Hypersonic Project Overview

presented at the

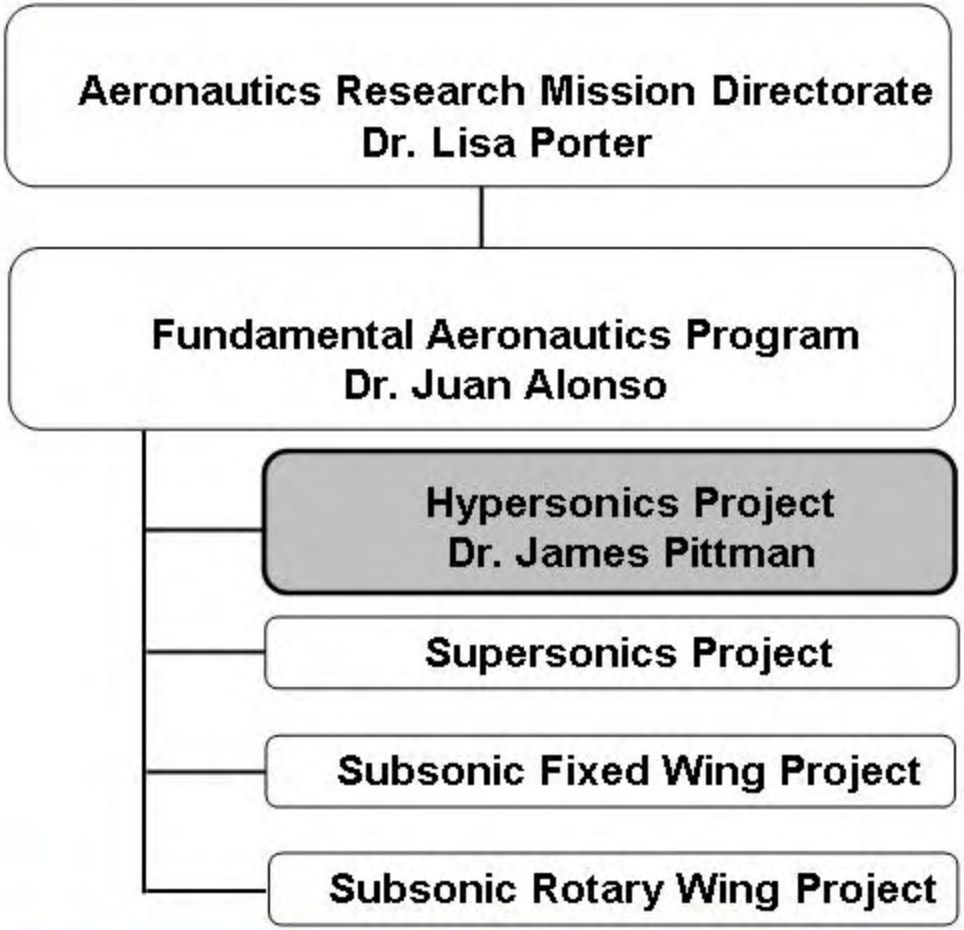
Fundamental Aeronautics Program
2007 Annual Meeting

by

Dr. James L. Pittman
Principal Investigator

October 30, 2007
New Orleans, LA

The ARMD Hierarchy

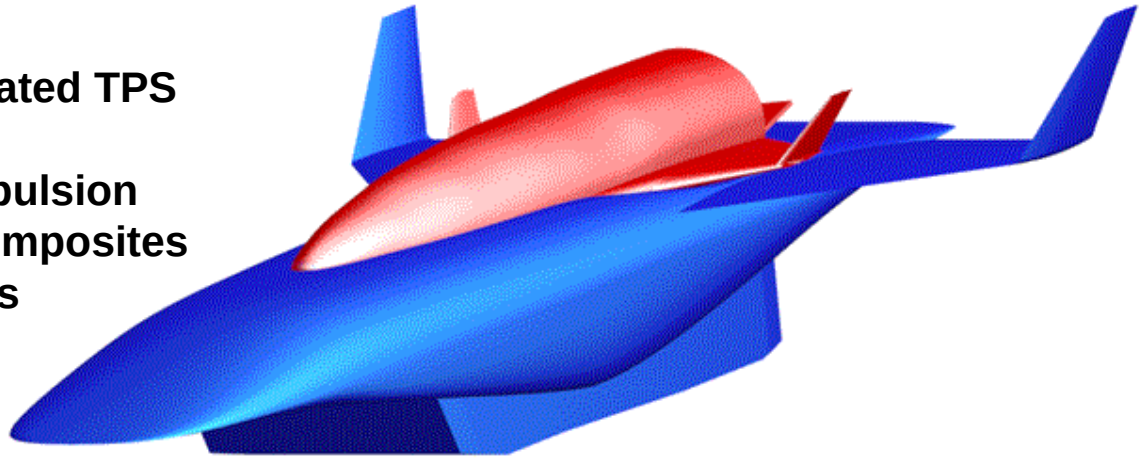


Fundamental Aeronautics Program: Conduct long-term, cutting-edge research in the core competencies of aeronautics in all flight regimes, producing knowledge /data/ capabilities/ design tools that are applicable across a broad range of air vehicles.

Hypersonics Project Focus

Highly Reliable Reusable Launch Systems
NASA Two Stage To Orbit Reference Vehicle

Structurally Integrated TPS
Hot Structures
Active-cooled propulsion
Ceramic Matrix Composites
Integrated Controls



CFD Methods
Physic Based Models
Physics Based MDAO
Vehicle Studies

Turbine Based Combined Cycle Propulsion
Combustion Physics
Non-Intrusive Diagnostic Tools
Embedded Sensors

Mission Statement: Conduct fundamental and multidisciplinary research to enable airbreathing access to space and high-mass entry into planetary atmospheres

Hypersonics Project Focus

High Mass Mars Entry Systems

Lower Density Ablators
High Fidelity Ablation Models
Flexible TPS

CFD Methods
Physic Based Models
Physics Based MDAO
Trade Studies
Novel Entry Vehicles

Mission Statement: Conduct fundamental and multidisciplinary research to enable airbreathing access to space and high-mass entry into planetary atmospheres

Project Management Structure

Hypersonics Project

PI: Jim Pittman

PM: Larry Olson
John Koudelka

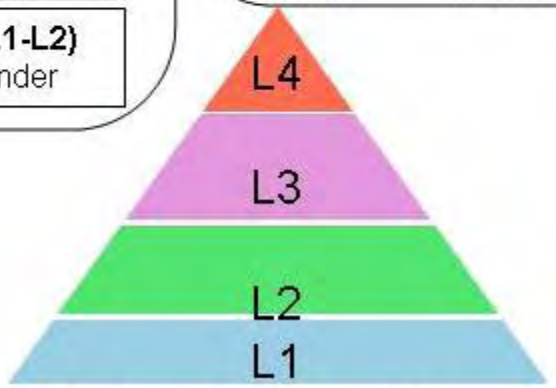
PS: Neil Cheatwood

Technical Leadership Team

- **PB-MDAO (L4)** — Jeff Robinson
- **Propulsion Technology Integration (L3)** — Ken Suder
- **Vehicle Technology Integration (L3)** — Kim Bey
- **Materials and Structures (L1-L2)** — Anthony Calomino
- **Aero/Aerothermo/Plasma Dynamics (L1-L2)** — Seokkwan Yoon
- **Guidance, Navigation & Controls (L1-L2)** — Don Soloway
- **Experimental Capabilities (L1-L2)** — Robert Okojie
- **Propulsion (L1-L2)** — Aaron Auslender

Special Projects

HSA* Mission	Mary Beth Wusk
Hy-BoLT	Steve Syrett
SOAREX	Marc Murbach
X-51	Sal Buccellato
Falcon	
M&S	David Glass
Aero/Prop	Ken Suder
HIFiRE	Neal Hass
RATTLRS	Chuck Trefny
PAI-DAE	Chuck Player
Phoenix	Mark Hodge



