



# Overview of Mars Sample Return – Earth Entry System Woven Roughness Heating Augmentation Test in NASA Langley's Mach 6 Wind Tunnel

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# Presentation Outline



- Motivation
- Test Overview
- Results
- Impact



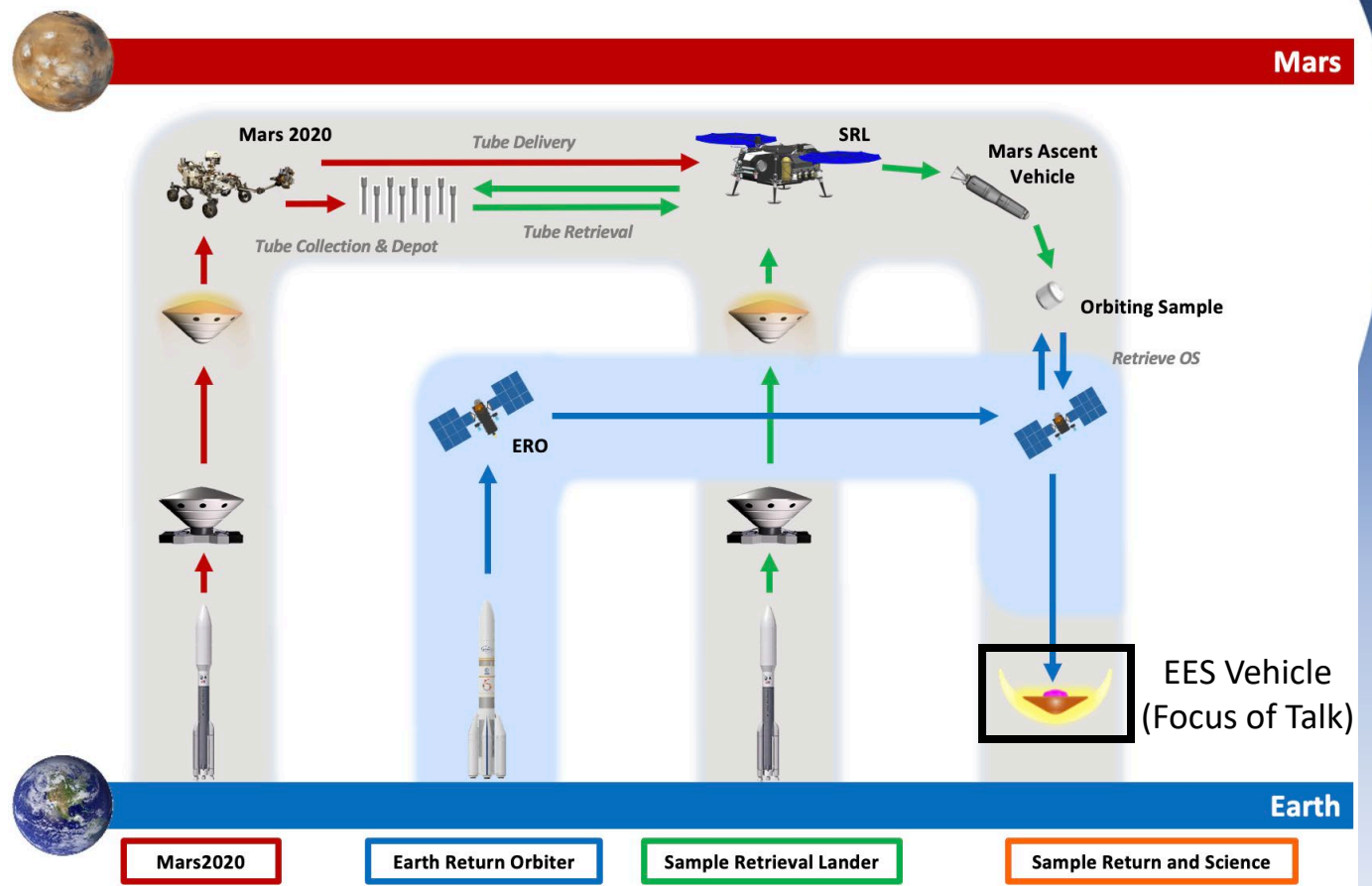


# Motivation

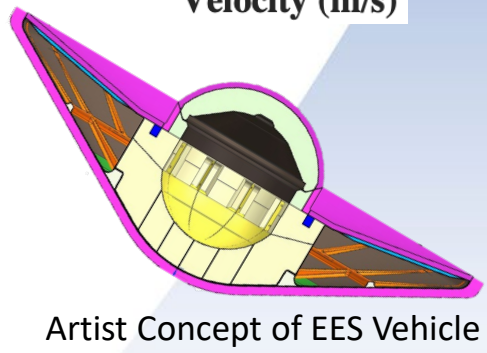
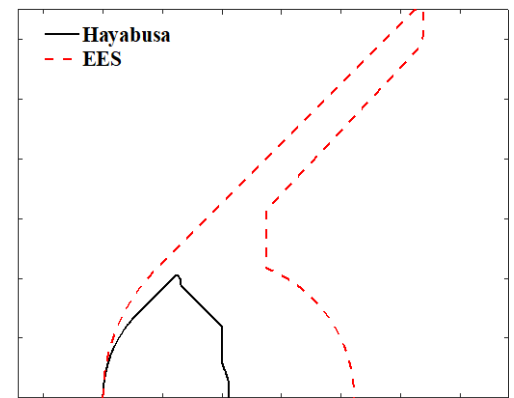
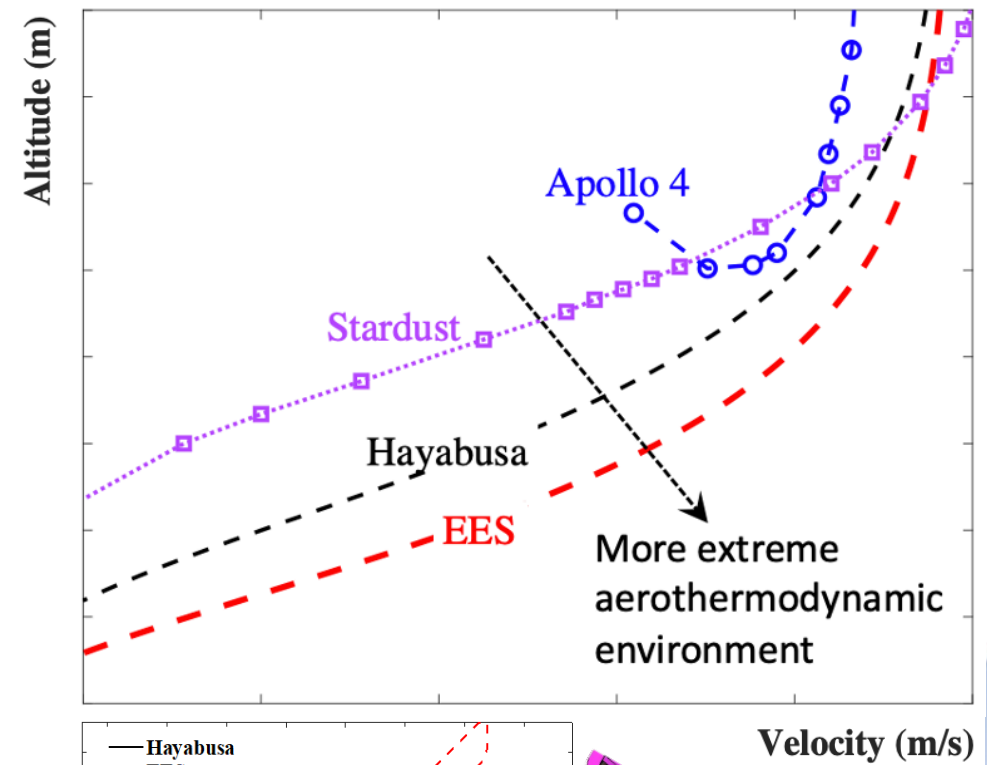


