Using Lunar Module Shadows To Scale the Effects of Rocket Exhaust Plumes

Site Preparation and Excavation

Excavating granular materials beneath a vertical jet of gas involves several physical mechanisms. These occur, for example, beneath the exhaust plume of a rocket landing on the soil of the Moon or Mars. We performed a series of experiments and simulations (Figure 1) to provide a detailed view of the complex gas-soil interactions. Measurements taken from the Apollo lunar landing videos (Figure 2) and from photographs of the resulting terrain helped demonstrate how the interactions extrapolate into the lunar environment. It is important to understand these processes at a fundamental level to support the ongoing design of higher-fidelity numerical simulations and larger-scale experiments. These are needed to enable future lunar exploration wherein multiple hardware assets will be placed on the Moon within short distances of one another. The high-velocity spray of soil from the landing spacecraft must be accurately predicted and controlled or it could erode the surfaces of nearby hardware. This analysis indicated that the lunar dust is ejected at an angle of less than 3 degrees above the surface, the results of which can be mitigated by a modest berm of lunar soil. These results assume that future lunar landers will use a single engine. The analysis would need to be adjusted for a multiengine lander.

Figure 3 is a detailed schematic of the Lunar Module camera calibration math model. In this chart, formulas relating the known quantities, such as sun angle and Lunar Module dimensions, to the unknown quantities are depicted. The camera angle Ψ is determined by measurement of the imaged aspect ratio of a crater, where the crater is assumed to be circular. The final solution is the determination of the camera calibration factor, α.

Figure 4 is a detailed schematic of the dust angle math model, which again relates known to unknown parameters. The known parameters now include the camera calibration factor and Lunar Module dimensions. The final computation is the ejected dust angle, as a function of Lunar Module altitude.

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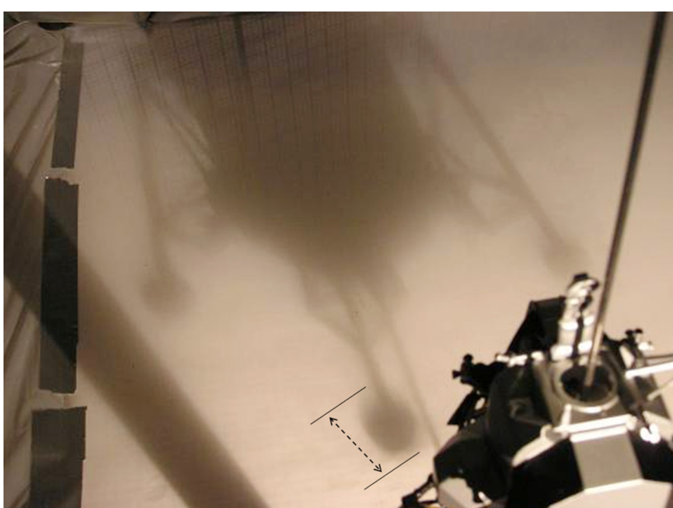

Figure 1. Scale model with "dust" beneath the angled transparent sheet.

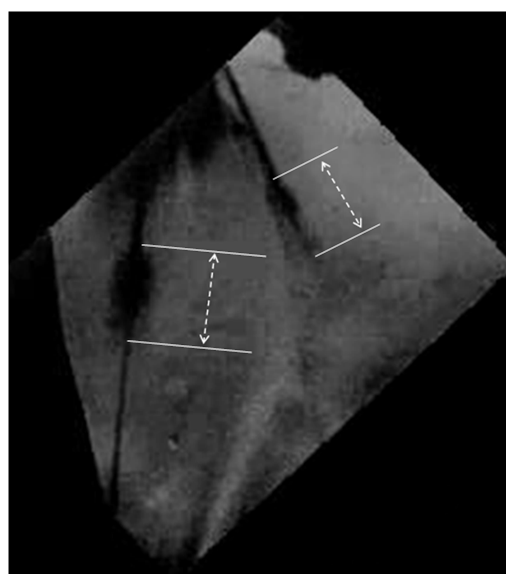

Figure 2. Video frame of Apollo 17 descent shadow, showing foot pad elongation resulting from the dust layer.

