The Program to Advance Inflatable Decelerators for Atmospheric Entry (PAIDAE)

An overview of results & lessons learned from Years 1 and 2

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Outline

- **PAIDAE’s Purpose**
- **Our Partners**
- **What we’ve been up to**
  - **FY07 – FY08 Activities**
- **and What’s next**
  - **FY09 Activities & Milestones**

Fundamental Aero's EDL Investment

Hypersonics Project

High Mass Mars Entry System

Conduct fundamental and multidisciplinary research to enable high-mass entry into planetary atmospheres

Supersonics Project

High Mass Planetary Entry Systems

Address the critical supersonic deceleration phase of future large payload Exploration and Science Missions

Inflatable Aerodynamic Decelerators are recognized as cross-cutting EDL technology.

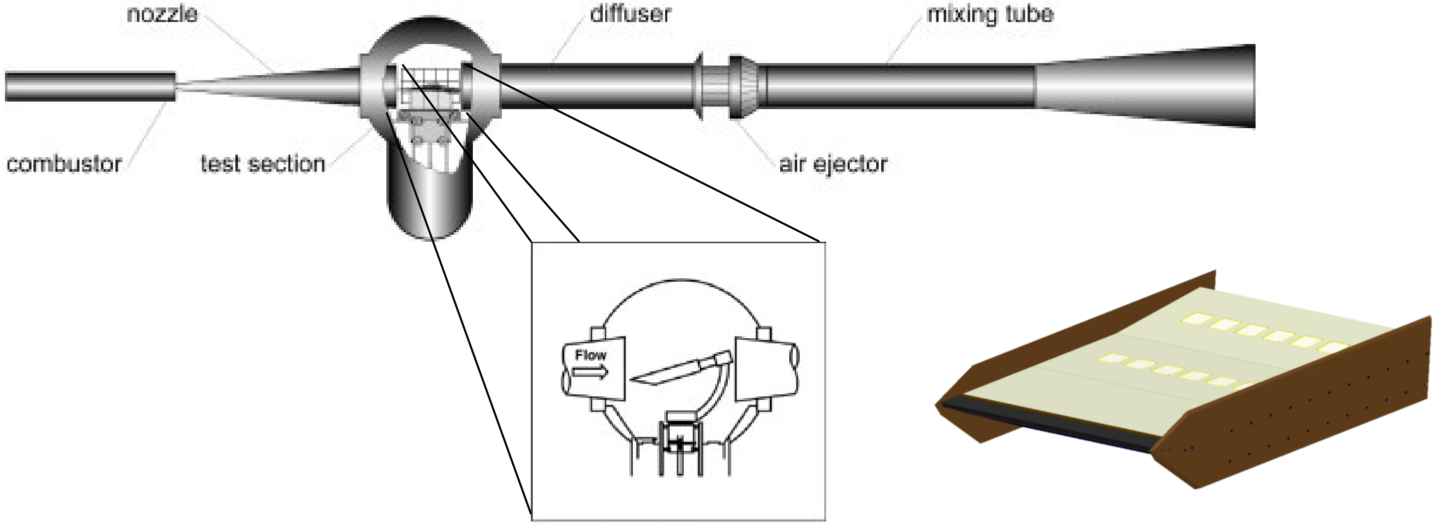
PAIDAE's purpose is to conduct the technology maturation activities necessary to bring IAD technologies off the drawing board and into flight

Industry & University Partners

- ILC Dover
  - Coupon Fabrication / Design for 8-ft High Temp Tunnel TPS Tests
  - Tension Cone Models for 10x10 SWT Test
  - NASA Research Announcement Award
    - Identify, test, & analyze the performance of bladder films and laminates for HMMES applicable IADs.
    - Design & Construct new structural system concepts of deployable aeroshells.
- National Institute of Aerospace
  - Georgia Tech
    - Co-Lead for 10x10 SWT & Unitary WT Tests
    - Trajectory Analysis – Trade Study & Roadmapping Support
  - UVA
    - "Hy-V2" Supersonic IAD Flight Test Feasibility Study
- Vertigo
  - NASA Research Announcement Award
    - Identify, test, & analyze potentially viable flexible material systems for IADs
    - Identify limitations of current manufacturing techniques/ technologies for future full-scale IAD fabrication
    - Demonstrate scalable current manufacturing capability thru fabrication of 5-10m tension cone mock-up
- Boeing
  - NASA Research Announcement Award
    - Perform research to develop an accurate strain and/or deformation sensor to enable fluid-structure interaction (FSI) model validation.

