Testing with the Laser-Enhanced Arc Jet Facility (LEAF) at NASA Ames Research Center

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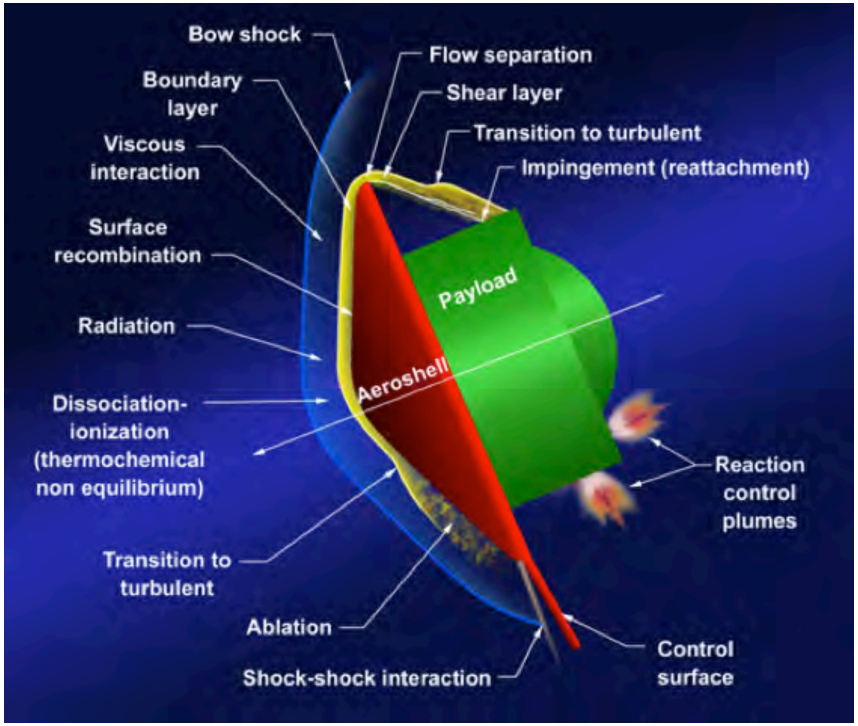
Outline – LEAF

- Background
- Requirements
- System Details
- Key Results
  - Calibration & Ablative TPS Tests
- Concluding Remarks

Background

- Entry heating includes shock-layer radiation for a number of NASA missions
  - Apollo (Lunar Return)
  - Galileo Probe into Jupiter
  - P-V
  - Stardust
  - Future in-situ robotic missions:
    - Venus
    - Sample Return Missions
      - (Mars, Comets and Asteroids)
    - Mars Entry
    - Titan Missions
- Near term driver
  - Orion – Lunar return

