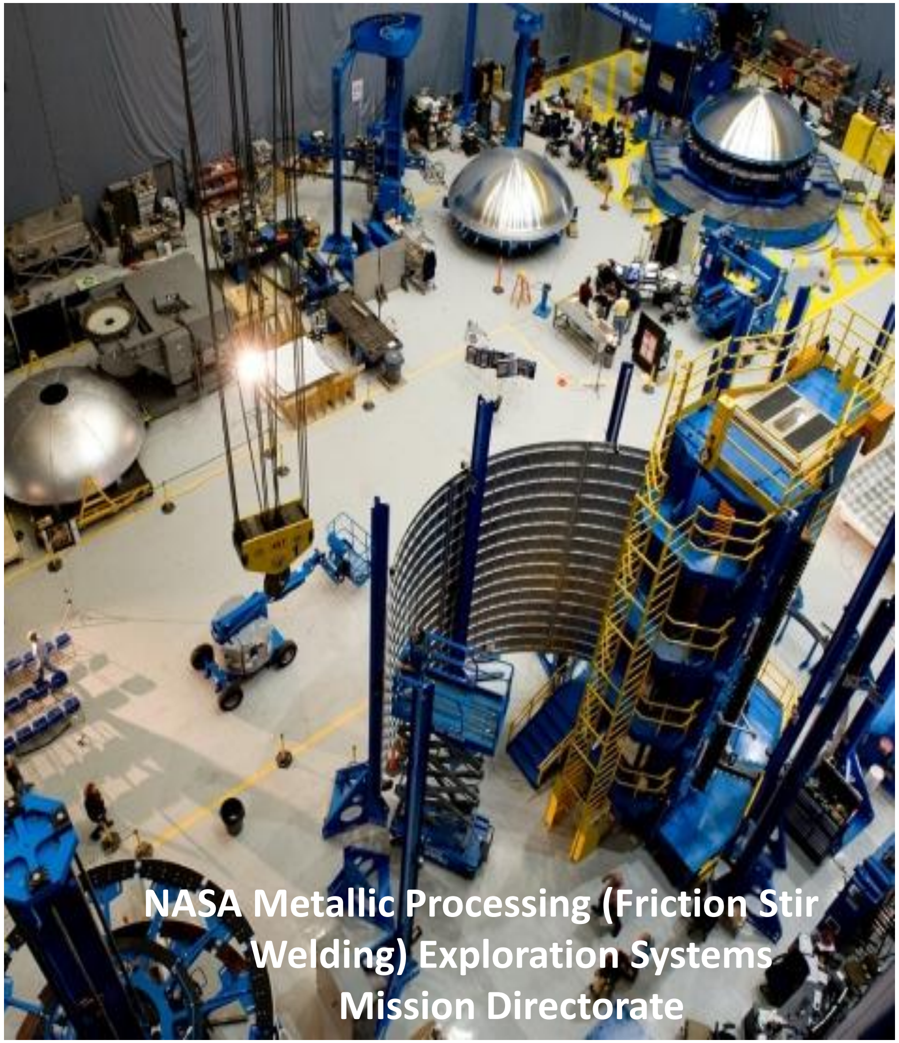
Virtual Digital Fleet Leader
Integrates multiple technology capabilities



Deployment of Flexible Material
JWST Sunshield Science Mission Directorate

Traceability to NASA Strategic Goals

- **Goal of Exploration/Science/ Aeronautics missions**
  - Mission technologies are synergistic/cross cutting (lighter, stronger, robust engineering methods, cost effective, sustainable, etc.)
- **Critical support to Space Shuttle and ISS safety of flight/operation**
  - Lessons learned: Importance of certification, sustainment, and reliability
- **Innovation and Education**
  - Development-directed science, technology, engineering and math (STEM) technologies and workforce



NASA Metallic Processing (Friction Stir Welding) Exploration Systems Mission Directorate

Technology Area Strategic Roadmap

Materials, Structures, Mechanical Systems and Manufacturing

Co Chairs: Bob Piascik and John Vickers

2.1 Materials

Lead: Bob Piascik
Anthony Calomino

- 2.1.1 Lightweight Structure
- 2.1.2 Computational Design
- 2.1.3 Flexible Material Systems
- 2.1.4 Environment
- 2.1.5 Special Materials

2.2 Structures

Lead: Steve Scotti
Dave Lowry

- 2.2.1 Lightweight Concepts
- 2.2.2 Design & Certification Methods
- 2.2.3 Reliability and Sustainment
- 2.2.4 Test Tools and Methods
- 2.2.5 Innovative, Multifunctional Concepts

2.3 Mechanical Systems

Lead: Jeff Stewart
Joe Pellicciotti

- 2.3.1 Deployables, Docking & Interfaces
- 2.3.2 Mechanism Life Extension Sys.
- 2.3.3 Electro-mech., Mechanical and Micromechanisms
- 2.3.4 Design & Analysis Tools and Methods
- 2.3.5 Reliability / Life Assessment / Health Monitoring
- 2.3.6 Certification Methods

