Predicting The Blast of Lunar Soil under a Rocket's Exhaust Jet.

by

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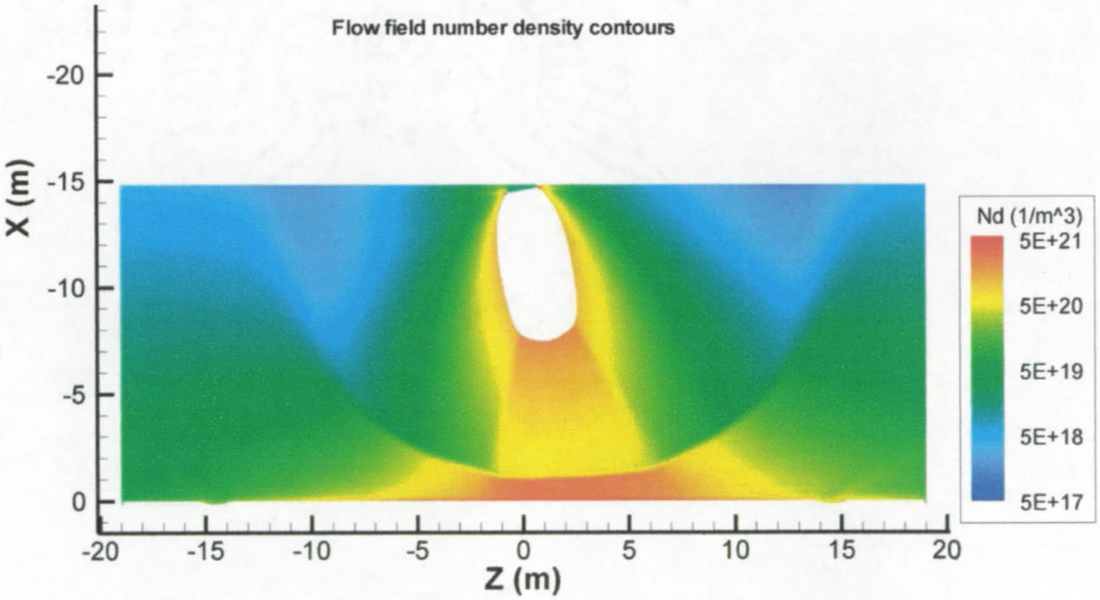
August 03, 2007

The blast of lunar soil represents a problem for the future missions planned for the moon. When the lander approached the ground during the Apollo missions, huge showers of dust particles were sent in all directions at extremely high velocities - including upwards towards the landing spacecraft. This represents a clear danger to the lander because the loss of visibility and the damage that can be produced to the vehicle itself. If there had been equipment on the ground, these showers of particles would have crated a sand blasting effect over the equipment, possibly damaging optics and contaminating the equipment and depending on the size and velocity of the particles maybe even more extensive damage as the particles penetrated the outer surface of the equipment. Since the there is no air on the moon to slow down the particles, they can travel large distances at high speeds, in fact in some instances they can reach near escape velocity and go into an orbit around the moon and come all the way back to almost the same point where they were at the beginning; meaning that some of the lunar dust that came up during landing will shower back over the site. Once on the surface, the extremely fine dust had a habit of getting itself everywhere. During the Apollo missions it not only covered the astronauts' suits, but managed to work its way inside, damaging airtight joints and scratching up

glass visors. The dust found its way inside the spacecraft, contaminating the floor and electronic systems inside, clogging air filters in the process. This is due to the fact that the lunar soil is extremely cohesive. The Lunar soil causes all of the same problems as sand does on Earth but unlike sand particles on Earth, which have smooth spherical shapes, the dust on the Moon is more like small particles of glass with sharper edges since there is no erosion on the lunar surface.

During the Apollo missions the dust problem did not cause a big problem due to the fact of the length of duration of the missions. But as NASA plans to have long term missions to the moon the dust problem becomes an issue, due to multiple landings and the equipment that will be accumulated on the site.

In order to mitigate these problems it is needed first to understand the physics of the problem in order to find the most suitable solution to protect equipment and vehicles during the next lunar missions.



