Sizing and Margins Assessment of the Mars2020 Acusil-II Thermal Protection System

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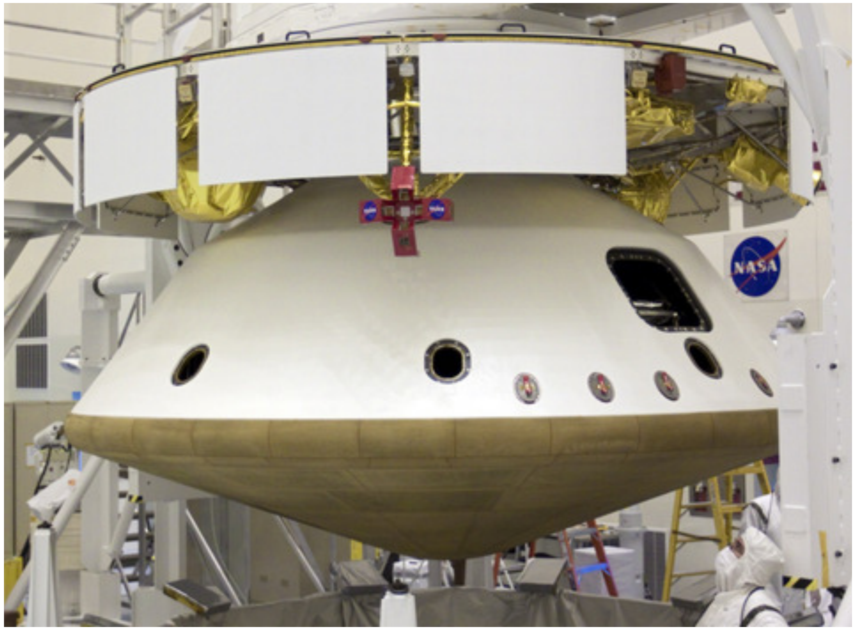
Outline

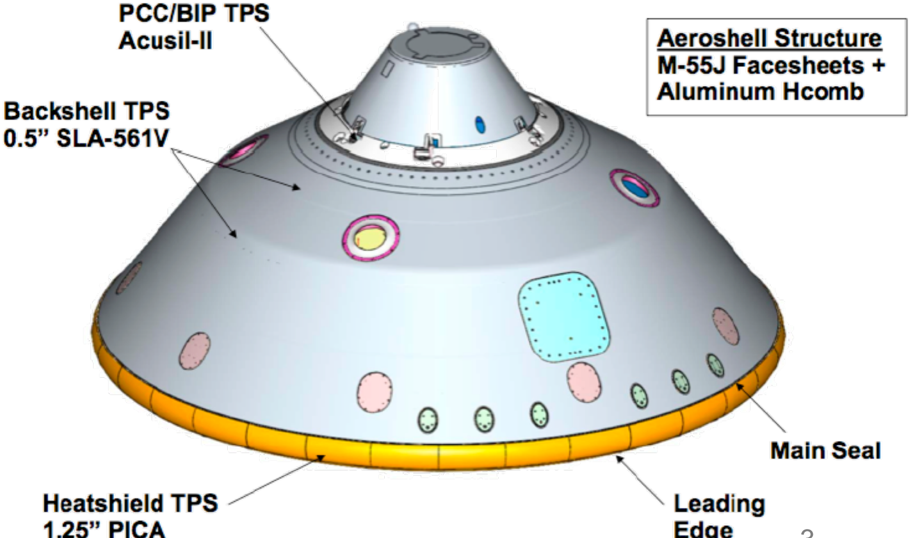
- Mars2020 entry vehicle overview
  - Need for TPS sizing
- PCC/BIP overview
- Heating environments
- TPS sizing methodology
  - Analysis locations
  - Margining process
  - Sizing assumptions
- Sizing results
- Summary and conclusions

Introduction

- **Mars2020 EDL sequence and entry vehicle design will be very similar to Mars Science Laboratory (MSL)**
  - Build-to-print with minor changes
  - No change to the three Thermal Protection System (TPS) materials and thicknesses
  - PICA on heatshield
  - SLA-561V on the backshell
  - Acusil-II on Parachute Closeout Cone (PCC) and Backshell Interface Plate (BIP)
- **Demonstrate that the as-built thickness of TPS materials is sufficient to withstand Mars2020 aerothermal environments**
  - Perform TPS sizing as was done for MSL and show that the as-built thickness is greater than sized thickness
  - Update environments and analysis assumptions as needed
  - This talk focuses on Acusil-II sizing on PCC/BIP
  - Heatshield and backshell sizing showed as-built PICA and SLA thicknesses have plenty of margin

MSL Entry Vehicle and Cruise Stage

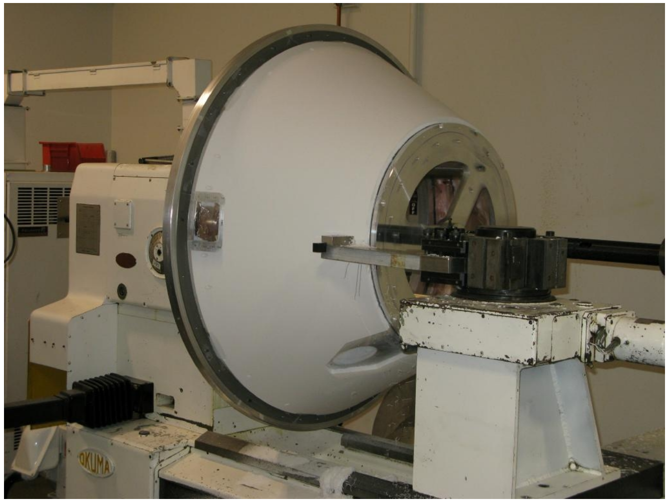




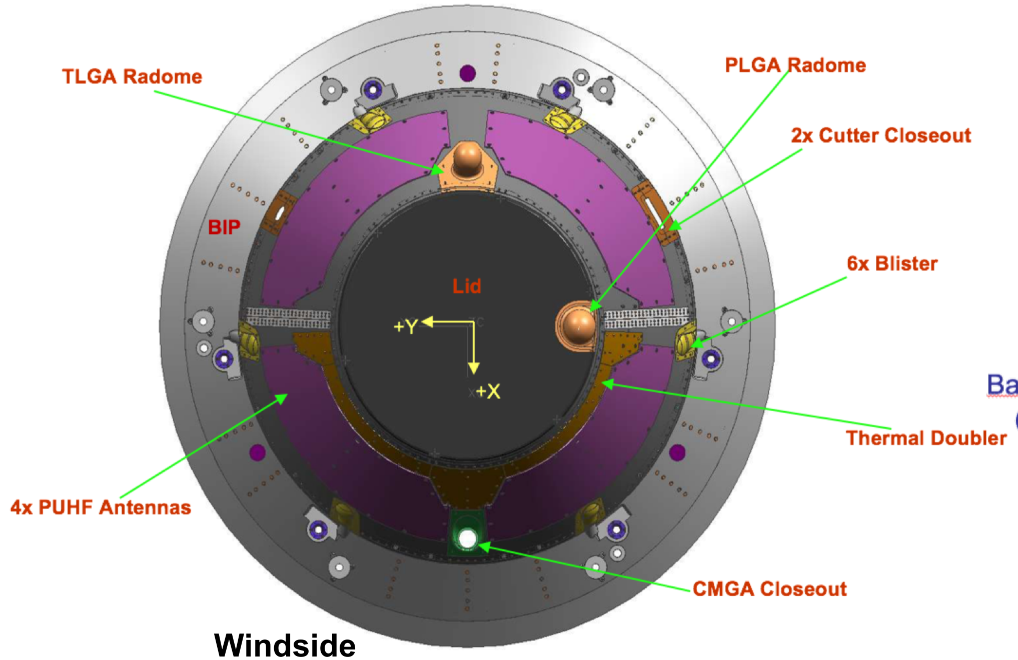
PCC/BIP Overview

- BIP is the primary aeroshell structure that interfaces with the descent stage, cruise stage and parachute support structure
- PCC houses the parachute assembly, multiple antennas and includes various closeouts for interfaces between aeroshell, rover and cruise stage
- Complex geometry, surface features and varying stack of substructure materials
- Aluminum doubler was installed on the windside of PCC in the regions of high heating

