Thermal Analysis of M2020 DRCS thrusters for various EDL trajectories

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Presented By
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DRCS thermal analysis was performed to assess updated aerothermal environments, additional radiative heating, and DRCS firing sequence for M2020 vs. MSL.

- LaRC provides aeroheating flux values to JPL Thermal
  - For the updated M2020 analysis, an additional radiative heating component was added
  - DRCS firing sequences were provided by JPL EDL

The MSL TMG DRCS legacy model was used to perform this analysis.

- Legacy model was in NX-IDEAS
- Temperatures results are comparable to those reported in the MSL RCS Hardware DDR Thermal Design and Analysis, 3/4/08, JPL D-68636
DRCS Locations
Thermal Model

- Thruster
- Bipods
- Bracket
- Annular Shield
- Nozzle
- Finger/blade Seal
- Upper Clamp Ring
- RCS Fairing
Thruster Locations/Other Thermal Concerns

Thruster 5 duty cycle is applied to thrusters 7 & 8 on outrigger 8 for this analysis.
LaRC provides aeroheating flux values to JPL Thermal

- Spatial flux maps at peak aeroheating (at peak dynamic pressure too)
  - Two sets of fluxes: values for “Thruster On” and “Thruster Off” conditions
  - Some peak values tabulated for key areas
- Fluxes with margins = 3x fluxes with zero margins
  - LaRC: 200% uncertainties cover laminar flow field predicts for turbulent flow reality
- Dynamic pressure transient variation over EDL
  - Serves as scaling factor for aeroheating loads on trajectory-dependent B/S or DRCS fairing locations
• **Baseline Aeroheating**
  – Based on 08-TPS-02 MAX (D-34661, MSL aerothermal environments)
  – Baseline heating is present at all times; roughly scales with free-stream dynamic pressure
  – Computed on a representative topology

• **Radiative Heating**
  – DRCS fairing radiative heating is applied across the entire fairing geometry
  – Since only a few backshell radiative heating data points are available, a uniform 2.4 factor increase is added to the leeside aeroheating spatial map
    • Factor was derived from Langley data; ratio of 08-TPS-01 aerothermal loads analyzed for TPS to 15-TPS-01 (M2020 EDL analysis) peak radiative heating

• **Heating Augmentation due to DRCS**
  – DRCS augmentation present during thruster firings
    • Impingement heating
    • Interference heating, roughly scales with free-stream dynamic pressure
  – Based on 16-TPS-01 (M2020 EDL analysis as most taxing thruster firing) duty cycle

• **Stacked WCH is a conglomeration of heating components from different trajectories to estimate worst possible heating**
The windside RCS fairing is used for the thermal analysis since it is the area where the largest plume fluxes are present. Fluxes shown have 200% uncertainty added.
• Margined convective heat flux is shown
  – The Mars 2020 thermal analysis also uses this heat flux map

**Peak Dynamic Pressure**

08-TPS-02 Nominal Trajectory at Peak $q_{\infty}$ (LAURA Laminar, $+3^\circ$)

$q_{\infty} = 16,100$ Pa

Yaw RCS Thrusters On

<table>
<thead>
<tr>
<th>$q_w$ (W/cm$^2$)</th>
<th>13.0</th>
<th>9.4</th>
<th>6.8</th>
<th>4.9</th>
<th>3.5</th>
<th>2.5</th>
<th>1.8</th>
<th>1.3</th>
<th>1.0</th>
<th>0.7</th>
<th>0.5</th>
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<tr>
<td>$q_w + 200%$</td>
<td></td>
<td></td>
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</table>
• The leeside radiative heating profile used in the thermal analysis, peaks at 4.5 W/cm²
• The radiative heating was calculated on the 15-TPS-01 design trajectory at a body point on the geometry that is close to the windside and leeside DRCS fairing locations
• The radiative heating was fit to freestream density and velocity
  - \[ q_{rad} = A(\rho_\infty^B)(V_\infty^C) \]
  - \( q_{rad} \) = radiative heat flux (W/cm²)
  - \( \rho_\infty \) = atmospheric density (kg/m³)
  - \( V_\infty \) = atmosphere-relative velocity (m/s)
• The radiative heating fit should be across the entire fairing geometry and added to the MSL model for convective heat flux
The windside (+Z) shows no significant radiative heating.

