



The NASA Ames Aerothermodynamics Branch (Code TSA)

Jeffrey Hill
Branch Chief

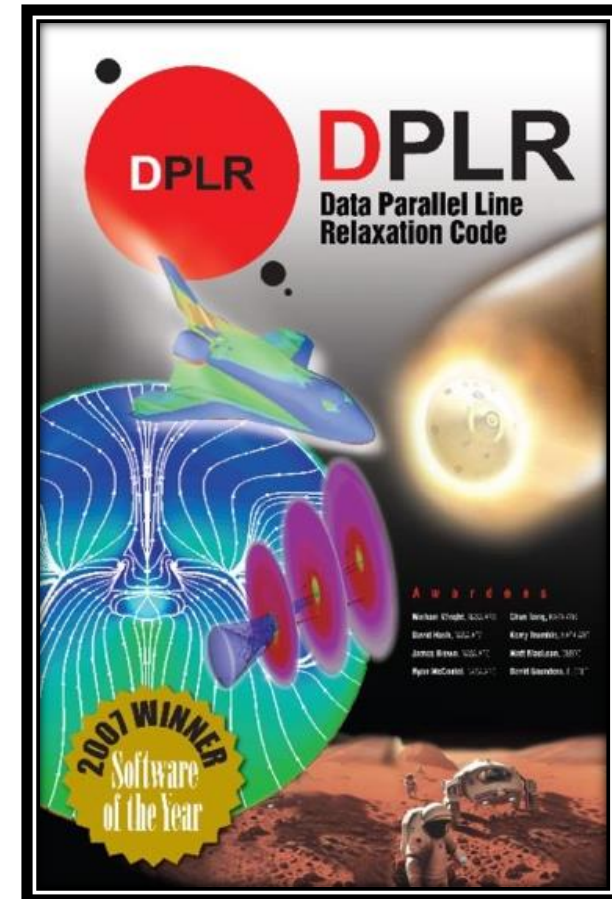
- **Mission:** Provide integrated modeling, simulation, and test capabilities in the areas of aerothermodynamics, shock layer radiation, and entry system design.
 - We define and validate the aerothermal environments used to design planetary entry systems.
- **Capabilities:**
 - CFD simulation for entry vehicles at hypersonic velocities.
 - Arc jet facility flow modeling and characterization.
 - Modeling and testing of shock layer kinetics and radiation.
 - Development of flow-field diagnostic techniques.
 - Aero- and Aerothermal testing via ballistic ranges.
- **Pedigree:**
 - TSA has roots dating back to founding of Ames in 1940s.
 - Models, tools developed in TSA are foundational in our field.

Branch Staff

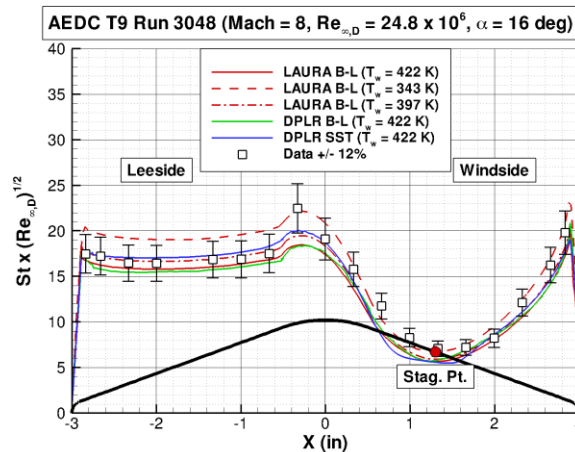
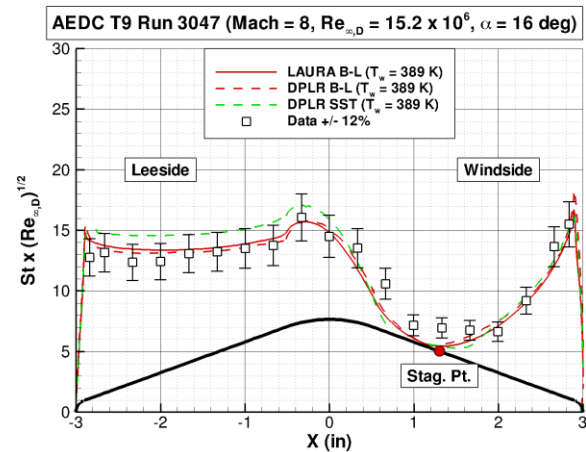


- Branch consists of 12 civil servants, 14 contractors.
- NASA Awards for Exceptional Achievement (3), Engineering Achievement (5), Scientific Achievement (1), Outstanding Leadership (1), and Public Service (3).
- 10 AIAA Associate Fellows.

