MODELING THE GAS/PARTICLE PLUME OF ENCELADUS. S. K. Yeoh[1], J. R. Kizer[1], D. B. Goldstein[1], P. L. Varghese[1] and L. M. Trafton[2], [1]Computational Fluid Physics Laboratory, The University of Texas at Austin, Austin, TX 78712 (skyeoh@mail.utexas.edu, jkizer@mail.utexas.edu), [2]Department of Astronomy, The University of Texas at Austin, Austin, TX 78712.

Introduction: Cassini first detected a water vapor composite plume near the warm, ice-covered south polar region of Enceladus in 2005 [1, 2, 3, 4]. Since then, more flybys have been made over the moon with the most recent occurring in autumn 2009. These flybys have not only captured many spectacular images of Enceladus but also provided more details on the plume structure and composition as well as the possible locations of the contributing sources. The observations suggest that the plume is made up of gas with tiny entrained ice particles [3, 9].

Based on the data and images collected by Cassini, we have constructed a hybrid model of the gas/particle plume. The model divides the plume into two regimes. The direct simulation Monte Carlo (DSMC) method is used in the region of the plume close to the vent where it is relatively dense and collisional. The results from the DSMC model are fed into a less-computationally expensive free-molecular model that simulates the far-field where the assumption of non-collisional dynamics is adequate. The simulation results to be obtained will be used to constrain the physical conditions at the sources of the plume, such as temperature, velocity, vent geometry, plume generation mechanism, etc.

Free-Molecular Model: The far-field plume model is constructed from 8 main point/disk shaped sources located along the tiger stripes [1] in the south polar region of Enceladus. In accordance with the findings of Spitale and Porco [5], two sources were placed on Damascus Sulcus, three on Baghdad Sulcus, two on Cairo Sulcus and one on Alexandria Sulcus. These sources eject gas molecules at a combined mass flow rate of approximately 100 kg/s and at vent velocities near thermal gas speeds. The gas molecules diffuse through the vents with a $\cos^2(\delta)$ distribution, where δ is the spreading angle, and merge with a simulated global sublimation atmosphere and the background E-ring gas. Together, the composite simulated sources allow for model calibration and comparison with in-situ H_2O gas density measurements collected by the Cassini INMS instruments during the recent close flybys of Enceladus. Furthermore, the INMS density data collected during the E3 and E5 flybys of Enceladus [6], in combination with the spacecraft trajectory data [7], allow these flybys to be simulated in the free-molecular regime and used to constrain vent orientations, strengths and the overall 3-dimensionality of the vapor plume. Figure 1 illustrates the Cassini E3 flyby trajectory simulated in the free-molecular far-field plume model. During this flyby the Cassini spacecraft passed within 50 km [8] of Enceladus at closest approach and flew directly through the composite plume and over the south polar region. Figure 2 shows the comparison between in-situ INMS H_2O density data and the simulated H_2O density provided by the free-molecular model.

DSMC Method: The source of the water vapor composite plume is modeled as a series of smaller vents along the tiger stripes [1]. The region near each vent is modeled using DSMC. The vent parameters are deduced from the data and images taken by Cassini. Water vapor issues from the vent in thermal equilibrium at 145 K [4] and at a sonic speed of 300 m/s [2]. The surface temperature is 75 K [4]. Each vent is assumed to be an axisymmetric circular source with a radius of 250 m to produce a gas mass flow rate of ~1 kg/s.

A preliminary run conducted for this abstract only includes 10-nm-sized particles coming out of the vent at the same speed as the gas at 300 m/s. The particle mass flow rate is calculated to be ~2 kg/s (~1:5000 particle-to-gas-molecule ratio). In the future, our model will incorporate micron-sized particles [9]. In addition, we will explore different sizes and initial speeds for the ice particles in an attempt to match observations.

The results from the preliminary run are shown in Figures 3 and 4. Figure 3 illustrates the particle trajectories and the gas streamlines at steady state. As expected, the particles initially track the gas flow before separating from it. For larger particles, we would expect the separation to occur earlier and the magnitude of the separation to be larger. We would also expect the initial speed of the particle to play an important role. Figure 4 shows the contours of gas speed with gas streamlines. As the gas expands out of the vent, it accelerates to speeds well in excess of the Enceladus' escape speed of ~240 m/s. Furthermore, the gas cools down from ~140 K to ~70 K (not shown here) as it expands, thus achieving supersonic speeds.

