NASA – Marshall Space Flight Center

Space Transportation Directorate

Advanced Space Transportation Program (ASTP)

Electron Beam Curing of Composites Workshop

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Enterprise Goals

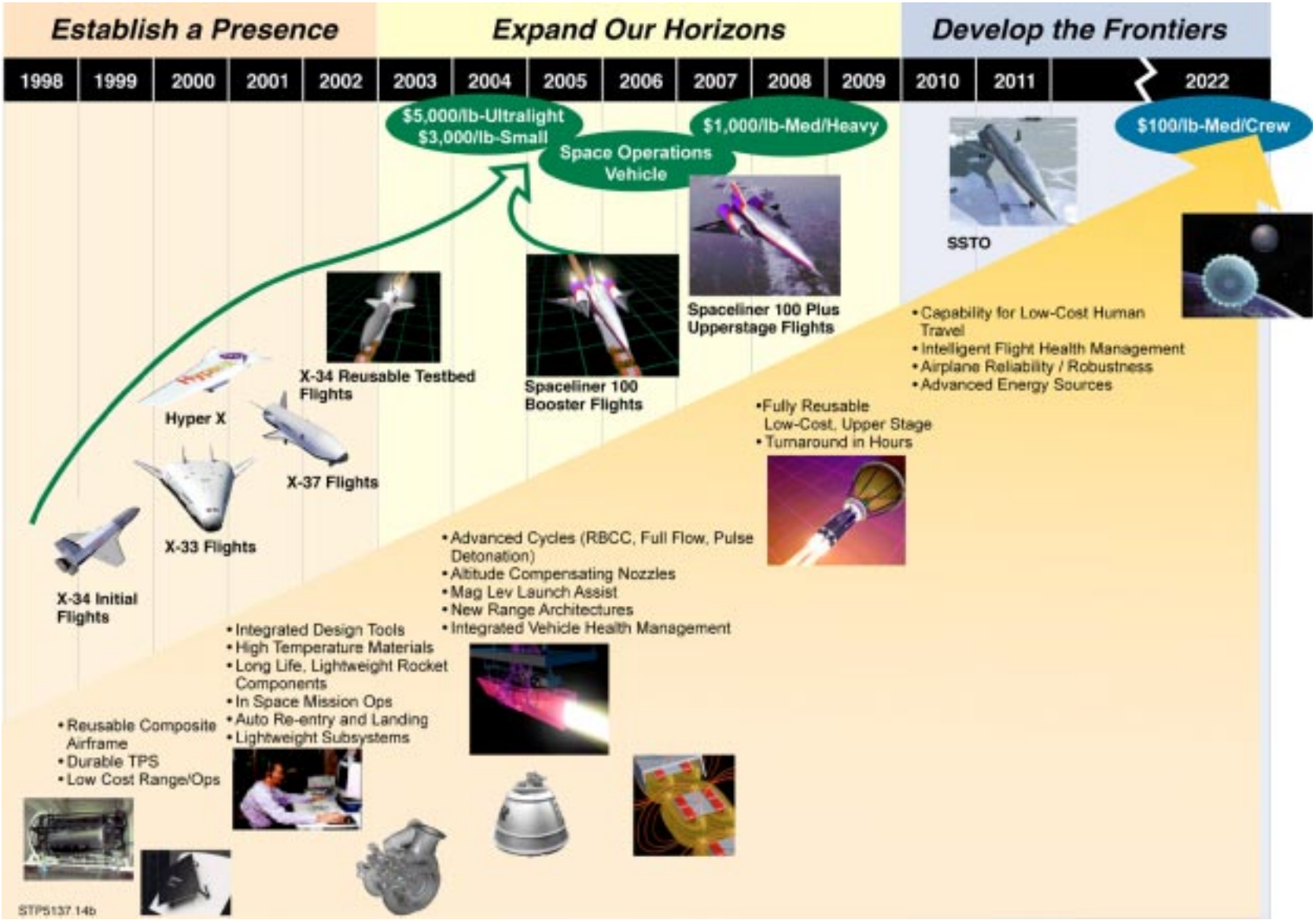
GOALS: Earth-to-Orbit

Reduce the payload cost to orbit by an order of magnitude, from $10,000 to $1,000 per pound, within 10 years and by an additional order of magnitude, from thousands to hundreds of dollars per pound, within 25 years

GOALS: In-Space Transportation

- Achieve with 15 years
  - A factor of ten reduction in the cost of Earth orbital transportation
  - A factor of two to three reduction in propulsion system mass and travel time required for planetary missions.
- Within 25 years
  - Enable bold new missions to the edge of the solar system and beyond by reducing travel times by one to two orders-of magnitude.

