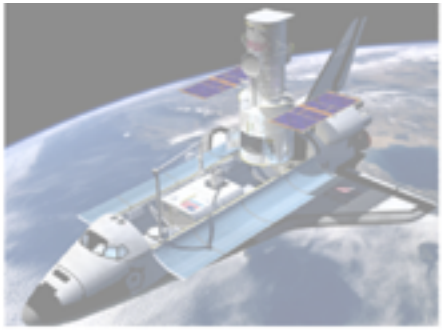
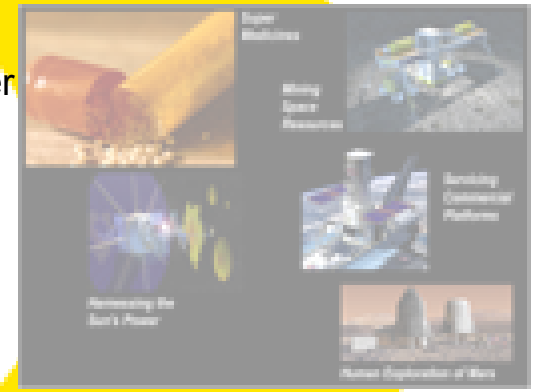
RVL Focused Technologies Support the 2nd Generation RLV Goals



Today: Space Shuttle
1st Generation RLV
- Orbital Scientific Platform
- Satellite Retrieval and Repair
- Satellite Deployment

2010: 2nd Generation RLV
- Space Transportation
- Rendezvous, Docking, Crew Transfer
- Other on-orbit operations
- ISS Orbital Scientific Platform
- 10x Cheaper
- 100x Safer



2025: 3rd Generation RLV
- New Markets Enabled
- Multiple Platforms / Destinations
- 100x Cheaper
- 10,000x Safer

2040: 4th Generation RLV
- Routine Passenger Space Travel
- 1,000x Cheaper
- 20,000x Safer

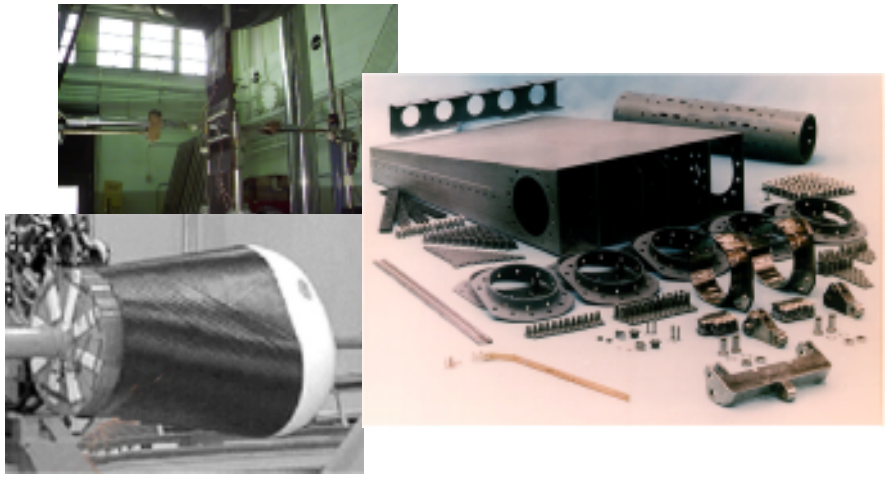
Background, Goals, and Objectives

- The RLV Focused Technology Project was conceived in FY98 to focus on high-risk RLV technologies including those areas identified as being inadequately addressed within the main-line X-33/RLV program.

- The **objectives** of the RLV-Focused Technology Project is to address critical component, subsystem, and system level technologies requirements in support of the development of a 2nd generation fully reusable launch vehicle.

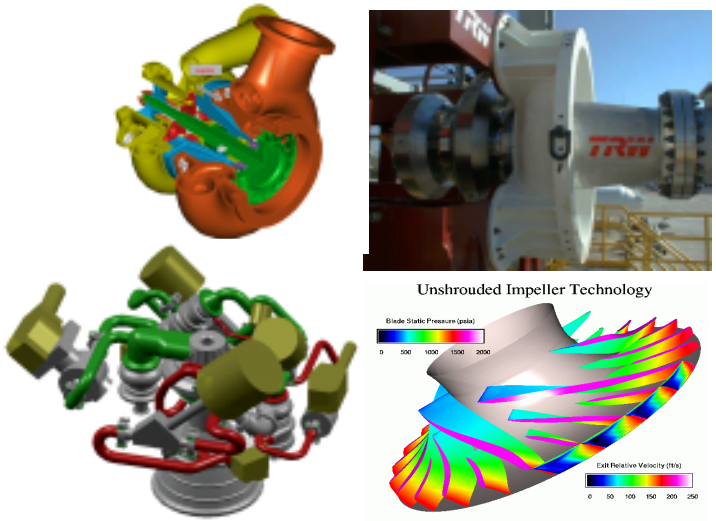
- The RLV-Focused Technology Project **directly supports Goal 9** of the ASTT Enterprise strategic plan
  - **Earth-to-Orbit**
    - **Within 10 years,**
    - **Increase the safety by two orders of magnitude**
    - **Reduce the cost to NASA transportation of placing payloads in orbit by one order of magnitude.**

