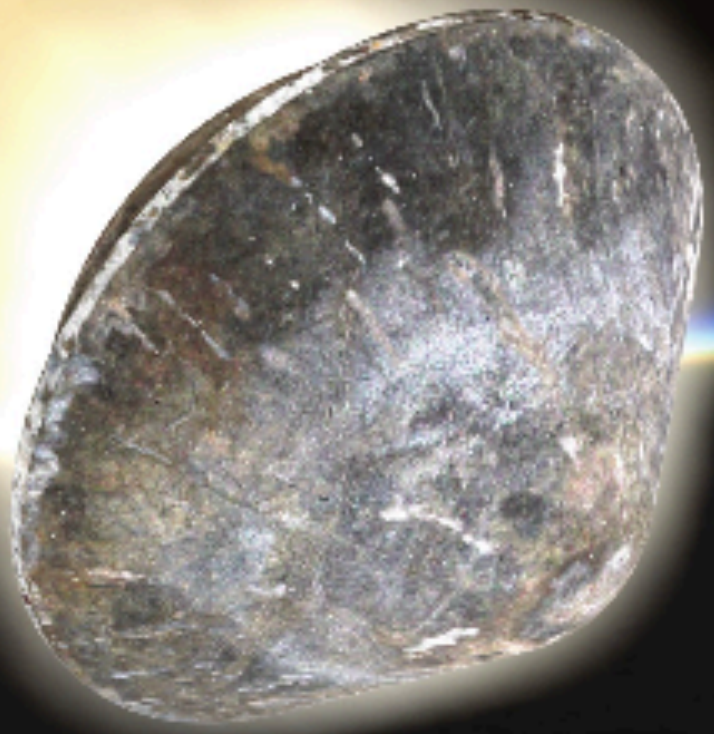
Entry Probes at the NASA Ames Research Center: Past, Present and Thoughts on the Future

By

Charles A. Smith
June 15, 2015

12th International Planetary Probe Workshop
Cologne, Germany



15th June, 2015

IPPW 2015

Focus and Disclaimers

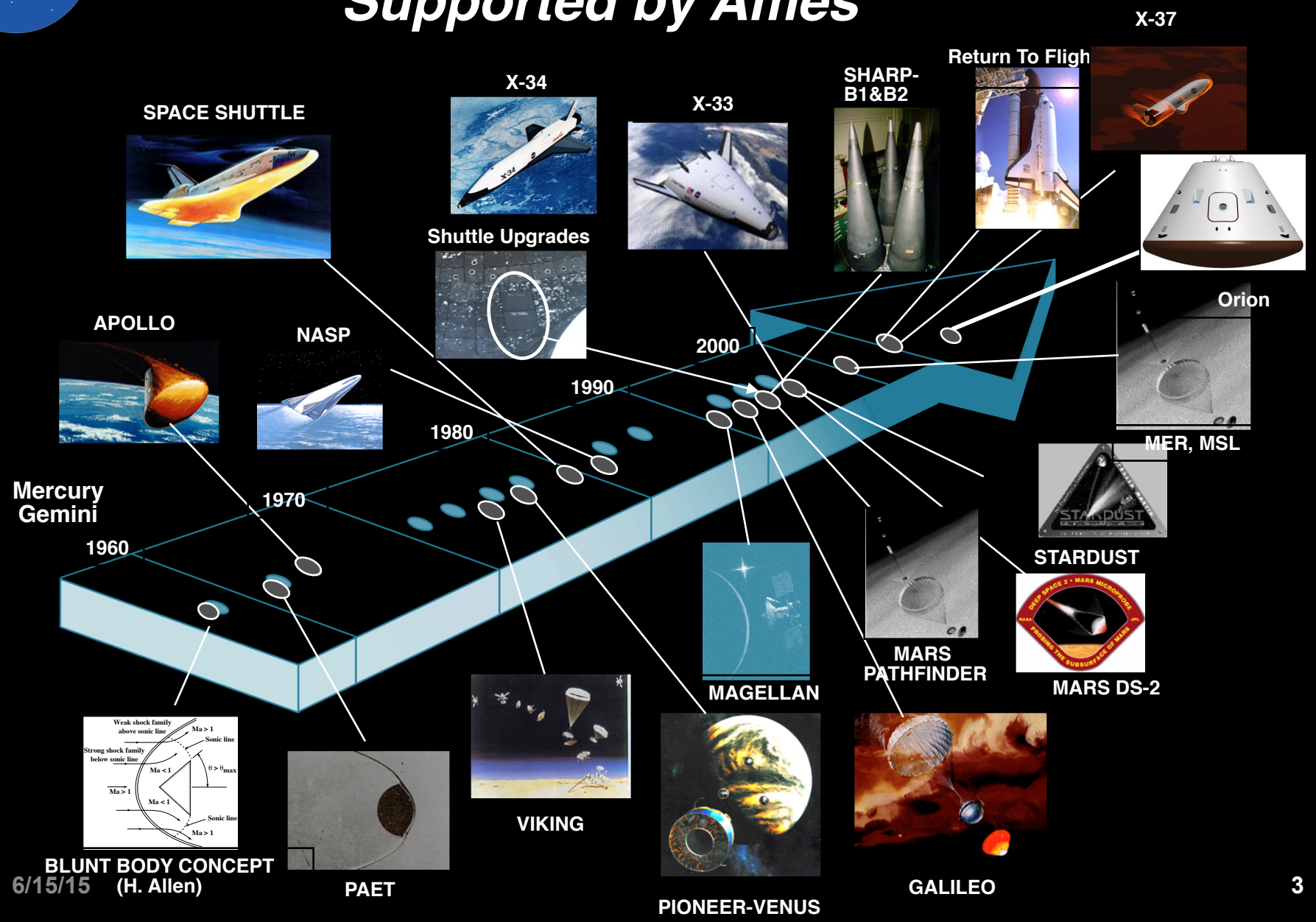
Presentation is Ames-centric.

Other key players in entry technology and its applications include our colleagues at LaRC, JSC, Sandia, the Department of Defense, U.S. industry, European Space Agency, Russia, Japan and others.