The leeside (-Z) radiative heating is applied uniformly to the thermal model with a scale average factor of the data points available:

- We took peak absolute heating from radiation analysis from previous slide (~4.5 W/cm²) and compared that to the aeroheating from Langley (08-TPS-01) and that ratio is roughly 2.4, which is how this factor was derived in order to incorporate to model. This ratio is consistent with the graphed ratio below.
- Ratio was easier to incorporate into thermal model than superimposing additional radiative load.

The points shown below constitute all body points that have been analyzed for TPS thermal sizing, MEDLI2 instrumentation, and venting analysis.

For the thermal analysis the radiative heating is applied as a uniform 2.4 factor increase to the leeside aeroheating spatial map.
• The thermal model simulates a single descent thruster cluster with two thrusters
• The DRCS thermal analysis assumes that both DRCS thrusters fire simultaneously with the largest thruster duty cycle (thruster #5).
  – Thruster 5 has highest duty cycle seen during bank reversals when interaction w/ heating deemed the worst
  – 16-TPS-01 MAX
## Predicted Thermal Margins

Radiation only on leeside, 16-TPS-01 MAX trajectory

<table>
<thead>
<tr>
<th>DRCS Hardware</th>
<th>MSL TIME OF PEAK</th>
<th>MSL MAX AFT</th>
<th>MSL MARGIN</th>
<th>M2020 TIME OF PEAK</th>
<th>M2020 MAX AFT</th>
<th>M2020 MARGIN</th>
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<tr>
<td></td>
<td>$T_{ESI, Peak}$</td>
<td>$T_{ESL}$</td>
<td>MARGIN</td>
<td>$T_{ESI, Peak}$</td>
<td>$T_{ESL}$</td>
<td>MARGIN</td>
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<td></td>
<td>[°C]</td>
<td>[°C]</td>
<td>[°C]</td>
<td>[°C]</td>
<td>[°C]</td>
<td>[°C]</td>
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<td>Thruster Seal</td>
<td>E+4.13</td>
<td>88</td>
<td>129</td>
<td>41</td>
<td>4.81</td>
<td>93.23</td>
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<td>Thruster O-ring</td>
<td>E+4.14</td>
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<td>205</td>
<td>27</td>
<td>4.81</td>
<td>189.23</td>
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<td>Valve Housing, PRT</td>
<td>E+4.81</td>
<td>117</td>
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<td>12</td>
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<td>RCS MTG Flange</td>
<td>E+4.81</td>
<td>634</td>
<td>1260</td>
<td>626</td>
<td>4.63</td>
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<td>E+4.81</td>
<td>653</td>
<td>1260</td>
<td>607</td>
<td>3.47</td>
<td>962.28</td>
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<tr>
<td>RCS Plenum</td>
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<td>354</td>
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<td>N/A</td>
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<tr>
<td>DIMU</td>
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<td>12</td>
<td>4.81</td>
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<tr>
<td>RCS BLADE SEAL</td>
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<td>1093</td>
<td>139</td>
<td>1.84</td>
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<tr>
<td>RCS FAIRING</td>
<td>E+4.79</td>
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<td>-41</td>
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<td>491.84</td>
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<tr>
<td>TI ANNULAR SHIELD</td>
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<td>B/S AT EA9394 SITE</td>
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<td>177</td>
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<td>BIPOD ASSY, FAIRING END</td>
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<td>BIPOD ASSY, RCS BRKT END</td>
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<td>29</td>
<td>450</td>
<td>421</td>
<td>4.81</td>
<td>38.40</td>
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</table>
Mars 2020 peak nozzle temp. prediction shows 962°C vs. 653°C in MSL prediction
  – Not clear what location was used for MSL prediction
  – However, all nozzle temperatures relatively similar between M2020 and MSL model
  – Value reported for MSL likely from colder part of nozzle
• Results of M2020 model consistent with MSL values for DRCS fairing
  – Peak temperatures (492°C) with fully stacked conservatism result in an AFT temperature violation of approximately 42°C (AFT = 450°C)
  – AFT violations occur multiple times during entry; unclear what rationale for accepting violation was on MSL
  – Current plan is to consult with mechanical/stress/materials to assess whether this is a concern

Total time over 450°C ~0.57 min.
• Results of M2020 model are higher than MSL values for the upper clamp shell ring
  – Peak temperatures with fully stacked conservatism result in an AFT temperature violation of approximately 35°C (AFT = 450°C)

Peak predicted temp. = 485°C
Total time over 450°C ~1.1 min.