Technical Challenges



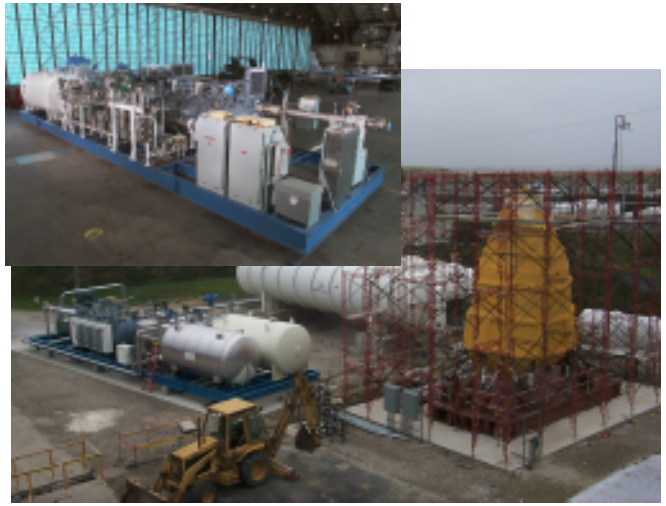
Composite Tank and Structures (LaRC)

- Materials and Manufacturing Processes



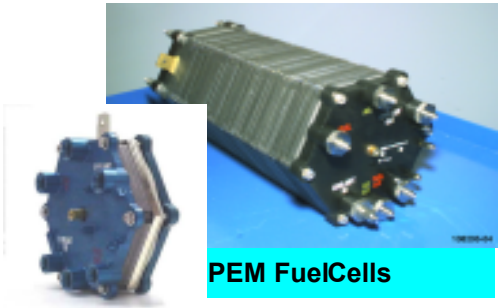
Propulsion (MSFC)

- Light weight, High-performance, Increased Safety Margins and Manufacturing



Propellant Densification (GRC)

- Reduced GLOW



Power (GRC)

- High Power Density and Reliability

TPS and Hot Structures (ARC/LaRC)

