TFAWS Interdisciplinary Paper Session

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LaRC 2019

Thermal Analysis of M2020 DRCS thrusters for various EDL trajectories

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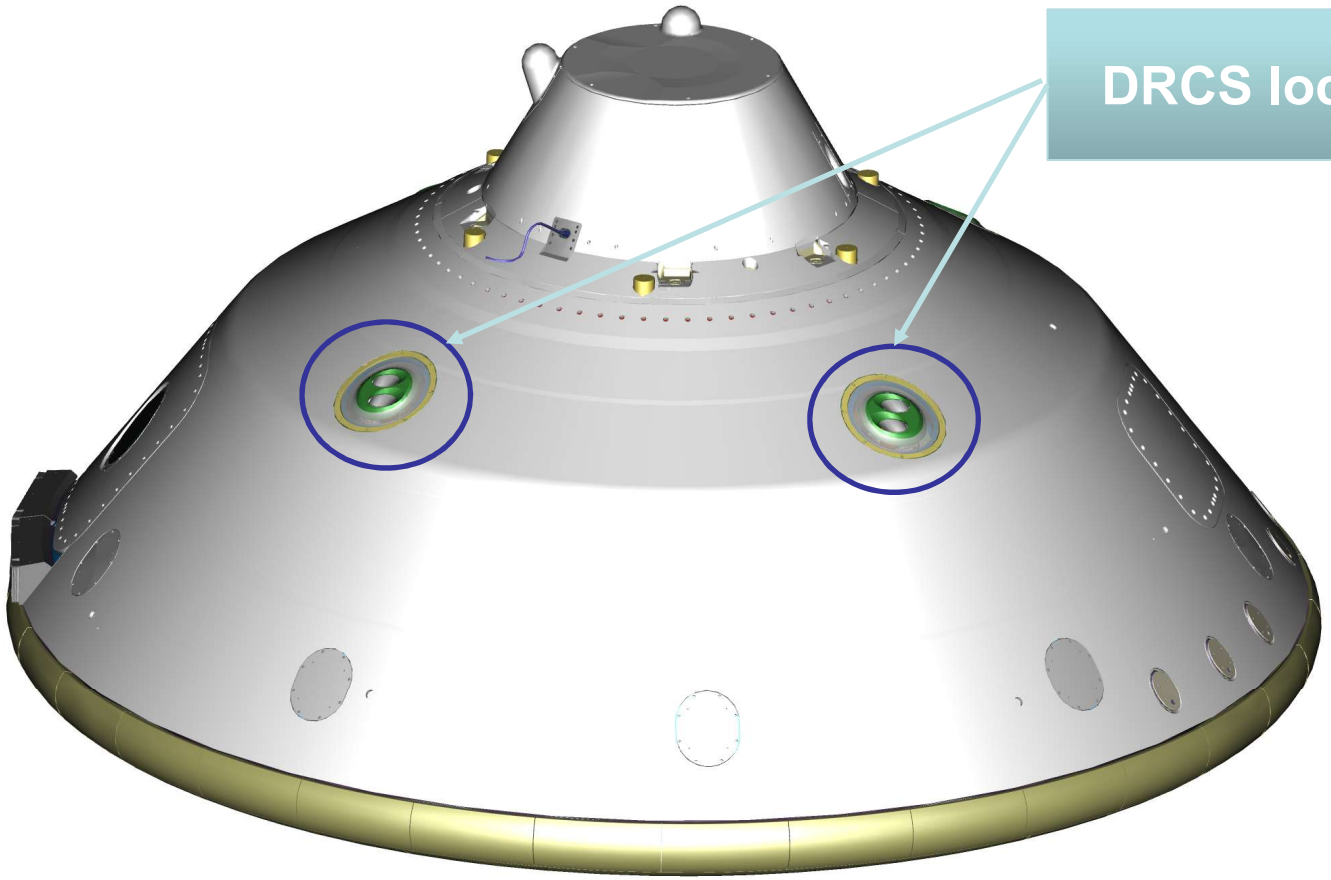
Summary

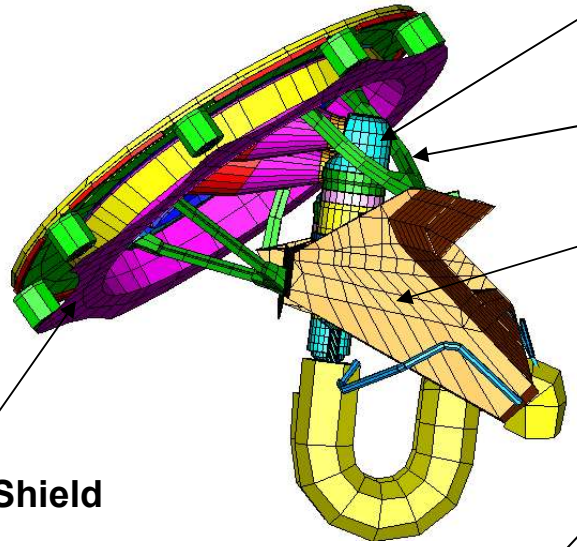
- DRCS thermal analysis was performed to assess updated aerothermal environments, additional radiative heating, and DRCS firing sequence for M2020 vs. MSL
  - LaRC provides aeroheating flux values to JPL Thermal
    - For the updated M2020 analysis, an additional radiative heating component was added
  - DRCS firing sequences were provided by JPL EDL

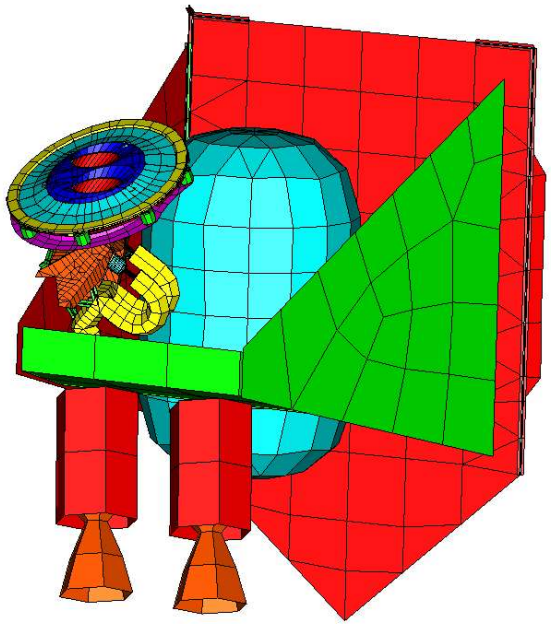
- The MSL TMG DRCS legacy model was used to perform this analysis
  - Legacy model was in NX-IDEAS
  - Temperatures results are comparable to those reported in the MSL RCS Hardware DDR Thermal Design and Analysis, 3/4/08, JPL D-68636

