NEW MILLENNIUM PROGRAM

Technology Maturation and Flight Validation Experience for NASA's ST8 Mission

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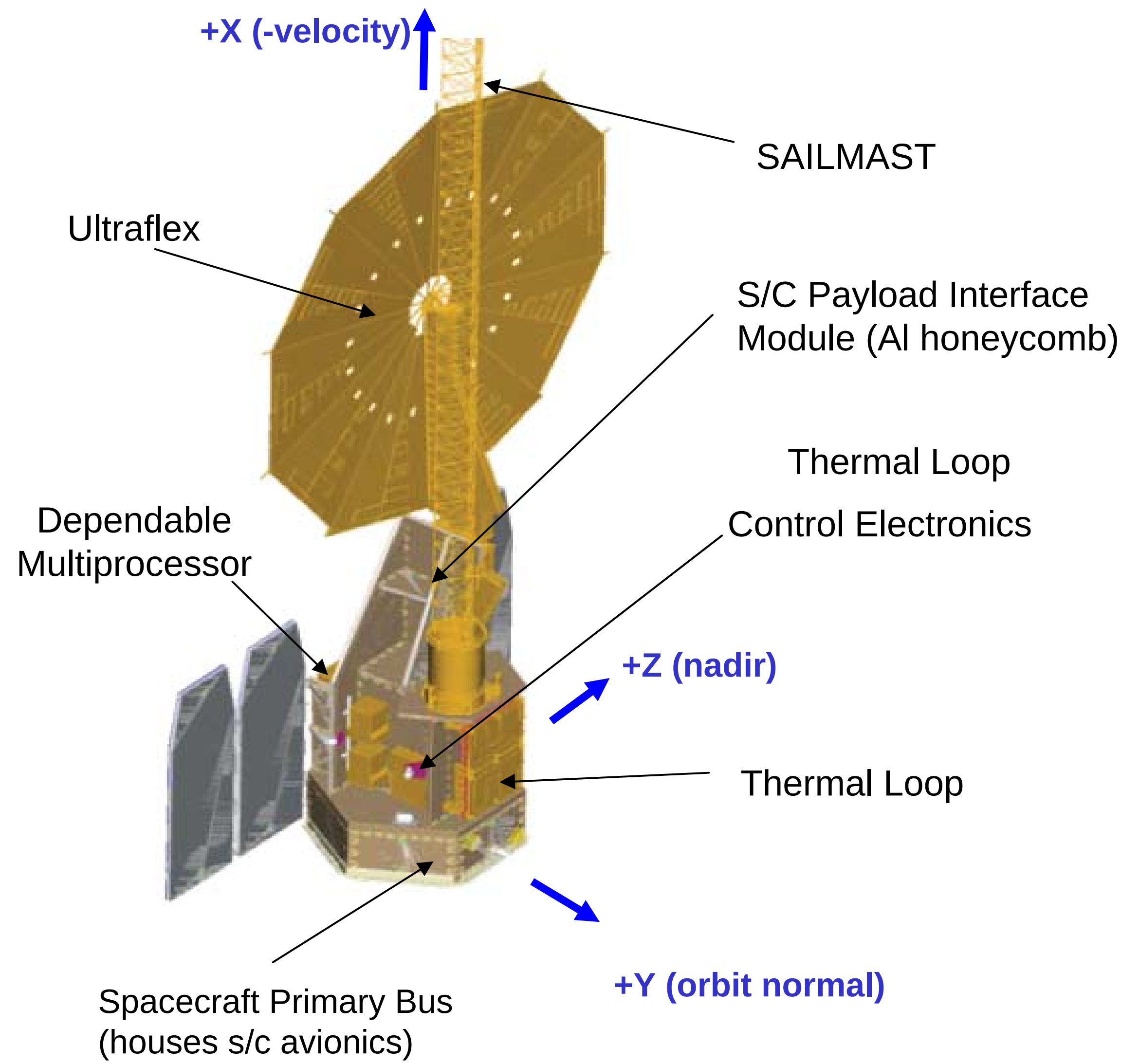
Overview

