Reusable Heat Shield For Re-Entry Capsules

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Abstract

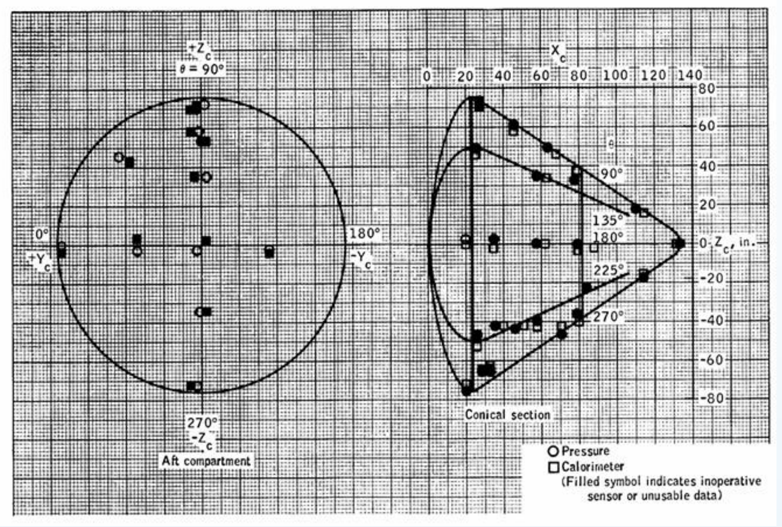
Capsule reentry currently relies on ablative shields with limited reusability. This project investigates an alternative: a reusable metallic conical heat shield with radial liquid-nitrogen-fed pipes and a transpiration manifold. To verify the underlying heat transfer models before designing flight geometry, a serpentine-channel rig was designed, fabricated, and instrumented. LN2 is driven through a 6 × 4 × 0.30 in plate containing a 0.40 × 0.10 in channel while T(x,y) and T(x,z) are measured under constant heat flux. The measured local heat-transfer coefficient *h(s)* along the channel arc length validates the models that drive the full-scale conical-shield forecast.

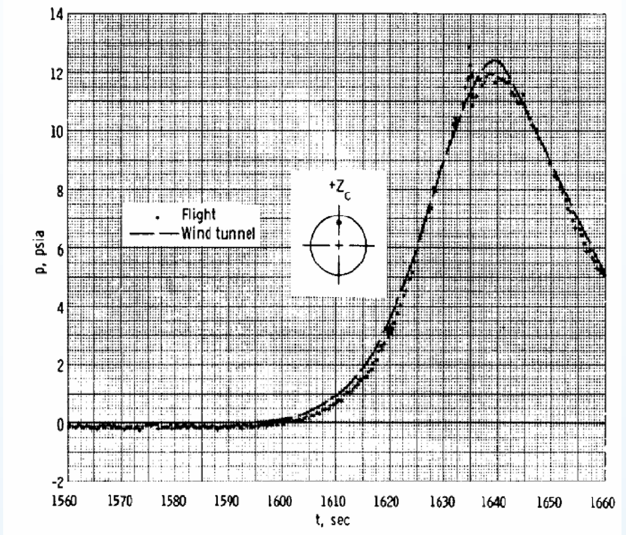
Project Goals

- Replace ablative heat shields with reusable, radially- and transpirationally-cooled shield
- Design must outperform existing heat shields on reusable economics
- Build computational models in COMSOL & MATLAB
- Build an experiment to measure phase change in LN2 to validate COMSOL and MATLAB

NASA Research

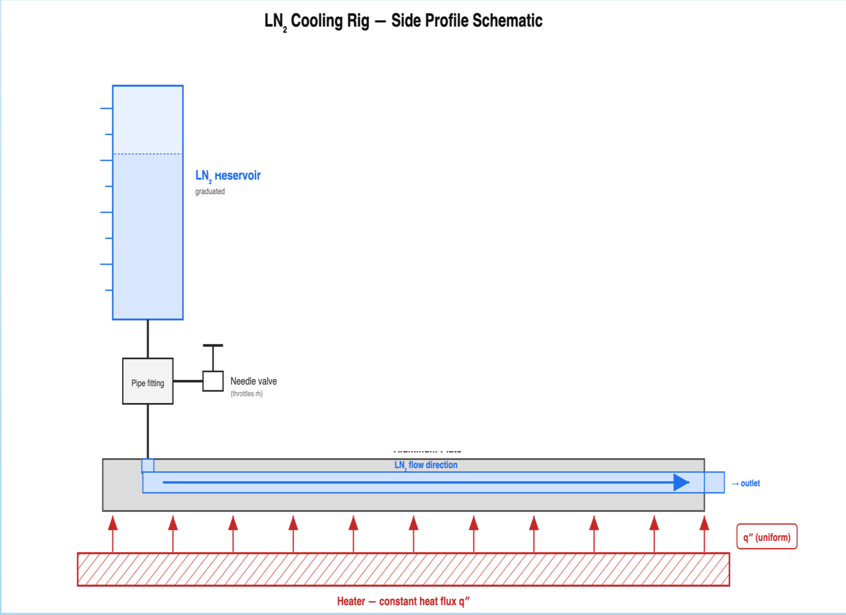
- Extensive research completed on capsule reentry profiles and existing ablative designs
- From this data, heat flux, temperature, and pressure can be quantified as a function of radius and time during reentry





