WHAT'S Z_0 GOT TO DO WITH IT? PART 2: CONSIDERATIONS FOR COLLECTING WIND PROFILING DATA FROM LANDED VEHICLES.

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Introduction: With apologies to Tina Turner (again), the title indicates that this report is a continuation of an abstract submitted to the 7th International Planetary Dunes Workshop [1], here focused on considerations for future spacecraft missions that may include the collection of wind profiling data to constrain z_0, the height at which a logarithmic wind speed profile is zero. A remarkable paper by Wieringa [2] describes several conditions that should be considered when collecting wind profile data to derive z_0.

Background: Bagnold [3, pg 47-49] plotted wind data on a linear velocity scale versus a logarithmic height scale; on this plot the wind data project along a straight line to a height of zero velocity for multiple wind conditions over the same surface, each line with a slope dependent on the shear stress (or friction speed). Bagnold further said that Prandtl related the height of the focus point (on a semi-log plot) to the roughness over which the fluid is moving; the height of the zero-velocity point is 1/30 the diameter of the roughness elements of the surface [3, pg 50]. The semi-logarithmic relationship between height and velocity is called the Prandtl-von Karman equation, or 'the Law of the Wall' [4, pg 44]. Wieringa [2] describes several conditions that affect the usefulness of wind profile data, and he makes the following important statement: The popular saying "z_0 is the height at which the wind speed becomes zero" is true in a purely algebraic sense only, since it implies extrapolation of the (Law of the Wall) equation below its limit of validity [2, pg 325].

Methodology: Wind profile measurements are typically collected using anemometers logarithmically spaced in height along a tower. Weiringa [2] states that the lowest anemometer height should be >20X the anticipated z_0 for the surface, the tower should be downwind of the nearest obstacle at a distance >15X the obstacle height, the fetch upwind of the tower should have consistent roughness elements for at least >80 m, at least four anemometers should be used for moderate roughness (z_0 ~10 cm) and preferably five or more over terrain smoother than this, and times near sunrise or sunset are to be avoided. A least-squares logarithmic fit is applied to the average wind speeds documented during time intervals where the wind increases systematically with height. The least-squares fit is then used to calculate the height at which the wind speed becomes zero (z_0).

Considerations for landed spacecraft: Caution is required to avoid spacecraft components from compromising the use of wind measurements to infer z_0 from wind profiling data. This measurement can be done, as was demonstrated during the Pathfinder mission [5], but it involves a non-trivial effort to constrain results to winds coming from a direction that minimizes spacecraft structure from affecting the upwind flow. There may be little control over the final surface orientation of the sensor array on a fixed lander, but on a rover, attention should be paid to the rover orientation relative to anticipated wind direction at stops planned for wind profiling data collection.

Heights of anemometer sensors above the spacecraft are less important than the height of the lowest sensor above the surface. A tower fixed to a landed spacecraft should place the lowest sensor considerably higher than Wieringa's suggested (twenty times z_0). If the spacecraft structure near the anemometer tower lacks significant obstacles, the lowest anemometer height could be as low as 10 cm above a smooth spacecraft deck. The height of the uppermost anemometer is not critical, but the anemometer array should be spaced logarithmically.

The estimated z_0 of 3 cm at the rocky Pathfinder site [5] implies that most 'safe' landing sites on Mars likely will have z_0 considerably smaller than 10 cm, the value used by Wieringa [2] for suggesting use of a minimum of four anemometers; consequently, five or more anemometers should be planned for future Mars landers, and the smaller the anemometers, the more can be used on a tower of modest total length. Aerodynamic roughness z_0 can be constrained using only two anemometers [3, pg 50], but the more sensors on the tower, the stronger the confidence of documenting a logarithmic profile.

The choice of anemometer tower location on the spacecraft should be guided by wind tunnel tests using a high-fidelity spacecraft model to optimize positions of minimal disruption of the logarithmic wind profile for winds coming from many directions. The landed anemometer array also should include temperature, pressure, and wind direction sensors.

Weiringa [2] described three flow types for wind blowing over surface roughness elements (Fig. 1). Surfaces involving closely spaced particles are consistent with 'skimming flow', which occurs 'when the surface is so closely covered with obstacles that flow in the spaces between obstacles has a regime quite separate from the bulk flow above' [2]. In this situation roughness height is less a result of the size of the individual particles than it is the cumulative effect from many closely spaced particles. Wind profiling over gravel-covered surfaces in the Puna of Argentina gave z_0 of ~1 cm regardless of whether gravel-covered megaripples were present in the upwind direction, suggesting that the closely spaced gravel particles caused skimming flow with only minimal influence from form flow over megaripples [6]. It is unclear how the atmosphere behaves in between closely spaced surface particles; use caution inferring the 'average' particle size of the surface to be 30X the value of z_0.