A Roadmap for Increased Safety, Reliability and Affordability



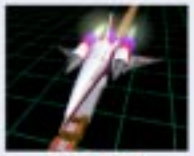
Technology Objectives

Goals

A Beautiful Machine
Safe — Reliable — Affordable

System Concepts

x10



x100

x1000

Upper Stages

Increased Design Margin

High-Strength High Temperature Lightweight materials
- PMC/CMC/MMC materials
- Tough TPS
- UHTC Leading Edge

Robust Design (Probabilistic Methods)
- Composite Life Prediction
- Probabilistic Methods

Propulsion Performance
- **lightweight materials**
- CMC/MMC
- **advanced cycles**
- IPD
- RBCC
- PDE
- **offboard energy**
- Mag Lev
- **high energy density propellants**
- **non-chemical energy sources**

Reduce Acquisition Cost

Mature System Technology
- Flight Demonstration

Advance Manufacturing
- Non-Autoclave PMC
- Advanced joining

Simplified Design/ Reduce Parts Count
- Integral Thermal-Structures
- Advanced Turbopump design

Rapid Design Cycle Advanced Design Tools
- Integrated Design Tools
- Advanced Aerothermal Prediction

Reduce Operational Complexity

Reduced Mating and Checkout
- SSTO
- Automated Umbilicals
- Micro-electro-mechanical Systems

Simple Range Ops
- Passive Coherent Location
- Autonomous Flight Safety
- Robust GN&C

Reduce Failure Rate/ Maintenance

Informed Maintenance

Advanced NDE
- Smart TPS
- E-Beam Repair
- IVHM Diagnostics
- High-Density Structial Sensors
- Smart Sensors

Near Term → Mid Term → Long Term

STD 5251

Project Types

Strategic Planning and Program Development	• Future X • Liquid Fly-Back Booster • Exploration	RA01 RA01 RA50
Operations Development	*Transportation Projects* • IUS • ICM • AR&C • CRV Propulsion Module	RA40
Flight Demos Flight demonstration of experiments, test beds,systems, and prototypes	*Reusable Launch Vehicle* X-33/Trailblazer X-34/Pathfinder	RA20 RA30
Focused Technologies focused on a specific application, configuration or vehicle	*Advanced Space Transportation* RLV Focused, Small Payload Focused, Upper Stage/In-Space	RA10
Core Broad core technologies applicable to several applications or configurations	Propulsion Systems Airframe Systems	RA10
Research Research into emerging space transportation technologies	Research	RA10