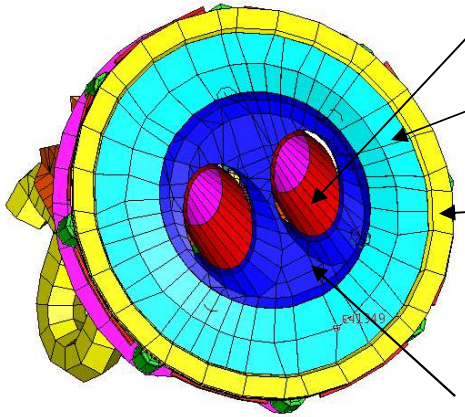
DRCS Locations

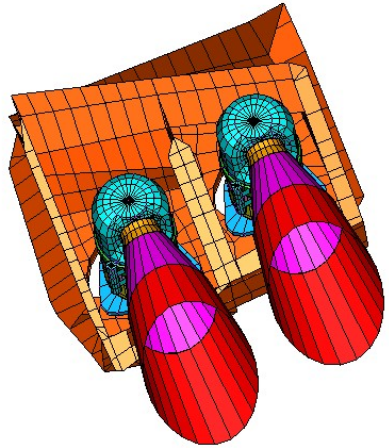


Thermal Model

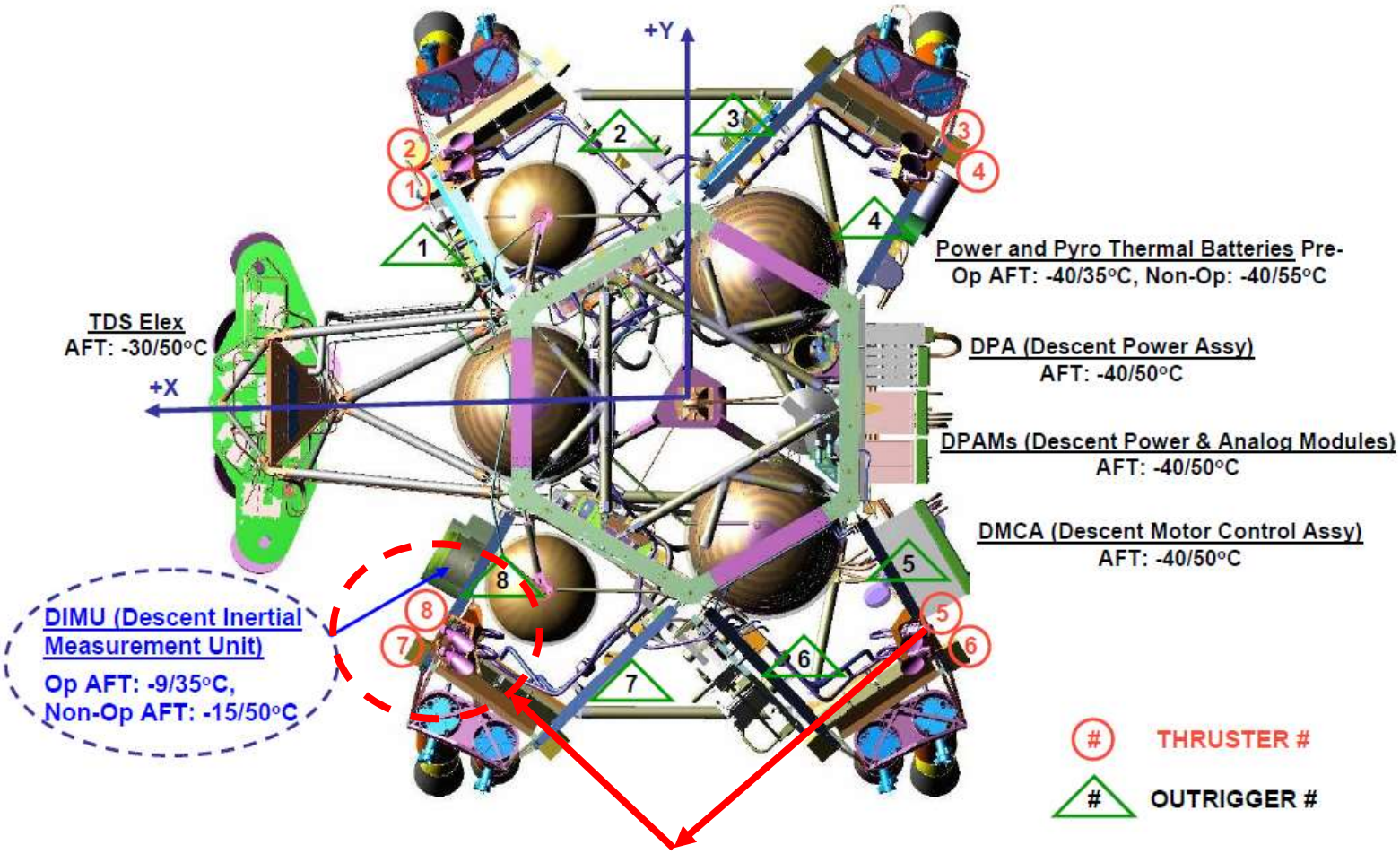








Thruster Locations/Other Thermal Concerns



Thruster 5 duty cycle is applied to thrusters 7 & 8 on outrigger 8 for this analysis