- Materials, Waterproofing,and Manufacturing

Customers and Stakeholders

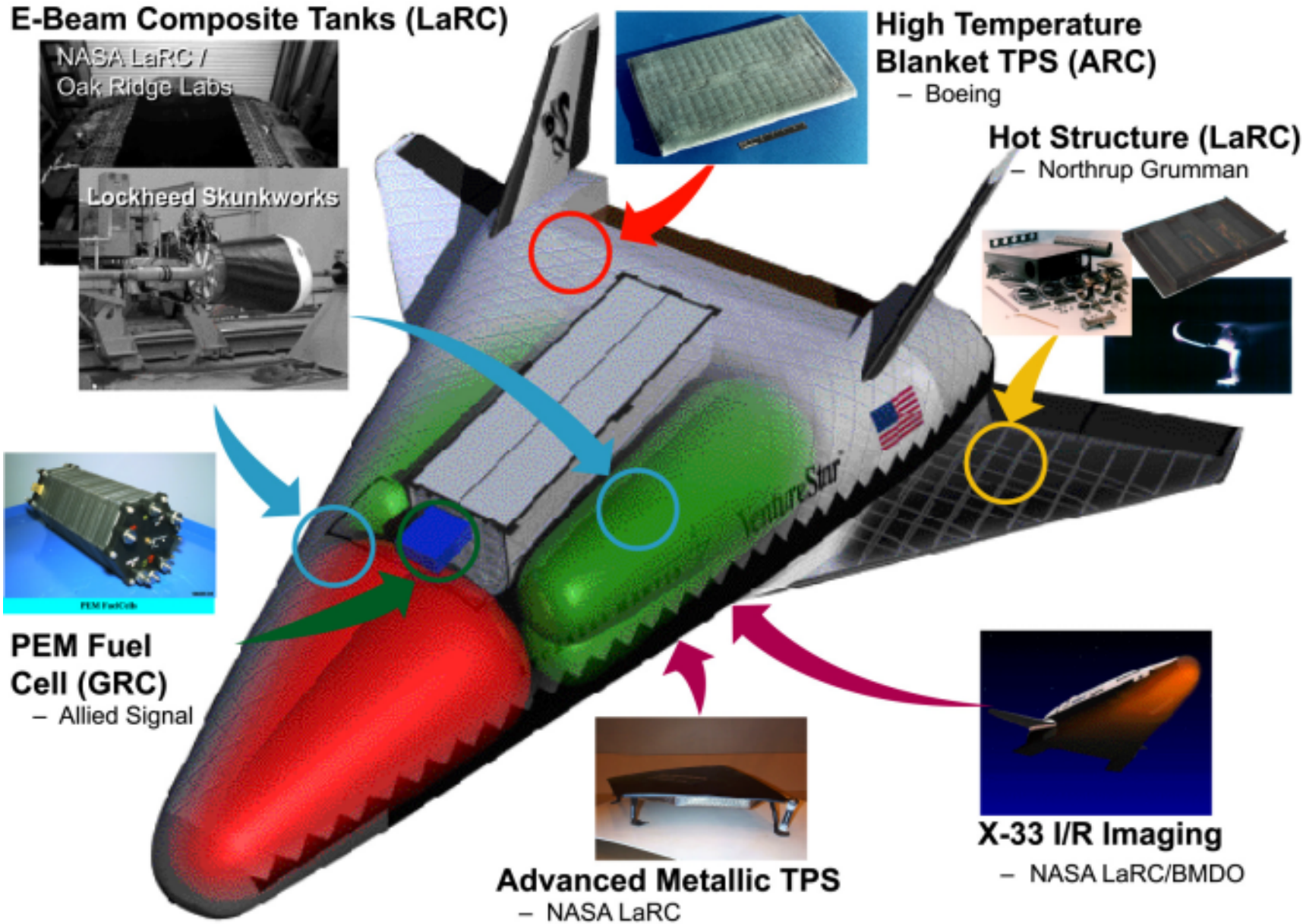
- **Key customers for the products of RLV Focused Technologies will be industry and government developers of the second generation Reusable Launch Vehicle systems.**
  - **The majority of current tasks are generic in their application and are not be specific to SSTO or TSTO RLV concepts.**

- **Industry and State Stakeholders include:**
  - **Nothrup-Grumman**
    - Activity with LaRC to develop Integrated Hot Structure using both PMS and CMC co-curing technology
  - **Allied Signal**
    - Cooperative effort to develop Proton Exchange Membrane (PEM) Fuel Cell Technology
  - **Boeing Rocketdyne**
    - Cooperative effort to develop metal matrix composites for propulsion component housings
    - Development of advanced turbomachinery and engine components for the Integrated Powerhead Demonstration
  - **Gencorp/Aerojet**
    - Development of advanced engine preburners for the Integrated Powerhead Demonstration
  - **Lockheed-Martin**
    - Composite design and manufacturing processes for both autoclave and non-autoclave fabrication
  - **State of Louisiana and the University of New Orleans**
    - Development of the National Center for Advanced Manufacturing to develop processes and design methodologies for advanced materials
  - **TRW**
    - Cooperative effort with SSC and MSFC to develop the 650 KLBF LO2/LH2 Ultra Low Cost Engine
  - **Boeing Phantom Works**
    - Conformal Reusable Insulation (CRI) is being developed under a Cooperative Agreement with ARC

Stakeholders

- **Government Stakeholders include:**
  - **Marshall Space Flight Center (MSFC)**
    - MSFC is responsible for overall project management, propulsion system integration, and development of propulsion subsystem and system technologies.
  - **Langley Research Center (LaRC)**
    - Langley is responsible for airframe and metallic TPS technologies.
  - **Stennis Space Center (SSC)**
    - Stennis is responsible for rocket propulsion system and subsystem testing.
  - **Glenn Research Center (GRC)**
    - Glenn is responsible for power, propellant densification and propulsion component and materials technology.
  - **Ames Research Center (ARC)**
    - Ames is responsible for advanced non-metallic TPS technology.
  - **Oak Ridge National Labs (ORNL)**
    - ORNL is working with both MSFC and LaRC to develop E-Beam curing technology for non-autoclave curing of advanced Polymer Matrix Composites for cryotanks, feed lines and ducts.
  - **Air Force Research Lab (AFRL)**
    - AFRL is working with MSFC and SSC to develop and test the advanced components of the Integrated Powerhead Demonstrator of the Integrated High Payoff Propulsion Technology Program
  - **Ballistic Missile Defense Organization (BMDO)**
    - BMDO is working with LaRC on infra-red imaging technology for in-flight Aeroheating analysis

