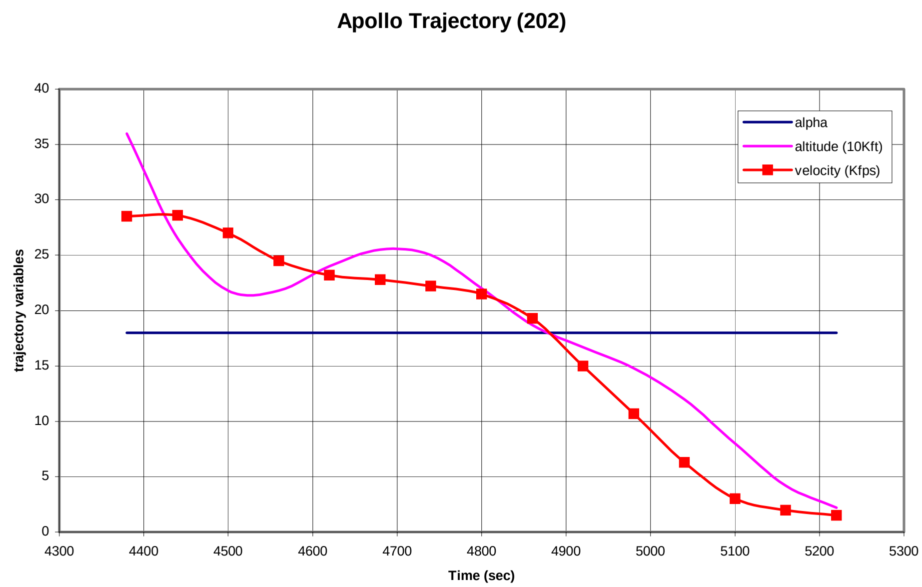
Analysis of Heating Rates on the Conical Surface of Apollo Command Modules flying AS-202 Flight

Abstract

The leeward conical surface of a hypersonic reentry vehicle is often difficult to simulate because of the flow complexity. Yet an accurate and timely simulation of a reentry body is essential to trim the non-value adding thermal protection system (TPS), to enhance its performance, and to ensure the safety of the crew. Conventional approaches to perform the aerothermal simulations include the correlation-based tools and the Computational Fluid Dynamic (CFD) codes. Though the Apollo Command Module has a relatively simple configuration, the high-heat-flux and high-shear flowfield near the shoulder of the base shield is difficult to be determined. The correlation-based codes such as MINIVER at best can approximate this region as the stagnation point of a simple object such as sphere. Recently Wright et. al. (AIAA 2004-2456) of NASA Ames used the DPLR Navier-Stokes code to predict the flowfield with good success. However, the CFD tools are too time consuming for design purposes, and cannot account for the transient effects of material response such as wall temperature and blowing.

Northrop Grumman Corporation applied a modified version of the MASCC/ATAC program, an inviscid flowfield code with boundary layer solver to simulate this scenario. The wall temperatures at every body point were accurately predicted by running a large number of indepth conduction simulations at every time-cut using the Charring Material Ablator (CMA) code, an one dimensional thermal conduction code with ablation capabilities.

This approach was found able to accurately and timely predict the complex flowfield. The results were validated with the Apollo AS-202 flight data, and will be presented in the paper. The AS-202 trajectory is presented in Fig 1, and is comprised of an initial high speed entry, a skip back to vacuum, followed by a second entry.



The predictions showed that the surfaces observed high heating during first entry, a benign skip followed by the second entry with relatively modest heating. However, the thermal soak-back during the benign skip caused the phenolic filler of the AVCOAT TPS to ablate while the honeycomb structure remained intact. The exposed honeycomb increased the surface roughness, causing heating augmentation. The locations of the calorimeters are obtained from Wright's paper and are presented in Fig 2. The prediction vs. flight data for sensor A is delineated in Fig 3.