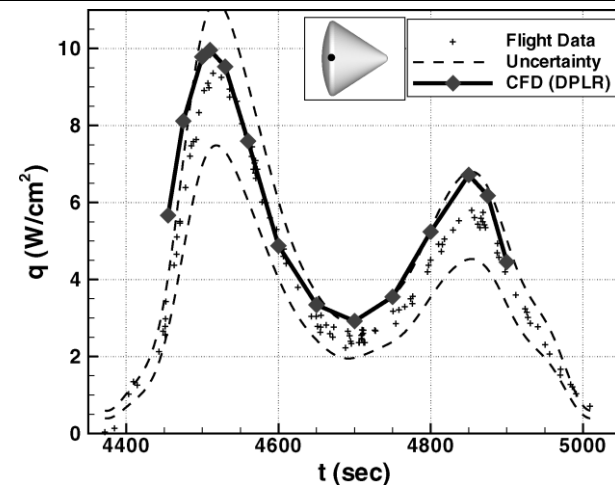
- DPLR is Code TSA's principal tool for aerothermal CFD analysis.
 - Developed by M. Wright, TSA Emeritus.
 - MPI parallel, block structured, finite volume code.
 - Simulates multispecies gas mixtures in chemical and thermal non-equilibrium.
 - Models for all planetary atmospheres, common TPS ablation and engine combustion products.
 - Two temperature model of C. Park, TSA Emeritus.
- DPLR (+LAURA from LaRC) is the foundation of NASA's entry system design process.
 - Used on every entry system of the past two decades.
 - Heavily validated against ground and flight test data.
- Code TSA collaborating with U. of Minnesota on development of US3D, the unstructured successor of DPLR.
 - Both codes in use, with slow migration towards US3D.
 - US3D provides new analysis capabilities not possible with DPLR.



Aerothermal CFD

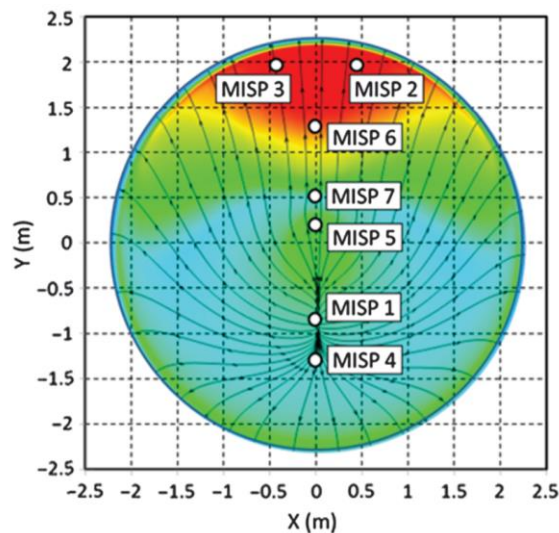
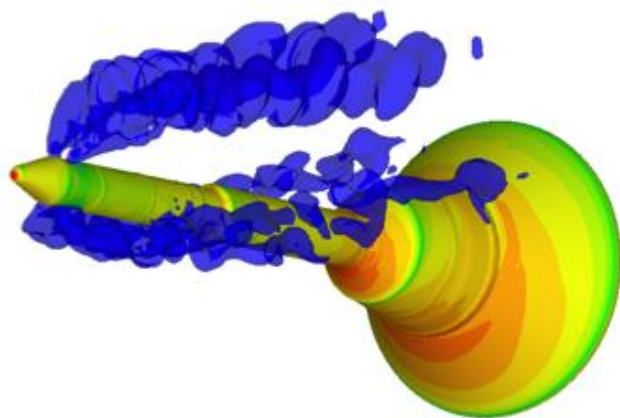


LAURA and DPLR Heat Transfer Compared to AEDC Tunnel 9 Data (AIAA 2009-4075)

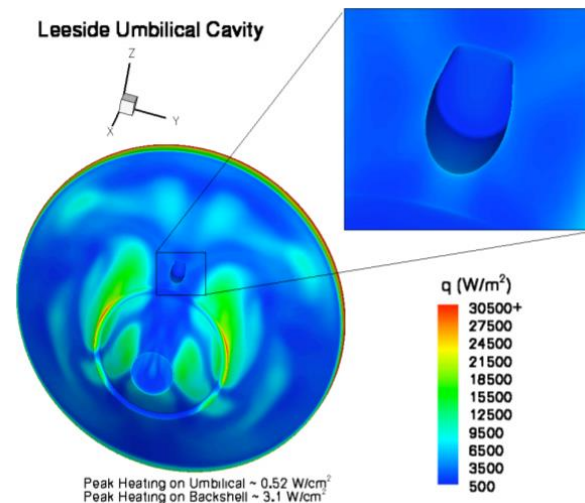


DPLR backshell heating comparison for Apollo AS-202 entry (JTHT Vol 20, No 1)

