FREE-MOLECULAR AND COLLISIONAL STUDIES OF ENCELADUS' WATER VAPOR PLUMES. B. J. Hanna[1], S. K. Yeoh[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 (ben.hanna@mail.utexas.edu, skyeoh@mail.utexas.edu), [2]Department of Astronomy, The University of Texas at Austin, Austin, TX 78712.

Introduction: In 2005 Cassini detected a water vapor plume near Enceladus' warm, ice-covered south pole during three orchestrated close flybys. Since then, several hypotheses about the origin of the plumes have been put forth, including the sublimation of water ice below 273K [1], the low-pressure boil-off of water at or near 273K [1], the release from clathrates [2], and the eruption of high-pressure bubbles of hydrogen and nitrogen molecules in the ice created by energetic ions in Saturn's environment irradiating the surface [3]. Recent flybys in 2008 have provided more details on the plume composition and the locations of the sources of these jets of water vapor.

In the present work a separate free-molecular model and a collisional direct simulation Monte Carlo (DSMC) method are used to simulate the plumes to attempt to match the observations [4]. The assumption of non-collisional dynamics is fairly accurate in the far-field, so the less-expensive free molecular model is used to obtain a qualitative, global picture of the plumes. The DSMC method is being developed to produce a more detailed and realistic model of the plumes. The results obtained will be used to constrain the conditions on the sources of the plumes, such as temperatures, velocities, pressures, vent geometries, and plume-generation mechanisms.

Free-Molecular Model: Source velocities in the free molecular model are calculated based on the assumption the source is a finite region where the gas is collisional and undergoes a collisional expansion as it loses internal energy to directed energy.

In an image returned by Cassini [1], it appears that point-like sources emit a larger amount of particulates than the slit-like warm "Tiger Stripe" regions near or in which they are located (Fig. 1). The free-molecular code has modeled vent geometries including slits only, point sources only, and will combine both for a comprehensive evaluation (Fig. 2). The findings from the simple slit-only model agree qualitatively with Cassini data in that the plumes can be made to have similar shapes and extend hundreds of kilometers beyond the surface of the moon [1]. This model is limited by its stark simplicity. Fig. 1 clearly shows a higher particle density in the central region of the plume, while the slit-only model shows more evenly distributed particle densities. For this reason, the incorporation of a distributed point source model is necessary. The locations of point sources in our current model will be taken from Spitale and Porco [5], in which the locations of the main point sources observed by Cassini are estimated. The direction and strength of each jet vary, as seen in Fig. 1, and the point source-only model will eventually incorporate these conditions.

DSMC Method: In the collisional flow simulations we examine a single axisymmetric source that has a uniform velocity of 200 m/s [6] and issues in thermal equilibrium at 145 K [4]. Surface temperature is assumed to be 75 K [4]. The assumed vent radius is 10 m, which is around the minimum pixel size from Spitale and Porco [5] since the vents are unresolved in those images. While the real plumes are composed of gas as well as condensates and/or ice grains and/or dust particles [7], the plume simulated in this initial run consists only of gas in the form of water vapor. The preliminary simulation result is shown in Fig. 3.

We plan to consider more complex three-dimensional vent geometries, including a fissure or edge source which might occur along the Tiger Stripes. In addition, particles are to be included in the simulation. Two "overlay" methods are used to model fine particulates. In the first method, small particles are treated simply as another molecular species. The second approach is to calculate the drag on the particles in a pre-calculated gas flow field and move them accordingly. Moreover, condensation in the plume can be modeled via the overlay approach by starting with seed dimers at the vent and using a sticking coefficient which determines if a molecule/cluster collision results in the formation or growth of a condensate. The trajectories of the gas flow and the particles can then be analyzed.