- Background
  - Introduction to ST8 Project
  - ST8 Project timeline
  - ST8 technology payloads
- Technology Readiness Levels (TRLs) as interpreted by NASA's New Millennium Program (NMP)
- Role of Technology Review Boards (TRBs) in the evaluation of technology maturity for the NMP ST8 Project
- Lessons learned from the ST8 TRB experience

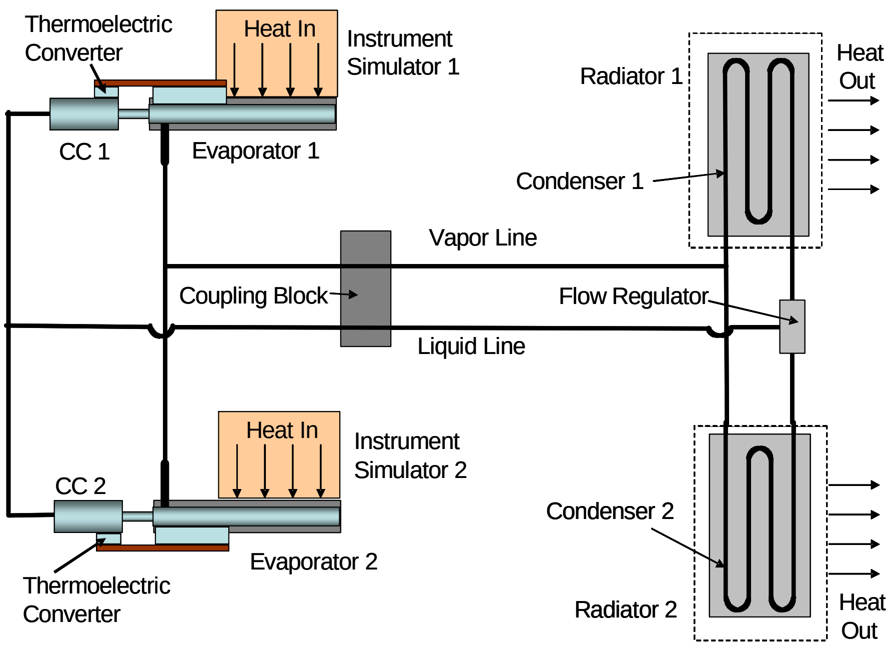
ST8 Spacecraft and Associated (Subsystem) Technology Payloads



ST8 Project Timeline

- 2/18/03: NRA for technology payloads released for the following technology capability areas:
  - Deployment of Ultra Lightweight Booms
  - Deployment of Lightweight Solar Array
  - Thermal Management Subsystem for Small Spacecraft
  - Commercial Off-The-Shelf (COTS)-Based High Performance Computing for Space
- 3/18/03: Technology payload proposals due
- 9/03: Technology payload suppliers selected for Phase A
  - Ultra Lightweight Booms (3 suppliers)
  - COTS (3 suppliers)
  - Lightweight Solar Array (2 suppliers)
  - Thermal Management Subsystem (2 suppliers)
- 12/8/04: Technology payload suppliers selected for Phase B
  - Ultra Lightweight Booms (ATK – Sailmast)
  - Lightweight Solar Array (ATK – UltraFlex 175)
  - COTS (Honeywell)
  - Thermal Management Subsystem (NASA/GSFC – Thermal Loop)
- 2/1/05: Start Phase B
- 8/3/05: Spacecraft vendor selected
- 10/06: Project Confirmation Review
- 2/1/07: Start Phase C/D
- 8/1/07: Project redefinition – flight segment cancelled/emphasis on completion of TRL6 validation activities
- 9/30/08: Project complete