Increasing TRL, Cost, Focus

6-4535

Space Transportation Directorate
RLV Focused

Objectives/Goals

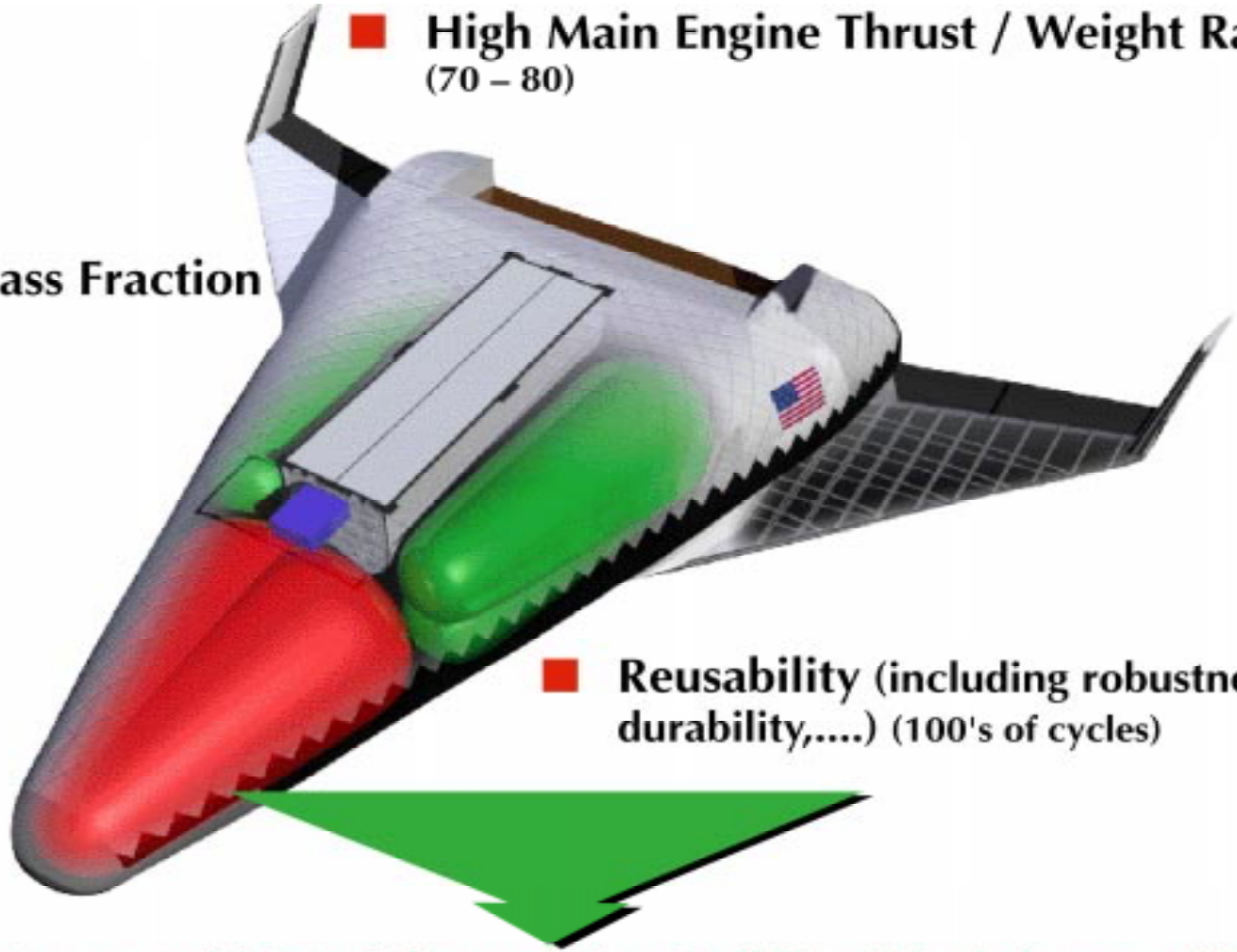
OBJECTIVE

- The RLV Focused Technologies will demonstrate critical airframe & propulsion technologies for a Reusable Launch Vehicle (RLV) in ground test.

GOALS

- To reduce risk and increase confidence in successful deployment of these enabling technologies to support a decision to proceed with commercial development of a full-scale RLV in the fiscal year 2000-2001 timeframe
- To demonstrate that these technologies provide significant system payoffs for a variety of RLV's by reducing vehicle weight and manufacturing costs and simplifying operations.