Source of EDL Aeroheating Flux Requirements

- 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

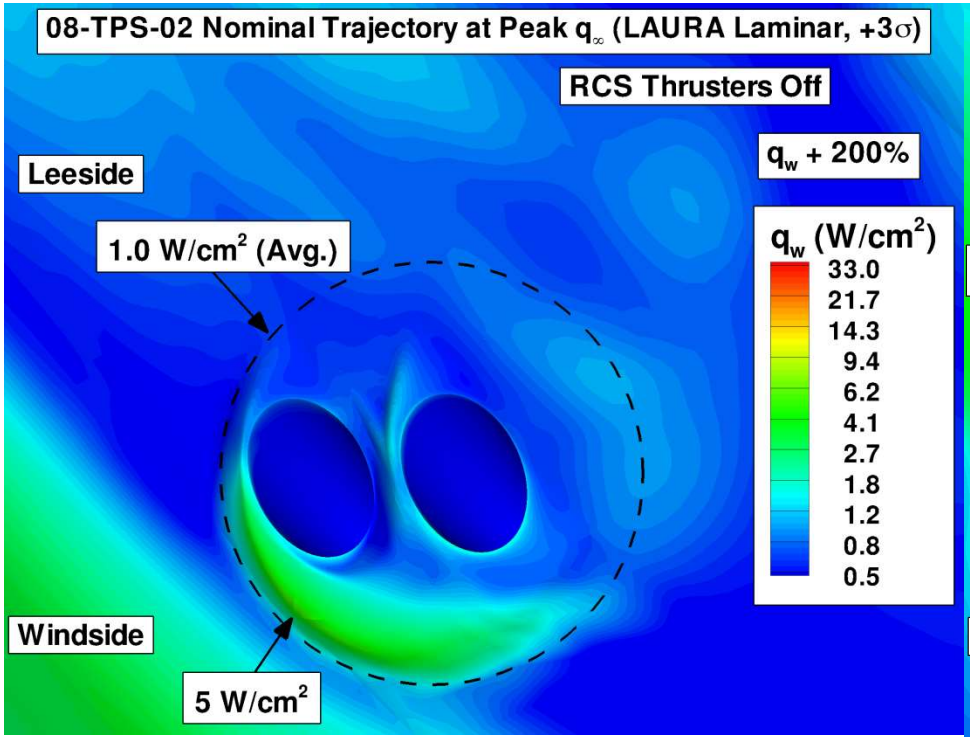
Environmental Fluxes

- 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

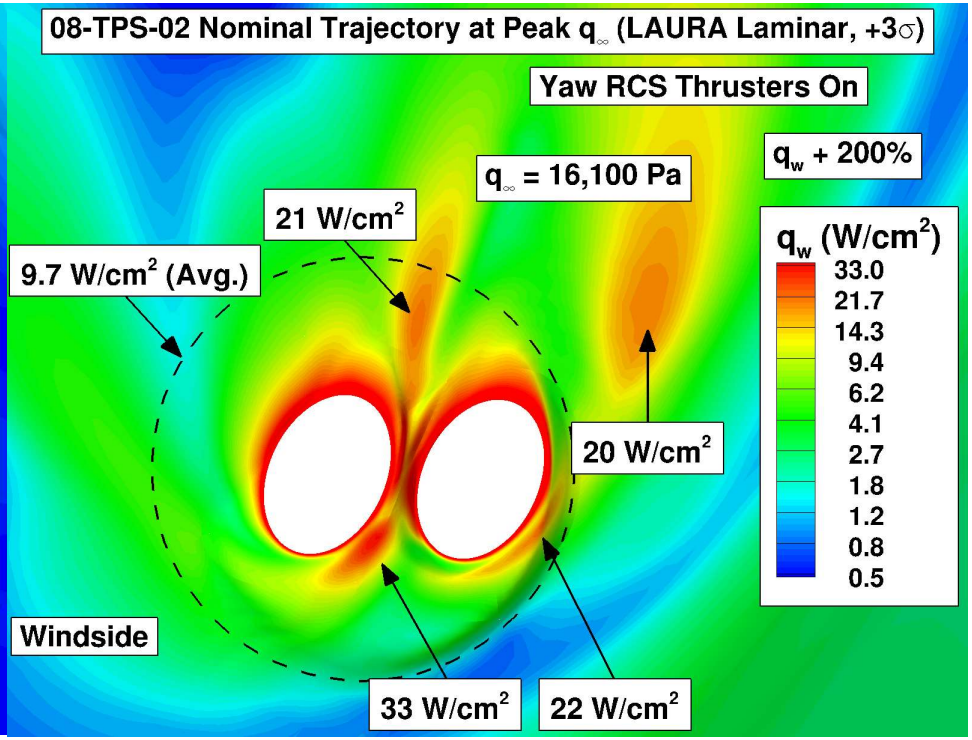
Mars 2020 DRCS Convective Heating (Windside Fairing)

- The windside RCS fairing is used for the thermal analysis since is the area where the largest plume fluxes are present
- Fluxes shown have 200% uncertainty added