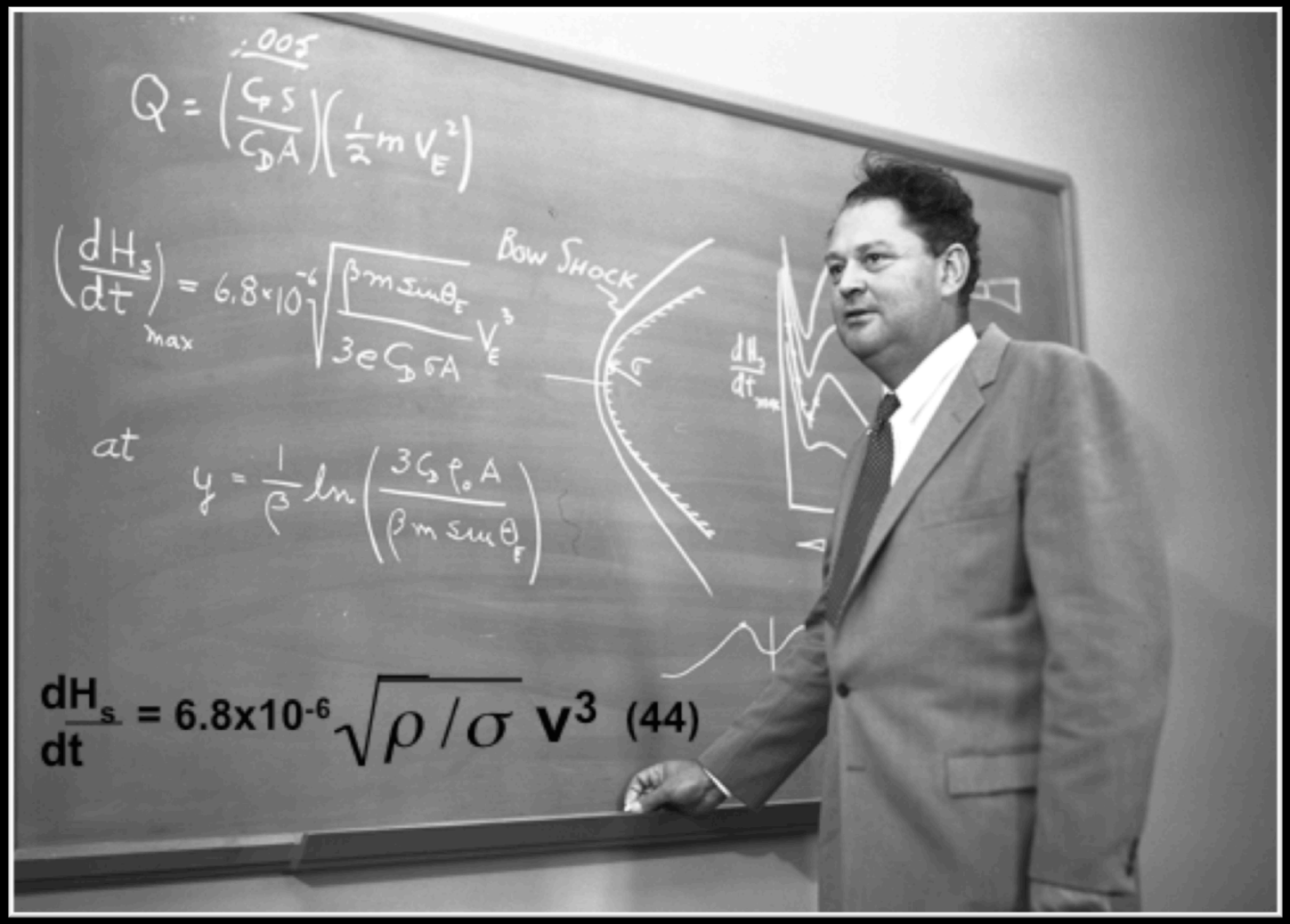
Did not/could not list all Ames contributors.

"Using material from one source is plagiarism, using material from many sources is called a review". A big Thank You to all members of the Entry Systems and Technology Division.

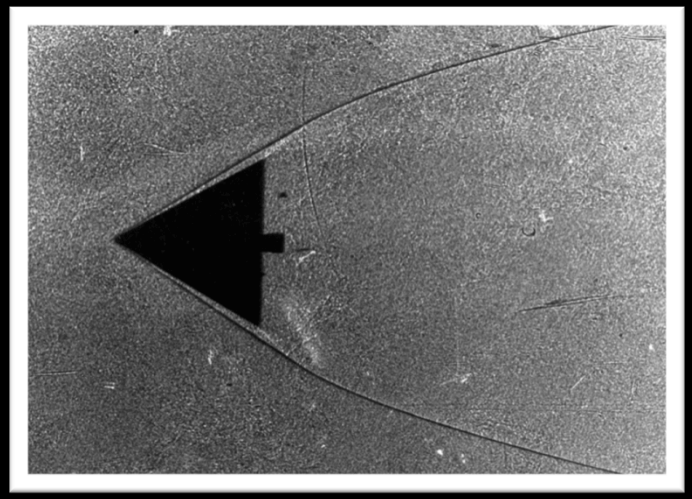
NASA Entry Systems and Vehicles Supported by Ames



Blunt Body Concept – H. Julian Allen

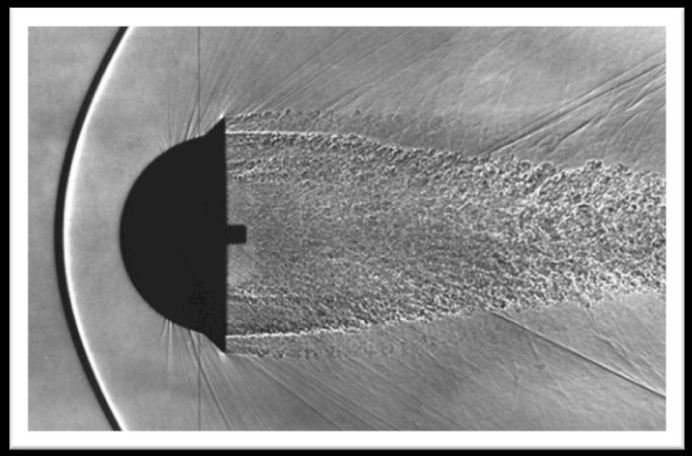


"PROCEED UNTIL APPREHENDED"



