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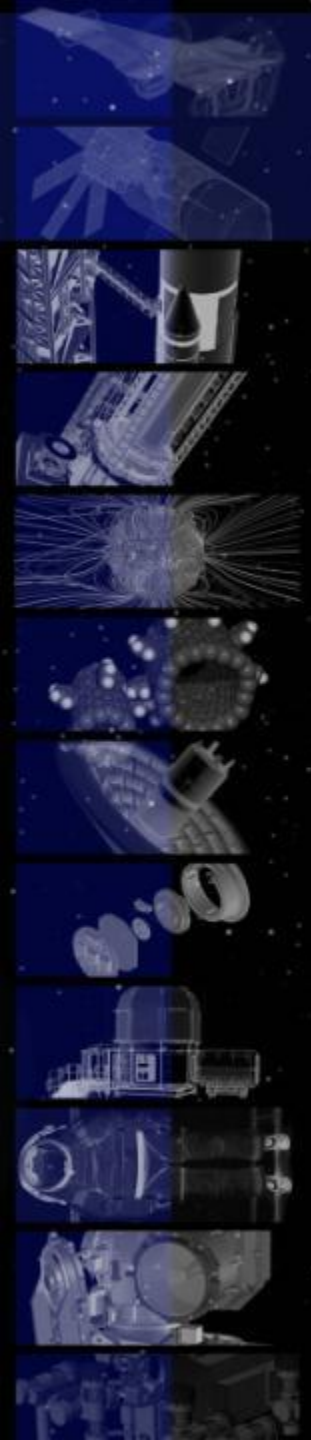

TA 1: Launch Propulsion Systems

2015 NASA Technology Roadmaps

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Roadmap Chair
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- Technology area breakdown structure
- New content
- New content evaluations (non balloon content)

- Balloon content will be covered in subsequent presentation

TA 1: Launch Propulsion Systems

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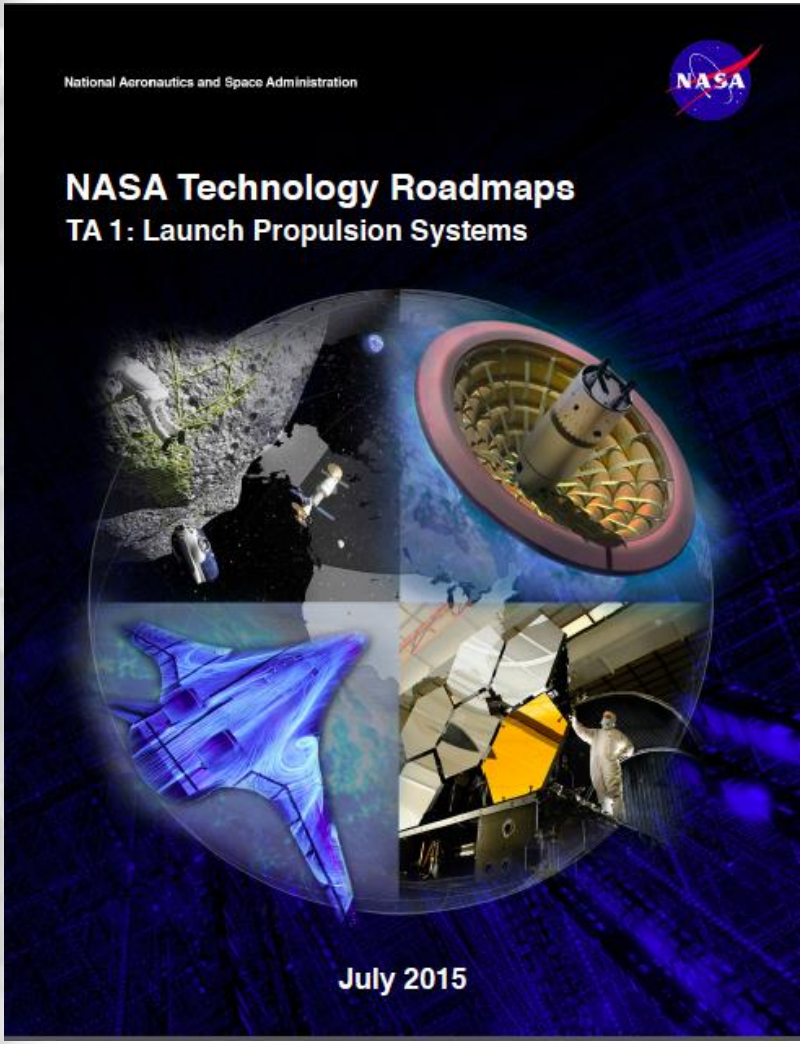

