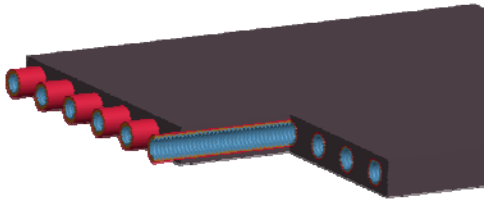
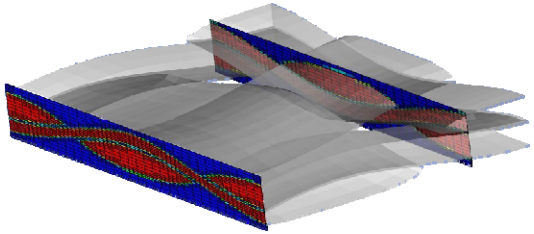
Hypersonic Materials and Structures

NASA FA Hypersonic Project

October 7, 2008

Dr. Anthony Calomino





Outline

1. Materials and Structures Focus
2. Technology Product Roadmap
3. CMC Design Capability
4. Advanced Structural Concepts
5. Durable Material Systems
6. Summary

Materials and Structures Focus

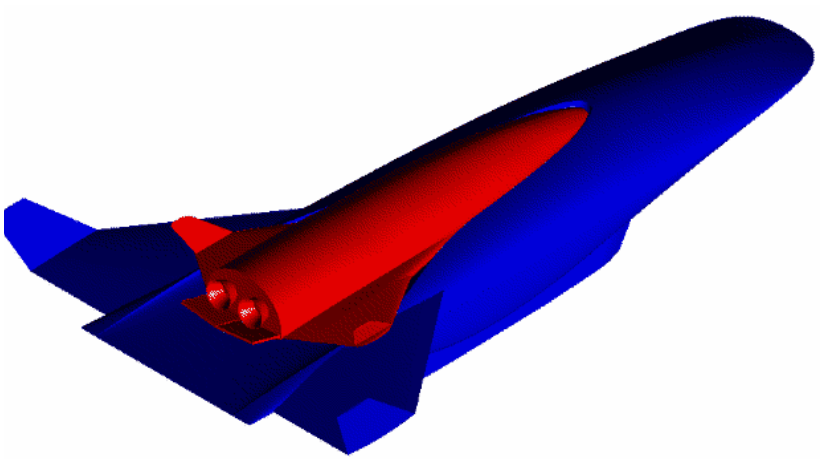
1. **Materials and Structures Focus**
2. Design Analysis Capability
3. Advanced Structural Concepts
4. Durable Material Systems
5. Structural Diagnostics
6. Summary

Hypersonic Materials and Structures Focus

Highly Reliable Reusable Launch Systems

HRRLS Materials & Structures

- Integrated Analysis Methods
- Advanced Structural Concepts
- Thermal Protection Systems
- High Temperature Composites

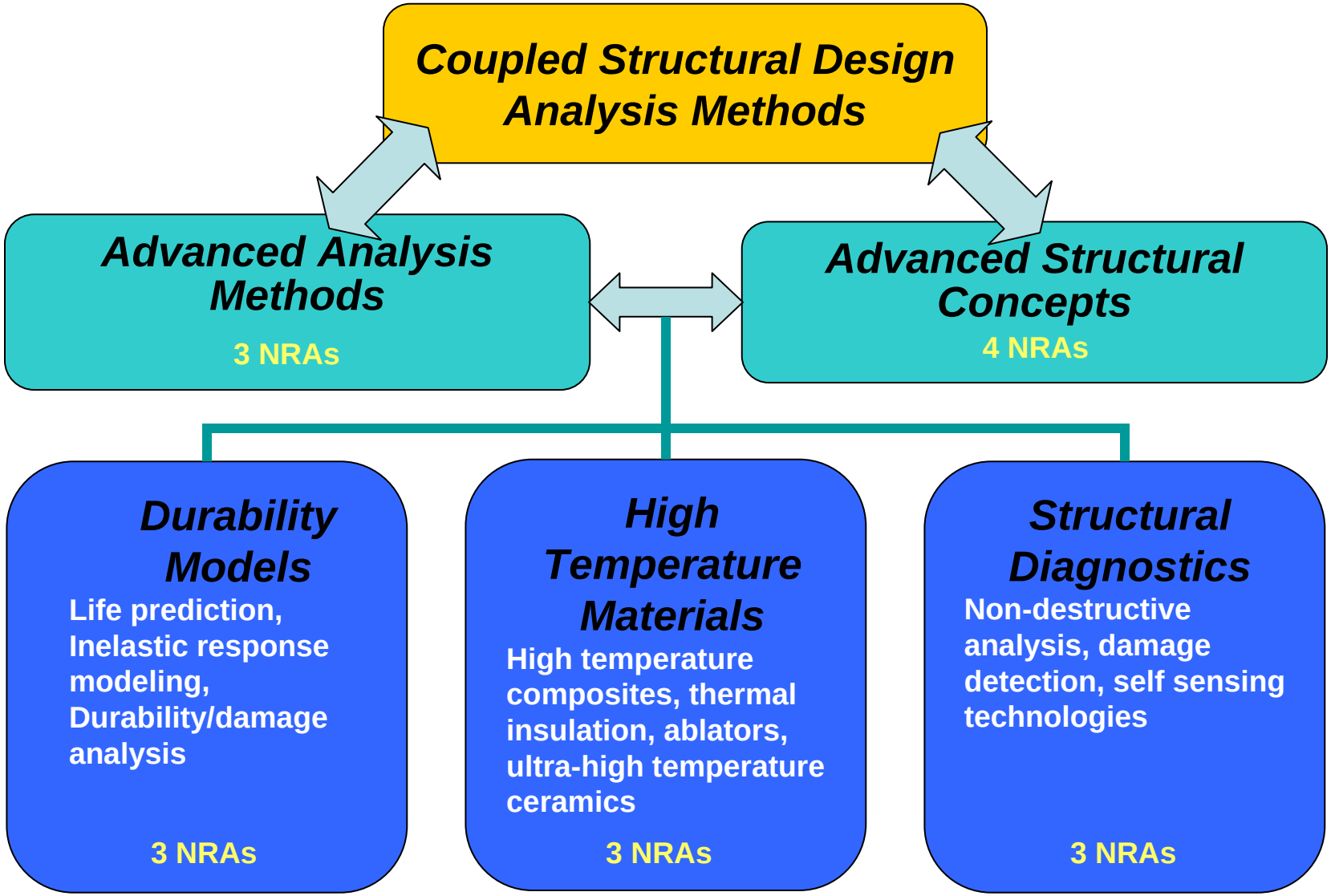


High Mass Mars Entry Systems

HRRLS Materials & Structures

- HMMES Materials & Structures
- High Fidelity Ablation Models
- Advanced lightweight ablators
- Deployable decelerator materials