2.4 Manufacturing

Lead: John Vickers

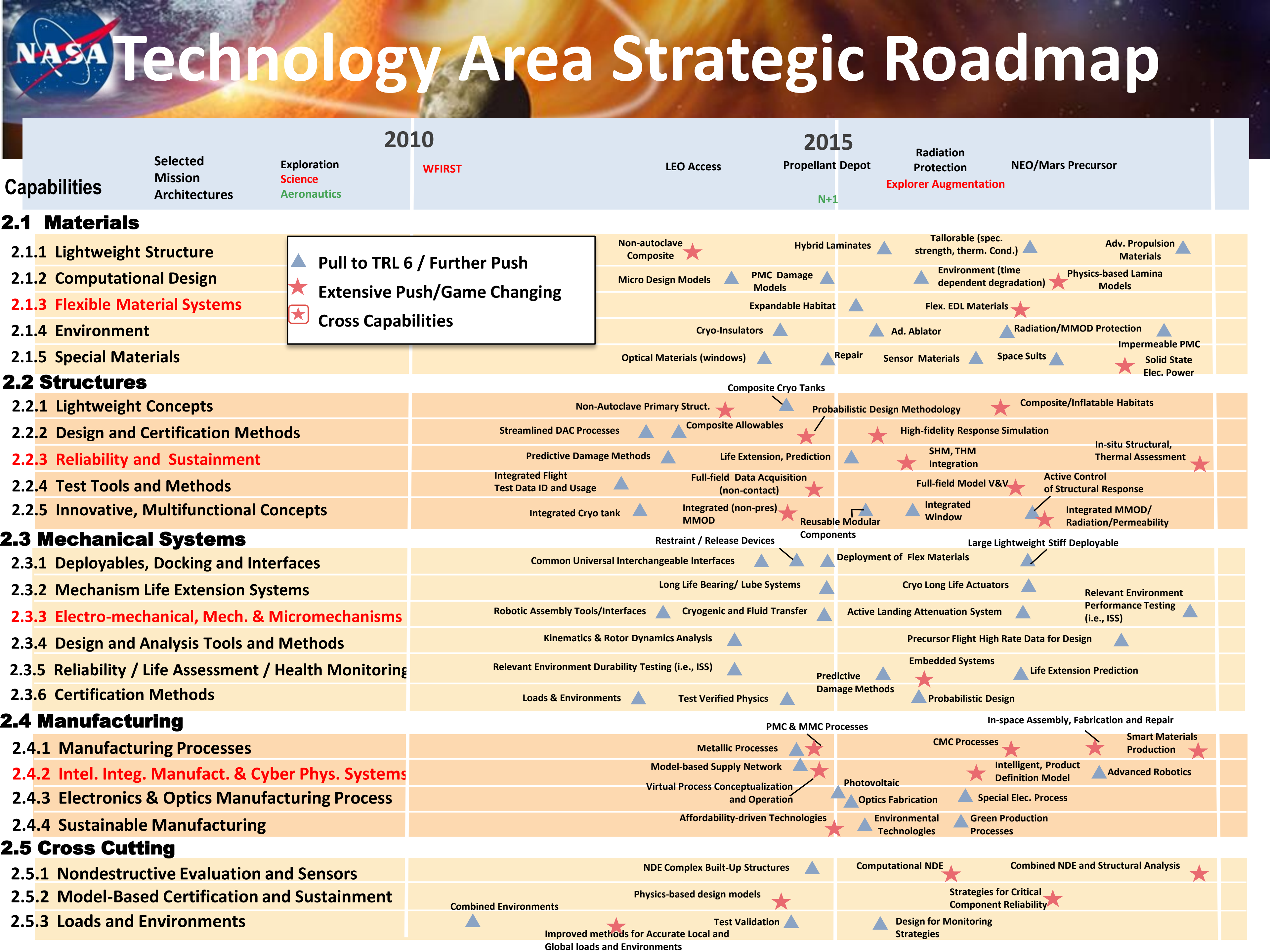
- 2.4.1 Manufact. Processes
- 2.4.2 Intelligent Integrated Manufact. & Cyber Physical Systems
- 2.4.3 Electronics & Optics Manufact. Process
- 2.4.4 Sustainable Manufacturing

2.5 Cross-Cutting

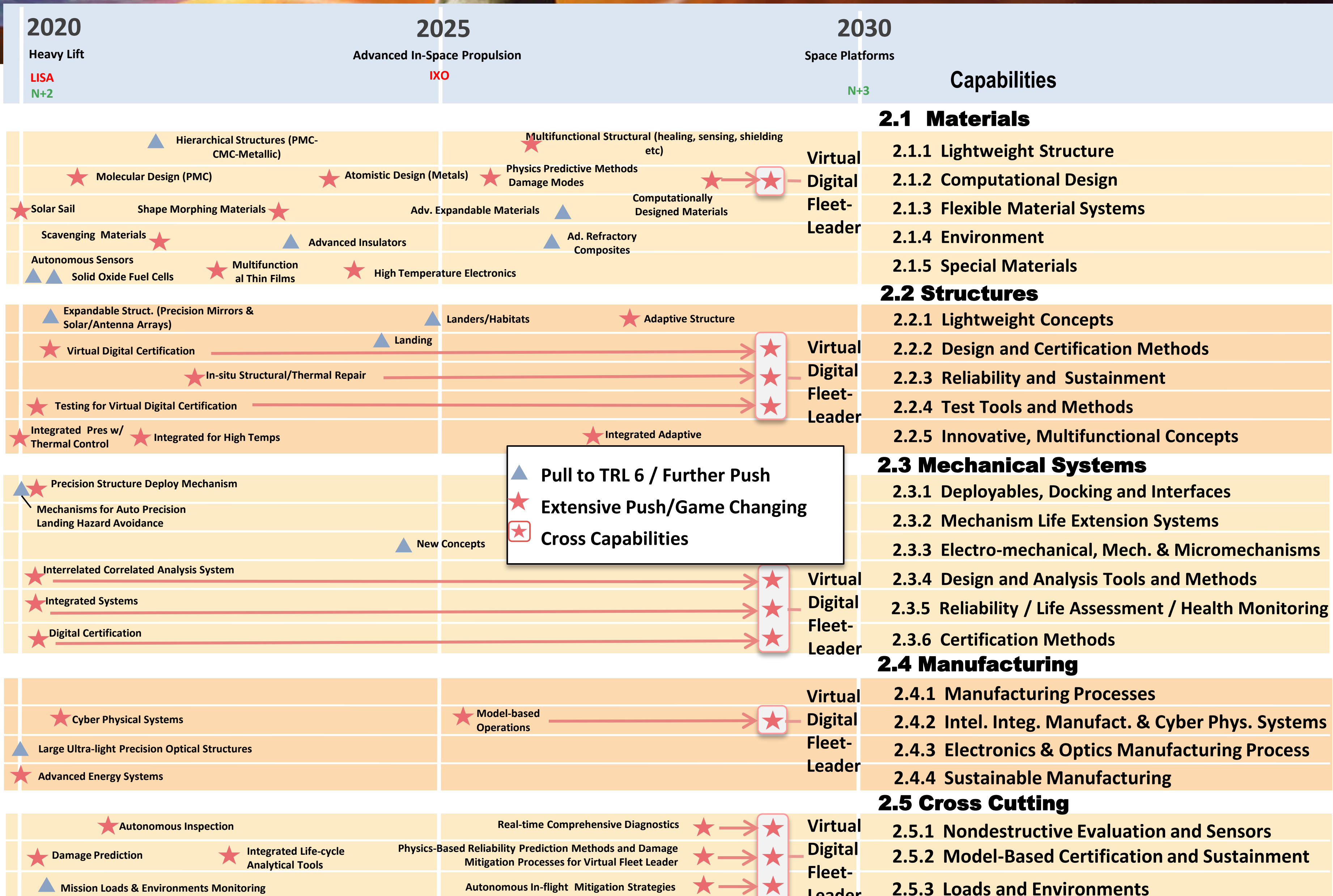
Lead: Bob Piascik
John Vickers

- 2.5.1 Nondestructive Evaluation and Sensors
- 2.5.2 Model-Based Certification and Sustainment Methods
- 2.5.3 Loads and Environments

