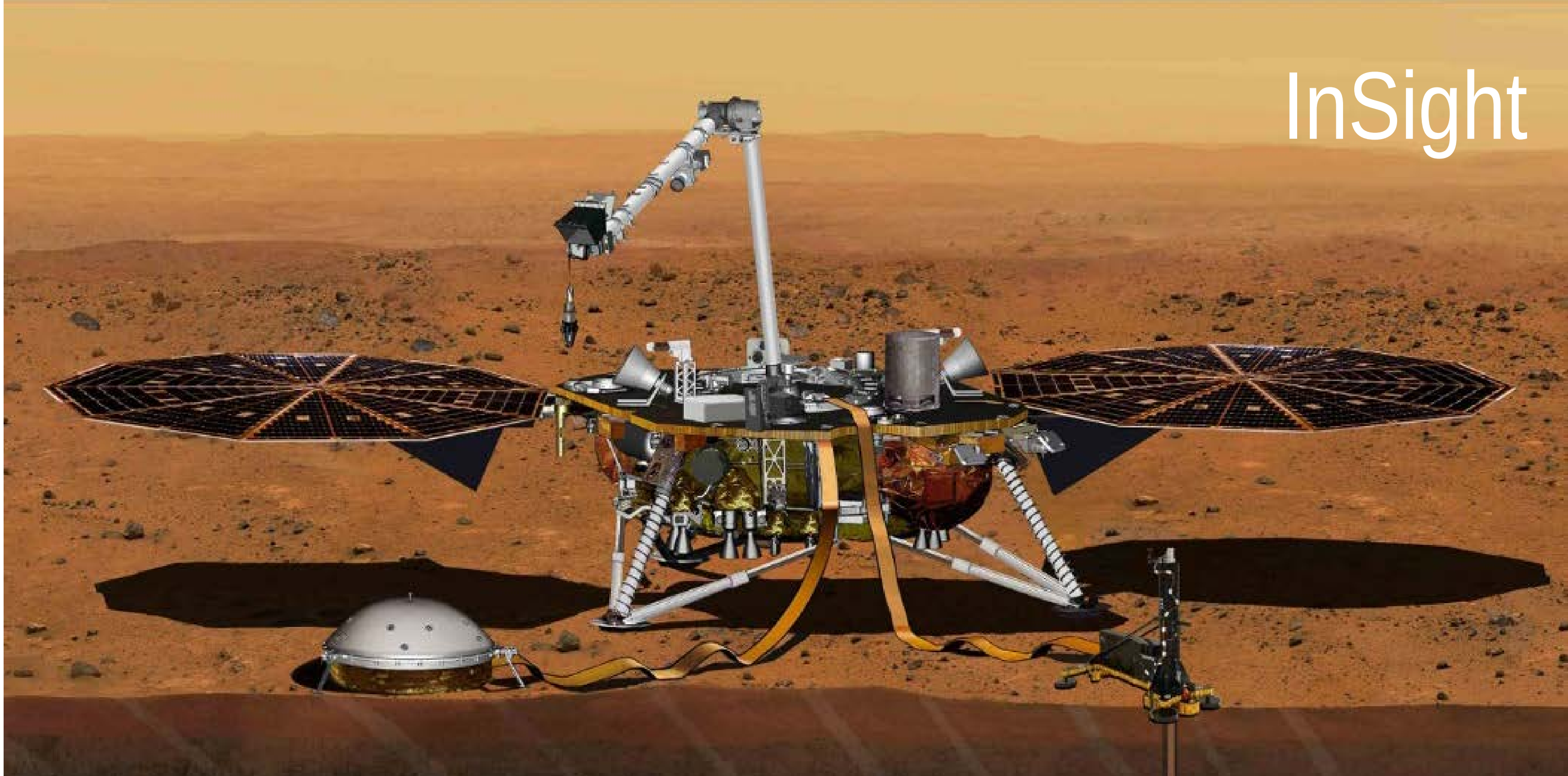

InSight Aerothermal Environment Assessment

Presented by

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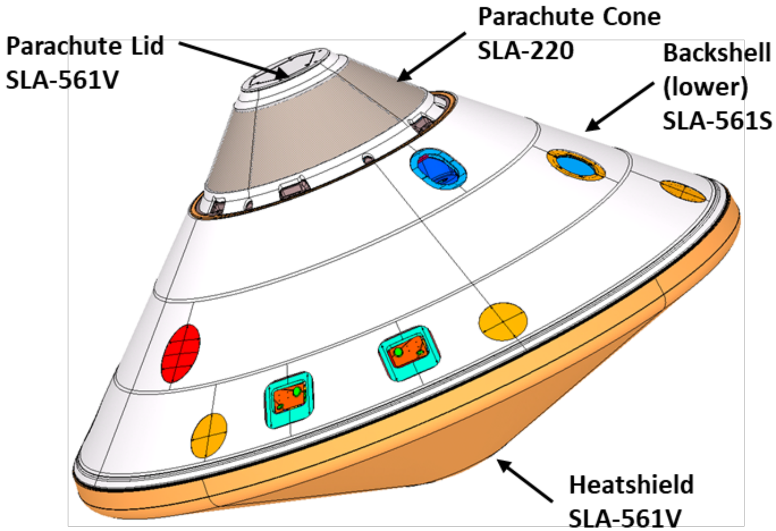
Overview

- InSight entry vehicle geometry
- Preflight aerothermal analysis approach
- A quick word about thermal protection system (TPS) materials sizing
- Postflight aerothermal analysis
- Summary and Conclusions

InSight Entry Vehicle Geometry and Design Trajectories

- Essentially build-to-print from Phoenix entry vehicle
  - – 70º sphere cone forebody configuration
  - – Conical backshell and parachute cone
  - – InSight landing was scheduled during Mars dust storm season
  - – Allowed for increase in forebody TPS due to dust erosion
- Design trajectories determined from Monte Carlo simulations about the target trajectory
  - – Bounding entries found that subjected the vehicle to the 99th percentile maximum heating rate (MHR) and the maximum heat load (MHL)
- Aerothermal analysis and TPS sizing was required to confirm Phoenix design was adequate