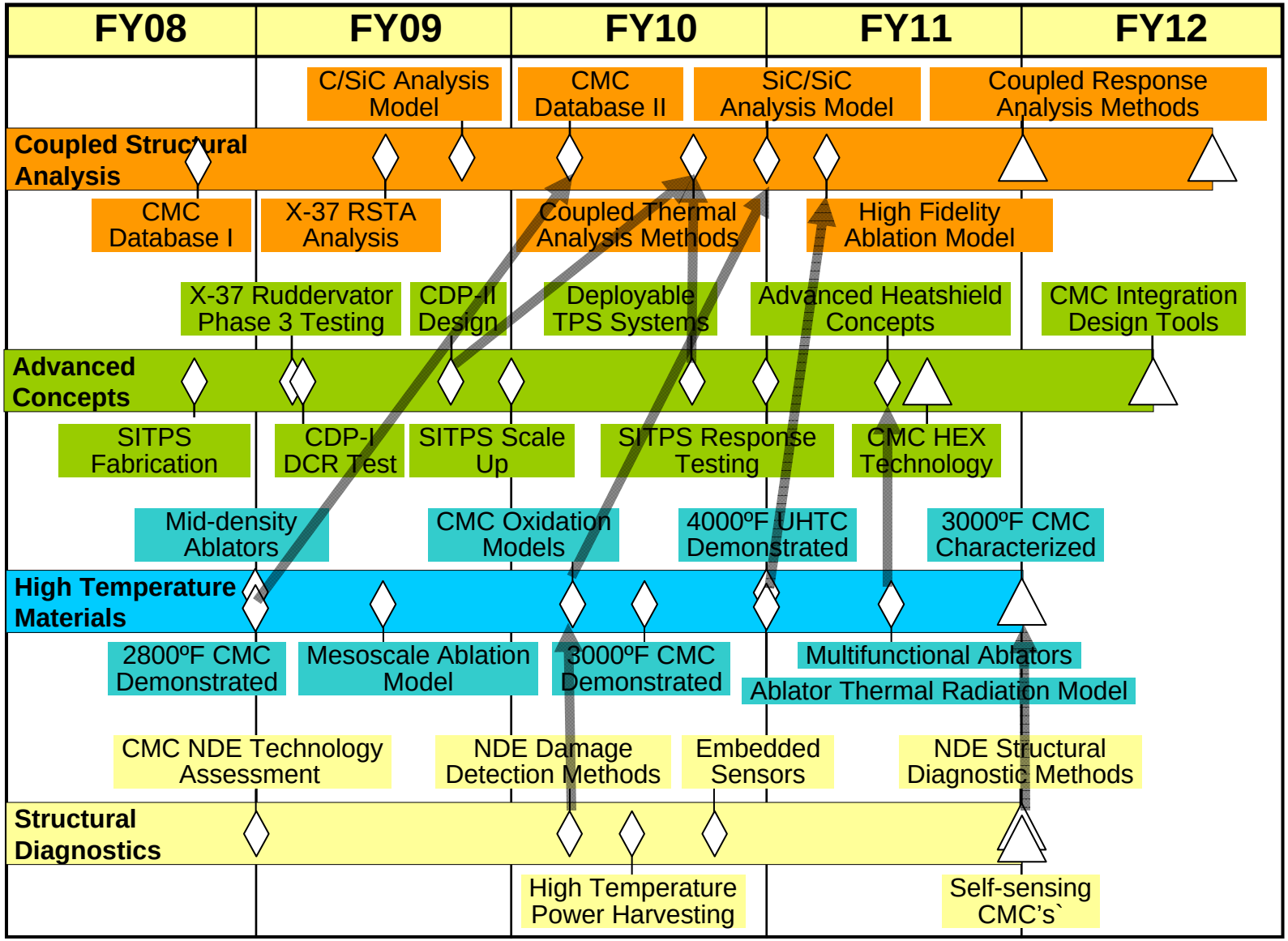
Discipline Approach



NRA Integration Strategy

Coupled Analysis Codes	System Design Concepts	Physics-based Prediction Tools	Extreme Env. Materials	Structural Health Tools
NRA POD Analysis Method CMC Database Oxidation Model	**NRA** Integrated TPS Insulated Structure CMC HEX Design Inflatable Decelerator	**NRA** Textile Modeling Design Properties Ab-initio Ablation Model	**NRA** CMC Coatings Adv. Ablators High Temp Titanium	**NRA** NDE Methods High temperature Sensor Assesment Therm. Electrics
NASA CMC Wiki Site CMC Database Meso-scale Modeling RSTA X-37 Analysis Ablation Analysis	**NASA** SITPS X-37 RSTA Tests DCR-CDP-II PAI-DAE CMC Integration	**NASA** C/SiC Oxidation CMC, UHTC Characterization CDP-I Testing DCR DSM Tests Ablator IHF Test HyMET Tests	**NASA** 3000ºF CMC's Oxidation Coating Titanium Alloy Development Multifunctional Ablator Aerogel Insulations	**NASA** Embedded Sensors Thermal Electrics NDE Methods
Analysis Methods	***Advanced Concepts***	***Durability Models***	***High Temp. Materials***	***Structural Diagnostics***