ST8 Technology Payload: Thermal Loop



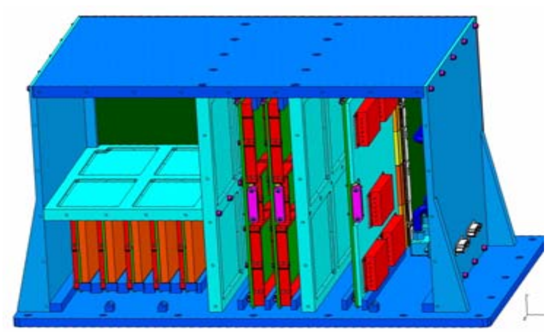
Technology Advance:

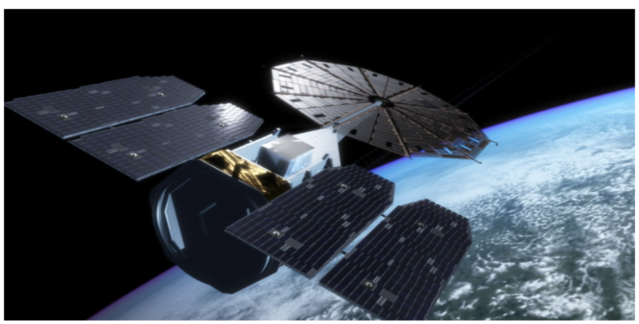
- A loop heat pipe featuring two evaporators (6.35 mm OD vs. 25 mm OD for current SOA evaporators) capable of cooling two separate instruments simultaneously and rejecting waste heat to space with two radiators
- Reduction in auxiliary heater power by making use of heat load sharing between the evaporators and by using thermo-electric coolers on the evaporator compensation chambers for reliable start-up of the loop
- Detailed thermal models for prediction of transient thermal performance of the loop

Validation Objective:

- Validate in space a miniature loop heat pipe thermal control system consisting of two evaporators and two condensers/radiators that is capable of reliable start-up, heat load sharing and can maintain operating temperature control within 0 to 35C.

ST8 Technology Payload: Dependable Multiprocessor





Technology Advance:

• Architecture for off-the-shelf, high performance, scalable, cluster processing in space – "SW-based SEU immunity enhancement"

• Ease of porting applications from lab to space

• Adaptable to environment: radiation, mission, mode

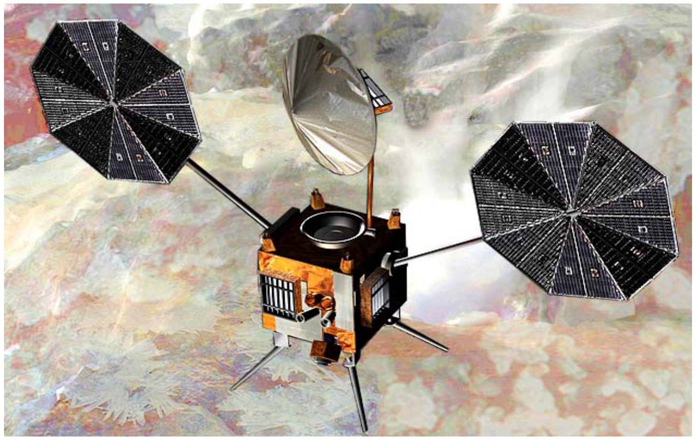
• Validated models that can predict system performance in future missions & environments

Validation Objective:

•Demonstrate delivered onboard computational throughput capability 10x – 100x more than any computer flying in space today