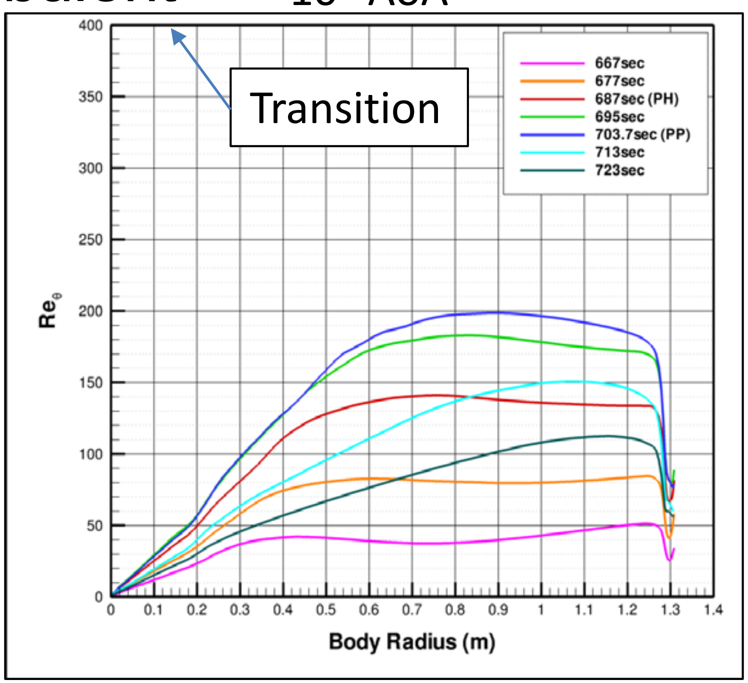
Aerothermal Analysis Approach

- Lockheed Martin performed extensive 2D/axisymmetric and full 3-D CFD utilizing the LAURA (Langley Aerothermodynamic Upwind Relaxation Algorithm) program on MHR and MHL trajectories
- NASA Ames provided IV&V (Independent Verification and Validation) by performing similar analyses using the DPLR (Data Parallel Line Relaxation) code
- Ballistic entry for 2-D runs, but 10º AoA 3-D analysis used to assess onset of turbulence
- Both codes analysis sets were performed with the Martian atmosphere modeled using a Mitcheltree 8-species, 12 reaction model over a supercatalytic wall in radiative equilibrium
  - CO_2, CO, N_2, O_2, NO, C, N, O

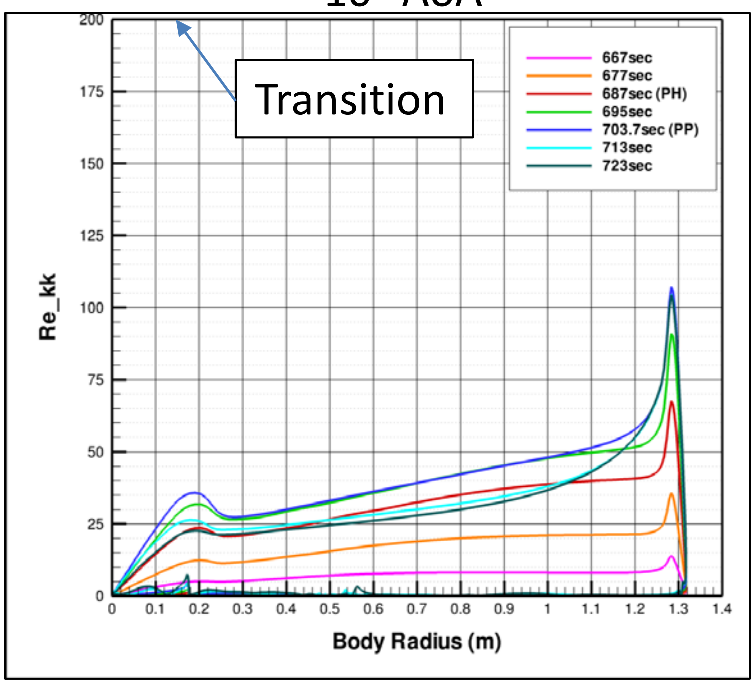
New Turbulent Transition Criteria Developed from MEDLI Data

- The MSL flight reconstruction along with MEDLI (MSL EDL Instrumentation) suite led to the development of an update to the criteria for turbulent transition
  - Smooth wall transition: $Re_\theta = 400$
  - Rough wall transition: $Re_{kk} = 200$
- Based on these criteria, InSight flow not expected to be turbulent