M&S Long Range Milestones



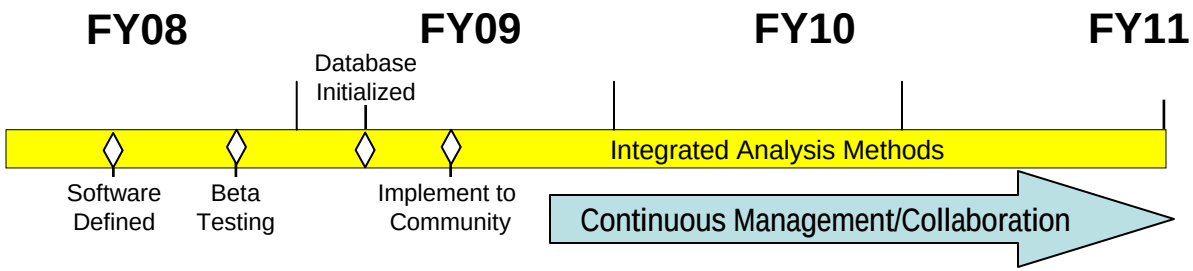
Design Analysis Capability

1. Materials and Structures Focus
2. **Design Analysis Capability**
3. Advanced Structural Concepts
4. Durable Material Systems
5. Structural Diagnostics
6. Summary

CMC Design Collaboration Site

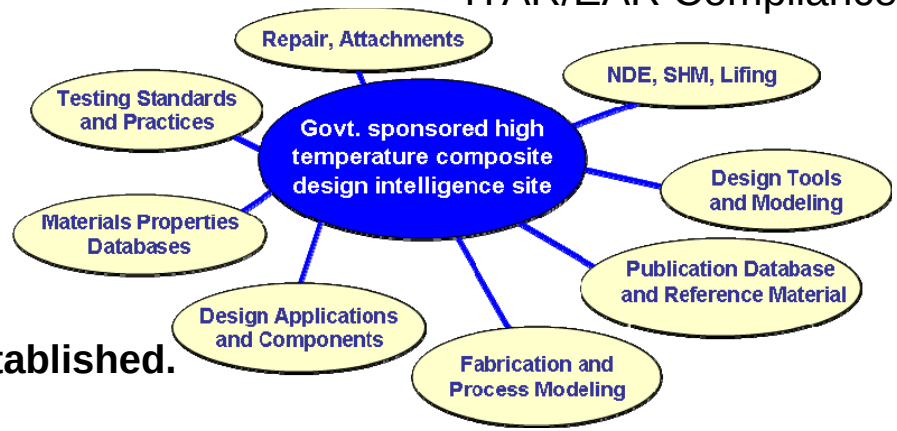
Objective:

Establish a secure environment for virtual collaboration of emerging high temperature composite component fabrication and design technology.



Potential Payoffs:
- Collaboration synergy
- Shared capability

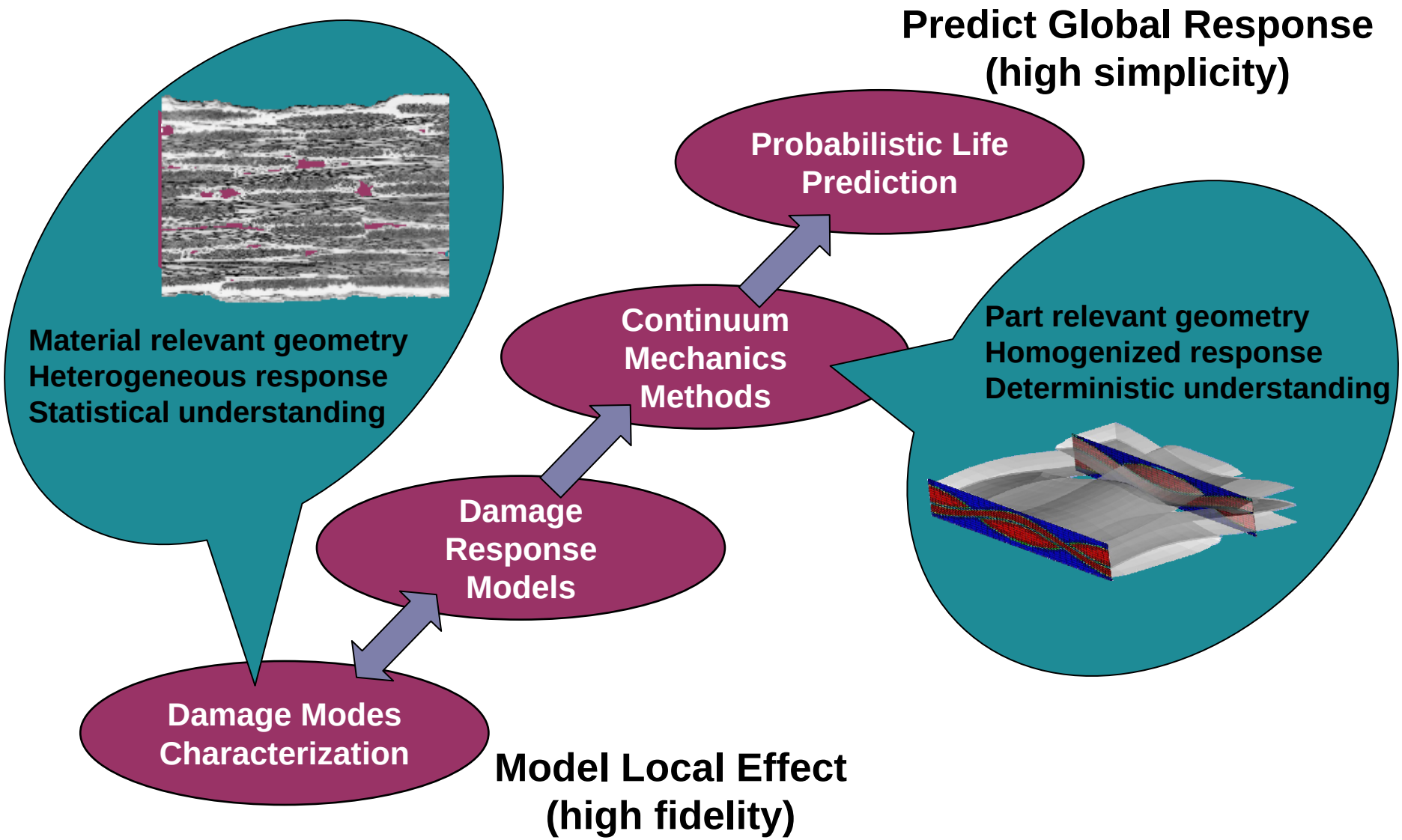
Challenges:
- Establish virtual environment
- Information management
- ITAR/EAR Compliance



