CALIBRATION AND VALIDATION OF THE TITAN WIND TUNNEL: A COMMUNITY RESOURCE AT THE PLANETARY AEOLIAN LABORATORY.

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Introduction: The discovery of extensive aeolian dunes covering ~20% of Titan's surface [1,2] provides a novel environment in which to explore aeolian processes. These dunes develop under lower gravity and lower-sediment-density conditions than dunes on Earth, Mars, and Venus, but under a thicker atmosphere [3, 4]. Because the dunes provide information on multiple processes (e.g., atmosphere-surface interactions, sediment transport rates, and resurfacing mechanisms), their discovery presents a scientific opportunity.

The detection of aeolian dunes on other planets led to the creation of wind tunnels to investigate the conditions of dune formation and the physics of saltation and other aeolian processes in different environments. These wind tunnels originally included the Mars Surface Wind Tunnel (MARSWIT) (also able to run at Earth conditions) [5] and the Venus Wind Tunnel (VWT) [6], located at the NASA Ames Research Center (ARC) Planetary Aeolian Laboratory (PAL) [3]. It was subsequently recognized, based largely on the Cassini findings, that a Titan wind tunnel was also needed.

To enable such experiments by the planetary aeolian community, we refurbished the VWT through the Planetary Geology and Geophysics (PGG) program to enable analog Titan work. This abstract describes this refurbishment process and publicizes this new experimental resource for the planetary aeolian community. Because PAL is a 'Regional Facility Instrument,' the TWT is available to investigators supported through NASA's Solar System Workings and other programs.

The Titan Wind Tunnel: The Titan Wind Tunnel (TWT; Figure 1), a remodel of the Venus Wind Tunnel, is a closed-circuit, high-pressure, boundary layer tunnel. It is certified to run at pressures up to 20 bars. Flow is generated by an 8-bladed fan, with maximum wind speed a function of pressure (Table 1).

TWT pressure	Max wind speed
1 bar	4 - 4.5m s^{-1}
12 bar	5 - 6 m s^{-1}

Table 1: Maximum wind speeds at representative pressures achievable in the TWT.

Downwind of the fan, flow straighteners minimize turbulence, and a settling chamber traps particulate material before the flow enters the test section.

The test section, 122 cm in length and 20.3 cm in interior diameter, moves laterally into or out of position within the wind tunnel. Floor plates have the same length as the test section (Figure 2A) and rest against the inside walls. The test section has one upwind observation port, and three downwind ports, including two ports on either side of the test section identical to the upwind port and a smaller top port to enable illumination of the test bed. The TWT operates with pressurized air that is desiccated to dew point of -40 ^{o}C. Static pressure is monitored using a calibrated gauge.

The TWT is fitted with a custom-made high-pressure, high-temporal-resolution transducer. Wind speed data, both for calibrations and threshold wind speed information, are collected using pitot tubes (Figure 2B) connected to this transducer. Transducer output consists of voltage as a function of dynamic gas pressure, P_{dyn}, according to manufacturer-supplied calibration curves. These dynamic pressures are converted to freestream wind speeds at height z, by

$$u(z) = (2P_{dyn}/\rho)^{1/2}$$

where P_{dyn}, is a function of z ($P_{dyn} = P_{dyn}(z)$).

TWT calibration: For derivation of threshold friction wind speeds in the Titan Wind Tunnel, different calibration data were required.

i) Although wind speed (dynamic pressure) data were required in the test section, where threshold was observed, the traversable pitot tube in the test section had to be removed during experiments to prevent clogging or disruption of air flow. Dynamic pressure data were collected instead using the fixed pitot tube on the opposite side of the wind tunnel (Figure 1). A correlation curve was derived to convert the freestream wind speed data collected during experiments into equivalent freestream wind speed data in the test section. We constructed this curve from separate calibration runs at fan motor speeds of 20% increments of maximum rated speed. During these runs, voltage data from the transducer were collected alternately from the traversable and fixed pitot tubes by switching the stack valve to read either the fixed pitot or traversable pitot for the same fan motor speed increment as described above.

ii) Freestream wind speed at height z, $u(z)$, is related to friction wind speed, $u*$, according to the 'law of the wall,'

$$u(z)= (u^*/\kappa)ln(z/z_0) \quad \text{(Eq. 1)}$$

where κ is the von Kármán constant (0.41) and z_0 is the roughness height, the height at which the wind speed is 0. Thus, to convert the freestream wind speeds at threshold ($u(z)_t$) into the desired friction wind speeds at threshold (u^*_t) requires knowledge of the roughness height. Equation 1 can be linearized to

$$ln(z)= (\kappa/u^*)u(z) + ln(z_0) \quad \text{(Eq. 2)}$$

Thus, the y-intercept of a plot of *ln(z)* versus *u(z)* is $ln(z_0)$, so that the value of $e^{(\text{y-intercept})}$ gives the roughness height. To derive this height, we performed a series of calibration runs with a traversable pitot tube and stepping motor assembly (Figure 2B). The stepping motor raised the pitot tube in logarithmically increasing steps above the plate. At each step, the voltage from the transducer was recorded on a laptop computer. The voltages were later converted to dynamic pressures using the appropriate correlation curve by pressure provided by the manufacturer, and these pressures were in turn converted to freestream wind speeds. These boundary layer data taken at different wind speeds show that the freestream boundary layer begins at ~1.9 cm and that z_0 =~0.003 cm. A more complete description of the TWT calibrations is found in [8].