Validation Application



AIAA 2013-2779

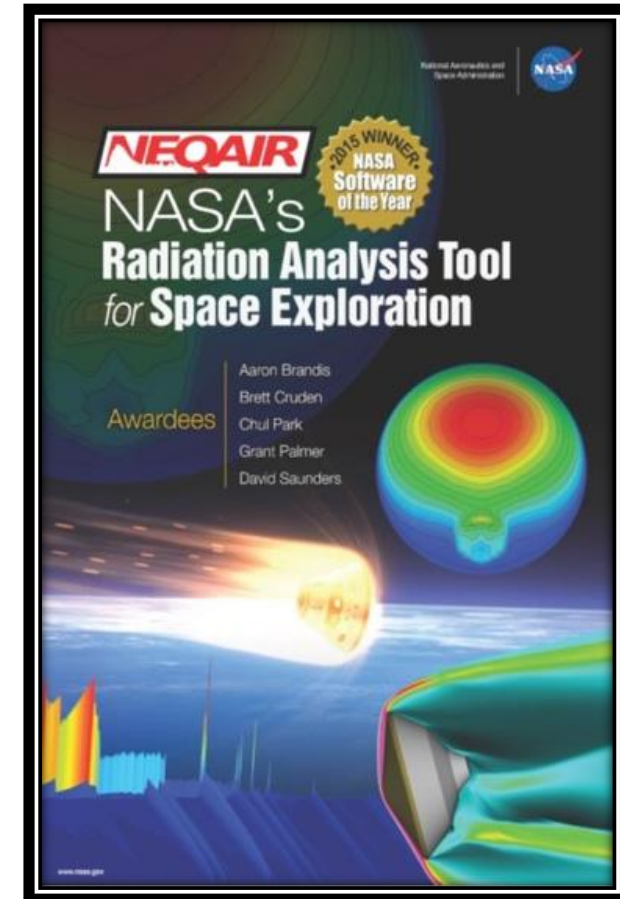


AIAA 2008-1279

Shock Layer Radiation



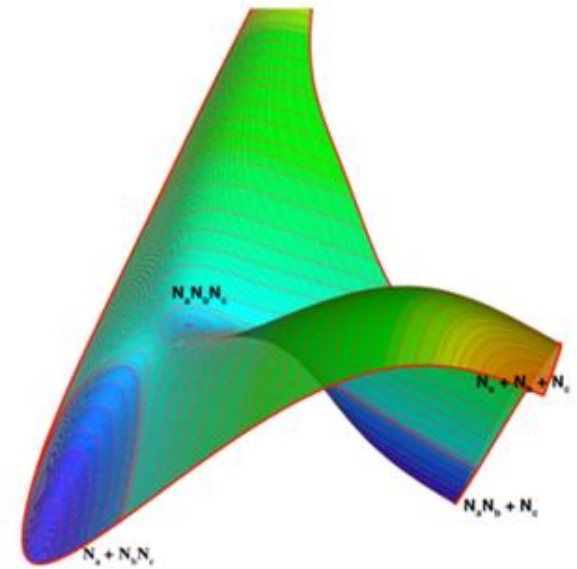
- Non-Equilibrium Air (NEQAIR) is Code TSA's primary tool for high temperature gas radiation modeling.
 - Line-by-line spectral computation of radiation intensity with solution of 1D transport equation.
 - Boltzmann or QSS models for excited states.
 - Includes all relevant physics needed for planetary entry to all solar system destinations.
- Enables radiative heat flux prediction for planetary entry systems:
 - Forebody: Tangent-slab approximation, ~days.
 - Backshell: Full angular integration, ~weeks.
- Heavily validated against shock tube experiments.
 - Some validation to flight measurements.
- Can be coupled to DPLR to account for radiative cooling of shock layer.
 - Yields significant reduction in radiative and convective heating for high speed, e.g. lunar return, entries.



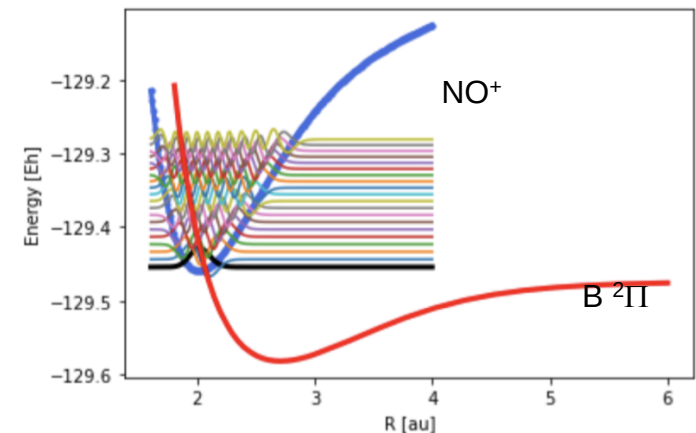
Shock Layer Kinetics



- Planetary entry modeling requires hundreds of parameters describing the non-equilibrium behavior of the gas.
- Historically, many key parameters were inferred from experimental data and have high uncertainties.
 - Models must be valid at high temperature conditions which are difficult to investigate.
 - Hard to construct experiments sensitive to details of the non-equilibrium kinetics.
- TSA currently leads an effort to develop non-equilibrium air chemistry model using computational chemistry techniques.
 - *Ab initio* potential energy surfaces (PES) for N_3 , N_4 , and CO_2 .
 - Rate coefficients for N_2+N , N_2+N_2 , $CO+Ar$, $CO+O$ collision processes.
 - Dipole transition moments for radiative emission.
 - Going beyond the 2-temperature (aka TTV) paradigm.