Management Team

Associate PMs

Darlene Pokora
John Orme
Jim Walker

NRA/SAA Manager

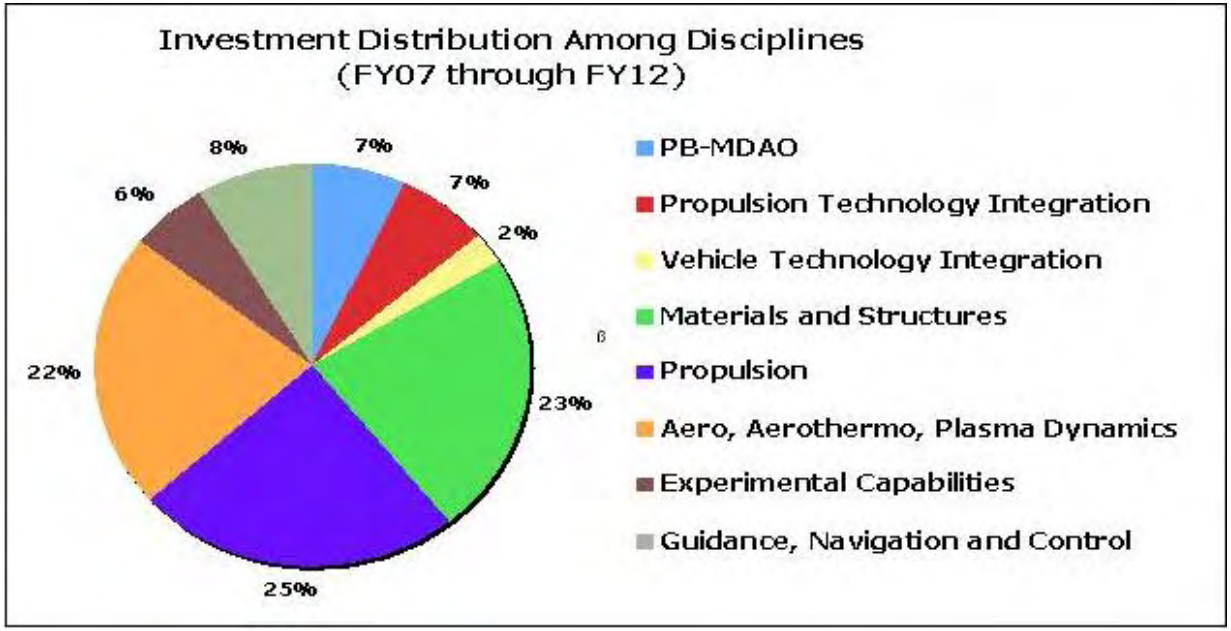
Bob Draper

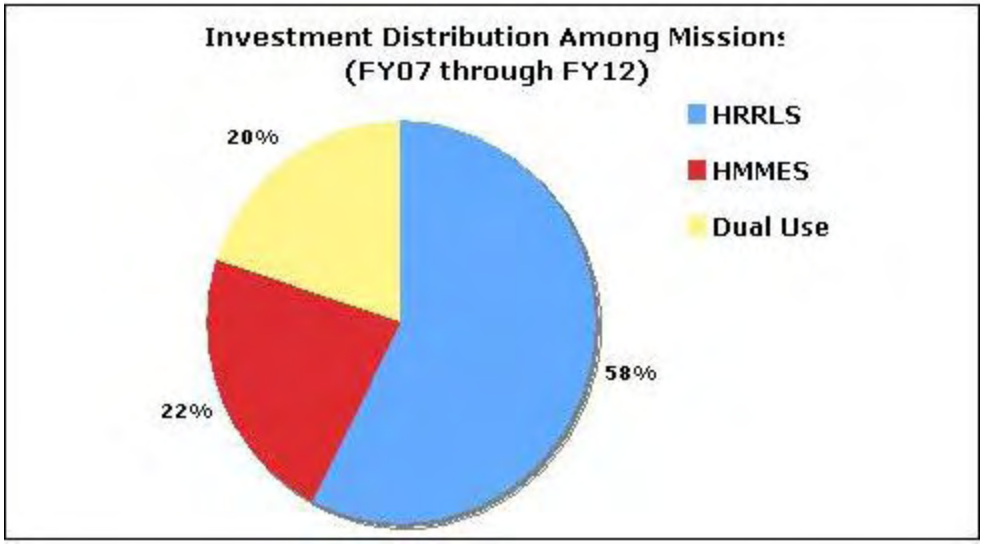
Business Team

Kathy Sablan, lead

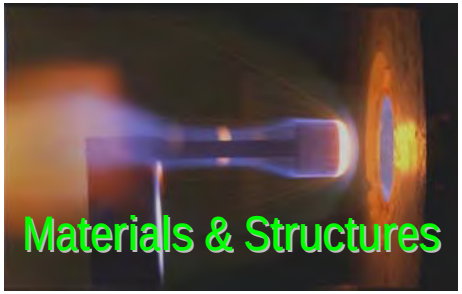
*HSA = Hy-BoLT/SOAREX/ALV X-1

Hypersonic Investment Strategy

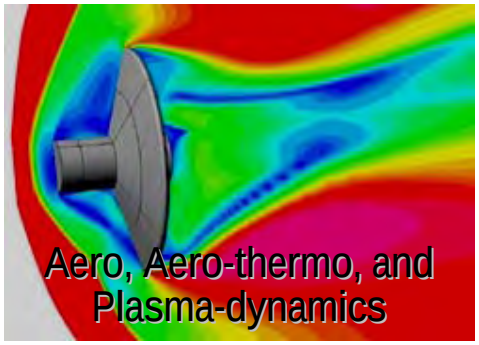




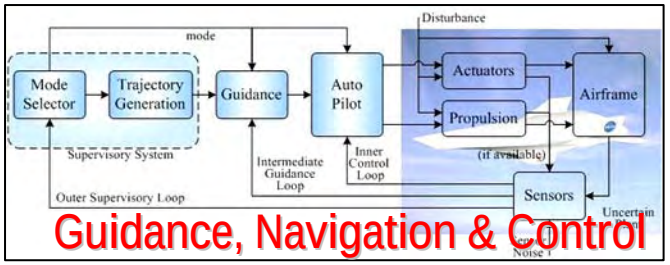
Round 1 (2006) Hypersonic NRA Results



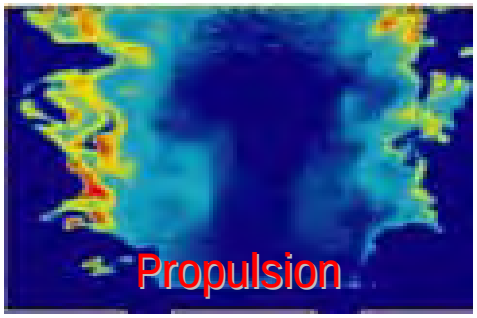
- 39 Proposals
- 8 Awards
- $3.4M



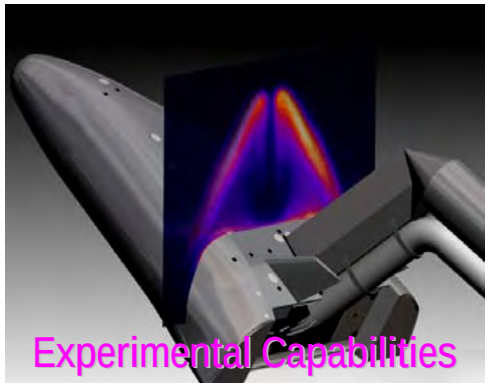
- 39 Proposals
- 8 Awards
- $4.0M



- 21 Proposals
- 7 Awards
- $3.6M



- 40 Proposals
- 7 Awards
- $3.6M



- 21 Proposals
- 7 Awards
- $3.2M

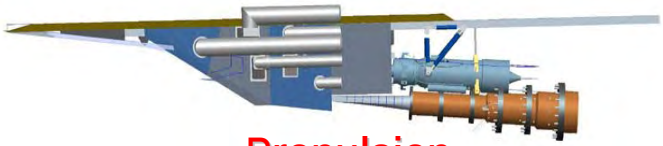
Total of 160 Proposls, 37 Awards, $17.8M over ~3 years

Round 2 (2007) Hypersonic NRA Results

Highly Reliable Reusable Launch Systems

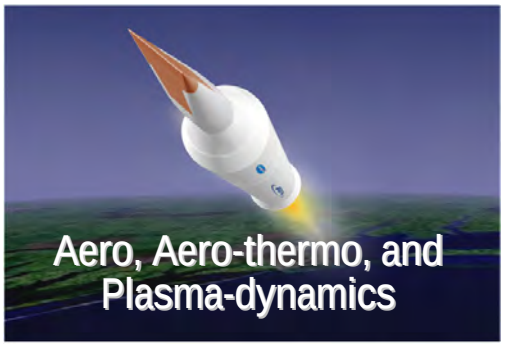
Materials & Structures

- 15 Proposals
- 7 Awards
- $2.7M



Propulsion

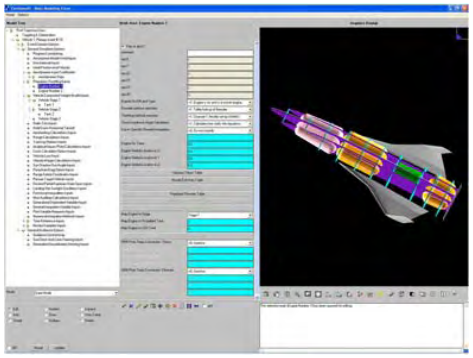
- 24 Proposals
- 6 Awards
- $3.7M



- 28 Proposals
- 6 Awards
- $3.6M

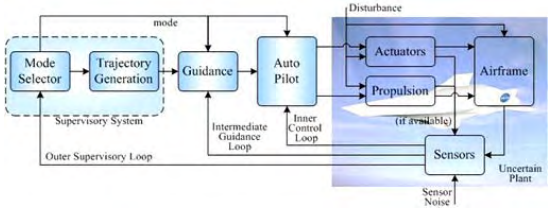
Experimental Capabilities

- 11 Proposals
- 3 Awards
- $1.5M



Multi-disciplinary Studies and Tools

- 34 Proposals
- 12 Awards
- $9.0M



Guidance, Navigation & Control

- 6 Proposals
- 2 Awards
- $2.5M

Total of 118 Proposals, 36 Awards, $23M over ~3 years

2007 EDL NRA Results

Joint with Supersonics Project

EDL Trades

10 Proposals

3 Awards

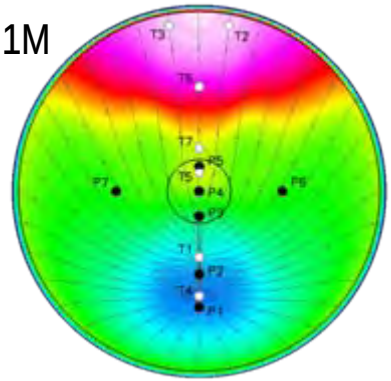
$1.7M

Experimental Validations

6 Proposals

3 Awards

$1.1M

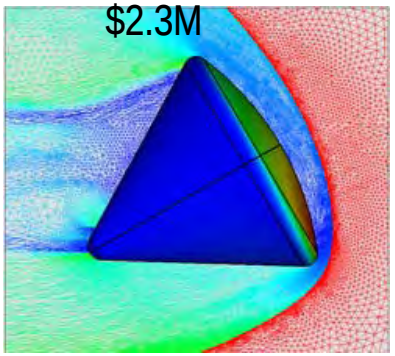


Fluid Dynamics

18 Proposals

6 Awards

$2.3M



Fluid-Structure Interaction

8 Proposals

2 Awards

$1.2M

Supersonic Propulsion

4 Proposals

2 Awards

$1.1M

Materials & Structures

6 Proposals

3 Awards

$2.2M

Total of 52 Proposals, 19 Awards, $9M over ~3 years

Strategic Linkages

Highly Reliable Reusable Launch Systems

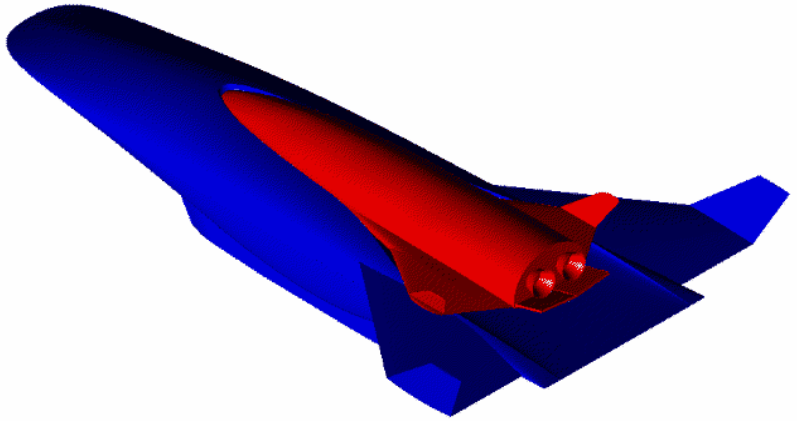
- DoD Joint Technology Office on Hypersonics
  - Coordination with NASA mandated in Congressional Language
- Air Force Operationally Responsive Space
  - Joint Roadmapping
- National Hypersonic Foundation Research Plan
  - Joint with AFOSR, Sandia Lab

