Brief Report

Movement of Surveyor 3 Spacecraft

R. F. SCOTT, T.-D. LU, AND K. A. ZUCKERMAN

Division of Engineering and Applied Science
California Institute of Technology, Pasadena 91109

An examination of the position of the Surveyor 3 spacecraft as it appeared in the photographs taken by astronauts C. Conrad and A. Bean of the Apollo 12 lunar mission in November 1969 suggested that some changes had occurred in the spacecraft's attitude since the Surveyor operation of April 1967. A detailed study was made by simulating in the laboratory the position of one of the Surveyor spacecraft's footpads and its imprints in the lunar surface. Photographs were taken both from the location of the original Surveyor television camera and from the estimated position of the astronauts. It was found to be impossible to match the footpad and imprint positions and attitude in pictures taken from the two points of view. Consequently, it is tentatively concluded that the Surveyor spacecraft moved a few inches at some time between May 1967 and November 1969. It seems most likely that this movement occurred as a result of a relatively sudden failure of one or two of the shock absorbers on Surveyor's landing gear, since 2 out of the 3 shock absorbers were collapsed at the time of the astronauts' visit.

The Surveyor 3 spacecraft landed on the moon on April 20, 1967, and was operated until May 3, 1967. The scientific and engineering results of its sojourn on the lunar surface have been reported [*Surveyor 3 Mission Report*, 1967]; those pertinent to this discussion will be repeated briefly here.

No communication was returned from the spacecraft after its first lunar night. At the termination of its multiple impact touchdown, the spacecraft came to rest on the inner eastern slope of a 200-meter-diameter crater. The ground slope was approximately 10° to 12°, and the inclination of the spacecraft's vertical axis from lunar vertical was determined to be 12.4°. One of the vehicle's footpads (number 2) was within the field of view of the television camera; another (number 3) was partly visible; and the third was obscured by spacecraft components. In the last stages of landing, footpad 2 left an impression on the lunar surface a few inches from its final location. The appearance of this apparently penultimate contact and the footpad itself from the point of view of the Surveyor television camera is shown in Figure 1.

Only the right side of footpad 3 could be observed; the footpad had plowed downhill through the soil, and in its final position the visible part of its top surface was a few inches above the soil level.

On November 19, 1969, the Lunar Module of the Apollo 12 spacecraft carrying astronauts C. Conrad and A. Bean landed near Surveyor 3, and in the second of their two excursions on the lunar surface the two astronauts visited their precursor. They took a number of photographs of Surveyor and removed several spacecraft components for return to earth. Some of the photographs, when compared with the original Surveyor pictures, suggest that, at some time between Surveyor 3 shutdown on May 3, 1967, and the time the photographs were taken by Conrad and Bean, the Surveyor spacecraft moved a few inches.

MOVEMENT STUDY

On their way toward Surveyor 3, Conrad and Bean took the photograph shown here as Figure 2. If the mast angle in this picture is measured with respect to the visible lunar horizon, it is found to be about 15°, in the plane of the picture. The maximum downslope angle of tilt would be somewhat greater. If the lunar horizon differs from the true horizontal in this picture by less than 2.5°, it would appear that the spacecraft has increased its inclination downslope since 1967. More positive evidence for this is apparent in Figures 3 and 4 of legs 1 and 3, respectively, also taken by the astronauts. In this picture, the shock absorbers of legs 1 and 3 are seen to have collapsed. Their normally extended position can be seen from the position of the leg 2 shock absorber in Figure 2. Here the extended shock absorber and its supporting strut form a straight line, in comparison with the angle visible in Figure 3 of leg 1. Study of the position of the leg 2 shock absorber in Figure 2 and comparison with the shock absorber of leg 3 in Figure 4 showed that the latter shock absorber is also collapsed.

All the shock absorbers were extended during the landing and communication life of Surveyor 3 in 1967. The shock absorbers contained helium gas at high pressure; the gas was retained by seals that can fail. It is concluded that the shock absorbers on legs 1 and 3 of Surveyor 3 collapsed at some time after the termination of communication with the spacecraft.