10º AoA



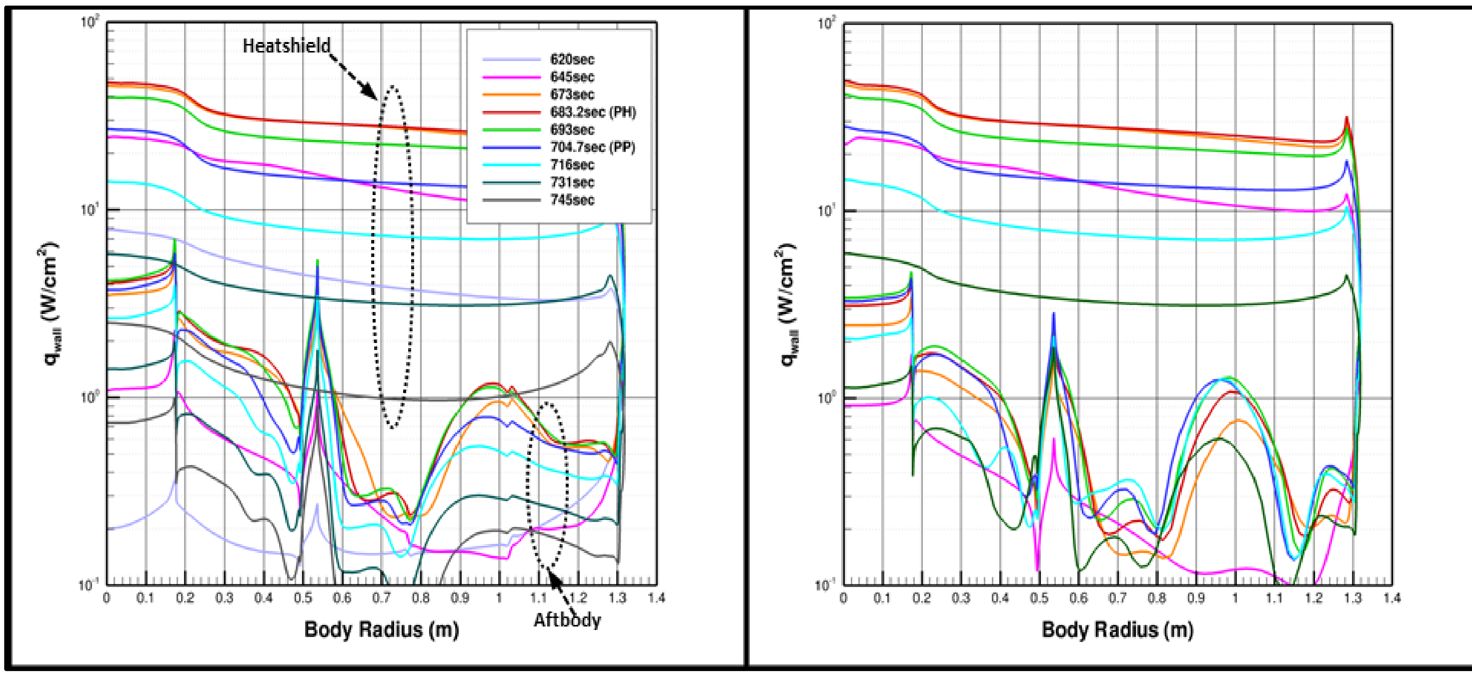
10º AoA



Comparison of Code-to-Code Aerothermal Results

- Laminar analyses of InSight entry vehicle showed nearly identical results on the heatshield
- Differences on the lower backshell occurred inside regions of flow re-circulation, which are unsteady
  - Peak heating values were used to size the TPS

LAURA results | DPLR results



InSight – Radiant Heating Analyses

- InSight was the first US mission to Mars to include the effects of contribution of radiation on the heating of the aftbody components
  - Previously thought to be negligible
  - Recent (to ~2014) theoretical analyses, simulations, experiments and flight data from Schiaparelli showed that heating from mid-wave IR CO_2 (prevalent in the wake) radiation would be significant
- Analyses showed that radiant heating was comparable and sometimes greater than convective heating on aftbody components

Radiant Heating Tools and Approach

Preflight

- HARA (High-temperature Aerothermodynamic RAdiation) and NEQAIR (Non-EQuilibrium Radiative Transport and Spectra) programs were used
  - Tangent slab analysis approach utilized (overly conservative)
  - Spotwise comparisons between full angular integration and tangent slab determined knock-down factors for various components

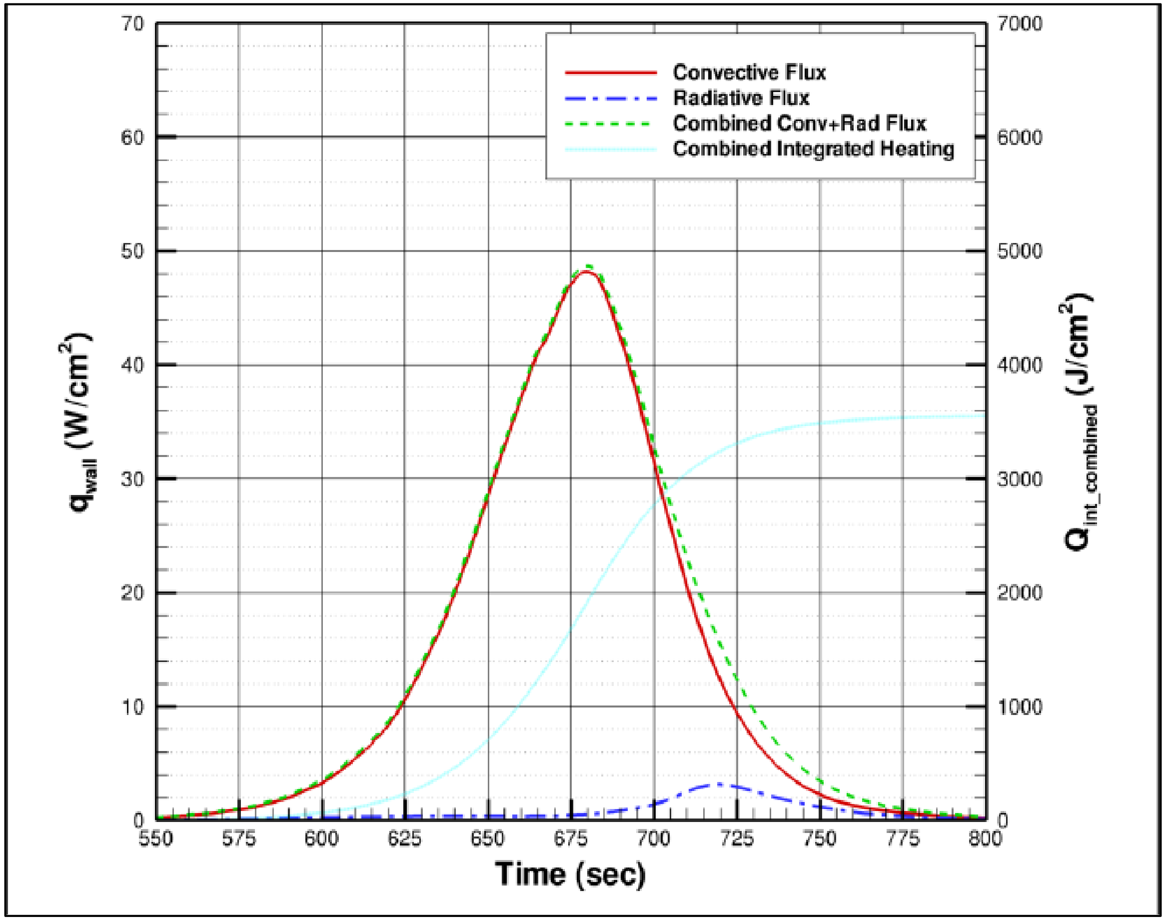
Postflight

- HARA and NEQAIR analyses with full angular integration were performed
  - Efficiency of these analysis techniques were improved between pre- and post-flight