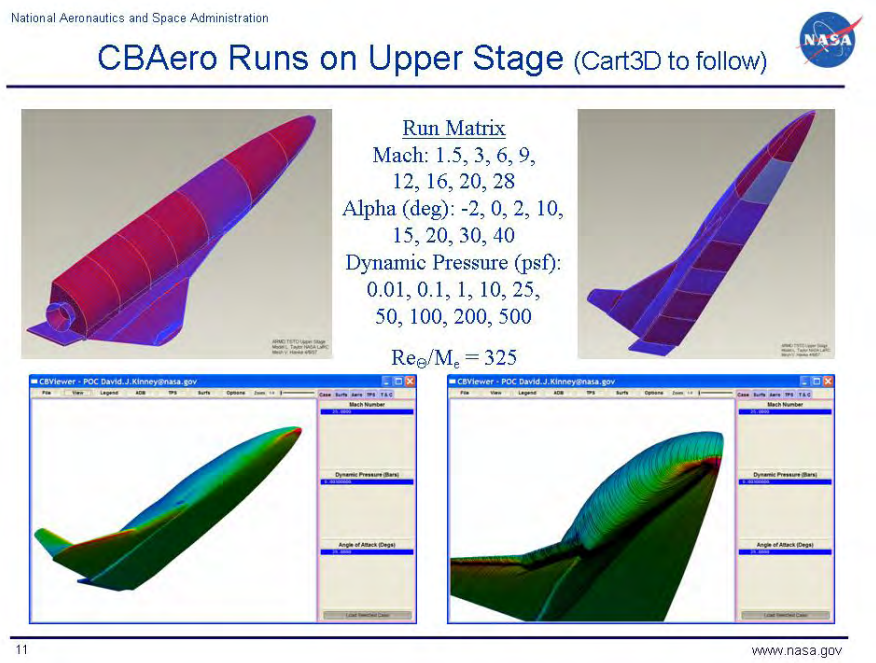
High Mass Mars Entry Systems

- NASA Mars Architecture Team

Two Stage to Orbit Concept

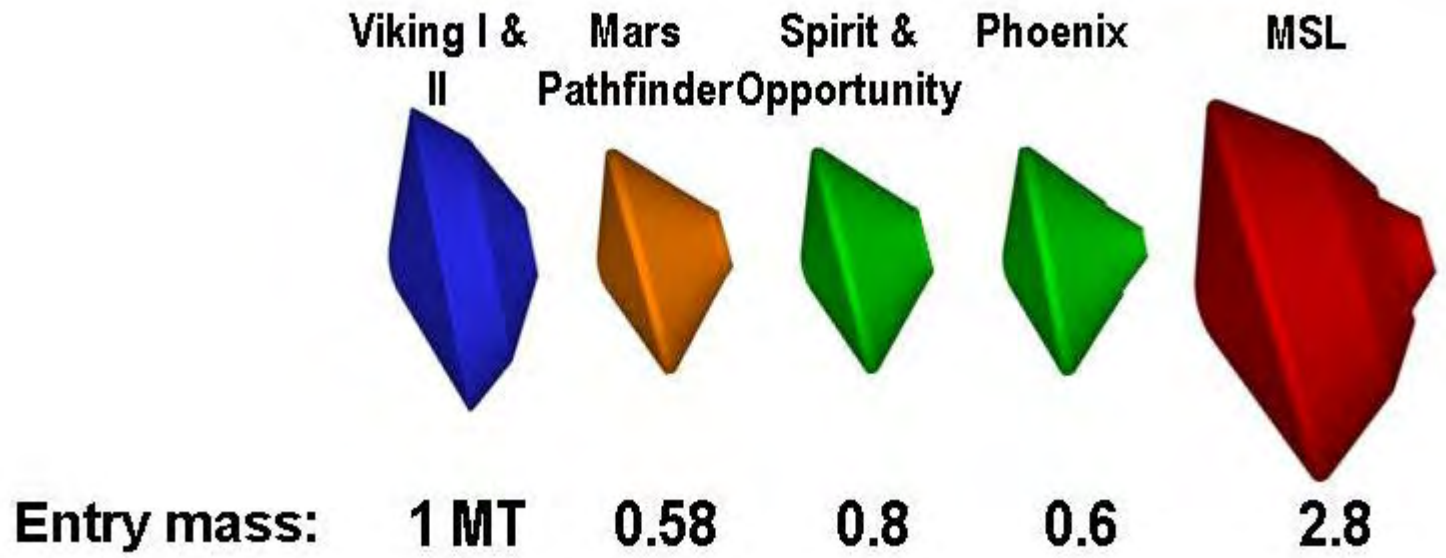
- Reference Vehicle for technology evaluation
- Focus of Level 4 tool development
- TBCC first stage and rocket powered second stage (current version)





Mars Architecture Study

Objective: Define options and technology challenges for human and large cargo mass to Mars and Earth return.



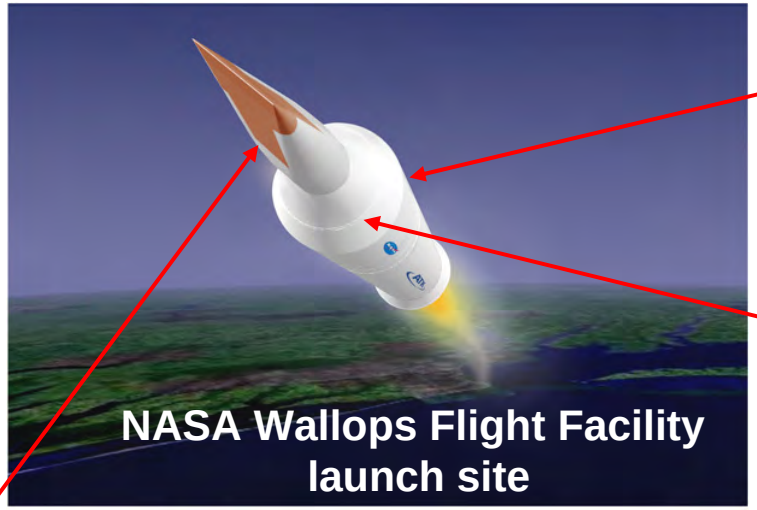
- NASA-wide study lead by Exploration Systems Mission Directorate
- Current Mars entry technology based on 1970s era Viking database
- Limits landed mass to 1 metric ton (MT)
- Human missions require 30-50 MT

Hy-BoLT/SOAREX/ALV X-1 Mission

Mission Objective: Obtain unique flight data for basic flow physics and Mars entry technology

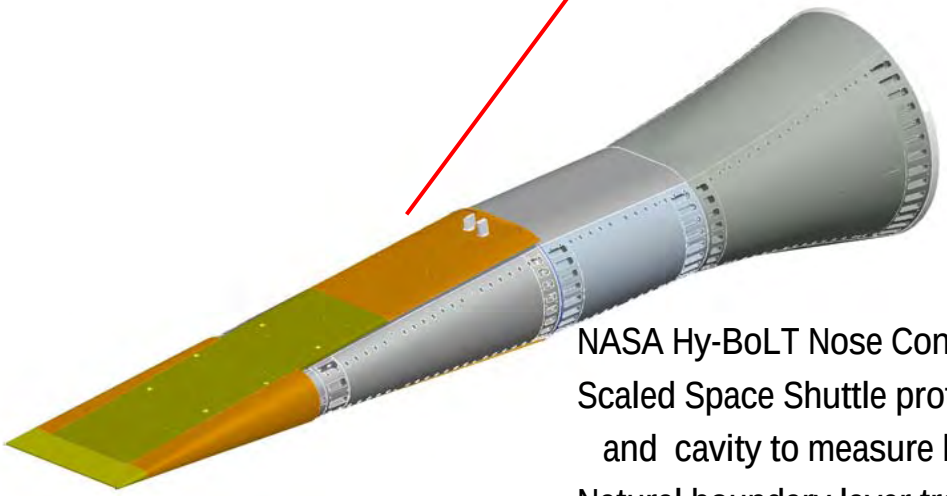
Cost-sharing partners:
NASA
ATK

Projected launch date:
Summer 2008



ATK Launch Vehicle (ALV X-1)

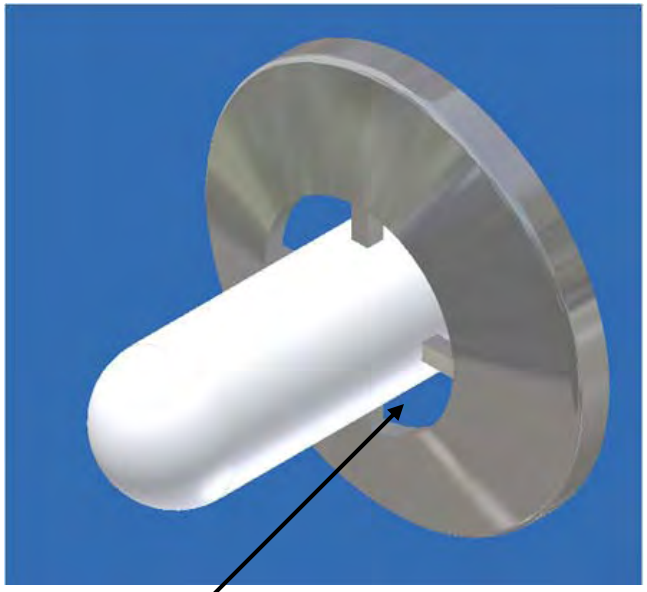
NASA SOAREX probe for future Mars missions. Probe carried internally and ejected at 500 km altitude



NASA Hy-BoLT Nose Cone:
Scaled Space Shuttle protuberance and cavity to measure heating
Natural boundary layer transition