RCS Off

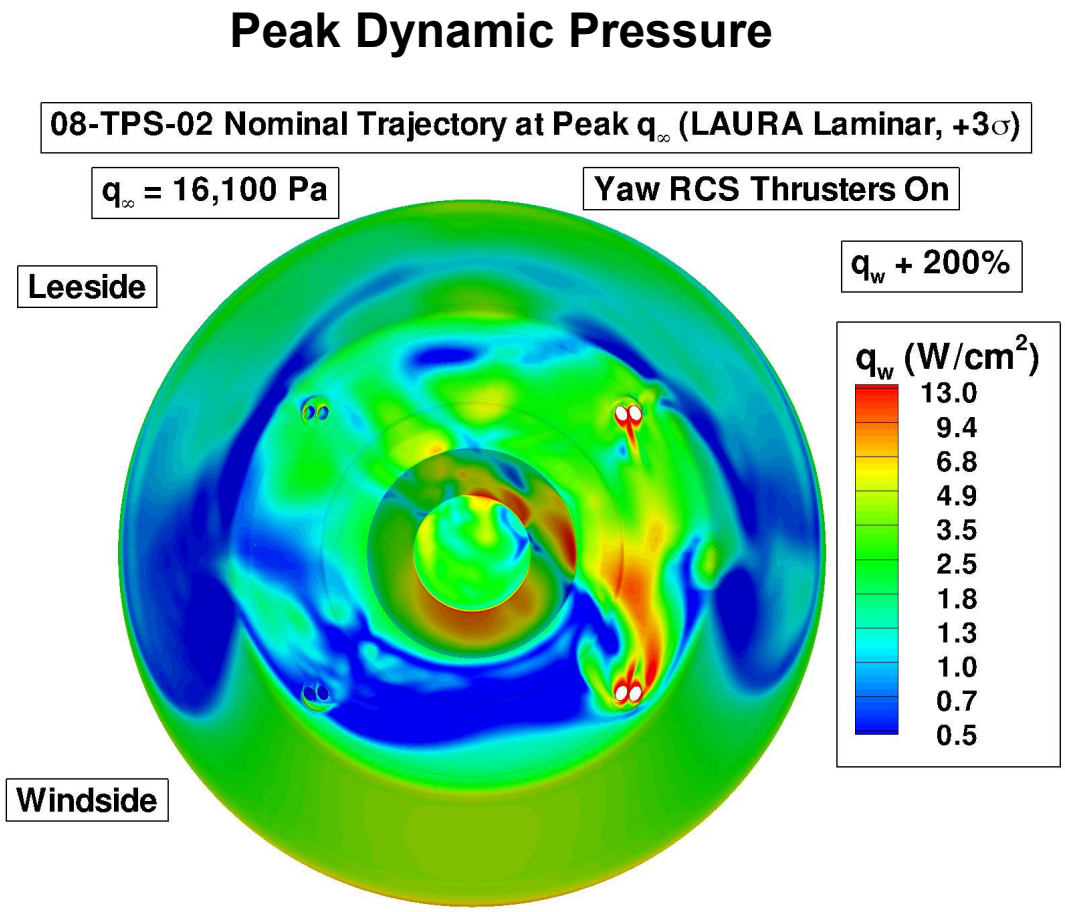


RCS On



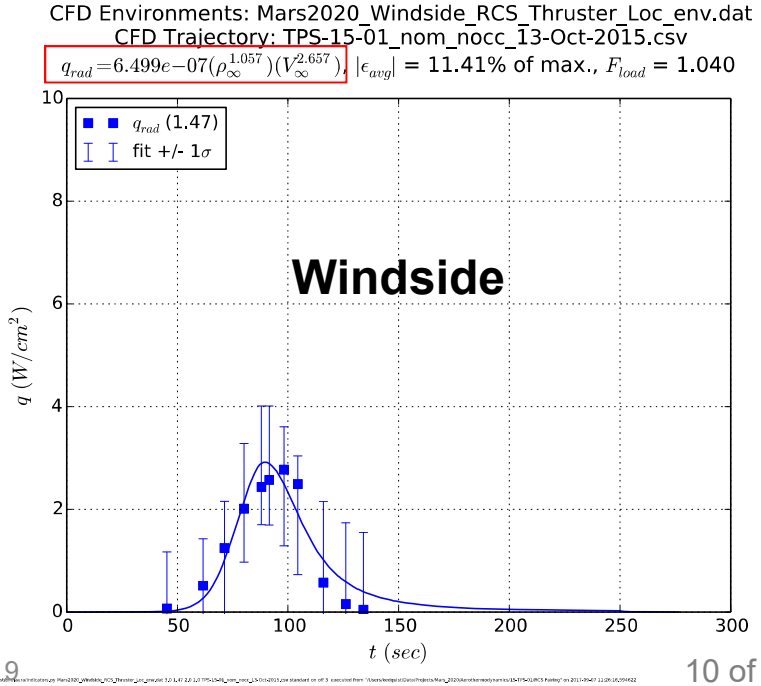
Backshell Convective Heating MSL Analysis (08-TPS-02)

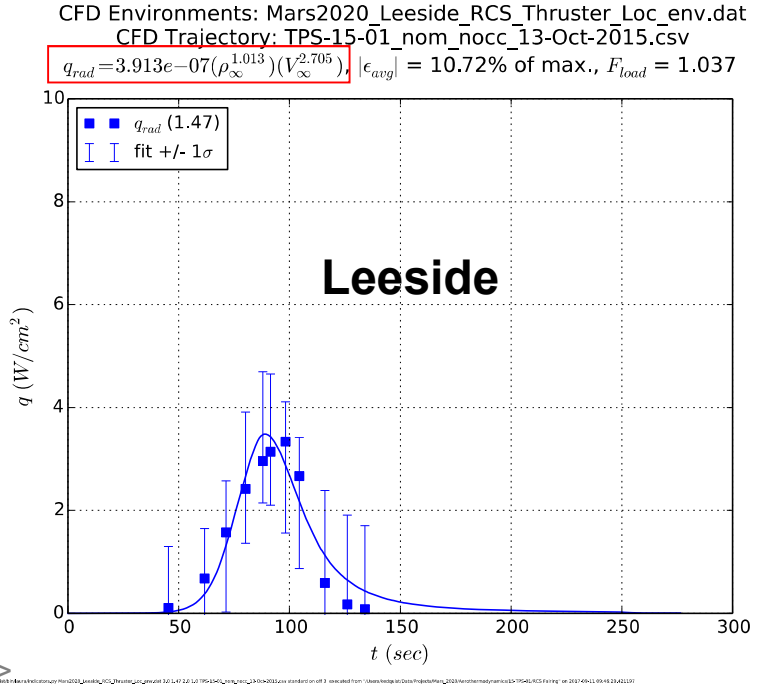
- Margined convective heat flux is shown
  - The Mars 2020 thermal analysis also uses this heat flux map



Mars 2020 DRCS Fairing Radiative Heating Fits

- The leeside radiative heating profile used in the thermal analysis, peaks at 4.5 W/cm^2
- 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/cm^2)
  - ρ_∞ = atmospheric density (kg/m^3)
  - V_∞ = 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

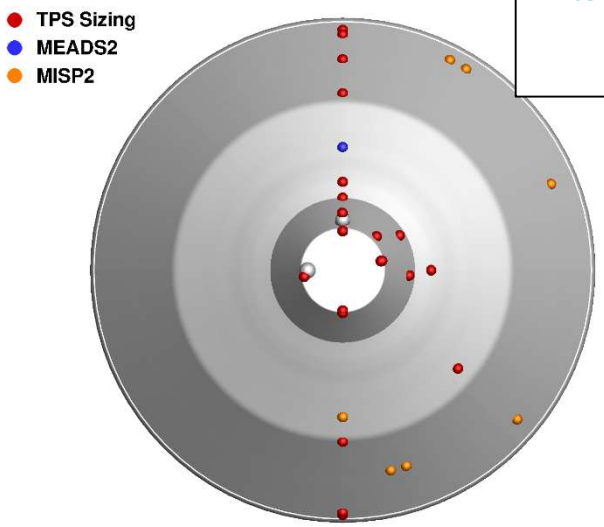




Mars 2020 Aerothermal Body Points

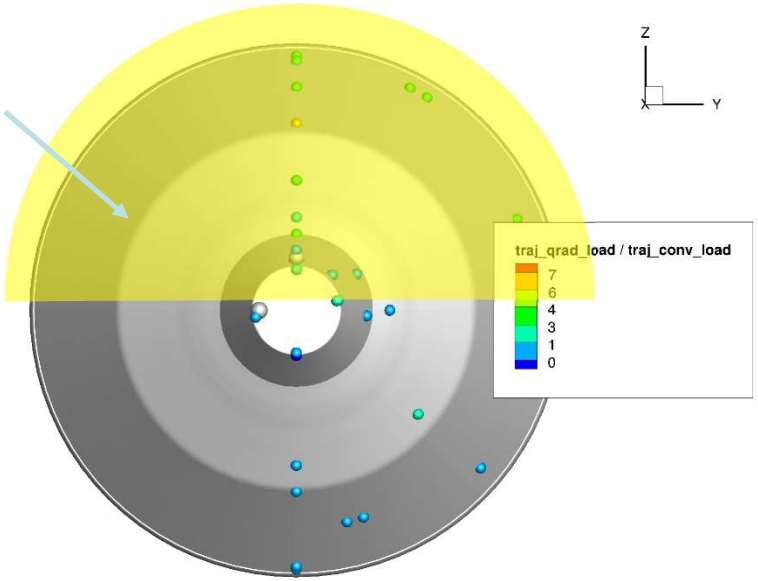
- The windside (+Z) shows no significant radiative heating
- The leeside (-Z) radiative heating is applied uniformly to the thermal model with a scale average factor of the data points available
  - We took peak absolute heating from radiation analysis from previous slide (~4.5 W/cm^2) and compared that 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