- Addresses technologies that enhance existing solid or liquid rocket propulsion technologies or related ancillary systems
  - Amended this cycle to include research balloon capability technologies or related ancillary systems
- This TA includes:
  - 6 level 2 technology areas
  - 51 technology candidates
    - 14 enabling
    - 39 enhancing

TA 1: Technology Area Breakdown Structure

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TA 1 — Launch Propulsion Systems

1.1 Solid Rocket Propulsion Systems	1.2 Liquid Rocket Propulsion Systems	1.3 Air Breathing Propulsion Systems	1.4 Ancillary Propulsion Systems	1.5 Unconventional and Other Propulsion Systems	1.6 Balloon Launch Systems
1.1.1 Propellants	1.2.1 LH2/LOX Based	1.3.1 Turbine-Based Combined-Cycle	1.4.1 Auxiliary Control Systems	1.5.1 Ground Launch Assist	1.6.1 Super-Pressure Balloon
1.1.2 Case Materials	1.2.2 RP/LOX Based	1.3.2 Rocket-Based Combined Cycle	1.4.2 Main Propulsion Systems (Excluding Engines)	1.5.2 Air Launch and Drop Systems	1.6.2 Materials
1.1.3 Nozzle Systems	1.2.3 CH4/LOX Based	1.3.3 Detonation Wave Engines – Open Cycle	1.4.3 Launch Abort Systems	1.5.3 Space Tether Assist	1.6.3 Pointing Systems
1.1.4 Hybrid Rocket Propulsion Systems	1.2.4 Detonation Wave Engines – Closed Cycle	1.3.4 Turbine-Based Jet Engines	1.4.4 Thrust Vector Control Systems	1.5.4 Beamed Energy and Energy Addition	1.6.4 Telemetry Systems
1.1.5 Fundamental Solid Propulsion Technologies	1.2.5 Propellants	1.3.5 Ramjet and Scramjet Engines	1.4.5 Health Management and Sensors	1.5.5 Nuclear	1.6.5 Balloon Trajectory Control
1.1.6 Integrated Solid Motor Systems	1.2.6 Fundamental Liquid Propulsion Technologies	1.3.6 Deeply-Cooled Air Cycles	1.4.6 Pyro and Separation Systems	1.5.6 High Energy Density Materials and Propellants	1.6.6 Power Systems
1.1.7 Liner and Insulation		1.3.7 Air Collection and Enrichment Systems	1.4.7 Fundamental Ancillary Propulsion Technologies		1.6.7 Mechanical Systems – Launch Systems
		1.3.8 Fundamental Air Breathing Propulsion Technologies			1.6.8 Mechanical Systems – Parachute
					1.6.9 Mechanical Systems – Floatation