# Planned Mars Sample Return Campaign Overview

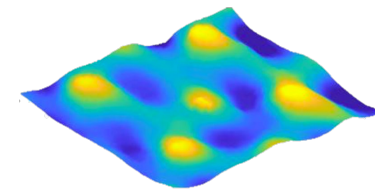
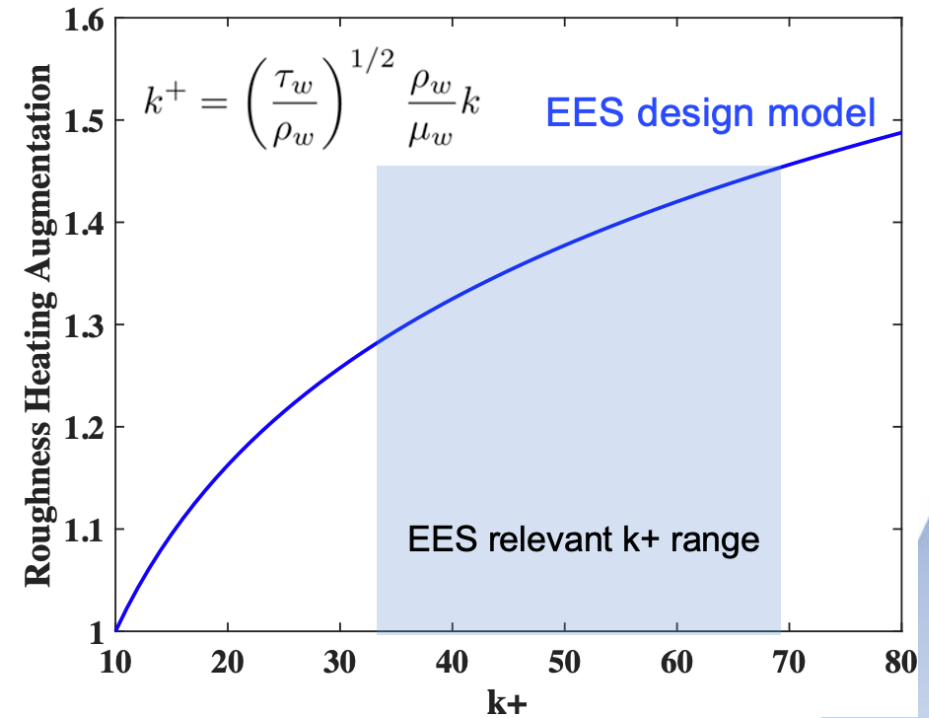
- The Earth-Entry System (EES) would be responsible for performing Entry, Descent, and Landing (EDL) at Earth
  - Strict one-in-a-million reliability requirement for EES poses many design challenges
- Computational tools and physics-based models used to characterize EES aerothermal environment
- These environments are used for thermal protection system (TPS) sizing and design
  - Heat flux determines TPS material
  - Heat load dictates TPS thickness



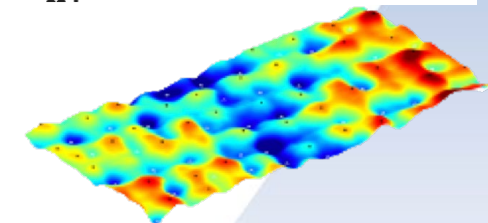
- EES concept is a 1.3-m diameter 52.5-deg sphere cone with a woven 3MDCP TPS
  - Would be first NASA mission to use this cone angle as well as the first to utilize a woven TPS
- EES's planned steep entry flight path angle and large size would result in a far more extreme aerothermal environment than past NASA Earth missions
  - EES would experience the highest peak heat flux seen by any NASA Earth entry vehicle
  - Unparalleled levels of roughness and turbulent effects on convective heating



- Computational solutions are obtained with NASA CFD solvers LAURA and DPLR
  - Cebeci-Smith turbulence model is used for attached flow regions
- Dahm roughness model is used to obtain convective heating augmentation factor
  - Factor is applied as a post-processing step to turbulent CFD convective heating results
  - Model is a correlation based on  $k^+$  (roughness Re)
  - Post arc-jet 3MDCP samples from turbulent tests scanned to obtain simulation roughness height