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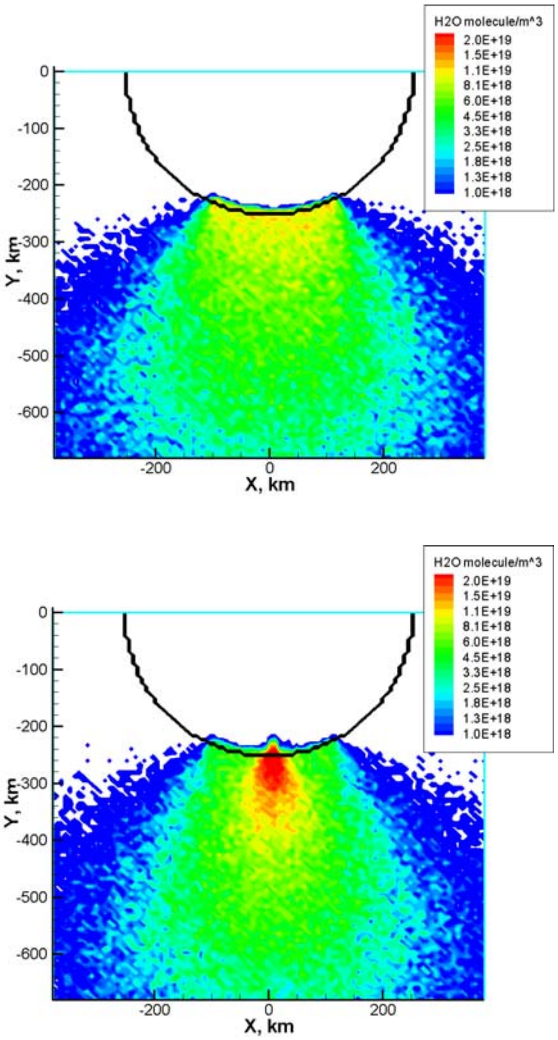

Fig. 2: 25 deg. slit-only source (top) viewed edge-on; 25 deg. slit with a single point source at the south pole, with mass divided equally between slit and point (bottom). Source temperatures are 145 K resulting in the rather broad spreading of the plume. Note the different color scales in Figures 2 and 3.

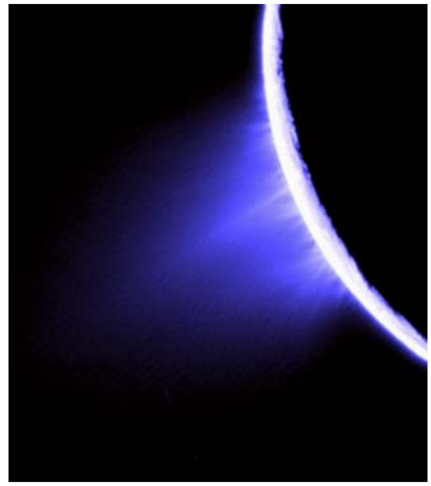

Fig. 1: An image from Cassini [1]. These plumes reach far out into the outer space (hundreds of kilometers) above the surface of Enceladus. The extremely thin particle jets suggest that the gas temperatures are low and the gas/dust flow has become decoupled.

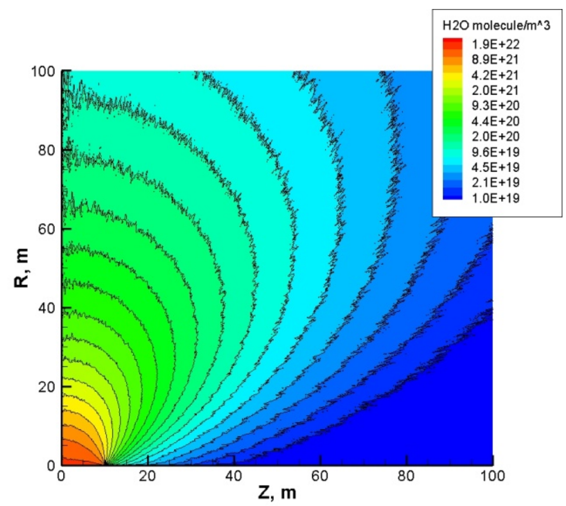

Fig. 3: Close-up view of the 10 m radius axisymmetric source with the same mass flux as in Fig. 2 (~40 kg/s). A 1 deg. wedge-shaped domain with a grid of 500x500x1 (1 cell in the azimuthal direction) and a time step of 0.00025 sec are used. Simulation is run until steady state is achieved. Note that the Knudsen number at the vent is ~3.5 x 10^{-6} (mean free path at the vent is ~70 μm), based on the vent diameter. An under-resolved calculation has been performed at that Knudsen number.