TAB Changes from Original Roadmap

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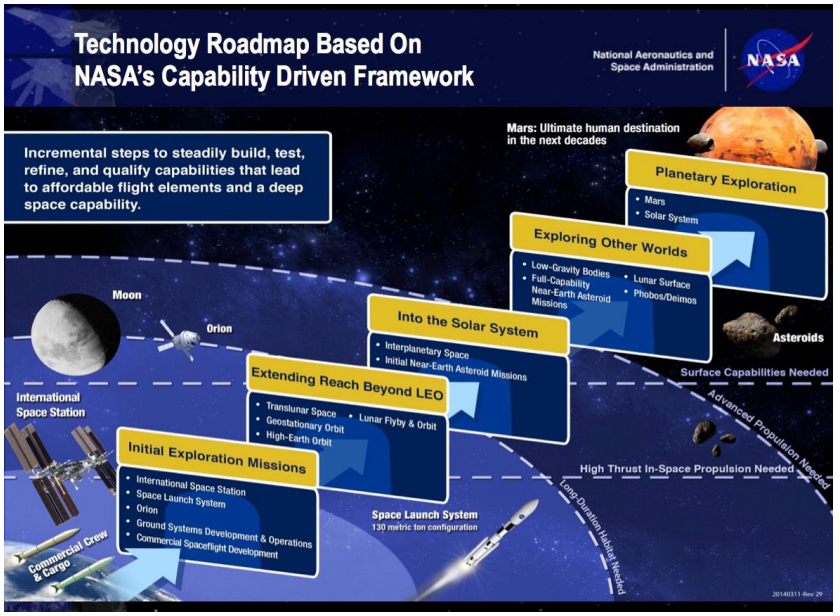
- Driven by missing capabilities
  - Solids TAB content clarified to include liner and integrated system technologies
  - Balloon technology did not have a home and placed in TA01
- Driven by change in roadmap scope
  - Original roadmap was more encompassing
    - Attempted to cover needs of entire nation, both commercial and government
  - Current roadmap driven by NASA's Capability Driven Framework only
    - Limits extent of technologies to be addressed to those that directly affect NASA mission needs
    - Areas with no technology identified are left in the TAB but grayed out and will be available in the future if roadmap scope changes



NOTE: All existing TABS had content updates that are not reflected here in this presentation

TA 1: New TAB Areas in the 2015 Roadmap

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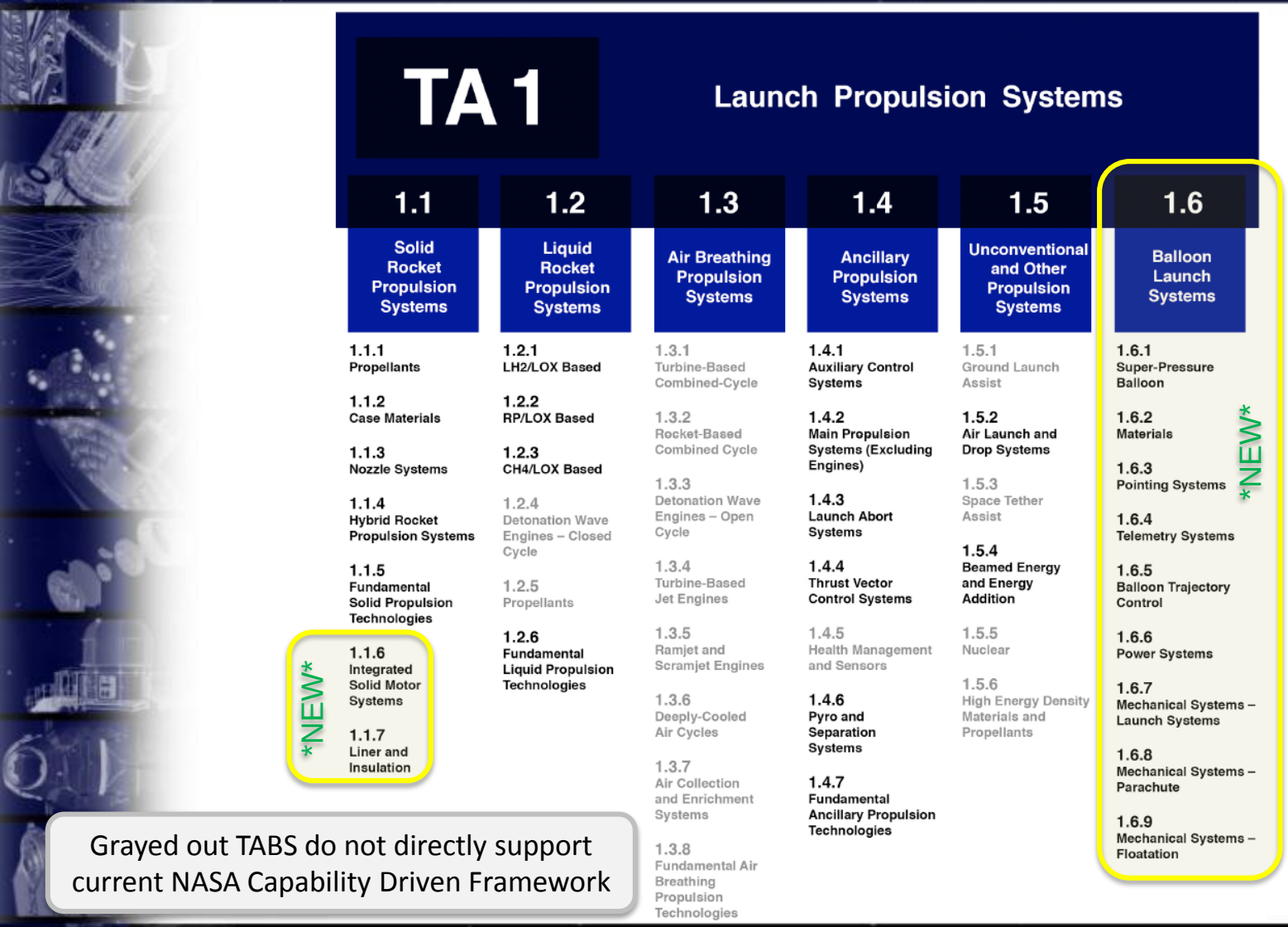