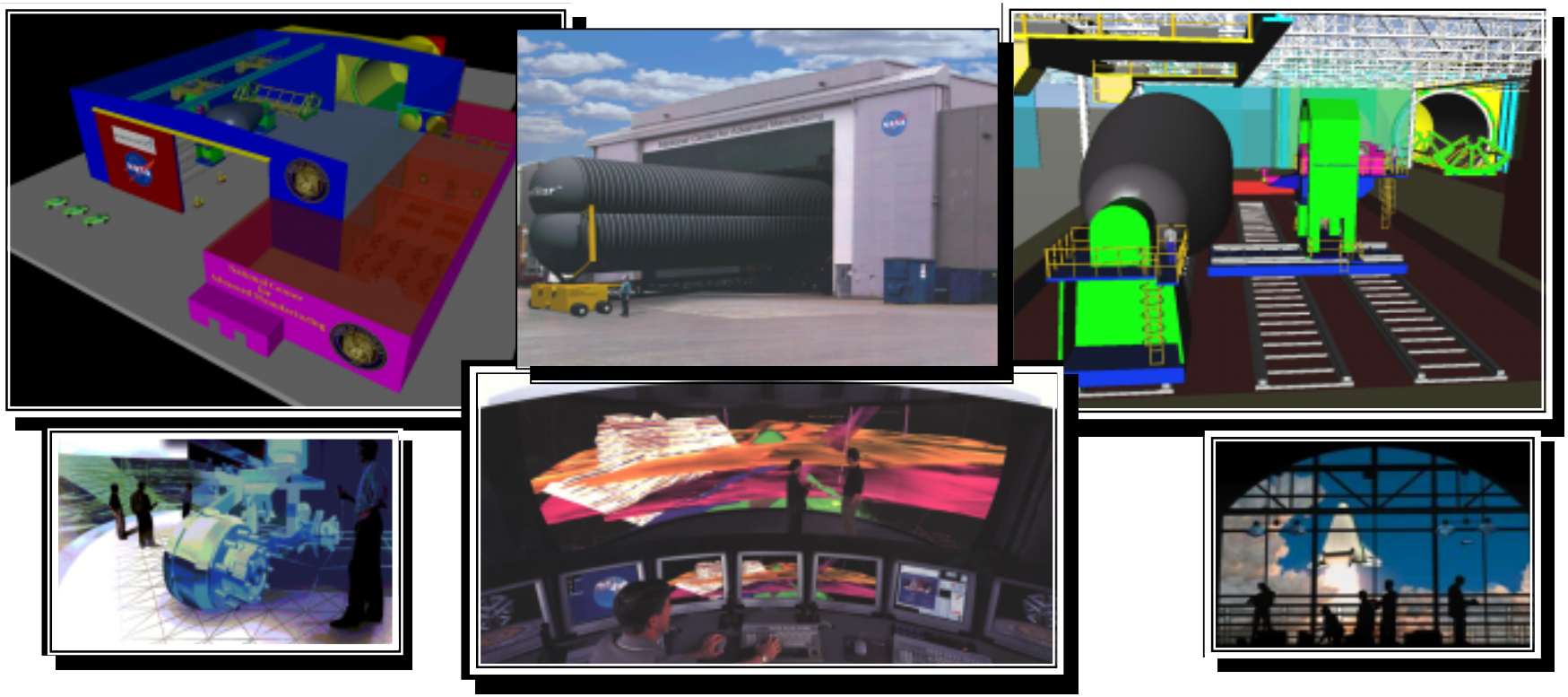
RLV Focused Airframe Systems Technologies