Acusil Installed on MSL PCC

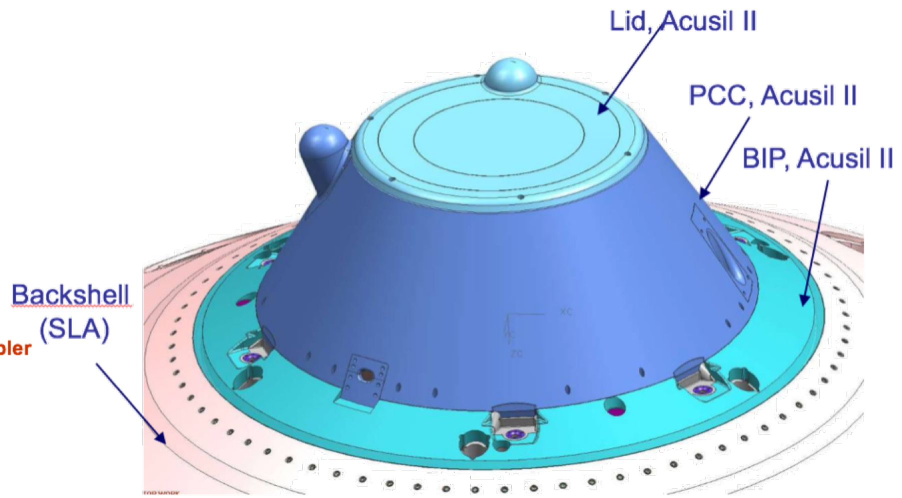


PCC/BIP without TPS



Windside

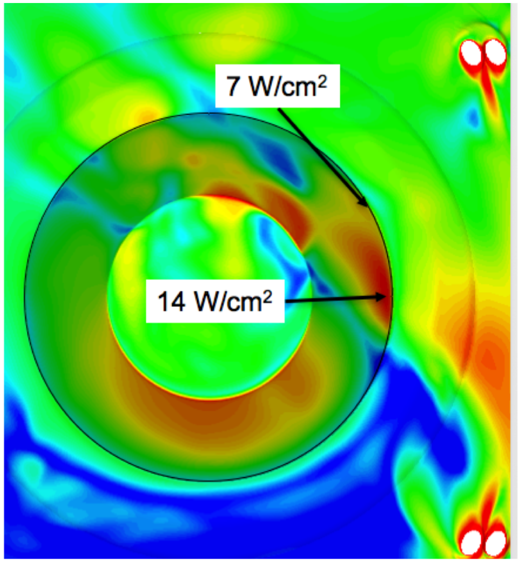
PCC/BIP with TPS



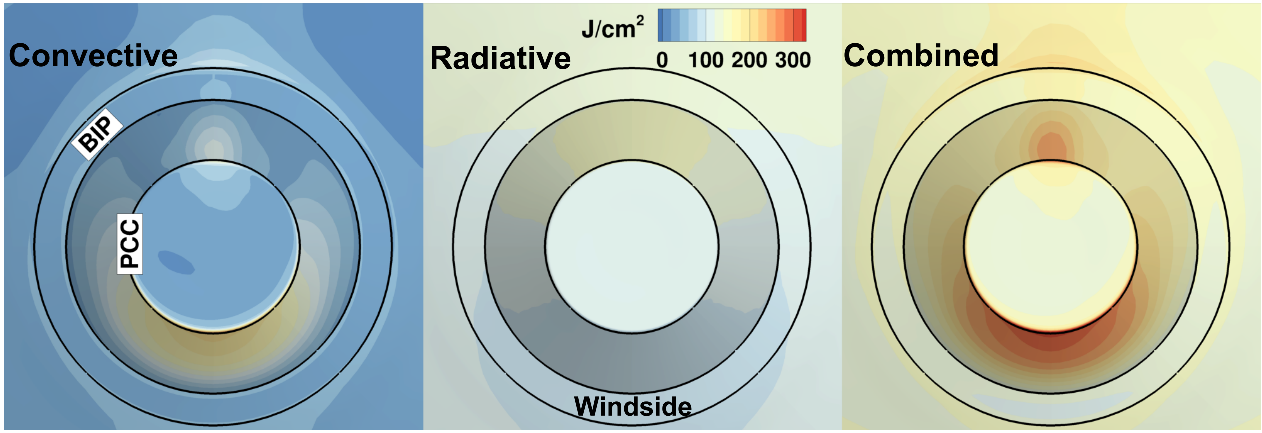
Trajectory and Heating Environments

- TPS stressing trajectory (15-TPS-01)
  - High entry velocity early in the arrival period
- Convective heating is simulated using NASA Langley's CFD code LAURA (Laminar, non-catalytic)
  - Impact of catalycity and turbulence quantified separately and accounted for in margins
- Radiative heating is simulated using NASA Langley's radiation code HARA (new for Mars2020)
- Primary simulations are done without antenna Radomes
  - A few solutions are obtained on a grid with antenna Radomes
- MSL simulations are leveraged to quantify impact of RCS thruster plume impingement on PCC/BIP
  - Peak convective heat flux is augmented for 8 seconds (estimated total firing time)

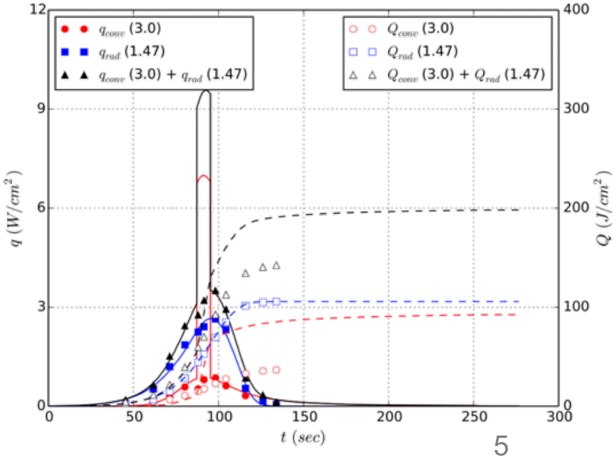
RCS Plume Impingement on PCC/BIP



Margined Heat Load from LAURA/HARA Simulations (No Radomes)