Status

- **Software architecture identified.**
- **Government/Industry Beta group established.**
- **Material database initialized**

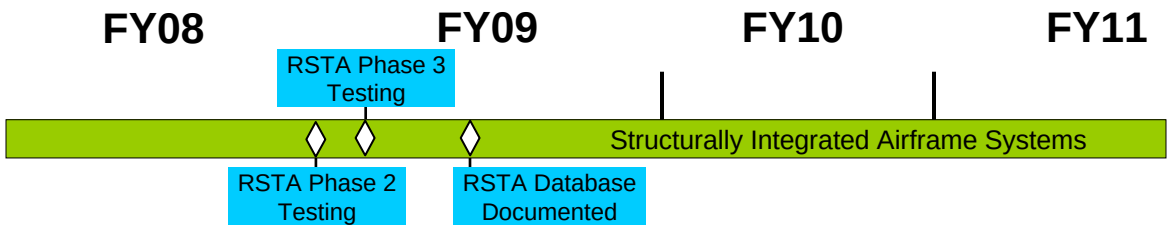
Improved Life Modeling



X-37 C/SiC Ruddervator Testing

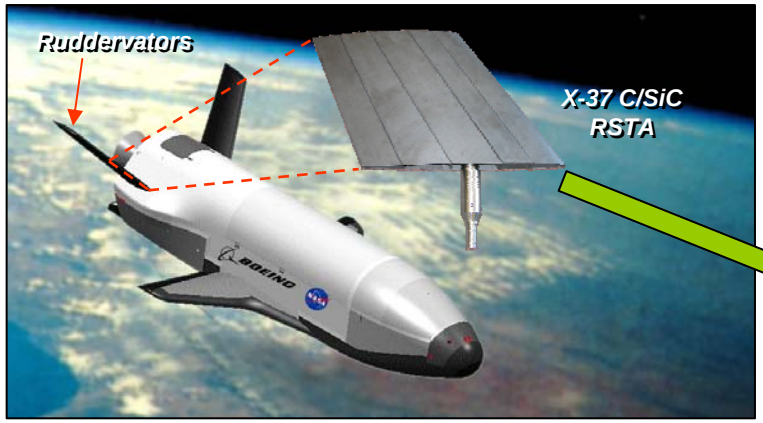
Objective:

Acquire response test data for a representative hypersonic structure subjected to simulated flight loads to support structural analysis developments.



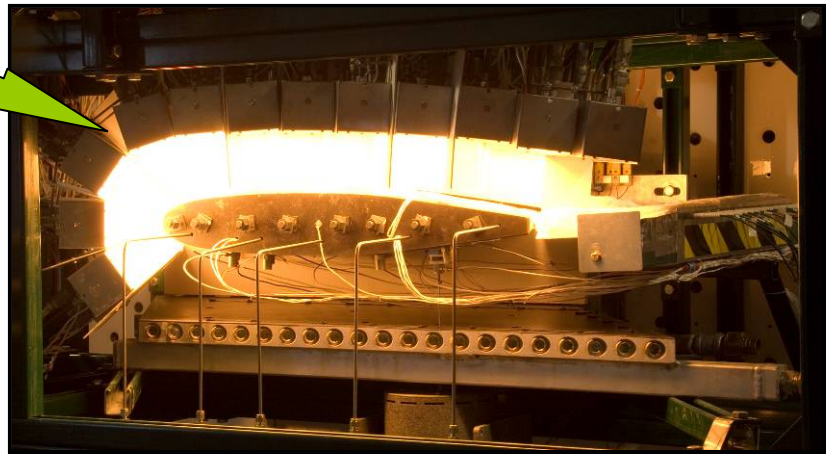
Potential Payoffs:

- Multi-mission affects on C/SiC
- Thermal/structural/vibro-acoustic data for analysis evaluation



Challenges:

- Rentry and trans-atmospheric trajectory simulations
- Instrumentation integration and attachment
- Combined thermal / modal survey tests



Status:

- **Hot GVT thermal/mechanical test series initiated.**
- **Flight simulation test hardware fabricated.**

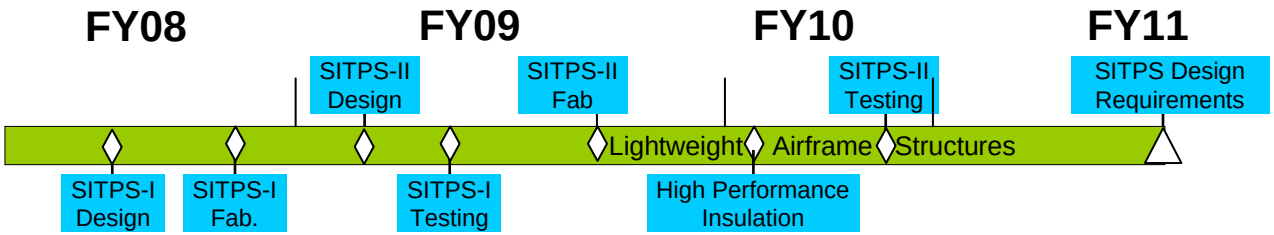
Advanced Structural Concepts

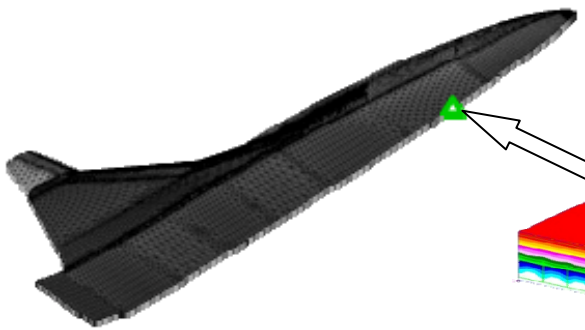
1. Materials and Structures Focus
2. Design Analysis Capability
3. **Advanced Structural Concepts**
4. Durable Material Systems
5. Structural Diagnostics
6. Summary

SITPS Demonstration Panels

Objective:

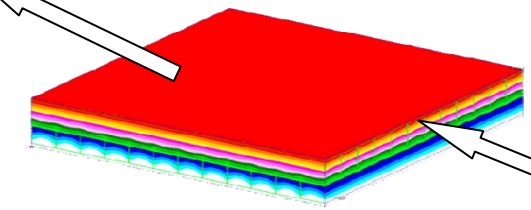
Demonstrate design and fabrication of requirements for structurally integrated thermal protection systems intended for load-bearing applications.





