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

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Presented at the 2018 National Space and Missiles Materials Symposium
Madison, WI June 25, 2018
Outline – LEAF

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

<table>
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<tr>
<th>Laser Count</th>
<th>(6” x 6”) Square (W/cm²)</th>
<th>(17” x 17”) Square (W/cm²)</th>
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<tbody>
<tr>
<td>50 kW</td>
<td>195</td>
<td>27</td>
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<tr>
<td>100 kW</td>
<td>390</td>
<td>54</td>
</tr>
<tr>
<td>150 kW</td>
<td>80</td>
<td>107</td>
</tr>
<tr>
<td>200 kW</td>
<td></td>
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</tbody>
</table>
• Major facility upgrades, in addition to the laser power system, include modifications to the plenum, new nozzle (9”), large wedges and overall operational safety.
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
• 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.
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

![Graph showing temperature over time for different heating conditions](image)

- Convective (Ref: 160 W/cm²)
- Radiative (168 W/cm²)
- Combined (88 C + 83 R W/cm²)

- 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.

- 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.
• 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

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