National Aeronautics and Space Administration

From Research to Flight:

Thinking About Implementation While Performing Fundamental Research

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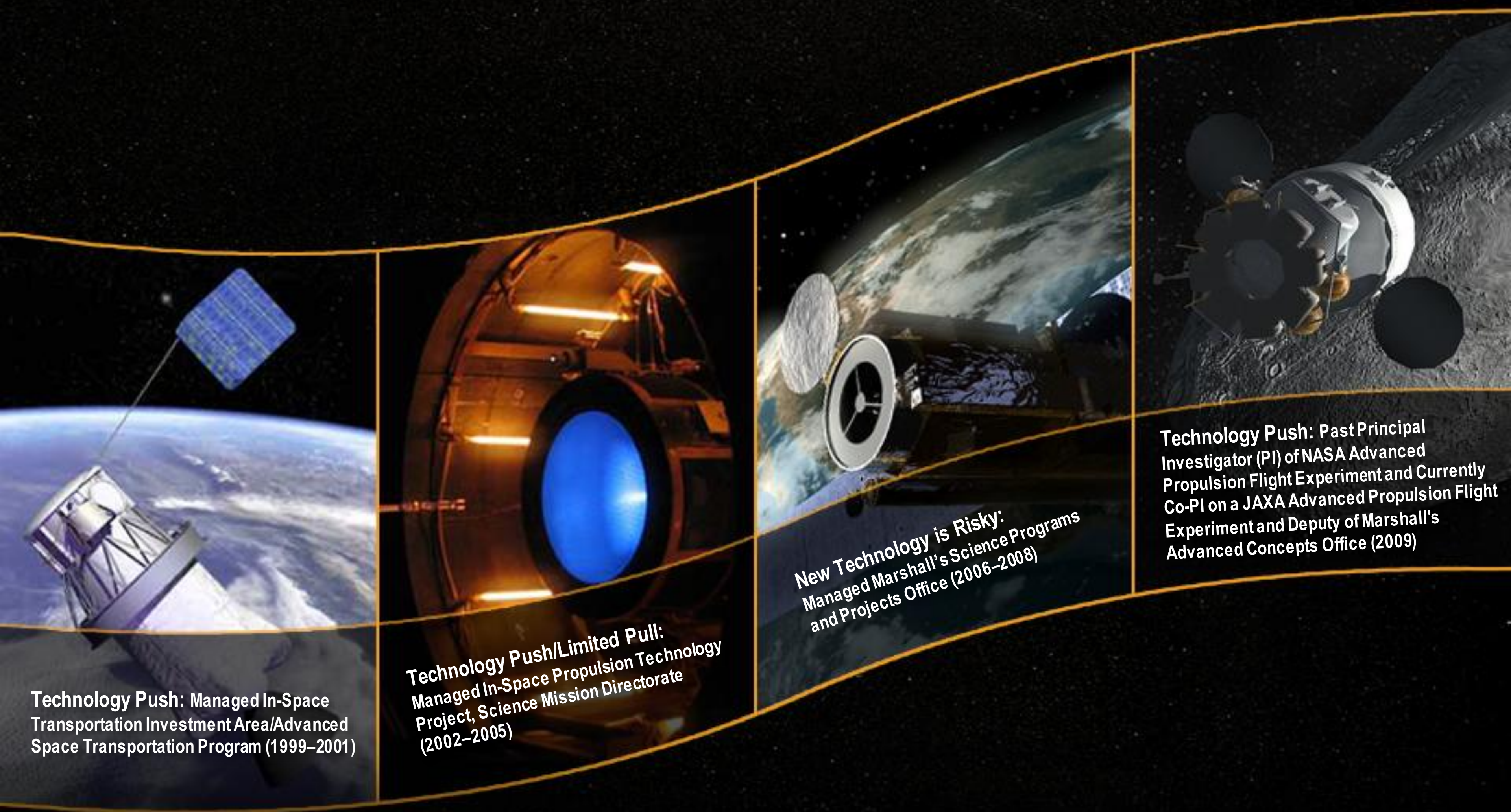
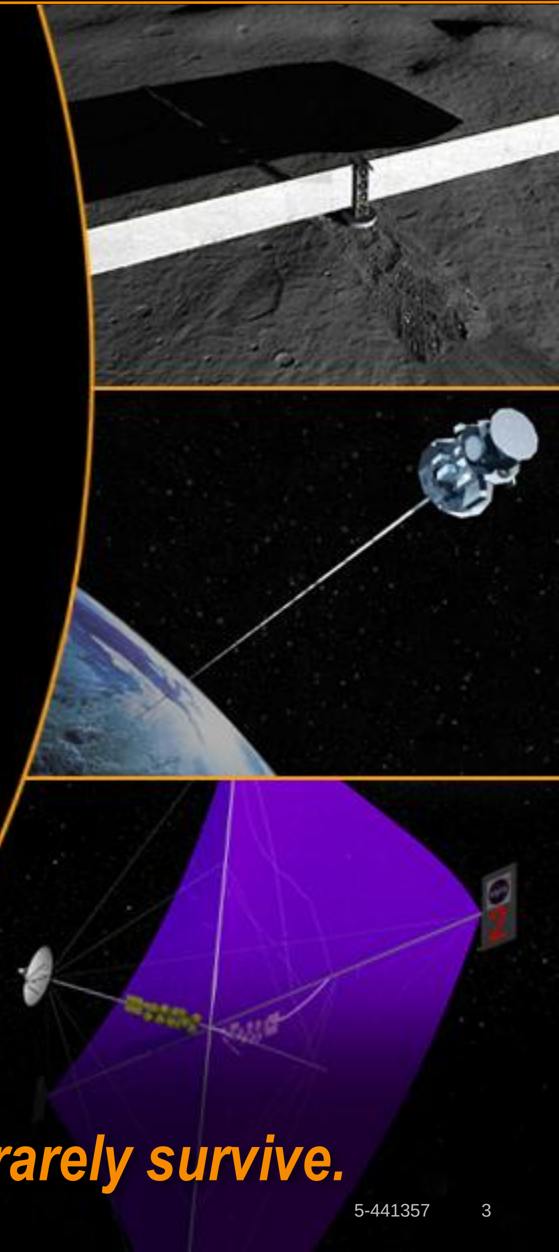
The Long and Winding Road