Prevailing Wisdom : Sharp Nose

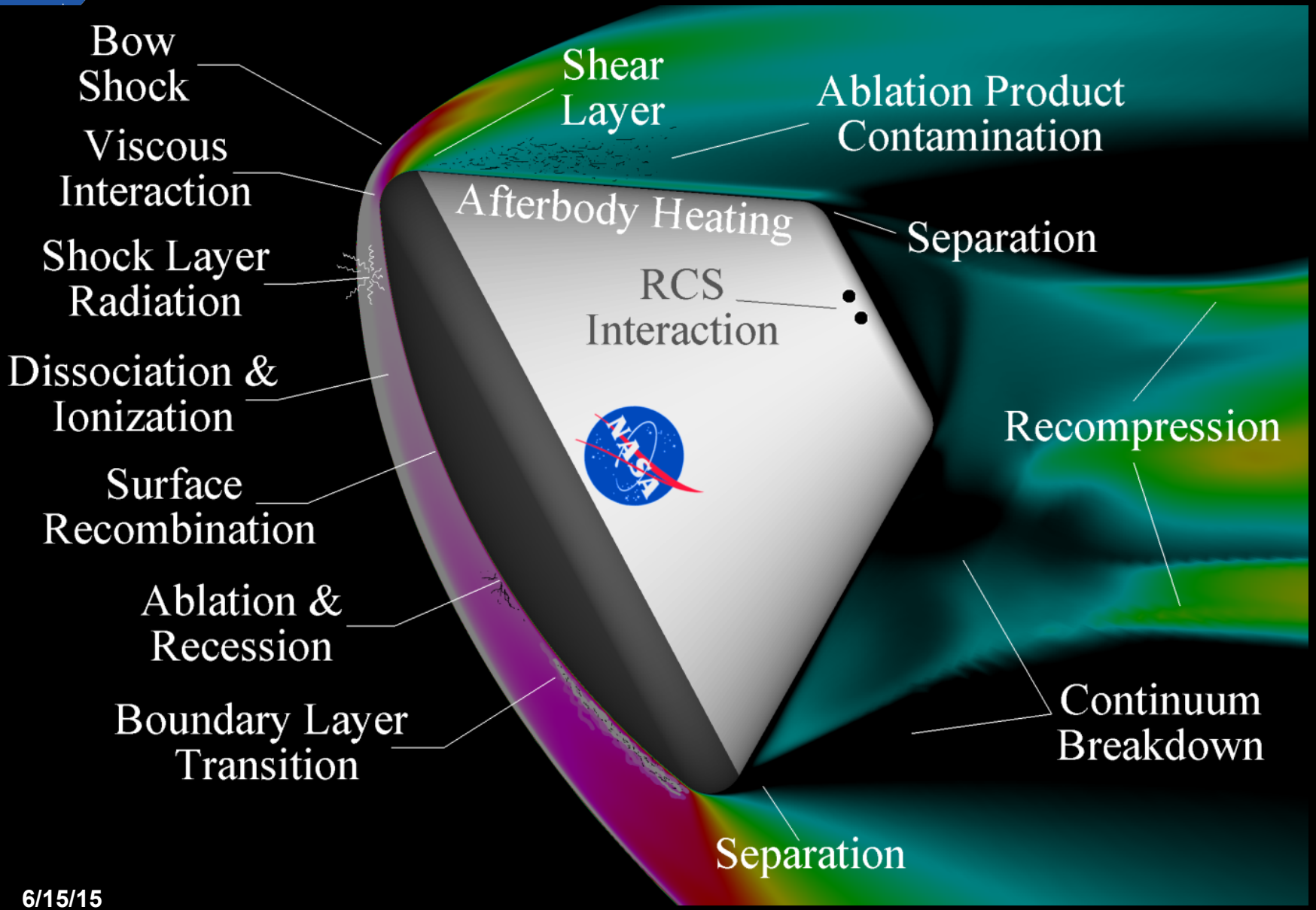
Ames Proposal: Blunt Nose for Predictable Performance



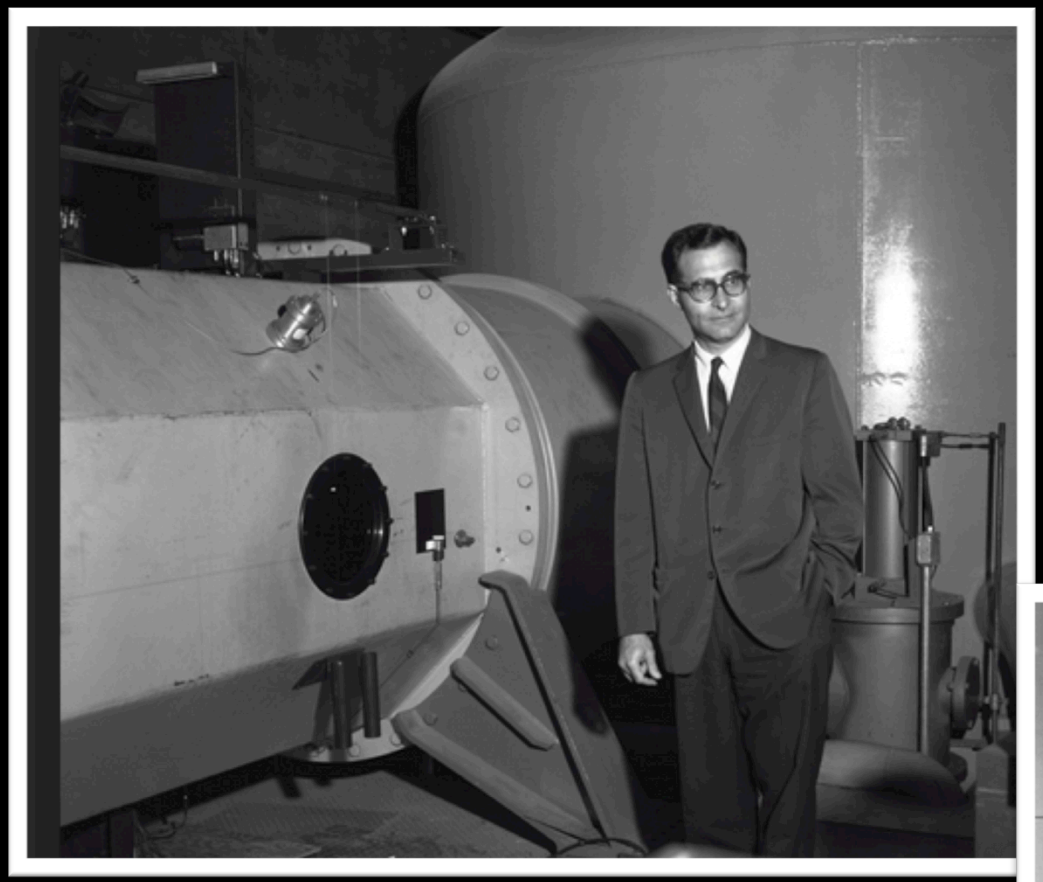
<u>Headquarters Reaction:</u>
It will never work

AMES IN ACTION!