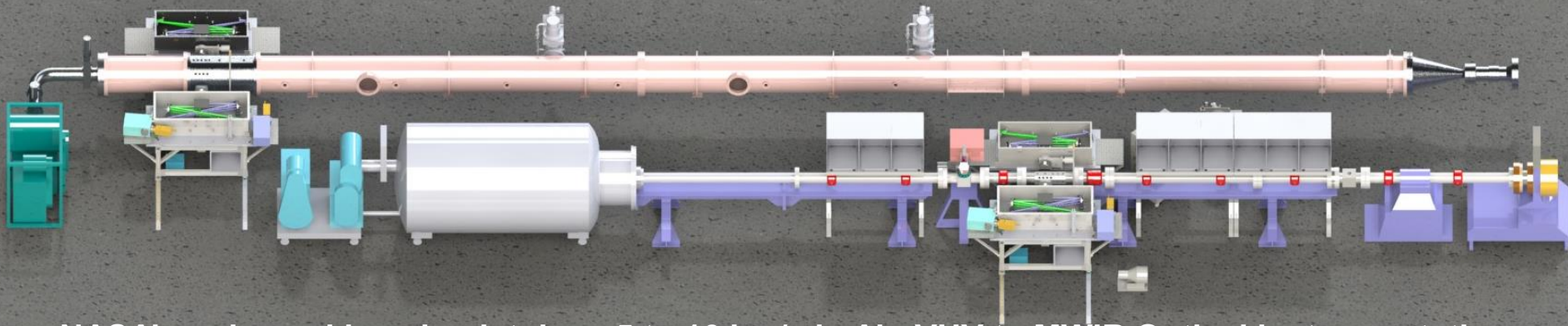


N_3 potential energy surface.



Nuclear dynamics simulation of NO dissociative recombination.

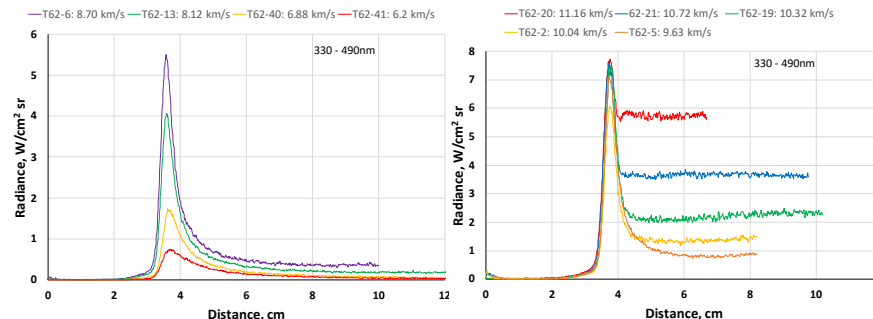
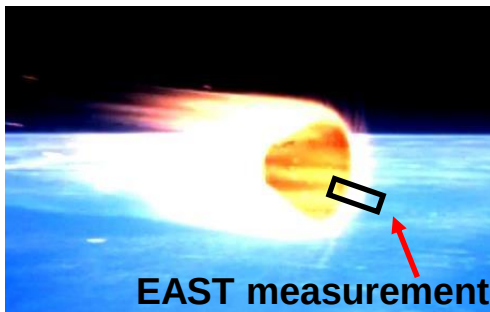
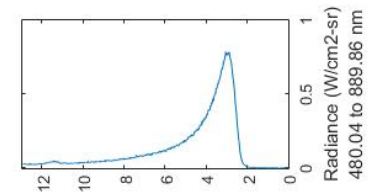
Electric Arc Shock Tube (EAST)



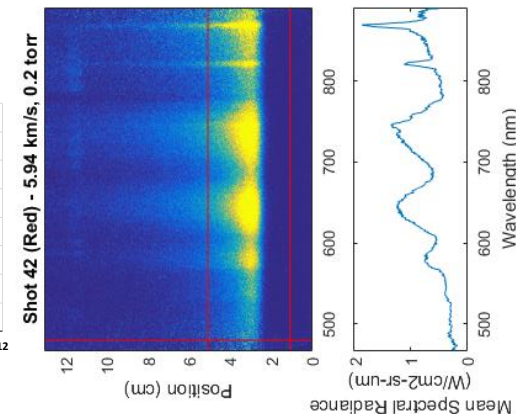
NASA's only working shock tube, ~5 to 16 km/s in Air, VUV to MWIR Optical instrumentation

- The shock tube produces conditions analogous to those behind bow shock of hypersonic flight vehicles
- Emission spectroscopy characterizes radiative heating from excited gas, spectral signatures and dissociation processes
- Measurements are used to benchmark radiative heating predictions, e.g. using NEQAIR, for flight missions and inform margin policy