A strategy is needed to mature advanced space transportation technologies for exploration beyond Earth orbit.

Taking Technologies to the Next Level



Technology "Push" Versus "Pull"

- NASA funds an abundance of research and development
- Technologies with strong mission pull are most likely to successfully transition from research to flight
- Fundamental research is mostly push, not pull
- Most technologies are not developed with a "take it to flight" mentality
- Current technology programs are based on mission pull
- Flight projects and selection processes are highly risk averse
- PIs rarely propose a mission that requires new technology because it will reduce the likelihood of being selected; there is little mission pull

Technologies that enter the "Valley of Death" rarely survive.

Welcome to the Dreaded Technology Readiness Level (TRL) "Valley of Death"

- Exploration through the ages has been enabled by advanced technologies
- New technologies are key to going farther, faster, and reaping the ultimate rewards of R&D investments
- Many potentially useful, enabling, or revolutionary technologies don't survive the journey from ground development to mission implementation

Exploration beyond Earth orbit opens limitless possibilities.

Multi-TRL Strategy to Infuse "Push" Technology

TRL 7–9
Demonstration, Qualification, & Operations

Testing & Applying Technologies

TRL 4–6
Component & Prototype Testing

Maturing Technologies

TRL 1–3
Fundamental/Basic Research R&D

Conducting Fundamental Science & Basic Technology Research for NASA's Missions

Technology advancements are essential to the next giant leap in exploration.

Technology Development-to-Flight Application: Space Shuttle Main Engine Advanced Health Management System

Technology Development

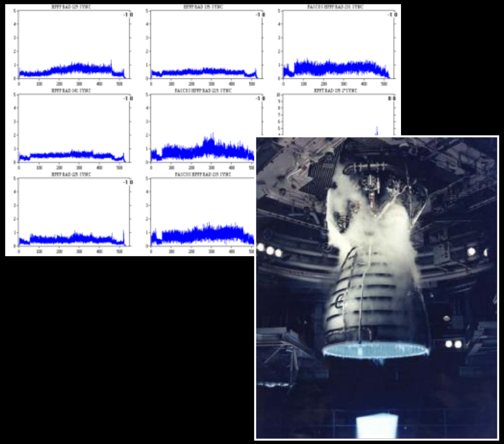
High-Speed Data Acquisition

1985–1996

Design, development, and implementation of high-speed data acquisition & processing. Systems and analysis algorithms resulted in the real-time vibration monitoring system (RTVMS), a vibration-based engine health monitoring system supporting the Space Shuttle Main Engine (SSME) Static Test Program.

TRL 1–3

Technology Maturation



RTVMS Technology Demonstration Flight

1996–2000

Implemented at Stennis Space Center (1996) as SSME health monitoring system; 500+ tests. Employed on HTD-2 Flight Experiment (STS–96). Proof-of-concept of high-speed vibration data acquisition and real-time processing in flight environment.