Technology Area Strategic Roadmap



Technology Area Strategic Roadmap



Technology Area Strategic Roadmap

WBS 2.1.3 Flexible Materials Systems

Key Technology/Challenge	What it Enables	TRL/Current Status	Steps to TRL 6
Textile-based materials and thin-film technology for large inflatable or deployable structures.	Lightweight deployed human habitats for space or Mars surface and large space-base observation platforms.	TRL 3; Large structure capability, e.g., McMurdo Antarctica Science Support Center Habitat, ground-based demo for space application.	Earth-based prototype demonstrators need to be applied in relevant environment and tested for long-term exposure effects.
Flexible TPSs for hypersonic entry systems.	Large mass payload delivery to Mars or low-heat entries for high-velocity Earth return.	TRL 3; Commercial off-the-shelf (COTS) TPS has been developed and ground tested.	Orbital fight demonstration of an 8-meter diameter aeroshell to demonstrate fluid-structure interaction stability and control authority.
Lightweight aluminized thin film systems for solar sail propulsion.	Fuelless propulsion using solar wind force on large reflective sails.	TRL 3 for second generation; CP1 sails have survived space environment for up to 7 years and meet all near-term performance requirements.	Ripstop and space environment testing UV sublimation at TRL 2.
Shape-Morphing Materials for deployable space structures.	Autonomous deployment and actuated shape control of large space structures.	TRL 2-3; Preliminary identification and process refinement of shape memory materials and self actuating/morphing materials.	Materials designed to actuate hybrid structures featuring embedded SMA must be demonstrated.
Advanced Flexible Materials.	Multifunctional softgoods technologies for self actuating and self sensing structures including habitats and large space platforms.	TRL 1-2; Several polymer and metallic material systems show small scale promise of achieving high strain capability and work output.	Systems are at the concept stage, but could incorporate the ability to provide tailorable properties with coating technologies for high emittance and reflectivity.

Technology Area Strategic Roadmap

WBS 2.1.3 Flexible Materials Systems

Selected Mission Architectures	Exploration Science Aeronautics	2010 WFIRST	LEO Access	2015 Propellant Depot N+1	Radiation Protection Explorer Augmentation	NEO/Mars Precursor
Capabilities						
2.1.3 Flexible Material Systems			**Expandable Habitat**		**Flexible EDL Materials**	

Develop textile based materials and thin film technology for deployable structures

Enables:

Lightweight deployed human habitats for space or Mars surface and large space-based observation platforms

Develop flexible TPS for hypersonic entry systems

Enables:

Large mass payload delivery to Mars or low-heat entries for high-velocity Earth return

Technology Area Strategic Roadmap

WBS 2.1.3 Flexible Materials Systems (cont.)

2020		2025		2030	
Heavy Lift LISA N+2		Advanced In-Space Propulsion IXO		Space Platforms N+3	**Selected Mission Architectures**
	Solar Sail Materials	**Shape Morphing Materials**	**Adv. Expandable Materials**		**Capabilities** **2.1.3 Flexible Material Systems**

Lightweight Aluminized thin film systems for solar sail propulsion

Enables:

Fuelless propulsion using solar wind force on large reflective sails

Shape-morphing materials for deployable space structures

Enables:

Autonomous deployment and actuated shape control of large space structures

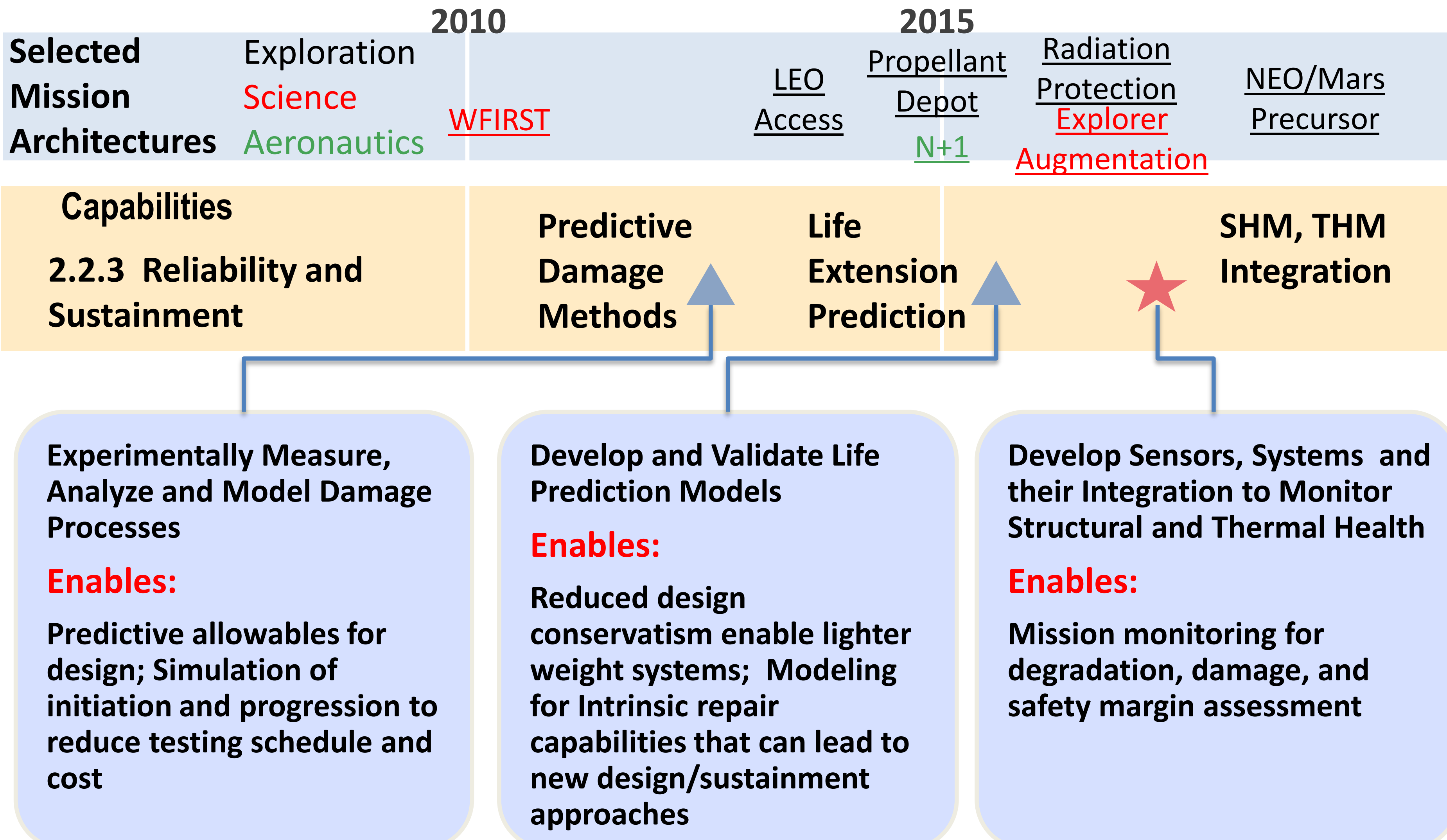
Advanced flexible materials

Enables:

Multifunctional softgood technologies for self actuating and self sensing structures including habitats and large space platforms

Technology Area Strategic Roadmap

WBS 2.2.3 Reliability and Sustainment



Technology Area Strategic Roadmap

WBS 2.2.3 Reliability and Sustainment (cont.)