•Demonstrate onboard processing throughput density > 300 MOPS/watt

ST8 Technology Payload: UltraFlex 175



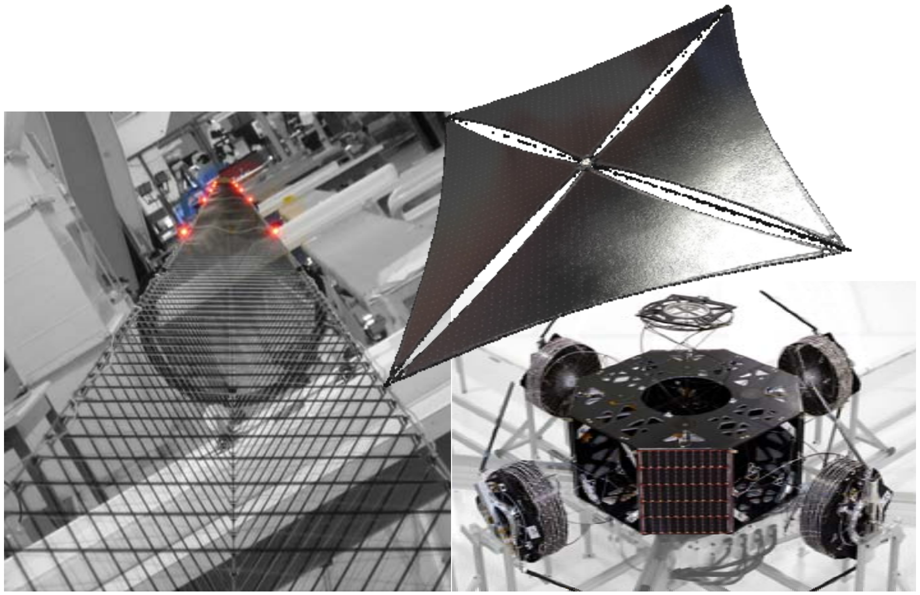
Technology Advance:

- UltraFlex-175 is 1/3rd the weight, 1/4th stowed packaging volume and > 3 times deployed stiffness of an equivalent SOA solar array
  - Accomplished via a unique open-weave substrate and solar cell laydown, fan-like unfurling deployment and pretensioned membrane deployed configuration

Validation Objectives:

- Deploy and operate in space an UltraFlex solar array and measure first mode frequency and photovoltaic power production
- Develop and test-validate analytical models, which will allow for scale-up performance predictions applicable to large UltraFlex solar arrays

ST8 Technology Payload: Sailmast



Technology Advance:

• Deployable boom 50% to 90% lighter than SOA (35 g/m)

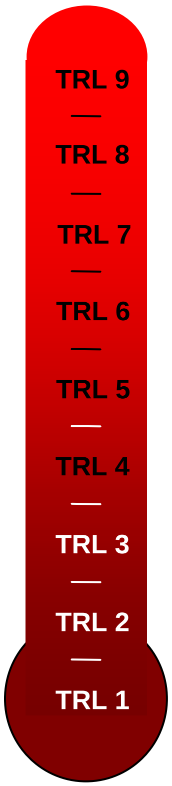
• Stows to less than 1% of deployed length (50% better than SOA

•10X more thermally stable (carbon fiber replacing heritage fiber glass)

Validation Objective:

• Deployment & operation in space to validate SAILMAST performance, scalable to >100m length

NASA Technology Readiness Levels (TRLs)



TRL 9 – Actual system “flight proven” through successful mission operations

TRL 8 – Actual system completed and “flight qualified” through test and demonstrated on the ground or in space

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NMP Domain

TRL 7 -- System prototype demonstrated in a space environment

TRL 6 – System/subsystem model or prototype demonstration in a relevant environment on the ground or in space

TRL 5 – Component and/or breadboard validated in relevant environment

TRL 4 – Component and/or breadboard validated in laboratory environment

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TRL 3 – Analytical and experimental critical function and/or characteristic proof-of-concept achieved in a laboratory environment

TRL 2 – Technology concept and/or application formulated

TRL 1 – Basic principles observed and reported

New Millennium Program experience on the ST5, ST6 and ST7 projects indicated that more detailed definitions were required for adequate assessment of TRLs

Candidate Technologies for NMP Validation Must be at TRL 3 Prior to Beginning of Phase A (Concept Development)

- TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept achieved in a laboratory environment
  - Laboratory tests have demonstrated that the **technology advance** performs as predicted by **analytical models** and has the potential to evolve to a practical device
  - **Analytical models** both replicate the current performance of the technology advance and predict its performance when operating in a breadboard environment
  - Determination of the “relevant environment” has been made

Analytical Models of the Technology advance(s) are Crucial for Success in NMP Technology Validation Projects

NMP Exit Conditions for TRL 4

- TRL 4: Component and/or breadboard validated in relevant environment
  - A “component” or “breadboard” version of the technology advance will have been implemented and tested in a laboratory environment
  - Analytical models of the technology advance fully replicate the TRL4 test data
  - Analytical models of the performance of the component or breadboard configuration of the technology advance predict its performance when operated in its “relevant environment” and the environments to which the technology advance would be exposed during qualification testing for an operational mission.

Technologies being validated by the New Millennium Program must satisfy these conditions prior to entry into Phase B (Formulation Refinement)

NMP Exit Conditions for TRL 5

- TRL 5: Component and/or breadboard validated in a relevant environment
  - The “relevant environment” is fully defined.
  - The technology advance has been tested in its “relevant environment” throughout a range of operating points that represents the full range of operating points similar to those to which the technology advance would be exposed during qualification testing for an operational mission.
  - Analytical models of the technology advance replicate the performance of the technology advance operating in the relevant environment
  - Analytical predictions of the performance of the technology advance in a prototype or flight-like configuration have been made

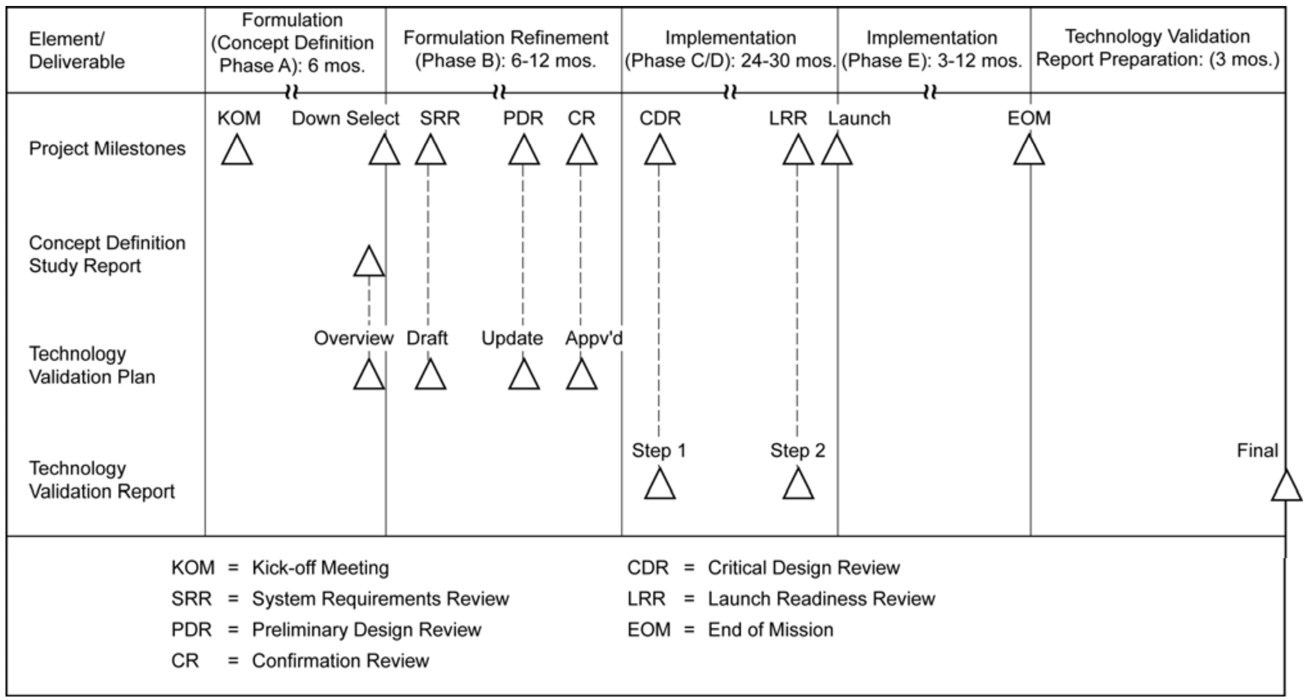
Technologies being validated by the New Millennium Program must satisfy these conditions prior to entry into Phase C/D (Implementation)