An indication that the failure of the shock absorber on leg 3, at least, may have been sudden is seen in Figure 4, taken by the astronauts and showing footpad 3. This picture indi-

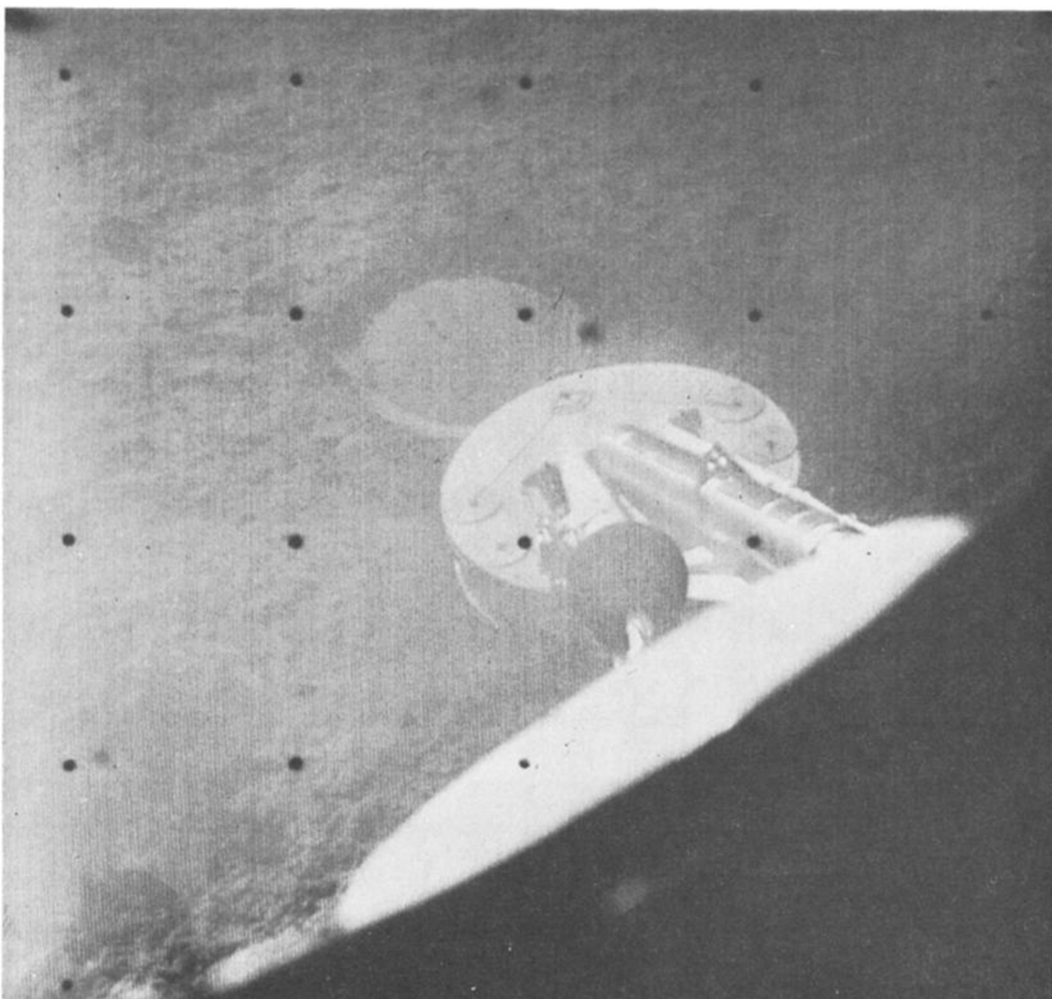

Fig. 1. Picture of footpad 2 from Surveyor 3 television camera, April 21, 1967. The image is hazy because a film of lunar dust was deposited on the mirror of the camera during the landing (GMT day 111, 07h 43m 38s).

cates that the edge of footpad 3 not visible to the Surveyor 3 camera dug into the lunar soil so that its upper surface became covered with soil. However, a lighter shading appears around the edge of the pile of soil on the footpad. This was at first interpreted [*Scott et al.*, 1970], it is now thought erroneously, as being lunar soil of a lighter color.