IAD TPS Testing
November 2007 – January 2008

NASA LaRC 8-ft High Temperature Tunnel



Test Section: 8’ dia. x 12’ long

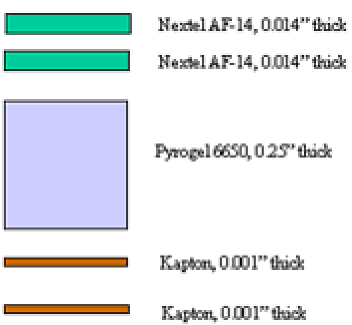
TPS Testing

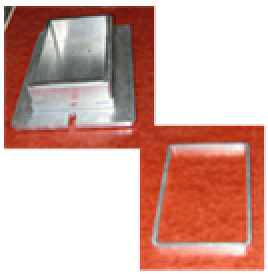
- FY07-08 Testing
  - Executed 20 runs with 10 different TPS Lay-ups, each made of various combinations of 8 different off-the-shelf fabrics
  - Each TPS lay-up was exposed to Heat Flux ranging from 6 – 20 W/cm^2
  - Testing proved valuable in developing test techniques for fabric TPS Testing
  - Data for validation of Thermal Modeling
  - Follow-on testing required to demonstrate repeatability of results, and to further narrow down the material sets to an optimal set.
  - Final results to be documented later this year in Technical Memo and subsequent publications.

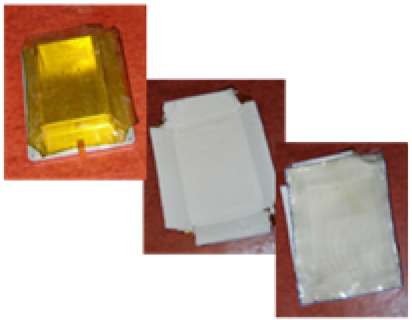
Materials, Hardware, & Instrumentation

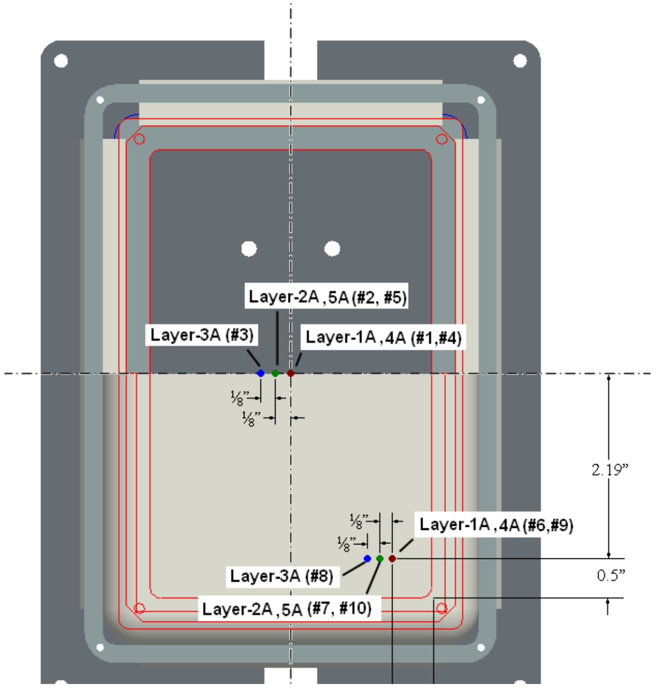
Outer Fabric		Insulator			Gas Barrier	
AF14		Pyrogel 6650			Kapton	Kapton
BF20		Pyrogel 6650			Kapton	Kapton
AF14	AF14	Pyrogel 6650			Kapton	Kapton
BF20	BF20	Pyrogel 6650			Kapton	Kapton
XN513		Refrasil 1800	Pyrogel 3350		Kapton	Kapton
Refrasil C1554-48		Pyrogel 6650			Kapton	Kapton
Refrasil C1554-48		Refrasil 1800	Pyrogel 3350	Pyrogel 3350	Kapton	Kapton
Refrasil C1554-49		Refrasil 2000	Pyrogel 6650		Upilex	Upilex
Refrasil UC100-28		KFA5	Pyrogel 3350		Upilex	Upilex
T300 Cloth		KFA5			Upilex	Upilex