National Center for Advanced Manufacturing

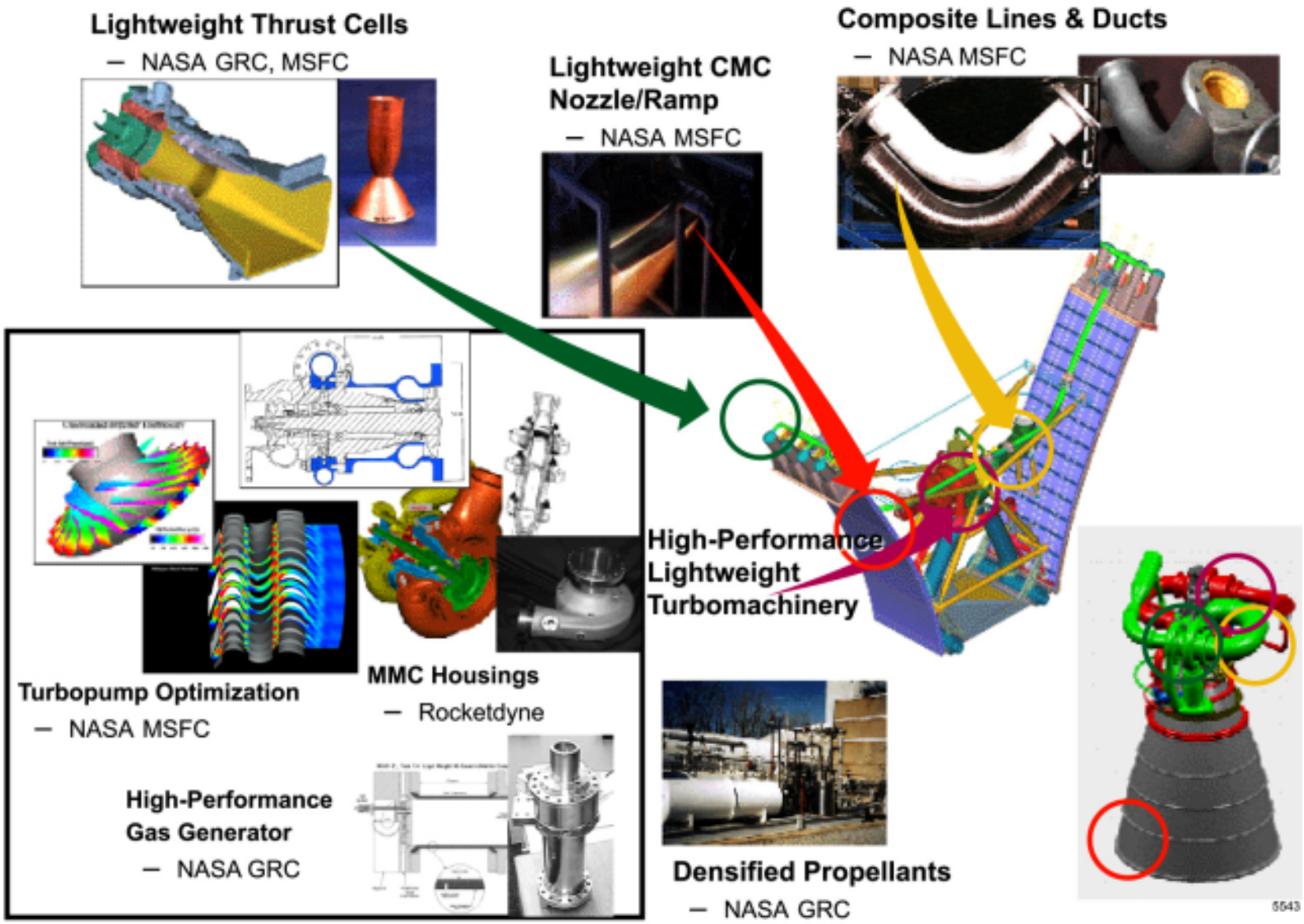
Manufacturing Technology Development

RLV Focused Project — 2000 PMC



- ***Provide World Class Manufacturing Capability Enabling Future Space Transportation Systems***
- ***Strengthen U.S. Competitiveness in Aerospace/Commercial Markets***
- ***Create Federal, State, University and Industry Mfg. Partnerships***
- ***Enhance Educational Development***
- ***Effect a cultural change in Manufacturing to Intelligent-Collaborative Environment***

Propulsion Technologies



Large Scale Propulsion Testbeds/Demonstrations

RLV Cryotank and TPS Technology

RLV Focused Project — 2000 PMC

2000 | 2002 | 2003 | 2004 | 2005

ISTP Dependent

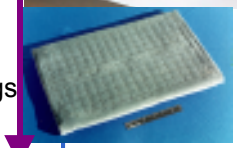
Major Milestones & Decisions

Key Tasks

- **Component/ Subsystem Demo**
- **Integrated Demo**

Robust, Operable Acreage TPS

- Ceramic, Flexible, Metallic, Hybrid Concepts
- Lightweight, Water, Erosion & Impact-Resistant
- Attachments, Rapid-Operable Change-out
- Reusability of Coatings and Coverings
- Low-Cost, Rapid Manufacturing /Processing