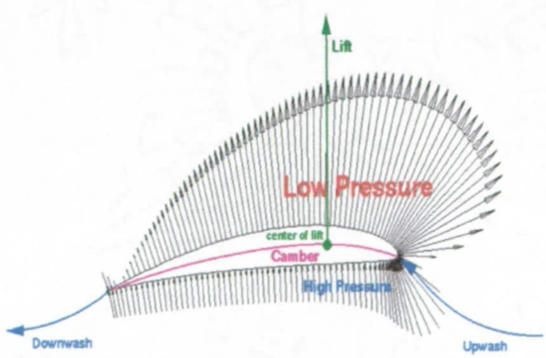
This is a representation of the flow produced by a jet exhaust allowing to be seen the interaction that the flow will have over the ground. There is a high velocity region that stops at a shock wave where under the shock wave there is a low velocity high pressure region that interacts with the soil. As this region expands along the shock wave the velocity of the flow increases producing the momentum needed to create erosion on the ground. As can be seen on the chart this velocities can reach the same velocities of the exhaust of the nozzle. Some of the particles of soil can be accelerated to the gas velocity.

During this summer I have been working on two theories. Leonard Roberts theory which establishes that :

$$\frac{1}{2} a u \frac{dm}{dt} = \tau - \tau^{*}$$

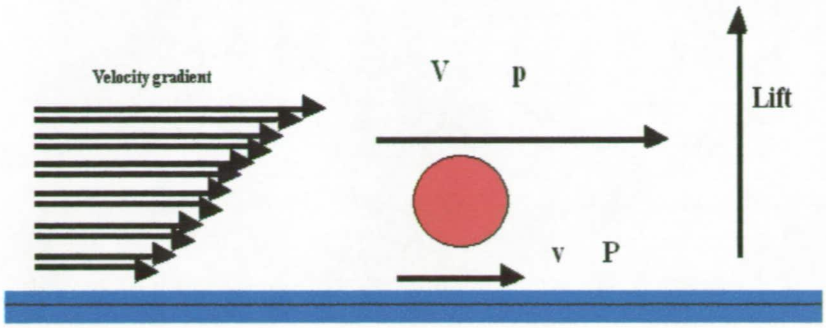
Where a is the dimensionless' velocity of the gas, u is the gas velocity, dm/dt is the rate of mass eroded. τ^{*} is the allowable shear stress of the soil and τ is the shear stress produced by the gas on the soil. The flow over the surface produces shear forces which acts on the soil particles causing them to be entrained by the flow and transported due to the transfer of momentum from the flow to the soil.

The second theory is that the velocity gradient on the boundary layer of the flow produces a difference in pressure over the particle hence producing a lift on the particle which is carried by the flow. This is similar to the principle of an air foil in which the



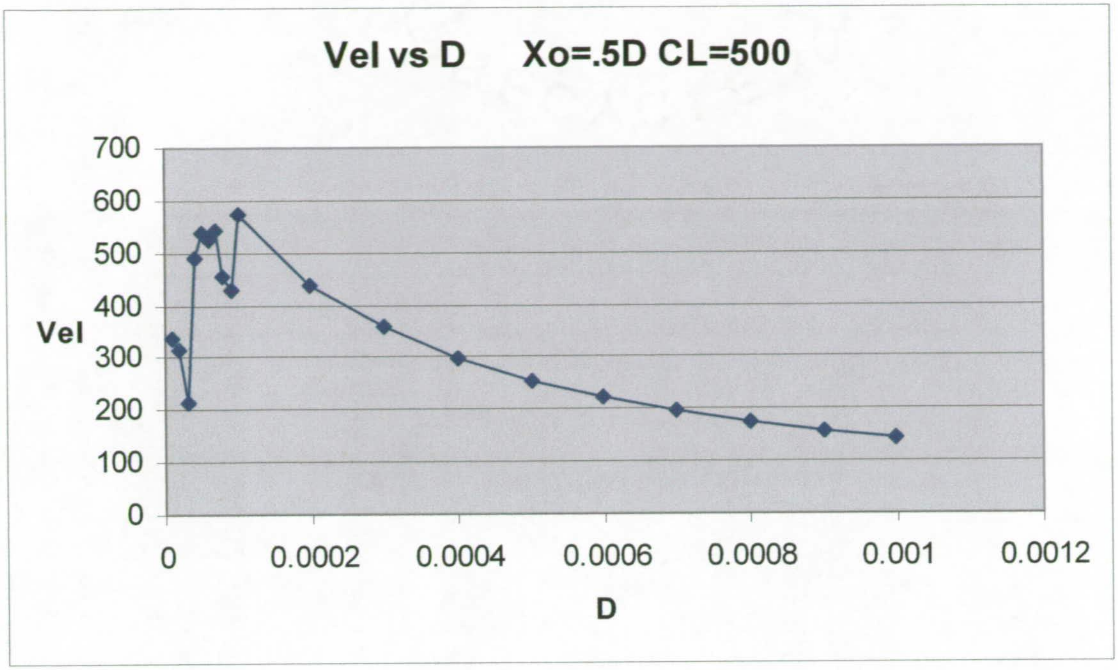
Pressure vectors and flow over a cambered section.

