DEVELOPMENT AND TESTING OF A UNIQUE CAROUSEL WIND TUNNEL TO EXPERIMENTALLY DETERMINE THE EFFECT OF GRAVITY AND THE INTERPARTICLE FORCE ON THE PHYSICS OF WIND-BLOWN PARTICLES

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In the study of planetary aeolian processes the effect of gravity is not readily modeled. Gravity appears in the equations of particle motion along with the inter-particle forces but the two are not separable. A wind tunnel that permits multi-phase flow experiments with wind blown particles at variable gravity has been built and experiments have been conducted at reduced gravity. The equations of particle motion initation (saltation threshold) with variable gravity were experimentally verified and the interparticle force was separated.

Wind tunnels suffer from several shortcomings in aeolian experiments, primarily due to limitations in size. The Reynolds Number that most strongly affects saltation threshold is based on the distance from the tunnel entry, and for most experiments a long distance is required to obtain a suffeciently large Reynolds Number to obtain the corresponding fully developed turbulent boundary layer.This presents a problem, especially when the equipment is to be flight or space borne.

A uniquely designed Carousel Wind Tunnel allows for the long flow distance in a small sized tunnel since the test section is a continous loop and develops the required turbulent boundary layer. The Carousel Wind Tunnel consists of two concentric drums with the test section being the entire space between the drums. Differential rotation of the drums causes an air flow between the drums which entrains particles placed there. Rotation of the outer drum produces a pseudo gravity force holding the particles to the surface in the same manner that gravity does. The force is psuedo in that the particles feel the force only while in contact with the surface. The tunnel is to be used in a micro gravity environment such as on the space station or in the shuttle.

A prototype model of the tunnel where only the inner drum rotates has been built and tested in the KC 135 "Weightless Wonder IV" zero g aircraft operated by NASA Johnson Space Center. Thus for these tests the gravity level was changed by the external environment rather than by the rotation of the outer drum. Reduced or zero g is obtained when the aircraft, after obtaining a suitable excess airspeed, climbs at a 45° angle and then enters a parabolic or nearly parabolic trajectory which produces the reduced or zero g for up to 30 seconds, Figure 1. The aircraft is able to fly 40 or more such trajectories in a single flight.

The wind tunnel, Figure 2, is built of clear polycarbonate plastic and the inner drum is made to spin by means of a variable speed fractional horsepower electric motor connected through a belt drive. The outer drum is 60 cm in diameter and 30 cm wide. The inner drum is 40 cm in diameter and is sized to provide a close fit along the side walls. There is a removable panel in the lower side wall for inserting and removing aeolian test material.

The drum speed is monitored by an AC voltmeter driven by a inductance pick-up which is energized by a magnet attached to the motor shaft. This is correlated with the actual drum rpm as determined with a photo-tachometer. A gravity meter utilizing a sensitive accelerometer displays the gravity level . The rpm, gravity level and particle motion are recorded by video camera during the tests for later analysis. The tunnel is mounted on a stand bolted to the floor of the KC 135.

The experiments were done in the following manner: a small quantity of aeolian material was placed in the test section and the inner drum was spun at a speed below that which would cause any particle movement. As the aircraft entered its maneuver the gravity level at which saltation threshold occured was recorded along with the drum rotation speed. The aircraft did both zero g and low g manuevers ranging from 0.05 tO 0.5 g. By varying the drum rotation speed for subsequent manuevers a matrix of data points were obtained. Often the drum speed was either too high so that a speed much above threshold was obtained or too low so that no particle movement took place. The drum speed could not be changed rapidly enough to to adjust the speed during a maneuver, however as the flights progressed experience allowed a better choice of initial drum rotation speed, obtaining values closer to saltation threshold. The video tape was analysed after the flight so that data obtained even on those maneuvers that exceeded threshold could be used by noting the momentary g level at which particle movement began. The test data were plotted and a reference line drawn through the minimum velocity where saltation occured, Figures 3 & 4.

Data were obtained for two sizes of material. Closely graded ground walnut shells with median diameters of 700 and 1080 microns were used in the two experiments conducted. Walnut shell were used instead of sand for several reasons: (1) they are not as abrasive as sand and do not scratch the wind tunnel as sand or other material does; (2) there is a great amount of of data on the saltation properties of walnut shell from previous experiments in the MARSWIT facility[4] and (3) walnut shell do not become as highly charged by electrostatics as other material, perhaps due to their moisture content (about 8% by weight).

These data were correlated with the friction threshold velocity at saltation threshold by calibrating the Carousel Wind Tunnel with a series of particles of known friction thresholds as obtained in conventional aeolian wind tunnels, thus giving a curve of u* verses drum rotational speed, Figure 5.

