



Mars Sample Return Earth Entry System Woven Roughness Mach 6 Aeroheating Test

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Presentation Outline



- Motivation
- Test Overview
- Results
- Impact

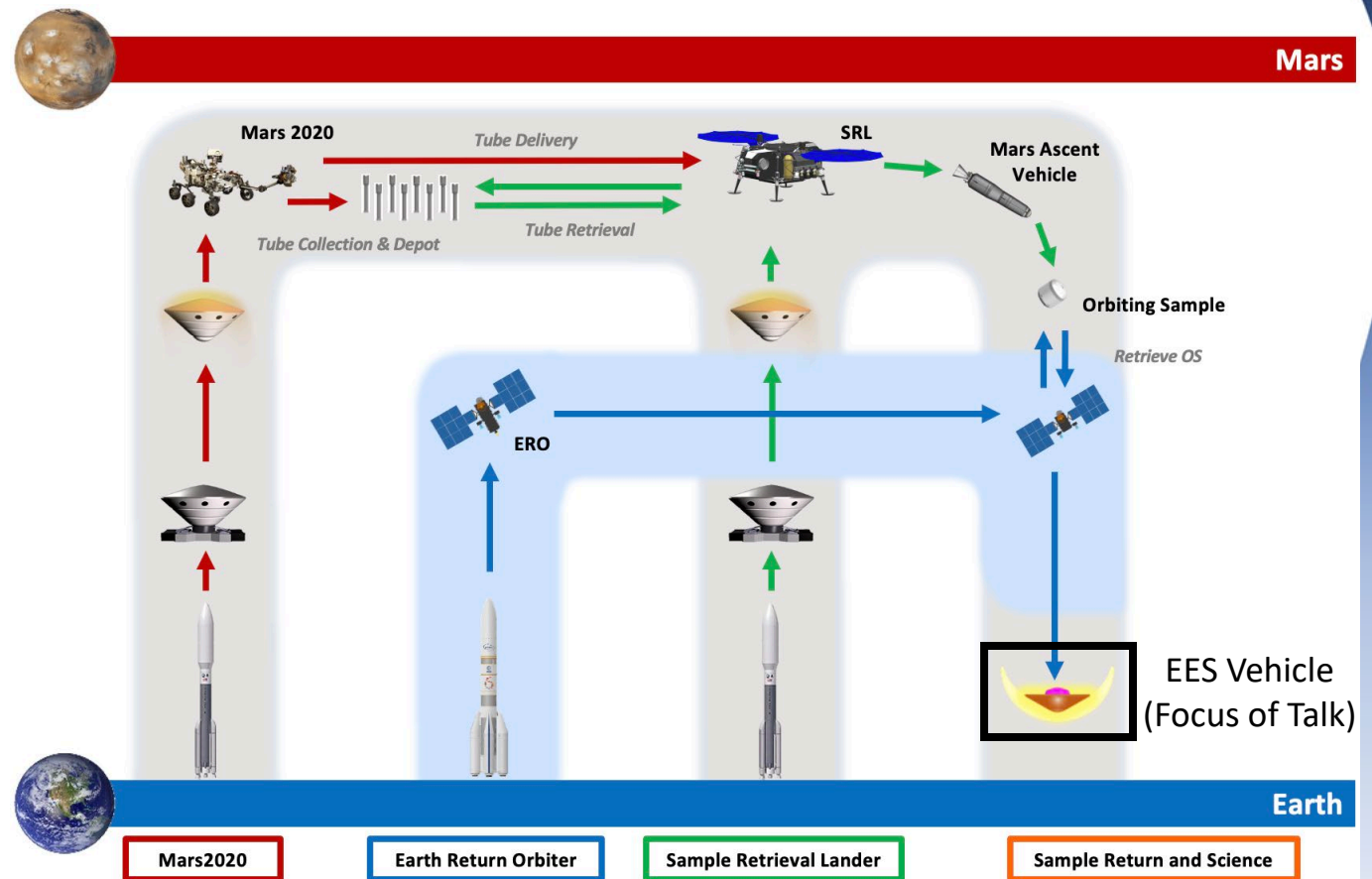




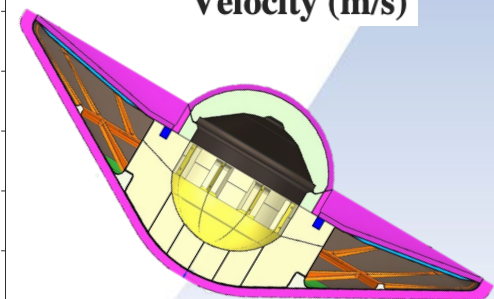
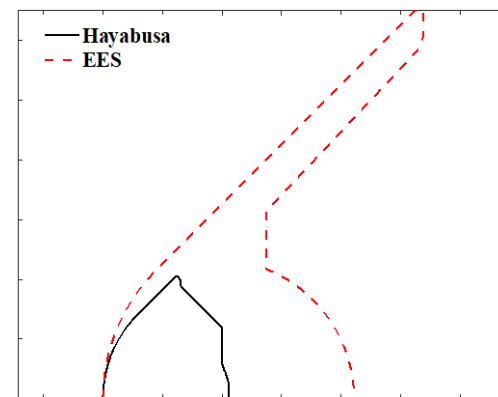
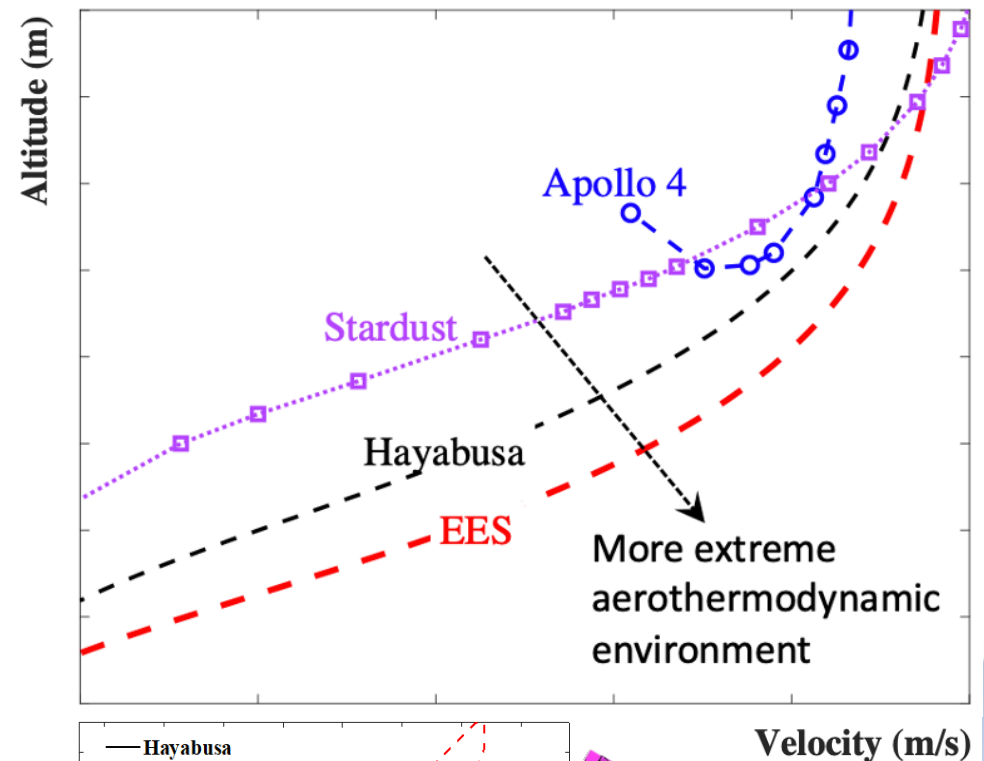
Motivation



- 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

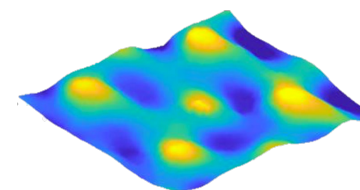
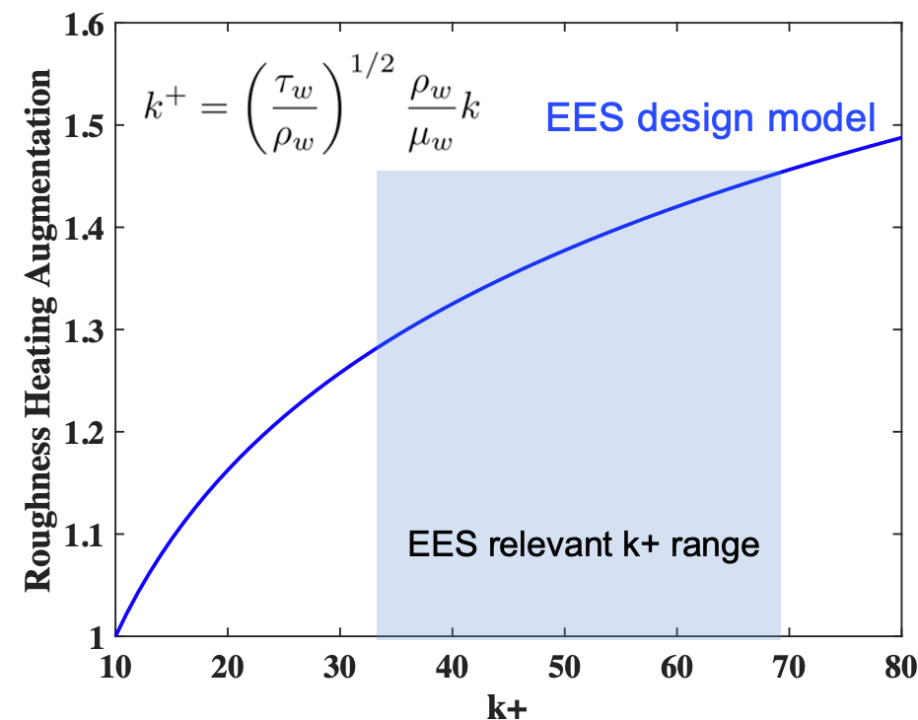


- EES concept is a 1.3-m diameter 52.5-deg sphere cone with a woven 3MDCP TPS
 - Would be first NASA mission to use this cone angle as well as the first to utilize a woven TPS
- EES has a planned steep entry flight path angle and its large size results in a much more extreme aerothermal environment than 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

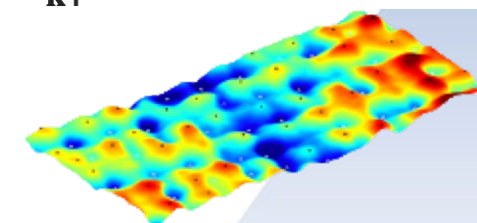


Artist Concept of EES Vehicle

- Computational solutions are obtained with NASA CFD solvers LAURA and DPLR
 - Cebeci-Smith turbulence model is used for attached flow regions
- Dahm roughness model [1] 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