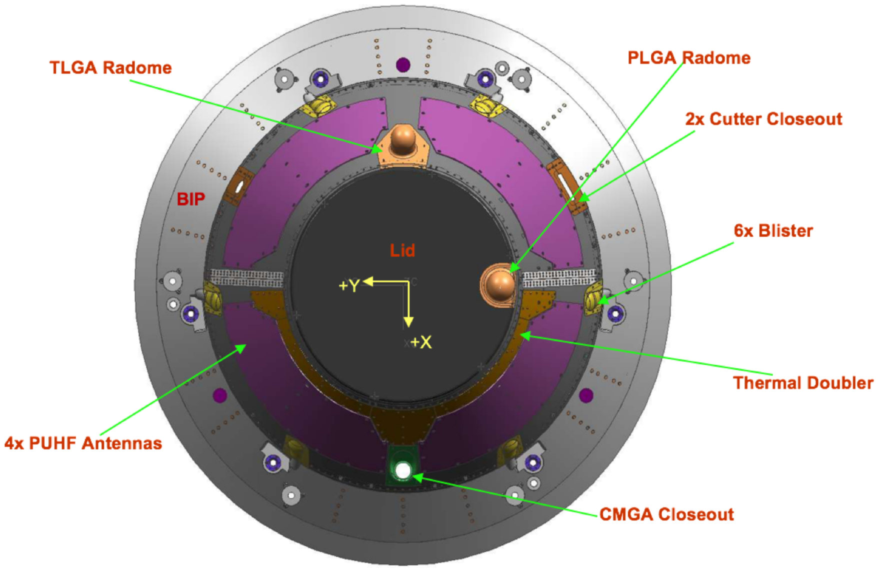
Heat Pulse Augmentation due to RCS Plume Impingement



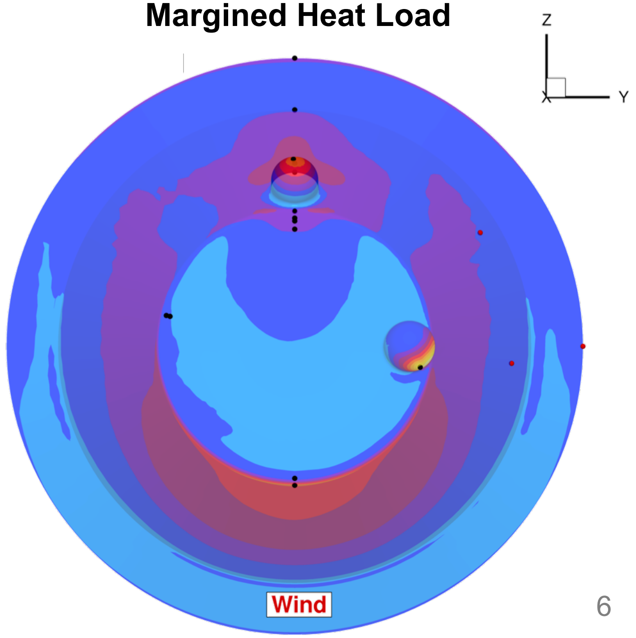
Need for Sizing at Many Locations

- We need to perform TPS sizing at multiple locations to ensure that as-built Acusil thickness is sufficient
  - Varying aeroheating conditions
    - Significant radiative heating that peaks at a different location than convective heating
  - Local heating augmentation due to RCS thruster plume impingement
  - Complex geometry and features, varying Acusil-II thickness (smooth OML)
  - Varying substructure material stack and thickness
  - Different bondline temperature limits
  - 1D modeling tools and validated 1D material models