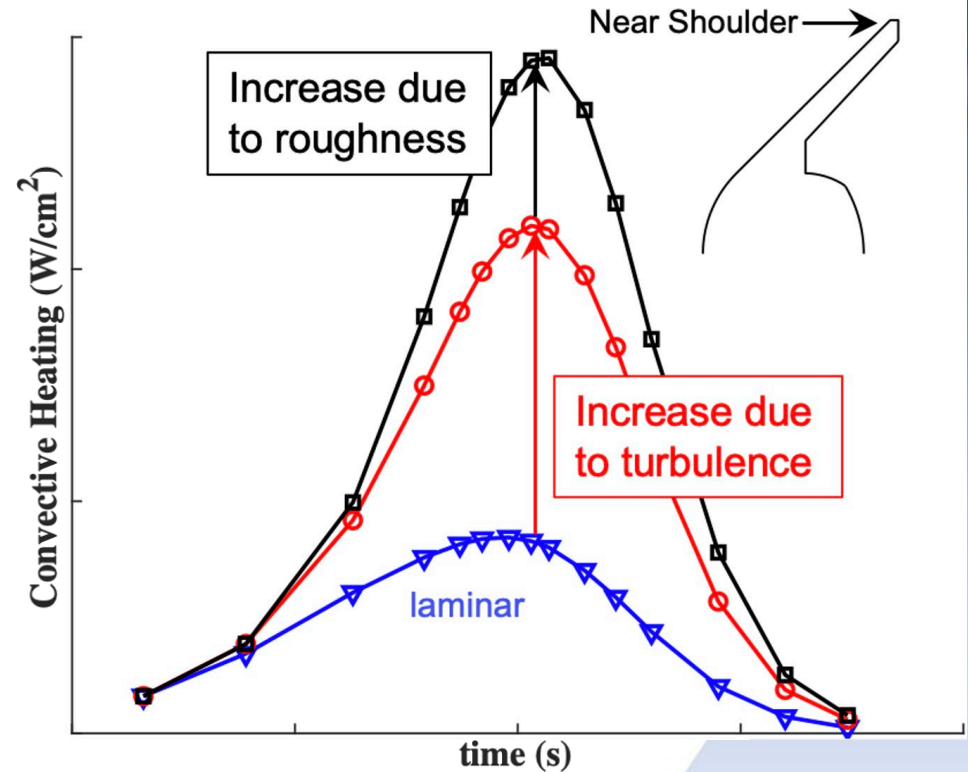


3MDCP roughness pattern



Post arc-jet scan of sample

- Heritage experimental data sets do not exist for:
  - Convective heating on a 52.5-deg sphere cone geometry
  - Roughness convective heating on a woven surface
  - Surface heating with supersonic flow near roughness elements
- Lack of validation data adds additional uncertainty to surface convective heating predictions obtained with CFD
- To reduce uncertainties, test campaign was launched at NASA Langley's Mach 6 air tunnel
  - Goal to obtain turbulent convective heating data on a 52.5-deg sphere cone geometry at EES relevant  $k^+$  values and roughness
- Data will be used to assess conservatism of physics-based CFD models for turbulent and roughness heating augmentation
  - Used to update convective heating margin for EES TPS design



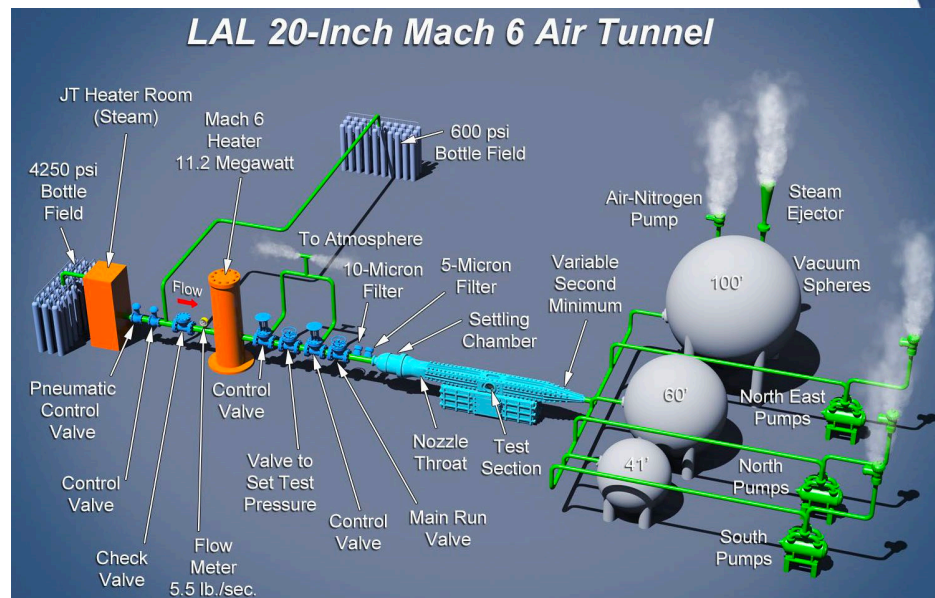
Near shoulder convective heating predictions