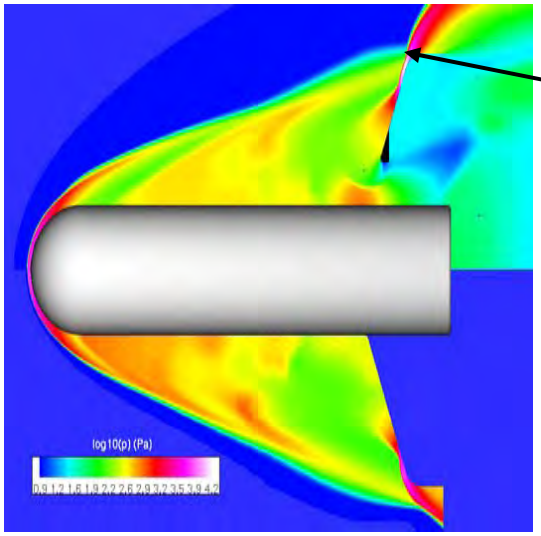
Slotted Compression Ramp - Scramp probe

Probe configuration



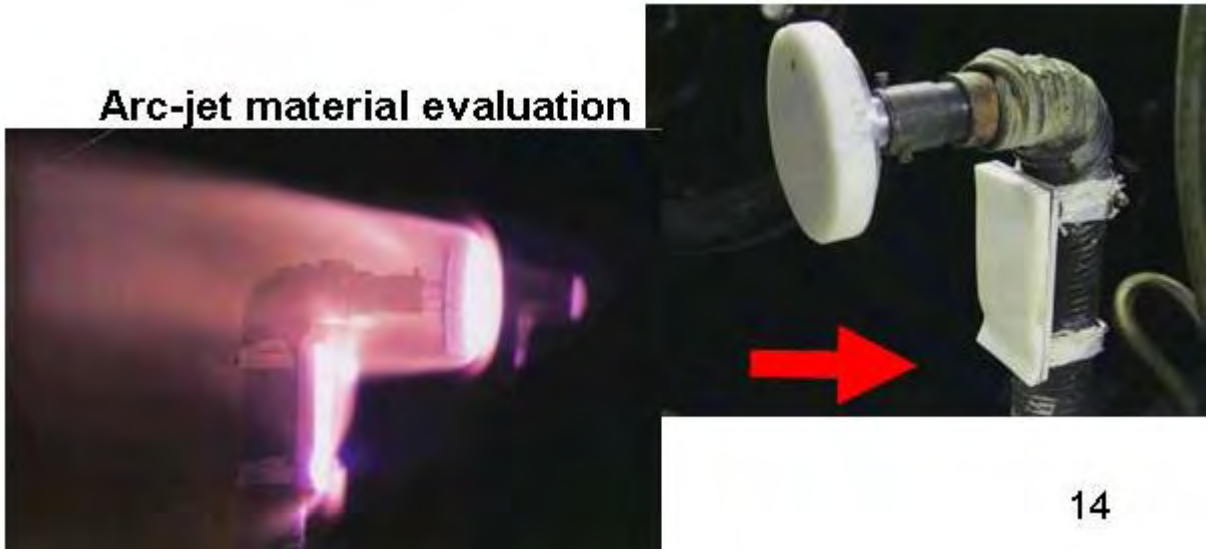
Slot enhances stability and drag

CFD Studies



Shock-shock interaction amplifies local heating

Arc-jet material evaluation



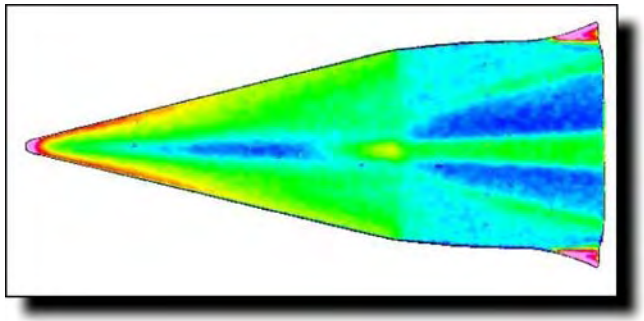
DARPA/Air Force Falcon Program

HTV-2

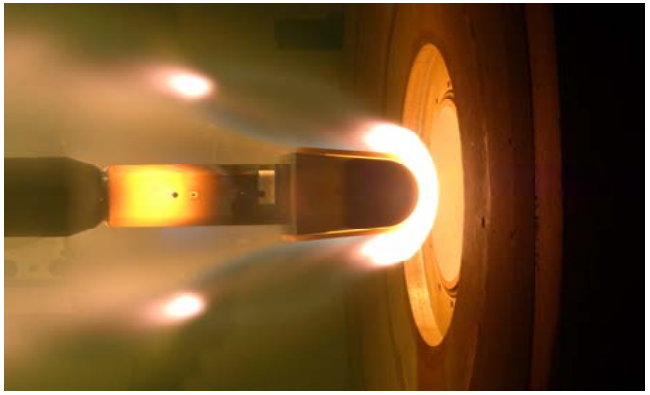
Program Overview

Joint DARPA/AF flight demonstration

Demonstrate enabling technologies for future operational hypersonic vehicles



NASA-developed surface heating patterns



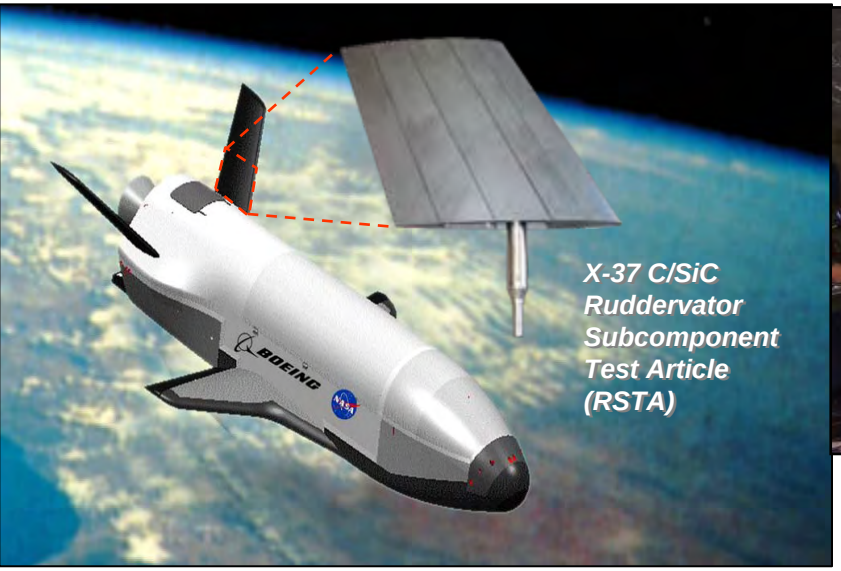
Arc-jet testing at AEDC

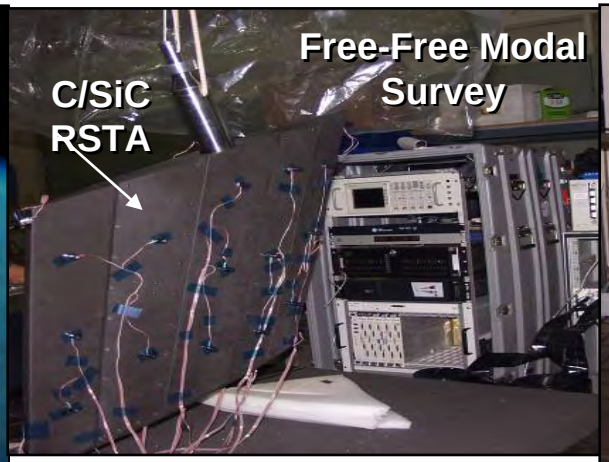
NASA Role:

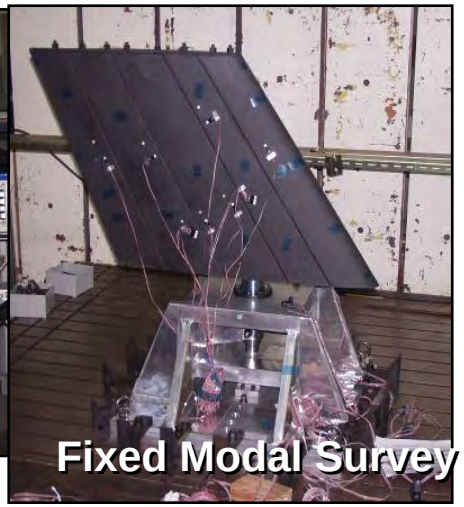
- **Subject Matter Experts**
- **Computational aerodynamics and aerothermodynamics**
- **Aerodynamic and aerothermodynamic ground testing**
- **Materials ground testing for oxidation and heating effects**

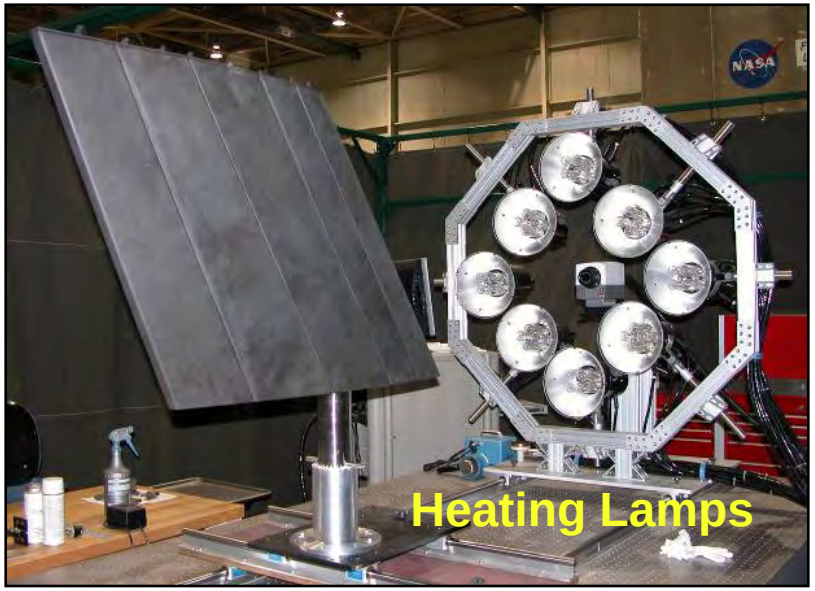
HTV-3

C/SiC Ruddervator Test and Analysis









- **Phase 1:**
  - X-37 vibration & acoustic loads testing
  - Phase 1 testing completed Jan 07
- **Phase 2:**
  - X-37 re-entry and Lockheed Martin Falcon derived thermal / mechanical load conditions
  - Develop high temperature GVT technique

3000°F SiC/SiC for Leading Edges

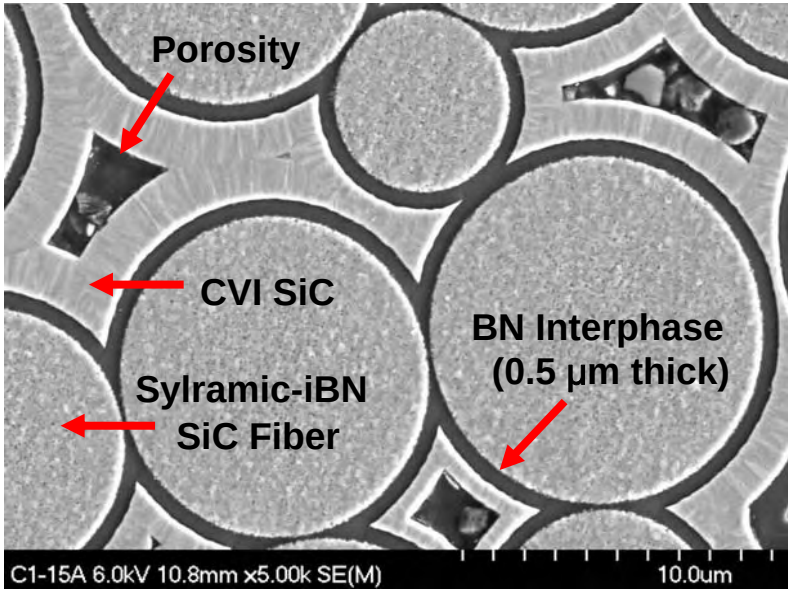
Objective: Develop durable 3000ºF SiC/SiC structural elements

Carbon fiber reinforced systems are state of the art.