Complex Geometry and Substructure Stack

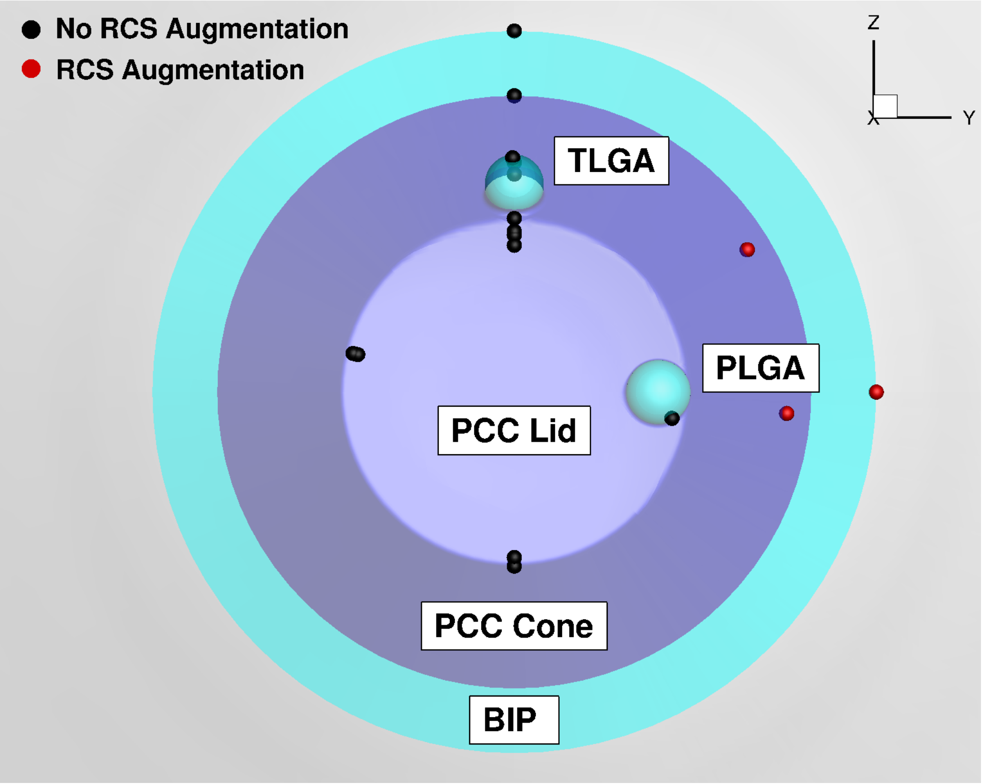


Margined Heat Load



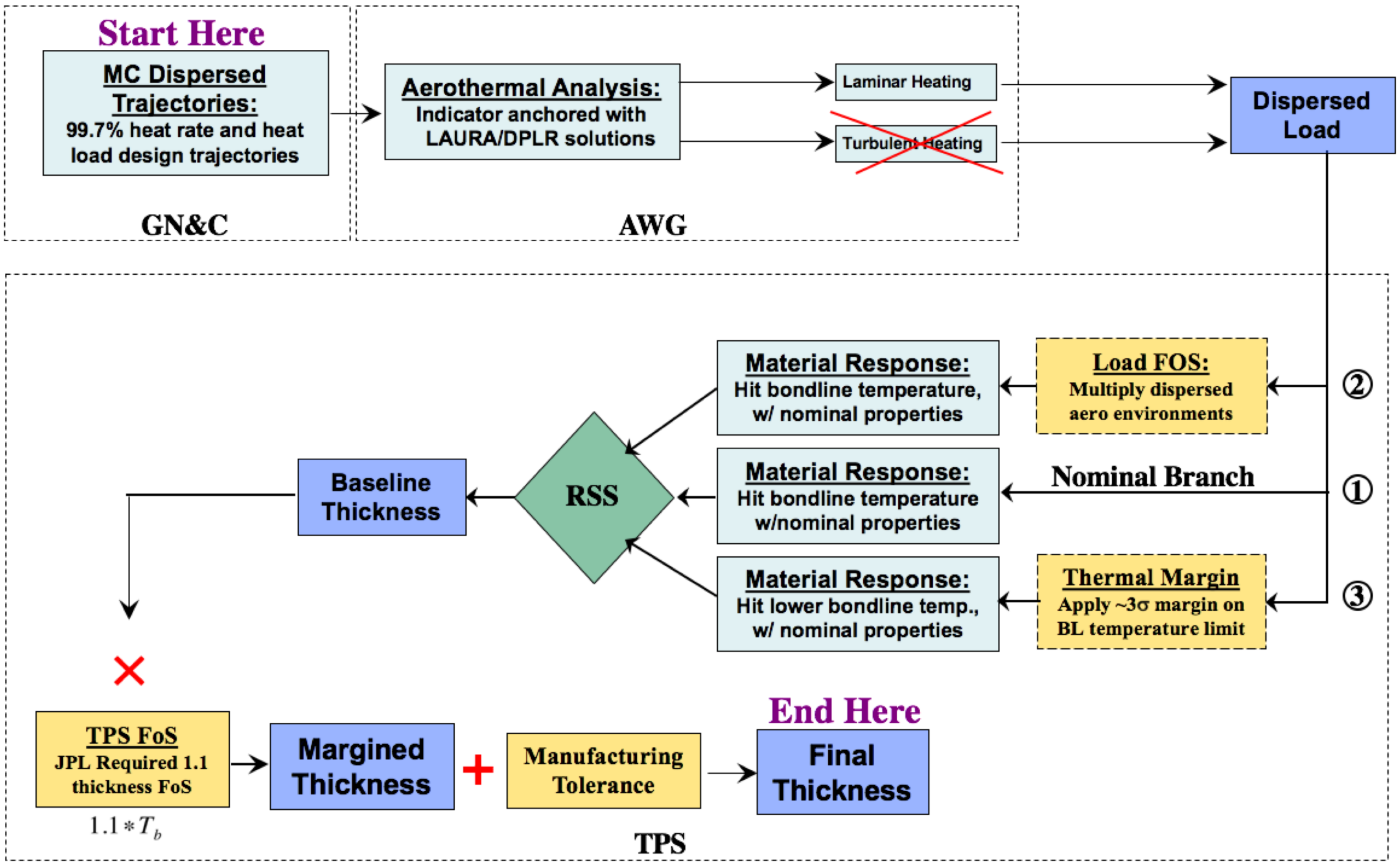
Sizing Cases

- **Investigated a total of 16 sizing cases**
- **PCC Cone (4 cases)**
  - Cone windside
  - Cone leeside
  - PUHF antenna
  - Megacutter
- **Radomes (4 cases)**
  - TLGA Radome
  - Two points at TLGA base
  - PLGA Radome
- **BIP (3 cases)**
  - Leeside near PCC
  - Leeside near backshell
  - RCS augmentation location
- **PCC Lid (5 cases)**
  - 1 case for the region with full thickness of substructure
  - 4 cases for the region with tapered substructure



Margin Process

- Various independent sources of uncertainty are RSS'ed in a three-branch sizing process to avoid stacked conservatism
- True Factor of Safety (FOS) can be calculated for the as-built Acusil thickness
  - As-built FOS = (As-built thickness– Manufacturing Tolerance) / Baseline Thickness



Reference: Wright et al., JSR 2014

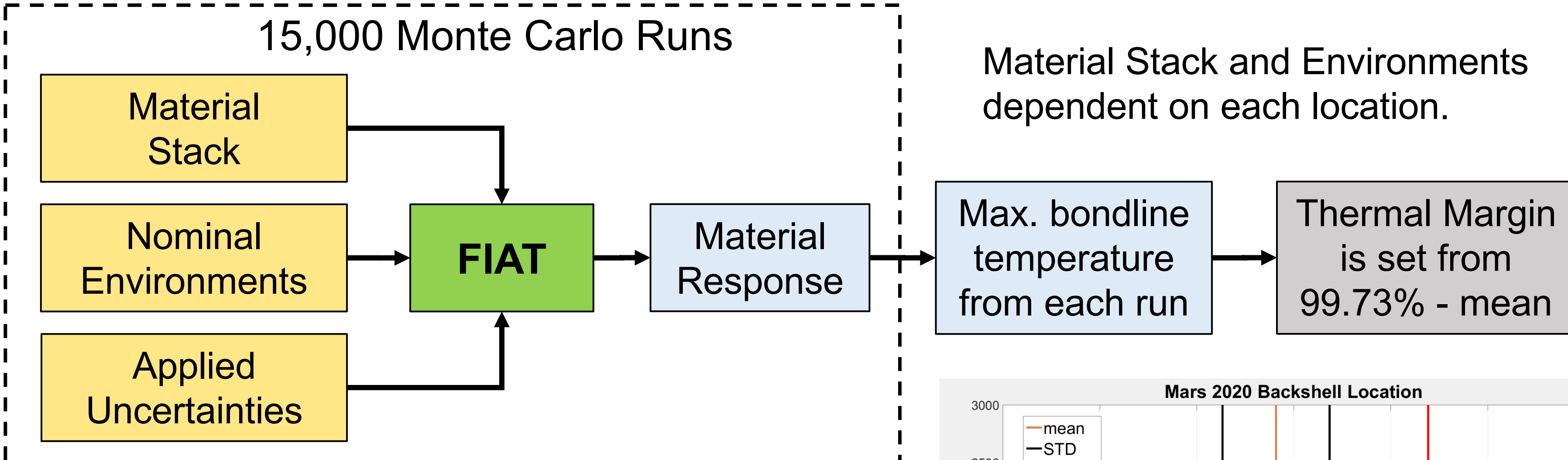
Sizing Assumptions

- Sizing is performed using NASA Ames ablative material response code FIAT (v3.1.1)
  - Location-specific material stack
- Heat flux predictions from LAURA/HARA solutions are curve fitted in time and applied directly as surface heating in FIAT
  - Convective heating margin: 3.0x (accounting for turbulence, uncertainties, biases)
  - Radiative heating margin: 1.47x
- Acusil thermal response model updated based on limited absorptivity data
  - Radiative heating was assumed negligible in MSL analysis
- Thermal response models for the various substructures (metallic and composite) and adhesives developed by MSL
- Initial temperature of 35 C for PCC and BIP
  - Margined maximum value derived from thermal analysis (prior to entry)
- Bondline temperature limits mandated by structural requirements
  - See table

Location	Bondline Temperature Limit (℃)
PCC Cone	150
BIP	55
PUHF	180
Radomes	230
PCC Lid	230

Bondline Temperature Margin

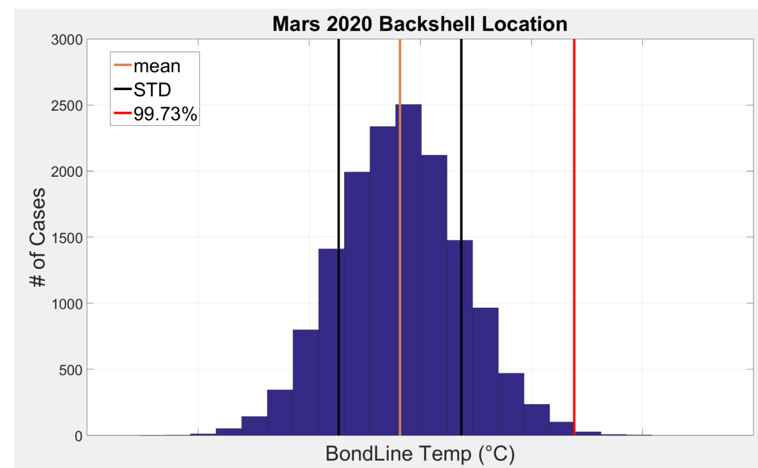
- Bondline temperature margin (used in 3rd branch of sizing) is estimated by performing Monte Carlo analysis around FIAT
  - 15,000-run Monte Carlo (16 Monte Carlo simulations for the 16 sizing cases)
  - Material properties are varied in each run based on data and engineering judgement
  - Max bondline temperature is recorded for each run; margin is calculated as 99.73% - mean (3σ)