However, the astronauts reported that the exposed spacecraft parts that were originally white were a light tan color at the time of their visit. This observation was subsequently confirmed by examination of the returned spacecraft parts [*Benson et al.*, 1970]. It is conjectured, therefore, that the footpad received a partial covering of soil in the landing in April 1967; this soil protected the underlying footpad surface from a process that either coated or, more probably, altered the white surface to tan in an unknown length of time. When the

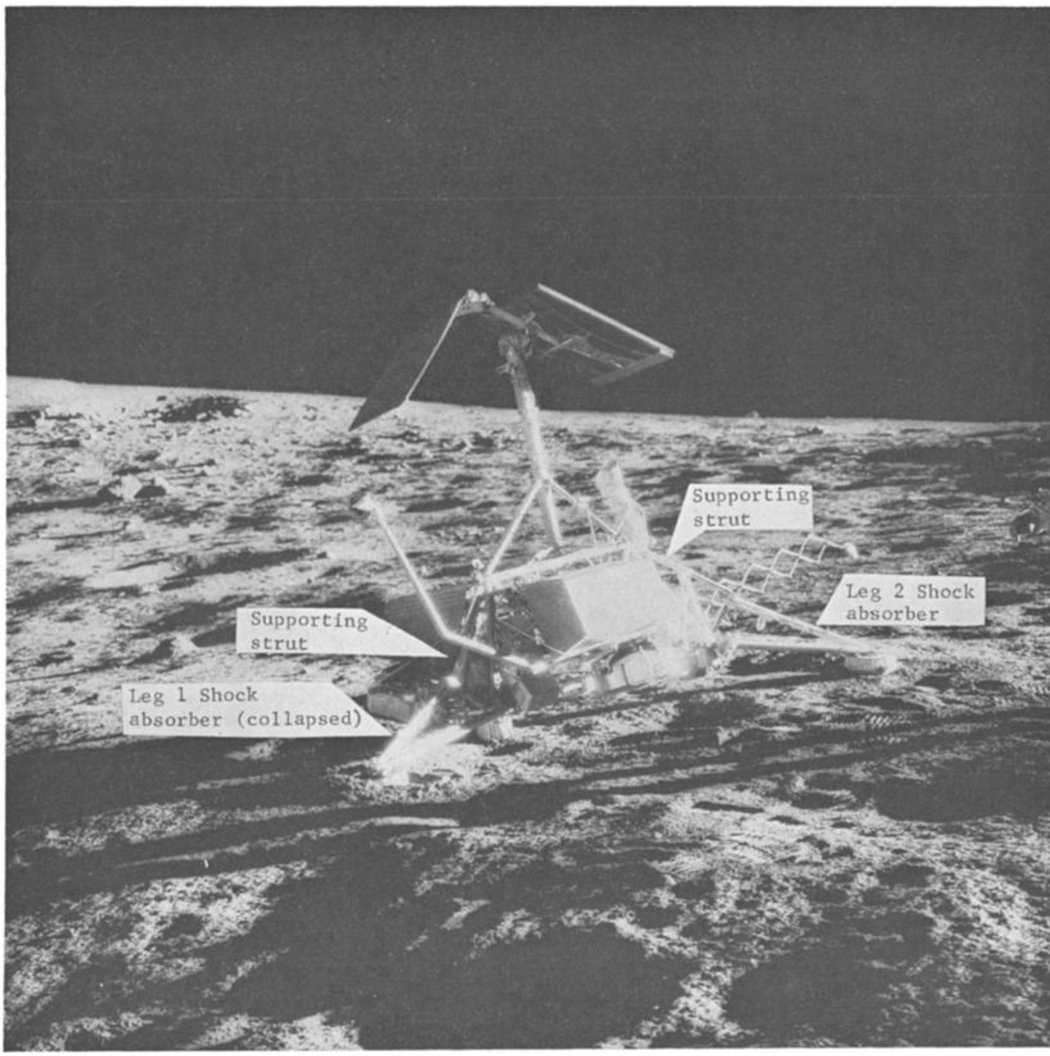