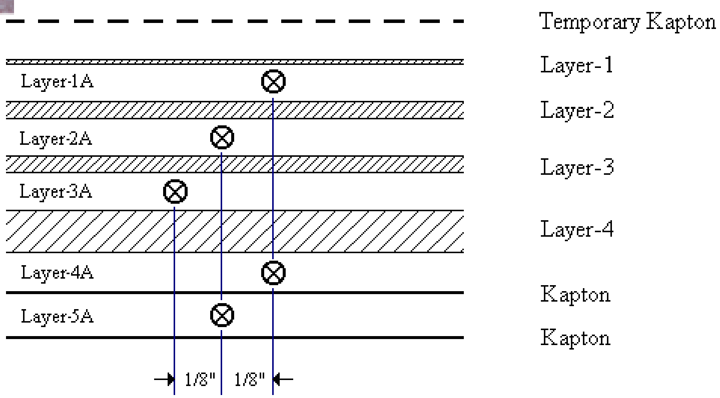
Schematic of Layup L3







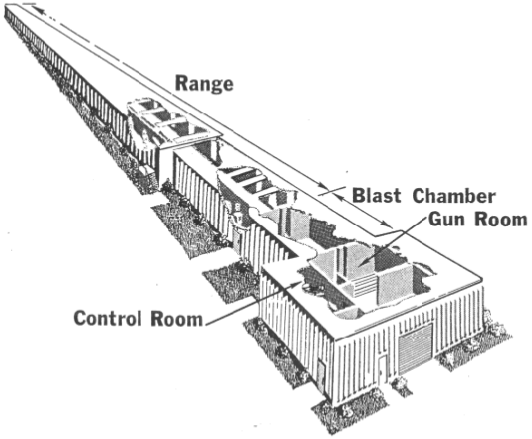




TPS Test Video

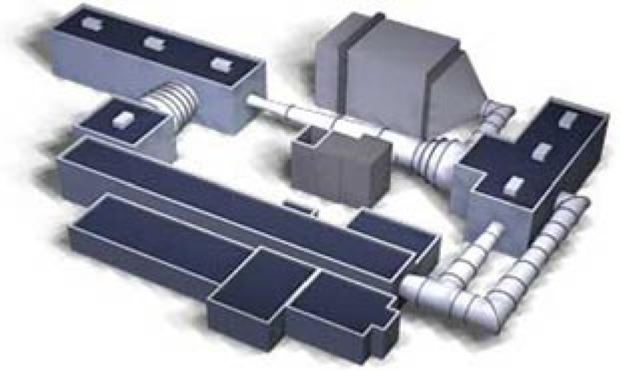
Aerodynamic Testing

Eglin AFB Ballistic Range



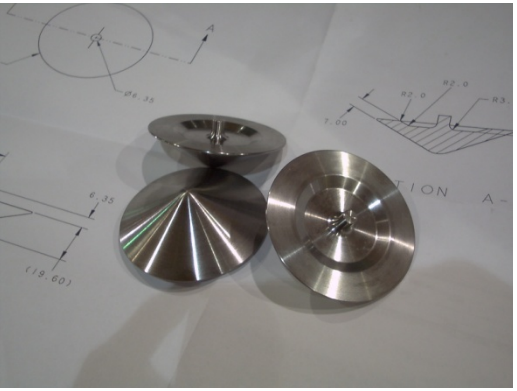
NASA LaRC 4'x4' Unitary Tunnel

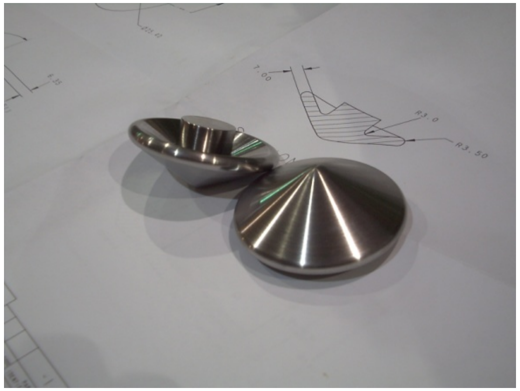
NASA GRC 10' x 10' Supersonic Wind Tunnel