Monte Carlo Inputs

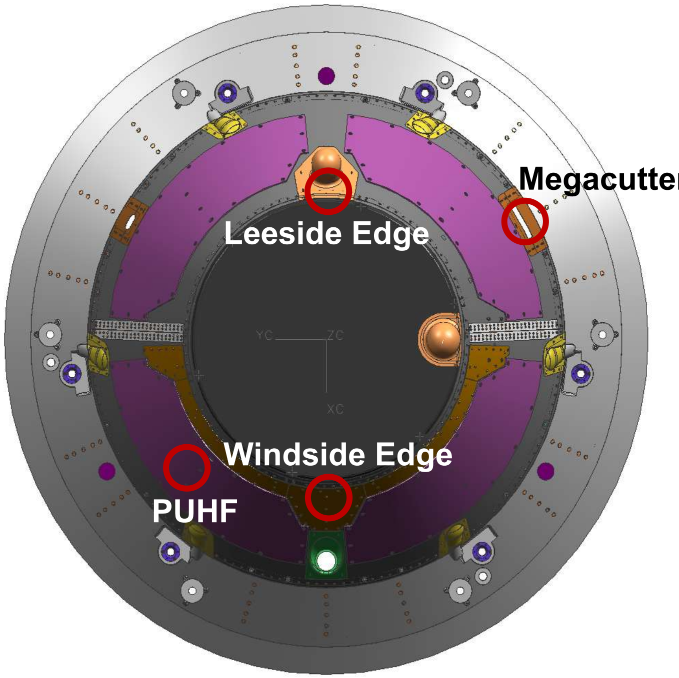
TPS Uncertainties	Substrate
Density	Density
Virgin Cp	Cp
Char Cp	K
Virgin K	ε
Char K	Thickness
Virgin ε	
Char ε	
Decomp Params	

Gaussian Distribution used for inputs



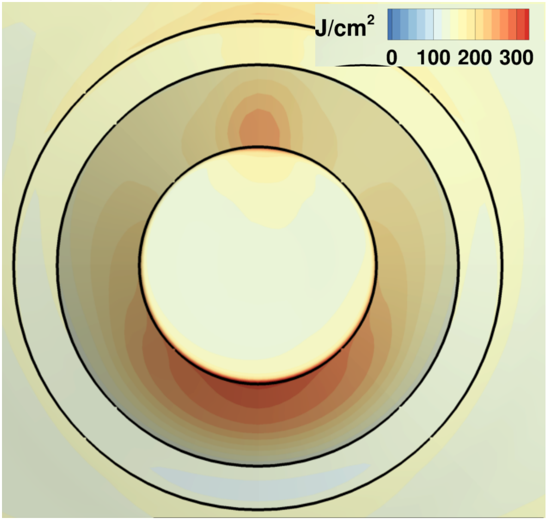
PCC Cone Sizing

- **Windside Edge**
  - Highest combined heating location
  - Aluminum doubler → more thermal mass but thinner TPS
- **PUHF Antenna**
  - Reduced Acusil thickness but more thermal mass
  - Higher bondline temperature limit
  - Apply windside edge heating for sizing (conservative)
- **Leeside Edge**
  - Highest heating for regions with maximum TPS thickness
  - No doubler → less thermal mass but full Acusil thickness
- **Megacutter**
  - Heating augmentation due to the RCS plume impingement
  - Reduced Acusil thickness due to different substructure design



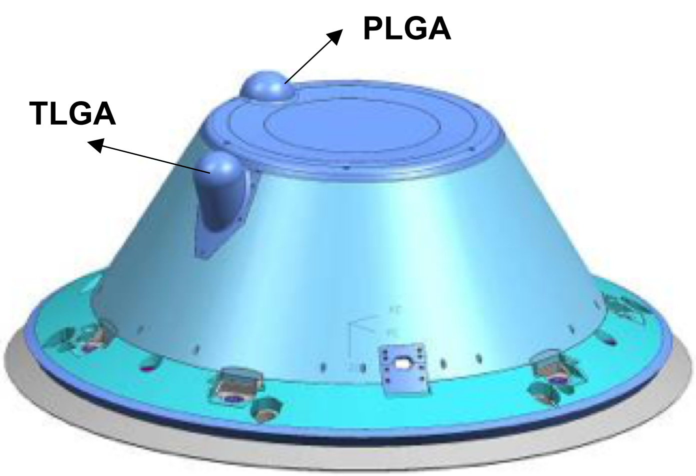
Sizing Case	Windside Edge	Leeside Edge	PUHF Antenna	Mega Cutter
Sized Thickness (cm)	0.93	1.58	0.76	1.24
As-Built Thickness (cm)	1.50	1.74	1.29	1.64
As-Built Factor of Safety (%)	79%	21%	90%	46%

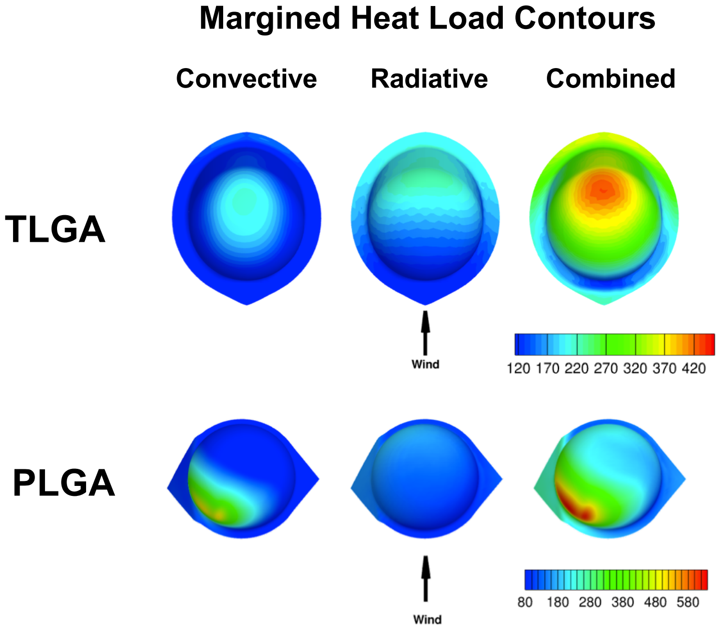
Margined Combined Heat Load



TLGA and PLGA Sizing

- CFD solutions were obtained at 5 trajectory points on a grid with Radomes
  - Conditions at maximum heat load location are used for sizing
- FIAT analysis is done using spherical geometry
- Radome structure is tolerant to a higher bondline temperature limit (230 C)
- Bondline temperature limit is enforced at parachute deploy for PLGA and backshell release for TLGA
- Sizing results show that the as-built thickness is more than adequate for Mars2020 environments





Sizing Case	TLGA	PLGA
Sized Thickness (cm)	1.84	2.00
As-Built Thickness (cm)	2.50	2.50
As-Built Factor of Safety (%)	49%	37%