NMP Exit Conditions for TRL6

- TRL 6: System/subsystem model or prototype demonstration in a relevant environment on the ground or in space
  - The technology advance is incorporated in an operational model or prototype similar to the packaging and design needed for use on an operational spacecraft
  - The system/subsystem model or prototype has been tested in its “relevant environment” throughout a range of operating points that represents the full range of operating points similar to those to which the technology advance would be exposed during qualification testing for an operational mission.
  - Analytical models of the function and performance of the system/subsystem model or prototype, throughout its operating region, in its most stressful environment have been validated empirically.
  - The focus of testing and modeling has shifted from understanding the function and performance of the technology advance to examining the effect of packaging and design for flight and the effect of interfaces on that function and performance in its most stressful environment.

Technologies being validated by the New Millennium Program must satisfy these conditions prior to start of Assembly, Test & Launch Ops (ATLO)

A Technology Validation Plan is Required for all NMP Projects



Exit conditions and success criteria for TRLs 4 - 7 are specified in the Technology Validation Plan

How Does the New Millennium Program Assess Technology Readiness Levels?

- A Technology Review Board (TRB) is formed to work with technology providers to:
  - Establish actions specific to each technology that address TRL exit conditions
  - Establish success criteria specific to each exit condition
  - Review and approve the Technology Validation Plan
  - Review and assess the progress of each technology at the TRL exit point with respect to the established success criteria
  - Inform the Project Office on the advisability of potential descope options with negative impact on the technology advance(s)
  - Assess the maturity of processes and procedures key to the success of the technology advance(s) prior to CDR
- TRB members are recruited from NASA centers, other government agencies, Federally-funded research and development centers (FFRDCs), universities and non-profit technical organizations
- TRBs are chartered by the New Millennium Program Office and report to the Program Chief Technologist

ST8 Project Has Four TRBs

- COTS [5 members representing UCLA, LSU, NASA/JSC, JPL & Aerospace Corp., plus a member from the NMP technology staff]
- SAILMAST [4 members representing NASA/LaRC, NASA/MSFC, JPL (ret'd), Univ. of Montana, plus a member from the NMP technology staff]
- UltraFlex 175 [4 members representing Univ. of Colorado, NASA/LaRC, NASA/GRC, Texas A&M, plus a member from the NMP technology staff]
- Thermal Loop [4 members representing NASA/JSC, NASA/GRC, Clemson University, Aerospace Corp. (ret'd), plus a member from the NMP technology staff]
- NMP Chief Technologist is also a member of each TRB
- The Principle Investigator for each technology payload is also a member of his/her respective TRB
- ST8 TRBs were organized at the beginning of Phase B (early 2005)

Roles Played by NMP Technologists and TRBs on ST8

- TRBs formed at the beginning of Phase B
  - Some TRB members were involved in evaluation of proposals submitted at the end of the Concept Formulation Phase (Phase A)
- Original project schedule stretched out at the beginning of Phase B
  - Insufficient funding for a project payload manager and a project contract technical manager (CTM)
  - NMP program technologists serving on the TRBs were loaned to the Project to serve as the CTM for their respective technology payloads for the first nine months of Phase B
    - TRBs acted in advisory role to the CTMs and technology payload principle investigators
- Project payload manager and CTM were assigned in early FY ’06, and NMP program technologists transistioned back to their roles as executive secretaries for their respective TRBs
  - Role of TRBs became unclear at this point (peer review only vs. advisory and peer review)
- Cancellation of ST8 flight and current emphasis on completion of TRL6 activities has resulted in greater involvement by the TRBs