# Test Overview

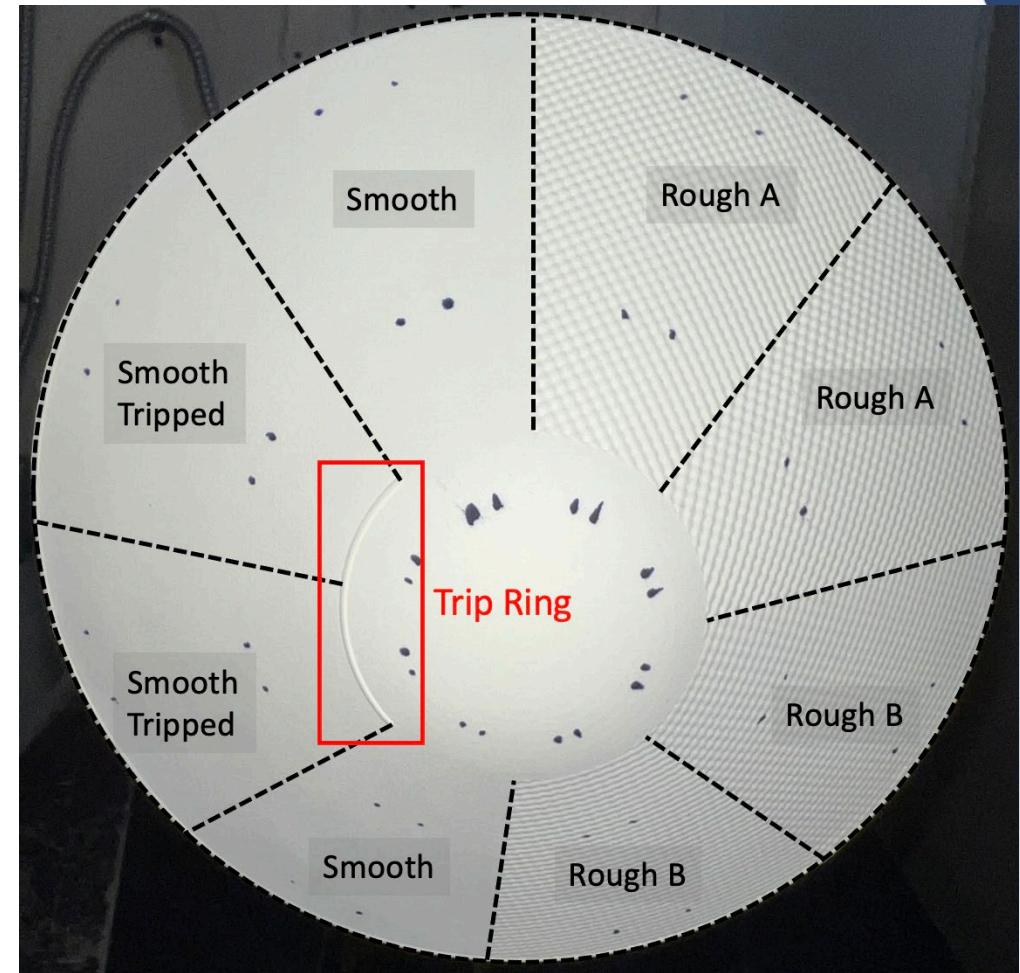


- First entry of MSR-EES test campaign in NASA Langley's Mach 6 air tunnel occurred in Spring 2023
  - Six cast ceramic 52.5-deg sphere cone models with a generic aftbody were tested
- Data for over 140 runs were obtained at Re spanning from 1-8 million/ft, encompassing a large range of  $k^+$  values
- Test goal was to measure roughness augmentation of convective heating on EES-relevant roughness patterns
  - Also was first comprehensive experimental aeroheating data set to be acquired on a 52.5-deg sphere cone geometry
- Global aeroheating measurements were made using phosphor thermography
  - Heating data are 3-D mapped to wind tunnel model geometry, enabling direct comparison to CFD