Grayed out TABS do not directly support current NASA Capability Driven Framework

TAB Changes Impact to Prior NRC Assessment of TA01

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- Previous high priority technologies identified by the NRC do not have any content in this revision as discussed above
  - Air Breathing Propulsion Systems: Rocket Based Combined Cycle (RBCC)
  - Air Breathing Propulsion Systems: Turbine Based Combined Cycle (TBCC)
- Current content does not significantly impact one of the two top technical challenges previously identified by the NRC
  - Reduced Cost: Develop propulsion technologies that have the potential to dramatically reduce the total cost and to increase reliability and safety of access to space.
    - Finding technologies that dramatically reduce launch cost is a tremendous challenge given the past lack of success.
    - Reliability and safety continue to be major concerns in the launch business. For NASA space missions, the cost of failure is extreme. Finding ways to improve reliability and safety without dramatically increasing cost is a major technology challenge.

TAB Changes Impact to Prior NRC Assessment of TA01 Continued

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- Current content does address the other top technical challenge
  - Upper Stage Engines: Develop technologies to enable lower cost, high specific impulse upper stage engines suitable for NASA, DOD, and commercial needs, applicable to both Earth- to-orbit and in-space applications.
  - Content is focused on NASA needs but has synergism with DOD and commercial.
- Final major finding from previous NRC report should still be valid
  - "The launch industry has searched for a breakthrough to lower launch costs for decades and, unfortunately, it has yet to materialize. The greatest potential for reduction in launch costs may reside in technologies included in other roadmaps."

New Content for TA 1

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1.1 Solid Rocket Propulsion Systems

- 1.1.6 Integrated Solid Motor Systems
- 1.1.7 Liner and Insulation

1.6 Balloon Launch Systems

- 1.6.1 Super-Pressure Balloon
- 1.6.2 Materials
- 1.6.3 Pointing Systems
- 1.6.4 Telemetry Systems
- 1.6.5 Balloon Trajectory Control
- 1.6.6 Power Systems
- 1.6.7 Mechanical Systems: Launch Systems
- 1.6.8 Mechanical Systems: Parachute
- 1.6.9 Mechanical Systems: Floatation

Area for NRC Review: 1.1.6 Integrated Solid Motor Systems

National Aeronautics and Space Administration

- A new five-segment advanced solid rocket booster is being developed for the SLS Block 1, which provides increased thrust to meet the 70 mt payload requirement.
- It is derived from the Shuttle four-segment SRB. An advanced booster option for SLS Block 1b and 2 is necessary to meet the 130 mt payload requirement.
- This booster will require improved propellant, composite case materials instead of metal, and larger-diameter segments.
- Three options exist to meet this need of which one is an advanced solid rocket booster
  - Other 2 options under consideration have technologies identified in the Liquid Rocket Propulsion Systems TAB 1.2.2

1.1.6 Integrated Solid Motor Systems Benefit Evaluation

National Aeronautics and Space Administration

Benefits: Allows the development of the large high-performance SRB required for the 130 mt payloads while reducing overall system cost.