- InSight established the methodology for modeling radiation for future missions – including margining approach

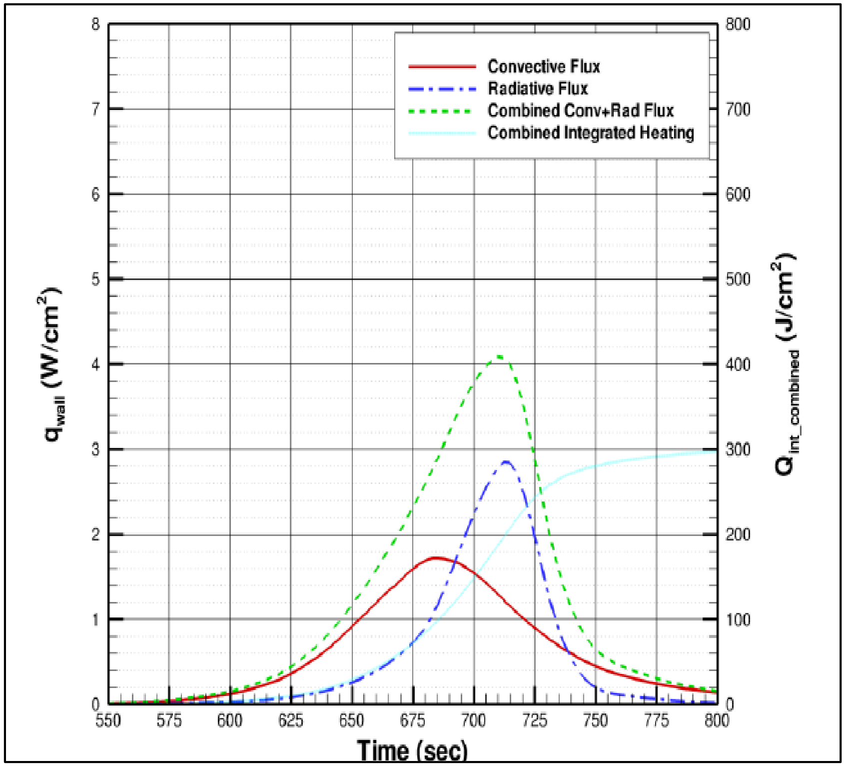
Predicted Forebody Aerothermal Heating

- Forebody stagnation point heating barely affected by including radiation

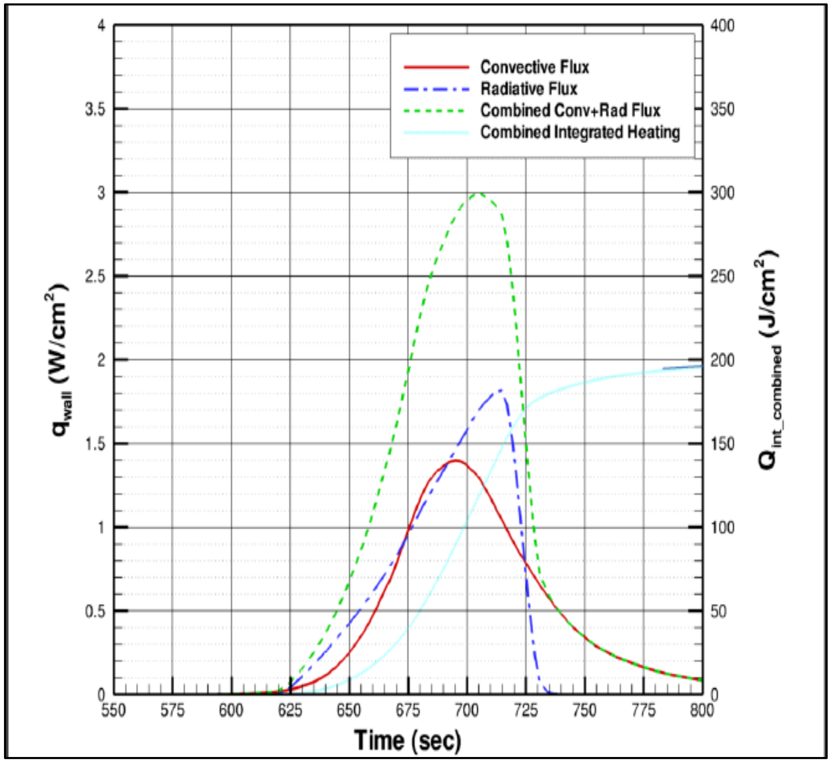


Predicted Aftbody Aerothermal Heating - 1

- Analysis on aft body components showed that radiation should be considered for vehicle TPS design
- Largest effects observed on the backshell