Oxidation resistance of these systems is poor.

Silicon carbide fiber reinforced material offers improved oxidation resistance over carbon fiber materials.

Extend creep resistance to 1450ºC+ and improve performance thru NDE and mechanical and thermal property assessment.

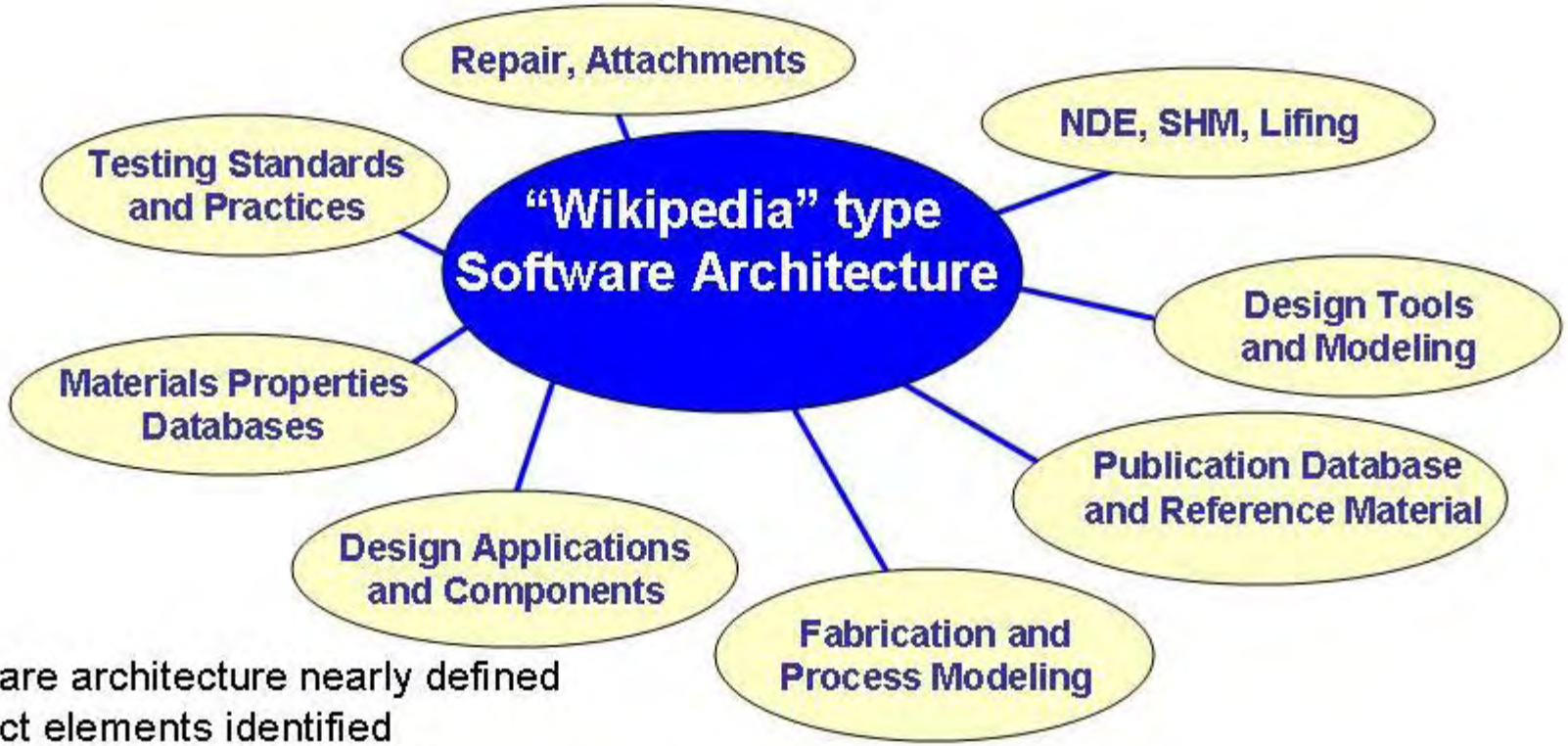


Microstructure of Sylramic-iBN SiC Fiber-Reinforced CVI SiC CMC

Develop processing improvements and heat treat cycles for improved thermal conductivity and creep resistance.
Establish relationship between mechanical performance, material constituents and microstructure and non destructive investigation

Ceramic Matrix Composite (CMC) Database

Objective: Develop secure site for registered users to share latest CMC information to accelerate technology development.



Status:

Software architecture nearly defined
Subject elements identified
Computer hardware specified

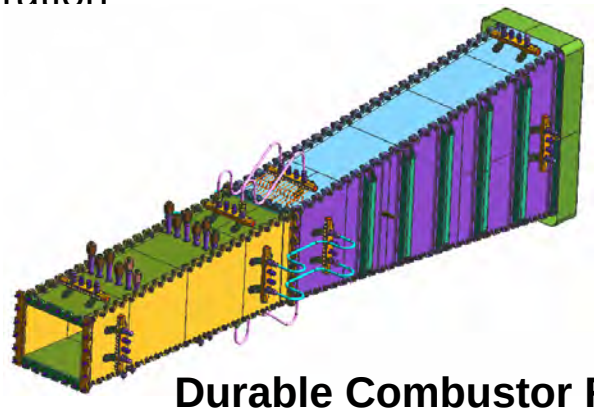
Actively-Cooled CMC Combustor Panels

Objective: Develop actively-cooled CMC combustor panels to reduce weight and to validate thermal/structural design tools for 2400ºF multiple cycle operation

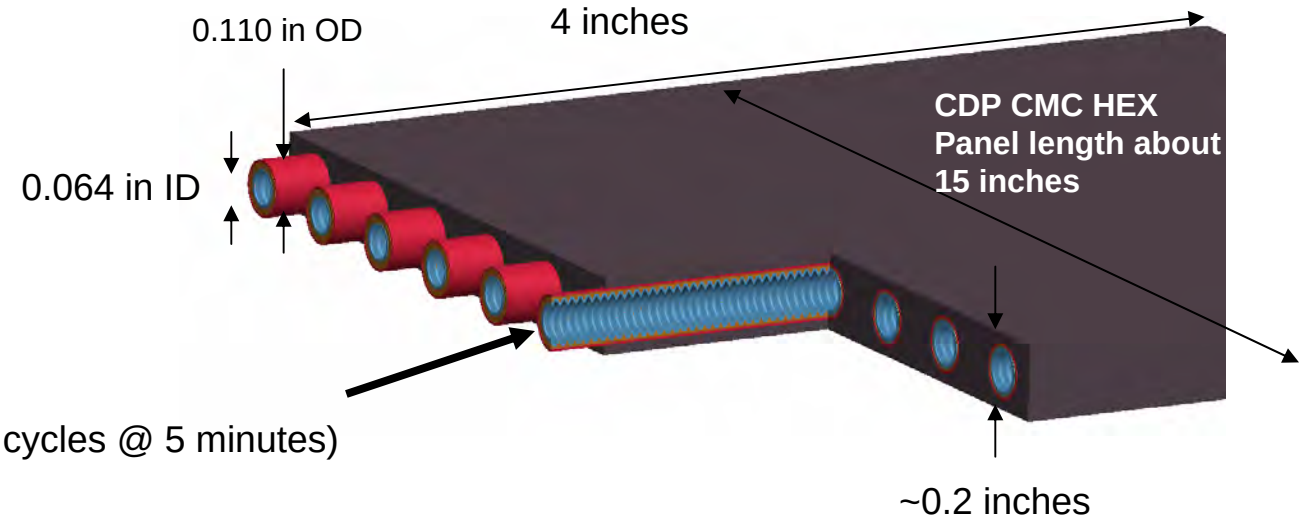
Inconel CDP-I in fabrication. Panel delivery is scheduled for 3Q07. Panel testing is scheduled for 1Q08.

CMC CDP-II fabrication initiated.