Critical Needs of Reusable Launch Vehicles



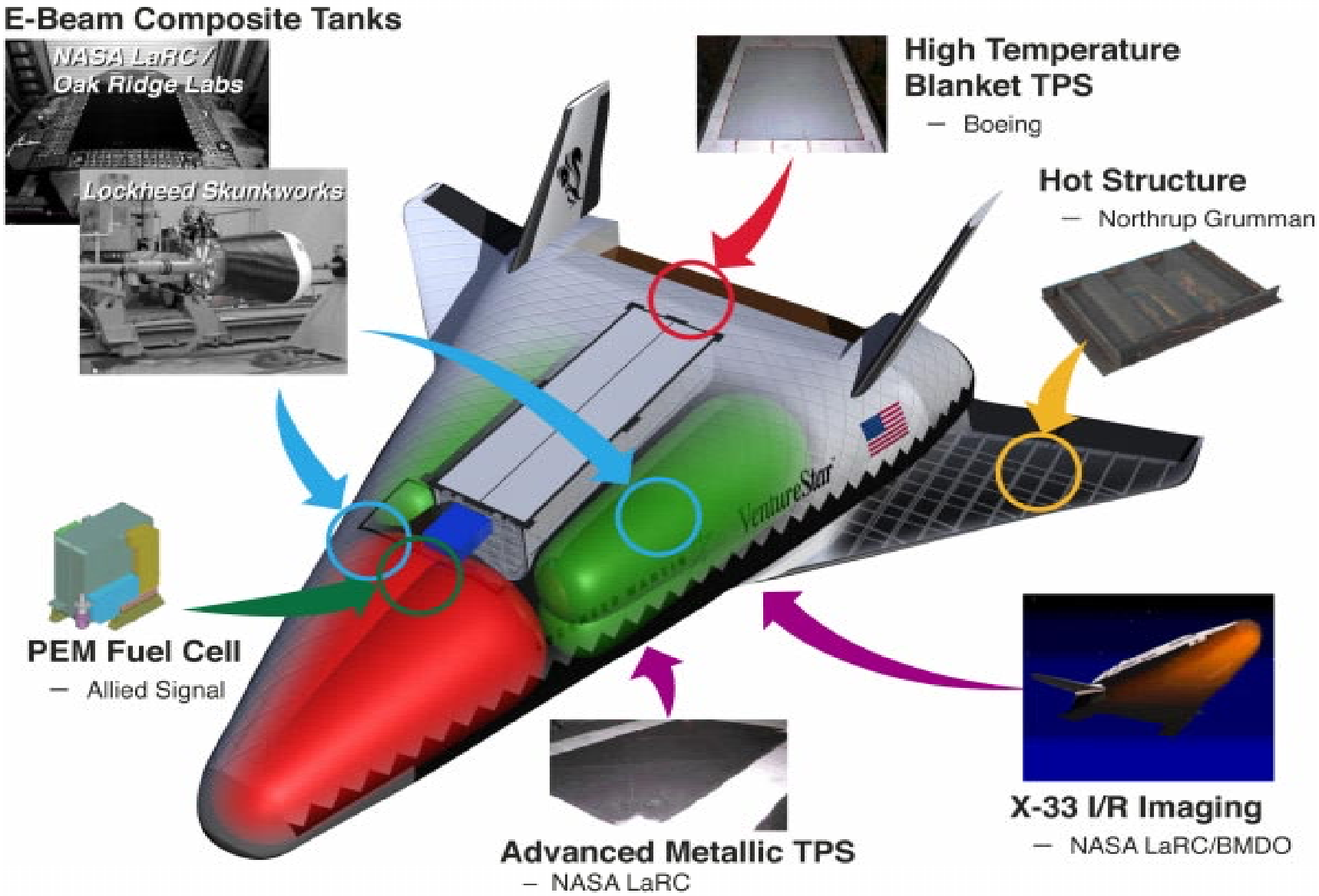
- **High Main Engine Thrust / Weight Ratio** (70 – 80)
- **High Mass Fraction** (> 0.90)
- **Reusability** (including robustness, durability,....) (100's of cycles)

Structures and Materials are a Key Building Block for any RLV

Status

- NRA 8-21 issued on March 23, 1998
  - Cycle 1: RLV Focused
  - Cycle 2: Core Focused
- Selection made on May 22, 1998
  - Available budget was $34M over 3 years
  - Received 56 proposals worth over $280M
- Most contracts awarded End of 1998(Contract period for 3 Yrs)
- Awards made in 2 major categories
  - Airframe Systems (Lead by LaRC)
    - Composite structures & tanks (LaRC, GRC, MSFC)
    - Advanced metallic TPS (LaRC)
    - Durable High Temperature TPS (ARC)
    - Hot structures (LaRC)
    - I/R Imaging of X-33 ((LaRC)
    - Advanced fuel cells (GRC)
  - Propulsion Systems (Lead by MSFC)
    - Composite Nozzle Ramp (MSFC, GRC, LaRC)
    - MMC housing (MSFC, GRC, SSC)
    - Lightweight Thrust Cells (MSFC, GRC)
    - Composite lines & ducts (MSFC, GRC, LaRC)
    - Lightweight gas generator (MSFC, GRC)
    - Turbopump optimization (MSFC)

Airframe Systems



Airframe Approach/Benefits

- **Integrated composite cryotanks (tank, insulation, TPS)**
  - Non-autoclave processing
  - LOX compatible composites
  - Low density structural foams (2 Lb/Ft3)
  - Improved joint designs (composite-to-composite & composite-to-metal)
  - 30% weight savings
- **TPS**
  - Foil gage metallic TPS
  - Internal multiscreen insulation (IMI)
  - Field repairable coatings
  - Conformable reusable insulation for leeward side application
- **High temperature integrated structures (500ºF)**
  - CMC outer face
  - Ceramic foam insulation
  - PETI-5 PMC structure
  - 30% weight savings, 30% reduction in acquisition cost, & 50% savings in LCC
- **IR Imaging**
  - Obtain laminar and turbulent aeroheating flight data
  - Validate tools for predicting laminar -> turbulent boundary layer transition