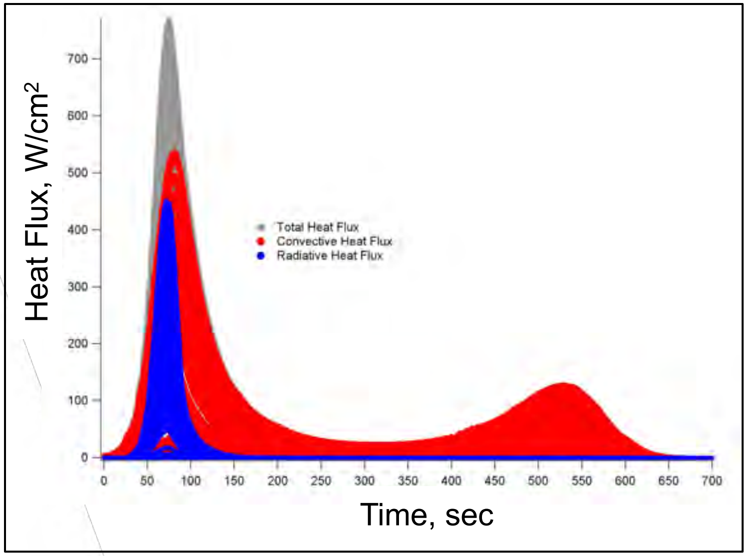


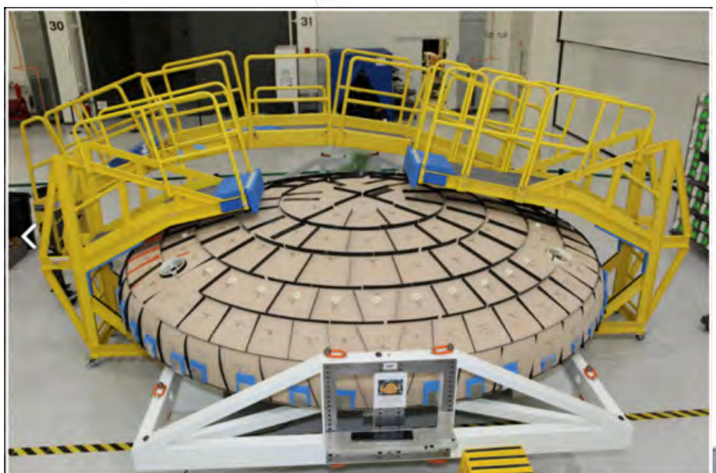
- Shock layer radiation is a significant percentage of entry heating
  - Understanding the ablative TPS material/system response
  - Designing and verifying adequate margin

LEAF Requirements:
Orion TPS Certification and Mission Assurance

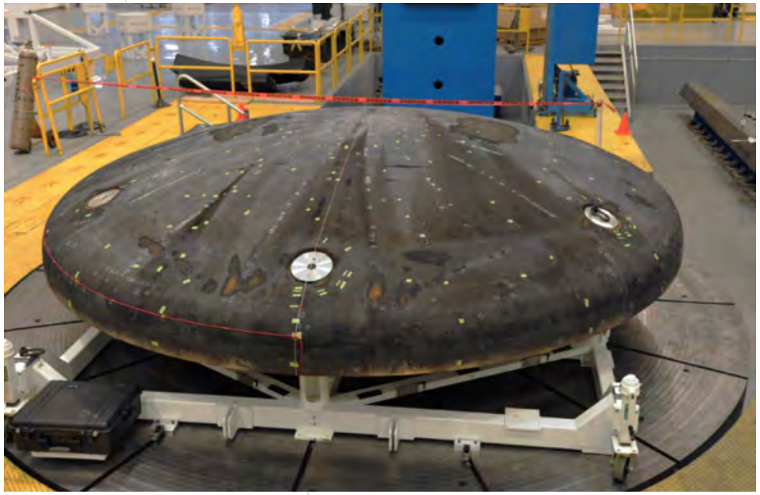
- Orion Heat shield design
  - EM1 & EM2
  - EM2 certification
- Heat Shield System Certification Challenges
  - Tiled System with gap-filler
  - Compression-pad region

Representative Entry Environment (Lunar Return)





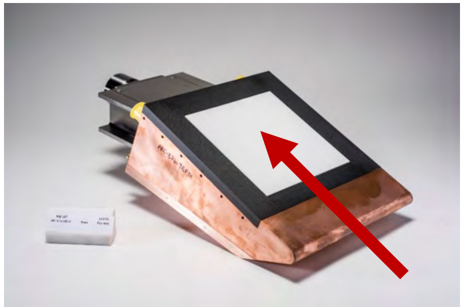
Orion Lunar Capable Heat Shield (Avcoat Tiles)



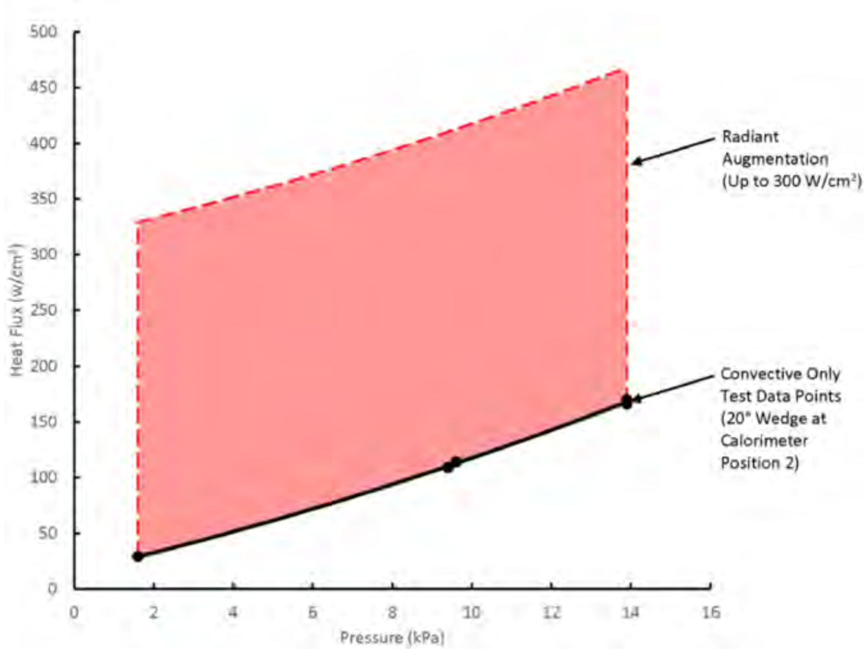
Crew and Service Module Attachment (Compression Pad with Tension Ties)