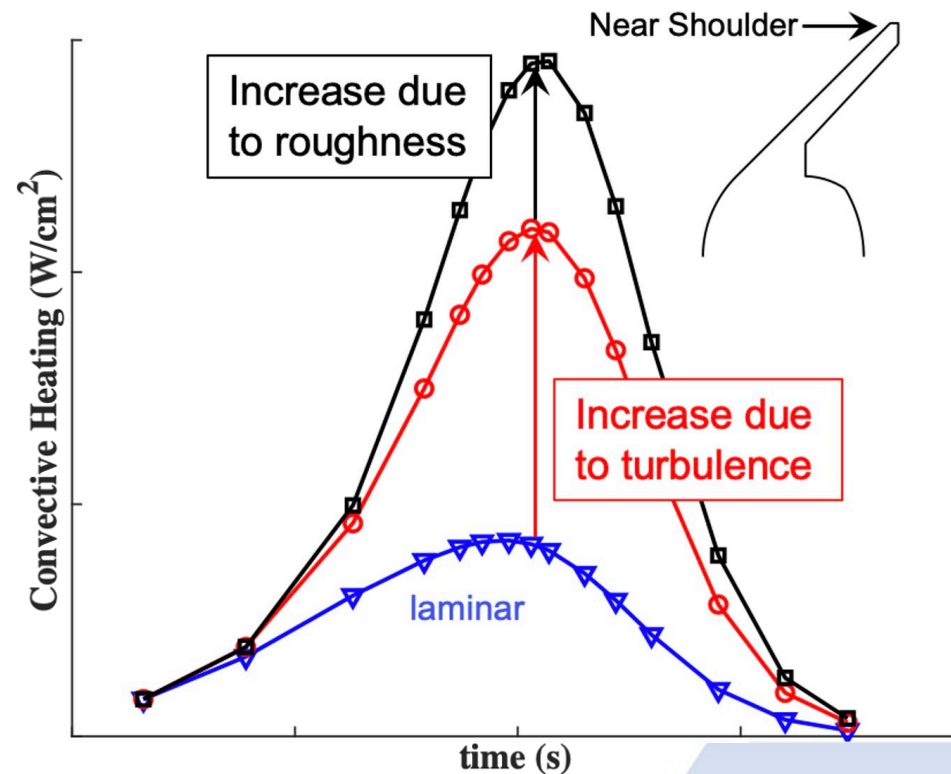


3MDCP roughness pattern



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 and improve models, testing was performed at the NASA Langley's Mach 6 facility
 - 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

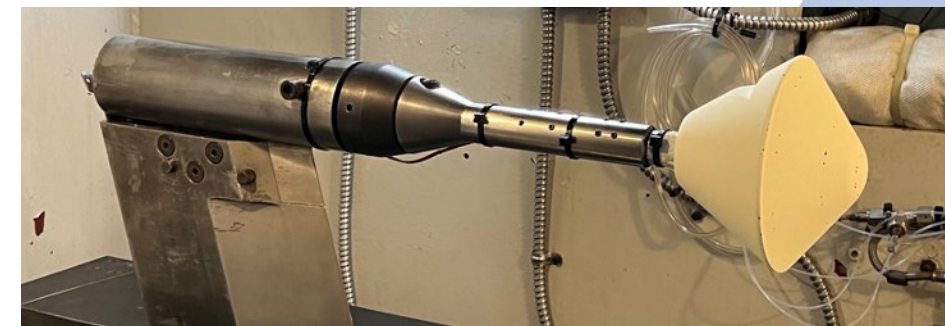
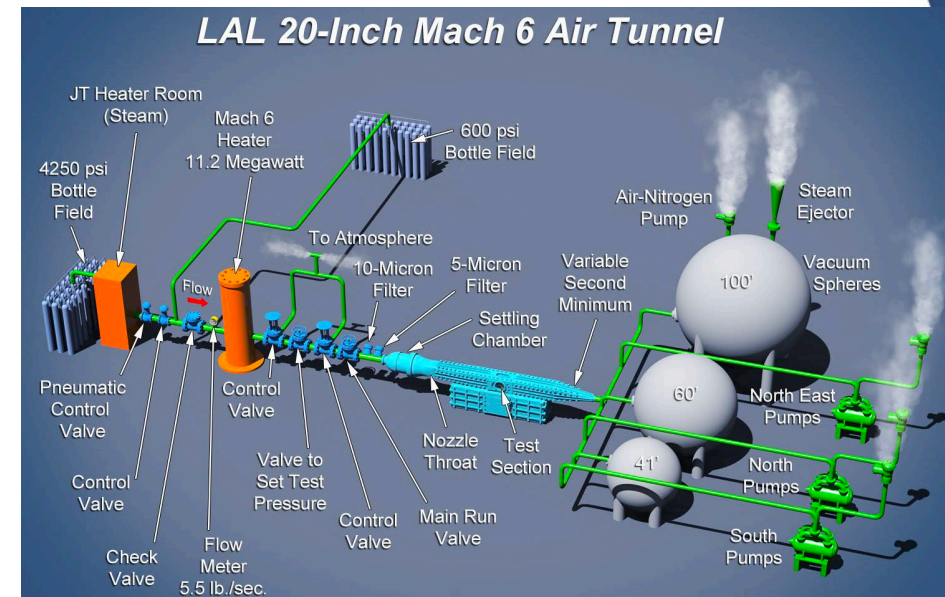