Example EAST data



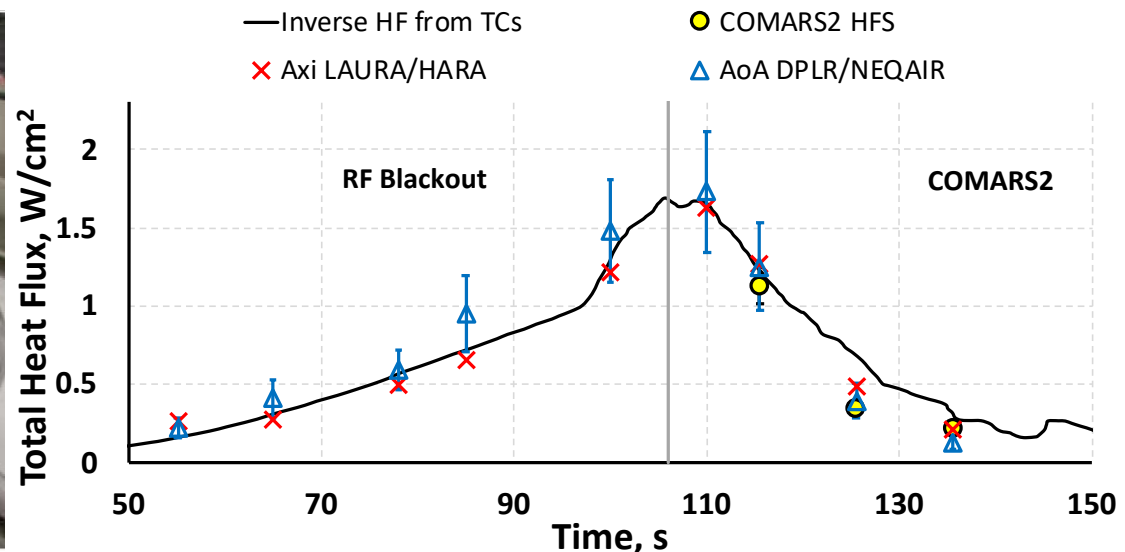
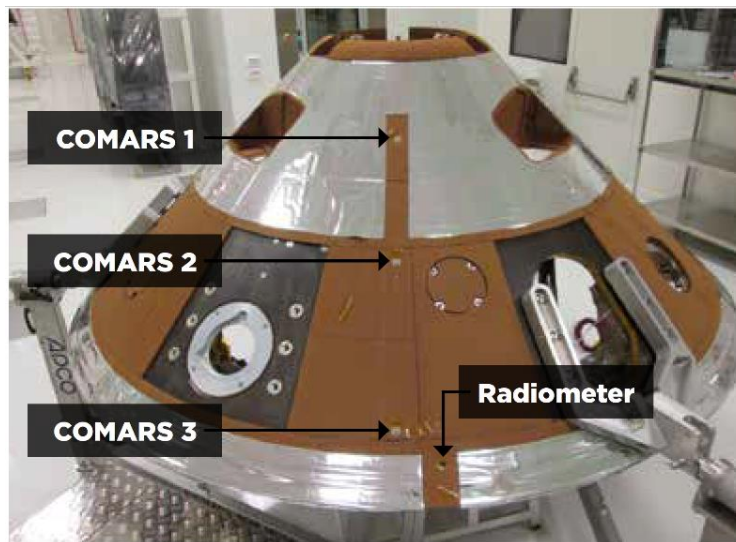
EAST UV data for N_2
from 6.2 to 11.2 km/s
AIAA 2018-3437



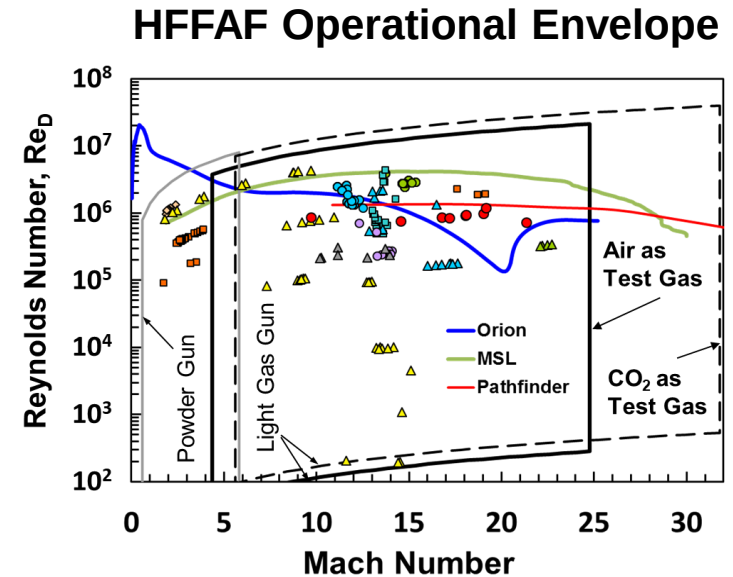
Schiaparelli Data Analysis^[1]