TRL 4–6

Space Transportation System Flight Application

AHMS Phase I Controller

Space Shuttle Main Engine
Advanced Health Management System

2000–Present

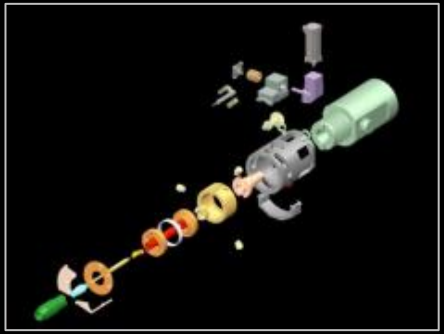
Developed into SSME Advanced Health Management System Phase I Flight Program, providing 23% ascent risk reduction. First flight in Dec. 2006 (STS–116). Have supported 12 STS flights to date.

TRL 7–9

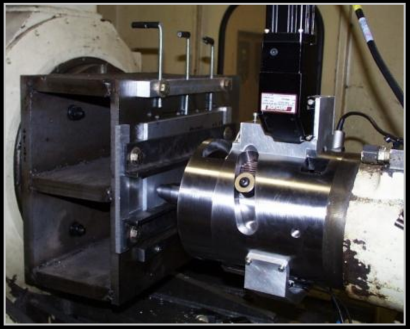
Taking technologies from R&D to flight operations.

Technology Development-to-Flight Application: Friction Stir Welding (FSW) (Auto-Adjustable Pin Tool)

1995 – Prototype Design (TRL 2)



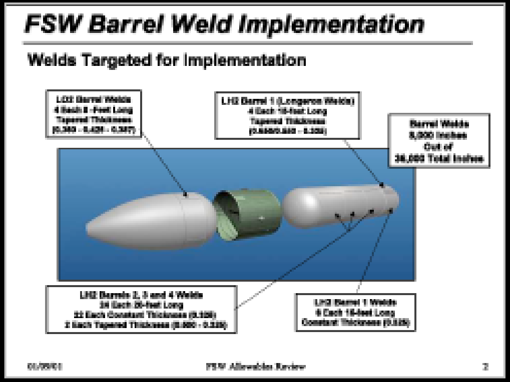
1996 – First Prototype Welding (TRL 4)



1998 – Welding Shuttle External Tank (ET) Barrel (TRL 6)

2002 – First ET Production Weld at Michoud Assembly Facility (TRL 6)

2002 through 2008 — Production Welding on External Tanks 132–138 MAF (TRL 7)



August 29, 2009 — First Friction Stir Welds Flown on STS–128 (TRL 9)

Developing manufacturing technologies for flight applications.

Cryogenic Fluid Management (CFM)

In-space cryogenic transfer stages are enabled & enhanced by low-gravity CFM technology development.

- Thermal control (enabling)
- Pressure control (enabling)
- Fluid transfer (enhancing → enabling)
- Zero boil-off (enhancing → enabling)
- Mass gauging (enhancing)
- Fluid acquisition (enhancing

State of the Art

- Over the past 40 years, numerous ground tests have been performed assessing cryogenic storage (thermal & pressure control)
- The remaining fluid handling technologies are less mature
- The only large-scale LH_2 CFM flight experiment was the Saturn IVB AS203 flight demo (1966)
- Current Centaur upper stage missions are 8 to 12 hours

Exploration Technology Development Program funds current research.

- Focused on ground tests examining component, subsystem, & integrated system evaluations

Managing cryogenic propellants in space provides a flexible path for long-duration missions.

Low-G, Long-Term CFM Experiment: Getting to TRL 6/7 (Flight Test)

Goals & Objectives

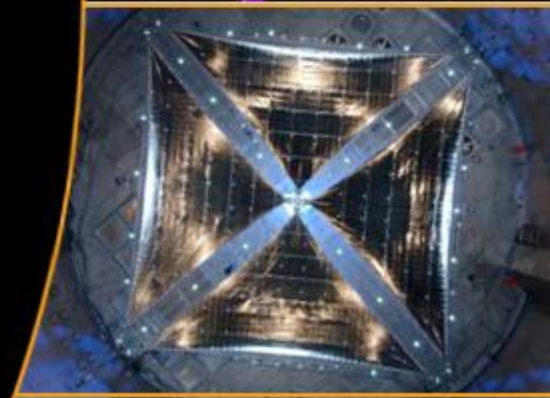
- First demonstration of integrated CFM technology components in low-gravity space environment
  - Target demo duration of 7 to 45 days as a free flyer
  - Produce data for analytical code validation
  - Provide low-G space environment data enabling scaling with previous 1-G tests
  - Establish confidence in CFM technologies and lead to application to large-scale transfer stages
  - Advance selected CFM technologies to TRL 6+

Human deep-space flight is an enabling pull for this technology.