Present Status and On-going Upgrades: The Titan Wind Tunnel is a fully functioning facility for investigating aeolian processes. A more sensitive high pressure transducer that will work at lower wind speeds will be installed in the spring of 2015, and other upgrades are in progress. With a pressure range of 0-15 bars, TWT vastly expands the physical conditions over that available in Earth and Mars tunnels. For example, possible past climates on Titan, when the atmosphere may have been more dense [9], can be simulated. With further upgrades, the pressure range could be increased to support anew Venus and other ultrahigh pressure studies. Such investigations are contingent upon PAL passing its NASA senior review scheduled for FY 15.

References: [1] Lorenz R.D. et al. (2006) *Science* 312, 724-727. [2] Radebaugh J. et al. (2008) *Icarus* 194, 690-703. [3] Greeley R. and J.D. Iversen (1985) *Wind as a Geological Process*. [4] Lorenz R. D. (2014) *Icarus* 230, 162-167. [5] Greeley R. et al. (1977) NASA TM-78423. [6] Greeley R. et al. (1984) *Icarus* **57**, 112-124. [7] Bagnold, R.A. (1941) *The Physics of Blown Sand and Desert Dunes.* [8] Burr D.M. et al. (2014) *Nature*, doi:10.1038/nature14088. [9] Lorenz et al. (1997) *Science* 275, 642-644.

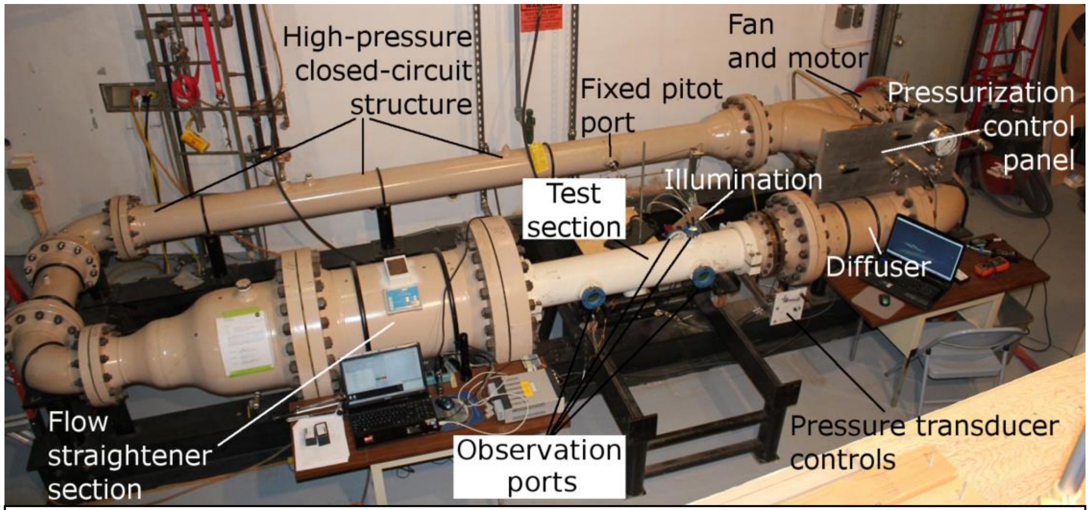

Figure 1: The Titan Wind Tunnel with important components labeled.

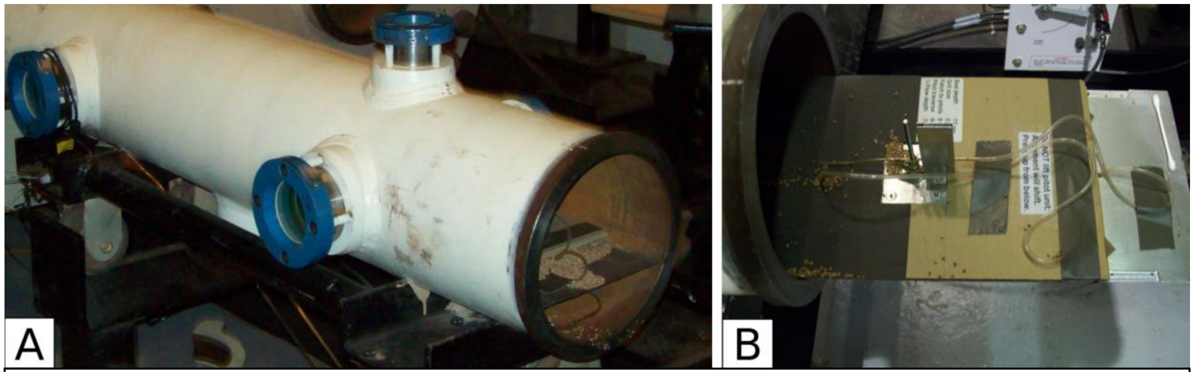

Figure 2: Downwind end of test section rolled out from the wind tunnel, showing the single upwind viewing port (far left) and the three downwind viewing ports (top of third port barely visible on far side of test section). The calibration plate is visible (lower right), with walnut shells and pneumatic lines visible. (B) Downwind end of test plate after partial removal from the test section showing the traversable pitot tube assembly (center). One-hundred-grit (125-micron-diameter grains) sandpaper, for development of the boundary layer, is visible to the left of the assembly.