Body Points



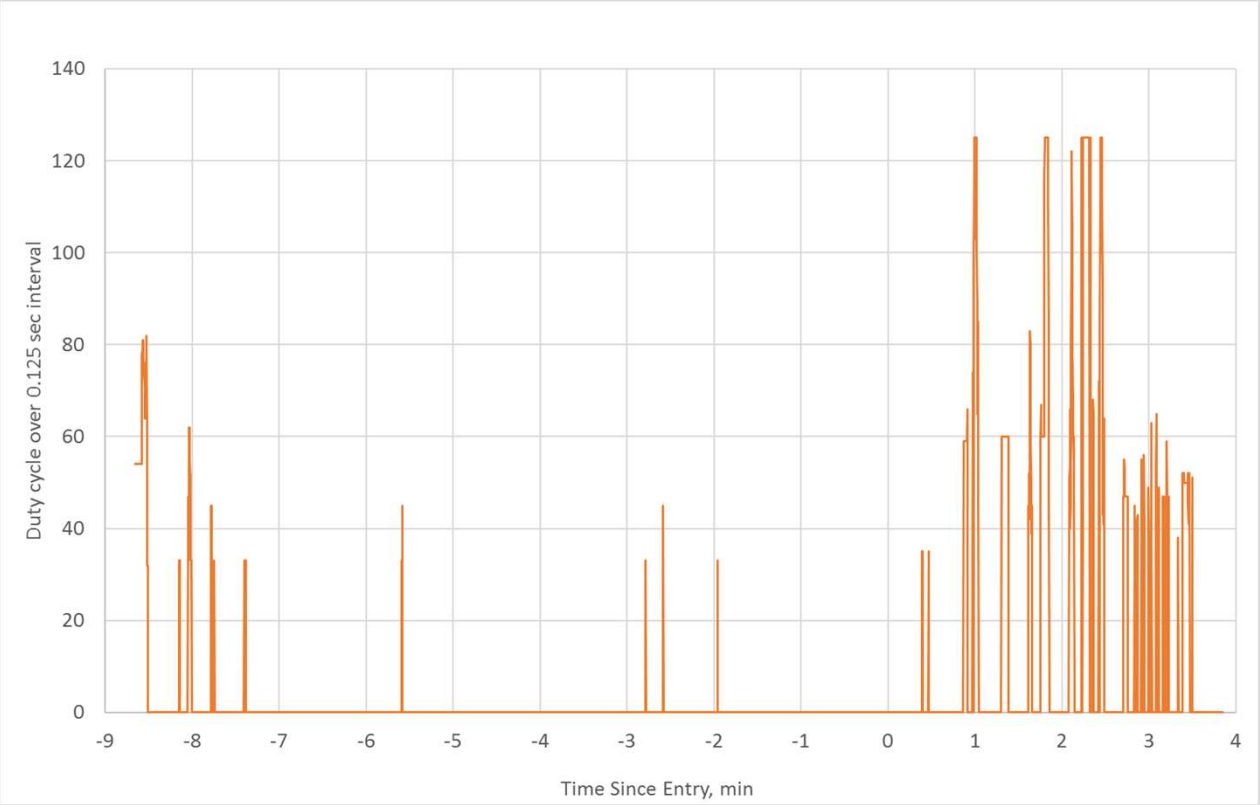
For the thermal analysis the radiative heating is applied as a uniform 2.4 factor increase to the leeside aeroheating spatial map

Ratio of Margined Radiative-to-Convective Heat Load



DRCS Firing Thermal Model Simulation

- 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

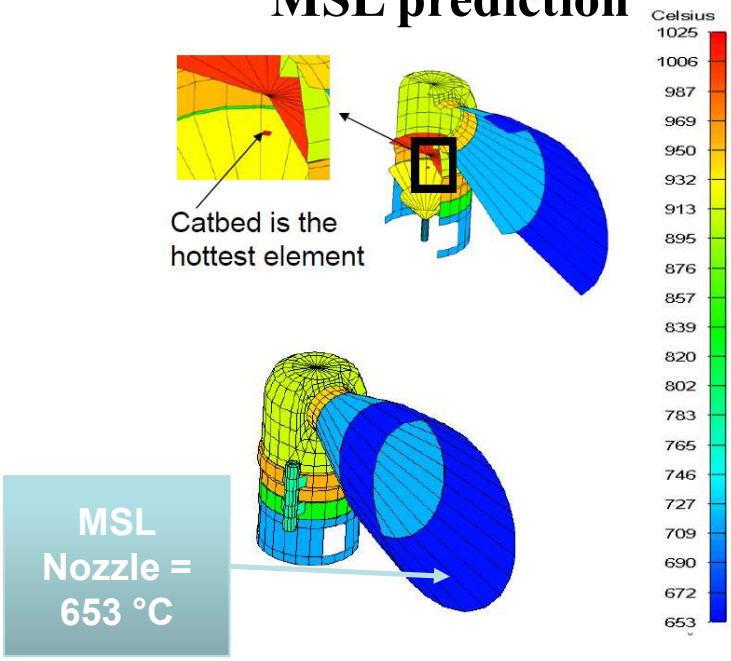
Radiation only on leeside, 16-TPS-01 MAX trajectory

	MSL				M2020			
DRCS Hardware	TIME OF PEAK	$T_{EDL, Peak}$ [°C]	MAX AFT [°C]	MARGIN [°C]	TIME OF PEAK E+(X) [min]	$T_{EDL, Peak}$ [°C]	MAX AFT [°C]	MARGIN [°C]
Thruster Seal	E+4.13	88	129	41	4.81	93.23	129	36
Thruster O-ring	E+4.14	178	205	27	4.81	189.23	205	16
Valve Housing, PRT	E+4.81	117	129	12	4.81	120.56	129	8
RCS MTG Flange	E+4.81	634	1260	626	4.63	627.67	1260	632
RCS Nozzle	E+4.81	653	1260	607	3.47	962.28	1260	298
RCS Plenum	E+4.81	906	1260	354	3.59	905.68	1260	354
I/F Standoff, RCS END	E+4.81	630	N/A	N/A	4.63	625.12	N/A	N/A
I/F STANDOFF, BRKT END	E+4.81	45	N/A	N/A	4.81	39.91	N/A	N/A
RCS MOUNTING BRACKET	E+4.81	44	N/A	N/A	4.81	39.08	N/A	N/A
OUTRIGGER AT BRK I/F	E+4.81	16	N/A	N/A	4.81	15.40	N/A	N/A
DIMU	E+4.81	23	35	12	4.81	22.28	35	13
RCS BLADE SEAL	E+1.72	954	1093	139	1.84	977.59	1093	115
RCS FAIRING	E+4.79	491	450	-41	2.48	491.84	450	-42
CLAMP SHELL RING, UPPER	E+2.24	273	450	177	2.48	485.34	450	-35
CLAMP SHELL RING, LOWER	E+2.52	125	450	325	3.55	282	450	168
TI ANNULAR SHIELD	E+4.81	204	450	246	4.81	139.05	450	311
B/S AT EA9394 SITE	E+4.81	83	177	94	4.80	115.14	177	62
BIPOD ASSY, FAIRING END	E+4.81	172	450	278	4.81	214.17	450	236
BIPOD ASSY, RCS BRKT END	E+4.81	29	450	421	4.81	38.40	450	412