Mounted model in injection box of tunnel

- Model designed to obtain rough, smooth-wall laminar, and smooth-wall turbulent heating data simultaneously
  - Provides three distinct sets of validation data per run
- Model forebody is split into eight panels, half smooth and half with an EES-relevant patterned roughness
  - Two smooth panels have a trip ring at the nose-flank junction to induce smooth wall turbulence (indicated in red)
  - Top roughness panels vary from bottom roughness panels either in orientation or spacing (denoted as A or B)
- Baseline model roughness parameters (roughness height and spacing) derived from post arc-jet scans of 3MDCP
- Additional models varied roughness pattern in either height, peak-to-peak spacing, or weave orientation



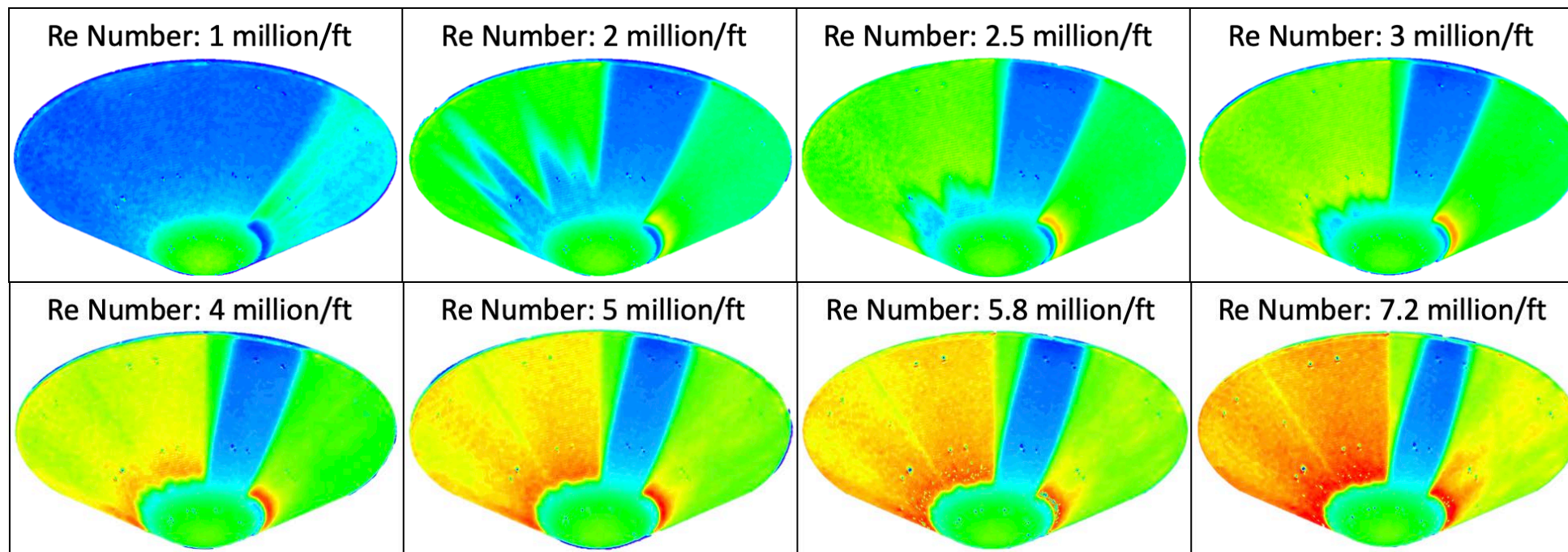
52.5-degree sphere cone model with panels denoted



