A WIND TUNNEL STUDY OF THE EFFECT OF DENSITY RATIO ON SALTATION THRESHOLD CONDITIONS

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Introduction: The aeolian saltation threshold is the minimum wind speed required to entrain sediment into saltation. Because sediment entrainment into saltation is required for all subsequent aeolian processes, the value of saltation threshold speed is a fundamental parameter in aeolian science and influences all aspects of sediment movement. These aspects include aeolian mass flux [1,2] and minimum aeolian erosion potential [3] and effectiveness [4]. Quantifying saltation threshold is thus critical to our analysis and understanding of phenomena from a local scale, like ventification [5] and dune orientation [6], to the global scale, like the relative importance of various resurfacing processes [7]. All of these processes have important implications for past climate conditions and climate change [8-11].

A general expression for aeolian saltation threshold is needed for the prediction and modeling of saltation threshold speeds on Earth as well as on the myriad other planetary bodies with aeolian sand transport [12-15]. Bagnold derived the threshold friction speed (u_{*t}) as:

$$u_{*t} = A\sqrt{\frac{\rho_p - \rho}{\rho} g D_p}, \qquad (1)$$

where A is the dimensionless threshold parameter, ρ_p is the particle density, D_p is the mean particle diameter, and g is the gravitational acceleration [16]. The A parameter is a function of the density ratio, the ratio of the density of the sediment or particle being entrained by the fluid (or wind) to the density of the fluid entraining the sediment (ρ_p/ρ), the interparticle force, and the Reynolds number (Re_{*t}). Previous work resulted in an expression for the dimensionless threshold parameter, A, as a function of the density ratio [12]. In this work, we investigate the validity of the density ratio term and its inclusion in the Iversen et al. threshold model [12]. This density ratio expression was based on data from threshold experiments in water, high-density air, and low-density air, giving a range of density ratios that cover five orders of magnitude. To minimize interparticle force and Reynolds number effects, the data used to derive this expression were filtered to include only data for grain sizes greater than 200 µm and particle Reynolds numbers greater than 10. However, the transitional portion of the curve, between low (<10) and high (>1000) density ratios, does not fit recent threshold data from the Titan Wind Tunnel [13] that are subject to the same filtering conditions.

Hypothesis: The null hypothesis is that the density ratio expression derived by Iversen et al. [12] is correct and the alternative hypothesis is that the derived expression is incorrect.

Methods: Testing the validity of the density ratio term– and thus, of the Iversen et al. model – entailed running new threshold experiments in the Titan Wind Tunnel (TWT) under a range of pressures and, therefore, density ratios conditions. The experimental materials covered a wide range of densities and grain diameters. This range enables comparison with past experiments, provides data that span the threshold curve, and overlaps as much as possible the parameter space for the density ratio from previous experiments. All experimental materials had a grain size larger than 200 microns to meet the filtering criterion used in Iversen et al. [12] density ratio plot.

During each experiment, the fan speed in the TWT was incrementally increased through stages [13] until threshold, where 50% of the grains are in motion, was qualitatively perceived by multiple observers. The threshold freestream speed was converted to a friction speed using roughness heights derived from boundary layer profiles (BLPs) collected in previous calibration experiments without sediment movement. These new threshold friction wind speeds were converted using equation (1) to dimensionless threshold parameter values (A).

Results: A total of 67 experiments along with 134 BLPs that bracketed the wind speeds and bed grain sizes were taken in the TWT. In order to recreate the dimensionless threshold parameter (A) expression with the inclusion of the density ratio term [$g(\rho_p/\rho)$] proposed by Iversen et al. [12], we applied the same criteria they used – $D_p > 200$ µm, and $Re_{*t} > 10$ – to filter the data in this study. Out of the 67 experiments conducted for this study, 19 of them had Reynolds numbers greater than 10. The values of density ratio vs A are plotted for these 19 experiments along with the experiments in Iversen et al. [12] and Burr et al. [13] (Figure 1) that match the same two criteria.

These experimental results do not overlap the density ratio curve within their error bars (Figure 1). Likewise, the previous TWT data points, with two exceptions, also do not fit the density ratio curve. Thus, a new density ratio curve was derived to fit the expanded data set using the same format as the previous expression but with a new value for an exponential parameter.