It is instructive to consider how changes to the least-squares logarithmic fit coefficients affect the extrapolated wind field (Table 1). Coefficients similar to those resulting from fits to field measurements in Argentina [6] were used as the starting point. The first lines in both sections of the table give z_0 for each fit. In general, small changes to either coefficient can affect the derived z_0, but any change to z_0 translates to smaller percentage changes in the calculated wind speed at heights well above the top anemometer; this could be important to modelers who use z_0 to estimate wind speeds at large heights above the surface.

Summary: Roughness height (z_0) can be constrained from tower-mounted anemometers on either fixed or roving landers if the data used are restricted to winds coming from a direction that minimizes possible upwind effects caused by spacecraft hardware. Rover mission planners should consider tower location relative to anticipated wind direction when selecting orientation for planned stops.

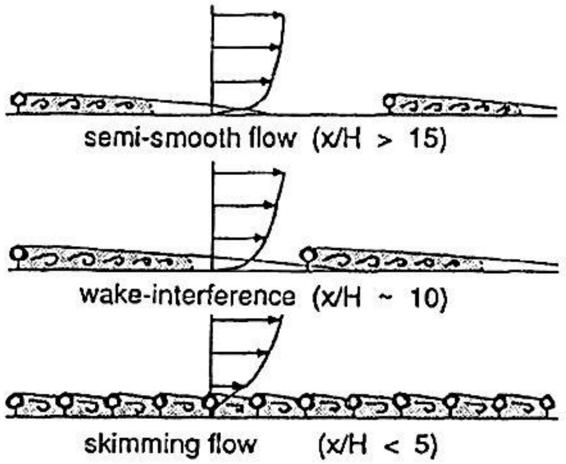

Figure 1. Flow categories over terrain obstacles, from Fig. 1 of Wieringa [2]. H is the height of a roughness element and x is the distance between obstacles.

Table 1. Changes to logarithmic best-fit parameters relative to a **reference condition** (values inside parentheses are percentage change from reference value shown in **bold** in each line). Both parameters influence the derivation of z_0, but parameter 'a' has a stronger effect on estimated wind speed above the tower than does parameter 'b'. Change to z_0 translates to relatively small percentage changes in the calculated wind speed at heights above the top anemometer.

$Y = a + b \ln X$ [where Y is wind velocity, X is height]

[**a = -.5**]

b = .6		b = .7		**b = .8**		b = .9		b = 1.0	
X (cm)	**Y** (m/s)	**X** (cm)	**Y** (m/s)	**X** (cm)	**Y** (m/s)	**X** (cm)	**Y** (m/s)	**X** (cm)	**Y** (m/s)
(+23%) 2.30	0	(+9%) 2.04	0	**1.87**	0	(-7%) 1.74	0	(-12%) 1.65	0
5.0	(-41%) 0.47	5.0	(-20%) 0.63	5.0	**0.79**	5.0	(+20%) 0.95	5.0	(+41%) 1.11
50	(-30%) 1.85	50	(-15%) 2.24	50	**2.63**	50	(+15%) 3.02	50	(+30%) 3.41
500	(-28%) 3.23	500	(-14%) 3.85	500	**4.47**	500	(+14%) 5.09	500	(+28%) 5.71

[**b = .8**]

a = -.3		a = -.4		**a = -.5**		a = -.6		a = -.7	
X (cm)	**Y** (m/s)	**X** (cm)	**Y** (m/s)	**X** (cm)	**Y** (m/s)	**X** (cm)	**Y** (m/s)	**X** (cm)	**Y** (m/s)
(-22%) 1.46	0	(-12%) 1.65	0	**1.87**	0	(+13%) 2.12	0	(+28%) 2.40	0
5.0	(+25%) 0.99	5.0	(+13%) 0.89	5.0	**0.79**	5.0	(-13%) 0.69	5.0	(-25%) 0.59
50	(+8%) 2.83	50	(+4%) 2.73	50	**2.63**	50	(-4%) 2.53	50	(-8%) 2.43
500	(+4%) 4.67	500	(+2%) 4.57	500	**4.47**	500	(-2%) 4.37	500	(-4%) 4.27

References: [1] Zimbelman, J. R. (2022) 7th IPDW Abs. 3011. [2] Wieringa J. (1993) *Bound. Layer Meteorol.*, 63, 323-363. [3] Bagnold, R. A. (1941). The Physics of Blown Sand and Desert Dunes. Chapman and Hall, London. [4] Lorenz, R. D. and J. R. Zimbelman (2014) Dune Worlds: How Windblown Sand Shapes Planetary Surfaces. Springer/Praxis, New York. [5] Sullivan R. et al. (2000) JGR, 105, 24547-24562, doi: 10.1029/1999JE001234. [6] Zimbelman, J. R. et al. (2022) *Lunar Planet. Sci.*, 53, Abs. 1502.