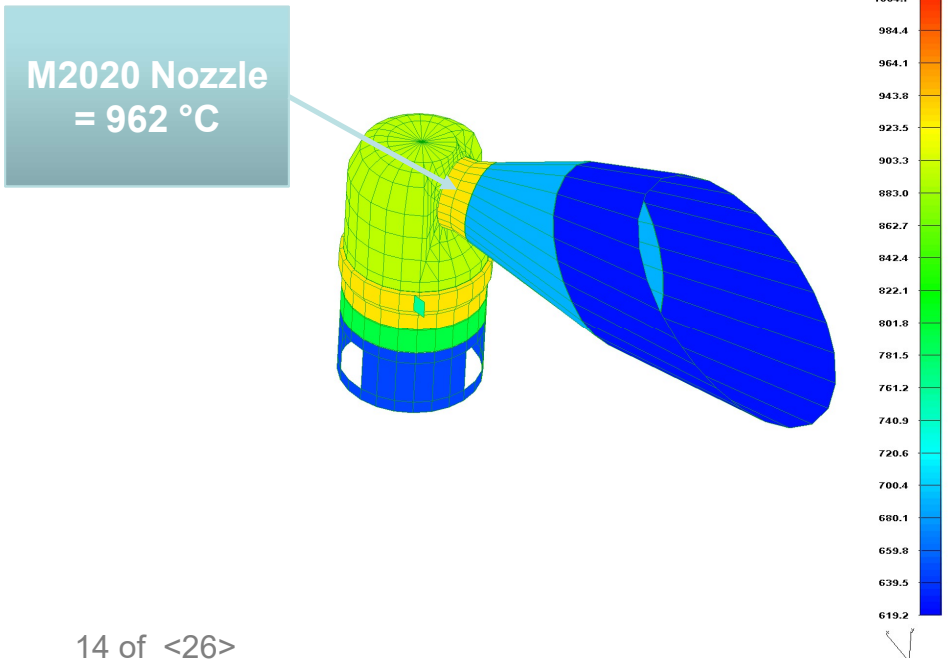
Nozzle Temperature Change

- **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**

MSL prediction

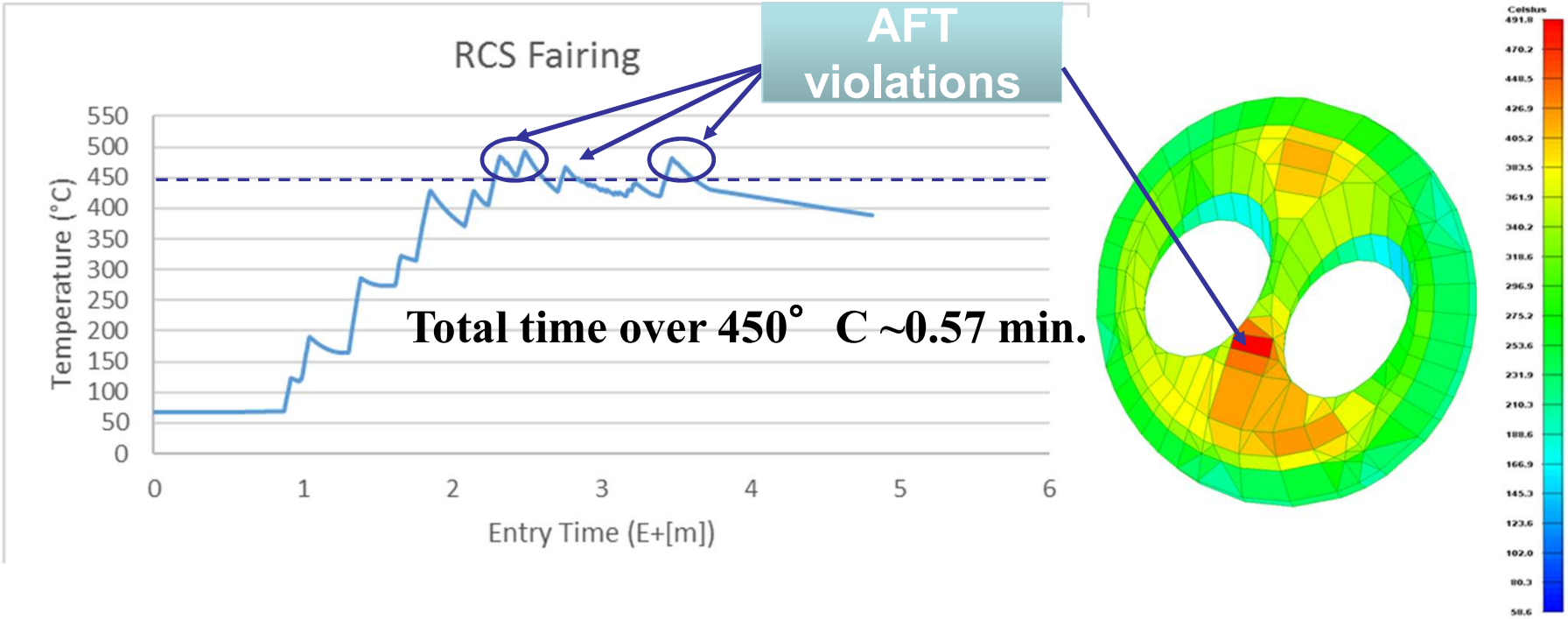


M2020 prediction



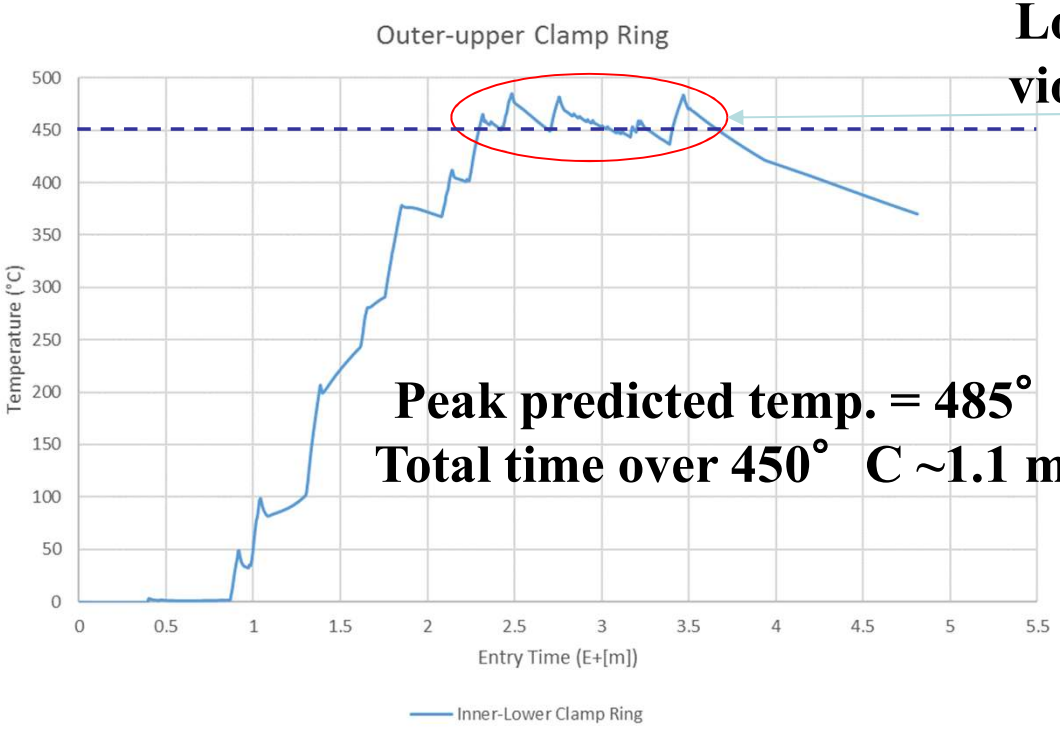
Ti Fairing AFT Violation

- **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**



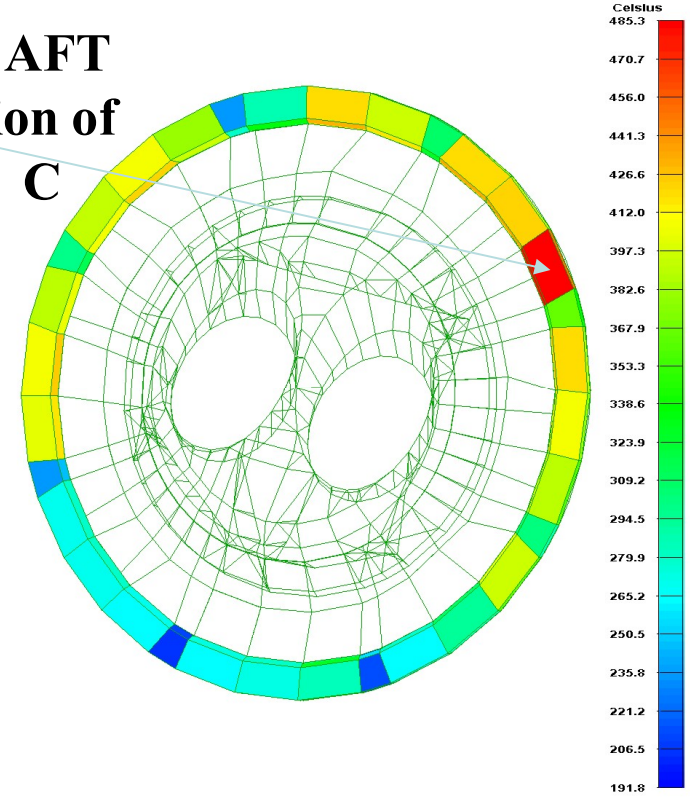
Clamp Shell Ring Violation (1/2)

- **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)**



Local AFT violation of 35° C

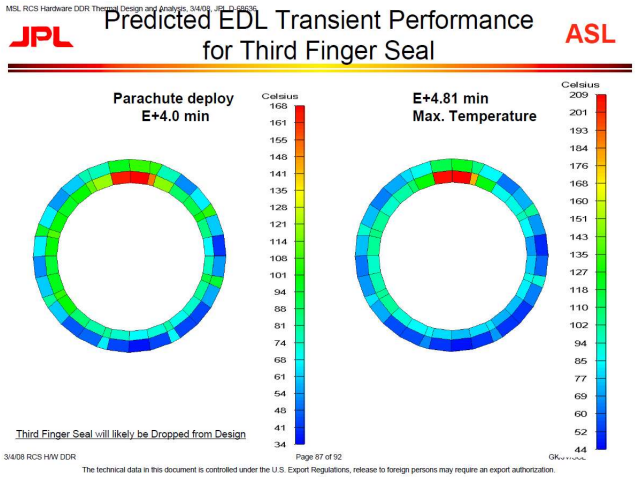
