Modeling Heatshield Erosion due to Dust Particle Impacts for a Martian Entry Vehicle.

G. E. Palmer[1] , E. Ching[2], M. Ihme[2], D. Kerkhoff[3], and A. Gülhan[3], [1]AMA, Inc., Mail Stop 230-2, NASA Ames Research Center, Moffett Field, CA 94035, grant.e.palmer@nasa.gov , [2]Department of Mechanical Engineering, Stanford University, Stanford, CA 94305, eching@stanford.edu, mihme@stanford.edu , [3]Institute of Aerodynamics and Flow Technology, DLR, ali.guelhan@dlr.de, dirk.kerkhoff@dlr.de

Brief Presenter Biography: Grant Palmer has worked for the Aerothermodynamics Branch at NASA Ames Research Center since 1985 in the fields of planetary entry, computational fluid dynamics, radiation modeling, and thermal protection system sizing.

Introduction: The structure and composition of the Martian atmosphere has been well-characterized [1] and consists primarily of CO_2, N_2, and Ar. One of the unique aspects of designing a spacecraft that will enter the Martian atmosphere is the need to account for the presence of dust. Small dust particles are present even under quiescent conditions, and the level of dust significantly increases when a major dust storm occurs. During or after a dust storm, the dust can extend to altitudes as high as 50 km [2].

Based on observations taken over decades, major global dust storms occur on the average of once every 3–4 Earth years [2]. They do not, however, happen at regular intervals. For example, two major global dust storms occurred in 1977, and these events provided the Viking landers with opportunities for gathering data on the dust storms.The concentration of dust in the atmosphere can be estimated by measuring the absorption of solar radiation. Based on measurements taken by the Viking landers and estimations of the strength of the vertical winds in the Martian atmosphere, it was determined that the residence time of the larger (5–10 μm diam) particles in the upper atmosphere was between 20 and 50 days after the beginning of a major dust storm [3].

Because planetary missions to Mars take years from initial design to arrival at Mars, and because of the unpredictability of major global dust storms, the design of the thermal protection system (TPS) of a Mars entry vehicle requires an estimation for the potential damage caused by dust particle impacts on the heatshield. This paper will review previous analytical and experimental approaches to modeling dust particle erosion and will compare the legacy models against more modern computational techniques and new dust erosion models that will be based on upcoming experiments in the German Aerospace Center (DLR) GBK facility. The various models will be compared by incorporating them into the Icarus material response code [3] applied to a representative vehicle entering the Martian atmosphere.

Legacy Dust Erosion Models: A previous attempt to model dust erosion on Martian entry vehicle [4] used particle impact damage equations that were based on Apollo-era experiments. The experiments fired 0.4 – 1.58 mm dimeter pyrex, aluminum, and sapphire spheres at glass plates. The experimental data, though based on projectiles much larger than Martian dust particles, was deemed in Ref. [4] to be the most appropriate data on which to base their impact damage models. The damage for an individual particle impact was a function of the velocity and diameter of the particle at impact. These parameters were determined by tracking the progress of the particles through the shock layer by solving a system of four ordinary differential equations (ODE) using a multi-step Runge-Kutta technique. The particle tracking process in Ref. [4] included free molecular and particle surface sublimation effects. A decoupled computational fluid dynamic (CFD) solution provided the fluid velocity and density profiles in the shock layer.

Discontinous Galerkin Particle Tracking Code: A research effort at Stanford University has developed the capability to compute hypersonic flows in dusty environments using high-order, discontinuous Galerkin (DG) methods [5]. The code uses a Lagrangian approach to tracking dust particles in the shock layer, coupled to an Eulerian gas-phase model. The model predicts augmented surface heat flux caused by the dust particles exchanging momentum and energy with the boundary layer and due to surface impacts. In this paper, results from the Stanford DG code will be compared against the ODE approach used in Ref. [4].

Dusty Flow Experimental Data: To aid in the validation of both the DG code development and the implementation of the particle impact boundary condition in the Icarus material response solver, a series of tests are planned in the DLR GBK experimental facility that will include the capability to inject particles into the wind tunnel flow. The GBK "small probe" used in the experiments consists of a 10 mm diameter hemispherical probe mounted on the end of a probe mount. The nozzle exit Mach number is approximately 2.1.

Icarus Material Response Solver: The Icarus material response solver is a three-dimensional, unstructured code developed at NASA Ames that solves the finite-volume formulation of the material response equations including the effects of material decomposition and ablation [3]. The Icarus code has been previously applied to analyze the Huygens vehicle during its entry into the atmosphere of Titan [6].

The Icarus code has an aeroheating boundary conditions that solves the surface energy balance (SEB) to determine the conduction heat transfer into the TPS material including the effects of convective and radiative heating and re-radiation. If the TPS material is an ablator, which will be typical for a Martian entry vehicle, the SEB will also include the effects of pyrolysis gas and surface ablation. The aeroheating boundary condition in the Icarus code will be modified to include the effects of dust particle impact damage and heating augmentation, using both the legacy and updated damage models, to provide a more comprehensive estimate of the heatshield erosion during a Martian entry.

References:

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