2020	2025	2030	
Heavy Lift LISA N+2	Advanced In-Space Propulsion IXO	Space Platforms N+3	**Selected Mission Architectures**
In-situ Structures, Thermal Assessment	**In-situ Structures, Thermal Repair**	**Virtual Digital Fleet Leader**	**Capabilities** **2.2.3 Reliability and Sustainment**

Development and Validation of Inverse Analysis Methods used with Health Monitoring Sensor Data

Enables:

Detection and characterization of degradation and damage during testing and service

Extraterrestrial Repair Materials, Tools, and Procedures (system specific)

Enables:

Validated restoration of thermal and/or structural integrity during a mission

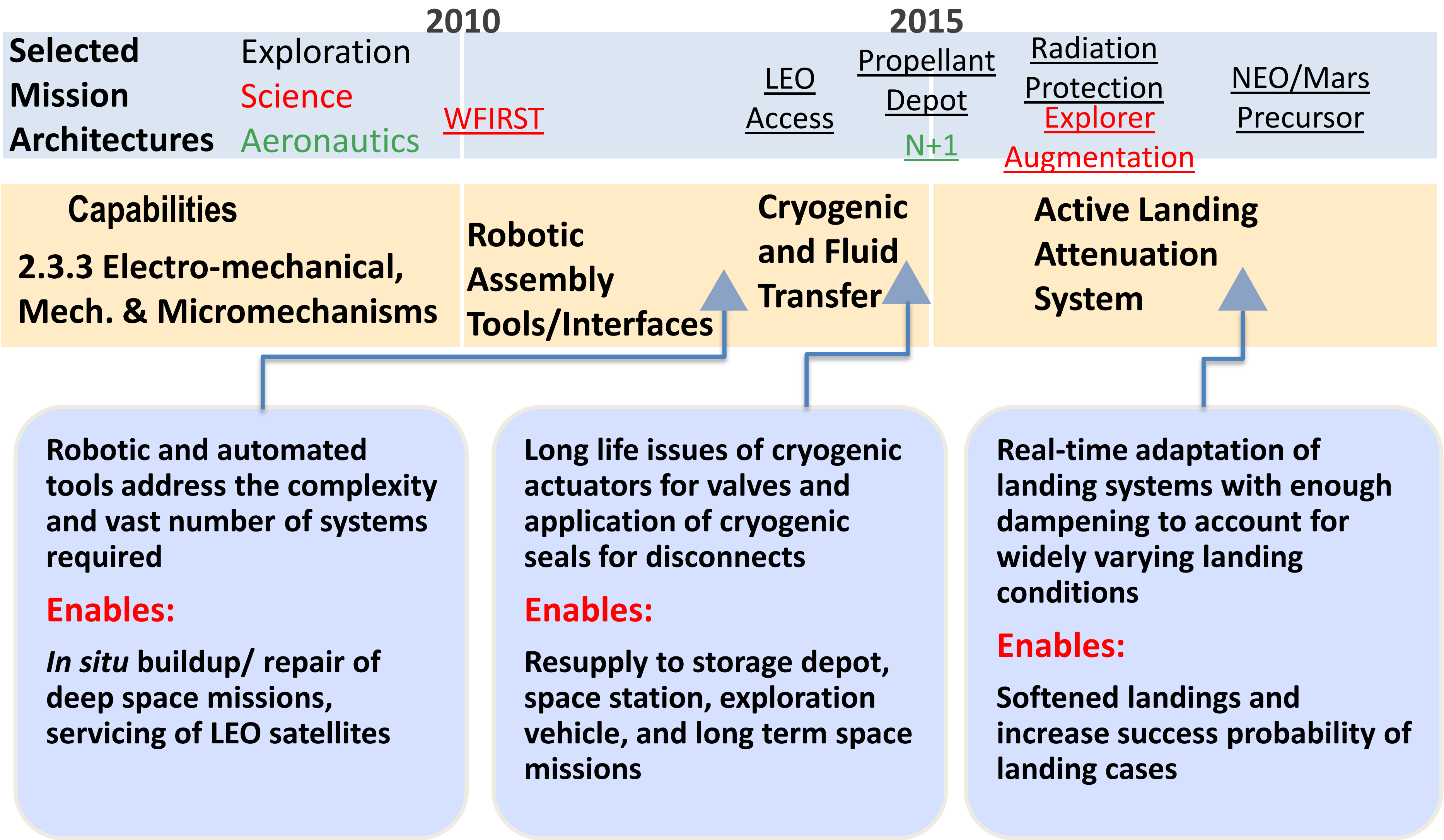
On-vehicle Integration of High-fidelity Models for Response, Damage, and Life Prediction with Health History Data into Full Simulation of Vehicle in its Present State

Enables:

Real-time assessments of margins and safety to support mission decisions

Technology Area Strategic Roadmap

WBS 2.3.3 Electro-mechanical, Mech. & Micromechanisms



Technology Area Strategic Roadmap

WBS 2.3.3 Electro-mechanical, Mech. & Micromechanisms (cont.)

2020	2025	2030	
Heavy Lift LISA N+2	Advanced In-Space Propulsion IXO	Space Platforms N+3	**Selected Mission Architectures**
Relevant Environment Performance Testing (i.e., ISS)	**New Concepts**		**Capabilities** **2.3.3 Electro-mechanical, Mech. & Micromechanisms**

Reproducing and combining of required environments into comprehensive tests (e.g. zero G is extremely challenging)

Enables:

More accurate model correlation/predictive modeling; reduced mass through better understanding of system margins

Overcome gearing and reliability problems of current actuators and controllers. Making controllers "bus addressable"

Enables:

Deep space missions due to higher reliability/efficiency simplified control, reduced weight/complexity of geared systems and actuators

Technology Area Strategic Roadmap

WBS 2.4.2 Intel. Integ. Mfg. & Cyber Physical Systems

	2010		2015		
Selected Mission Architectures — Exploration / Science / Aeronautics	WFIRST	LEO Access	Propellant Depot; N+1	Radiation Protection Explorer Augmentation	NEO/Mars Precursor
Capabilities — 2.4.2 Intel. Integ. Mfg. & Cyber Physical Systems	Model-based Supply Network		Virtual Process Conceptualization and Operation		Intelligent, Product Definition Model

Terrestrial and in-space collaborative supply networks

Enables:

Full-knowledge of the design, manufacturing, and operations supply chain

Mathematically accurate models that are linked to manufacturing

Enables:

High-fidelity simulations used to define manufacturing and improve productivity

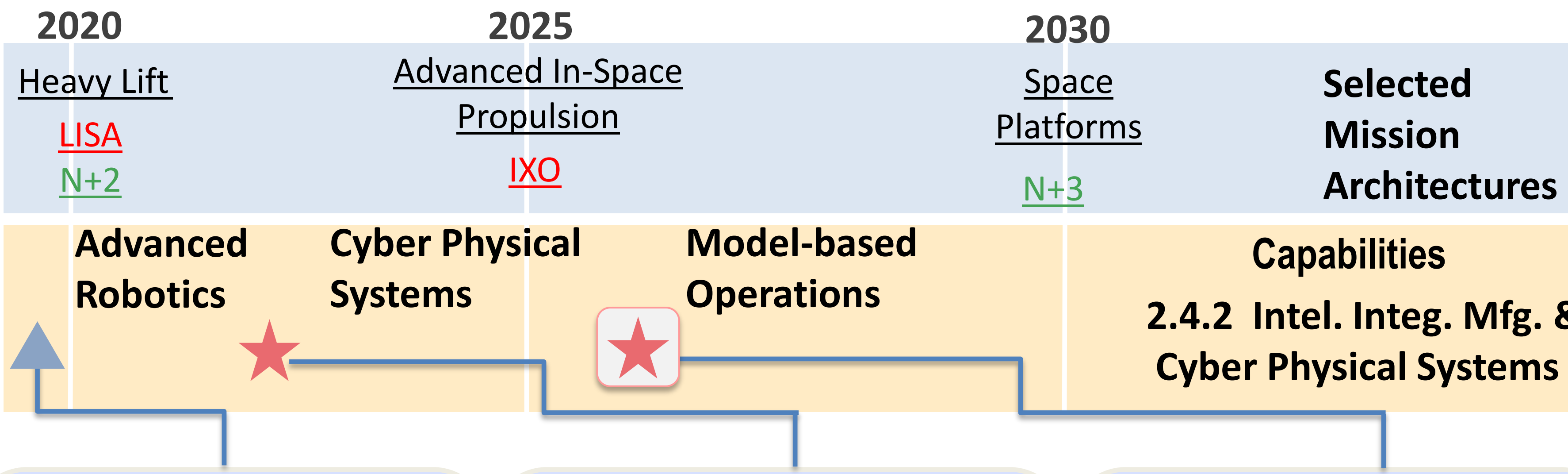
Digital product definition contains complete design and manufacturing information

Enables:

Life-cycle analysis and efficiencies for product development, manufacturing, and sustainment

Technology Area Strategic Roadmap

WBS 2.4.2 Intel. Integ. Mfg. & Cyber Physical Systems (cont.)



Next generation of robotics and automation for manufacturing

Enables:

Automated operations capable of intelligent actions and responses

Highly advanced coordination between the system's computational and physical elements

Enables:

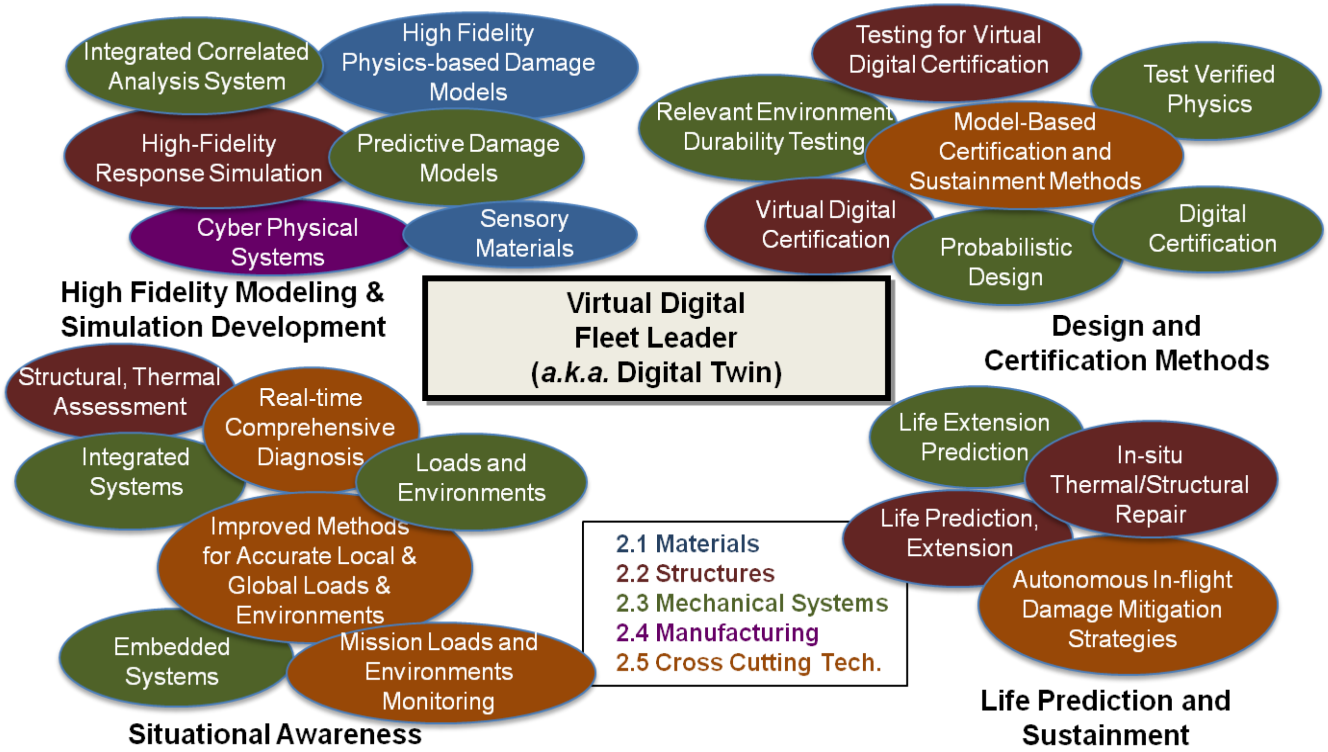
New manufacturing capability, systems and facilities operated for optimum availability and performance

Integrates factory, process, reliability and equipment models

Enables:

Virtual design, checkout, and optimization of processes and physical operations

Virtual Digital Fleet Leader (VDFL) – Advanced Technology for Cost Effective, Reliable & Safe Space Travel