This new, lower, exponent effectively increases the value of A in the transitional portion of the curve.
The new expression is as follows:

$$A = \frac{0.2}{\sqrt{\left(1 + 2.3\left\{1 - e^{\left[-0.0032(\rho_p/\rho - 1)^{0.89}\right]}\right\}\right)}} \quad (2)$$

Conclusion: This result is consistent with the use of previous Titan Wind Tunnel threshold data that were found to be higher than predicted by the model [13]. However, the mismatch between the previous density ratio curve of Iversen et al. [12] and this new curve (Fig. 1) is still not well-understood. This mismatch could be due to how the data from the TWT were reduced. The previous density ratio curve was derived using threshold experiments that had varying definitions of threshold. Threshold for the transitional portion of the curve, was defined as occurring when groups of grain began to saltate sporadically, whereas we used the definition of when 50% of the grains are in motion, which was consistent with the previous MARSWIT work [14]. The data from the TWT are being reduced using a threshold definition of 'patches' [13], that better corresponds to the definition used in the transition portion of the curve. We are also exploring alternative fitting of the boundary layer profiles to derive roughness heights, used for deriving the friction wind speed [e.g., 13] based on the 'law of the wall'.

To improve the accuracy of the density ratio curve, more threshold experiments will need to be conducted. The curve is missing data for density ratios between 10 and 50. At the moment, it is not possible to achieve these density ratios as the TWT can only reach a pressure of 20 bar. If the tunnel is recertified for higher pressures, then these density ratios can be achieved.

With the completion of the on-going work described above, this newly derived curve will increase the accuracy of predicting saltation threshold friction speeds, which will serve to not only improve planetary models but terrestrial ones as well.

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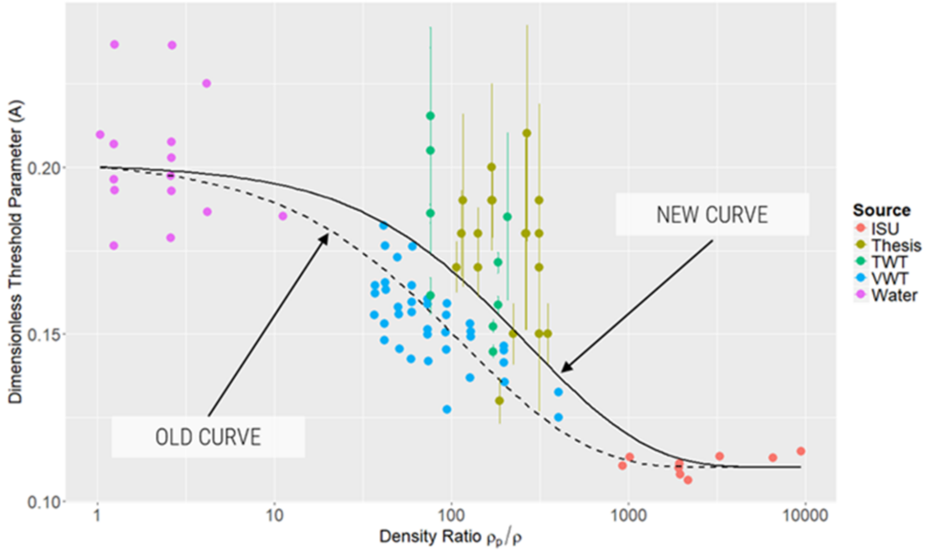

Figure 1: Threshold parameter A plotted as a function of the density ratio for various fluids for particles > 200 μm diameter and Re_{*t} >10. Adapted from Iversen et al. [12]. A subset of data for the same filtering conditions collected from the Titan Wind Tunnel [13] is also plotted along with the results from study. The density ratio curve derived by Iversen et al. [12] is the dashed line and the solid line is the curve derived in this thesis. The sources of the data are the Iowa State University wind tunnel (ISU) [14], the Venus Wind Tunnel (VWT) [15], flume experiments [17], and Titan Wind Tunnel experiments from Burr et al. [13] and this study.