NASA:	Panel fabrication requirements
ATK/GASL:	System design requirements
Hypertherm:	Ceramic composite fabricator
Team:	Fiber architecture preform



Durable Combustor Rig



Goals: Fuel Coolant Tubes
- H2 gas
- 2000 psi
- 2400 F
- Multiple cycle operation (10 cycles @ 5 minutes)
- Impermeable to Hydrogen

Program to Advance Inflatable Decelerators for Atmospheric Entry (PAI-DAE)

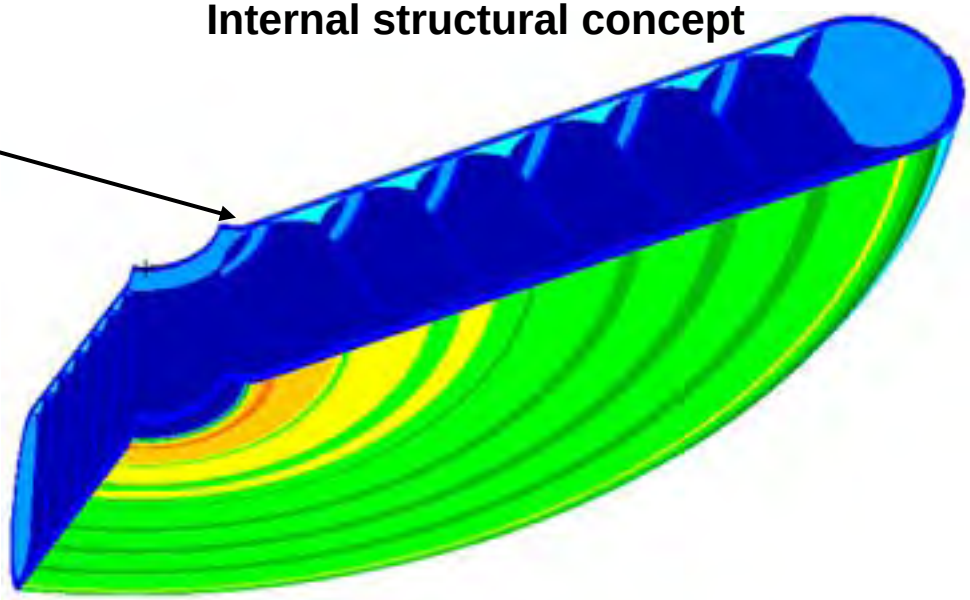
Objective: Develop large diameter (> 4.5 m) inflatable, semi-rigid entry vehicle technology

- **Seven Missions Identified for potential application of IAD technology**

Constraint: Launch vehicles limit diameter of entry vehicle to 4.5 m. Inflatable, semi-rigid vehicles can be much larger, allow greater mass needed for human exploration of Mars

Entry vehicle

Internal structural concept



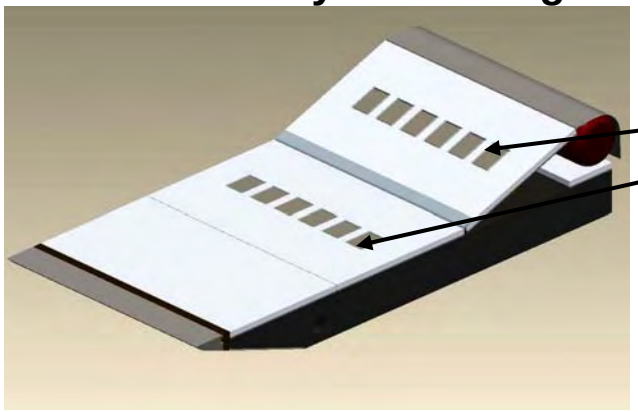
NASA Hypersonics Role:

- **High temperature testing of flexible heat shield materials**
- **Computational Tool validation**

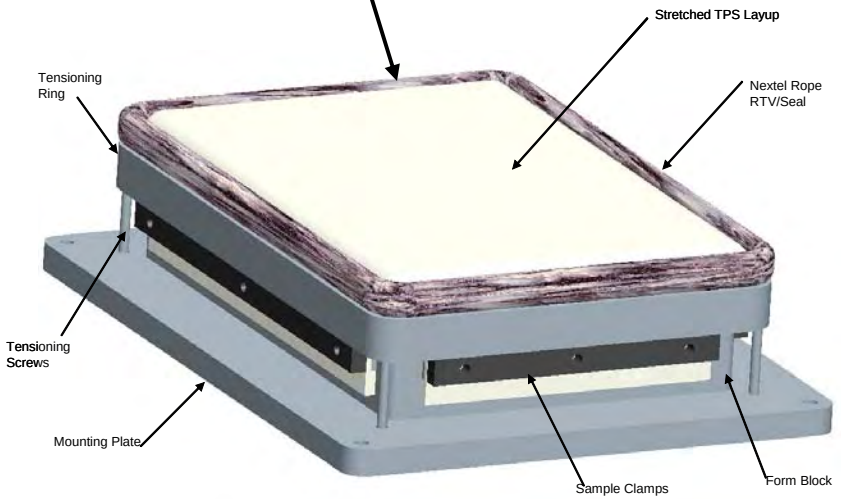
PAI-DAE 8’ HTT Test

Objective: Test candidate flexible TPS materials and lay-ups in relevant heating environment (Mach 7)

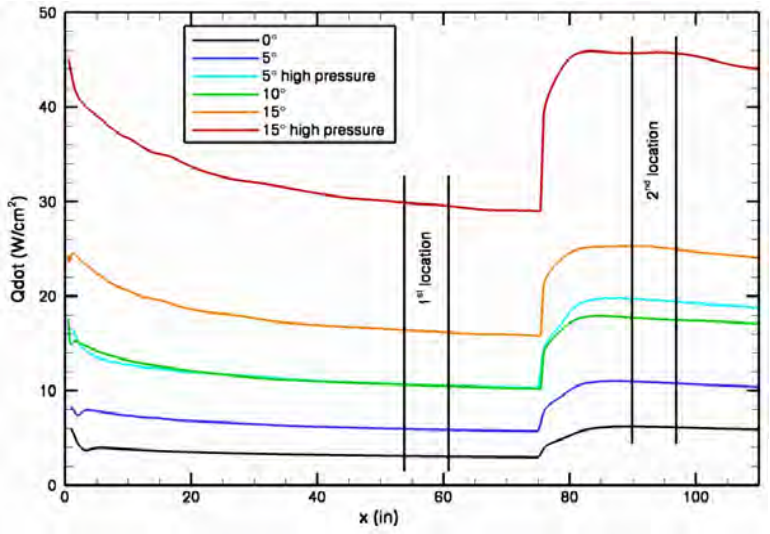
8’ HTT Test article
4’ 7” wide by 9’ 10” long



Test Coupons

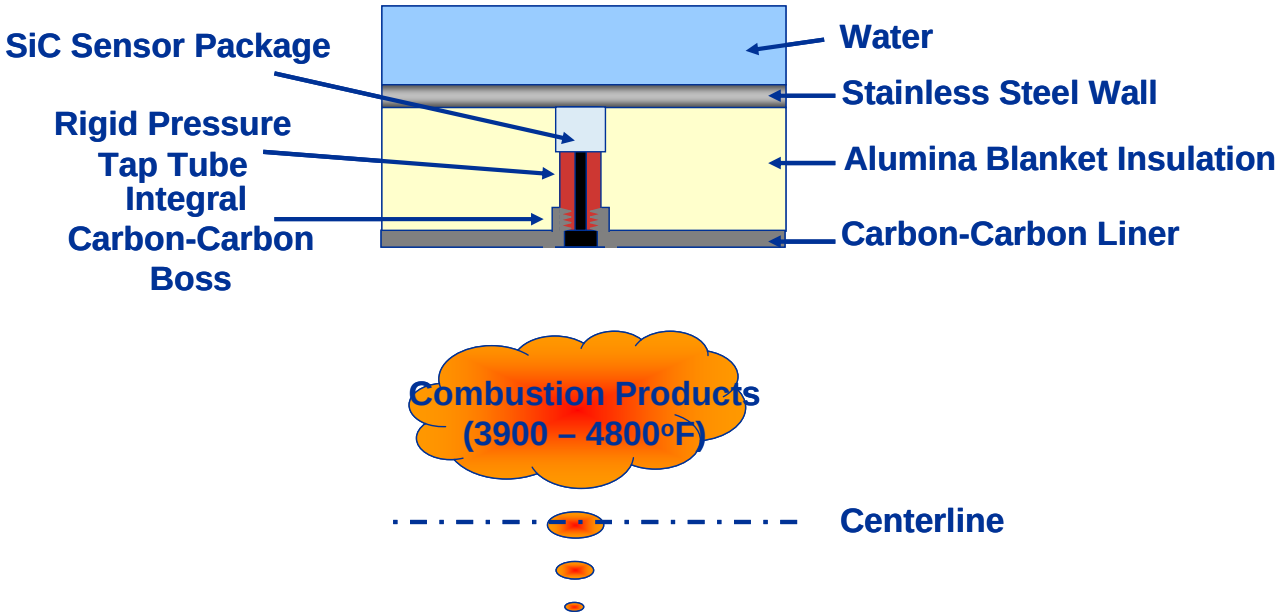


Predicted Heating Rates



Example TPS systems:
Kevlar
Kapton
Nextel

Fabrication processes for composite material based pressure sensors

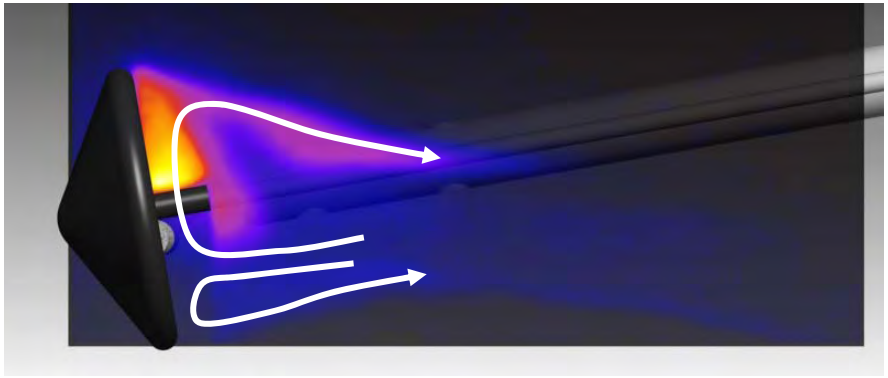


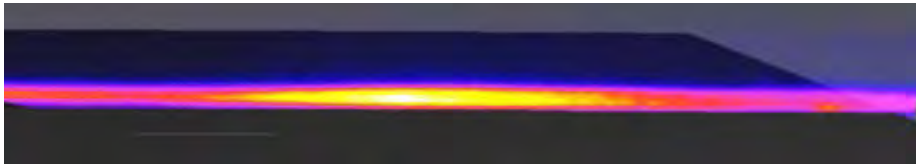
- Sensor operation demonstrated at 600 °C under HyFly Project with JHU-APL;
- Second generation to be demonstrated at 1000 °C by end of 1st quarter FY08;
- Third generation to be embedded in C/SiC panel (collaboration with M/S Discipline)

Application:
Direct flow velocity measurements in flow path to validate Hypersonic CFD codes

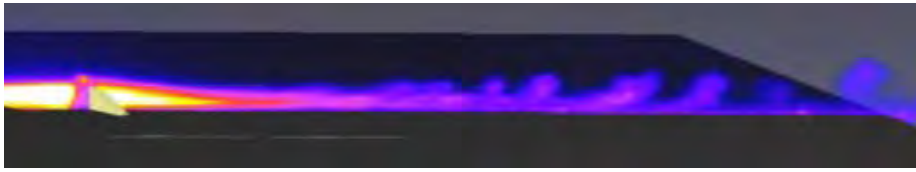
NO PLIF Imaging

Objective: Develop NO (nitric oxide) PLIF (planar laser-induced fluorescence) to provide off-body flow visualization and quantitative measurement in hypersonic flows