LEAF System Requirements

- LEAF is designed to add radiant heating to the IHF (Interaction Heating Facility) at NASA Ames Research Center
- Test article configurations
  - Wedge (6”x6”) in a conical nozzle

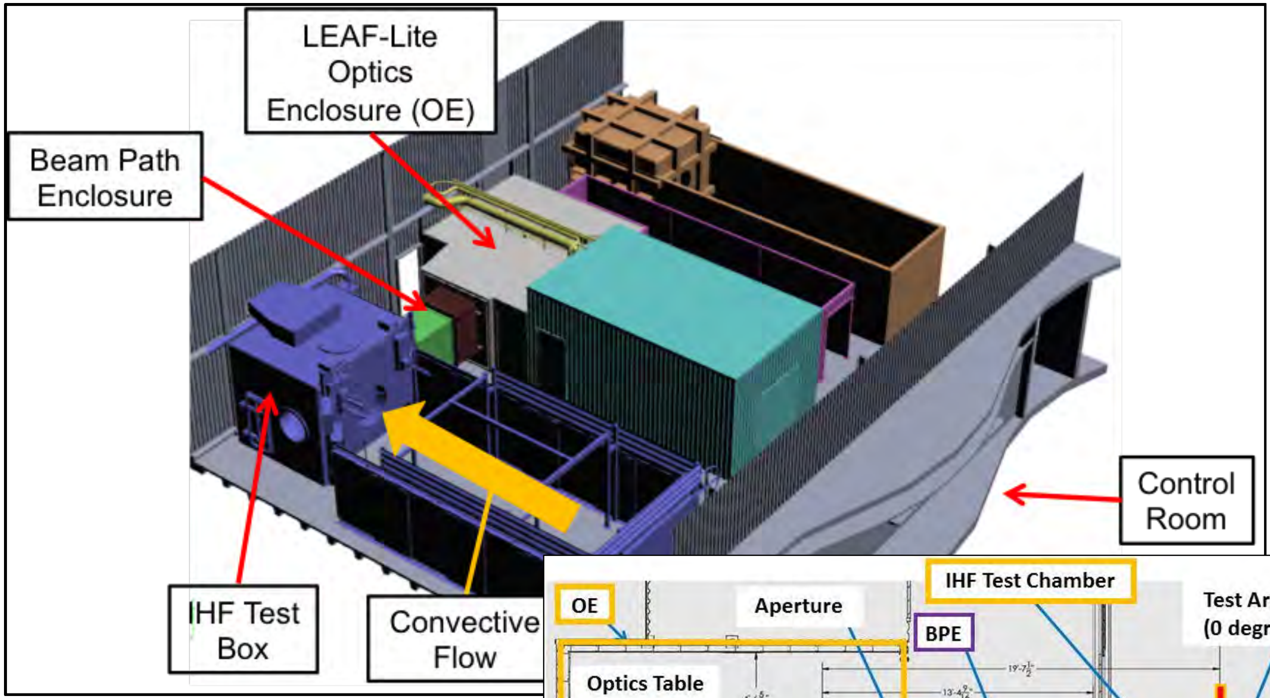


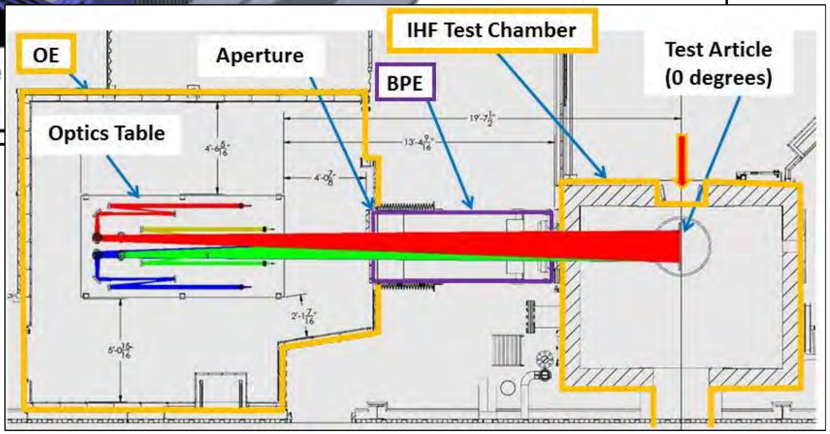
  - Panel (17’x17”)
    - In a semi-elliptic nozzle