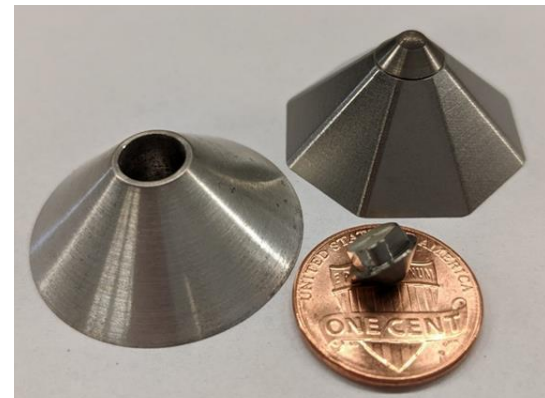
- Until recently, NASA design practices did not consider radiative heating on the backshell; believed insignificant.
- EXOMARS studies in Europe suggested that MWIR radiation from CO₂ could exceed convective heating.
- Schiaparelli lander was instrumented to measure total & radiative heating on the backshell → first flight measurement of CO₂ radiation.
- Analysis of this data demonstrated that EAST-derived radiation models enable accurate prediction of measured heating.



Hypervelocity Free Flight Aerodynamic Facility (HFFAF)



- Free-flight simulation of entry aerodynamics and aerothermodynamics
 - Light Gas Gun launches models through quiescent test gas.
 - Enable observation of vehicle dynamics without model-support interference.
 - Infrared thermal imaging provides global heat transfer maps on vehicle surface.
- Operational Envelope
 - Velocity: 0.2 km/s to 8.5 km/s
 - Pressure: 4×10^{-5} to 1 bar
 - Test Gas: Air, N_2 , CO_2 , He/H_2 , Ar, etc.
 - Diameter: 8 mm to 38 mm



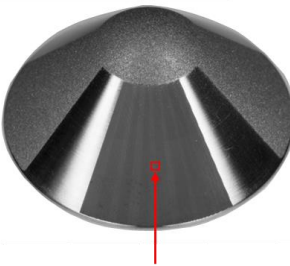
Mission Relevant Roughness^[1]



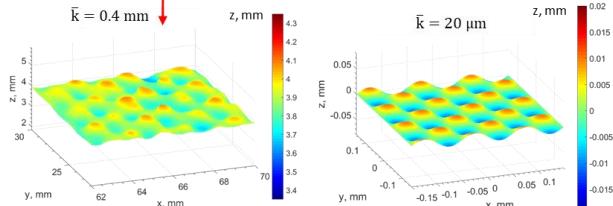
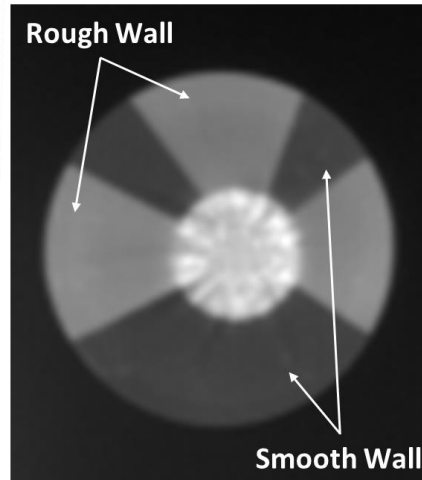
Arcjet-Ablated HEEET



Ballistic-Range Model
Laser-Etched HEEET

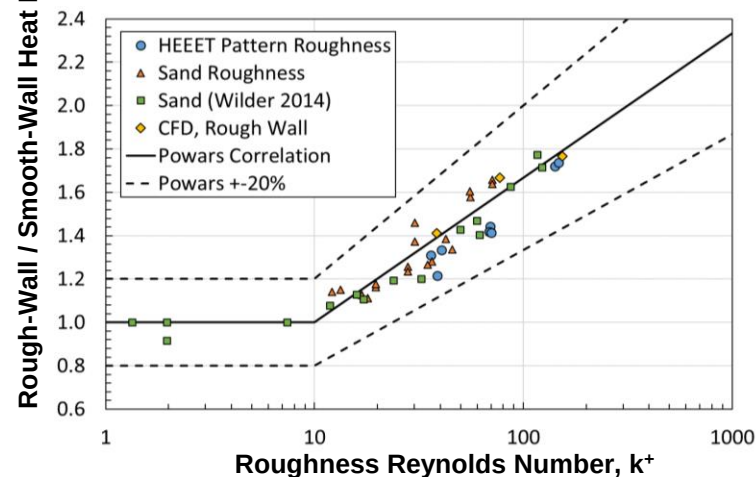


IR Image of Model in Flight
 $M = 8.5$



Scan of HEEET → Idealized and Scaled

Turbulent Heat Transfer Augmentation



- Current CFD state-of-the-art unable to reliably predict hypersonic turbulent heat transfer for rough surfaces.
- Current design practices apply test-derived augmentation factors to CFD smooth wall heatflux predictions.
- Legacy correlations based on sand grain roughness, but modern woven TPS materials have highly regular, anisotropic surface patterns.
- Work underway to extend correlations to mission-relevant surface roughness.