Experimental Set Up

- 4" x 6" x 0.3" Aluminum Plate with interior channels
- LN2 is flowing through the plate at a mass flow rate of 2.5 g/s
- Constant heat flux (15,500 W/m^2) applied to heater



Results and Analysis

- Academic correlation model corrected by a global factor (accounting for the unique experiment geometry) was within 42.5% of experimental value
- COMSOL model agrees with experimental and corrected simulation data, and captures fluid-mechanical effects invisible to experiment (Figure 1)
- COMSOL model is preferred for final design simulation.
- Figure 2: experimental temperature measurements used to obtain experimental h

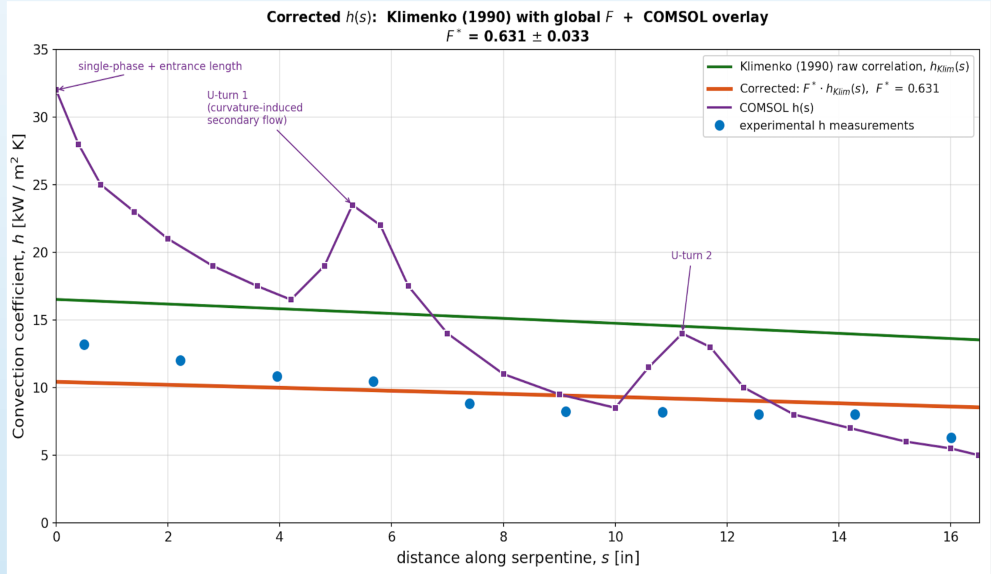


Figure 1

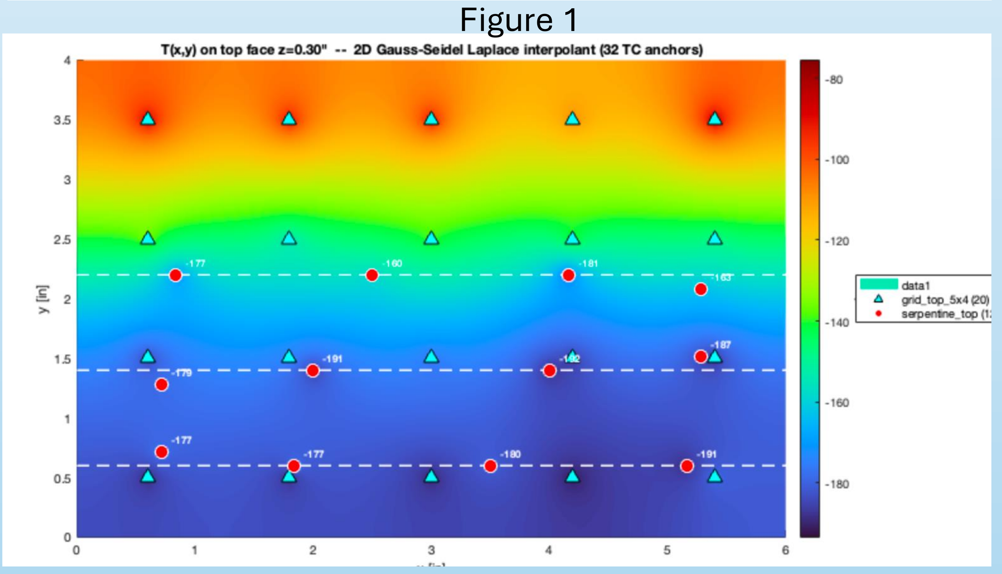
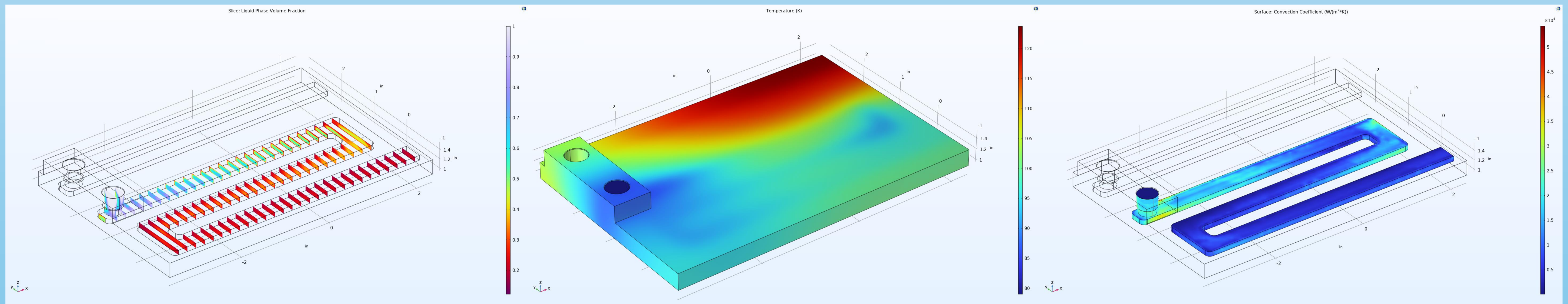


Figure 2

Building Models for Analysis

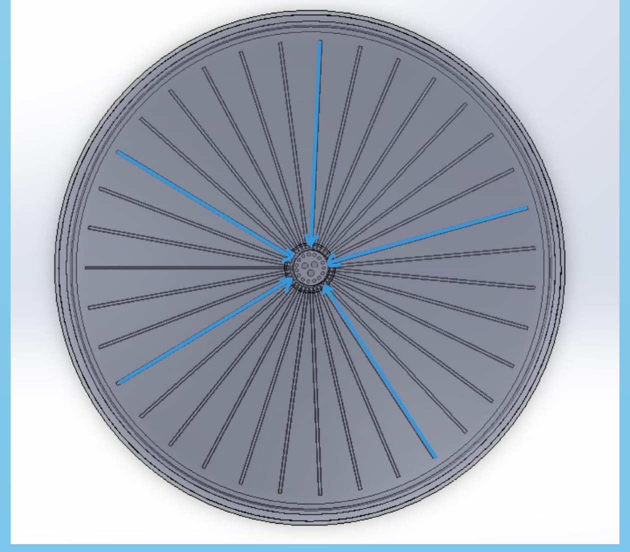
- 3D Gauss-Seidel Finite Differencing MATLAB model created to model heat flux on the wall of the passage.
- Experimental temperature measurements imported into the finite differencing model to determine experimental convection
- Klimenko (1990) correlations used to predict internal heat transfer along passage

FEA Simulations



Conceptual Transpirational, Reusable Heat Shield Design

- **Requirements:** Inner max temp= 422K, must outperform AVCOAT design assuming full reusability
- Liquid Hydrogen flows inward towards heat shield center
- LH2 is ejected through transpirational center manifold
- 35 pipes, wall thickness of 20mm, 4bar, shield mass 1.74T
- **Design feasible after 65 flights (full reusability)**



Acknowledgements

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References

[1] V. V. Klimenko, "A generalized correlation for two-phase forced flow heat transfer," *Int. J. Heat Mass Transfer*, vol. 31, no. 3, pp. 541–552, 1988.
[2] D. B. Lee, J. J. Bertin, and W. D. Goodrich, *Heat-Transfer Rate and Pressure Measurements Obtained During Apollo Orbital Entries*, NASA TN D-6028, National Aeronautics and Space Administration, Washington, DC, Oct. 1970.