0	1	3	9
Unlikely to make significant improvement	Minor improvement	Major improvement	Game-changing, transformational capability

1.1.6 Integrated Solid Motor Systems Alignment Evaluation

National Aeronautics and Space Administration

Alignment to NASA Need: This area has 3 tech candidates with 7 enabling and 3 enhancing DRMs

Alignment to Non-NASA Aerospace Technology Goals: Provide stability to material supply chains

Alignment to Non-Aerospace National Goals: No impact

- Alignment with NASA Needs

0	1	3	9
Not directly applicable	Impact one mission in one mission area	Impact multiple missions in one mission area	Impact multiple missions in multiple mission areas

- Alignment with non-NASA Aerospace Technology Goals

0	1	3	9
Little or no impact	Impact limited to niche roles	Impact a large subset of activities	Broad impact

- Alignment with non-Aerospace National Goals

0	1	3	9
Little or no impact outside aerospace	Impact limited to niche roles outside aerospace	Useful to specific community outside aerospace	Widely used outside aerospace community

1.1.6 Integrated Solid Motor Systems Technical Risk and Challenge Evaluation

National Aeronautics and Space Administration

Challenges: Liners and insulation.

- Technical Risk and Reasonableness

1	3	3	9	1
Very low, feasible to complete development	Low, cost/timeframe not to exceed past efforts	Moderate/high, cost/timeframe to exceed past efforts	Moderate/high, cost/timeframe not to exceed past efforts	Extremely high

- Sequencing and Timing

-9	-3	-1	1
Extremely complex, highly dependent on multiple other projects	Roughly sketched out, no clear identified users	Clear plan, obvious need, no specifically identified users	Clear plan, obvious need, joint funding likely

- Time and Effort to Achieve Goals

-9	-3	-1	0
National endeavor, >5 years, substantial facilities/organization	Major project, >5 years and substantial new facilities	Moderate effort, <5 years, moderately sized teams	Minimal effort, few years, small team

Area for NRC Review: 1.1.7 Liner and Insulation

National Aeronautics and Space Administration

- Solid rocket motor (SRM) case liner and insulation materials that are asbestos-free and still maintain the SRM internal case temperature below the thermal limits.

1.1.7 Liner and Insulation Benefits Evaluation

National Aeronautics and Space Administration

Benefits: Eliminates health issues by developing an asbestos-free liner and insulation system within thermal limits. Reduces weight, eliminates process issues being addressed today, and maintains the solid rocket booster internal case within temperature limits.

0	1	3	9
Unlikely to make significant improvement	Minor improvement	Major improvement	Game-changing, transformational capability

1.1.7 Liner and Insulation Alignment Evaluation

National Aeronautics and Space Administration

Alignment to NASA Need: This area has 2 tech candidates with 16 enabling and 0 enhancing DRMs

Alignment to Non-NASA Aerospace Technology Goals: Limited synergism

Alignment to Non-Aerospace National Goals: No impact

- Alignment with NASA Needs

0	1	3	9
Not directly applicable	Impact one mission in one mission area	Impact multiple missions in one mission area	Impact multiple missions in multiple mission areas

- Alignment with non-NASA Aerospace Technology Goals

0	1	3	9
Little or no impact	Impact limited to niche roles	Impact a large subset of activities	Broad impact

- Alignment with non-Aerospace National Goals

0	1	3	9
Little or no impact outside aerospace	Impact limited to niche roles outside aerospace	Useful to specific community outside aerospace	Widely used outside aerospace community

1.1.7 Liner and Insulation
Technical Risk and Challenge Evaluation

National Aeronautics and Space Administration

Challenges: Polybenzimidazole (PBI) processing

- Technical Risk and Reasonableness

1	3	3	9	1
Very low, feasible to complete development	Low, cost/timeframe not to exceed past efforts	Moderate/high, cost/timeframe to exceed past efforts	Moderate/high, cost/timeframe not to exceed past efforts	Extremely high

- Sequencing and Timing

-9	-3	-1	1
Extremely complex, highly dependent on multiple other projects	Roughly sketched out, no clear identified users	Clear plan, obvious need, no specifically identified users	Clear plan, obvious need, joint funding likely

- Time and Effort to Achieve Goals

-9	-3	-1	0
National endeavor, >5 years, substantial facilities/organization	Major project, >5 years and substantial new facilities	Moderate effort, <5 years, moderately sized teams	Minimal effort, few years, small team