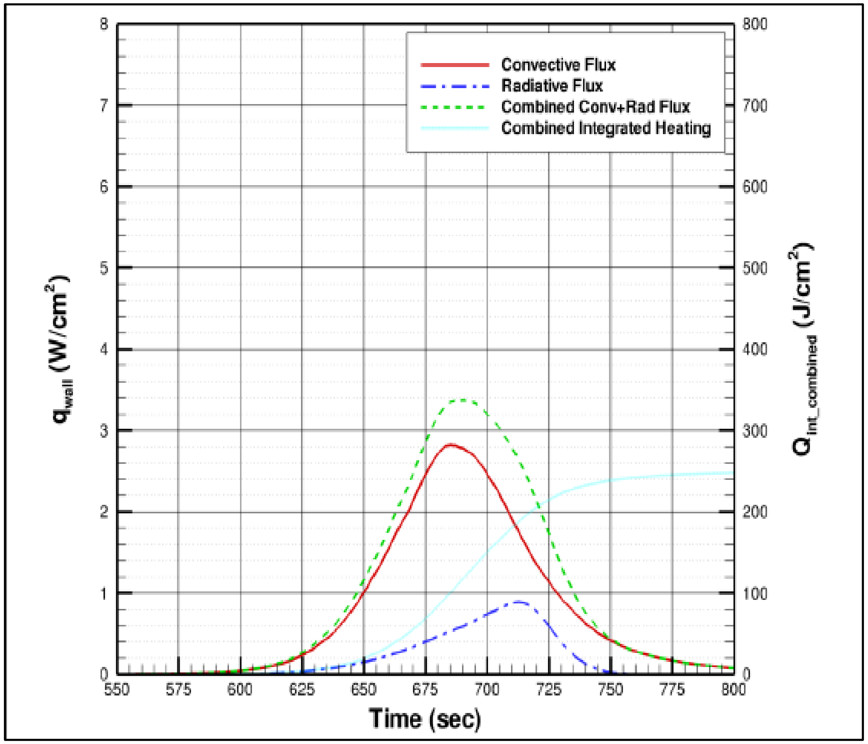
Main seal heating



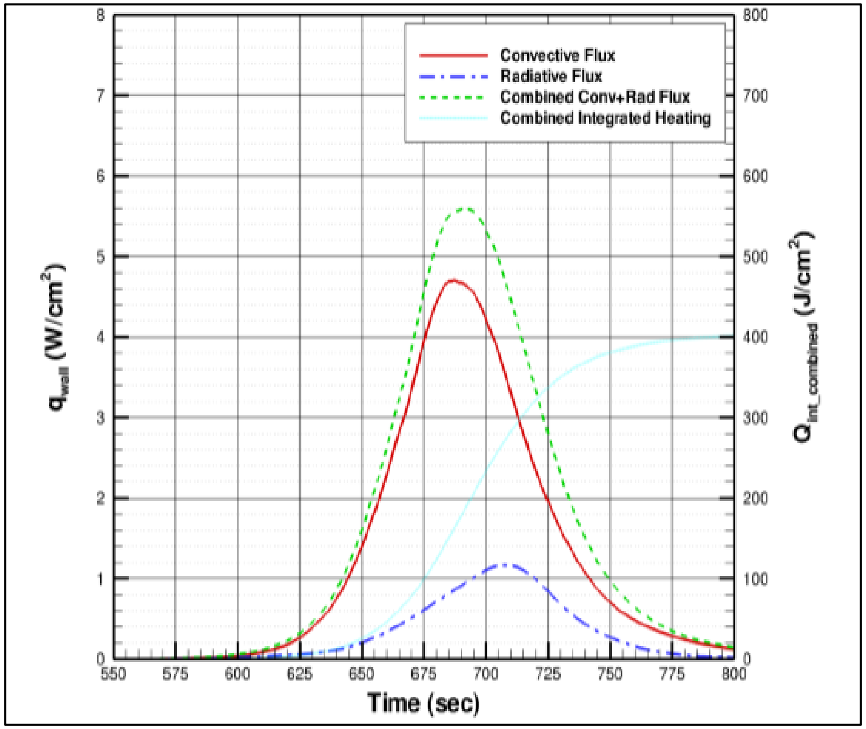
Mid lower backshell heating

Predicted Aftbody Aerothermal Heating - 2

- Parachute cone and lid radiation effects smaller, but certainly not negligible



Parachute cone heating



Parachute lid heating

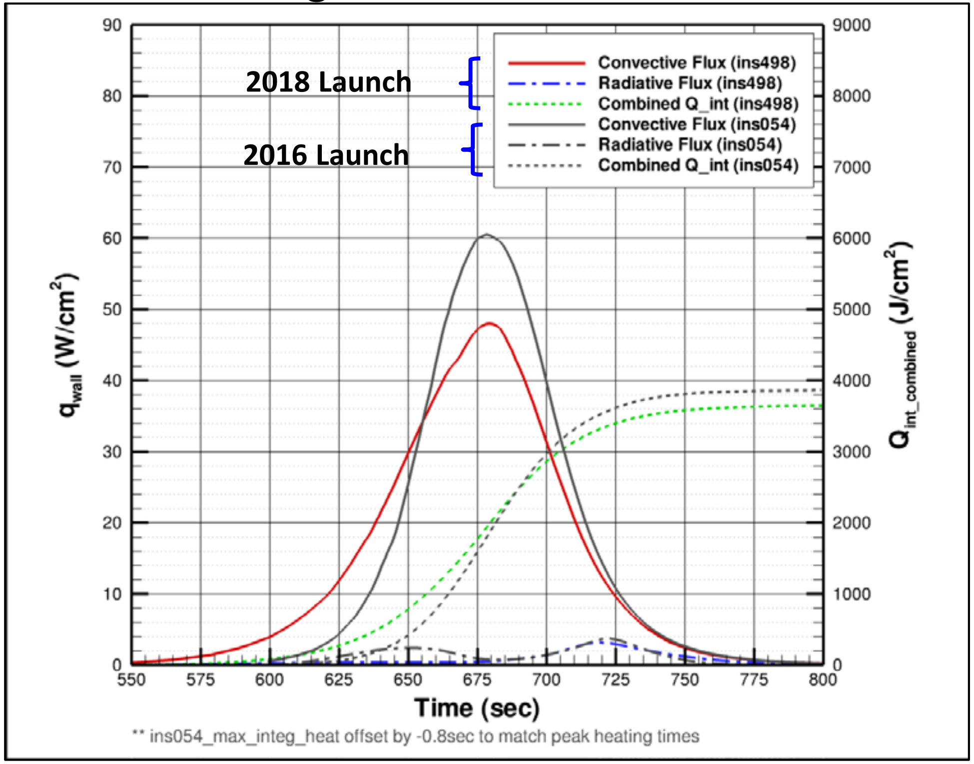
TPS Sizing Approach

- Sizing based on MSL model of RSS-ed thicknesses required for nominal environments, margined environments, and for a reduced bondline temperature due to uncertainties in material properties
- Phoenix designed with constant TPS thicknesses for each component (no thermal binning)
- First pass looks at peak heating for a component placed at the location with the least thermal mass (on that component)
- Heatshield peak heating is at the stagnation point (due to laminar heating)
  - Dust erosion evaluated based on engineering approximations
  - Total heatshield thickness based on sum of aerothermal sizing and dust erosion
- Analyses for all other components showed that Phoenix design was adequate

TPS Sizing Surprises For Delayed Launch -- 1

- Initial sizing based on 2016 launch showed Phoenix design was adequate, space craft was built and stored prior to delay
- Quick look in 2016 at 2018 launch trajectories showed lower peak heat fluxes and comparable heat loads for all components, so no worries (we thought)