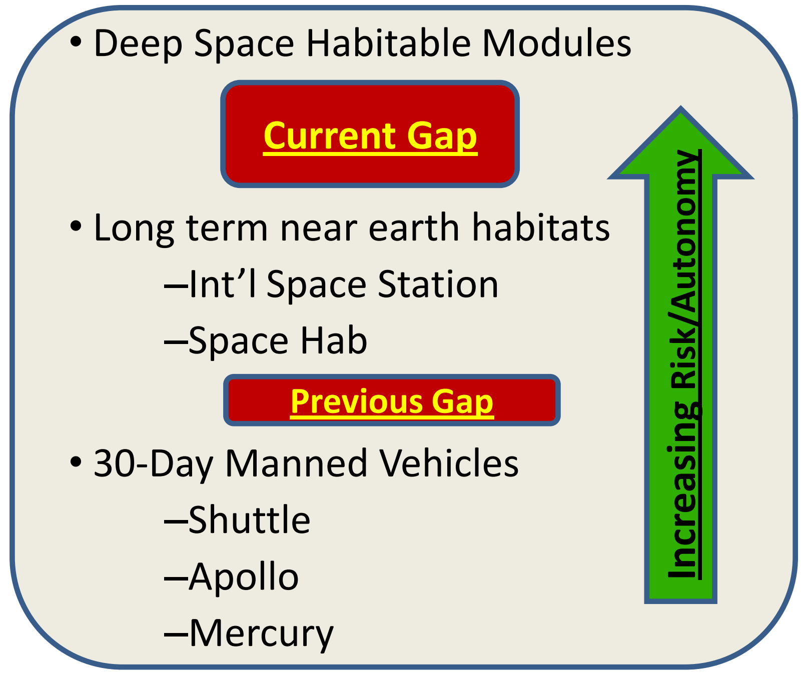


- **Real-time-mission-life virtual construct of system**
- **Continuous monitoring provides model updates for high-fidelity, multi-physics, multi-scale system simulation**
- **Comprehensive diagnostic and prognostic capabilities for system health, life, and probability of mission success**

Why Virtual Digital Fleet Leader (VDFL)

- **Extended duration deep space travel requires a shift away from "low-earth-orbit strategies" (safe haven, resupply, replace, etc.)**

- **VDFL is a suite of technologies that focus on certification of physics-based models to enable lower cost, higher reliability, long life structures/systems with reuse & autonomous life assessment/update, etc. (i.e. hardware designed to 3-σ conditions that sustain a nominal launch could then be reassessed *in situ* for longer life)**

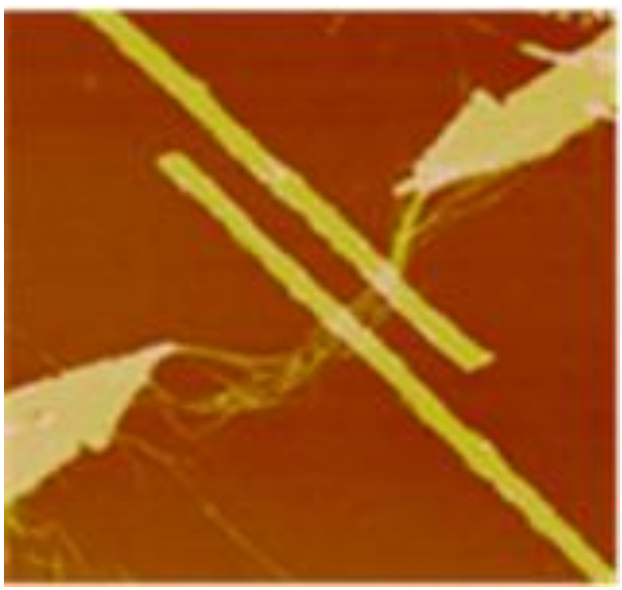


- **This synergistic approach will spin off critical technologies (NASA and National)**
  - **Health monitoring, probabilistic design/assessment, life prediction/extension, self-healing, sustainment, *in situ* repair/mfg, computational materials design, etc.**

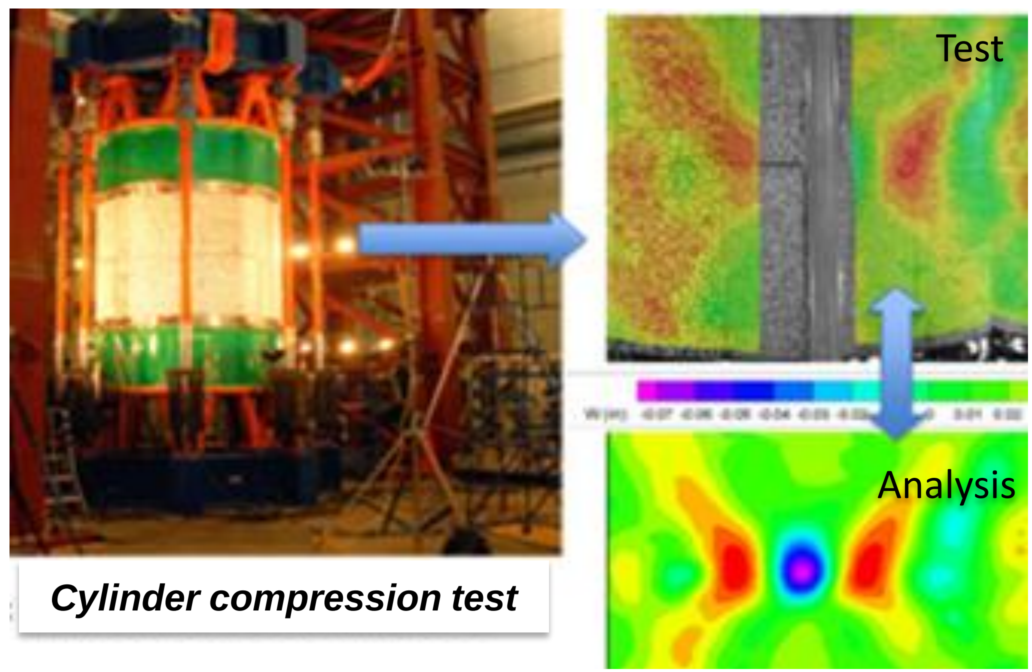
Top Technical Challenges

Overall Top Challenges

1. **Radiation protection** (multifunctional materials & design and unique manufacturing)
2. **Reliability** (Cross Cutting)
   a. Physics-based performance modeling (understanding damage/failure modes)
   b. Advanced certification methods (design, materials, manufacturing)
   c. Sustainment (environment and health monitoring, repair)



Photonic fiber loaded with fluorescent material for radiation detection

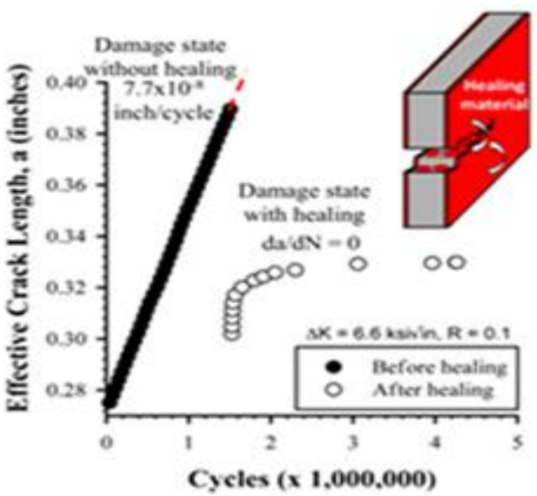


High-fidelity analysis of non-linear shell buckling and verification with full-field test data