The flight data were corrected for the nominal aircraft cabin pressure of 12.25 psi and the datum points closest to the reference line are presented along with the theoretical curve obtained from the equation

$$u_{*t}^{2} = \left(0.0166\frac{rho_{p}gD_{p}}{rho}\right)\left(1+\frac{0.006}{rho_{p}gD_{p}^{2.5}}\right)/\left(1.928R_{*}^{0.092}-1\right)$$

The data correlates well with the gravity term for values of g less than 1, Figures 6 & 7. An attempt was also made to obtain values of saltation threshold from 1.0 g to 1.8 g during the aircraft pullup and pullout maneuvers. This was done by speeding up the drum during the maneuver until saltation occured. The data did not prove satisfactory due to the slow acceleration of the drum mentioned earlier and also due to the fact that there is a lag time between the time that the drum reaches a rotation speed and the time that the air flow reaches a constant value.

The above equation can be written in the form:

$$\text{rho } u_{*t}^2 = f(R_{*t})((\text{rho}_p g D_p+(K\ I_p)/D_p^2)).$$

If plots are made of

$$\text{rho } u_{*t}^2 \quad \text{vs.} \quad \text{rho}_p g D_p$$

and the interparticle force (I_p) is zero these should go through the origin. These are presented in Figures 8 and 9. It appears that the curves intercept the y-axis at a small positive value, indicating that the interparticle force has been identified and separated from the gravity force for these two tests.

Future work includes further experiments with walnut shell in the KC 135 with sharply graded particles of widely varying median sizes including very small particles to see how interparticle force varies with particle size, and also experiments with other aeolian material.

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[4] Geophysical Research Letters, Vol. 3 no. 8, pp 417-420 Greeley, et.al.