Stagnation Point Results



- Analysis resumed in late 2017 to confirm TPS adequacy

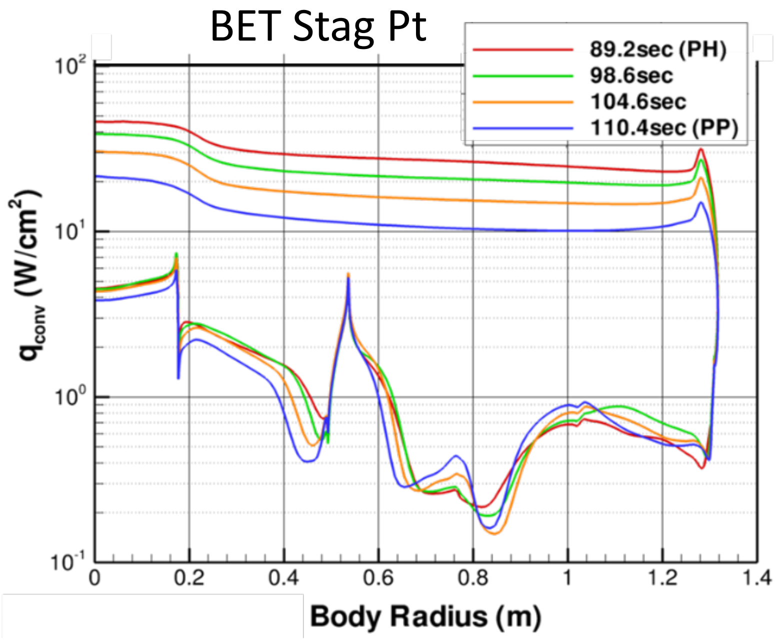
TPS Sizing Surprises For Delayed Launch -- 2

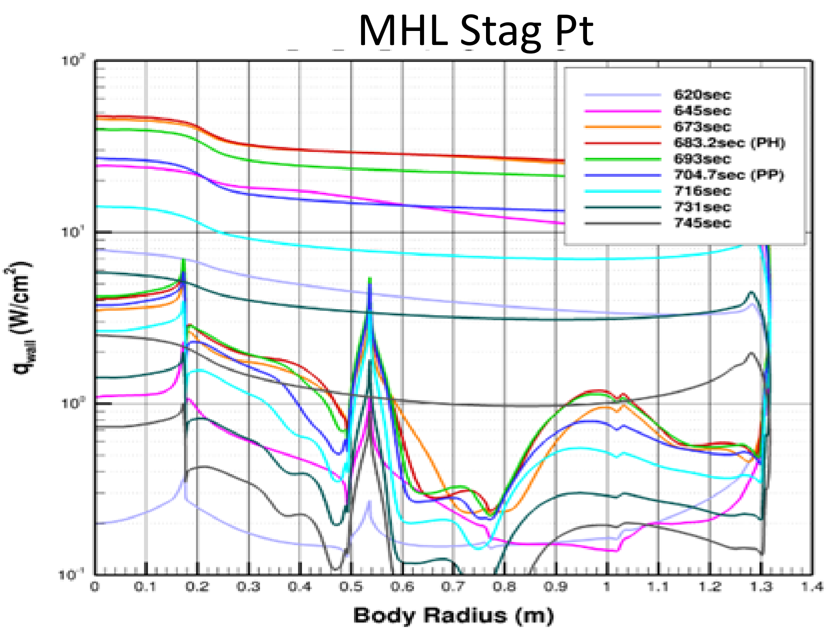
- Analyses showed that 2018 launch required more TPS for all components!
  - With lower heating and comparable heat load to 2016 entry?
- Found that the length of the heat pulse had a large effect in the increases
- “Pencils were sharpened”
  - Thicknesses now evaluated at several locations on each component with the local heating and local structure (no more “worst on worst”)
- InSight as-built thicknesses were assessed to be adequate

- Moral: just looking at heat flux and heat load is not enough to inform TPS designers when comparing one trajectory to another

Post-flight Aerothermal Analysis of Best Estimated Trajectory

- BET was used to determine the predicted heating on the spacecraft and compared to the predictions used for design
- BET peak heating conditions very similar to MHL design conditions
- BET peak pressure condition(faster descent) lower than MHL