Fig. 2. Astronaut photograph of Surveyor 3. Leg 2 and the surface sampler appear to the right. The lower member of the leg is the extended shock absorber, which lies almost in a straight line with the fixed support running from the upper end of the shock absorber to the spacecraft structure. To the left and pointing almost toward the camera is leg 1 with the footpad imbedded in the soil. The shock absorber on this leg is seen to be at an angle to the supporting member. (AS 12-48-7121.)

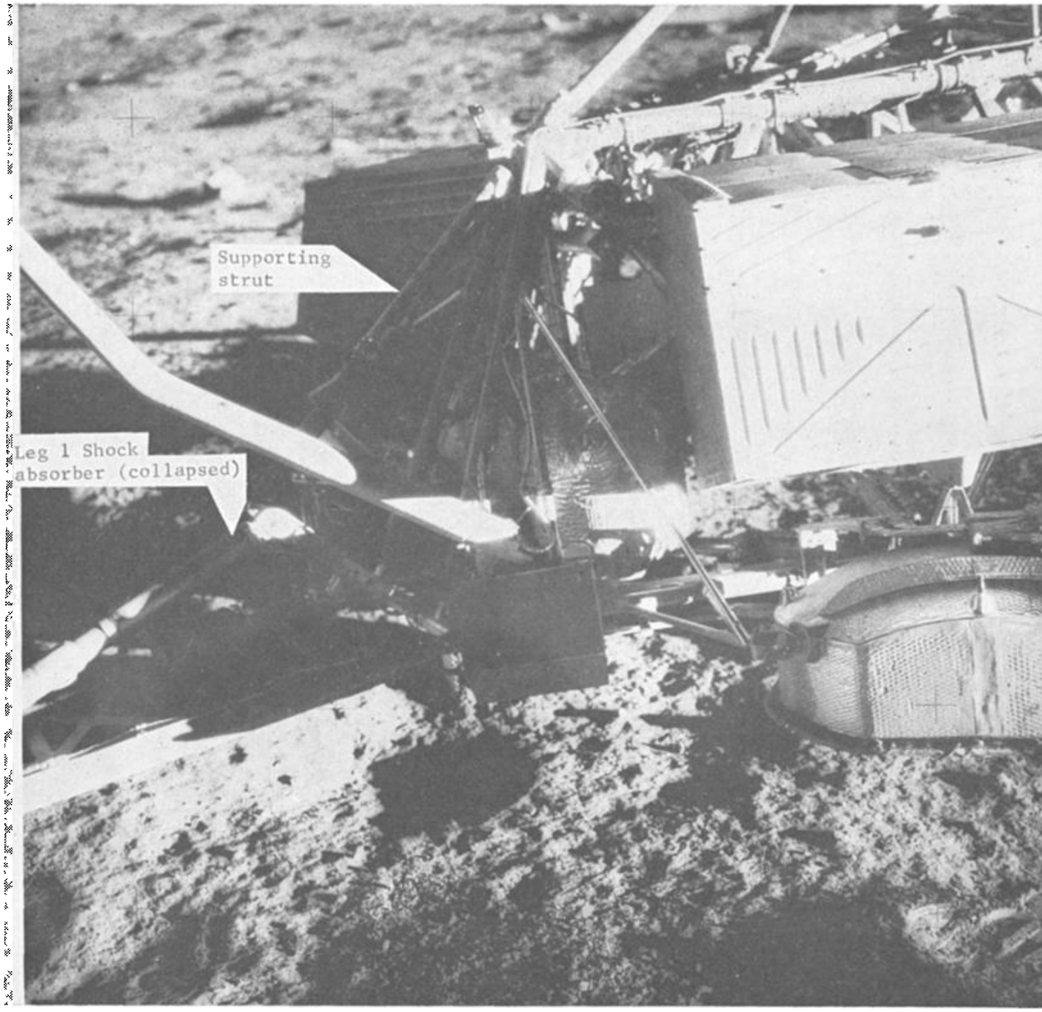

Fig. 3. Astronaut photograph showing detail of collapsed shock absorber connection on leg 1, to left, partly in shadow (AS 12–48–7118).