the difference in pressure is caused by the difference in velocity due to the shape of the air foil. On this theory the velocity gradient on the boundary layer produces this difference in pressure creating a lift on the particles.



I worked on a computer model using numerical analysis that predicts the trajectory of a particle until the particles and the gas flow reaches vacuum. This data is going to be used to try to develop a quantitative model for the particles erosion and to help view the relationships between the factors that influence the erosion. We are just beginning in the process of gathering and generating of the data that then will be used to compare to the Roberts model into an attempt to create a more accurate model that predicts the erosion. This is an extremely complex and difficult process since not even for the earth case models to predict erosion have been created. But for the moment the model is consistent to the visual studies done to the Apollo lunar landings videos in which can be observed that smaller size particles escape les than 3 degree angle and that bigger size particles do it no more than 9 degree angle.

The model predicts that particles can reach up to 570 m/s with the lander approaching at a 40 ft above ground with is actually still high.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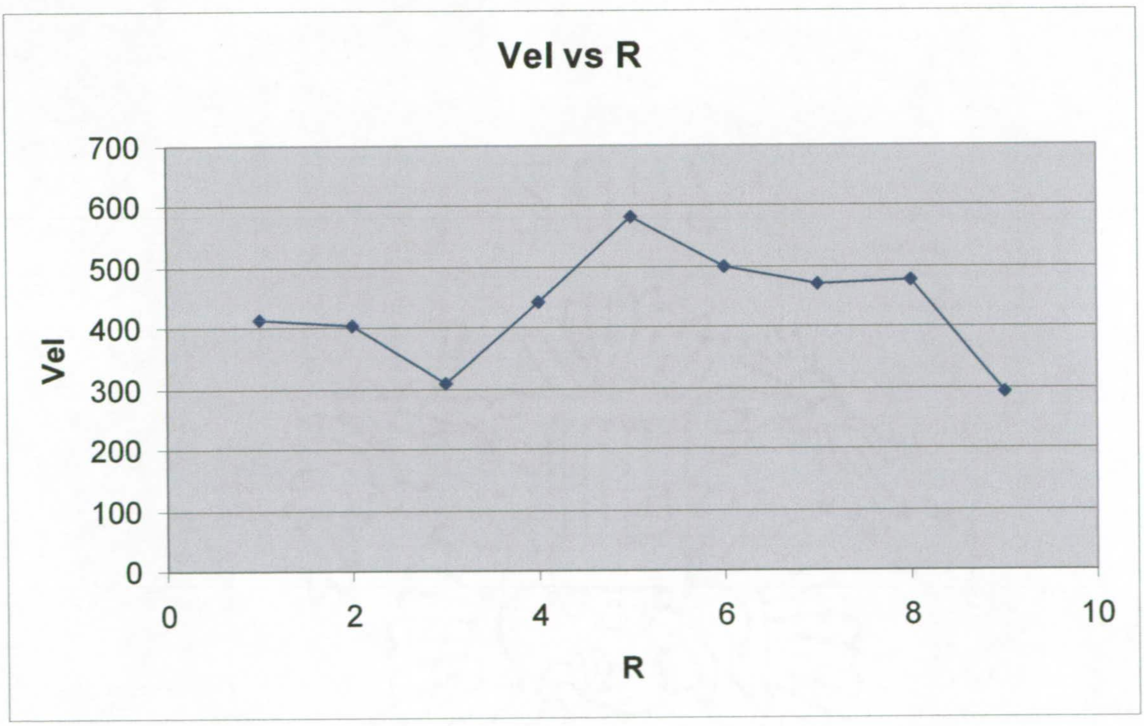
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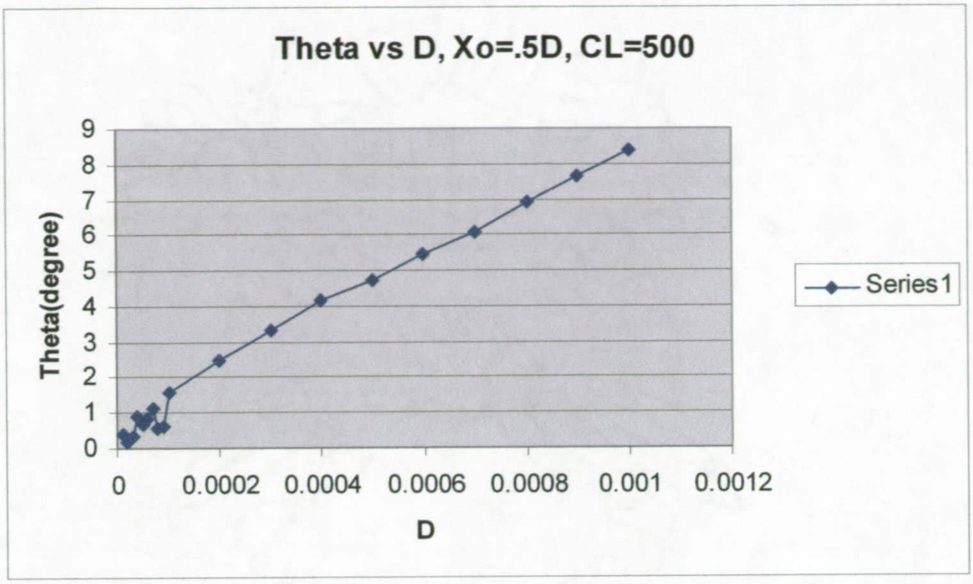
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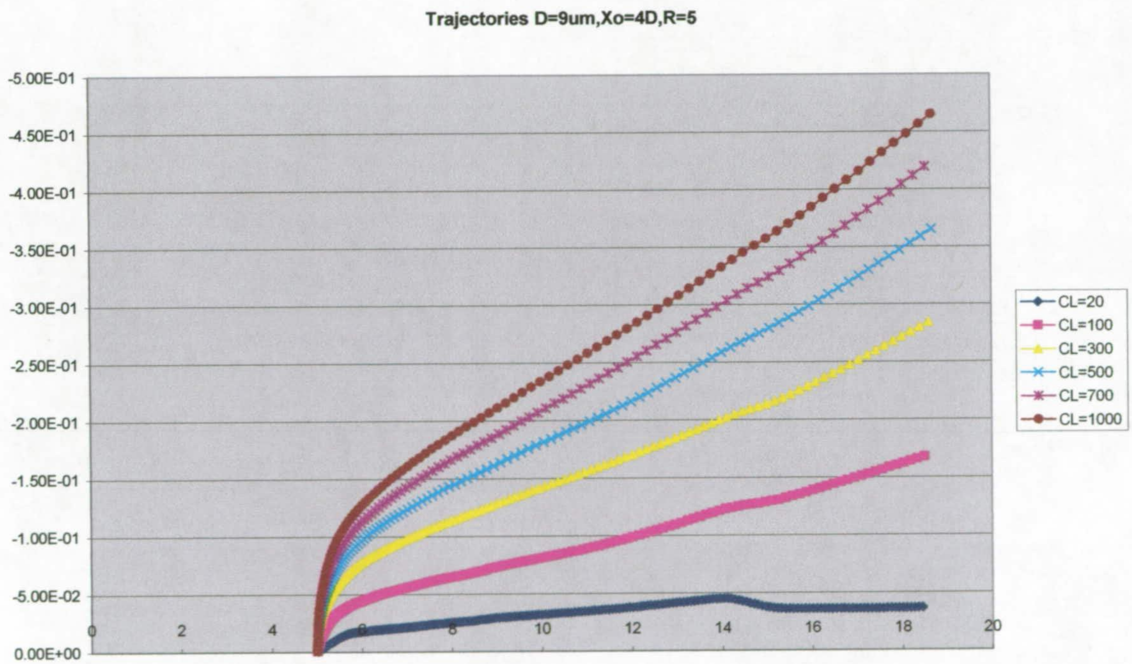
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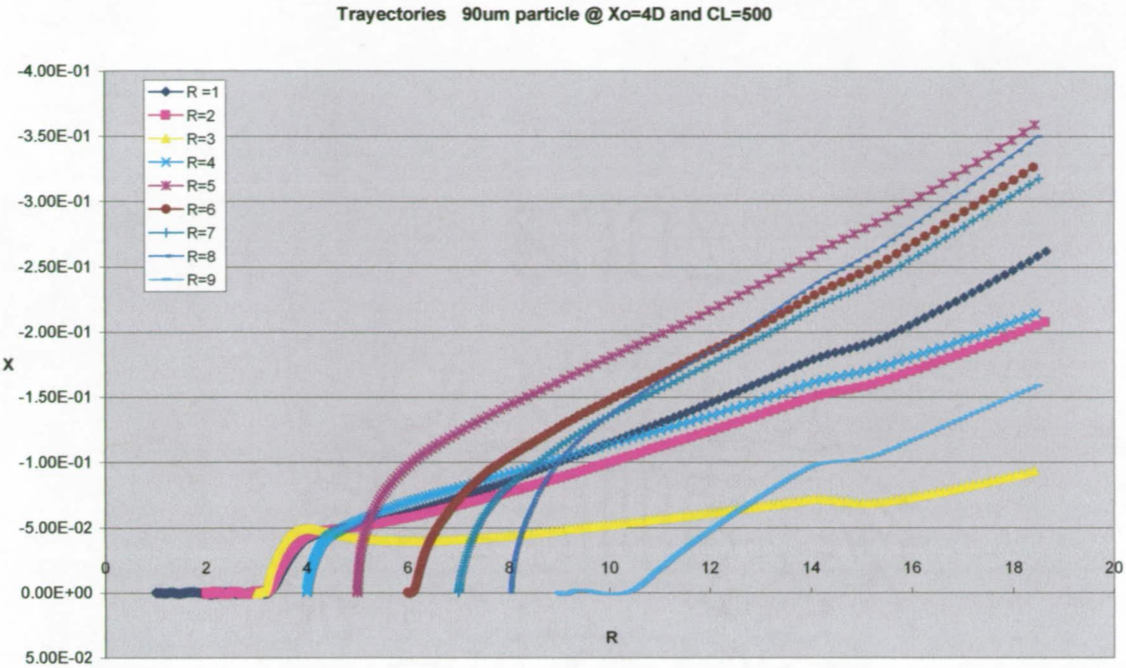

The above graph shows some of the parameters and how velocity and the trajectories vary due to those parameters and also the angle of escape of the particles as they go into vacuum.

In conclusion there is a lot of work to be done in order to develop a reliable model to predict the blast of lunar soil under a rocket's exhaust jet in order avoid the problems and possible dangers that this can cause to the lunar missions planned. This is an extremely time consuming process but with enough resources and man power can be achieve. As difficult this problem is, it is imperative to be solve in order to ensure the success of the future missions to the moon and in order to use this experience that can also be applicable to the possible Mars missions.

Acknowledgements

I would like to thank and acknowledge a few people and organizations which have helped and guided me during this project: Dr. Phil Metzger, NASA KSC Granular Physics Lab Research Physicist who acted as mentor and guide. Dr. John Lane. NASA KSC / ASRC Aerospace, Research Engineer, whose computer coding work provided the computational basis for this project. Adam Cankaya, intern from The Florida Space Grant Consortium. Finally, the NASA MUST program with HCF and UNCFSP; and the entire NASA KSC Office of Education which has made this experience possible.