The Challenge of Entry Probes

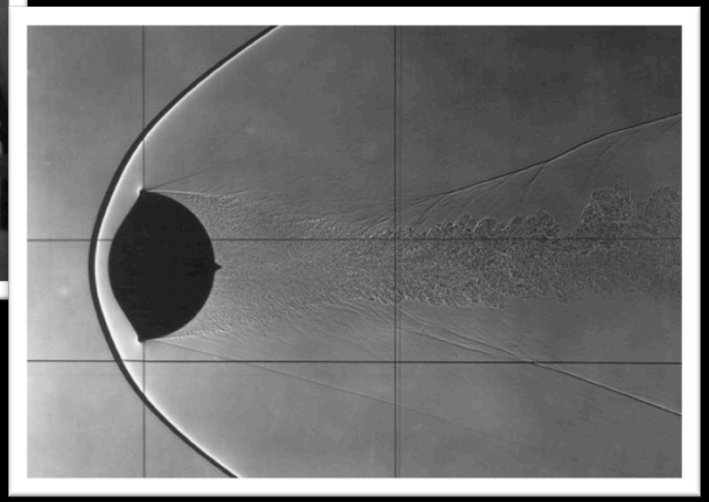


PAET, Alvin Seiff

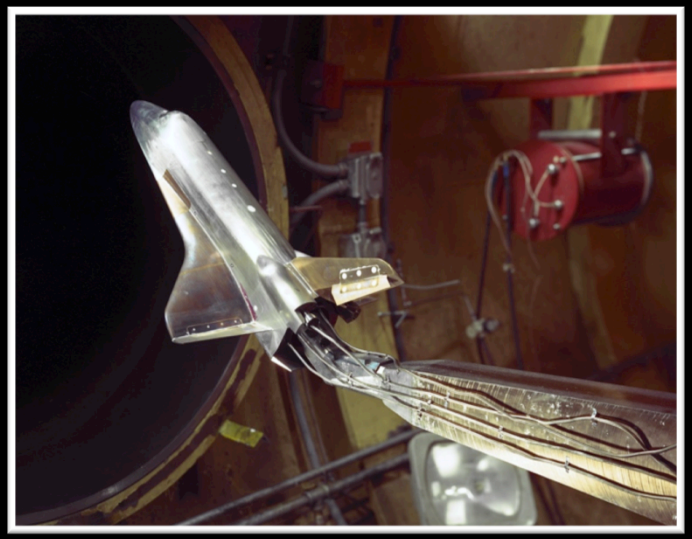


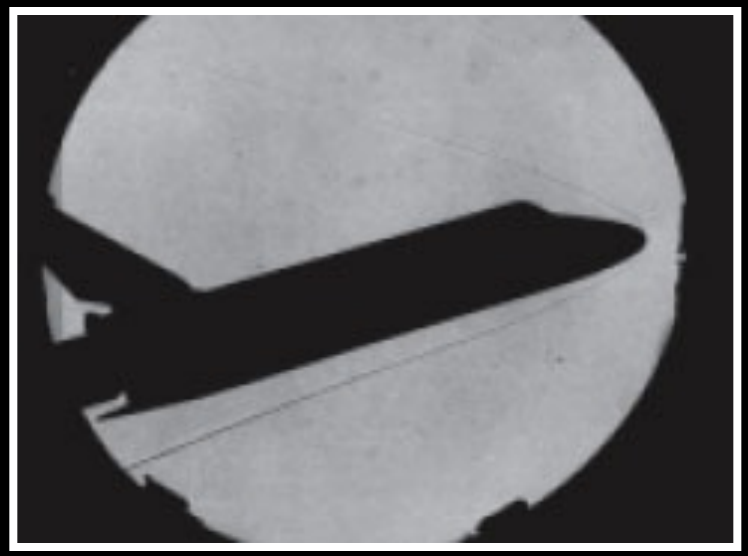
Alvin Seiff at Ames Hypervelocity Free-Flight Facility. Dec. 2, 1966

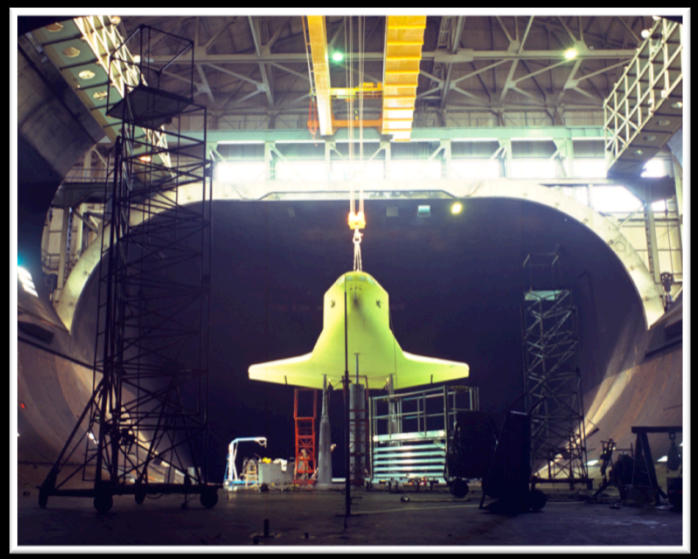
A Schileren Image of the Planetary Atmospheres Experiment TEST (PAET)

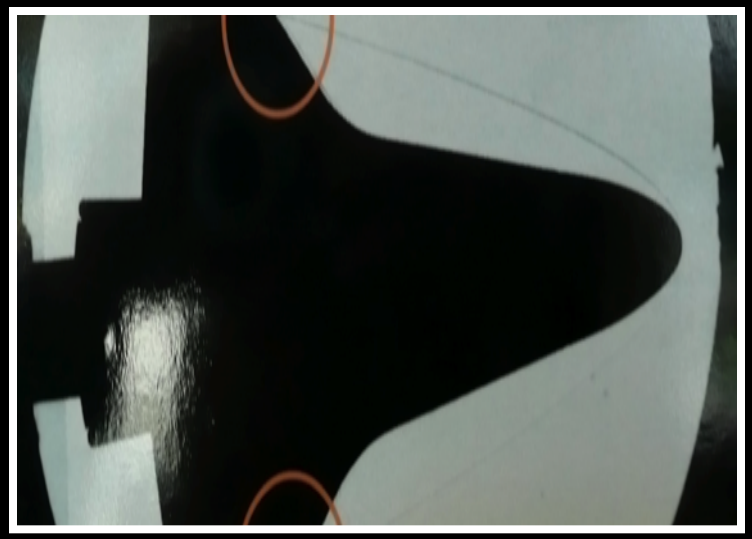


Space Shuttle: Aerodynamics





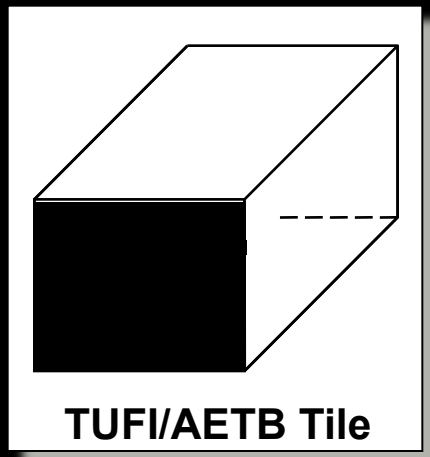


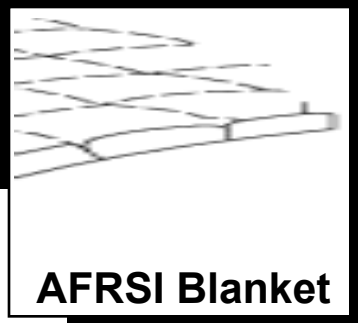


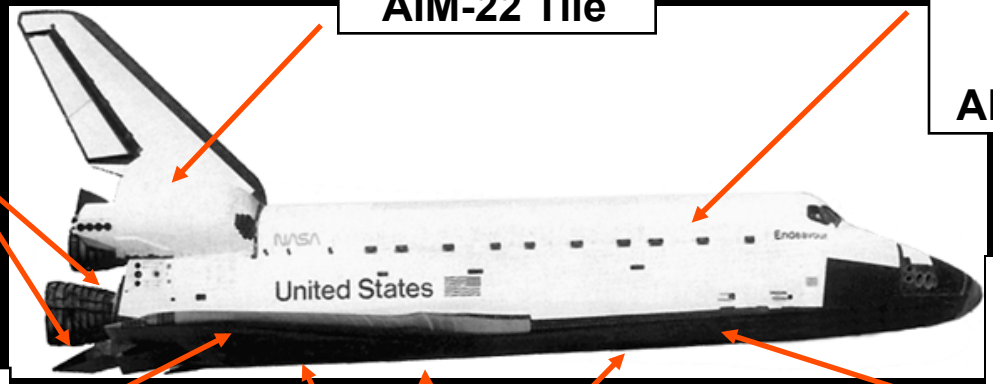
Ames did more than 50% of Shuttle's wind tunnel testing