Laser Count	(6” x 6”) Square (W/cm²)	(17” x 17”) Square (W/cm²)
50 kW	195	27
100 kW	390	54
150 kW		80
200 kW		107

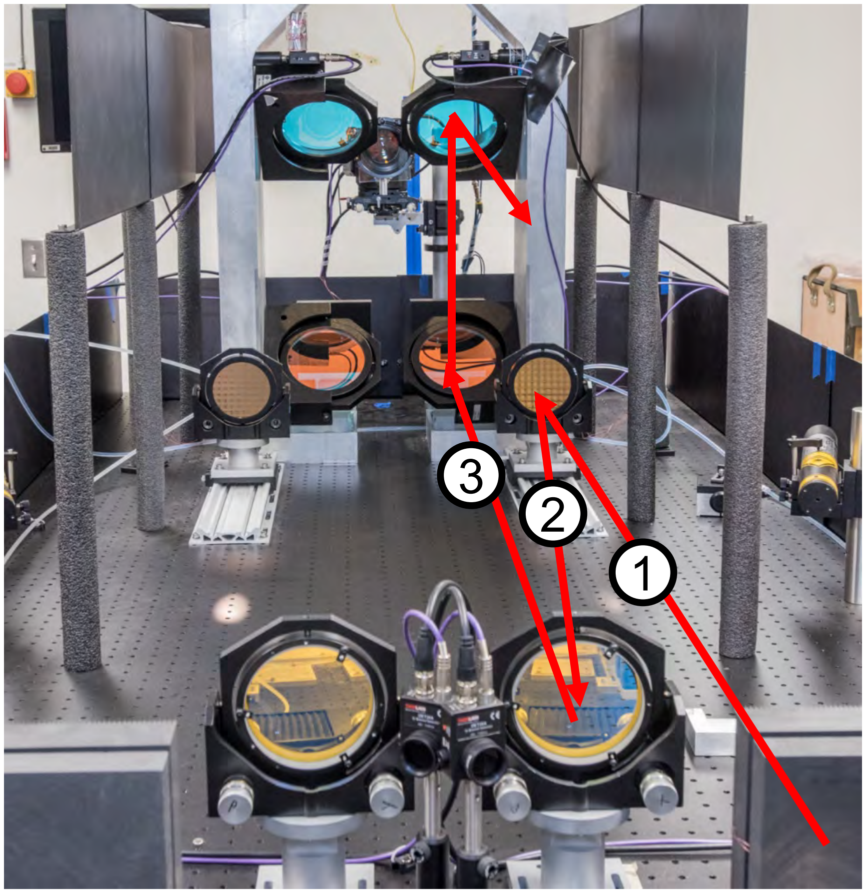
Integrated IHF and LEAF Setup



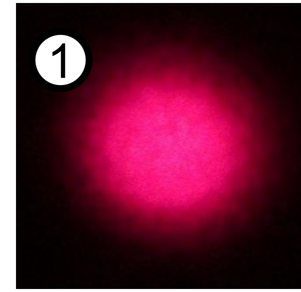


- Major facility upgrades, in addition to the laser power system, include modifications to the plenum, new nozzle (9”), large wedges and overall operational safety.