footpad was jerked by the hypothetical shock absorber collapse, the soil on the pad moved, and the protected white footpad surface was revealed in contrast to the tanned surface. An argument against this explanation is that the lunar soil has repeatedly demonstrated the property of adhering to spacecraft surfaces. Thus, it is not clear that the soil on the footpad could have slid sideways to reveal a relatively white, rather than a soil-covered surface. However, the appearance of the footpad in Figure 4 is difficult to account for by another explanation. The explanation would have to be that, since the lunar soil probably adheres to itself more strongly than to the spacecraft, under lunar conditions, an impulse such as that of the postulated sudden shock absorber collapse generated footpad accelerations high enough to cause shearing at the soil/footpad interface rather than through the soil.

In Figure 1, the spacecraft's view of footpad 2 shows an impact mark a few inches uphill of the footpad's final resting place. The same footpad as viewed by the astronauts' camera is shown in Figure 5, in which a second imprint can be seen between the previously observed mark and the footpad. The clarity of this second imprint was somewhat surprising, since it is not apparent in Figure 1, although its presence was suggested in the Surveyor 3 report. From this unexpected result and the consideration discussed above, the question arose: Was footpad 2 as observed by Conrad and Bean (Figure 5) in the same position as it had been 31 months earlier (Figure 1)? It was decided to attempt an answer by simulating the geometrical arrangement of footpad 2, lunar soil imprints, and both Surveyor and Apollo 12 cameras. It was not difficult to arrange a Surveyor footpad, and the Surveyor 3 camera position correctly, because the location and orientation of the spacecraft parts was known. To obtain the first imprint position, a slide projector was set up at the Surveyor camera location and set at the correct angle. A slide of Figure 1 was inserted in the projector, and the full-scale footpad and imprint were adjusted until the projected image overlay them correctly. The result of this operation is shown in Figures 6*a* and *b*. Figure 6*a* is a photograph of the final arrangement taken by a camera in the Surveyor 3 television camera position. For Figure 6*b*, the projector was set up at the Surveyor 3 camera position and projected an image of Figure 1 on the footpad and soil. A camera was positioned as nearly as possible in the line of sight of the projector and took the photograph shown as Figure 6*b* using the illumination of the projected image. It can be seen that the overlap of the projected Surveyor 3 image on