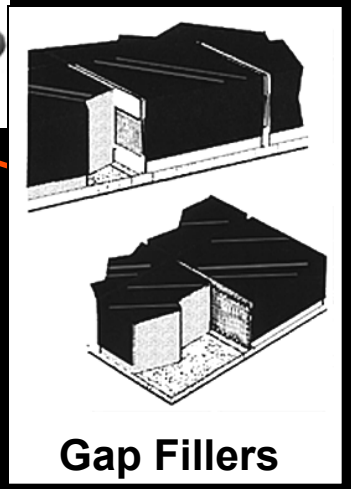
Ames' Contributions* to Shuttle TPS

Tile concept by Robert Beasley et. al., Lockheed





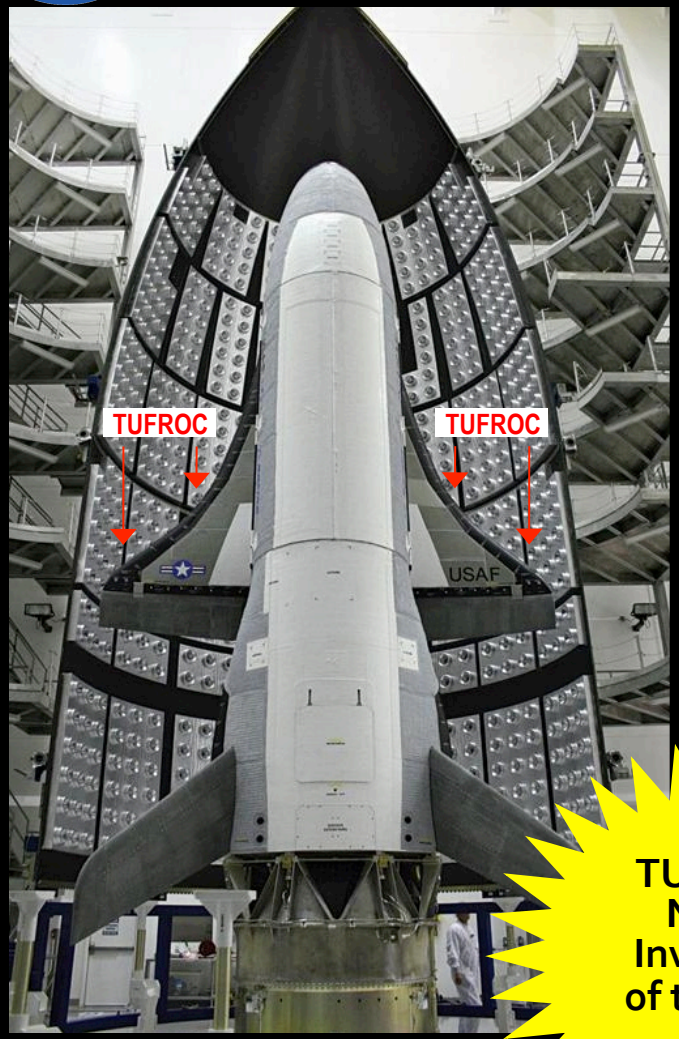




Goldstein, Covington, Leiser, Smith, Estrella, Katavalla, Stewart, Swako, Riccitelio, ……

***All elements shown were patented by Ames**

TUFROC – Breakthrough TPS



X-37B Preparing for launch, Ap

TUFROC: Flight Proven on X-37B

TUFROC spans USAF X-37b wing leading edge

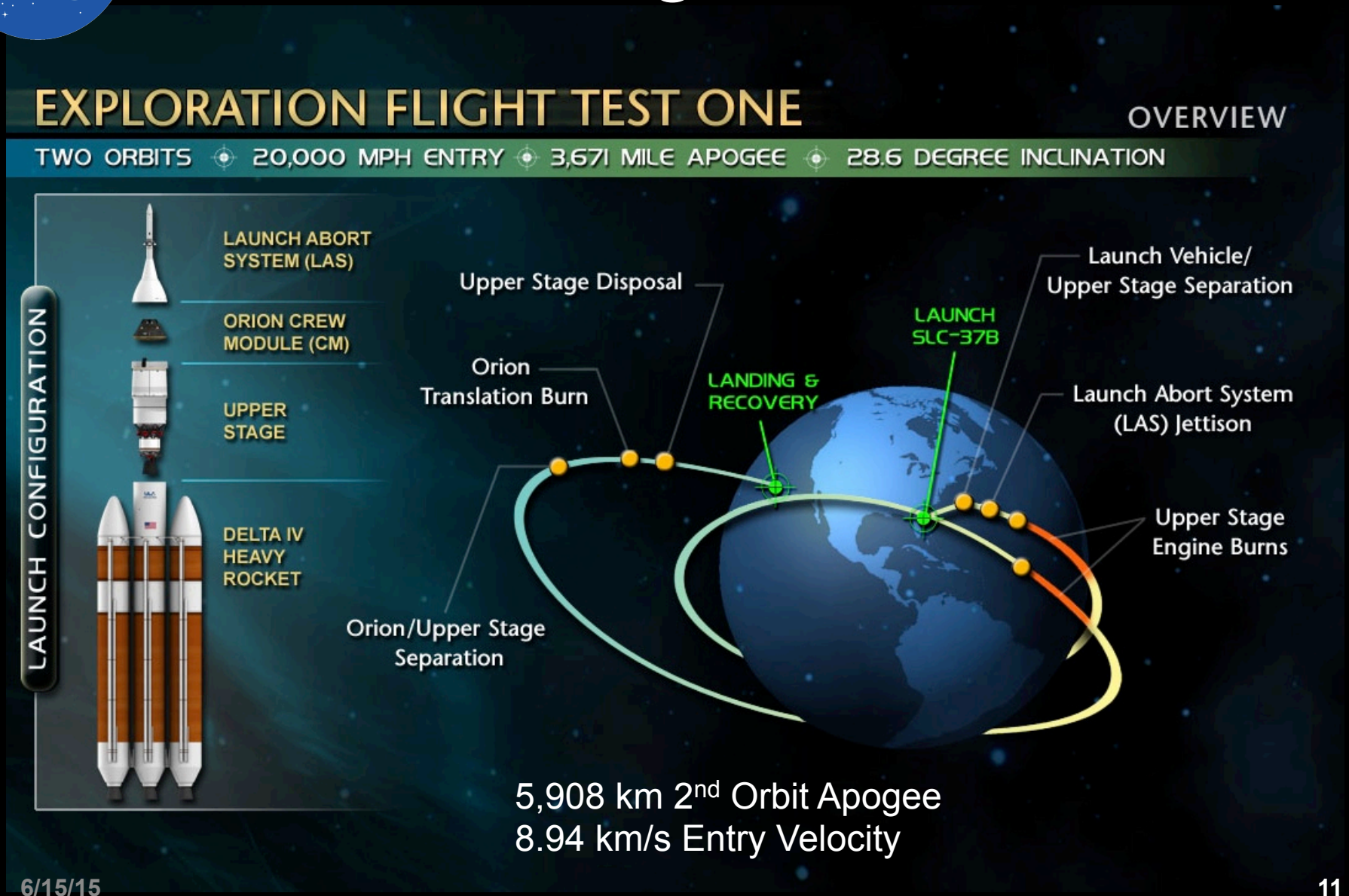
- Government developed (NASA Ames), transferred to commercial sector (Boeing)
- 1st mission successfully completed Dec 2010
- 4th mission in progress