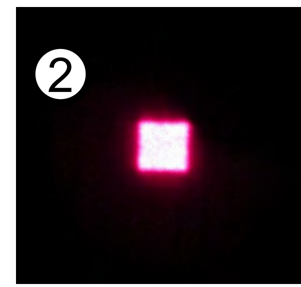
LEAF Optical Setup



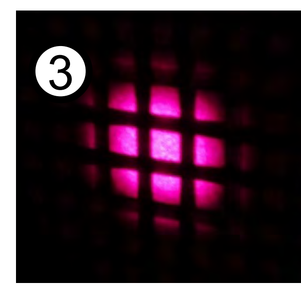
1) Gaussian beam emerges from collimator



2) Beam at the focus of the integrator (1cm x 1cm square spot)



3) Converging beamlets to be reimaged



*Images of red guide beam

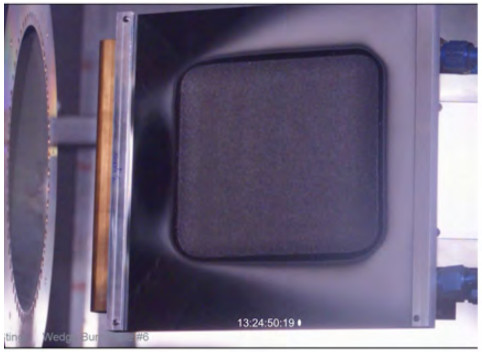
LEAF Explained by the Lead Engineer

- Movie here

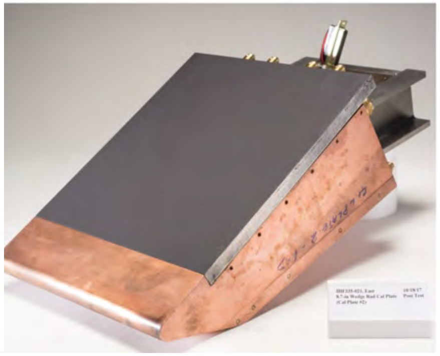
Initial System Verification and Avcoat Tests

- **Purpose:**
  - Test wedge configuration (6” x 6”)
  - Verify low variation in irradiance
  - Evaluate max heat flux
  - Nearly 40 Tests
- **Tested:**
  - Burn Plates
  - Cal Plates
    - Conv. Cal Plate 6 Gardon Gauges and 3 Pressure Ports
    - Rad. Cal plate - only Gardon Gauges
  - Heatshield materials
    - RCG Coated Tiles (non-ablative)
    - Avcoat – Ablative - Orion
- **Successful with no major problems.**

