Ares I-X DFI Lessons Learned
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Presented By
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Outline

• Brief introduction to Ares I-X
• Instrumentation types
• Lessons learned
  – Instrumentation locations
  – Installation
  – Data acquisition techniques
  – Other/general
• Conclusions
Ares I-X

- Demonstrated control of a long, solid-fueled, single-motor flight vehicle with a low fundamental structural frequency.
- Provided an overall assessment of crucial design and induced environments.
- Partially validated selected Ares I thermal environments math models and processes.
Aerothermal Instrumentation Summary

- 50 Calorimeters with embedded sensor thermocouples
- 6 Radiometers
- 7 Gas temperature probes (GTP)
- 47 Static pressure gauges
- 2 Flow direction probes
Why These Gauges?

- Main measurement is heating rate (\( \dot{q} \))

\[
\dot{q}_{\text{total}} = h_c (T_{\text{rec}} - T_{\text{wall}}) + \dot{q}_{\text{rad}}
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measured by</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \dot{q}<em>{\text{total}}, T</em>{\text{wall}} )</td>
<td>Calorimeter, Thermocouple</td>
</tr>
<tr>
<td>( T_{\text{rec}} )</td>
<td>Calculated or Gas temperature probe</td>
</tr>
<tr>
<td>( \dot{q}_{\text{rad}} )</td>
<td>Radiometer</td>
</tr>
<tr>
<td>( h_c )</td>
<td>Calculated</td>
</tr>
</tbody>
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- \( h_c \) determined more accurately than in the past
- Flow direction probes characterize plume induced flow separation region
- Static pressures provide local flow conditions and CFD validation data
What Makes Data Unique?

• First NASA launch vehicle to fully utilize calorimeters with embedded sensor temperature measurements

• Ascent
  – Very long vehicle length causes thick boundary layer
  – First Stage (FS) nozzle instrumented for the first time
  – Single Solid Rocket Motor (SRM) plume induced radiation, convection, and gas temperature measured for the first time

• Near-field small motor plume impingement heating data acquired
  – Roll Control System (RoCS) and Booster Deceleration Motor (BDM) plume impingement heating

• FS re-entry data expands Aerothermal database
  – Low altitude tumble is unique
  – Top plate configuration outside Aerothermal database
  – Instrumented thermal curtain in flight for the first time
Calorimeters

- Schmidt-Boelter type with type K thermocouple mounted next to thermopile
  - Medtherm model 20850

- Performance
  - Sensor temperature measurements worked well (only lost one late in re-entry)
  - Only one high flux gauge failed

- Lessons Learned
  - When in doubt, specify higher range gauge
RoCS Module B (-Roll) Burns #3-6 Calorimeter Response

043306 Over Ranged

RoCS Chamber Pressure

Heat Flux

Chamber Pressure

AAD274R (CA043306)

Module B -Roll Motor Pc
Calorimeters

- In high heat flux areas:
  - Gauges were ranged correctly
  - Most functioned and survived

![Graph showing heat flux and pressure over time](image-url)
Radiometers

• Calorimeter with a sapphire window
  – Medtherm model 20850

• Performance
  – Mortality rate higher than desirable

• Lessons Learned
  – GN$_2$ purge required to mitigate contamination (Al$_2$O$_3$ or other) and allow acquisition of mid-to-late flight data
Radiometers

- All radiometers appear to fail eventually
Gas Temperature Probes

• **Base Gas Temperature Transducer**
  – Medtherm model 11190

• **Performance**
  – All gauges functioned

• **Lessons Learned**
  – Must account for radiation losses
Pressure Gauges

• Thin Line IS Pressure Transducer
  – Kulite LL-080 Series

• Performance
  – Gauge type and installation were not tolerant to significant heating

• Lessons Learned
  – 0-20 psi gauges provided the necessary level of fidelity
Pressure Gauges

- The gauge was completely burned out by the BDM firing.
Flow Direction Probes

- Flow direction probes
  - Medtherm model 50532

- Performance
  - Newly designed, functioned well

- Lessons Learned
  - May interfere with other gauges: shock heating to nearby calorimeter
Flow Direction Probes

X57194 - Aft Segment Attach Ring Stub

AAD119P (DP057194)  AAD122P (DP057032)

Pressure

Time from 15:30:000.217 (sec)
Lessons Learned - Instrument Locations

• Ensure there are a few true clean skin calorimeters
  – Measured heating amplifications due to proximity of cork runs near gauges
  – Below, separation occurs over the protuberance due to cork run / antenna
Lessons Learned - Instrument Locations

• Avoid instrument interference/installation effects (e.g. instrument island in the proximity of the flow direction probe)
Lessons Learned - Instrument Locations

- Add internal aft skirt camera for thermal curtain breakup nature and timing
Lessons Learned - Instrument Locations

• Coordinate with other disciplines to avoid redundancy of measurements
• Co-locate external nozzle calorimeters and GTP’s
Lessons Learned - Installation

• Clearly specify installation procedures
  – Foam trimming, etc.
  – Need to have person on-site for some critical installation steps such as last minute foam application

  – One of the groups of gauges similar to this set was completely foamed over during close out operations.
    • No data was acquired from those gauges.
Lessons Learned - Data Acquisition

• Pre-flight channelization and calibration constants a must
• 2Hz filter was not good - must specify a higher range next time
• Gauge acquisition ranges
  – Want cooling measured
  – Utilize dual range on high flux if possible
• GTP junction temperatures must be measured
Lessons Learned- Other/General

• Measure one or two chamber pressures from all small motors if possible
  – BDM’s, USM’s, BTM’s, ReCS, RoCS
• Have plan in place to specify T=0.0 ASAP after flight
Conclusions

• The flight test was successful
• Useful data were obtained
• The gauges used were appropriately selected and performed well
• Most problems are understood
  – Failures were few and far between.
  – Relatively simple procedural fixes have already been documented and put into action.