An Overview of the Aerothermodynamic Database for the Mars Sample Return Earth Entry Vehicle

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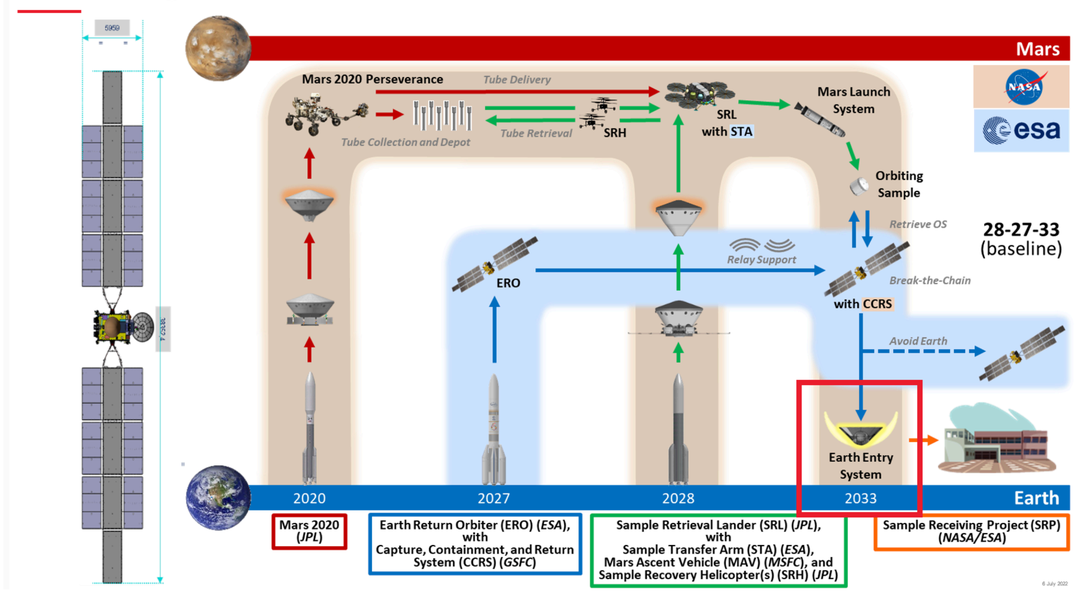
MSR-CCRS

Abstract: The Mars Sample Return Earth Entry System (MSR-EES) is a capsule that is part of the Mars Sample Return mission that will return Martian soil samples to Earth in 2033. Due to the steep flight path angle and relatively large vehicle size, the MSR-EES capsule will experience the highest peak heating rate of any previous Earth entry vehicle. The aerothermal database for MSR-EES is primarily characterized by numerical CFD, DSMC, and radiation simulations. Margins are applied to the convective and radiative heating rates. Surface roughness effects and margins are also included in the database formulation. The aerothermal database can be used to extract information at any body point location, perform trade studies in trajectory space, and provide inputs for material response simulations.

The Mars Sample Return (MSR) Mission

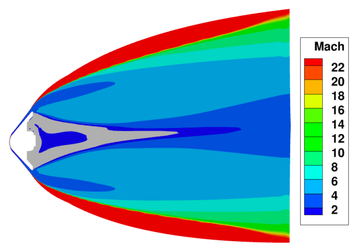
- The MSR mission is a multi-year joint venture between ESA and NASA to return samples of Martian soil to Earth.
- The Earth Return Orbiter (ERO) will be launched from Earth in 2027. Once it reaches orbit around Mars, tubes containing the Martian soil samples will be transferred into the Capture, Containment, and Return System (CCRS) that is part of the ERO.
- The Earth Entry System (EES) capsule, part of the ERO system, will return the CCRS to the surface of the Utah desert in 2033.

MSR Program Architecture



Analysis Tools

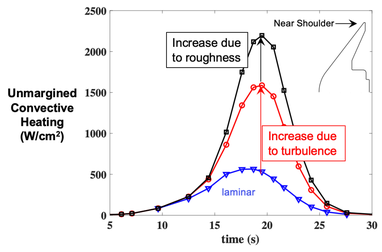
- The aerothermal environment of the MSR-EES capsule is characterized primarily by numerical simulations augmented with experimental arcjet and wind tunnel data.
- Langley Upwind Relaxation Algorithm (LAURA): Navier-Stokes CFD flow solver [1].
- Data Parallel Line Relaxation (DPLR): Navier-Stokes CFD flow solver [2].
- MAP: DSMC code used at higher altitudes where non-continuum effects are present [3].
- HARA: Line-by-line radiation code [4]. Coupled fluid-radiation simulations are performed for freestream velocities greater than 8 km/s.