Non-autoclave Processing, LOX Compatible Composites, and Cryo Insulation for Thermal Structural Systems

(Principal Investigator: Dr. Brian Jensen)

Objective:

- **Establish databases on selected materials which support**
  - Non-autoclave processable composite structures for cryogenic tanks
  - Cryogenic foam insulation
  - LOX compatible composite
- **System Payoffs:**
  - Lightweight, robust, low cost, composite cryogenic tank and RLV airframe structure 30% vehicle weight savings for SSTO with composite cryogenic tank
- **Participants:**

Langley Research Center (lead)
Lewis Research Center
Applied Poleramics, Inc.
Rensselaer Polytechnic Inst.
Northrop Grumman
Oak Ridge National Laboratory (ORNL)
Lockheed Martin Skunk Works
Science Research Labs (SRL)
Marshall Space Flight Center

Non-autoclave Processing, LOX Compatible Composites, and Cryo Insulation for Thermal Structural Systems

Approach

- **Non-autoclave Processing**
  - E-beam curing
  - Vacuum bag/ Oven cure
  - Resin transfer molding
  - Robotic placement/ In-situ consolidation
- **Structural Foam Development**
  - Develop lightweight structural foam which can operate -250°C to 250°C
  - Low thermal conductivity for cryogenic applications
- **Develop LOX Compatible Composites**
- **Evaluate State-of-the-Art of Cryogenic Sealants**

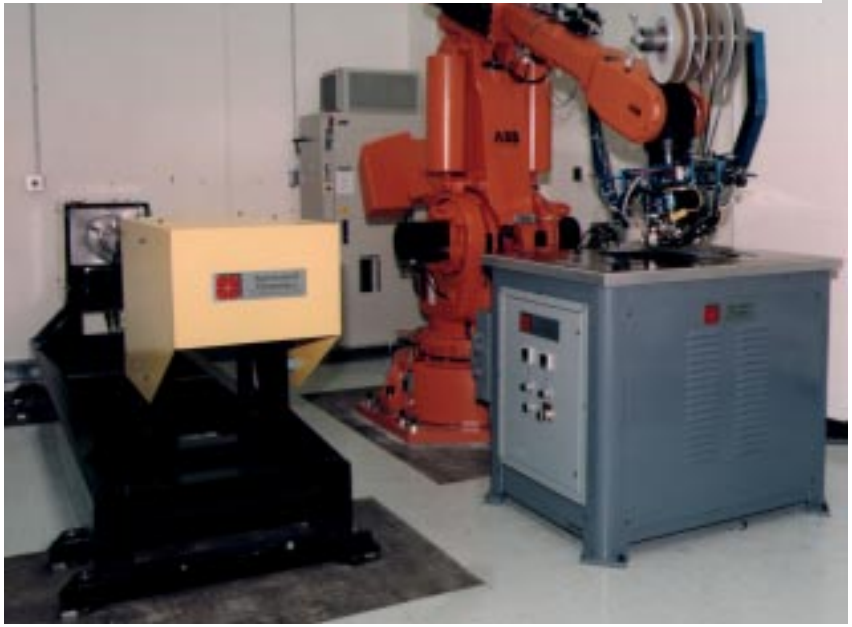
Non-autoclave Processing, LOX Compatible Composites, and Cryo Insulation for Thermal Structural Systems

Accomplishments

- New adhesive compositions display excellent properties when processed using vacuum bag pressure only - will make prepreg for composite preparation
- Development of HSR resins with RTM/RFI processability producing high quality composites continues
- Thermoplastic polyimide purchased, some converted to tape for automated placement, in-situ consolidation

Robotic Placement/ In-situ Consolidation

- Thermoplastics
- To be fitted for "on-the-fly" ply by ply e-beam cure



Joining Technology

(Principal Investigator: Dr. Wayne Sawyer)

Objective

- Develop innovative joint design concepts for both cryogenic tanks and dry structure, and electron-beam curable adhesives for joining cryogenic tanks

System Payoffs

- Reliable and efficient joint designs for cryotanks fabricated without an autoclave that meet thermal and mechanical cyclic load requirements for RLV
  - Secondary Bonded
  - Electron-Beam Cured
  - Oven Cured
- Reliable, efficient and cost effective joint concepts for assembly of large graphite-composite shell structure