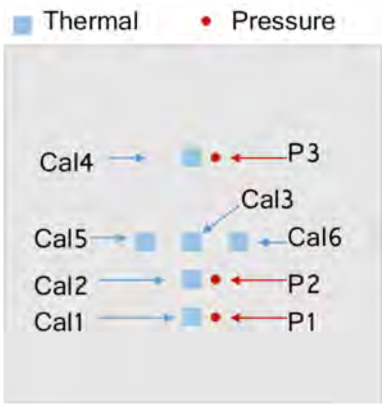
R3 Burn Plate

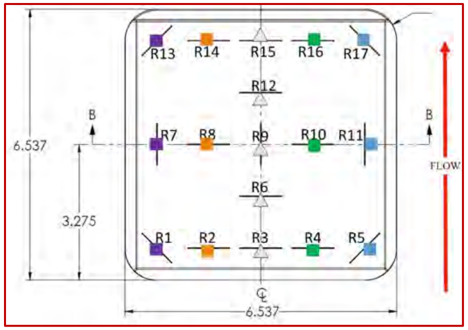


Radiative Cal Plate

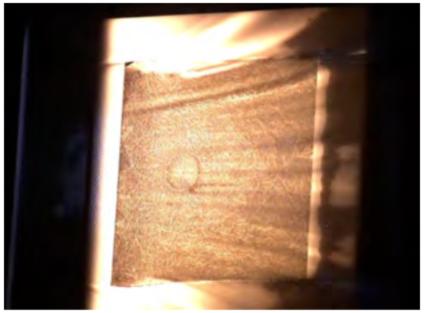


Convective Cal Plate



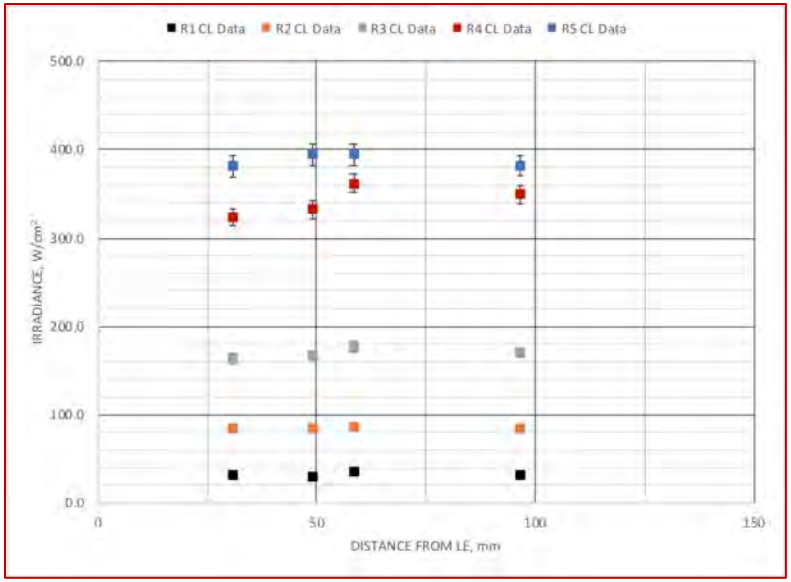


RCG L1-2200 coated plate with 17 near-surface TCs.