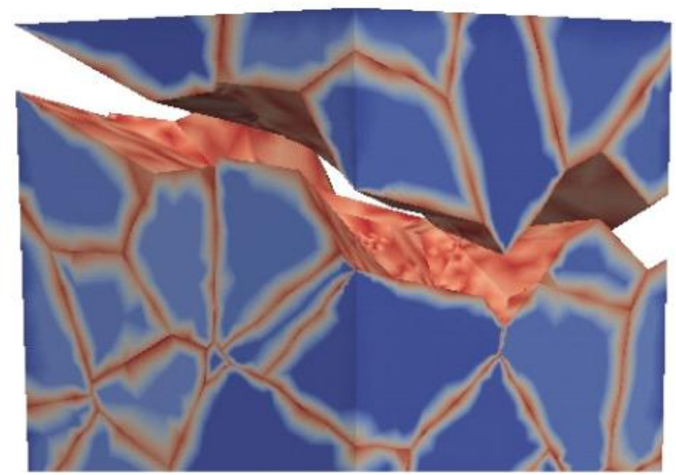
Top Technical Challenges

Materials

1. **New tailored materials** developed and utilized for specific applications (laminate, extreme environment, healing, sensory, MMOD, etc.)
2. **Computational materials technologies** matured for effective low cost materials design and physics-based certification / sustainment methods



In-situ Healing Coating for Ti Alloys



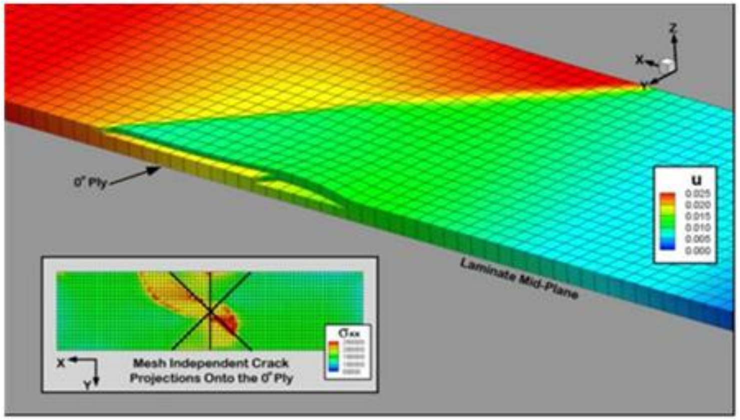
Simulation of microstructurally small crack growth in an aluminum alloy

Top Technical Challenges

Structures

1. **Robust lightweight structures** developed and utilized that are **multifunctional** (e.g. thermal, expandable, protective - radiation and MMOD)
2. **Virtual digital fleet leader** develop first-of-a-kind real-time reliability and physics-based methodologies

Predictive damage methods for laminated composites

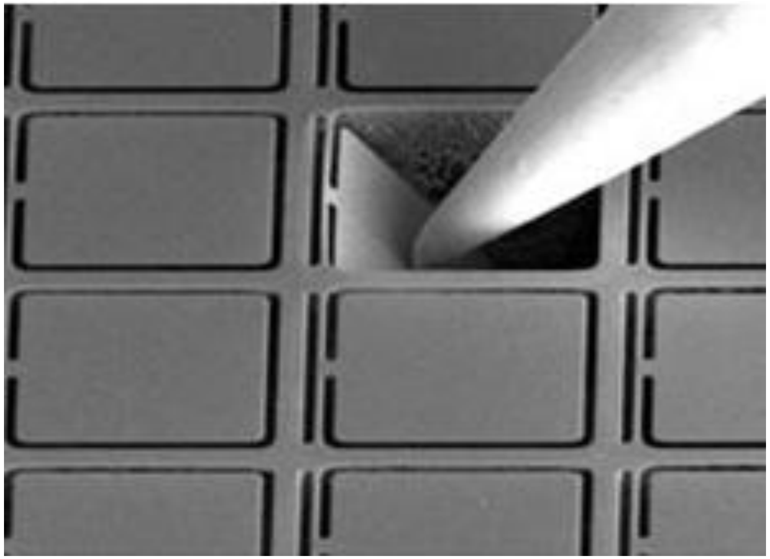


Shape-morphing structures provide variable geometry aerodynamic surfaces

Top Technical Challenges

Mechanical Systems

1. **Highly reliable** (predictable performance) mechanical systems for extreme environments
2. **Precision deployable** mechanisms for large space structures



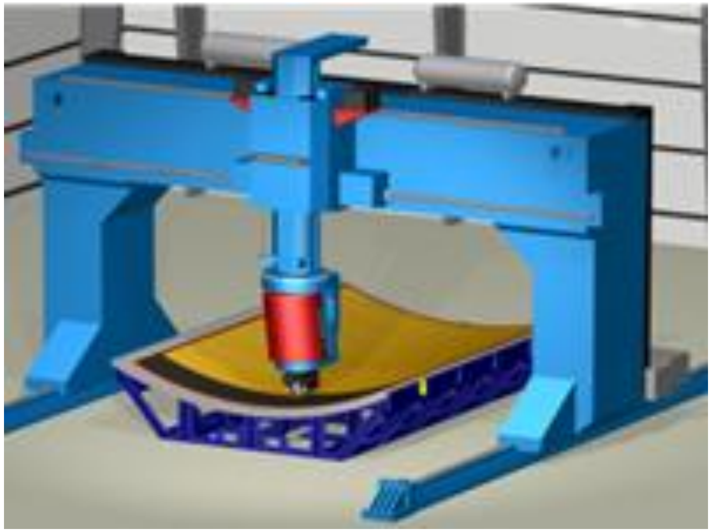
JWST microshutter (micromechanism)

Large deployable mesh antenna

Top Technical Challenges

Manufacturing

1. **Advanced manufacturing process technology** fundamentally changes how products are invented and manufactured
2. **Sustainable manufacturing** transforms manufacturing of products to minimize negative environmental and economic impacts



Virtual process manufacturing concepts

In-space assembly, inspection and repair

Top Technical Challenges

National Challenges Addressed

1. **Restore and improve urban infrastructure** (NAE) – Sustainment methodology (self healing, sensory, structural health management, hydrogen containment, etc.)
2. **Make solar energy economical** (NAE) – new materials
3. **“Building a Smarter Planet”** IBM in the NY Times (biggest leap in business, science and society for the next decade is the use of data) - Practical applications of virtual methods for MSMM multi-disciplinary life-cycle