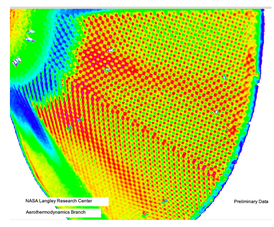
Flow contours around MSR-EES capsule

Surface Roughness Effects and Margins

- 3MDCP is a woven TPS material and will experience heating augmentation due to surface roughness.
- Surface roughness model based on experimental tests performed for the MPCV Orion project and more recent tests in the NASA Langley Mach 6 wind tunnel.
- Margins applied to nominal convective and radiative heating rates consist of two components - a comparison between experiments and relevant experimental data and a term representing parametric uncertainty. The total margin is the RSS combination of these two terms.



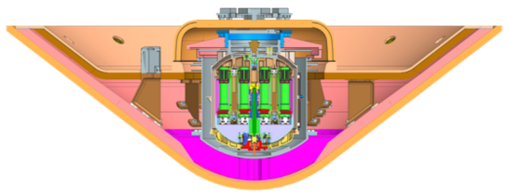
Impact of roughness on surface heating rate



Langley Mach 6 tunnel roughness test

The MSR-EES Capsule

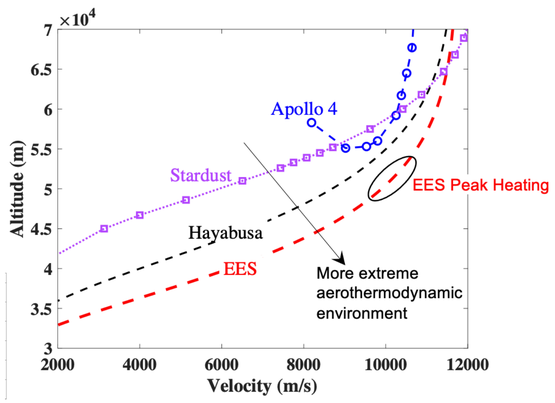
- The MSR-EES capsule shape is a 1.25 meter diameter, 52.5-degree sphere cone.
- The baseline thermal protection system (TPS) for the heatshield is 3-D Medium Density Carbon Phenolic (3MDCP).
- The afterbody geometry is designed to surround the CCRS. The afterbody TPS is SLA-561V.



The MSR-EES Capsule

Aerothermal Environment

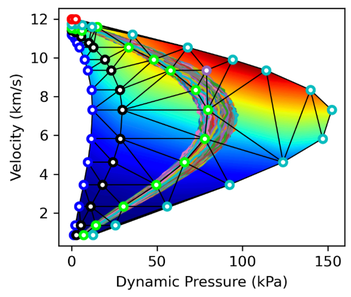
- Due to the steep entry flight path angle and relatively large capsule size, the MSR-EES will experience a severe aerothermal environment.
- The peak heating rate will be the highest ever for a non-military Earth entry capsule - higher than the Apollo 4, Stardust, and Hayabusa capsule environments.
- Unmargined turbulent heating rates will exceed 1500 W/cm2 on the heatshield.



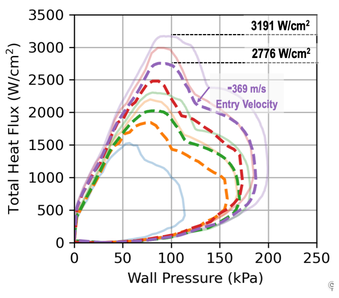
MSR_EES entry trajectory

Aerothermal Database Development

- The margined CFD/DSMC/radiation solutions are used to anchor and construct a database that spans the entire trajectory space.
- The aerothermal database allows the MSR-EES capsule to be “flown” through different entry trajectories and allows a quick turnaround analysis of the effect of changing entry velocity, flight path angle, etc.
- Other applications for the aerothermal database include:
  - Determining peak heating rate, pressure, shear, etc. at any body point location.
  - Supports trajectory-space trade studies, e.g., prograde vs retrograde trajectories, effect of increased capsule mass, etc.
  - Provide surface boundary conditions at any body location for in-depth material response analysis.
  - Create “butterfly” plots to allow quick visualization of aerothermal conditions.



MSR-EES aerothermal database. Color contours indicate stagnation point heat flux.



Butterfly plot of heat flux and wall pressure as a function of entry velocity.

References:
[1] Mazaheri, A., Gnoffo, P., Johnston, C., and Kleb, B., “LAURA Users Manual: 5.5-76679, NASA TM 217800, 2017.
[2] Wright, M., White, T., and Mangini, N., "Data Parallel Line Relaxation (DPLR) Code User Manual Acadia - Version 4.01.1, 2009
[3] Liechty, D. S., “Object-Oriented/Data-Oriented Design of a Direct Simulation Monte Carlo Algorithm,” AIAA Paper 2014-2546, July 2014.
[4] Johnston, C., Hollis, B., and Sutton, K., “Spectrum Modeling for Air Shock-Layer Radiation at Lunar-Return Conditions,” *J. Of Spacecraft and Rockets*, Vol. 45, No. 5, 2008, pp. 865-878.