Murtaugh

ABSTRACT: This ATM describes recent scientific evidence, and resulting conclusions relating to the Apollo Landing Site Surface Model in the specific areas of cohesion, bearing strength and "effective slope." The possible effects of these changes on the ALSEP design and deployment are also discussed.

Prepared by: Frank E. Wilburn
F. E. Wilburn

Approved by: L. McCartin
L. McCartin

SUMMARY:

The recent successes of the Surveyor and Lunar Orbiter Programs have made it possible to re-evaluate the original Lunar Surface Model (Ref. 1 page 31). This report enumerates the evidence pertaining to the specific areas of cohesion, bearing strength and "effective slope." The effect on ALSEP of incorporation into the Lunar Surface Model the modifications suggested by the most recent moon explorations is as follows:

1. Incorporating a cohesion specification to read from 0.02 - 0.05 psi (Ref. 2, page 20, para. 5) will relax the requirement for 100% dust cover. Presently the lunar surface cohesion is implicit in the bearing strength specification. However, subsequent Surveyor missions will determine whether the LM ascent plume will cause dust to be deposited on horizontal surfaces. The specific experiments to determine the dispersion of dust during LM ascent are the firing of small retro-rockets and the "scissor and scoop" experiment designed by Dr. Ron Scott of the Surveyor Lunar Surface Mechanical Properties Committee.

Mr. N. W. Hinners of Bellcomm, Inc. (Ref. 3, page 4, para. 5) has recommended that dust covers be removed from vertical surfaces because the dust particles on the lunar surface are not electrostatically charged and thus will not adhere to vertical surfaces.

2. Changing the bearing strength specification from 1 psi to greater than 5 psi will result in a redesign of the footpad. By tapering the footpad on the module, it can be more easily anchored by pushing it into the lunar surface.

3. Changing the "effective slope", from "not to exceed 12°" to "less than 3°" will eliminate the requirement for leveling legs. The Surveyor I landing site has a slope of $< 3°$ and photographs taken from Lunar Orbiter I indicate that the Surveyor I site is typical. However, the preliminary analysis of Lunar Orbiter II, photographs with a camera of higher resolution than Lunar Orbiter I, is not yet available.

COHESION:

Mr. Hinners (Ref. 3, page 2) states the reason for initially requiring 100% dust cover in the following statement:

"The original specification of 100% dust cover of external surfaces was put in for the reason that the lunar surface was believed to be covered to some unknown depth (estimates ranged from centimeters to kilometers) with small particles which might be highly cohesive. Placed in motion either by electrostatic levitation or as secondary meteoroid ejecta such material could potentially stick to thermal control surfaces, thus unfavorably altering thermal absorption and emission properties."

Further lunar explorations by Rangers, Surveyor, Lunar Orbiter and the Lunar series (in addition to laboratory experimentation) indicate that changes in the lunar surface model can be made.

Mr. Hinners states in his report (Ref. 3, page 3, para 2.) that

"........Gault and coworkers at Ames Research Center have long (> one year) maintained that the crater shapes observed in high resolution Ranger lunar photographs were indicative of impacts into weakly cohesive or non-cohesive particulate material. Their conjecture was based upon laboratory simulation of lunar cratering into various soils."

Analysis of data from Surveyor I by JPL (Ref. 2, page 20, para. 1) verifies these findings:

"The appearance of the disturbed surface material and the rim of the impact depression suggest that the surface is a granular soil like medium of unknown but fine grain size and size range. On disruption by the impact some fine-grained material was thrown out in a spray, possibly from the original surface layer, and the underlying material was broken up to some extent.

The behavior of the material is consistent with its possession of a distinct but small amount of cohesion, and its manner of deformation appears to be qualitatively similar to that which might be exhibited by a terrestrial, damp, fine grained soil."

The report goes on to state:

> "Although this bearing capacity can be developed by materials having a wide range of properties, one possibility, considering all the available data, is a soil with a cohesion in the range of 0.02 to 0.05 psi ($1 \times 10^3$ to $4 \times 10^3$ dynes/cm$^2$) and a friction angle ......."

This level of cohesion is consistent with experiments performed by Dr. Scott (Ref. 4, page 3, para. 4).

> "Assuming a density of 1.5 g/cc, Scott finds the best fit of measured data is obtained by a soil having 5 psi static bearing strength, 0.02 psi cohesion, and a 35$^\circ$ angle of repose."

The scientists who analyzed the photographs from Lunar 9, (Ref. 5, page 77, para. 5) state that:

> "It is remarkable that no traces of a structureless dust layer could be seen anywhere within the limits of the panorama including the slopes of craters lying in the immediate vicinity of the television head. All visible sections were distinguished by the presence of clear cut structurally connected formations produced, probably, by aggultination of fine particles."

From available data, the nature of the lunar surface material is best summarized by Dr. Eugene Shoemaker of the U.S. Geological Survey, one of the principal investigators for the Surveyor Project (Ref. 6, page 591, para. 3).

> "The moon's face is certainly not a deep sea of very fine dust. Undoubtedly half the materials are finer than the smallest particles we can see in Surveyor pictures, and we have measured and counted particles no bigger than a fiftieth of an inch. That is to say, it is like fine sand or finer, in grain size. But, distributed through this are many coarser particles. So it is a very gritty, siltlike material with blocks and chips throughout.
>
> It is relatively easily disturbed. The effects of the Surveyor footpads landing on its surface are not unlike the effects of walking on a freshly plowed field."