TPS Characterization and Performance Limit Validation

- Life-Cycle Testing
- Ground Test Traceability to Flight Environments
- Arcjet,Thermo-Mechanical, Vibro-Acoustic, Impact, and Thermal Cycling Testing

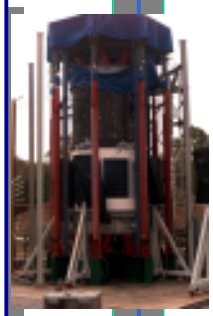
TPS Component Life Cycle Testing

- Total Mission Operations Cycle

- **NCAM**
- **RLV Focused technologies**

Composite Cryotank Systems

- **LO2 Resistant Tanks and Components**
- **LH2 Permeability Resistance**
- **Out-of-Autoclave Processing**
- **Conformal Designs**
- **Damage Tolerance and Field Repair**
- **Material/Structural Life-Cycle Characterization**



Objectives

- Meet Safety Goals
- Meet Cost Goals
- Meet Ops Goals
- Meet Weight Goals
- Validate Life-cycle Performance
- Robust/Durable

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RLV Propulsion Technology

RLV Focused Project — 2000 PMC

	2000	2002	2003	2004	2005

ISTP Dependent

Major Milestones & Decisions

From IPD Program

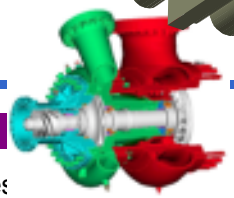
FFSC Cycle Validation Complete

Key Tasks

- Component/ Subsystem Demo
- Integrated Demo

Lox Pump

- Hot and cold flow tes
- Highly instrumented
- LOX rich turbine



Fuel Pump

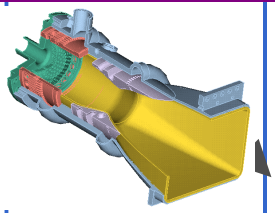
- Hot and cold flow tests
- Highly instrumented
- Hydrostatic bearings

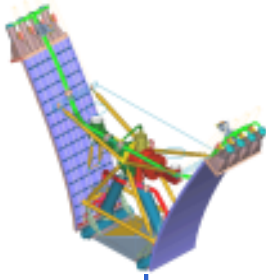
FFSC Cycle Validation

- Brassboard cycle demonstrator
- Provides engine environmental data
- Facility control system
- Heavywt injector, nozzle and chamber

Lightweight / high Performance Component Dev.

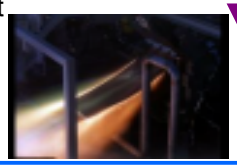
- High-performance, lightweight Thrust Cells
- MMC Pump & Valve Housings
- Composite and nano-phase lines/ducts





CMC Ramp Devel.

- Material Development and characterization
- Manufacturing process development
- CMC Joining and manafolding



Powerpack/Engine Level Demo

- Thrust Cell and Ramp Validation

Objectives

- FFSC Cycle Demo
- Lightweight Engine Componenets
- High Perf. Components
- Integrated control and health monitoring

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Major Accomplishments FY98/99/00

Date		Progress	
Planned	Actual	Accomplishment	Significance
		Light-Weight Ceramic GG	
May 1999	July 1999	High Temperature and pressure testing of Silicon Nitride rocket thruster of Lightweight GG materials	Effectiveness of filament winding on low-shock-tolerance alumina Capability of monolithic silicon nitride t withstand GG environments
		Ultra-Low Cost Booster Engine	
June 1999	Sept. 1999	ULCB Test hardware received from TRW at SSC.	Hardware has been mounted in the test stand at SSC with the TRR planned for Feb. 00.
		Conformal Reusable Insulation (CRI)	
April '99	April '99	Completed first series of Arc Jet tests	Demonstrated thermal resistance of novel formulations for
May '99	June '99	Completed Phase 1 Pad Weather Tests	Establishes baseline performance
Sept '99	Sept '99	Conformability Demo of Infiltrated CMC	CRI performance requirement
Dec '99	Dec '99	Completed 2nd series of Arc Jet tests maturing formulations	Demonstrated thermal resistance of