Dynamic Capsule Stability

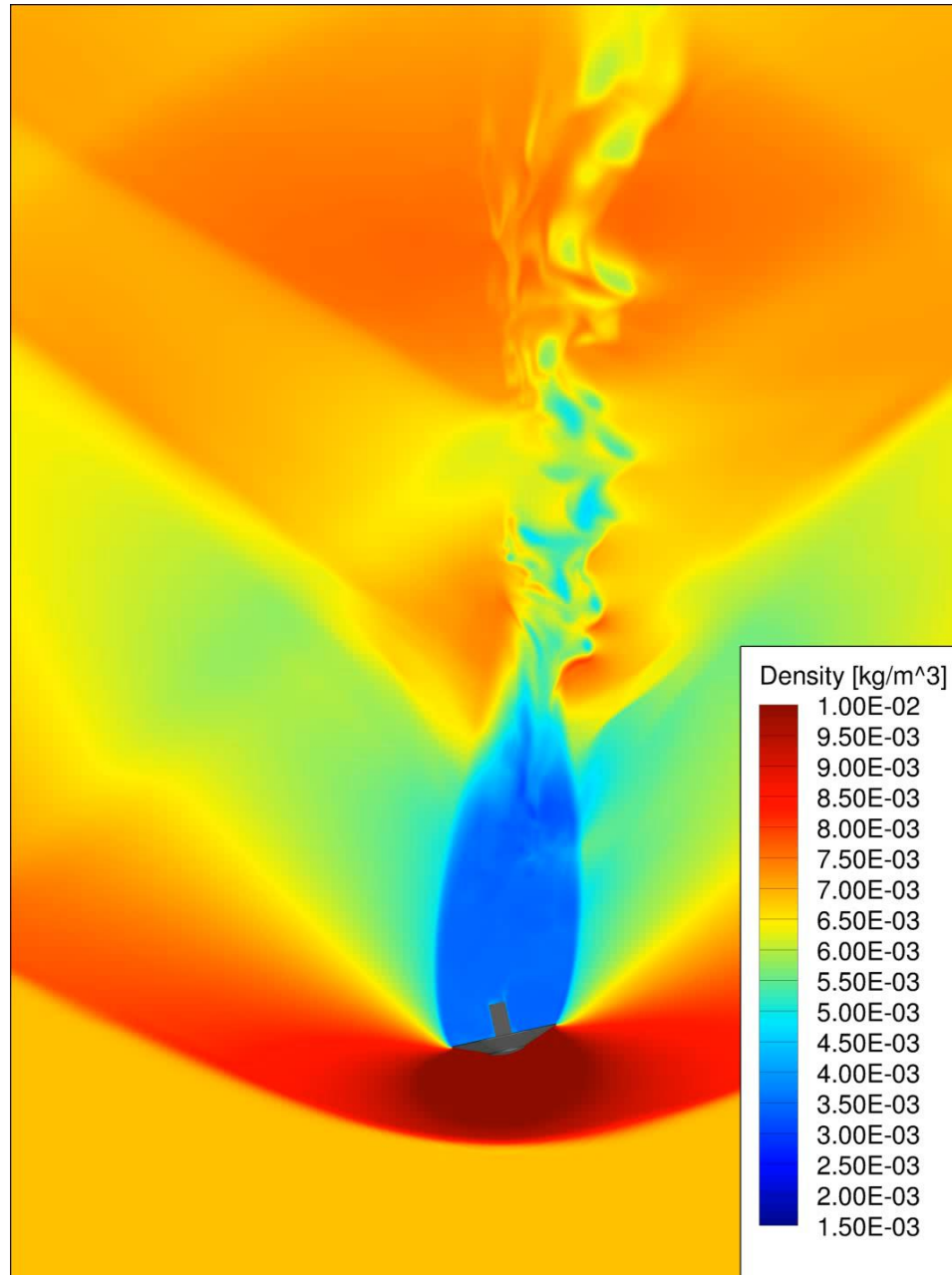


- To date, assessment of capsule dynamic stability at NASA has relied exclusively on experimental data.
- Code TSA is leading an effort to develop time-accurate simulation tools able to accurately predict the onset and growth of dynamic instability.
- Capsule stability depends on accurate simulation of the massively unsteady wake, which present unique numerical challenges:
 - Requires low-dissipation, high-resolution flux schemes.
 - Requires high-accuracy, efficient time integration schemes.
 - Requires high-quality, high-resolution wake grids.
 - Requires generalized, quality-preserving grid motion strategies.

TSA seeks to break reliance on heritage aeroshell shapes by reducing the expense required to characterize the stability of new designs.