Potential Payoffs:

- More durable and reliable
- Less weight



Challenges:

- Closeout and joint design
- Managing heat shorts
- Material thermal mismatch
- Handling complex geometries

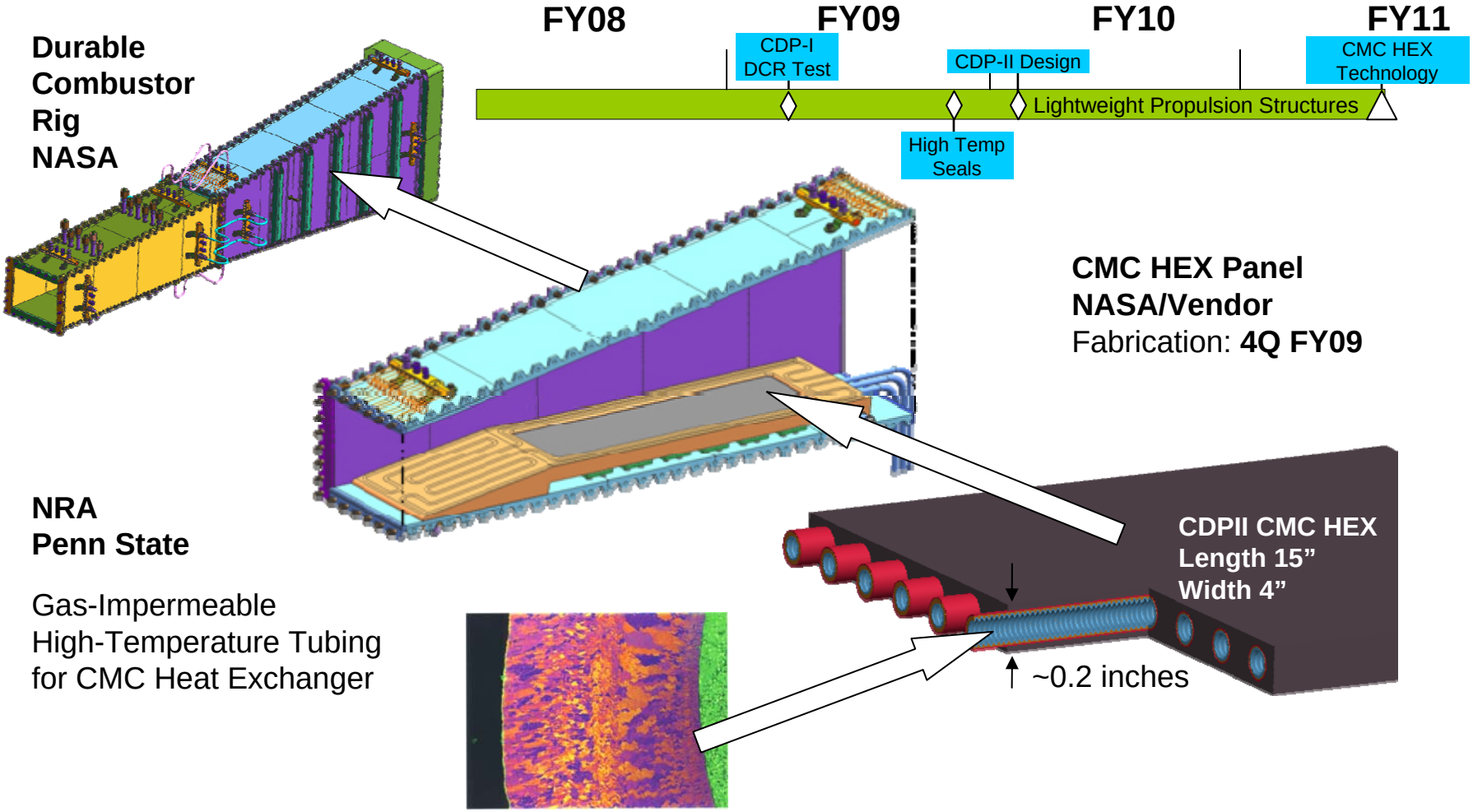
Status

- **Initial architecture/constituents selected.**
- **Fabrication concept demonstrated July 2008.**
- **Scale-up capability effort under contract.**

CDP-II Fuel Cooled CMC HEX Panel

Objective:

Develop structural concepts for actively cooled CMC scramjet combustor wall.



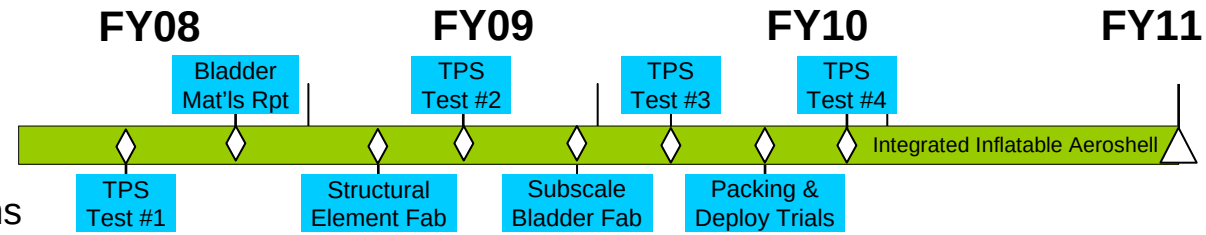
PAI-DAE Materials Development

Objective:

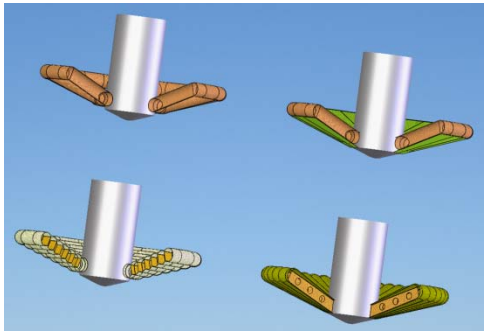
Identify, validate, and integrate an inflatable aeroshell TPS and structure.