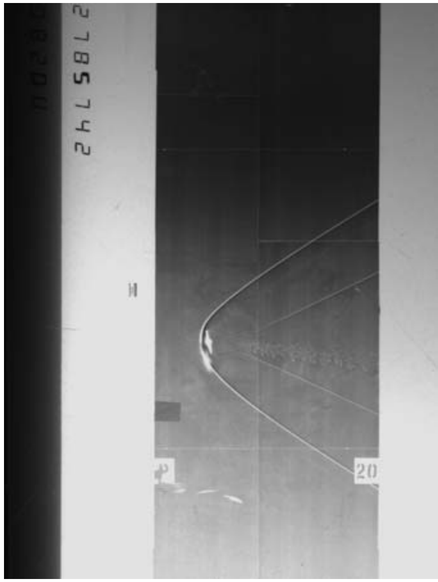


Ballistic Range Testing

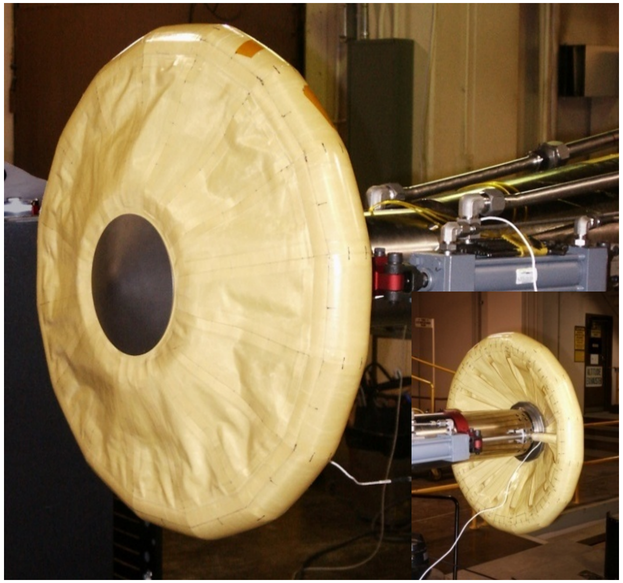
- FY07 Testing
  - Executed 40 shots with 9 different vehicle configurations
  - Primary objectives were to determine if aeroshell shoulder radius and aft-body aspect ratio configurations had significant impact on entry vehicle dynamic stability
  - Results show that neither configuration change had a significant impact
    - Payload tucked in behind aeroshell is overall a very stable configuration
- FY09 Testing
  - Follow-on testing required to demonstrate repeatability of results, verify c.g. variation did not impact initial results
  - Further mid to low supersonic data
  - Include Supersonic IAD Configurations







Supersonic Wind-Tunnel Testing



Unitary Wind-Tunnel Test

- Force & Moment Test
- Pressure Distribution Test
- Scaled version of GRC10x10 models
- Aerodynamic Performance and data for CFD validation
- Rigid vehicle baseline for characterization of variations due to flexibility.

GRC 10x10 Supersonic Wind-Tunnel Test

- Semi-rigid Model *(not shown)*
  - Provides characterization of fully inflated tension cone without inflation and deployment complications
- Inflatable Model *(shown above, inflated, under no load)*
  - Exploration of Inflation Dynamics and Torus Pressure Variation
  - An assessment of inflation and flexible material effects on overall aerodynamic performance

GRC 10'x10' Supersonic Wind-Tunnel Test

Qualitative Objectives

- Semi-Rigid and Inflatable Models
  - Determine stability of the flowfield
  - Determine aeroelastic stability of tension cone
- Inflatable Model
  - Characterize how deployment of the tension cone occurs

Quantitative Objectives

- Semi-Rigid and Inflatable Models
  - Determine static aerodynamic characteristics
  - Determine shape and position of shocks
  - Determine shape of tension cone
  - Determine time history of unsteady forces and moments

Quantitative Objectives

- Inflatable Model
  - Determine inflation pressure required for deployment
  - Determine time history of forces and moments during deployment
  - Determine inflation pressure required to eliminate wrinkling of torus
  - Determine minimum inflation pressure required to prevent buckling
  - Determine minimum inflation pressure required to re-deploy