Thermal Loop Maturation Experience

- Significant differences between hardware used to demonstrate TRL4 and hardware proposed to demonstrate TRLs 5, 6 and 7
  - Different wick materials and design
  - Complicated by change of vendors
  - TRB found this situation unacceptable
- Technology provider offered alternate hardware for TRL5, 6 & 7 validation, but with smaller evaporator OD (6.4 mm) than that used for TRL4 validation (12.7 mm OD)
- TRB accepted alternate hardware, but required a partial rerun of TRL4 tests before beginning of TRL5 validation effort
  - Smaller diameter evaporator also lead to questions regarding differences in performance on the ground and in space
  - TRL5 tests indicated that gravity had some effect on Thermal Loop performance and that the analytical model could predict these performance differences
- Some questions regarding scaling criteria remain unanswered

Dependable MultiProcessor (DM) Maturation Experience

- Early Phase B
  - TRB was key in defining the technology advance, the relevant environment, and the DM architecture
  - TRB acted in the capacity of a technical expert to the technology provider
    - Fault tolerance development strategies
    - Test and validation approaches
- Follow-on Activities
  - TRB played an instrumental role in determining priorities and optimal descope approach as budget, schedule and spacecraft/orbit realities impacted DM development
  - TRB continues to be a strong force in steering the DM development as the project transitions from a flight-oriented activity to a TRL6 end-goal
  - TRB continues to promote the technology and ensure that the development, though significantly descoped, results in a high ROI for NASA and a path to product for the technology provider

SAILMAST Maturation Experience

- The SAILMAST TRB initially worked with the technology provider to:
  - Establish criteria with specific metrics to be met for accomplishment of TRLs 5 & 6
  - Provide advisory insights based on the TRB's understanding of issues that are important to the user community
  - Share relevant past experience with analysis, testing and data correlation
- The SAILMAST Experiment featured a unique cost-saving approach
  - The 40-meter flight article was fabricated in Phase B
  - Ground testing for TRLs 5 & 6 performed with the flight article
- Project resource constraints forced consideration of descoping experiments
  - TRB assessed and prioritized the descope options
  - As part of the prioritization process, the TRB established a floor for a minimum-level validation experiment that was judged worth pursuing

UltraFlex 175 Maturation Experience

- The UltraFlex 175 TRB initially worked with the technology provider to:
  - Establish criteria with specific metrics to be met for accomplishment of TRLs 5 & 6
  - Provide advisory insights based on the TRB's understanding of issues that are important to the user community
  - Share relevant past experience with analysis, testing and data correlation
- An innovative design solution for tensioning the membrane substrate of large fan-fold Ultra-Flex arrays was developed in Phase B
  - This controlled tensioning permits scaling to sizes ~6m diameter with predictable dynamic characteristics
  - Ground testing for TRLs 5 & 6 performed on test articles incorporating this feature
- Project resource constraints forced consideration of descope options
  - TRB assessed the descope options and prioritized them
  - As part of the prioritization process, the TRB established a floor for a minimum-level validation experiment that was judged worth pursuing

Lessons Learned

- Get TRBs involved as early as practicable
- TRB membership should be composed of:
  - Domain experts (technical experts in the specific field and experts in technology validation/verification/qualification)
  - Representatives from the future user community
  - Flight systems experts with knowledge of spacecraft systems, constraints and environments
- Keep TRBs involved and informed throughout the project
  - Foresee upcoming problems
  - Help determine priorities, alternatives, descopes and approaches as constraints and programmatic situations evolve
- NMP project offices need to keep technology validation plans up to date and available for TRB review