Dr. Newell sums up the justifications that no loose dust exists on the lunar surface with the following three observations (Ref. 6, page 591, para. 6)

a) "First, by looking at Surveyor's footprint. The robot's foot has sunk a little way down just as it would in freshly cultivated soil or in wet beach sand."

b) "Second, the very fact that Surveyor landed so well indicates that there could not be a thick bed of loose dust. Had there been, the landing signal would have penetrated deeply into the dust, and would have deceived the radar about the craft's altitude in the last moments before landing."

c) "There is still another indication. No continuous layer of dust was observed by the television camera on any of the parts of the spacecraft, and obviously, no dust gathered on the camera lens or our pictures would have been fogged or blurred."

Based on these findings Mr. Hinners (Ref. 3, page 3, para. 3) concludes in making his recommendation for a relaxation on the amount of dust cover required for ALSEP;

"......we are warranted at this time in concluding that lunar surface material is granular, predominately sub-millimeter in size, weakly cohesive to non-cohesive and not highly porous beneath optical depths."

At this time the recommendation has been made by Mr. Hinners, Bellcomm, Inc. (Ref. 3, page 4, para. 5) to remove the requirement for dust covers on the vertical surfaces. The removal of the horizontal surface dust covers depends on the outcome of "scissor and scoop" experiment and/or firing of the retro-rockets on Surveyor 3.

SURFACE BEARING STRENGTH:

The present Lunar Surface Model conservatively specifies the lunar surface bearing strength to be $\approx 1$ psi. However, examination of Surveyor I data by JPL (Ref. 2, page 13, para. 2) indicates:

"The design of the spacecraft landing gear is such that the forces and motions of the spacecraft during landing as indicated by the data are largely independent of the mechanical properties of the surface for surface materials whose static bearing capacity is greater than approximately 5 psi ($4 \times 10^5$ dynes/cm$^2$)."

Consistent with the observed data, JPL further asserts that (Ref. 2, page 20, para 4):

"If to a depth of the order of the footpad diameter (1 ft. or 30 cm), the material is homogeneous and similar to that observed at the surface, a simplified landing dynamics analysis indicates that the soil has a static bearing capacity, at the scale of the Surveyor footpad, of about 5 psi ($4 \times 10^5$ dynes/cm$^2$)."

As previously stated under Cohesion, Dr. Scott determined by using complicated soil equations and simplified spacecraft equations to study the effects of soil variables, that:

"....The best fit of measured data is obtained by a soil having 5 psi static bearing strength,..........."

Therefore, it seems feasible to consider a redesign of the central station foot pads to obtain greater stability.

SLOPE:

The Lunar Surface Model specification (Ref. 1, page 31) on the lunar slope at the landing site is $12^{\circ}$.

The experience of both Lunar 9 and Surveyor I was that the surrounding terrain was generally flat.

Analyses of Lunar 9 pictures (Ref. 5, page 63, para. 6) indicate that:

"The lunar landscape appears to be generally flat in the panaorama with the corrected horizon line."

It is further stated that the Lunar 9 landing site "is a quite level surface with a well defined relief with hills noticeable on the line of apparent horizon."

Surveyor I data, analyzed by JPL (Ref. 2, page 26, para. 2) states that:

"A detailed examination of the horizon positions, corrected for spacecraft tilt, has been made for 65 directions over a range of azimuth of 250 degrees extending from north to southwest. The results show that the moon, at the Surveyor I landing site, is both relatively smooth and nearly level on a kilometer scale. The standard deviation of the angle to the horizon is only 0.7 deg. The average horizon position in the three quadrants examined is the same within 0.5 deg."

JPL (Ref. 2, page 26, para. 1) had determined by:

"Rough analog reduction of the stellar position data shows that the spacecraft axis is tilted from the astronomical vertical by $1.7 \pm 0.5$ deg. in a direction south of east."

If the Surveyor I landing site can be shown by Lunar Orbiter Flights to be a typical lunar surface site, it would be possible to eliminate the leveling legs.

A curve of Cumulative Frequency distribution of particles on the lunar surface determined from Surveyor I photographs is shown in (Ref. 2, page 32, Fig. 27). If the Lunar Orbiter verifies this distribution, the slope at the landing site can be specified to be less than 3°. Data from Orbiter II is presently being analyzed. No formal report has been released.

## BIBLIOGRAPHY

1. "LED-520-ID" Grumman Aircraft Engineering Corporation, Contract NAS9-1100- 15 May 1965.

2. "Surveyor I - A Preliminary Report" National Aeronautics and Space Administration - NASA SP-126 June 1966.

3. N. W. Hinners, "ALSEP Environmental Specification Revision: Lunar Dust - Case 340" Bellcomm, Inc., 22 September 1966

4. C. R. Murtaugh, "Discussion with Dr. Ron Scott re Lunar Surface Mechanical Properties". Interdepartmental Memorandum - Bendix Systems Division - 971-21, 15 August 1966

5. "The First Panoramic Views of the Lunar Surface", National Aeronautics and Space Administration, NASA Technical Translation F-393, October 1966.

6. Homer E. Newell, "First Color Photographs on the Moon's Rocky Face". National Geographic, Vol. 130 No. 4, October 1966, pp. 578 - 592.