Major Accomplishments FY98/99/00

Date		Progress	
Planned	Actual	Accomplishment	Significance
		Light-Weight Thrust Cells	
Mar. 1999	Mar. 1999	Concepts selected for analysis, development and fabrication of thrust cells	Concepts identified that will potentially reduce the structural jacket weight by up to 40%.
Jan. 2000	Apr. 2000	Hot fire testing of sub-scale demonstration cells	Validation of concepts for proceeding into full-scale fabrication.
		National Center for Advanced Manufacturing	
Mar. 1999	Mar. 1999	MOU NASA/LA/UNO	Stepping stone to realization of NCAM signed at MAF
Aug. 1999	Aug. 1999	UNO composites classes begun	First UNO NCAM participation
		Propellant Densification	
June 1999	June 1999	LOX Densifier complete and Cold Shock Tested	Verified the readiness of the system for LOX testing
March 1999	June 1999	Receive LOX STA at GRC	Tank required to begin test buildup

Major Accomplishments FY98/99/00

Date		Progress	
Planned	Actual	Accomplishment	Significance
		PEM Fuel Cell	
April. 1999	Sept. 1999	First Subscale Stack Test of the PEM Fuel cell	Test Results Indicated a Number of Necessary Stack Design Modifications required for full-scale development
		Turbine Optimization	
2/1/99	4/15/99	Baseline CFD analysis completed	Identified major areas of lost; provided confidence to continue with optimzation
6/1/99	7/1/99	Phase 1 of the design code completed	Enabled quick iteration of design analysis with optimization
8/1/99	12/1/99	Preliminary design completed	Optimized design predicted at ~8.5% more efficient than baseline

Milestone Status

- ***Composite Tank Fabrication Processes Demonstration***

  G

  - Planned Completion Date: **July 2001**
  - Output: Validation of PMC cryogenic LH_2 and LO_X tanks to include validation of compatible materials systems and processes, fabrication and joining of large-scale articles.
  - Outcome: Significant weight reduction for RLV cryotanks and primary structure can be quantified through actual test data.
  - **Current activities have been delayed due to complications with the resins and the tank testing will slip into FY01.**

- ***Advanced TPS panel development, fabrication and test***

  G

  - Planned Completion Date: **August 2000**
  - Output: Database of TPS performance—Launch pad environment and flight survey of existing state-of-the-art materials (including advanced conformable reusable insulation concepts). Analytical model for optimization of flexible TPS design in a virtual environment.
  - Outcome: TPS that is more robust and requires significantly less maintenance than current ceramic tile and blanket TPS.
  - **Activities are proceeding as planned with no outstanding issues**

Milestone Status

- **Demonstration of a PEM fuel cell** — G
  - **Planned Completion Date: September 2000**
  - **Output:** Life cycle validation of PEM technology and validated design for future applications. Demonstrate compatibility with pure oxygen reactant and to demonstrate performance goals of 5.25 kW, 30 V on full-stack test article.
  - **Outcome:** Compared to the present alkaline STS fuel cell technology, the PEM technology offers the following advantages: Lower cost with significant future cost reductions; lower maintenance and longer life (10,000 hours vs. 2,000 hours); reduced weight (approximately 50 percent more power for same weight
  - **Effort is proceeding on schedule and should complete as planned with no outstanding issues**

- **Selection of CMC cooled ramp concept for RS-2200** — G
  - **Planned Completion Date: February 2000**
  - **Output:** Minimum of two concepts meeting the preliminary screening criteria for ramp development
  - **Outcome:** Validation of high-temperature tolerant material that may eliminate the requirement to actively cool the nozzle ramp of the Aerospike during the critical descent where currently projected heat loads are the most severe
  - **Potential sources have been identified and awards are pending**

Milestone Status

- **Lightweight, long life thrust cell delivery**

G

  - **Planned Completion Date: August 2000**
  - **Output:** Deliver for test multiple full-scale composite thrust cells in both a PMC and MMC configurations and perform analysis to assess the viability for using the materials on the development and flight aerospike engines
  - **Outcome:** Validation of a highly reliable and long-life thrust cell with a reduction in weight of up to 40 percent over the baseline design
  - **Task is proceeding to plan but final validation testing will slip into FY01**

- **Fabrication of the Integrated Powerhead Demontrator LOX pump**

G

  - **Planned Completion Date: July 2000**
  - **Output:** Complete fabrication and and delivery for test of the IPD Oxidizer turbopump
  - **Outcome:** New generation of highly reliable turbomachinery for Oxidizer-Rich engine applications with enhanced life and operational characteristics.
  - **Remaining turbopump hardware is in final fabrication and should meet schedule for on time delivery to SSC for test**