Test Overview



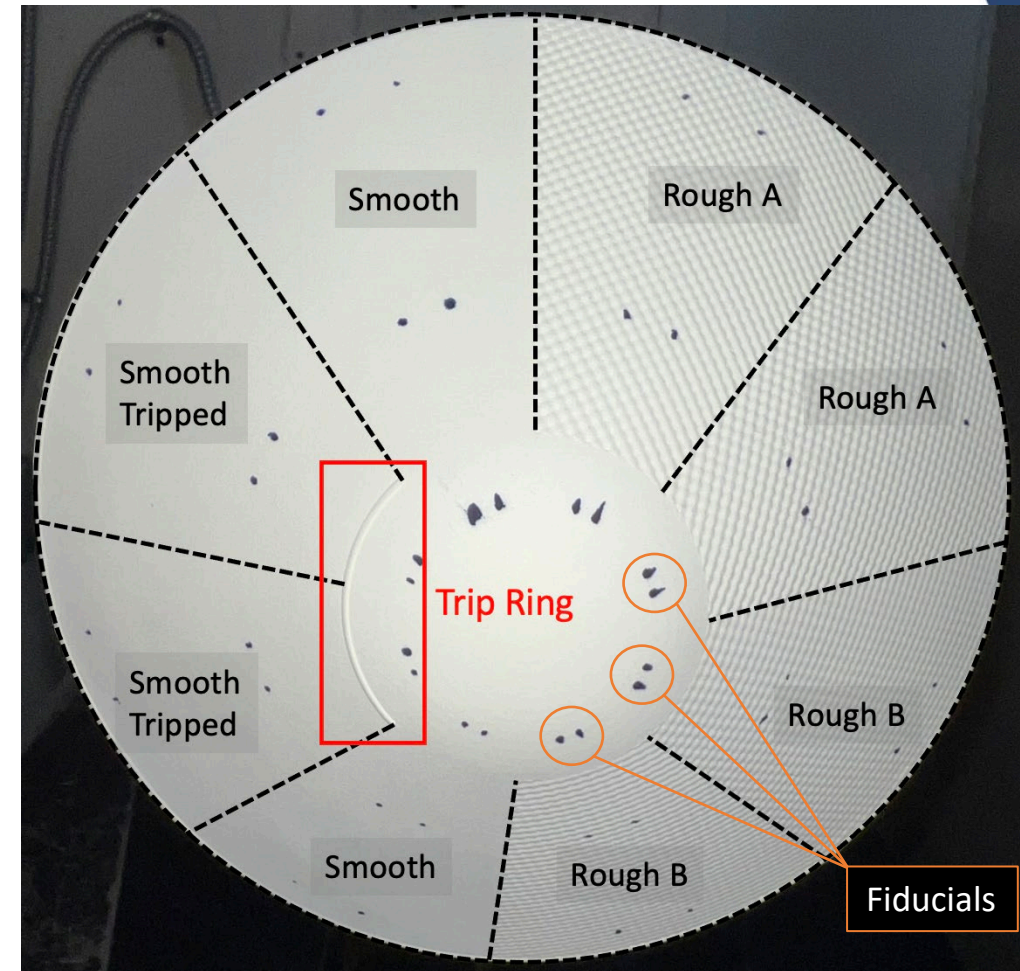
MSR-EES Mach 6 Test Campaign

- First entry of MSR-EES test campaign in the NASA Langley's Mach 6 air tunnel occurred in Spring 2023
 - Six 6-inch cast ceramic 52.5-deg sphere cone models with a generic aftbody were tested
 - Aftbody chosen to provide mounting strength, does not affect aeroshell forebody flow field
- 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



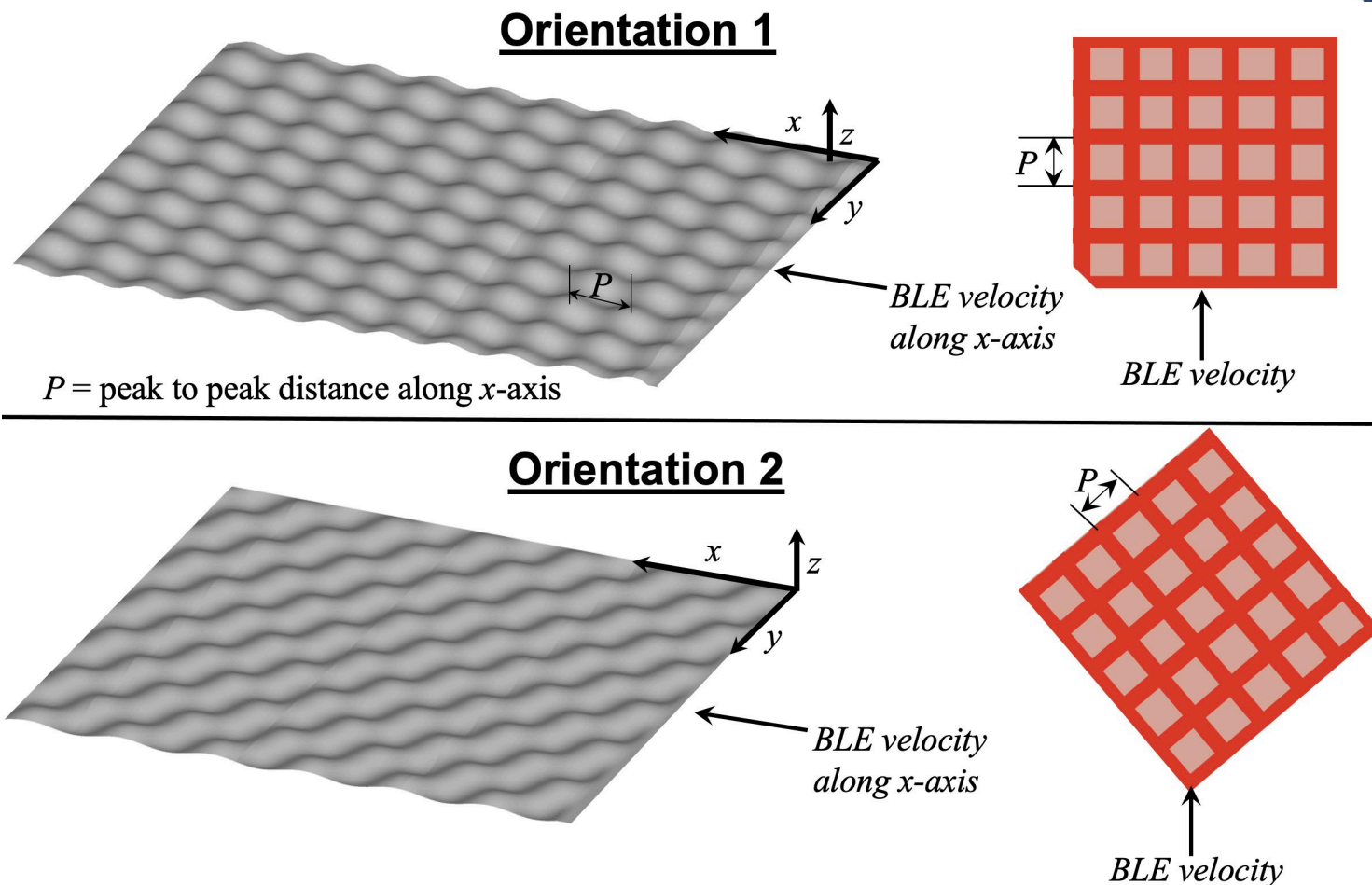
Mounted model in injection box of tunnel [Source: NASA]