Participants

NASA Langley Research Center (lead)

Lockheed Martin Skunk Works

Boeing (Huntington Beach)

Northrop Grumman (Hawthorne, CA)

Assembly Joint Test Specimens

Progress and Accomplishments

- Boeing Fluted Core Splice joints are in testing
  - Some fasteners have failed and are being replaced with stronger fasteners
- Two additional fluted core designs have Been Fabricated

Fluted Core Splice Joint

Electron-beam Curing of Composite Cryogenic Propellant Tanks (Task Manager- Dr. Wayne Sawyer)

Objective

- Develop and demonstrate the technology for out-of-autoclave fabrication of a composite cryotank using electron-beam curing
- Develop and demonstrate the technology for fabricating a cryotank with inverted domes

Payoffs

- Reduced composite cryotank fabrication costs - eliminate the need for a construction of a huge autoclave
- Reduce vehicle structural weight and improve vehicle center of gravity location by more efficient packaging of vehicle components

Participants

Lockheed Martin - Prime contractor
NASA LaRC - Design, analysis, and test support
NASA MSFC - Test of cryotank test component

Electron-beam Curing of Composite Cryogenic Propellant Tanks

Approach

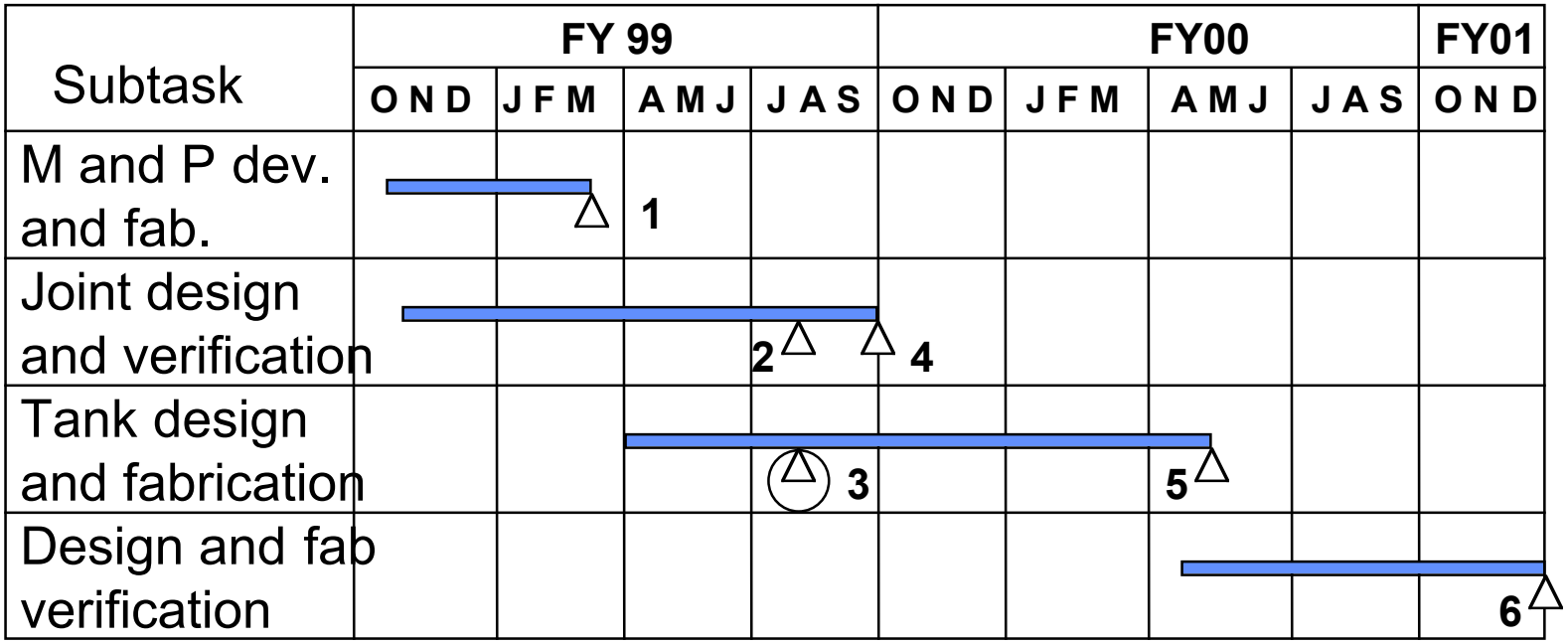
- Select material system and fabrication process
- Develop limited material properties for electron-beam cured materials
- Develop and verify barrel-to-inverted dome joint design and fabrication technology for electron-beam curing
- Design and fabricate 8 foot diameter duel-lobe cylindrical cryotank with inverted domes and assemble using electron-beam cured joints
- Verify integrity of cryotank component through hydrogen pressure tests