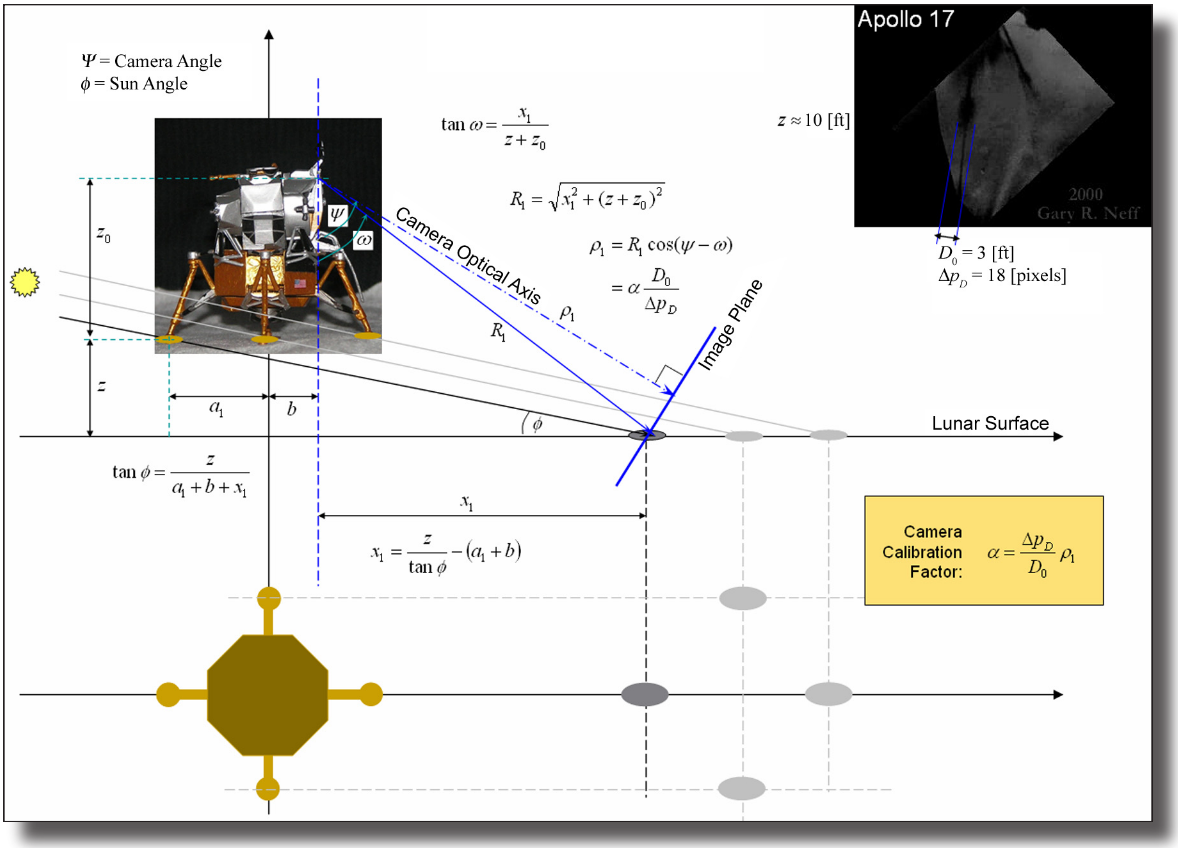

Figure 3. Camera calibration model.

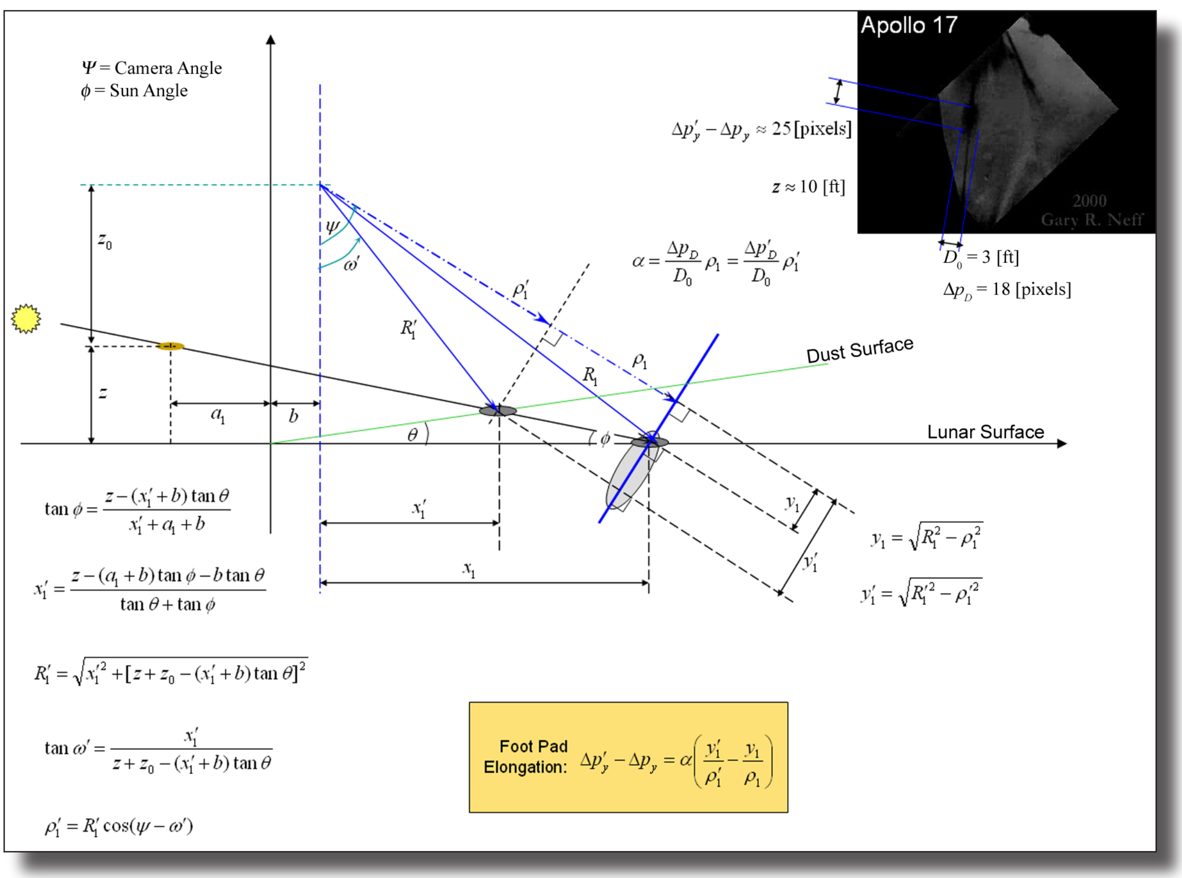

Figure 4. Lunar Module foot pad elongation model.