Key enabling technology for a critical USAF Program

X-37B after 224 days (90 million miles) **in orbit, Dec 2010**

TUFROC: NASA Invention of the Year 2011

EFT-1 Flight Profile



5,908 km 2nd Orbit Apogee
8.94 km/s Entry Velocity

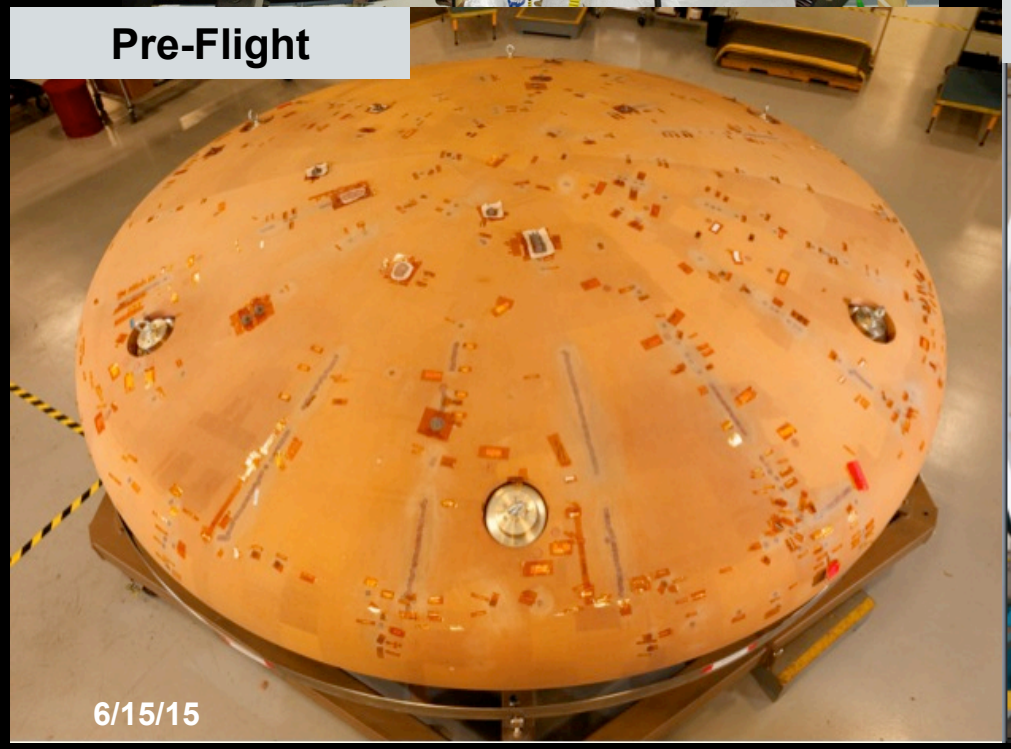
Orion's Avcoat Heat Shield

Manual Cell Filling

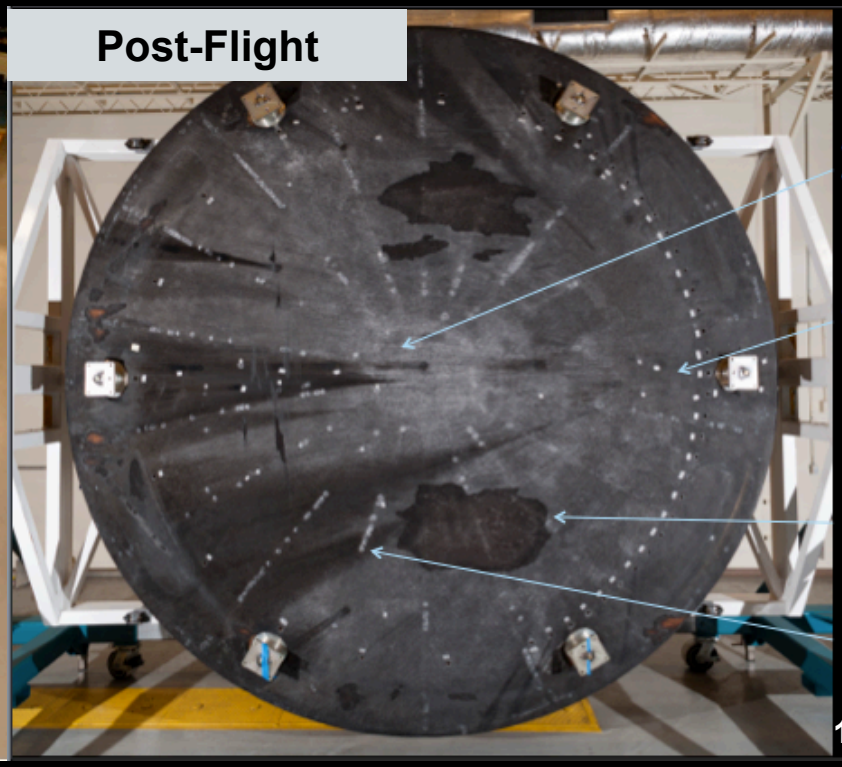
Pre-Test

Post-Arcjet Test

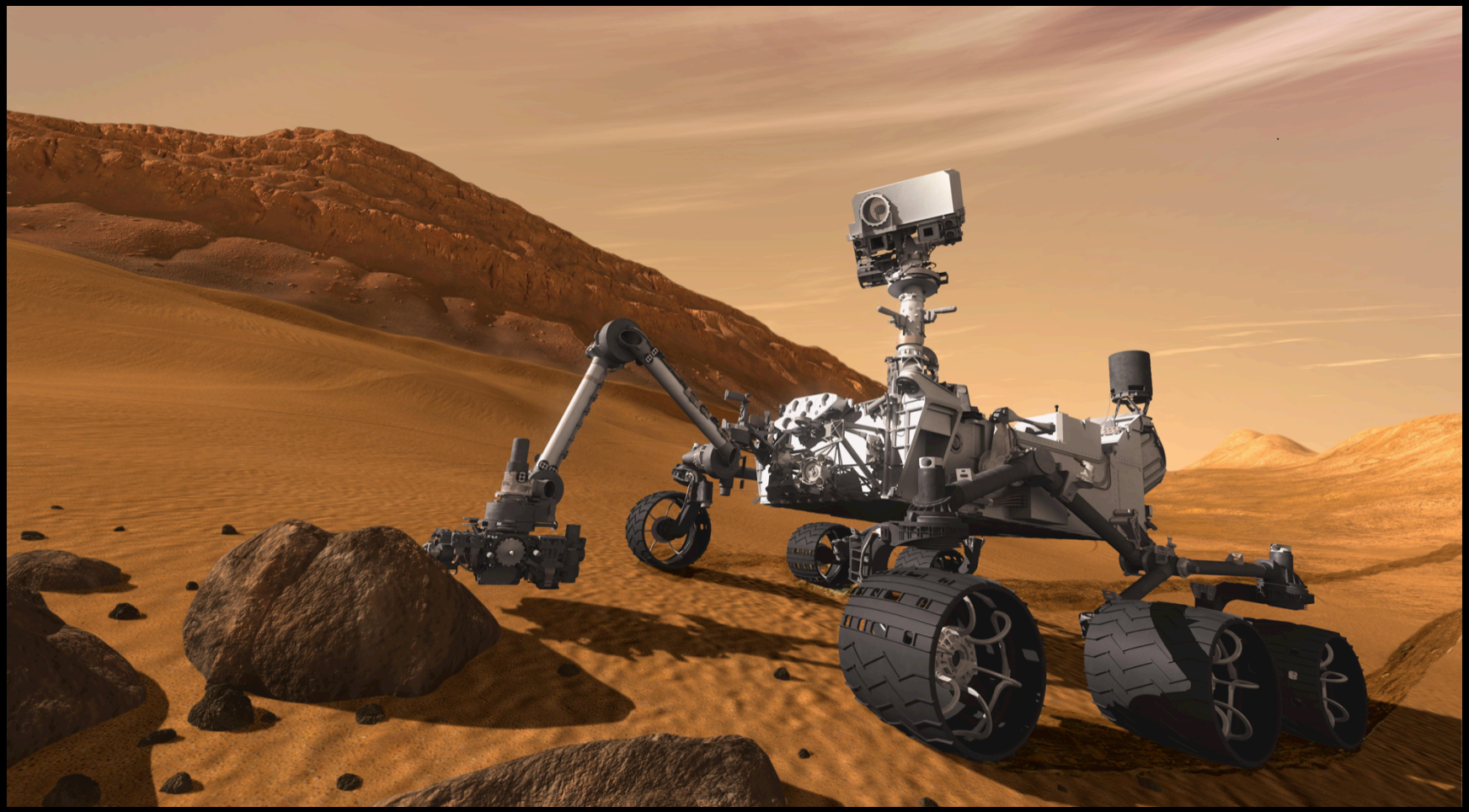
Pre-Flight