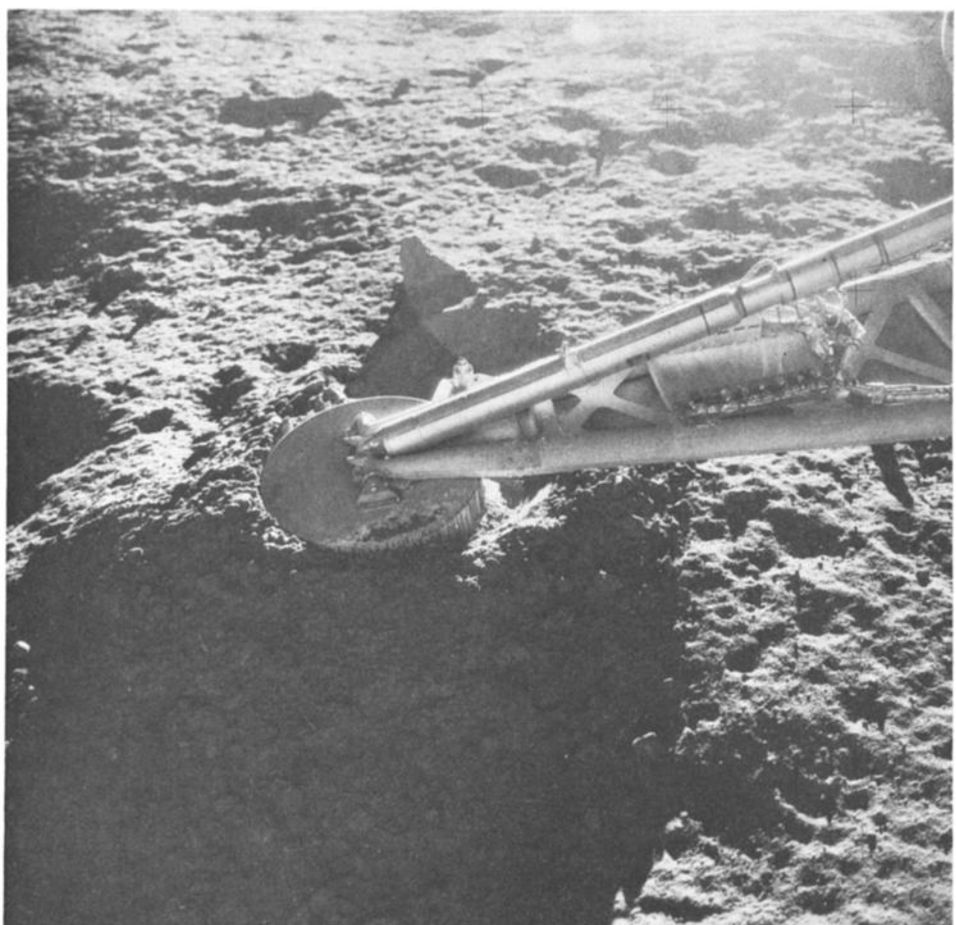

Fig. 4. Astronaut photograph of footpad 3 and part of leg 3. The collapsed shock absorber is the upper tubular member. On the footpad some soil can be seen, with adjacent lighter-colored areas. (AS 12-48-7124.)