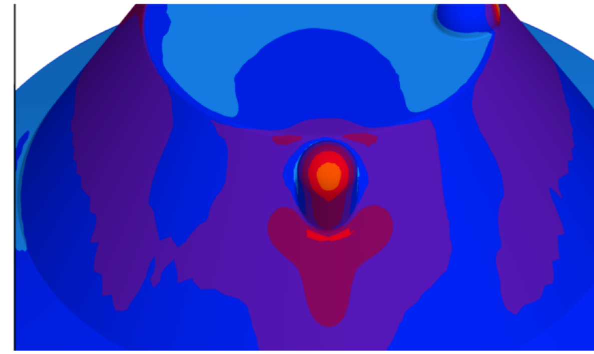
TLGA Base Sizing

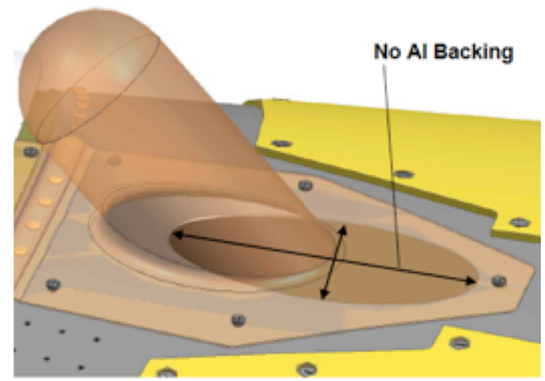
- Need for sizing at TLGA base
  - CFD solutions with Radomes showed areas of augmented heating at the base
  - Radome structure overlaps with the PCC cone → reduced TPS thickness in that region
  - Different substructure stack and bondline temperature requirements in this region (area with no Aluminum backing)

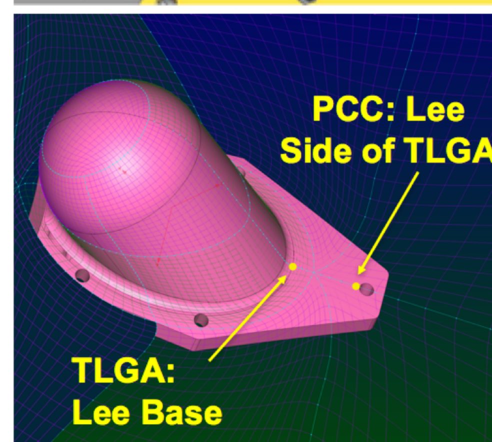
- Two sizing cases were investigated
  - **TLGA Lee Base**: peak environments for the region with no Aluminum backing
    - 230 C temperature limit enforced at the top of Radome structure
  - **PCC Leeside of TLGA**: peak environments for the region that has Aluminum backing
    - 150 C temperature limit enforced at the top of Aluminum

Sizing Case	TLGA: Lee Base	PCC: Leeside of TLGA
Sized Thickness (cm)	0.60	0.83
As-Built Thickness (cm)	1.59	1.59
As-Built Factor of Safety (%)	199%	113%

Heat Load Contours Show Local Hot Spots at the Base of TLGA





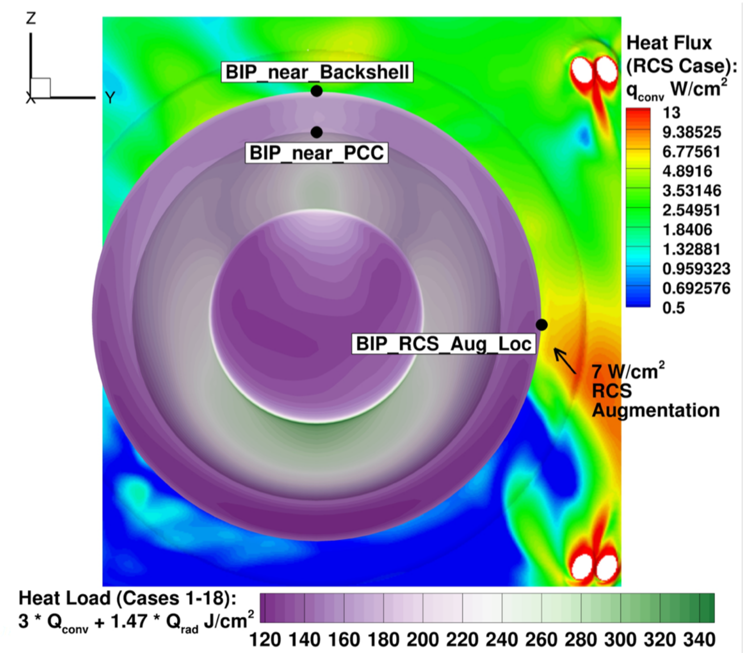


BIP Sizing

- Peak heating occurs on the leeside
- RCS plume impingement near 3 o'clock location
- Varying Acusil thickness on the BIP from PCC to backshell

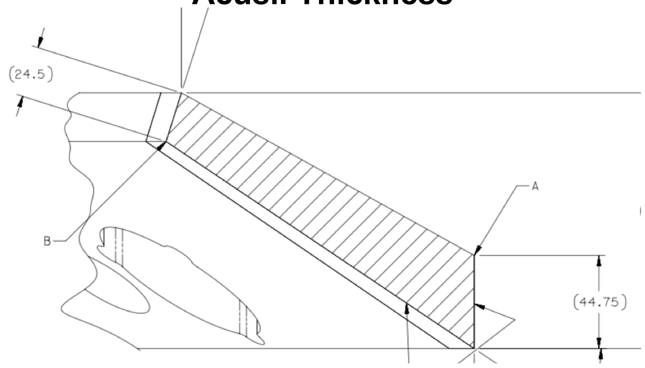
- 3 sizing cases were investigated
  - **BIP-near-PCC**: peak environments for the thinnest region of Acusil
  - **BIP-near-Backshell**: peak environments for the thickest region of Acusil
  - **BIP-RCS-Aug-Loc**: local environments at the 3 o'clock location augmented with RCS effects

RCS Impingement on BIP Perimeter



Sizing Case	BIP-near-PCC	BIP-near-Backshell	BIP-RCS-Aug-Loc
Sized Thickness (cm)	2.22	2.35	2.29
As-Built Thickness (cm)	2.45	3.97	2.45
As-Built Factor of Safety (%)	21%	87%	17%

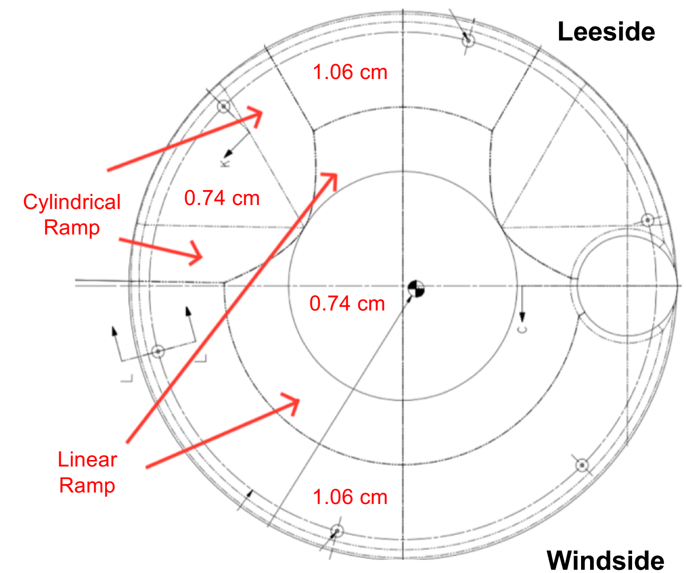
BIP Cross Section Showing Varying Acusil Thickness