Peak predicted temp. = 485° C
Total time over 450° C ~1.1 min.

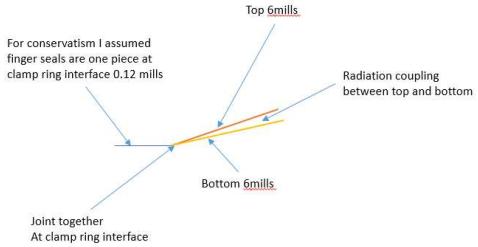


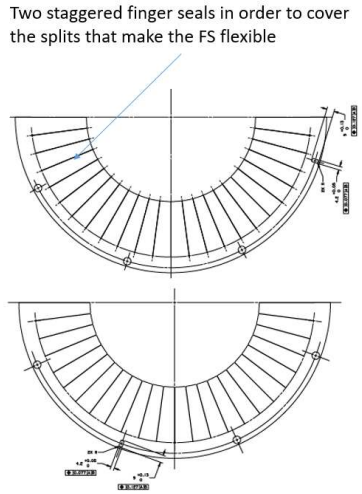
Clamp Shell Ring Violation (2/2)

- 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)

MSL DDR Slide







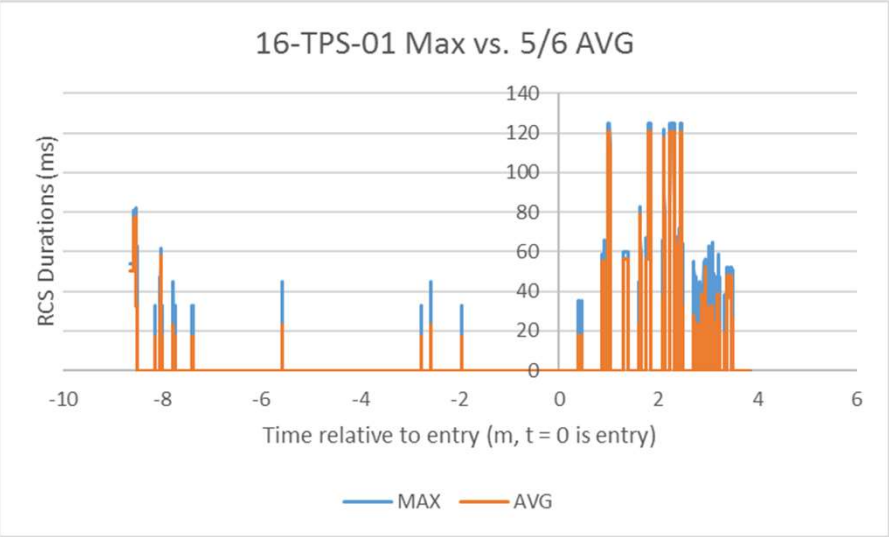
Stacked Conservatism

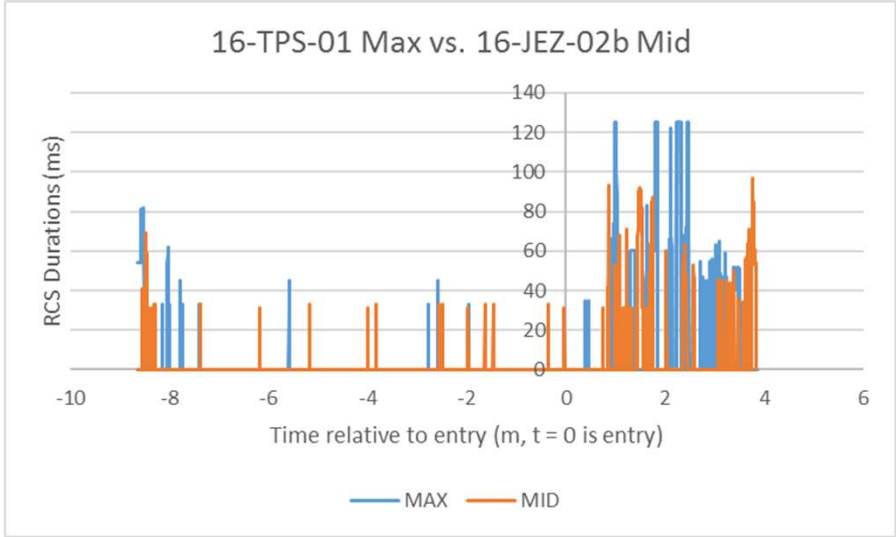
- **Conservatism results from several levels of assumptions**
- **We can reduce conservatism in these areas to try to eliminate AFT violations on RCS fairing and upper**