Benefits to Other National Needs

- **Development and operation of efficient civil and military aircraft**
  - Incorporate new materials with quantified reliability
  - Streamlined development and certification through physics-based modeling
  - Knowledge-based maintenance for reducing costs while maintaining safety
- **Quantified methodologies for aging US infrastructure (e.g., bridges, dams, buildings)**
- **Improved efficiency (i.e., energy use, life, etc.) and safety in transportation sector (e.g., lightweight structures, self-healing materials, low-wear mechanisms)**
- **Broadened manufacturing base and faster product improvement through cyber-physical approaches (e.g., direct CAD-driven part fabrication)**

Interdependency with Other TAs

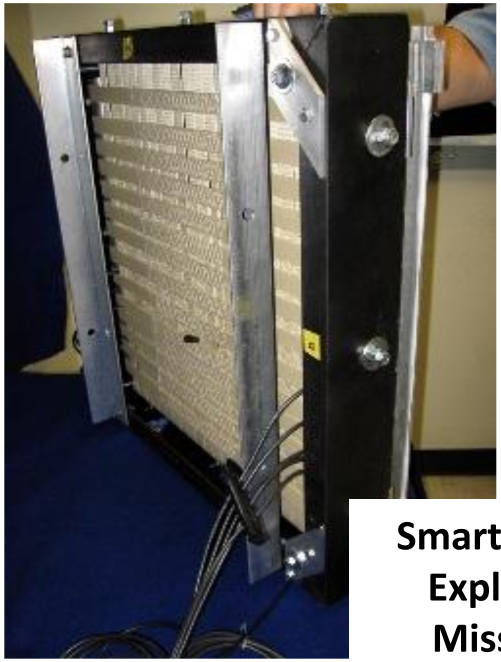
Roadmap TA Interactions with Materials, Structures, Mechanicals Systems & Manufacturing	
Technology Area (TA)	**Technical Areas Requiring Interactions**
TA1 Launch Propulsion Sys.	Propellant, case, insulation, nozzle, and engine materials
TA2 In-Space Propulsion Sys.	High Temperature Materials, Structures and Circuits
TA3 Space Power and Energy Storage Sys.	Solar arrays (Mech. Sys.), materials*, manufacturing*
TA4 Robotics, Tele-robotics, and Auto Sys.	Rendezvous/capture, docking, health monitoring, etc. (Mech. Sys), Materials*, Manufacturing*
TA5 Communication and Navigation Systems	Bandwidth for Health Monitoring/Test correlation
TA6 Human Health, Life Support and Hab. Sys.	Radiation shielding/protection
TA7 Human Exploration Destination Sys.	In-space manufacturing assembly and repair*
TA8 Scientific Instruments, Observatories and Sensor Sys.	Optics manufacturing, large precision structures
TA9 Entry, Descent, and Landing Sys.	Pyros. and deployable descent mechanisms, deployable landing mechanisms, high temp. structures (re-entry), structural response/attenuation (landing)
TA10 Nanotechnology	Computational materials design, structure needs, manufacturing*
TA11 Modeling, Sim., Info., Tech. and Processing	Model/Test Correlation, Vehicle Certification
TA13 Ground and Launch Processing	Environmental technologies, modeling to support design and operations, Integrated vehicle health mgmt, composite system repair
TA14 Thermal Management Sys.	Insulation and TPS materials, environmental effects on materials, TPS, and hot structures, novel thermal control sys. (e.g., flexible shields and radiators), thermal-structural dimension control

* Denotes broad areas of interdependencies

Summary

- TA 12 technologies enable future human/ science space exploration
- Roadmap includes 23 critical Agency capabilities focused on innovations and game changing inventions or technologies
- The roadmap addresses mission architecture timing – "pulls" and important technology needs, "push" not addressed by the missions
- Roadmap technologies are aligned with NASA's strategic objectives and other National needs
- The Roadmap identifies/addresses top overall NASA technical challenges
  - Radiation protection
  - Reliability (Cross Cutting)

Hypervelocity Impact



Smart MMOD Shielding
Exploration Systems
Mission Directorate

BACK UP CHARTS

Technology Area Strategic Roadmap

Selected Mission Architectures - Aeronautics

NASA's Subsonic Transport System Level Metrics

CORNERS OF THE TRADE SPACE	N+1 = 2015*** Technology Benefits Relative To a Single Aisle Reference Configuration	N+2 = 2020*** Technology Benefits Relative To a Large Twin Aisle Reference Configuration	N+3 = 2025*** Technology Benefits
Noise (cum below Stage 4)	-32 dB	-42 dB	-71 dB
LTO NO_x Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%	-50%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

***Technology Readiness Level for key technologies = 4-6. ERA will undertake a time phased approach, TRL 6 by 2015 for "long-pole" technologies

** RECENTLY UPDATED. Additional gains may be possible through operational improvements

* Concepts that enable optimal use of runways at multiple airports within the metropolitan area

NASA's Space Missions

LEO Access	LEO Missions	Cargo and Crew Transportation to LEO and the International Space Station (ISS) .
Propellant Depot	In space or on-orbit propellant depot	An on-orbit propellant depot allows spacecraft to be fueled in space. The depots are likely to be placed in LEO, at the Lagrange points or in Mars orbit.
Radiation Protection	Space Radiation Protection to achieve human exploration objectives	The primary radiation sources in outer space are the galactic cosmic rays (GCR), and the solar particle events (SPE). Research and develop advanced material s and design concepts for improved radiation shielding for future exploration missions to Mars.
NEO/Mars Precursor	Exploration Precursor Robotic Missions	Exploration Precursor Robotic Program and Exploration Scout: Two Elements of ESMD's Preparation to Explore Near Earth Objects. Mars Orbiter/Mars Lander.
Heavy Lift Vehicle	Broad HLV vehicle architecture and propulsion tradespace	Research and development required for a Heavy Lift System required to conduct human space exploration activities.
Advanced In-Space Propulsion	Advanced in-space propulsion technologies	In-space propulsion begins where the launch vehicle upper stage leaves off, performing the functions of primary propulsion, reaction control, station keeping, precision pointing, and orbital maneuvering.
Space Platforms	Human space Platforms	A series of human-rated 'platforms' that could be outfitted for different missions to enable deep space missions.

NASA's Science Missions

WFIRST	Wide Field InfraRed Survey Telescope	An observatory designed to settle questions in both exoplanet and dark energy research, and which will advance topics ranging from galaxy evolution to the study of objects within our own galaxy
Explorer Program Augmentation	The Explorer Program	Augmenting a program that delivers a high level of scientific return on relatively moderate investment and that provides the capability to respond rapidly to new scientific and technical breakthroughs
LISA	Laser Interferometer Space Antenna	A low frequency gravitational wave observatory that will open an entirely new window on the cosmos by measuring ripples in space-time caused by many new sources, including many nearby white-dwarf stars, and will probe the nature of black holes
IXO	International X-ray Observatory	A powerful X-ray telescope that will transform our understanding of hot gas associated with stars and galaxies in all evolutionary stages