8'High Temp Tunnel TPS Testing:

- 6-20 W/cm2 Heat Flux
- OTS Aerospace Fabrics & Films
- Thermal Model Validation



Bladder Structure & Materials



NRA - ILC Dover

- Bladder Materials Test
- Structural Elements
- Subscale Aeroshell

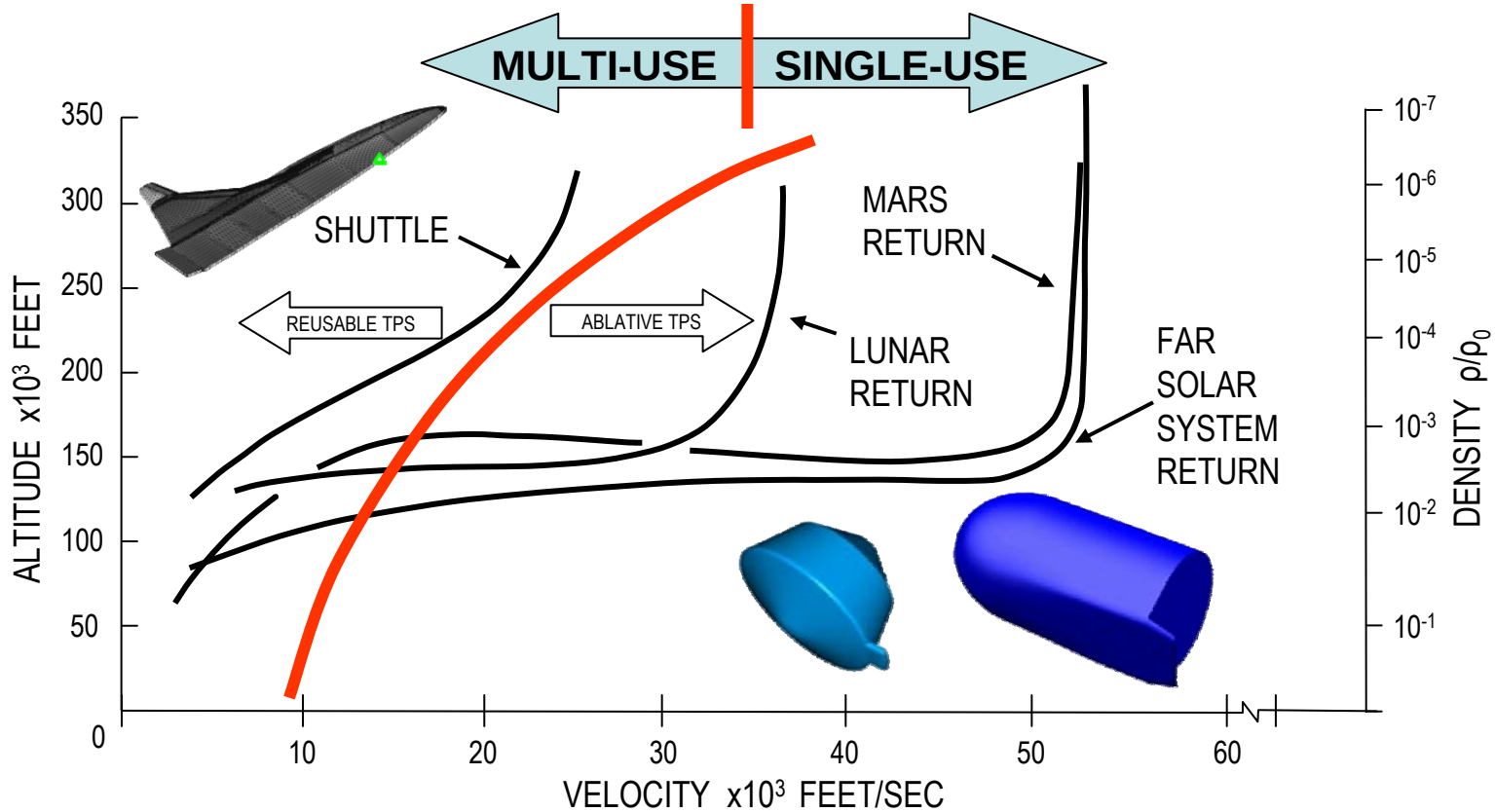
NRA - Vertigo

- Bladder Materials Study
- Fabrication Requirements
- Subscale Aeroshell

Durable Material Systems

1. Materials and Structures Focus
2. Design Analysis Capability
3. Advanced Structural Concepts
4. **Durable Material Systems**
5. Structural Diagnostics
6. Summary

High Temperature Materials



High Temperature Materials Objectives

Advance fundamental understanding of material.

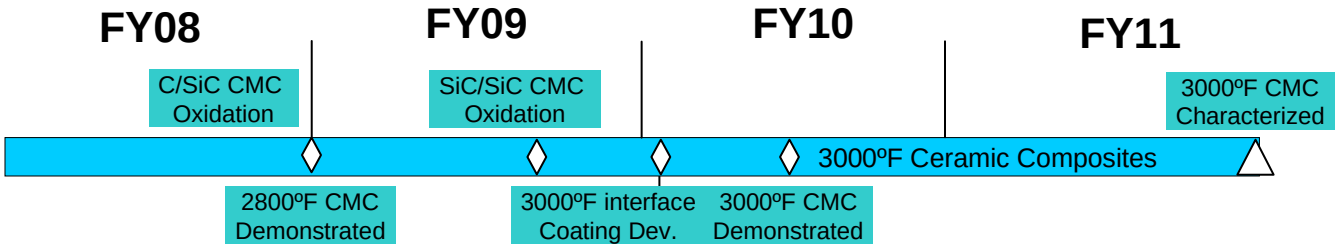
Extend high temperature performance capability.