No Trip: Laminar



Triangular Trip: Transitional/Turbulent

- M = 10, Inflatable Reentry Vehicle Experiment (IRVE) model, AoA = 10º.
- Seeding from a single location allows a form of streamline visualization; varies with AoA

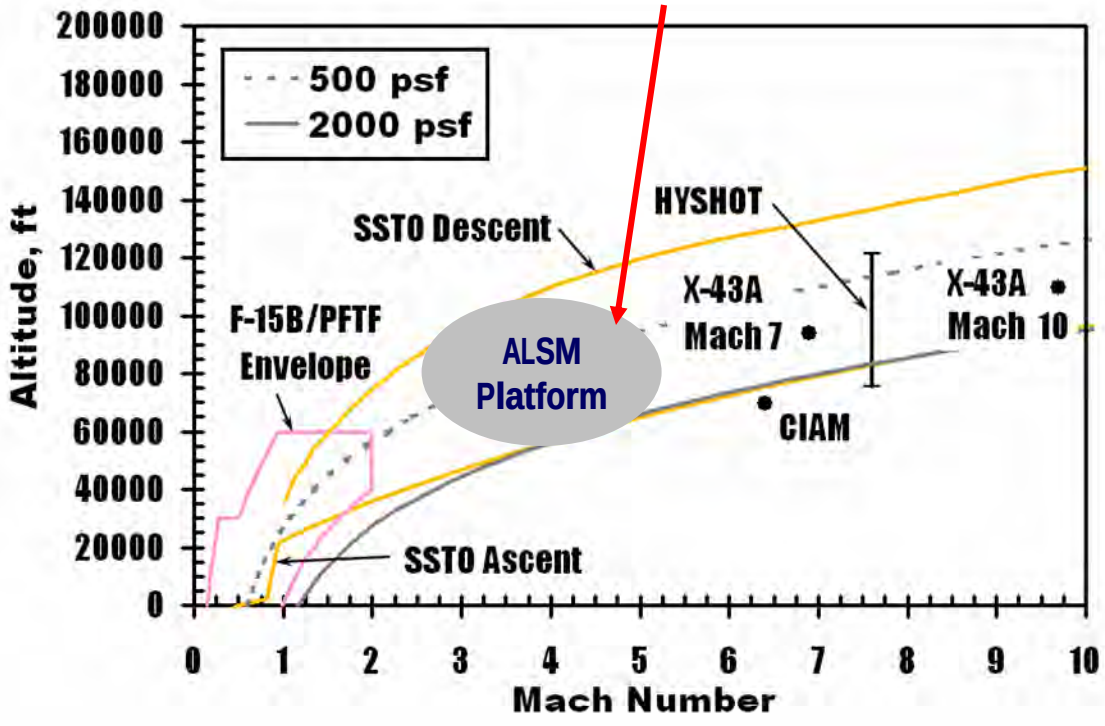
M = 10, flat plate, M_e = 3.9

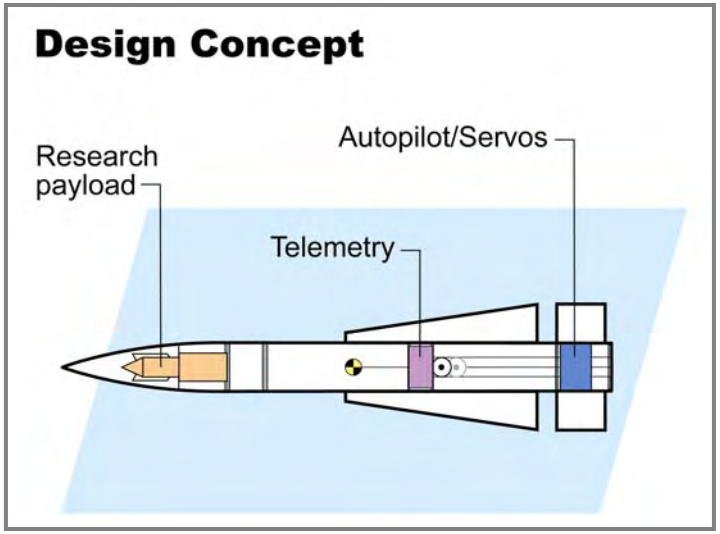
Phoenix Missile Studies

Objective: Evaluate surplus Navy missiles as a low-cost, routine hypersonic/supersonic flight test platform

Phoenix Missile

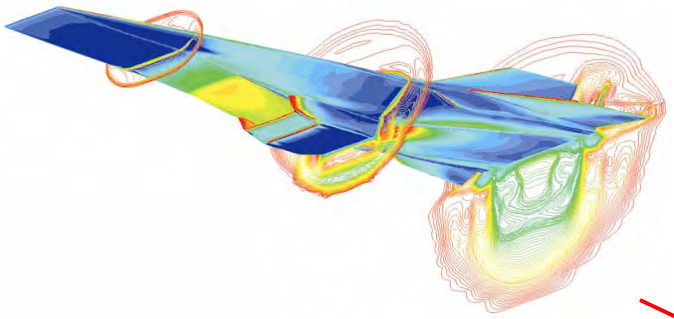
Phoenix Flight Envelope





Propulsion Roadmap

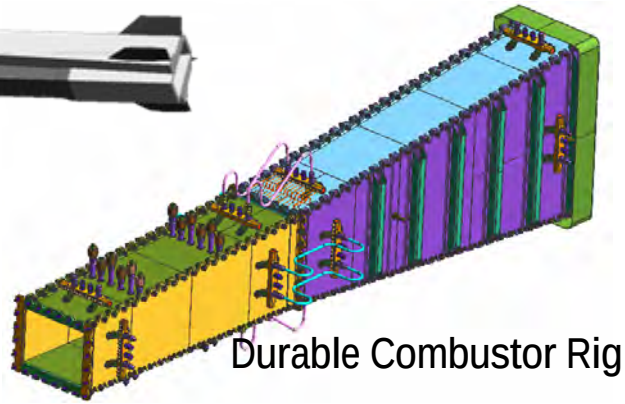
X-43A
- Integrated Vehicle Demonstration
- Scramjet Engine
- Short Duration Flight (Heat Sink Materials)



Long Duration

Dual Mode Scramjet
- Actively Cooled Structure for long duration flight

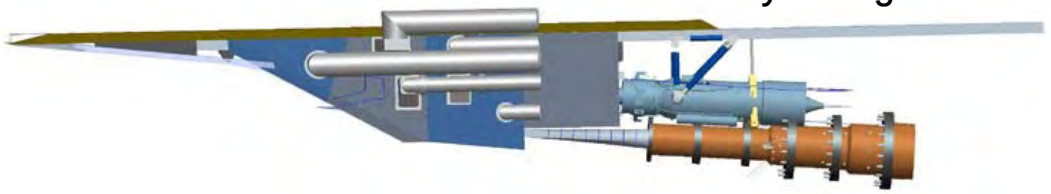
X-51



Durable Combustor Rig

Combined Cycle

Turbine Based Combined Cycle Rig



Flight Experimentation

HIFiRE

X-51A Scramjet Engine Demonstrator

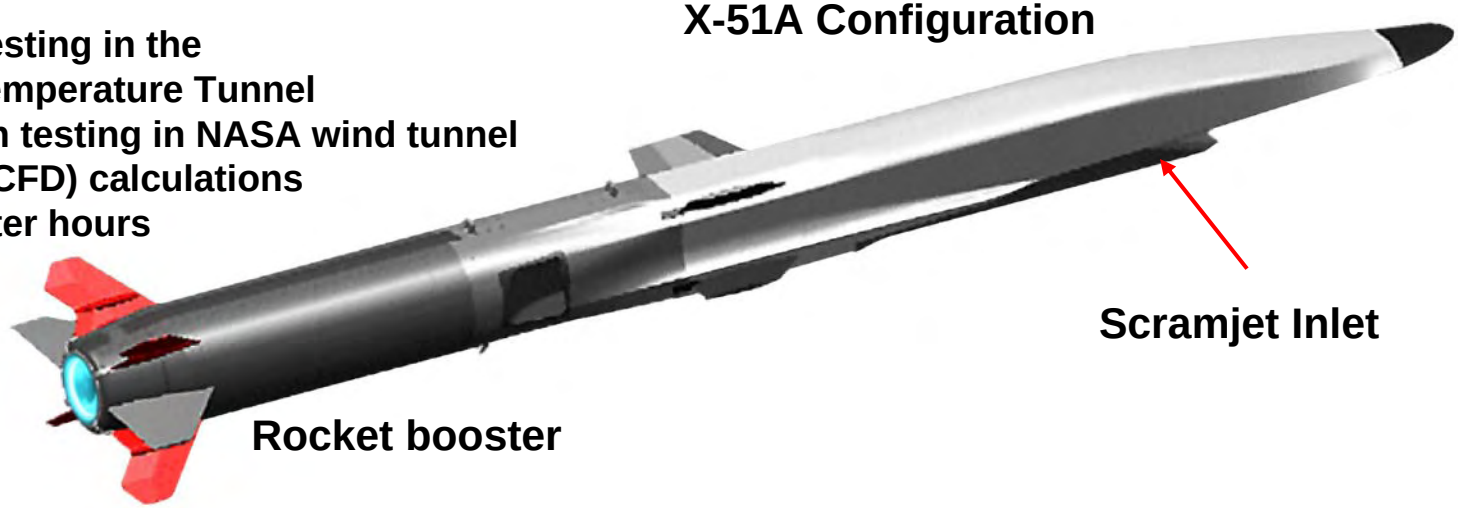
Program Overview

- Joint AFRL/DARPA/NASA flight demo
- Hydrocarbon-fueled and cooled scramjet
- Scramjet flight from Mach 4.5 to 6.5
- 5 minute-plus flight duration
- Four to eight flights (FY09 1st flight)

NASA Role:

- Full-scale propulsion testing in the NASA 8-Foot High Temperature Tunnel
- Sub-scale configuration testing in NASA wind tunnel
- Computational Fluids (CFD) calculations
- Columbia supercomputer hours