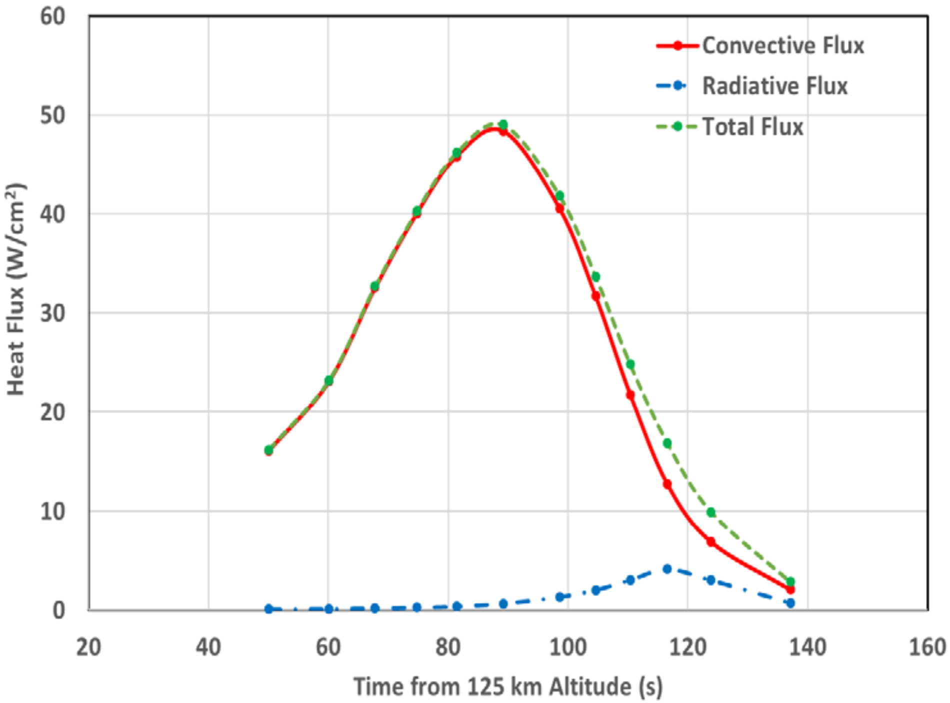




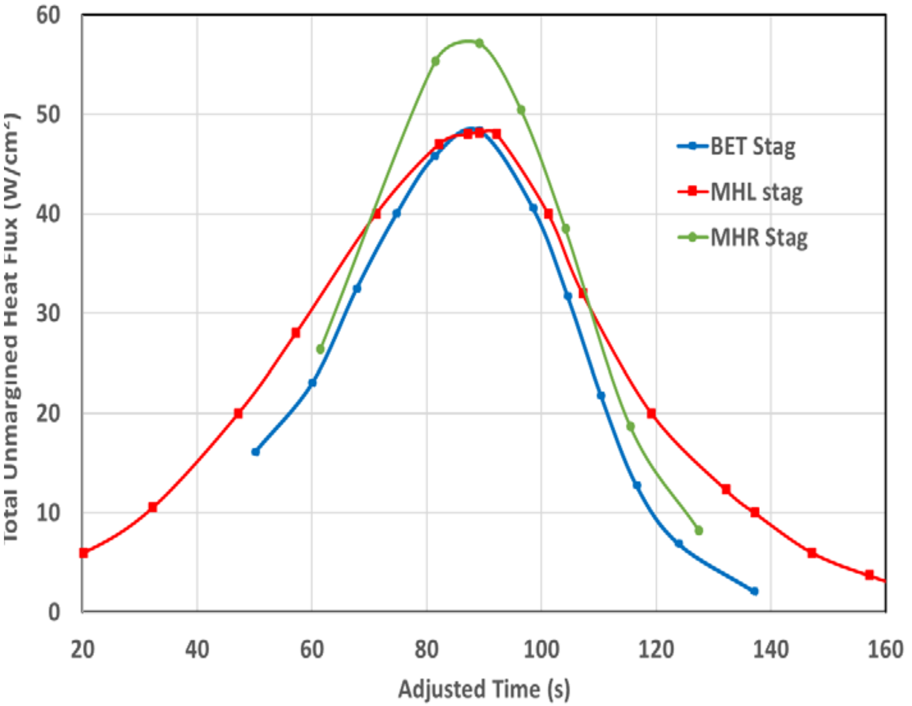
BET vs MHL Stagnation Point Heating History Comparison

- BET peak heating rate ~same as the MHL design trajectory
- BET pulse time much shorter than MHL (comparable to MHR)
- Atmospheric observations showed little-to-no dust
- Based on TPS sizing lessons learned, TPS thicknesses should have adequately protected the heatshield (no instrumentation to confirm)

Predicted Stag Pt Heating for BET



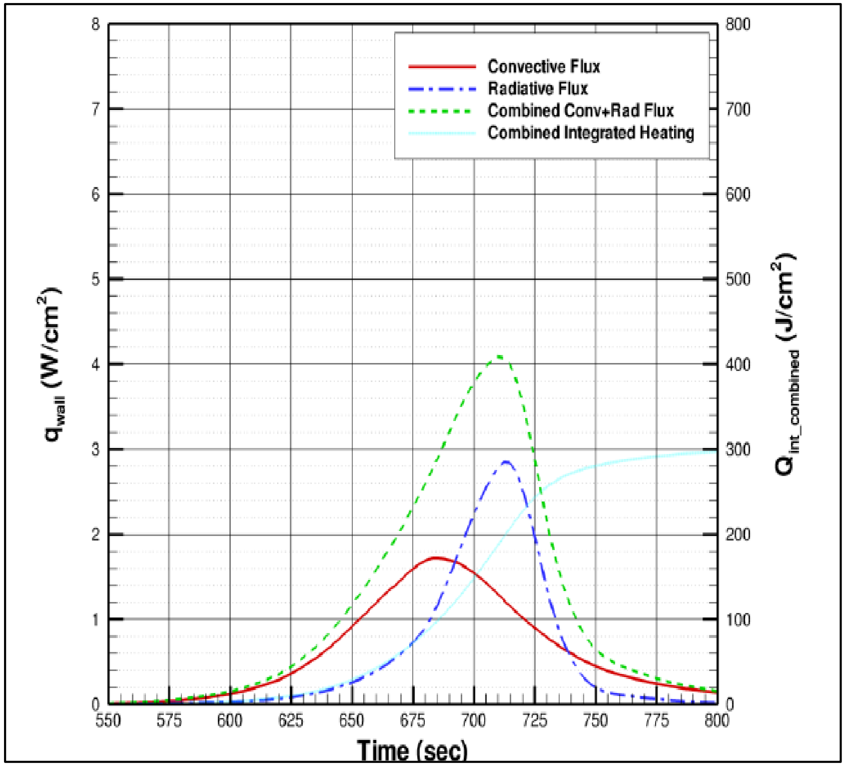
Comparison of Stag Pt Total Heating



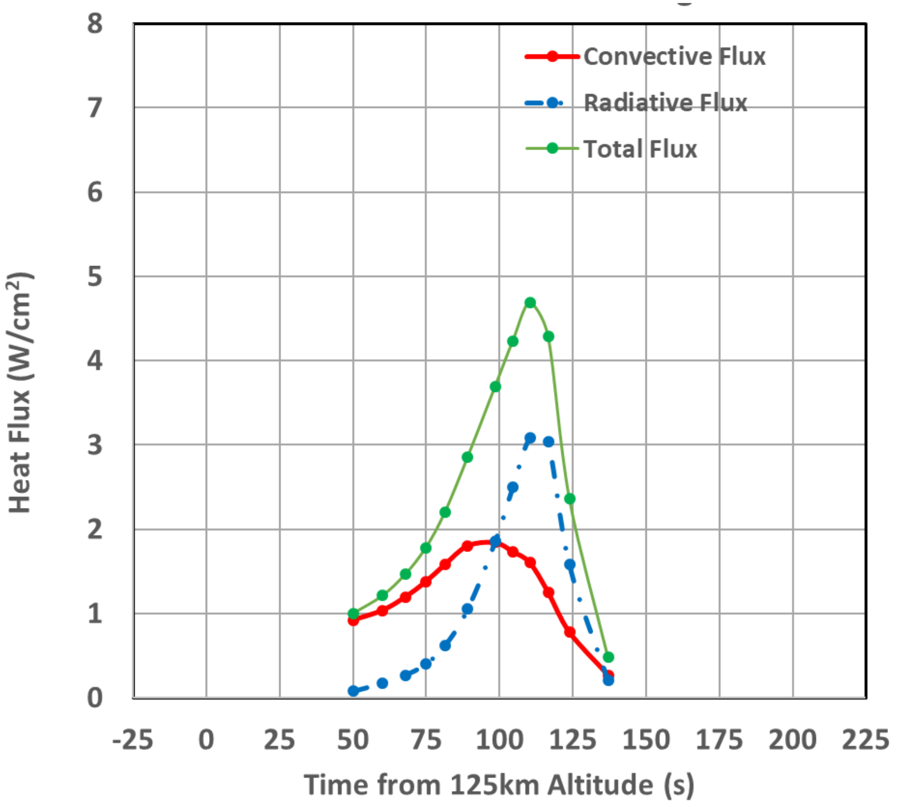
Comparison of Predicted Heating on Main Seal