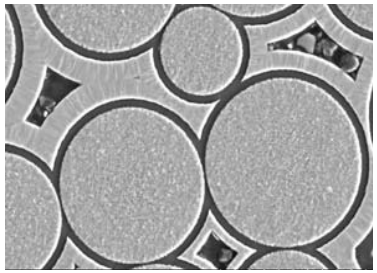
Establish physics-based damage response models.

3000°F High Temperature Composites

Objective:

Develop 3000ºF CMC materials for leading edge, control surface, and propulsion component application.



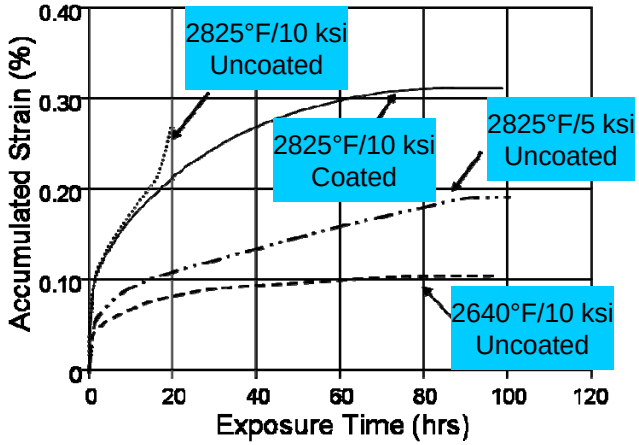


Potential Payoffs:

- Extended life
- Reduced Maintenance
- Lower Weight

Challenges:

- Improve creep resistance
- Improve environmental durability
- Establish design limits



Status

Demonstrated 100 hour life capability:

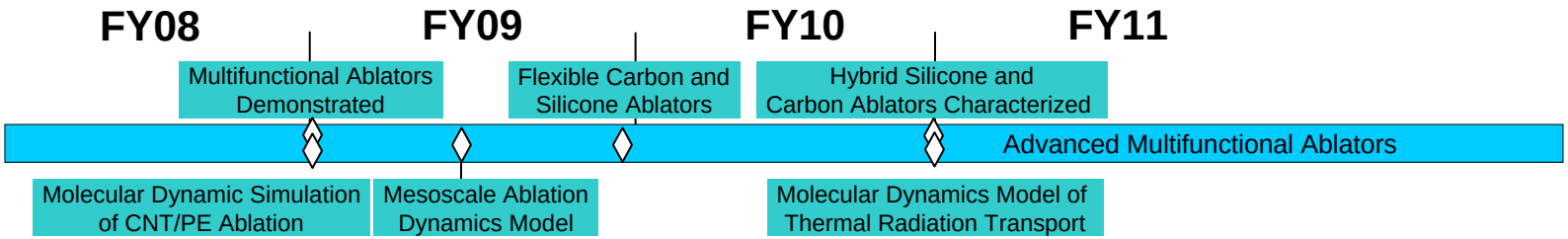
2640°F @ 10 ksi (94% retained strength)

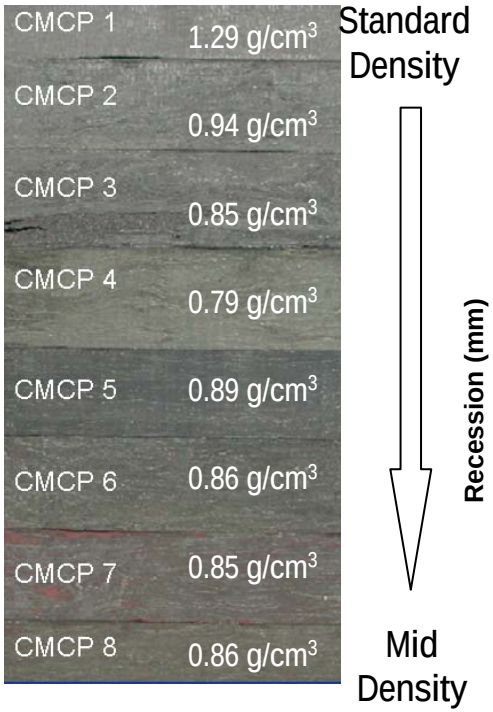
2825°F @ 5 ksi (69% retained strength)

Advanced Ablator Development

Objective:

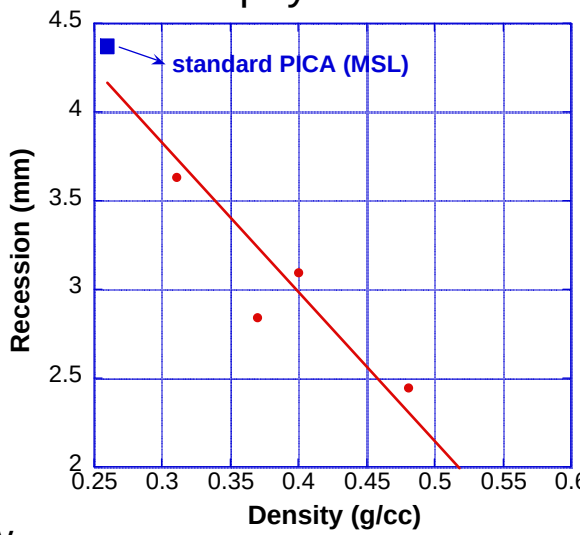
Establish mid density PICA and CMCP ablators.