FLIGHT PATH OF KC135 AIRCRAFT

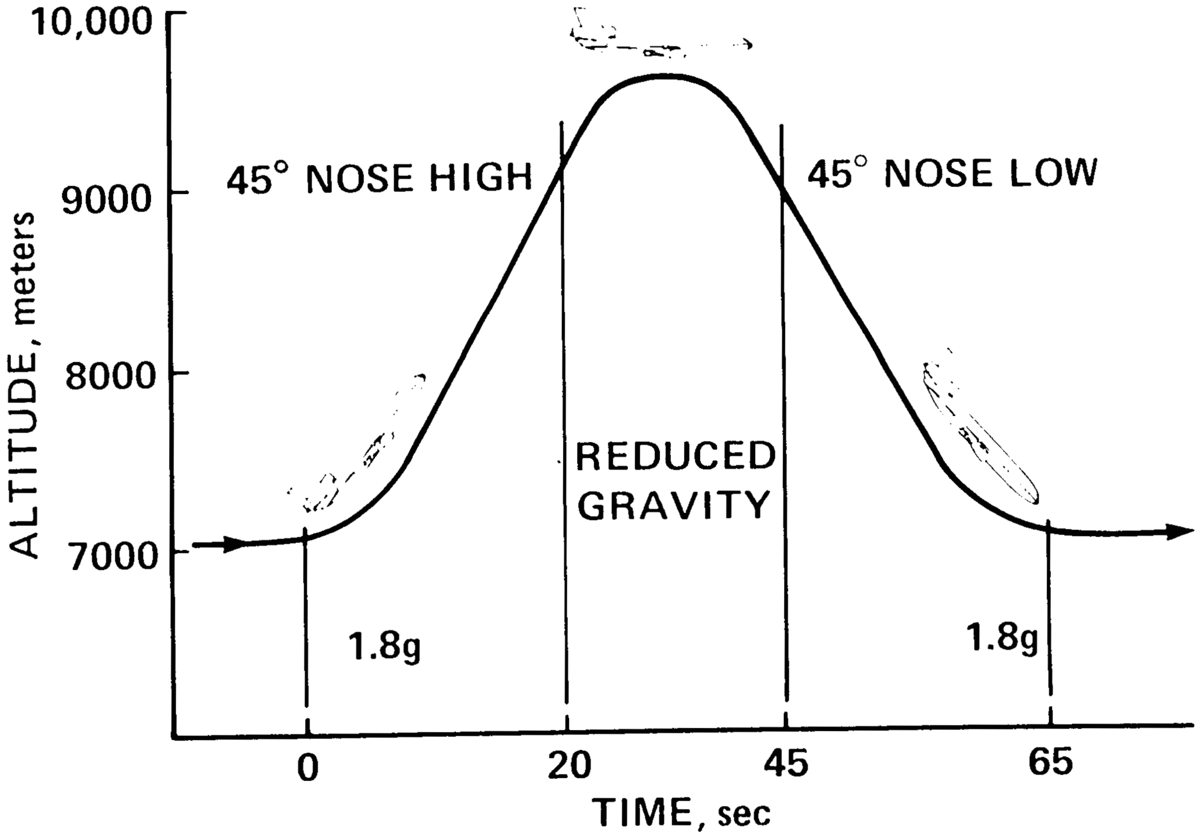

FIGURE 1

ORIGINAL PAGE IS
OF POOR QUALITY

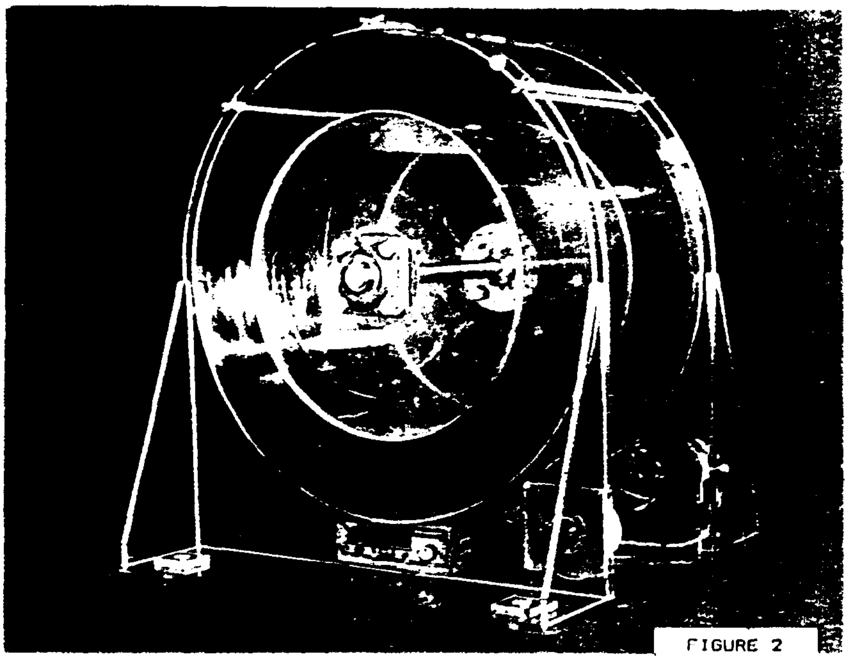

FIGURE 2

RPM SQUARED VS. GRAVITY
1080 MICRON WALNUT SHELL

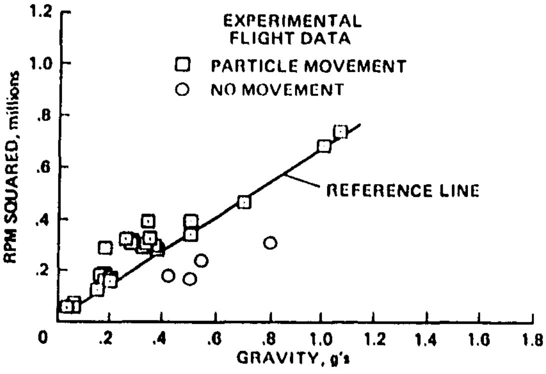

FIGURE 3

RPM SQUARED VS. GRAVITY
700 MICRON WALNUT SHELL