Local AFT violation of 35°C
In MSL DDR slides, thermal model references configuration with “third” finger/blade seal

- This third seal not present in current version of TMM; current version of TMM reflects flight configuration for MSL and M2020
- Third seal not in flight configuration for MSL or M2020
- This is likely why temperatures are different now (485°C) from what was shown in original DDR slides (273°C)
Conservatism results from several levels of assumptions

- We can reduce conservatism in these areas to try to eliminate AFT violations on RCS fairing and upper LARC 3x aerothermal loads.

- Both thrusters firing for entire duty cycle
  - LARC 3x aerothermal loads
  - Stacked WCH trajectories

Reduced conservatism, if necessary

Nominal Duty cycle
- (relatively easy to plug in different trajectory’s duty cycles into thermal model)

Single thruster firing
- (Would require LARC to re-do aerothermal flux with only a single thruster firing)
  - LARC < 3x aerothermal loads (not the primary driver of AFT violations)
  - Make thermal loads consistent with trajectory (aerothermal loads scale by dynamic pressure)
Two additional firing cases were investigated to reduce conservatism against 16-TPS-01 MAX

- 16-TPS-01 5/6 AVG
  - Average duty cycle across thrusters 5 and 6 for the 16-TPS-01 trajectory
  - Slightly less stressing than MAX
- 16-JEZ-02b MID
  - Less stressing trajectory than MAX
## Predicted Thermal Margins

- Radiation only on Leeside, 16-TPS-01 5/6 Avg and 16-JEZ-02b MID

### DRCS Hardware

<table>
<thead>
<tr>
<th>DRCS Hardware</th>
<th>M2020 16-TPS-01 max</th>
<th>M2020 16-TPS-01 5/6 avg</th>
<th>M2020 16-JEZ-02b-mid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TIME OF PEPEDL, Peak</td>
<td>MAX AFT</td>
<td>MARGIN</td>
</tr>
<tr>
<td></td>
<td>E(X) [min] [°C]</td>
<td>[°C]</td>
<td>[°C]</td>
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<td>Thruster O-ring</td>
<td>4.81</td>
<td>189</td>
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<td>3.59</td>
<td>906</td>
<td>1260</td>
</tr>
<tr>
<td>I/F Standoff, RCS END</td>
<td>4.63</td>
<td>625</td>
<td>N/A</td>
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<tr>
<td>I/F STANDOFF, BRKT END</td>
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<td>RCS MOUNTING BRACKET</td>
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<td>OUTRIGGER AT BRK I/F</td>
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<td>DIMU</td>
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<tr>
<td>RCS BLADE SEAL</td>
<td>1.84</td>
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<tr>
<td>RCS FAIRING</td>
<td>2.48</td>
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<tr>
<td>CLAMP SHELL RING, UPPER</td>
<td>2.48</td>
<td>485</td>
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<td>3.55</td>
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<td>TI ANNULAR SHIELD</td>
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<td>450</td>
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<td>BIPOD ASSY, FAIRING END</td>
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<tr>
<td>BIPOD ASSY, RCS BRKT END</td>
<td>4.81</td>
<td>38</td>
<td>450</td>
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</tbody>
</table>

16-TPS-01 max temperatures used in stress analysis by Kevin Le (6.13.18)
The 5/6 AVG case still results in an AFT violation on both the RCS fairing and Upper Clamp Shell ring:

- Negative margin is decreased to 3°C and 23°C for the Fairing and Clamp Shell ring, respectively.

![Graph showing temperature response for different components and margins.](image-url)

Max AFT limit = 450°C
Conclusion

- Two predicted temperature limit violations
  - RCS fairing
    - Was present during MSL analysis
    - Possibly accepted on MSL by arguing duration of excursion beyond AFT limit was short
  - Upper clamp ring
    - Violation not present during MSL analysis
    - MSL analysis included third finger/blade seal, which was not part of flight configuration and is not part of M2020
    - Current TMM reflects flight configuration

- AFT violations are sensitive to changes in trajectory
  - 16-TPS-01 5/6 AVG and 16-JEZ-02b MID both decrease negative margin, but only MID results in positive margin for both components
  - Stress team completed analysis using temp. predicts for 16-TPS-01 Max; stress margin is positive

- Radiation does not seem to play a major role in DRCS temperatures
  - Additional radiation term had little impact on increasing temperatures relative to plume heating