Potential Payoffs:

- Lower weight
- More payload



Challenges

- Increase virgin/char strength
- Maintain recession performance
- Reduce thermal conductivity

Status

Met APG Milestone with PICA
Demonstrated
- **50% reduced recession**
- **20% reduced heat transfer**

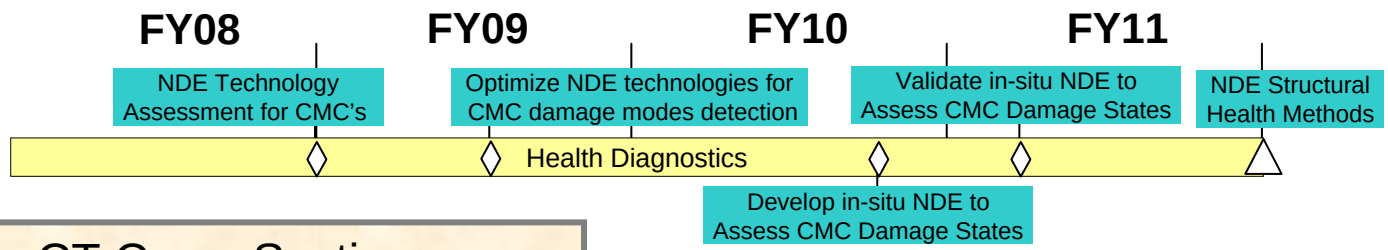
Structural Diagnostics

1. Materials and Structures Focus
2. Design Analysis Capability
3. Advanced Structural Concepts
4. Durable Material Systems
5. **Structural Diagnostics**
6. Summary

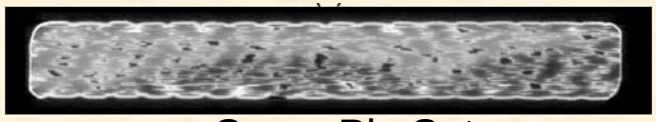
Health Diagnostics Technology

Objective:

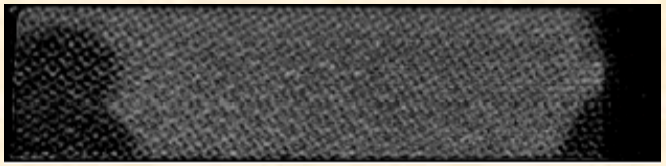
Develop validated non-destructive technologies as inspection and safety assurance tools for reliable operation of reusable structures.



CT Cross Sections
Both Are Post-Exposure



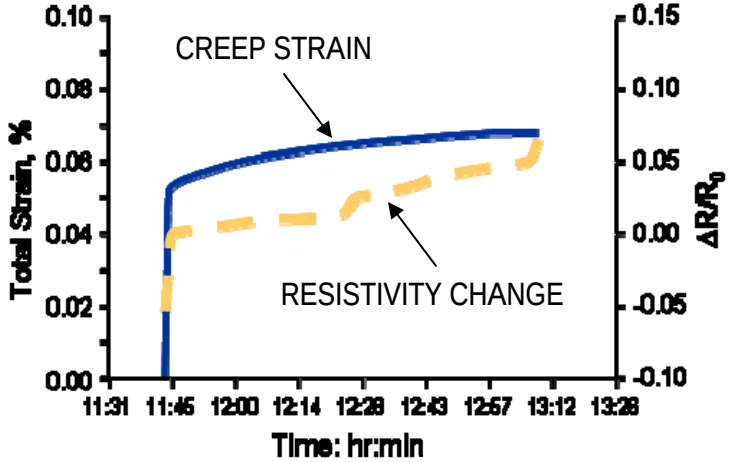
Cross-Ply Cut



Cut Parallel to plies

Potential Payoffs:
- Improved reliability
- SHM Metrics

Challenges
- Damage correlation
- NDE sensitivity



Status

Baseline NDE characterization of SiC/SiC
SiC/SiC NDE standards panels fabricated
Electrical resistivity studies initiated

Summary

1. Materials and Structures Focus
2. Design Analysis Capability
3. Advanced Structural Concepts
4. Durable Material Systems
5. Structural Diagnostics
6. **Summary**

Summary

- NASA FA Hypersonic Materials and Structures is focused on technology developments required to extend space and planetary access capability.

- Significant part of the effort is focused on basic research
  - Physics-based material modeling and life prediction tools
  - Advanced lightweight high temperature materials

- Basic research results support the development of multidiscipline analysis capabilities.
  - Integrated analysis and design tools
  - Advanced structural concept development

NRA Efforts

Advanced Ablators	Advanced computational tools that will enable predictive modeling and design of nano-structured multifunctional phenolic ablator materials for light-weight thermal protection of HMMES vehicle systems.
Creep Resistant Titanium	Process modeling capability to enhance beta formation routes for titanium alloys
High Temperature CMC	Low cost processing technique to fabricate a cost-effective, high strength and oxidation-resistant carbon fiber-reinforced composite for ultrahigh temperature TPS applications
Integrated Thermal Protection	Design, fabricate, and test a multi-functional load-bearing acreage thermal protection system structural concept for will reduce airframe weight and increase safety of current or future vehicles
Life Prediction	Generate finite-element based models for predicting life expectancy of carbon-fiber reinforced silicon carbide ceramic composites
Test Methods	Validated test techniques that enable the measurement of material properties for ceramic matrix composites that are critical to predicting elevated temperature performance.
High Fidelity Analysis	Advance the computing capability in the area of nonlinear reduced-order structural response analysis as it applies to hypersonic flight regime and vehicle structures
Validated NDE Methods	Develop non destructive evaluation methods capable of identifying and quantifying ceramic composite defects and develop analytic models capable of predicting effects on material behavior

NRA Efforts Continued

High Temperature Sensors	Comprehensive review of performance, manufacturing capabilities, and technology readiness of current sensors and sensory materials.
Structurally Integrated TPS	Develop rigid honeycomb insulation concepts for structurally integrated thermal protection systems.
Physics-Based Models	Establish a stochastic, hierarchical textile model based on fabric topology to model CMC property variations.
Multifunctional Materials	Develop a high temperature thermal electric system that is compatible with silicon-based composite systems for application at 2000°F
CMC Database	Assessment of the manufacturing capability, scale-up readiness, design readiness of high temperature composite.
Cool CMC Structures	Develop a fabrication process of functionally graded, hydrogen impermeable coatings for ceramic-metal composite heat exchangers.
Durable Materials	Investigate new UHTC coating systems for ceramic composites for extended life of reusable components.