- 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 to match EES relevant k^+ values
- Additional models varied roughness pattern in either height, peak-to-peak spacing, or weave orientation



6-inch, 52.5-degree sphere cone model with panels denoted [Source: NASA]

- Two primary weave orientations studied were 0-deg (orient. 1) and 45-deg (orient. 2)
 - Angle is peak-to-peak direction with respect to oncoming flow
 - Weave roughness represented by idealized sinusoidal patterns
- Model 6 deviated and contained surface weave patterns at 22.5-deg
 - Analysis performed of weave orientation effect on convective heating augmentation
- In flight, EES vehicle surface would encompass entire range of orientations (0-45 deg)
 - Models were primarily fabricated with weave orientation at the limits of this range

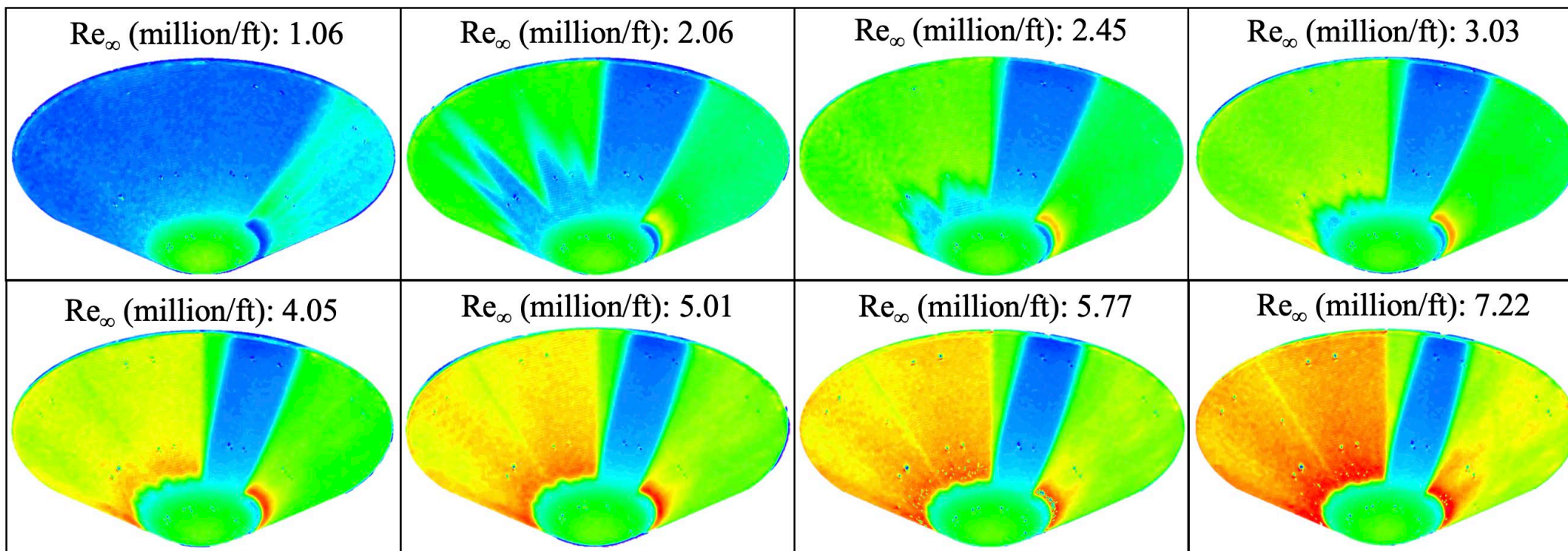




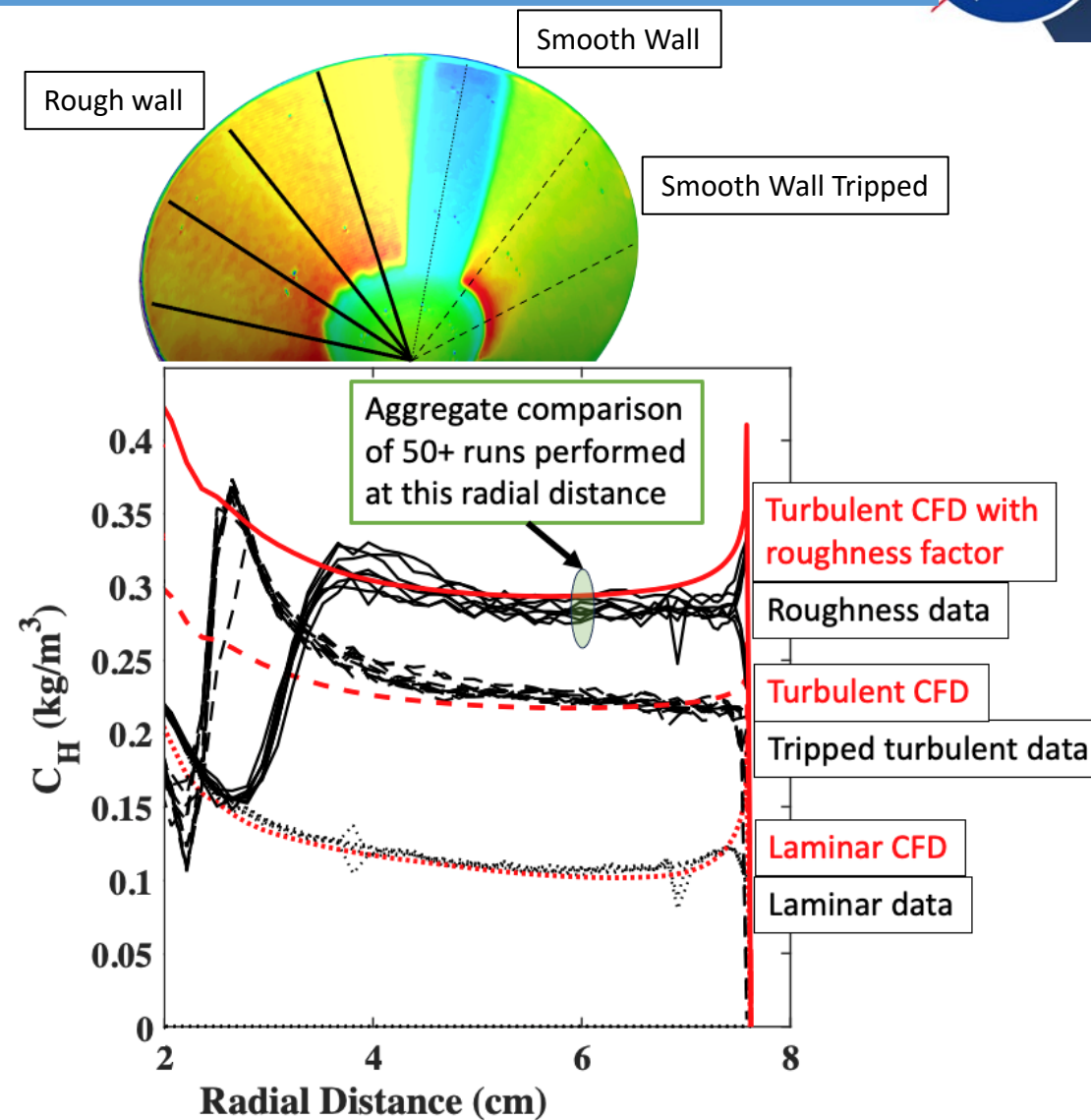
Results



- 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 number of models)
- 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
- Multiple aggregate comparisons of rough-wall turbulent heating were performed to validate computational models for a wide range of k^+ values
 - Location chosen far downstream to eliminate initial flow disturbances
- Direct comparisons assess conservatism of computational tools that characterize the aerothermal environment EES would see