Electron-beam Curing of Composite Cryogenic Propellant Tanks

Progress and Accomplishments

- Contract initiated November 3, 1998
- Material process specimens fabricated and testing in progress
- Scaled up panels for thermal and structural testing are designed, fabrication begun, some delay due to problems with customs (Canada)
- Design and analysis of inverted dome concept progressing - currently designing test articles

Electron-beam Curing of Composite Cryogenic Propellant Tanks



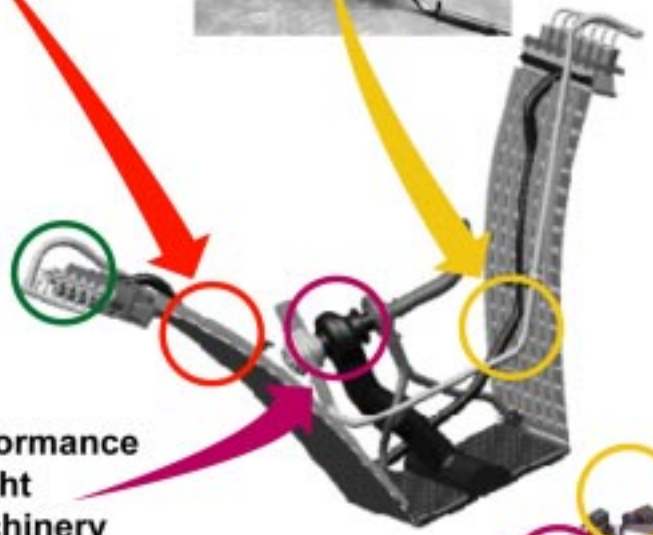
Milestones: 1) Material and process development complete, 2) Joint specimens fabricated, 3) Fabrication of cryotank initiated, 4) Joint tests completed, 5) Cryotank fabrication completed, 6) Cryotank tests completed: Potential off-ramps are circled

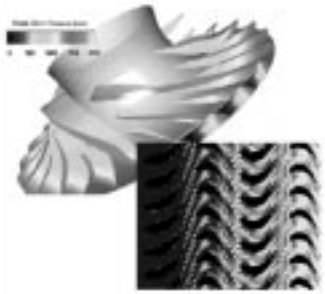
Propulsion Technologies

Lightweight Thrust Cells
– NASA LeRC, MSFC

Lightweight CMC Nozzle
– NASA MSFC

Composite Lines & Ducts
– NASA MSFC

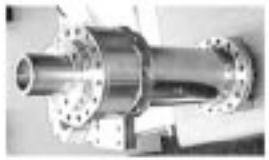




Turbopump Optimization
– NASA MSFC

MMC Housings
– Rocketdyne

High-Performance Gas Generator
– NASA LeRC



High-Performance Lightweight Turbomachinery

Densified Propellants
– NASA LeRC

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Propulsion Approach/Benefits

- Lightweight composite ramp
  - 2 Lb/Ft3 weight goal
- Lightweight, long life thrust cell
  - Reduce weight of chamber assembly (over XRS-2200) by 20%
  - CMC & Cu-8Cr-4Nb liner concepts
  - PMC & MMC structural support concepts
- Lightweight annular gas generator combustor
  - Uncooled, impermeable ceramic composite
  - Joining technology
- Composite lines, valves and ducts
  - Polymer matrix composite
  - Both LOX & LH2 environment
  - 8” diameter ducts and full scale valve housing
- MMC turbopump housing
  - Cooper based MMC (8 alloys investigated)
  - Oxygen rich environment
  - 50% weight savings

Propulsion Approach/Benefits

- **High head unshrouded impeller pump stage**
  - **Reduce stages from 3 to 2**
  - **50% weight reduction**
- **Turbine performance optimization**
  - **Improve turbine efficiency by 8 points**
  - **Reduce mass flowrate by 10% (Isp > 1.5 sec)**

Or

  - **Reduce turbine temperature by 275 ºR (potential for uncooled metal blades)**