Dynamic Capsule Stability

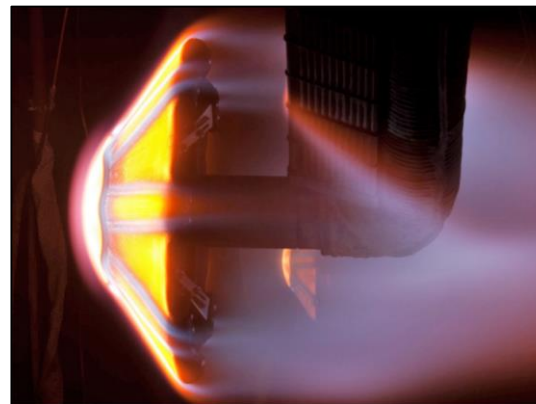
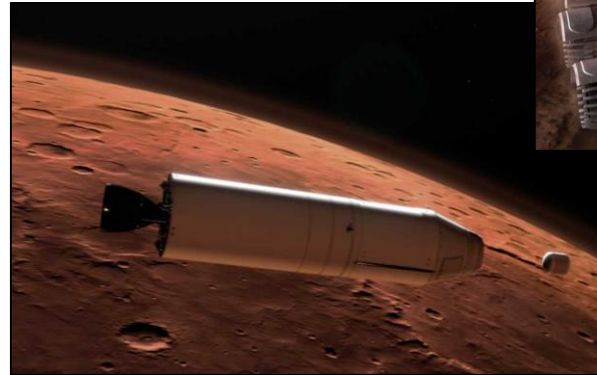
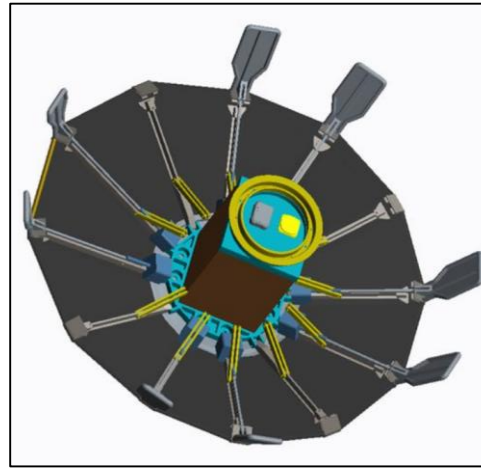


Looking Forward

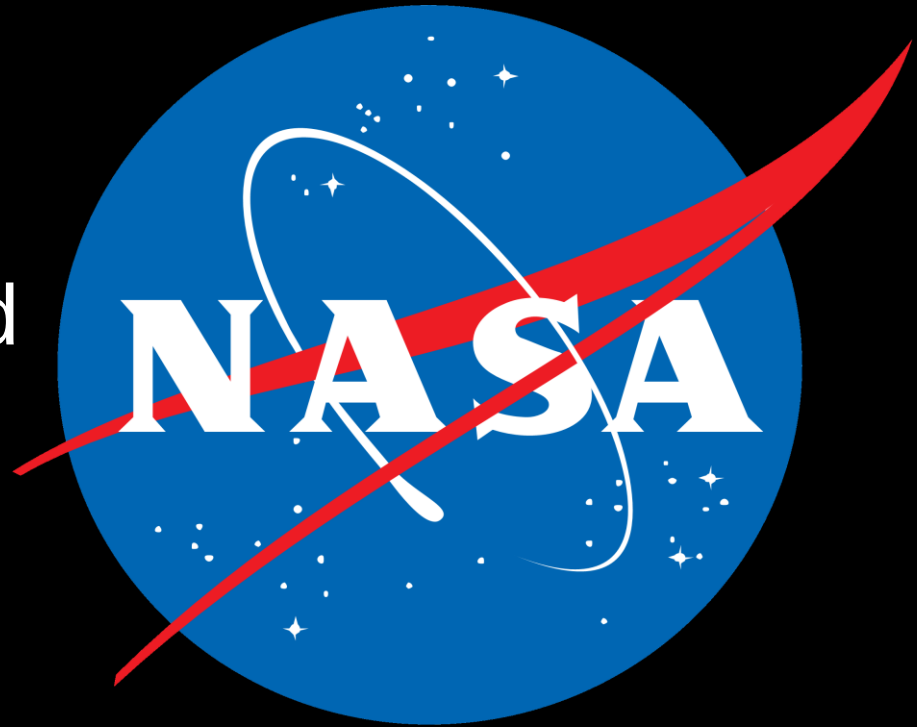


- NASA is already hard at work designing a new generation of space missions.
- These ambitious missions will demand novel entry systems that exceed existing design and analysis capabilities.
- TSA will continue to leverage our rich history and innovative spirit to help solve NASA's entry systems challenges.

Code TSA is a trusted mission partner enabling NASA's vision to *Go, Land, Live and Explore* beyond Earth.



National Aeronautics and
Space Administration



Ames Research Center
Entry Systems and Technology Division