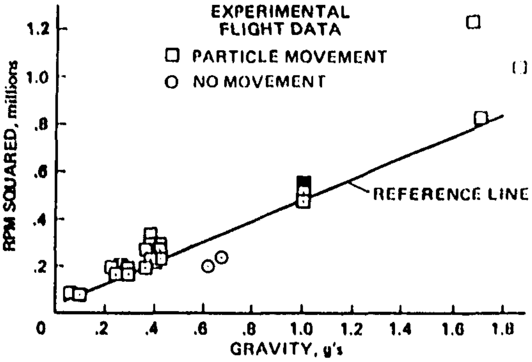

FIGURE 4

μ. CALIBRATION OF CAROUSEL WIND TUNNEL

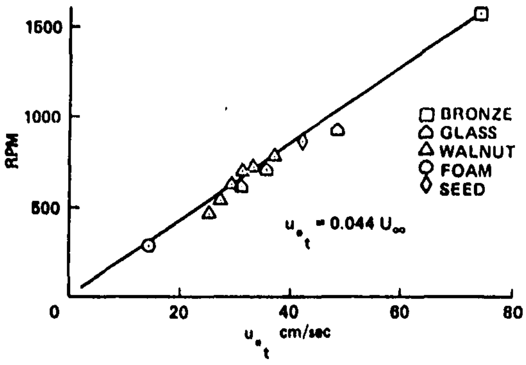

FIGURE 5

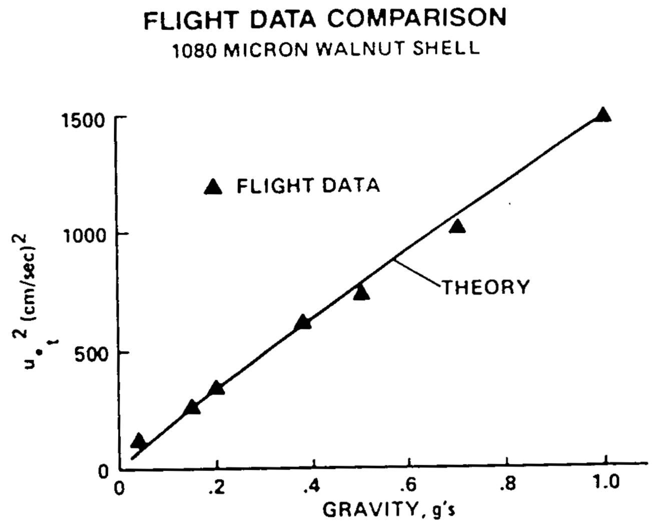

FIGURE 6

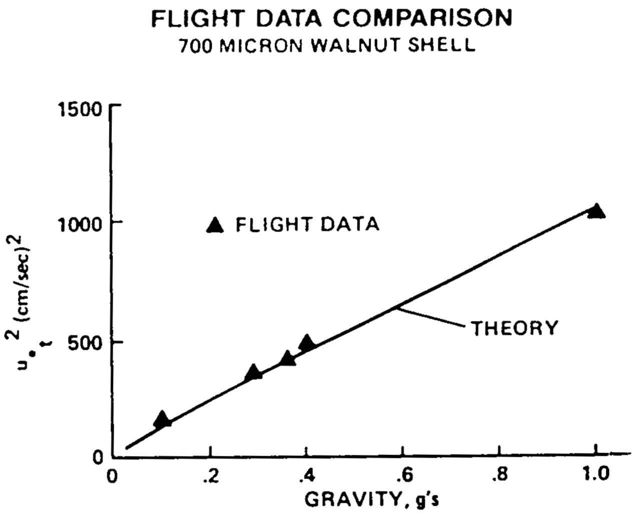

FIGURE 7

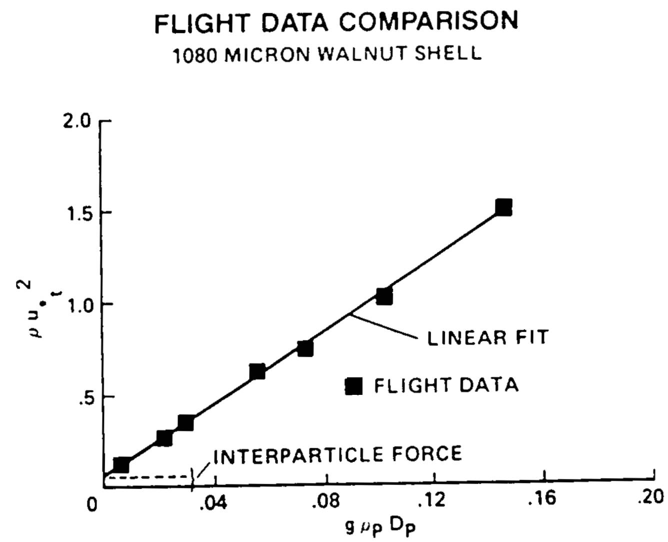

FIGURE 8

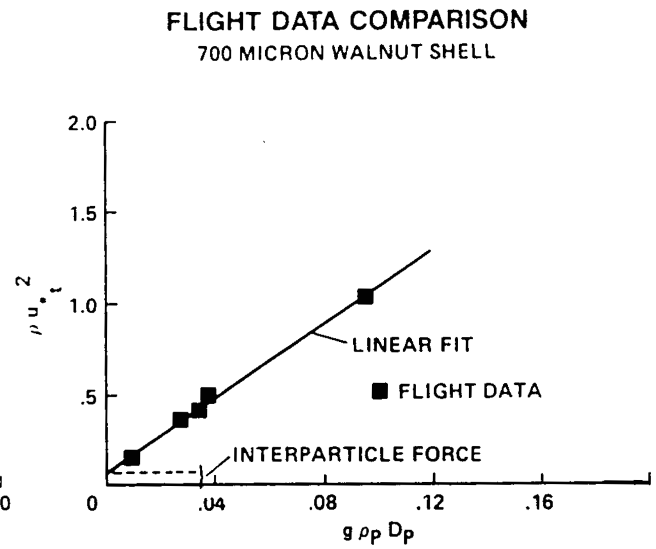

FIGURE 9