- Main seal predictions show peaks are higher, however, duration *much* shorter than design
- Structure at main seal very "beefy", so no concerns about TPS

MHL Design Trajectory Predictions



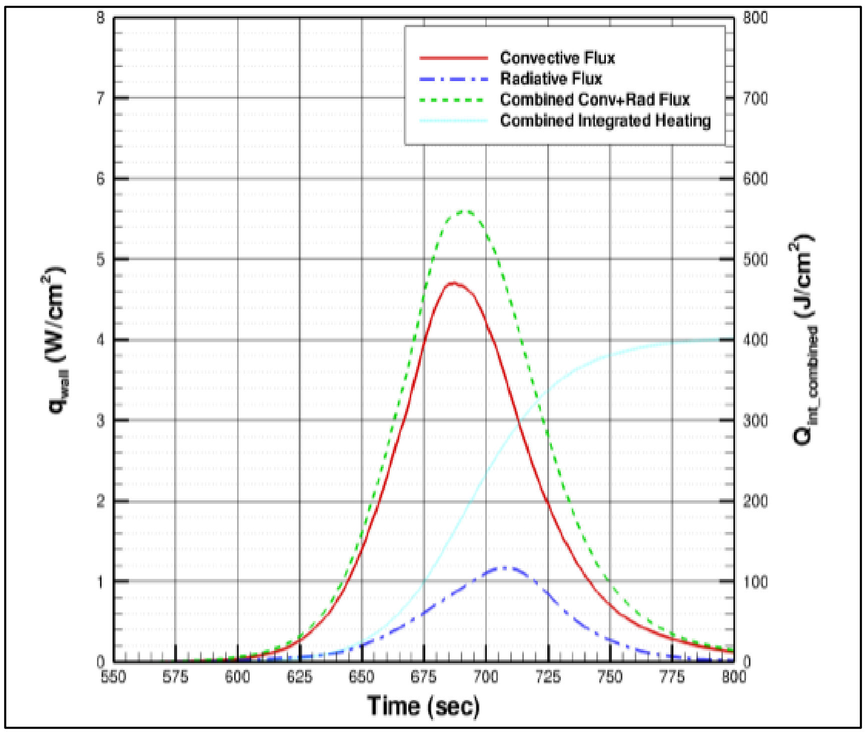
BET Predictions



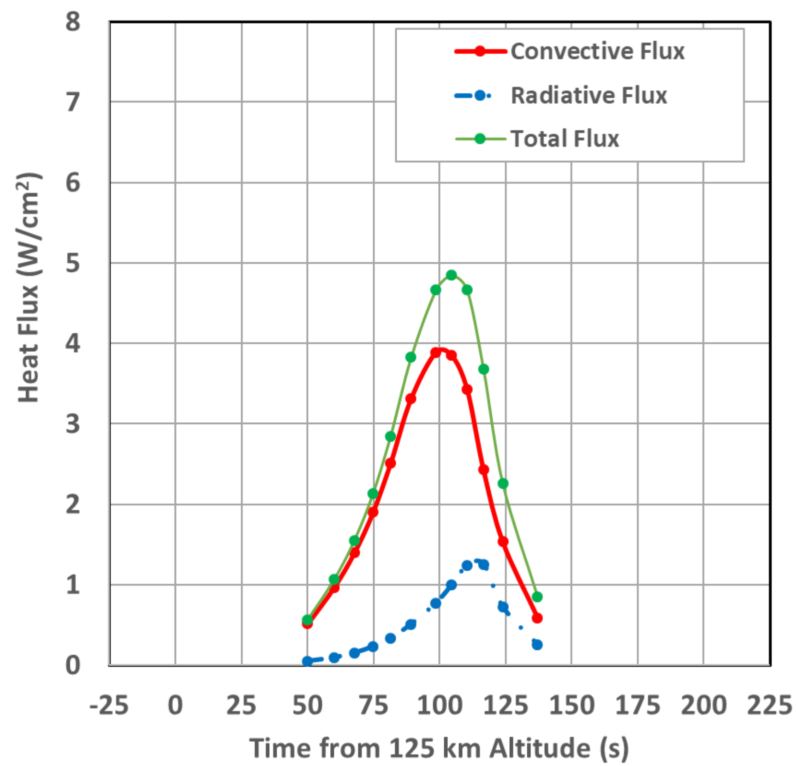
Comparison of Predicted Heating on Parachute Lid

- All heating lower (and shorter times) for BET for the parachute lid

MHL Design Trajectory Predictions



BET Predictions



Summary and Conclusions

- InSight was the first US Mars mission to consider the radiative heating contribution for the TPS sizing
  - Radiative heating on forebody predicted to be nearly negligible
  - Radiative heating on aft components predicted to be comparable to or larger than convective heating
- Predicted BET environments were less severe than design environments
  - All as-built TPS thicknesses assessed as adequate with no concerns
- In the future, NASA will not neglect radiation when designing TPS for spacecraft going to Mars
- For confirmation of these effects, MEDLI2 (to fly on Mars 2020) will measure radiative and total heat flux on the backshell

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