Solar Sail Propulsion

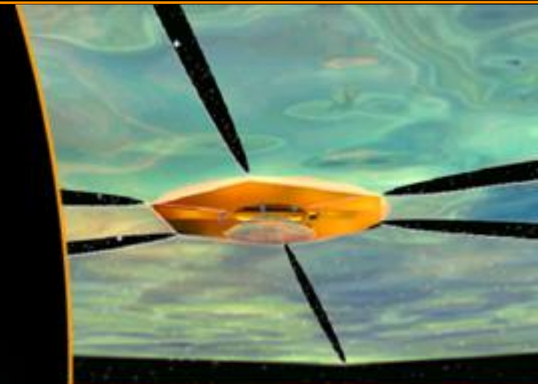
Technology Area Status

- Two competing teams designed, fabricated, and tested solar sails and performed system-level ground demonstrations
  - 100 m^2 system ground demonstrators were developed and tested in 2004
  - 400 m^2 system ground demonstrators designed, fabricated, and tested under thermal vacuum conditions in 2005
- Developed and tested high-fidelity computational models, tools, and diagnostics
- Multiple efforts completed: materials evaluation, optical properties, long-term environmental effects, charging issues, and assessment of smart adaptive structures



Providing continuous low thrust without fuel.

Full Scale (40-m × 40-m)
Solar Sail Propulsion Flight Demonstration



Enabling new destinations and new vantage points for robotic science missions.

Why are New Technologies so Difficult to Field?

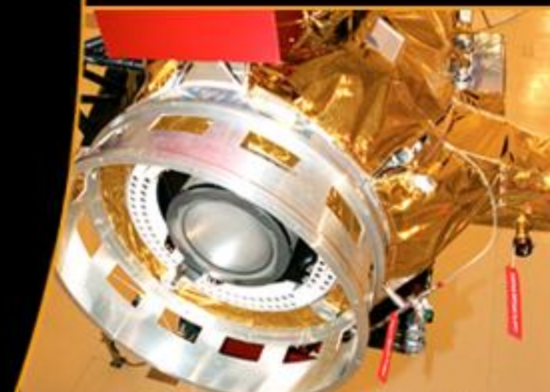
- Technologists are NOT Flight Hardware Engineers
  - Little thought is given to how a bench-top demo might actually become flight hardware (materials selection, power requirements, required operating conditions, etc.)
- Technology Managers are NOT Flight Project Managers
  - Limited understanding of the system-level impact of actually infusing the technology into a flight system
  - Focus is on the research (NASA Research Announcements (NRAs), grants, etc.) with little appreciation of how to get flight projects to adopt the technology
  - Reluctance to fund ongoing systems studies to guide future investments—"studies aren't technologies!"
- Cost and risk models for flight systems consider new technologies to be expensive and risky
  - Budgets are limited and risks are not easily tolerated by "the system"

Flight system models consider new technologies to be too costly and risky.

Why Are New Technologies So Difficult to Field? *(Continued)*

- Rigorous mission selection process favors science with low risk and potential cost growth over innovative and revolutionary science enabled with new technology, which has high risk and probability of cost growth

- Example Result: Solar Electric Propulsion
  - The Deep Space 1 mission in 1998 demonstrated this technology
  - NASA has selected only one additional Solar Electric Propulsion flight mission, Dawn, which launched in 2007



NASA needs an integrated approach to validating new technologies in space to retire the risk.

Gedankenexperiment

Scenario

- You are a Principal Investigator
- You may have two flight missions in your career
- You want to do great science

Criteria

- Highly competitive proposal process
- Ground rules include low risk and low cost
- New technology is considered high risk

The Challenge

- How would you advocate for a flight experiment that requires advancing new technologies to obtain GREAT science?

Advocacy can make the impossible possible.

Conclusion and Recommendations

- Fundamental research is critical to taking the next giant leap in the scientific exploration of space
  - NASA should be pushing the envelope and asking “what if?”
- Technology push enables new capabilities
  - When NASA began, everything was enabling
- Technology pull is often required to meet current mission requirements
- Technology management requires more than issuing NRAs and overseeing contracts
  - Continuous assessment, peer review, and system systems studies are vital to credible TRL advancement

A strategy for taking technology R&D to new heights will lead to discoveries at far-reaching destinations.

Conclusion and Recommendations *(Continued)*

- There must be a plan or opportunities for flight validation
  - To reduce the bottleneck of new technologies at the TRL Valley of Death
  - To allow frequent infusion of new technologies into flight missions
- Risk must be tolerated for new technology flight experiments
  - They are experiments, not missions!
- Risk must also be accepted on early-adopting missions
  - Enabling new capabilities is often worth the extra risk
- Still an increased risk and cost to the Mission

Traversing the TRL Valley of Death will propel the next giant leap in space exploration.

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