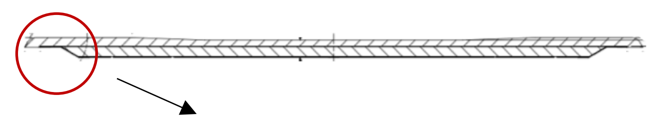
PCC Lid

- Acusil thickness on the lid varies from 0.74 cm to 1.06 cm
  - Minimize lid mass due to parachute re-contact risk
  - Thickness was reduced in areas of low heating
- The lid substructure is made of Aluminum honeycomb and facesheet sandwich
  - Tapered on the edge to only facesheet
- Doublers are applied on the tapered region for structural reasons
  - Three zones of doubler thickness
  - The region labeled as “**outer**” is guaranteed to have the thickest doubler configuration
  - The region labeled as “**inner**” has the thinnest doubler configuration
- Varying material stack and thickness combined with varying environments necessitates sizing at multiple locations

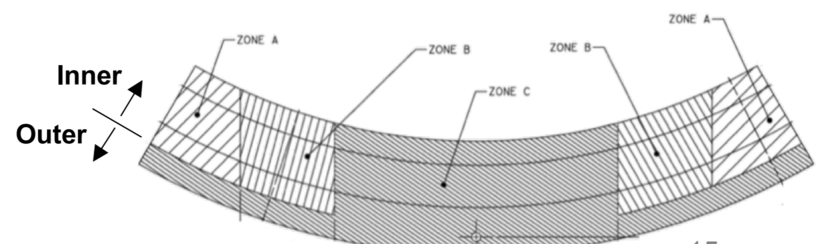
Lid Top View Showing Varying Acusil Thickness



Lid Side View Showing Substructure Tapering



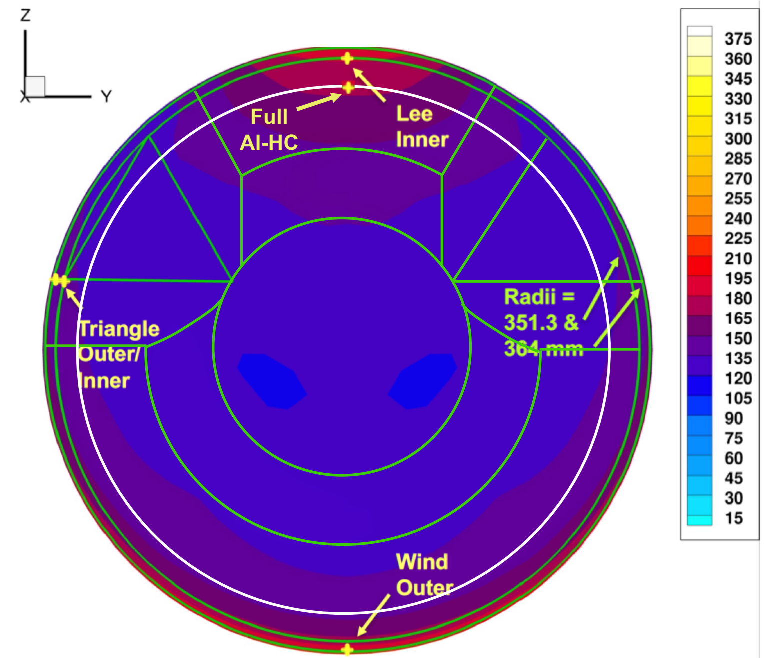
Bottom View of Tapered Region Showing Three Thickness Zones for Doublers



PCC Lid Sizing

- **Full Al-HC**: Peak heating in the region with full thickness of Al-HC sandwich
  - Acusil thickness varies from 0.74cm to 1.06cm
- **Windside-Outer**: Peak heating in the region with maximum thickness of doubler
  - Acusil has its max thickness (1.06cm)
- **Leeside-Inner**: Peak heating in the region with minimum doubler thickness
  - Acusil has its max thickness (1.06cm)
- **Triangle-Outer**: Peak heating in the regions that have max thickness of doubler and less-than-max thickness of Acusil
- **Triangle-Inner**: Peak heating in the regions that have min thickness of doubler and less-than-max thickness of Acusil

PCC Lid Margined Heat Load Overlaid on Acusil and Substructure Thickness Boundaries



*Based on this analysis, Acusil as-built thickness was reduced from 1.06 cm to 0.96 cm to alleviate lid mass increase

Sizing Case	Full Al-HC	Windside-Outer	Leeside-Inner	Triangle-Outer	Triangle-Inner
Sized Thickness (cm)	0.62	0.60	0.84	0.44	0.70
As-Built Minimum Thickness (cm)	0.74	1.06*	1.06*	0.74	0.74
As-Built Factor of Safety (%)	33%	98%	40%	90%	16%

Summary and Conclusions

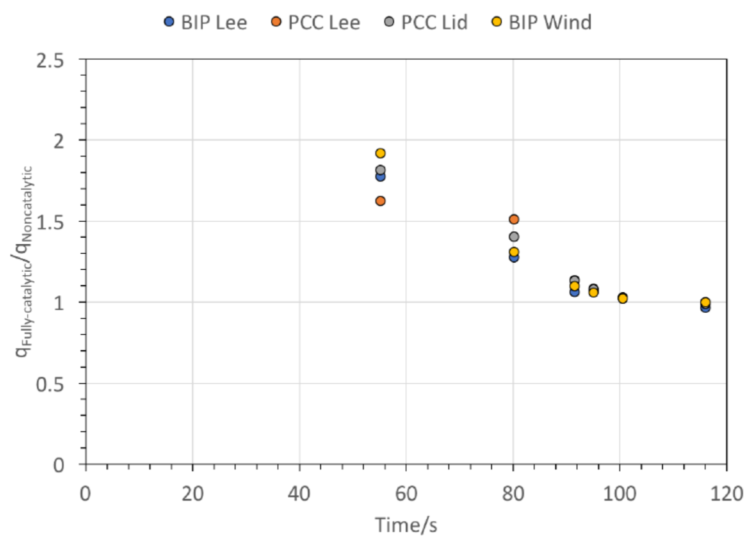
- TPS sizing had to be performed at many locations due to:
  - Varying aeroheating conditions
  - Varying substructure material stack and thicknesses; Varying Acusil thickness
  - Different bondline temperature limits
  - Availability of only 1D thermal response model for Acusil-II
- Sizing results showed that the as-built Acusil-II on Mars2020 PCC and BIP has sufficient thickness to protect the underlying structure from aeroheating environments
  - All locations have positive margin in case of future sizing threats
  - Improved and more detailed analysis process compared to MSL
  - Lid sizing was critical in reducing Acusil thickness to alleviate increase in lid mass due to parachute design changes
- Many sizing iterations were done to arrive at the final results shown in this talk
  - Refined environments, techniques and assumptions to fit within the as-built thickness
- Multi-dimensional analysis capability and thermal response models would have significantly improved and simplified this sizing effort
  - By taking advantage of in-plane conduction, we would have been able to show even greater sizing margins with multi-dimensional analysis

Questions?