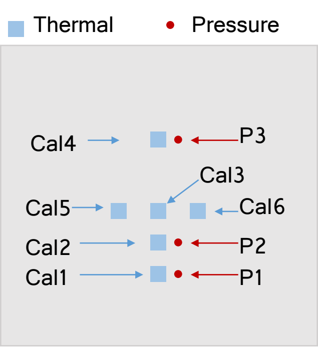
Avcoat

Radiative Heating Calibration Results



Radiative calibration along centerline

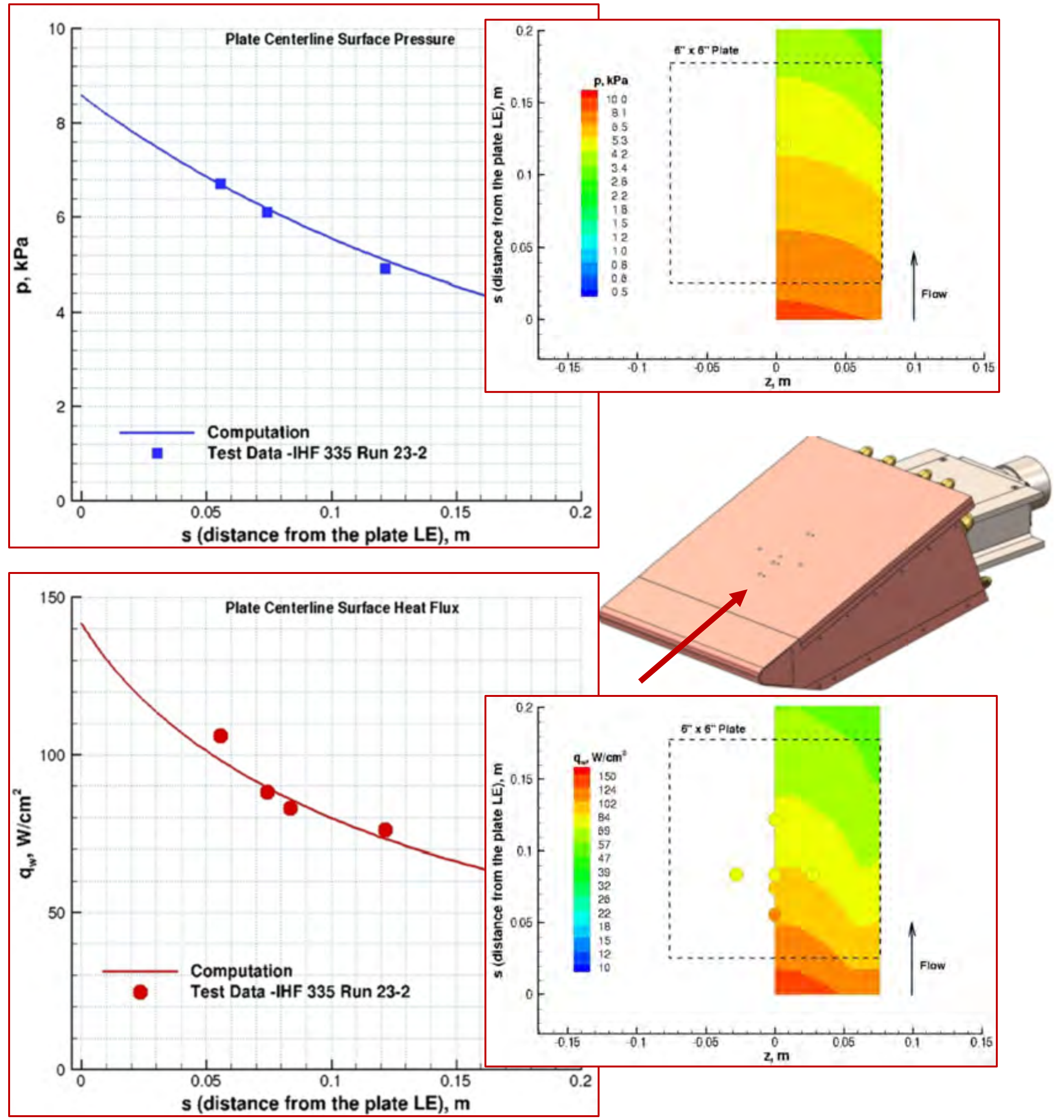
Radiative calibration across centerline



- **Beam is uniform within 6% of the average irradiance across all conditions.**
- **Measurements across multiple runs, for R3 and R4, run-to-run variability is <11%.**

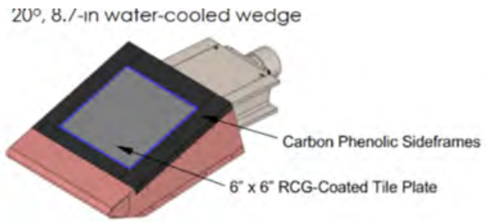
Convective Heat Flux Calibration Results & Comparisons with CFD

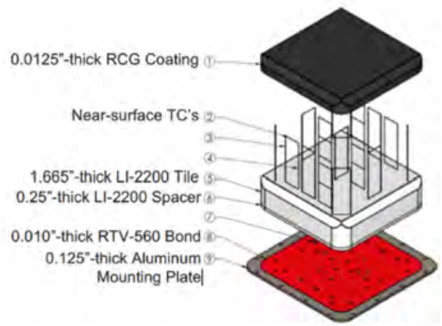
- Convective pressure and heat-flux measured were compared with CFD
- As predicted, the heat-flux and pressure decrease with increasing distance from leading edge
- The comparison shows the measurement and CFD are in agreement