Post-Flight



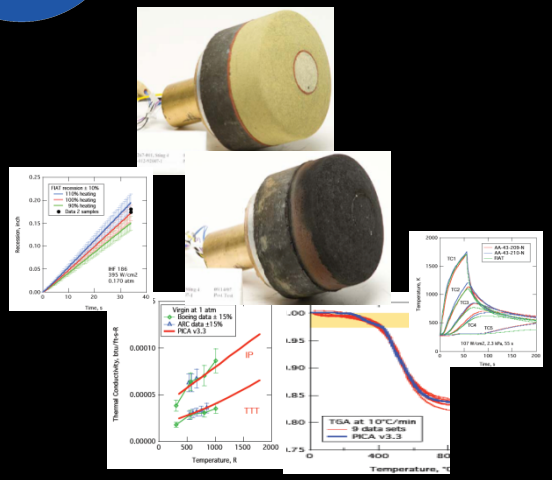
Mars Science Lab - Curiosity



PICA Heat Shield

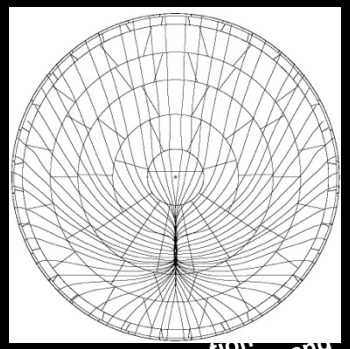
- Phenolic Impregnated
  Carbon Ablator = PICA
  FIRST USE at MARS!
- 4.5 meters (~15 feet) in diameter
  THE BIGGEST!
- Tiled design
  First ever at Mars
- Embedded sensors to measure pressure and temperature upon entry
  10 TIMES MORE ENTRY DATA THAN ALL PREVIOUS MARS MISSIONS COMBINED!