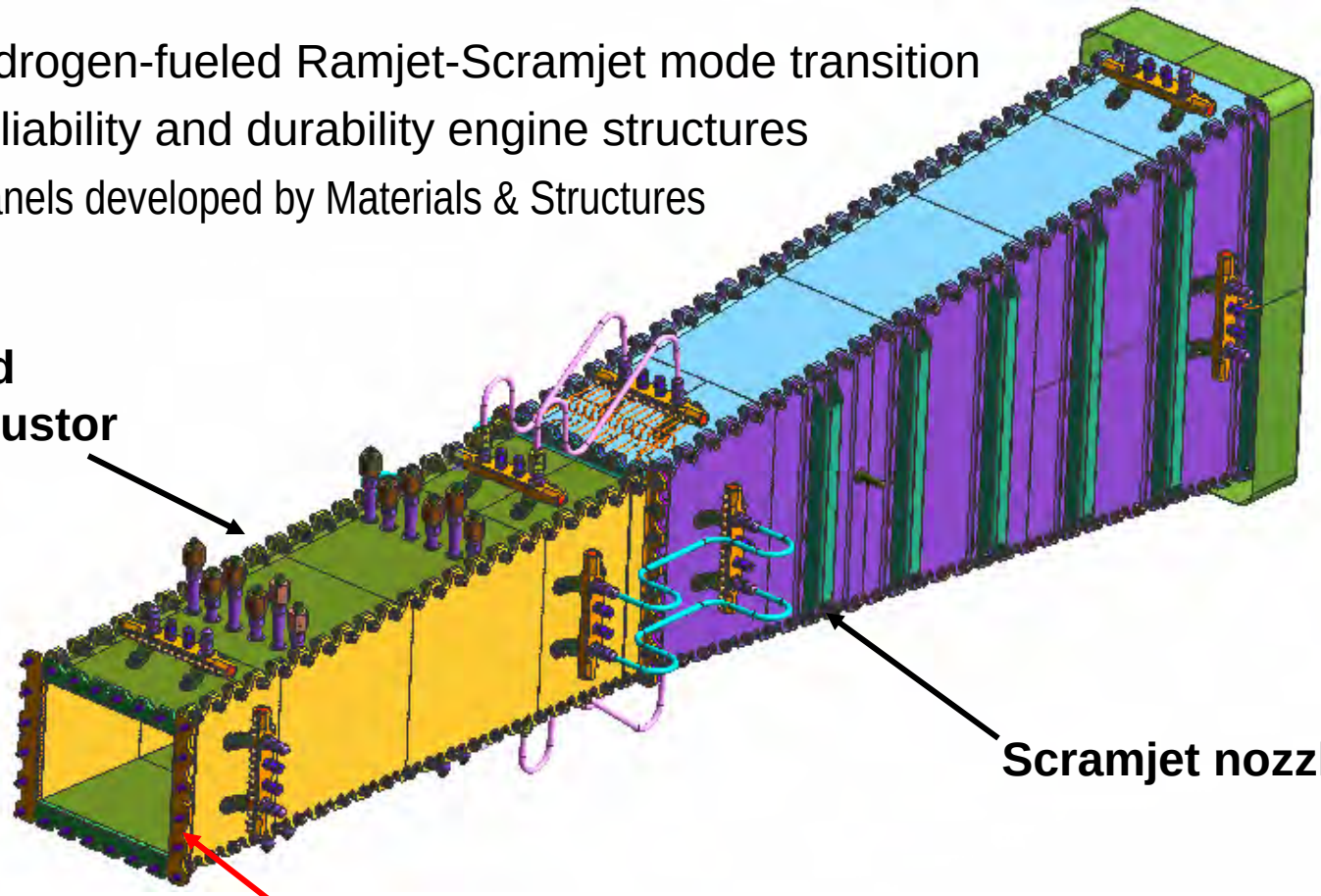
X-51A Configuration



Durable Combustor Rig

Objectives:

- Investigate Hydrogen-fueled Ramjet-Scramjet mode transition
- Improve the reliability and durability engine structures
  - Structural panels developed by Materials & Structures



HIFiRE Program

Flights 2, 6 & 9 are scramjet propulsion flight tests

Sounding rocket launch

Status:

Test objectives of Flight 2 & 6 re-scoped to increase technical value
- Stronger focus on mode transition

Trajectory modified to increase technical value

New cost and schedule options in development

RATTLRS

Develop and flight demonstrate (TRL 7), payload flexible, multi-mission high speed system with a cost goal under $600K AUPC/2500 missiles

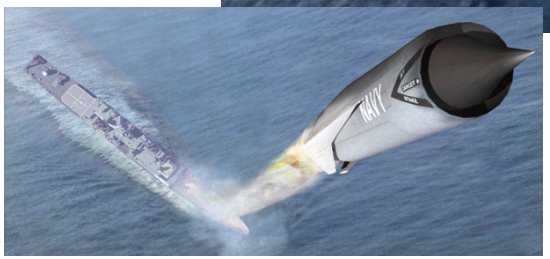
Minimum Flight Demonstration Objectives by FY2008:

- ✓ Subsonic air launch, no booster
- ✓ Transonic acceleration >0.25 g-level flight (0.5 goal)
- ✓ Mach 3+ cruise speed for >5 minutes (15 min goal)
- ✓ **Minimal changes to demo Mach 4 system**
- ✓ ***Demonstrate a tactical flight profile***
- ✓ ***Demonstrate sub/supersonic submunition and penetrator***
- ✓ ***Joint tactical weapon system traceability***

Growth Flight Demonstration Objectives by FY2010 (UNFUNDED):

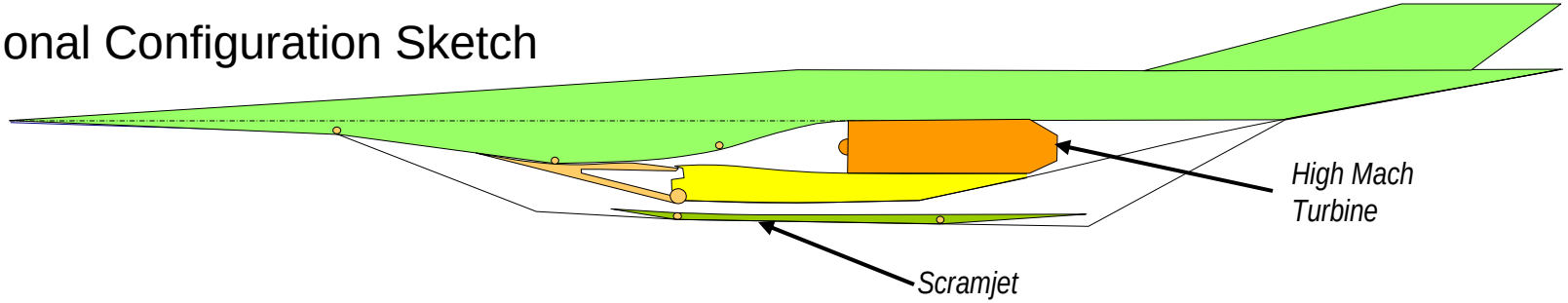
- ✓ Mach 4+ max speed, cruise for >15- minutes

STATUS:
• First flight 2nd quarter '08

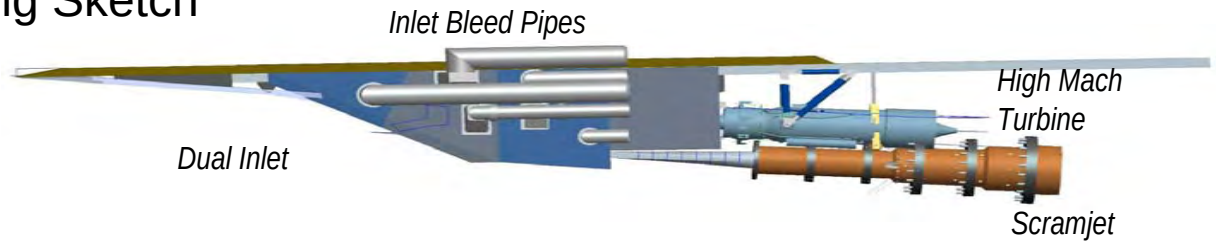


Turbine Based Combined Cycle (TBCC)Engine

Notional Configuration Sketch



TBCC Test Rig Sketch



OBJECTIVES

Proof of concept of over/under split flow inlet for TBCC.
- Demonstrate mode transition at large-scale.
- Validate CFD predictions
- Develop realistic inlet distortion characteristics

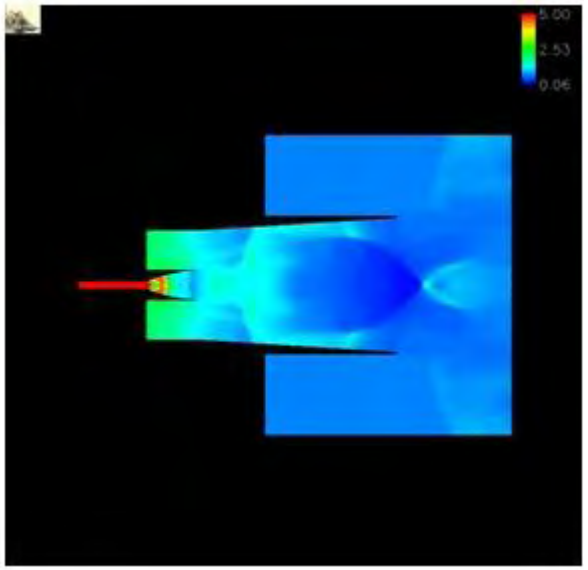
Testbed for integrated inlet/engine propulsion system tests
Testbed for inlet/engine/controls research

Rocket-Based Combined Cycle Technology

Objectives:

- Investigate low-speed RBCC cycles
- Investigate pulsed primary flow on low speed (injector) and vacuum (rocket mode) operation of a representative RBCC propulsion system

Unsteady Pulsed-Detonation RBCC Simulation. 2-D finite-rate, time accurate, pressure contours



Task Element/Status:

- Initial 2-D CFD studies of pulsed-primary RBCC cycle complete (document: JANNAF 2007).
- Initiating 3-D CFD modeling of Penn State test rig (NRA award).
- Utilize existing RBCC-cycle performance algorithms/codes to generate propulsion database for vehicle studies.

FY 2007/08 Key Deliverables and Milestones:

- FY'07 3rd qtr – Deliver RBCC propulsion data (analytical predictions) to MDAO
- FY'07 4th qtr – Document SOA-RBCC cycle performance prediction for steady and pulsed primary
- FY'08 4th qtr – Develop enhanced-cycle performance method for pulsed primary

Closing Remarks

Hypersonics focused on tools and technologies to enable airbreathing access to space and high mass Mars entry

Significant refocusing on foundational, discipline, and multi-disciplinary research

Numerous partnerships established to advance hypersonic technology