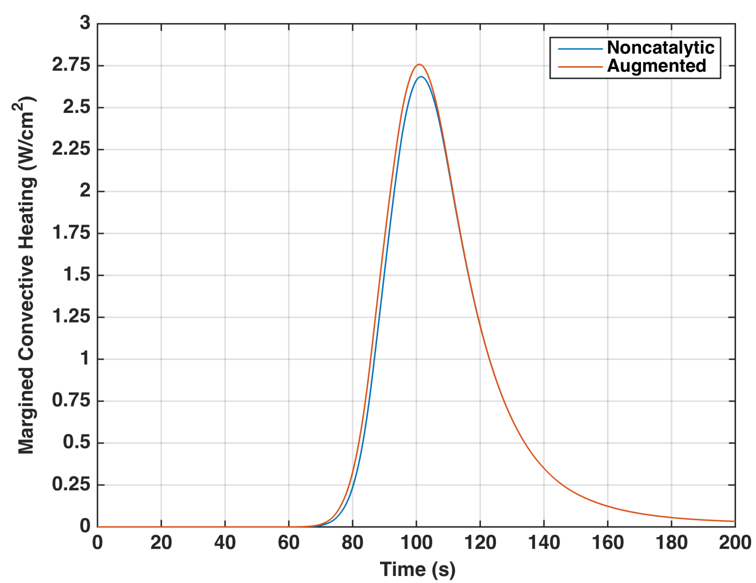
Effect of Catalycity

- DPRL simulations were performed to determine the impact of catalycity on PCC and BIP environments
- A time-varying catalycity augmentation factor was derived by dividing the turbulent fully-catalytic heating by the turbulent non-catalytic heating
- Sizing was done at a few locations using the catalycity augmentation factor
  - The impact on heat load and sizing is very small due to the fact that the augmentation factor approaches 1 around peak heat flux time

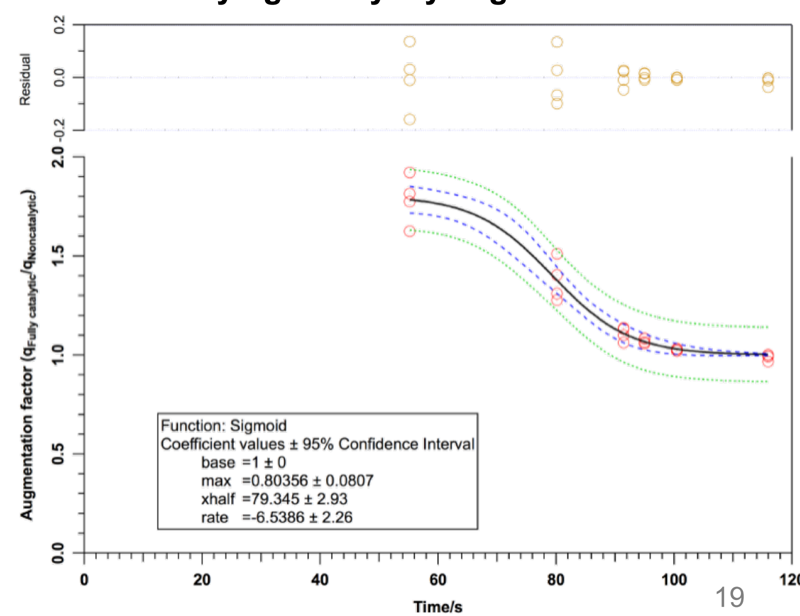
Heat Flux Ration from DPLR Simulations



Catalycity augmentation Factor Applied to the Heating Environment for PCC Leeside Sizing Location

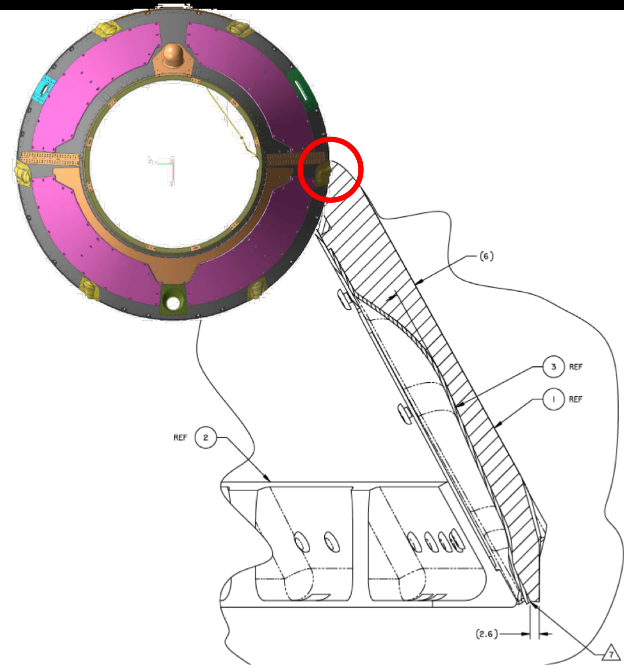


Time-varying Catalycity augmentation Factor

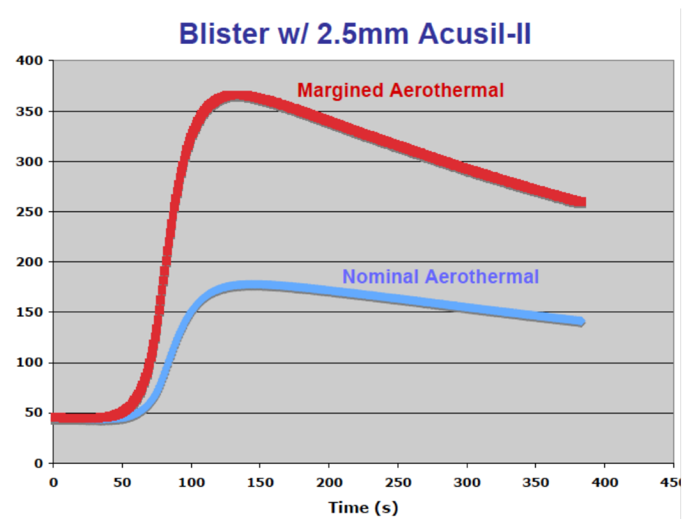


Blister Analysis

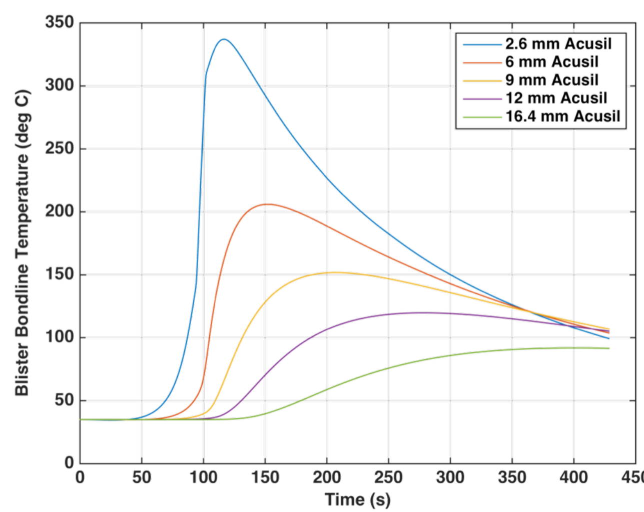
- Varying TPS thickness over the blisters
  - Minimum TPS thickness is 2.6mm at the bottom of the blister
  - Local minimum of 6mm near the top
- Heating augmentation up to 14 W/cm^2 from RCS plume at the 3 o'clock blister
- MSL approach
  - FIAT analysis was done assuming 2.5mm of Acusil using margined heating environments
  - Peak bondline temperature of 360C was deemed acceptable
  - Arcjet test was done to verify
  - Measured temperatures at the backface of Aluminum was significantly lower than model predictions (conservative model)
- For Mars2020, we performed FIAT analysis and showed that blister bondline temperature is bounded by MSL analysis



MSL FIAT Analysis with Margined Environments



Mars2020 FIAT Analysis with Margined Environments



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