Computational Fluid Dynamics Modeling of the NASA Titan Wind Tunnel

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Abstract

The equatorial region of Titan, the largest satellite of Saturn, has extensive expanses of aeolian dunes revealed in synthetic aperture radar (SAR) images and suggested to be composed of organics or organic-coated water ice. The dunes are among the youngest surface features and appear to be similar to dunes previously been observed on Earth, Mars, and Venus, and their presence on Titan indicates active processes of production, transport, and arrangement of sand sized particles. Understanding what wind regimes can mobilize particles to form and migrate these dunes is essential to understanding many questions for Titan such as seasonal versus epochal winds, particulate sources and sinks, sand fluxes, resurfacing processes, and aeolian sedimentation. Specifically, knowledge of the threshold wind speed—or the minimum wind speed at which particles are moved or redistributed by wind—is essential. This wind speed is usually empirically derived as a complex function of the physical parameters and surface conditions. Wind tunnel experiments are a well-controlled approach to determining threshold wind speeds, but this approach requires carefully controlled boundary (wind tunnel) conditions for correct derivation of this value. The NASA Titan Wind Tunnel (TWT) at the NASA Ames Research Center in Mountain View, CA is a community resource for the planetary science community, is uniquely able to simulate flow under high-pressure atmospheres such as on Titan. Characterizing flow in the TWT is highly desirable to ensure accurate results, as the results cannot be reproduced in any other facility, but is likewise challenging due to the small (20 cm diameter) closed (pressurized) configuration of the facility, which limits internal instrumentation. Consequently, in this study, we pair empirical results from the TWT with a series of Computational Fluid Dynamics (CFD) simulations for corroboration of flow in the TWT. We use the CFD and Particle Tracing Modules in the COMSOL Multiphysics® software to model turbulent isothermal flow matched to both the Titan Wind Tunnel pressure and temperature conditions (P=1.25E6 Pa of (~79% N_2, ~20% O_2); T=293 K) and approximate Titan surface ambient conditions (P=1.44E5 Pa of N_2; T=94 K) using both a 2-D center section slice of the wind tunnel as well as a full 3-D model of the wind tunnel geometry. We vary the test bed end shapes and thicknesses, roughness, obstructions, sediment particle sizes, and instrumentation geometry. We find that wind tunnel flow conditions are rather sensitive to experimental setup, which has evolved over time for the TWT. We also find that fluid/particle density ratios are—as expected—more important for Titan conditions than for terrestrial conditions. Overlapping and validation

of the CFD and Wind Tunnel results allows greater confidence in extending our modeling in both terrestrial and extraterrestrial environmental conditions.

Figures used in the abstract

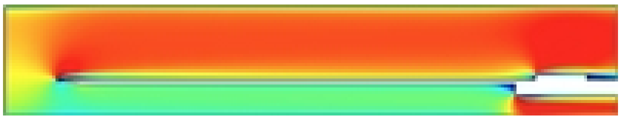

Figure 1: Velocity field for center section of the Titan Wind tunnel showing test plate and instrumental flow obstructions