Milestone Status

- **Pressure fed component testing of The TRW 650K Thrust Chamber Assembly (TCA)** G
  - **Planned Completion Date: April 2000**
  - **Output:** A hot-fire test to verify proper operation fluid system priming and operation of the igniter system as installed on the TCA, and provide timing data to verify proper sequencing in the start-up timeline.
  - **Outcome:** The engine is designed for lowest cost, using a simple gas generator cycle, simple pintle injector, ablative chamber, and low cost foil bearing turbopumps. Validation of the operating characteristics of this engine would baseline the designs for a new family of low-cost booster class engines for ELV applications.
  - **TCA is currently in the test stand at SSC awaiting test and should meet planned schedule**

- **LOX Densifier verification testing and completion of hydrogen densifier build** G
  - **Planned Completion Date: April 2000**
  - **Output:** Validate design, technology and operational characteristics of X-33scale liquid oxygen propellant densifier, and prove readiness for use in experimental propulsion ground test or flight test program. Completion of Hydrogen densifier assembly.
  - **Outcome:** Data base for design and development of operational equipment for densification which when employed provides a 5-15% volume advantage that directly translates into reduced cost/increased performance.
  - **Preparations for the final planned testing of the LOX densifier are proceeding on schedule**

Milestone Status

- **Deliver Integrated Powerhead Demonstration LOX pump** — G
  - **Planned Completion Date: June 2000**
  - **Output:** LOX pump represents major advancement in LOX-Rich turbine drive pump technology including advanced bearings and low-parts count technology.
  - **Outcome:** IPD will be implemented in a step-by-step buildup leading to a system level test of a Full-Flow Staged Combustion cycle which will validate this cycle for possible development of the next-generation main engine for many of the 2nd Gen. RLV concepts.
  - **IPD LOX TPA is currently on schedule for on- time delivery**

- **IPD Lox Pump Cold-flow** — G
  - **Planned test date: September 2000**
  - **Output:** First test of the advanced low part count LOX turbopump
  - **Outcome:** First major step in system development leading to validation of the full-flow staged-combustion cycle engine at the 250klbf level.
  - **LOX pump is fully funded and facility buildup for the test at SSC is in work.**

Primary and Hot Structures Technology

2000 PMC

RLV Focused Project

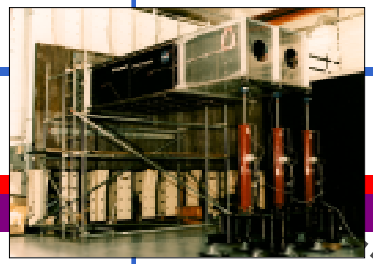
2000 | 2002 | 2003 | 2004 | 2005

ISTP Dependent

Major Milestones & Decisions

Key Tasks

- Conceptual Design/ Vehicle Integration
- Component/ Subsystem Demo



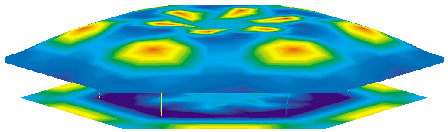
Composite Primary Structures

- RLV Focused technologies
- High-Temperature Materials
- Non-Autoclave Manufacturing
- Low-Cost Manufacturing
- Damage Tolerance and Field Repair
- Material/Structural Life-Cycle Characterization

To Integrated Structure Roadmap

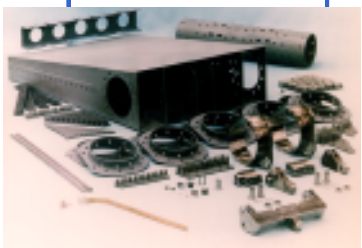
Metallic Primary Structures

- Near-Net Shape Manufacturing
- Welding and Joining
- Damage Tolerance and Field Repair
- Material/Structural Life-Cycle Characterization



Hot Structures

- Materials and Coatings
- Heat-Pipe Cooled Structures
- Damage Tolerance and Field Repair
- Material/Structural Life-Cycle Characterization



Objectives

- Validated full-scale primary structures (insulated and warm)
- Validated full-scale hot structures (control surfaces & leading edges)

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Energy Storage & Power Generation Roadmap

RLV Focused Project — 2000 PMC

	2000	2001	2002	2003	2004	2005
Major Milestones & Decisions	ISTP Dependent	Fuel Cell Accessory Section dev. comp.	Prototype PEM Powerplant dev. comp.			Fuel Cell Powerplant Qual. test complete
Key Tasks						
• Component/ Subsystem Demo	♦ Components development & test; PEM FuelCells					
• Integrated Demo			♦ PEM Fuelcell Powerplant prototype development & test	♦ Fuelcells flight experiment fab & test; ♦ PEM Fuelcells flight exp.		♦ Powerplant Qual. program

PEM FuelCells

Objectives

- ♦ Develop PEM Fuel Cells technology
- ♦ Flight demonstrate PEM Fuel Cells

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