Mars Science Laboratory Entry Vehicle

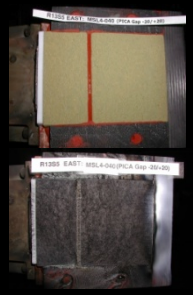


Properties and Characterization Testing and Model Development

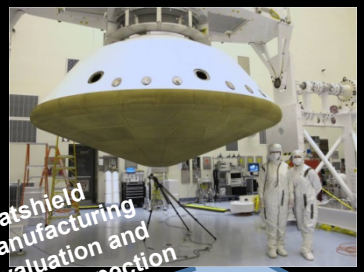
MSL Design 4.5-m dia, 113 tiles



MSL: Specification and Gap Dimensions and Placement Requirements



Gap Filler Definition, Design and Testing

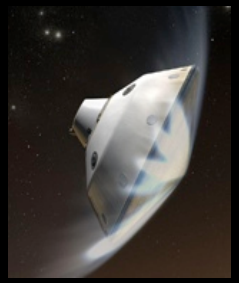


Heatshield Manufacturing Evaluation and ATLO Inspection

Technology Lifecycle

Parachute certification

Post Flight Reconstruction

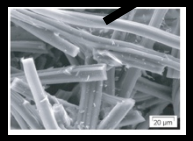


MEDLI/MISP Instrumentation Design, Development and Manufacturing

TPS Development and Qualification Testing

Materials Conceptualization and Development

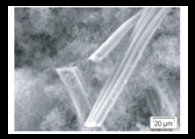
Carbon Fiberform™



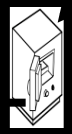
Phenolic Resin + Additives

Resin Infiltration

Gelling Cycle

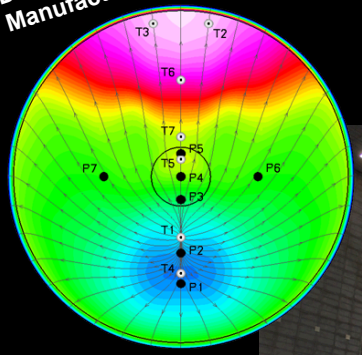


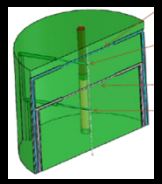
PICA

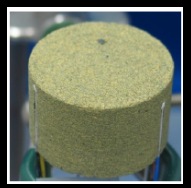


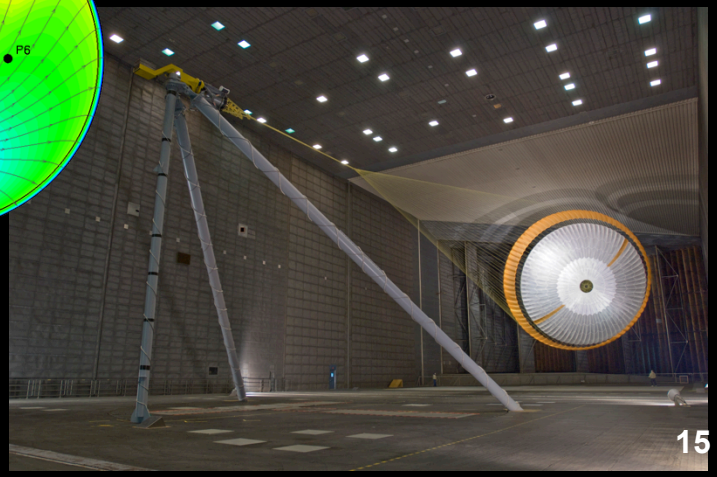
Drying Cycle

Stardust: Material Used in Single Piece







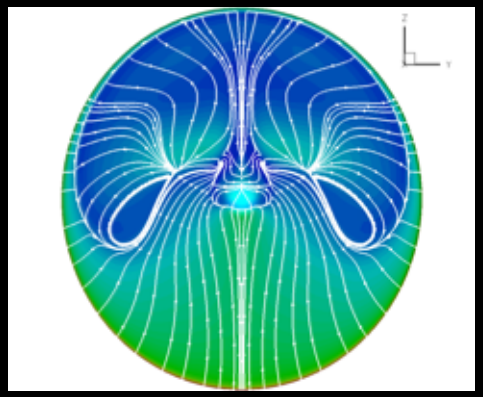


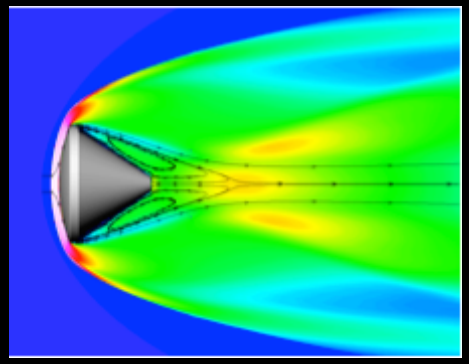
Data Parallel Line Relaxation - DPLR

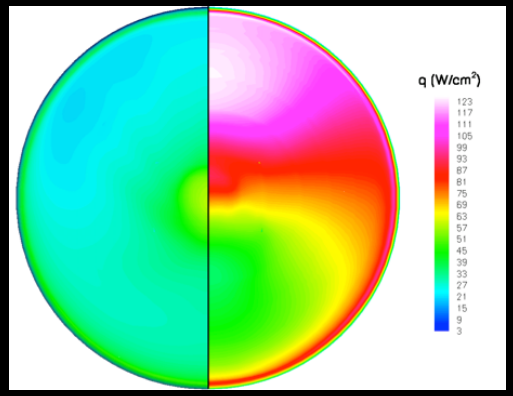
ARC-Developed Hypersonic Continuum CFD Code

- Physical models for high speed planetary entry
- Reacting Navier-Stokes equations
- Both laminar and turbulent flow models
- 2D, axisymmetric and 3D models
- Thermal equilibrium or non-equilibrium
- Generality makes incorporation of new physics models straightforward

DPLR: NASA Software of the Year 2007







Thoughts on the Future

"Prediction is very hard, especially about the future"
Yogi Berra

Future Vision and Goals: Human and Science Explorations

Pioneering Space - Goals

"Fifty years after the creation of NASA, our goal is no longer just a destination to reach. Our goal is the capacity for people to work and learn and operate and live safely beyond the Earth for extended periods of time, ultimately in ways that are more sustainable and even indefinite. And in fulfilling this task, we will not only extend humanity's reach in space -- we will strengthen America's leadership here on Earth."

- President Obama - April, 2010

Vision and Voyages

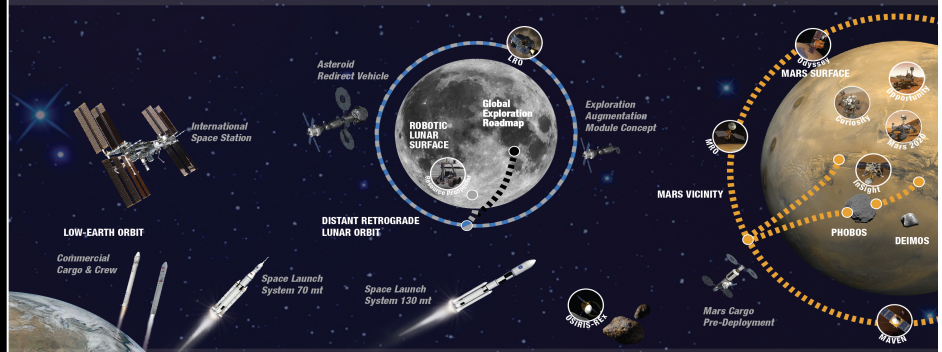
For Planetary Science in the Decade 2013-2022

Steve Squyres
Cornell University
Chairman, Planetary Science Decadal Survey

EVOLVABLE MARS CAMPAIGN

A Pioneering Approach to Exploration

EARTH RELIANT | PROVING GROUND | EARTH INDEPENDENT



THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

Cis-lunar Trades
- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades
- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

New Frontiers 4 Selection

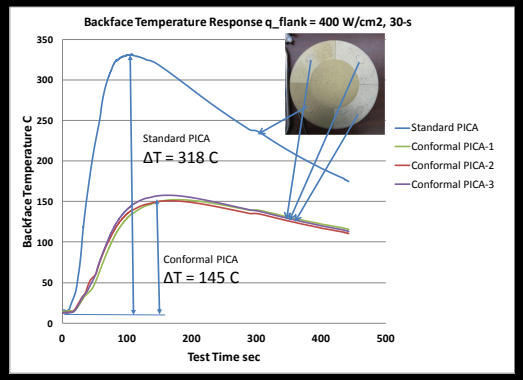
- Select NF-4 from among:
  - *Comet Surface Sample Return*
  - *Lunar South Pole-Aitken Basin Sample Return*
  - *Saturn Probe*
  - *Trojan Tour and Rendezvous*
  - *Venus In Situ Explorer*
- No relative priorities among these are assigned.
- If the selected NF-3 mission addresses the goals of one of these, remove that one from the list.

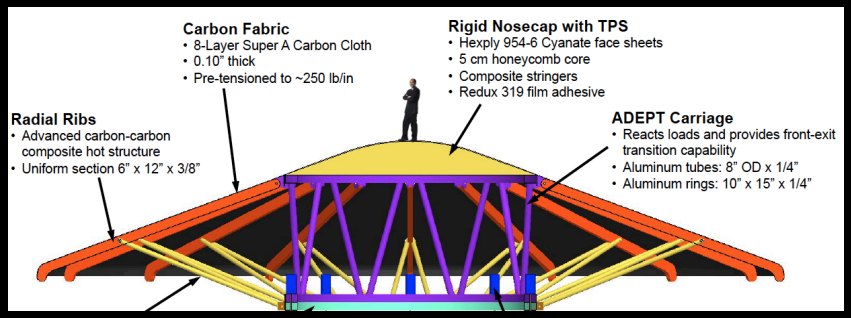
26

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Developments Underway

- Conformal TPS
- 3-D Woven TPS
  - 3-D MAT for Orion EM1
  - HEEET for Venus, Saturn and Sample Return Missions
- ADEPT for Human Mars
- Consolidation and Upgrade to Arc-jet facilities
- Ballistic range and Electric arc shock tunnel
- Asteroid entry and break-up





Concluding Remarks

- Ames has had a long standing heritge of enabling Planetary Science and Human missions since 1950's
- This tradition continues:
  - By inventing and investing in new technologies aligned with NASA vision, missions and goals
- Senior management is committed:
  - Keeping Ames' leadership in entry technologies