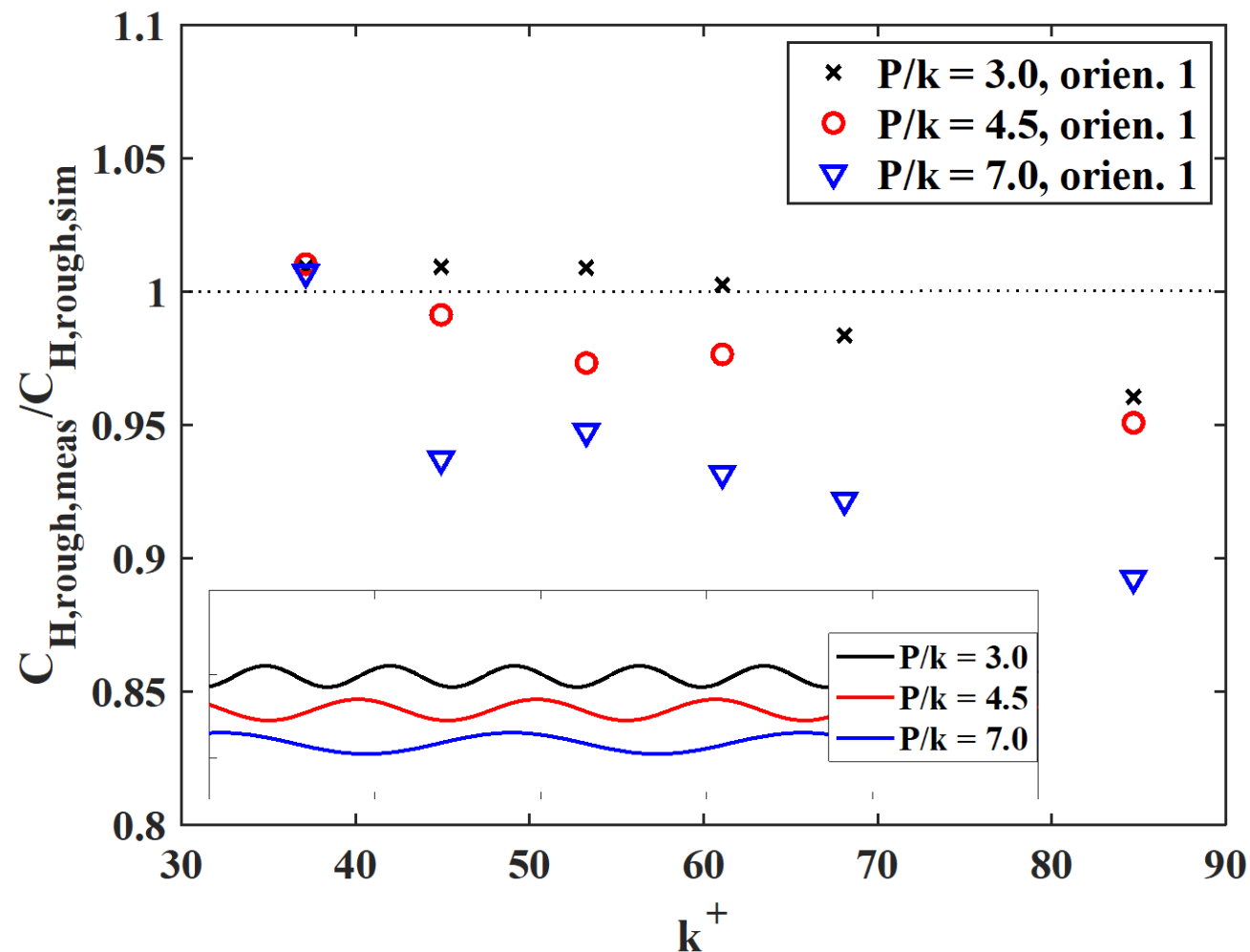




Impact

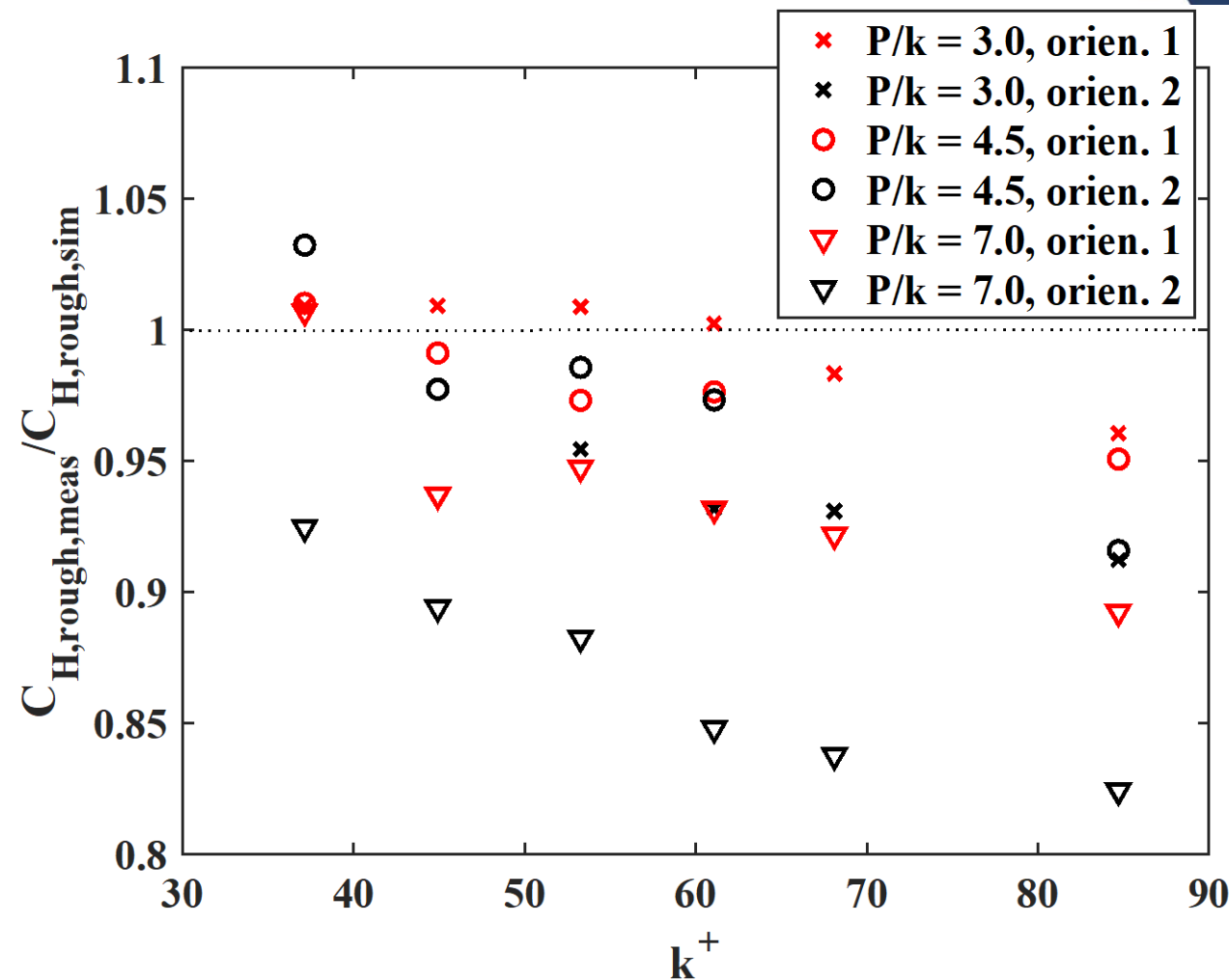


- Study of weave spacing effect on convective heating augmentation shows good agreement between CFD and experimental data
 - All data plotted were for woven roughness at 0-deg (orient. 1)
- Heating augmentation increases with decreased spacing
 - Maximum impact of weave spacing was found to be 10%
 - Spacing trend consistent with studies of other patterned roughness types