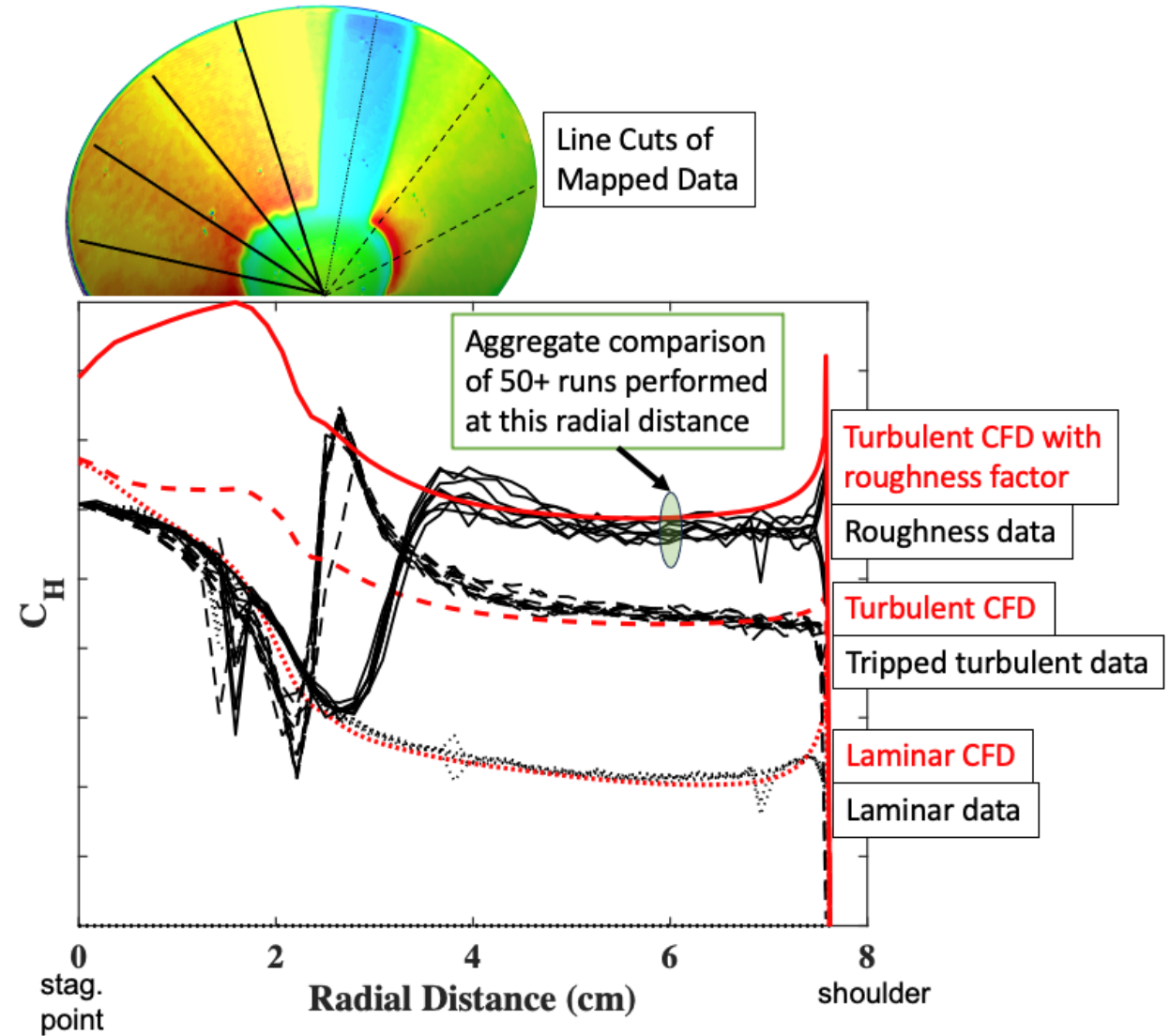
# Results



- Four of the eight panels of the wind tunnel model forebody are visible for a given run
  - Models can be rotated 180-deg to obtain heating data on both roughness types of each model (reducing the number of models needed)
- From mapped data, line cuts are taken of each panel and directly compared to computational predictions
  - Experimental data encompasses a large range of  $k^+$  values, capturing a wide range of flow behavior over roughness elements



- Line cuts used to directly benchmark computational turbulent and rough wall convective heating predictions
- Preliminary aggregate comparison performed for 50+ runs to validate computational physics-based models for wide range of  $k^+$  values
  - Location chosen far downstream to eliminate initial flow disturbances
- Direct comparisons help assess conservatism of computational tools that characterize the aerothermal environment EES would see