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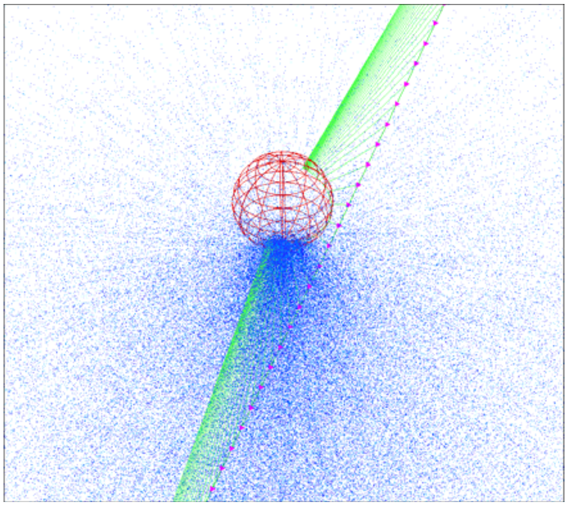

Figure 1: Visualization of E3 Enceladus flyby by the Cassini spacecraft simulated in the free-molecular model. The Cassini trajectory is marked by the green line and pink arrows and the plume can be seen ejecting gas molecules from eight point sources located in the south polar region.

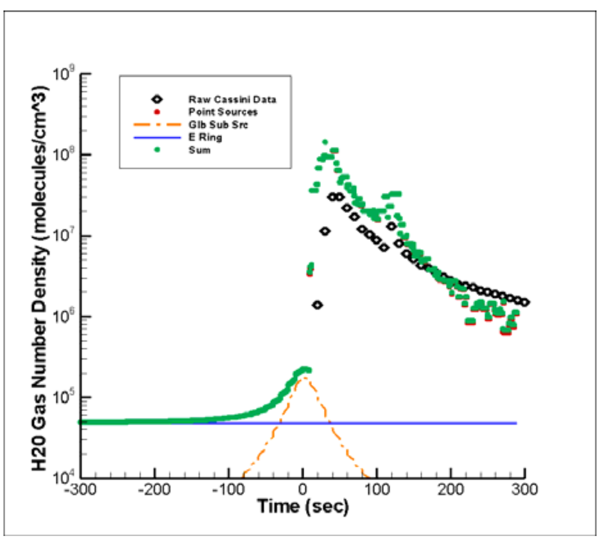

Figure 2: Comparison between in-situ density data and free-molecular model results. The Cassini INMS data can be seen as the black diamonds. The free-molecular model superimposes the eight point sources (red dots, hard to distinguish), a global sublimation source (dot-dash orange line) and a background E-ring density (blue line) to create a total H_2O simulated number density (green dots) to compare with Cassini data.

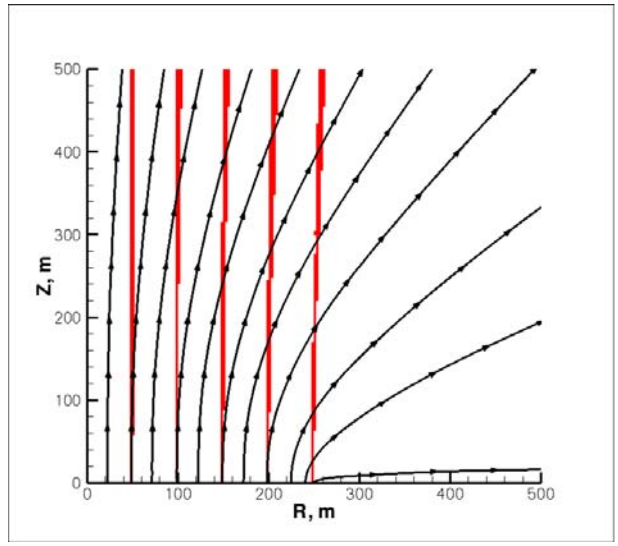

Figure 3: 10-nm-particle trajectories (red streaks) and gas streamlines (black lines with arrow heads). Each vent is a 250-m-radius axisymmetric source. Note that the particle trajectory and the gas streamline deviate more near the edge of the vent where the gas turns more rapidly as it expands out of the vent.

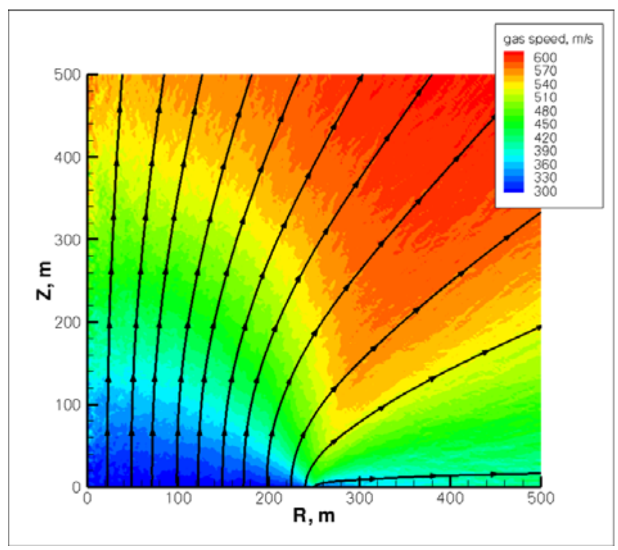

Figure 4: Contours of gas speed and gas streamlines. The gas cools down as it expands to speeds much higher than the escape speed from Enceladus, thus achieving supersonic speeds as it escapes into space.