Worst case thruster duty cycle (roll reversals, many short pulses)	**Reduced conservatism, if necessary**	**Nominal Duty cycle** ***(relatively easy to plug in different trajectory's duty cycles into thermal model)***
Both thrusters firing for entire duty cycle		**Single thruster firing** ***(Would require LARC to re-do aerothermal flux with only a single thruster firing)***
LARC 3x aerothermal loads		**LARC < 3x aerothermal loads** ***(not the primary driver of AFT violations)***
Stacked WCH trajectories		**Make thermal loads consistent with trajectory** ***(aerothermal loads scale by dynamic pressure)***

“Nominal” Duty Cycle

- 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

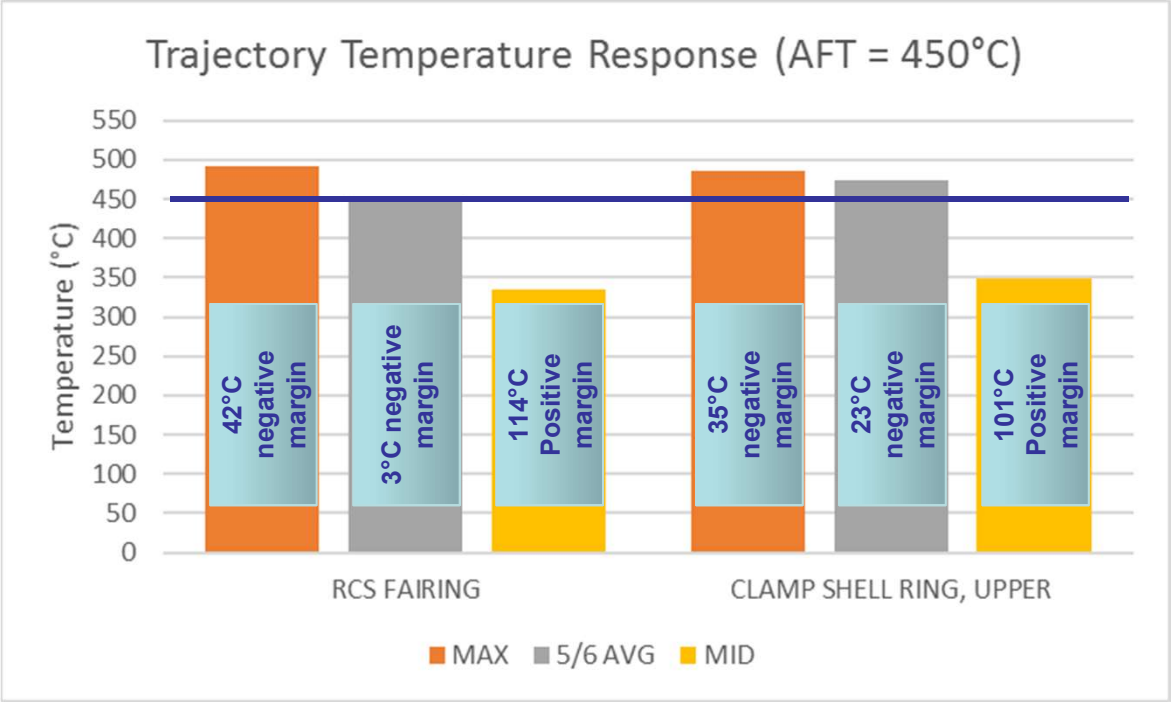
- Radiation only on Leeside, 16-TPS-01 5/6 Avg and 16-JEZ-02b MID

	M2020 16-TPS-01 max				M2020 16- TPS-01 5/6 avg				M2020 16-JEZ-02b-mid			
DRCS Hardware	TIME OF PE E+(X) [min]	$T_{EDL, Peak}$ [°C]	MAX AFT [°C]	MARGIN [°C]	TIME OF PE E+(X) [min]	$T_{EDL, Peak}$ [°C]	MAX AFT [°C]	MARGIN [°C]	TIME OF PE E+(X) [min]	$T_{EDL, Peak}$ [°C]	MAX AFT [°C]	MARGIN [°C]
Thruster O-ring	4.81	189	205	16	4.79	190	205	15	4.79	162	205	43
Valve Housing, PRT	4.81	121	129	8	4.79	122	129	7	4.79	97	129	32
RCS MTG Flange	4.63	628	1260	632	4.61	625	1260	635	4.79	584	1260	676
RCS Nozzle	3.47	962	1260	298	2.48	932	1260	328	3.85	840	1260	420
RCS Plenum	3.59	906	1260	354	3.58	888	1260	372	4.11	816	1260	444
I/F Standoff, RCS END	4.63	625	N/A	N/A	4.61	622	N/A	N/A	4.79	582	N/A	N/A
I/F STANDOFF, BRKT END	4.81	40	N/A	N/A	4.79	39	N/A	N/A	4.79	29	N/A	N/A
RCS MOUNTING BRACKET	4.81	39	N/A	N/A	4.79	39	N/A	N/A	0.00	0	N/A	N/A
OUTRIGGER AT BRK I/F	4.81	15	N/A	N/A	4.79	15	N/A	N/A	4.79	13	N/A	N/A
DIMU	4.81	22	35	13	4.79	22	35	13	4.79	21	35	14
RCS BLADE SEAL	1.84	978	1093	115	1.65	933	1093	160	1.53	920	1093	173
RCS FAIRING	2.48	492	450	-42	2.48	453	450	-3	2.45	336	450	114
CLAMP SHELL RING, UPPER	2.48	485	450	-35	2.48	473	450	-23	2.45	349	450	101
CLAMP SHELL RING, LOWER	3.55	282	450	168	2.81	274	450	176	2.66	205	450	245
TI ANNULAR SHIELD	4.81	139	450	311	4.79	136	450	314	4.79	92	450	358
BIPOD ASSY, FAIRING END	4.81	214	450	236	4.79	215	450	235	4.79	145	450	305
BIPOD ASSY, RCS BRKT END	4.81	38	450	412	4.79	38	450	412	4.79	27	450	423

16-TPS-01 max temperatures used in stress analysis by Kevin Le (6.13.18)

Predicted thermal Margin

- 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



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**