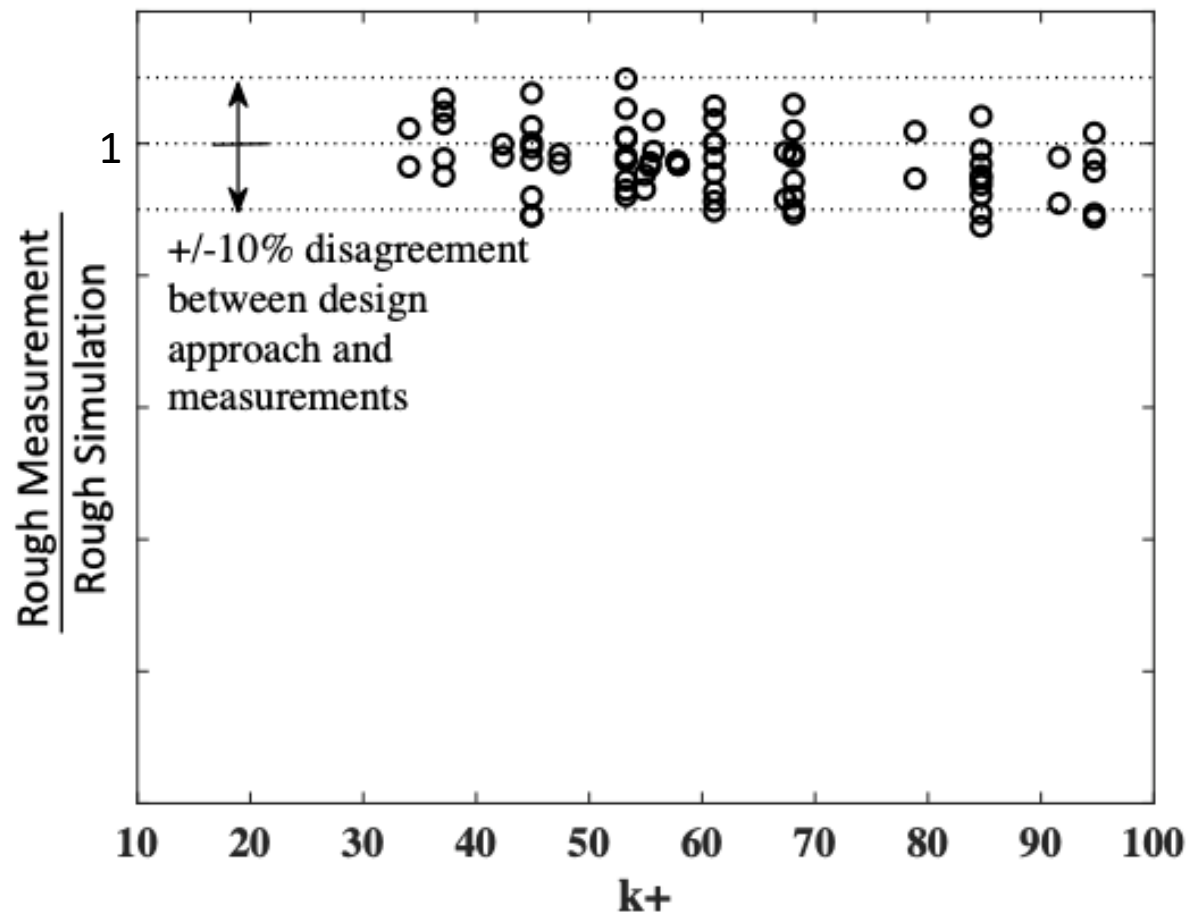




# Impact



- Preliminary comparison between experimental data and CFD for 50+ runs shows good agreement (within +/-10%)
  - Wide range of  $k^+$  values were plotted, fully encompassing the EES relevant  $k^+$  range
- This agreement provides confidence in the physics-based models used in CFD for the 52.5-deg sphere cone geometry and woven surface roughness
  - This comparison is used directly in margin assessment for TPS sizing and design



Comparison between experimental and CFD for 50+ runs



# Conclusions and Future Work



- The Earth Entry System would see the highest peak heat flux of any NASA Earth entry vehicle
  - Neither a 52.5-deg sphere cone geometry nor a woven TPS have been flown on a NASA mission prior
  - No heritage validation data sets exist, adding uncertainty to computational results
- To minimize uncertainty in CFD, a test campaign was launched in NASA Langley Mach 6 facility
  - Initial test entry was completed in Spring 2023, obtaining first experimental aeroheating data on woven surface roughness and the first aeroheating data on a 52.5-deg sphere cone
- Preliminary comparisons show good agreement between data obtained and computational predictions, providing confidence in CFD results and helping assess conservatism of physics-based CFD models and update the convective heating margin used for EES TPS design
- Largest remaining uncertainty in aerothermal environments for EES is impact on heating of supersonic flow near roughness elements
  - Additional tests are planned in Mach 6 in the coming months to reduce this uncertainty
  - Tests would provide the first experimental aeroheating data capturing this physical phenomenon