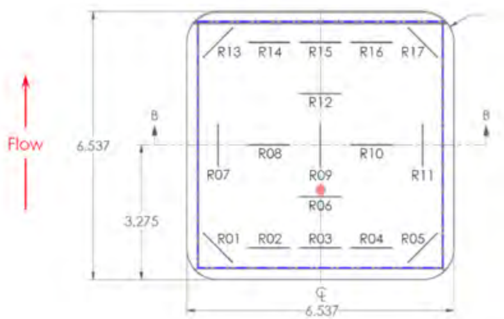


CFD Simulation in support of Orion : Dr. Gockcen

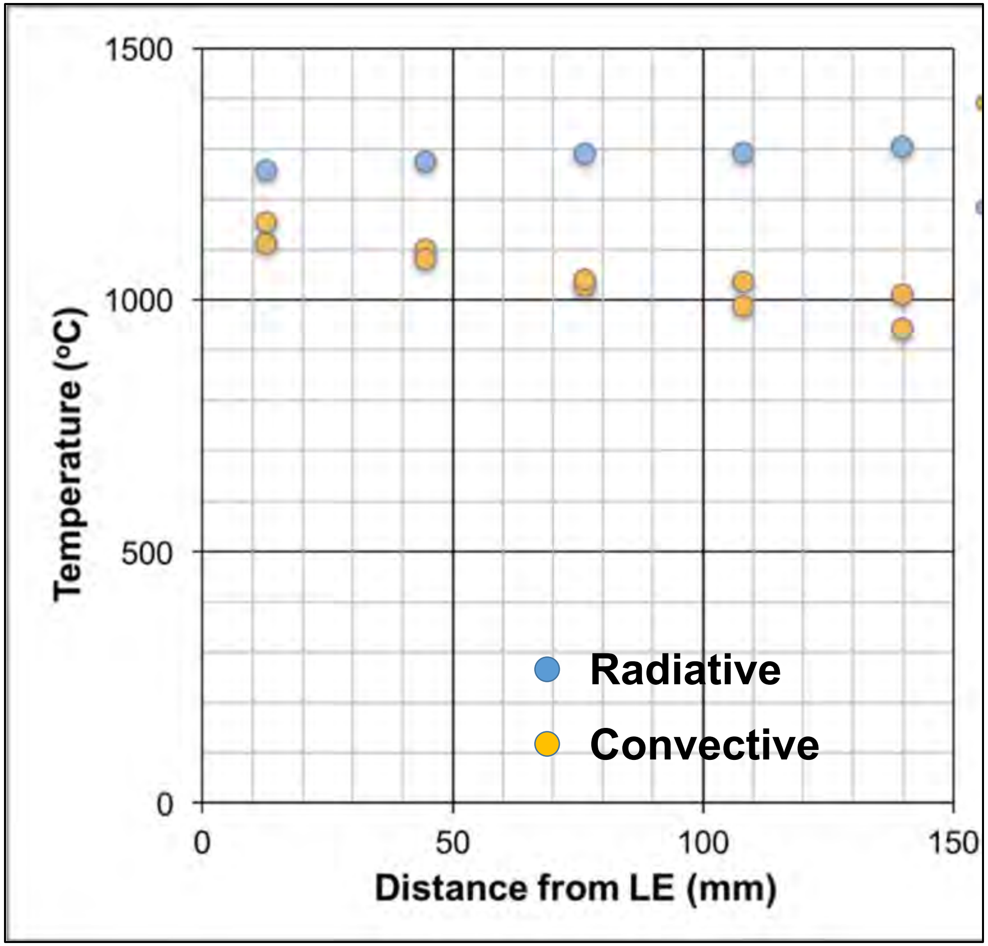
RCG Coated Tile Test Results





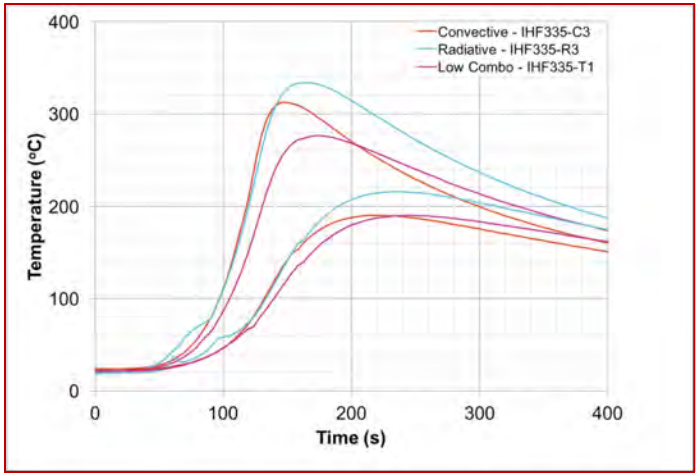


Centerline Data



- **Near Surface Thermocouple on RCG coated test article captures the trend observed with convective and radiative cal plates**
  - Run at lowest convective (and radiative conditions

Avcoat Test Results



- Avcoat test results show differences between radiative, convective and combined heating

• Entire surface covered in glass	• Glass limited to periphery	• Glass limited to periphery

Near- and Longer-Term Use

- Near-term focus is to support Orion and EM2 certification using the combined convective and radiative heating capability

Near Term Radiative Capability

Laser Count	(6” x 6”) Square (W/cm^2)	(17” x 17”) Square (W/cm^2)
50 kW	**195**	**27**
100 kW	**390**	**54**
150 kW		**80**
200 kW		**107**

- Longer-term use by both NASA and other customers envisioned.
  - The shock layer radiation for most of planetary entry missions, with the exception of Jupiter, are below 1000 W/cm2
  - Testing at higher heat-flux on a reasonably size articles could be achieved (with some facility and optical system modifications).
    - 200 kW system on a 6” x 6” article (> 700 W/cm2 radiative)
    - Testing in vacuum with radiative heating alone can provide insight into material behavior

Concluding Remarks

- LEAF, a unique capability, is now available for combined radiative and convective testing
- 100 kW system has been successfully installed and operational
  - The beam uniformity is established
- Preliminary Avcoat testing
  - Completed and results are being analyzed.
- A system upgrade is in progress
  - 200 kW power capability.

Acknowledgement & Contact Information

- Thanks to the staff of the NASA Ames Entry Systems and Technology Division that has contributed to the development of this new capability

- Thanks to the Orion Program Office for funding this expanded testing capability for future crewed, and un-crewed, missions

POC:

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