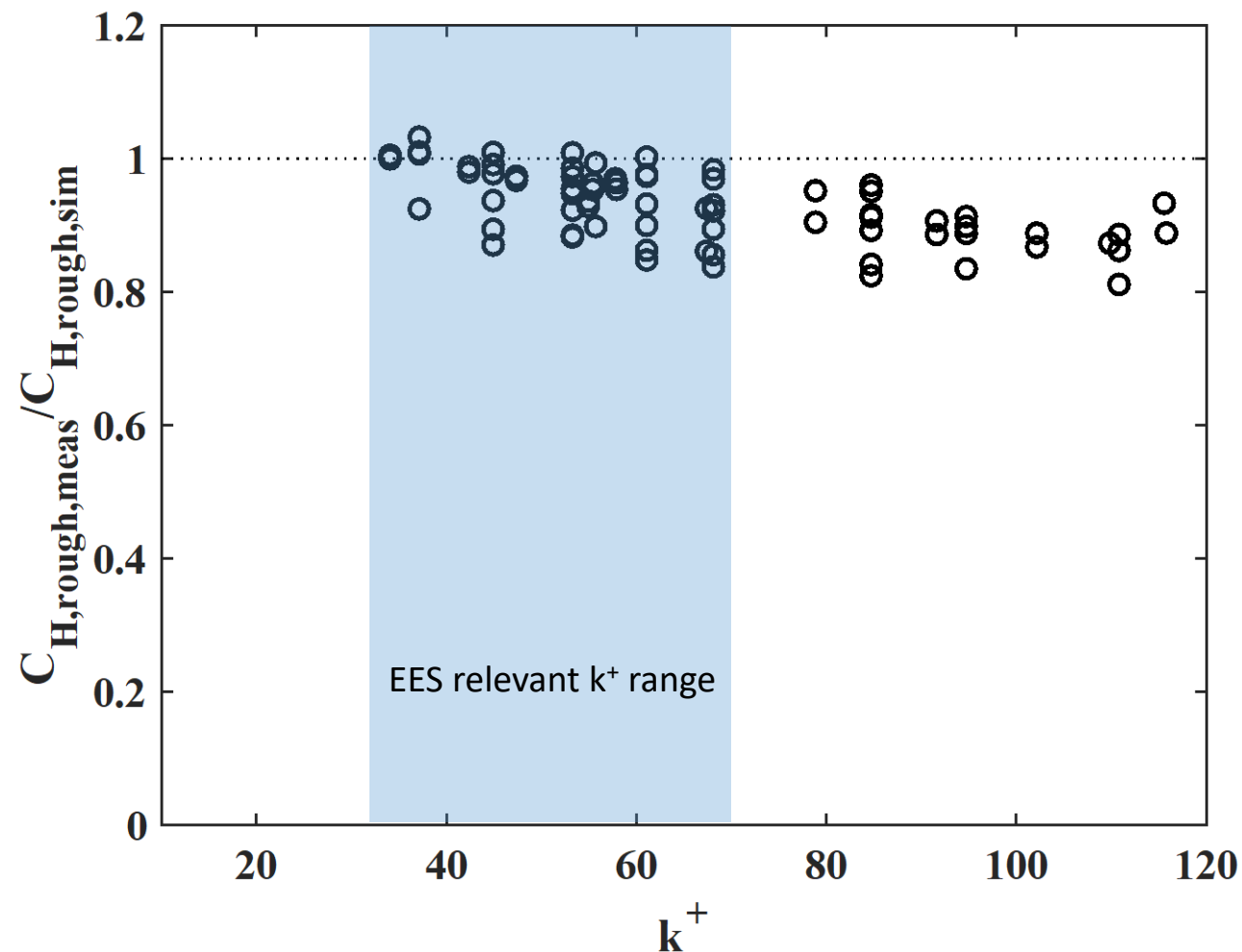
Comparison between experimental and CFD for 15+ runs

- Comparison was performed analyzing the effect of weave orientation on convective heating augmentation across 30+ runs encompassing a wide range of k^+ values and all weave spacings
 - Only 0-deg (orient. 1) and 45-deg (orient. 2) weave patterns were compared
- Convective heating augmentation for 0-deg weave orientation (orient. 1) was found to be up to 8% larger than 45-deg weave orientation (orient. 2)
 - In conjunction with weave spacing effects, can result in an overprediction of convective heating of 15–20%



Comparison between experimental and CFD for 30+ runs

- Comparison between experimental data and CFD for 50+ runs shows good agreement (within 20%, largest overprediction is 4%)
 - Wide range of k^+ values were plotted, encompassing 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
 - 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 the NASA Langley Mach 6 facility
 - Initial test entry was completed in Spring 2023, obtaining one of the first NASA experimental aeroheating data sets on woven surface roughness [2] 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
 - Experimental data set is also valuable across the planetary community and is extremely useful in validating computational solutions on roughness-resolved grids, which is an area of ongoing research
- Largest remaining uncertainty in aerothermal environments for EES is impact on heating of supersonic flow near roughness elements
 - Test entry was performed in November 2023 of sphere cone models at a 21-deg angle-of-attack to obtain aeroheating data on supersonic flow near surface roughness elements
 - Test entry was one of the first NASA experimental aeroheating data sets capturing this physical phenomenon
 - Initial analysis shows good agreement between experimental data and computational predictions