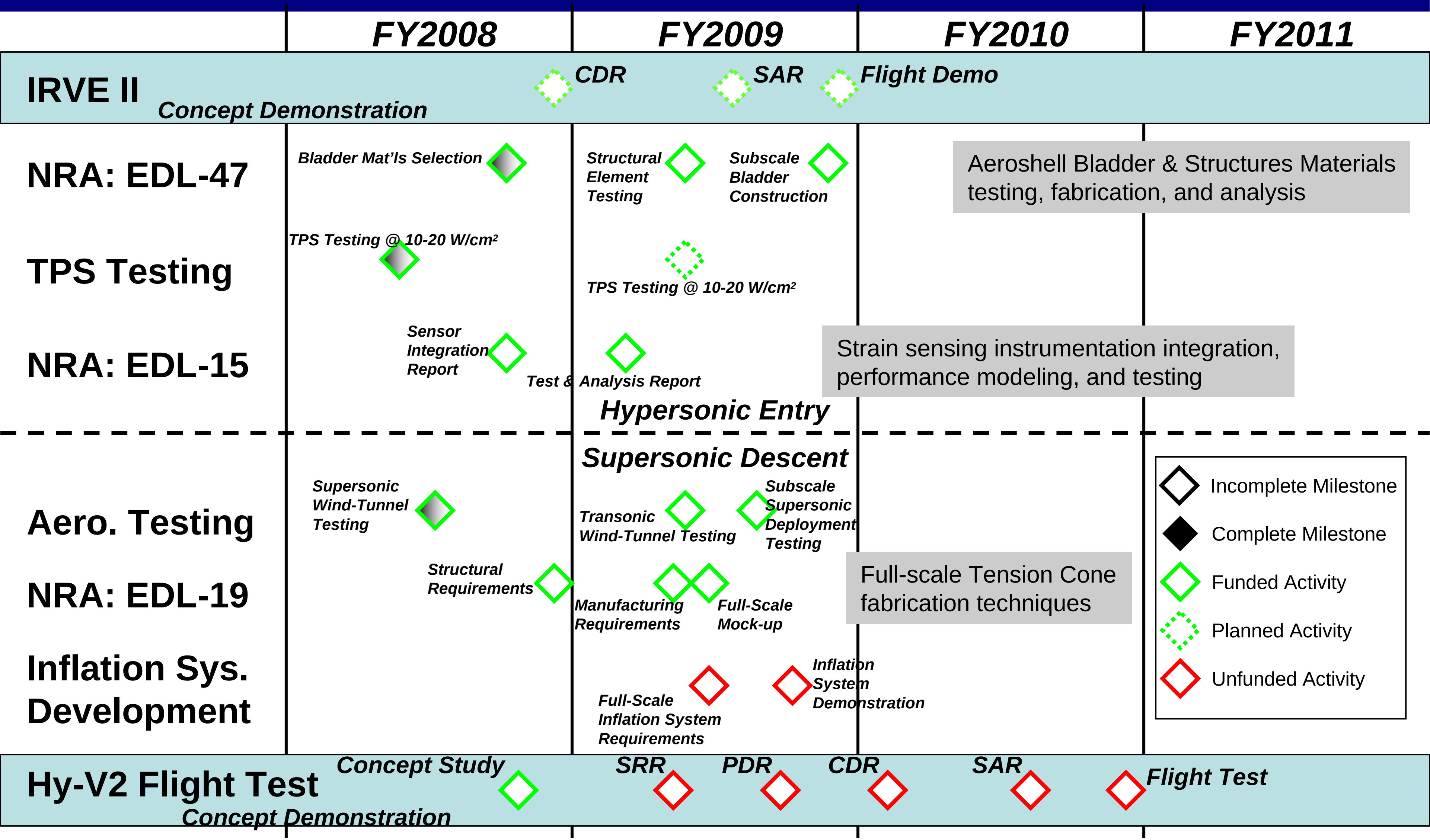
GRC 10’x10’ SWT Deployment Video

Other Ongoing PAIDAE Activities

- NRA Guidance & Oversight
- Flight Test Concept Development
- Material Property Testing at relevant entry environment
- Trade Studies & Technology Roadmapping

What's next

PAIDAE FY09 Milestones



FY09 Highlights

- **TDT Testing**
  - Characterize Transonic & Subsonic Tension Cone Performance
  - Characterize Transonic & Subsonic Isotensoid Performance
    - Eventual down-select between Tension Cone & Isotensoid
  - Engage measurement techniques to measure aeroelasticity affects
- **Ballistic Range Testing**
  - Repeatability of FY07 shots
  - Characterize mid-low supersonic dynamic stability
  - Determine dynamic stability characteristics of supersonic IAD configurations
- **8-ft High Temperature Tunnel Testing**
  - Repeatability of FY08 runs
  - Adopt lessons learned & new test techniques from FY08 runs
  - Evaluate new candidate materials
- **Material Property Testing Complete**
  - Incorporate material properties into analytical TPS models
- **NRA Completion**
  - New IAD bladder materials, construction techniques, and instrumentation techniques evaluted.
  - Guide further research & development efforts
- **Hy-V 2 Feasibility Assessment Complete**
  - Propose supersonic IAD sounding rocket flight test
  - Provide solution of HRRLS experimentalist
- **Partner w/ ARC for next IAD SWT**
  - Summer 2009
  - Validate ARC test techniques
  - Match Reynolds #, up to Mach 3.5, measure aeroheating & shoulder effects

For Further Information

- TPS Testing

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