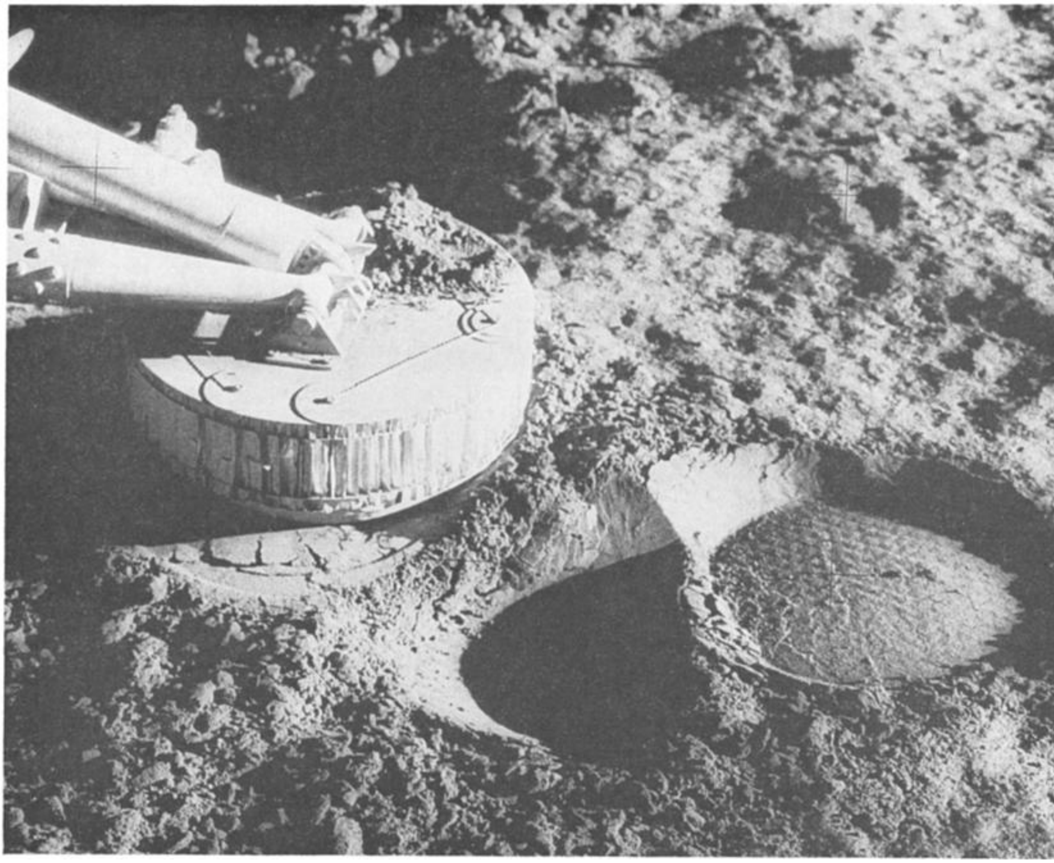

Fig. 5. Enlargement of part of astronaut photograph showing pad 2 of Surveyor 3 and lunar surface imprints. (AS 12-48-7110.)

the laboratory model is reasonably good except at the left edge of the pad. The slight mismatch there does not affect the conclusion. It was found that the appearance of the footpad as viewed from the Surveyor 3 camera position was extremely sensitive to the angle of footpad tilt. It is considered that the angle in the simulation is within $\pm 1°$ of the angle in the Surveyor photographs.

A collimated light source was directed to light the scene at the sun angle of the Apollo 12 photograph (Figure 5), and the position and orientation of the footpad imprints in that photograph were duplicated. The footpad was maintained at the position and orientation of the Surveyor 3 pictures (Figures 1 and 6). With this arrangement it was found to be impossible to obtain a photograph that matched Figure 5 with respect to footpad position and orientation. The closest reproduction is shown in Figure 7. The footpad was then adjusted until a photograph was obtained that was a close duplication of Figure 5. This required a footpad translation of approximately 3 inches, in effect obtained by a lateral rotation of the spacecraft about footpad 1 and a footpad tilt of approximately 5° in the counterclockwise direction when viewed from the astronaut position of Figure 5. The resultant photograph, to be compared with Figures 5 and 7, is Figure 8.

A view of this arrangement from the Surveyor 3 camera position is seen in Figure 9. In this picture the second imprint is clearly observable, in contrast with Figures 1 and 6*a*. In Figure 6*a* the second imprint was present in the correct position with respect to the first imprint according to the Apollo 12 photograph of Figure 5. In addition, the appearance of the footpad, because of its change of tilt, is entirely different in Figure 9 from that in Figure 6*a* or Figure 1.

It appears, therefore, from this simulation study, that a television picture of footpad 2 on a Surveyor 3 spacecraft in the same position as observed by the astronauts would have clearly showed the second imprint. It would also have showed a footpad tilt angle different from that in the original Surveyor 3 picture (Figure 1). Alternatively, an astronaut picture of footpad 2 on a Surveyor 3 in its April 1967 position would have showed a less-obvious second imprint, and a footpad at a different angle.

A further, minor piece of evidence for spacecraft rotation is that the original Surveyor pictures appear to show the inside edge of footpad 2 resting on an essentially level soil surface. Pictures taken by the astronauts show a ridge of soil along this edge almost to the top of the conical portion of the pad. However, the viewing angles are so different in the Surveyor 3 and Apollo 12 pictures that it is difficult to be sure that the same area is being observed.

Fig. 6*a*. Laboratory photograph simulating position of Surveyor 3 footpad 2 and lunar soil imprints. Picture taken from Surveyor 3 camera position for comparison with Figure 1. In this picture both imprints visible in the astronaut picture (Figure 5) are present in their correct positions relative to each other, but the second imprint is concealed from the camera by the footpad.

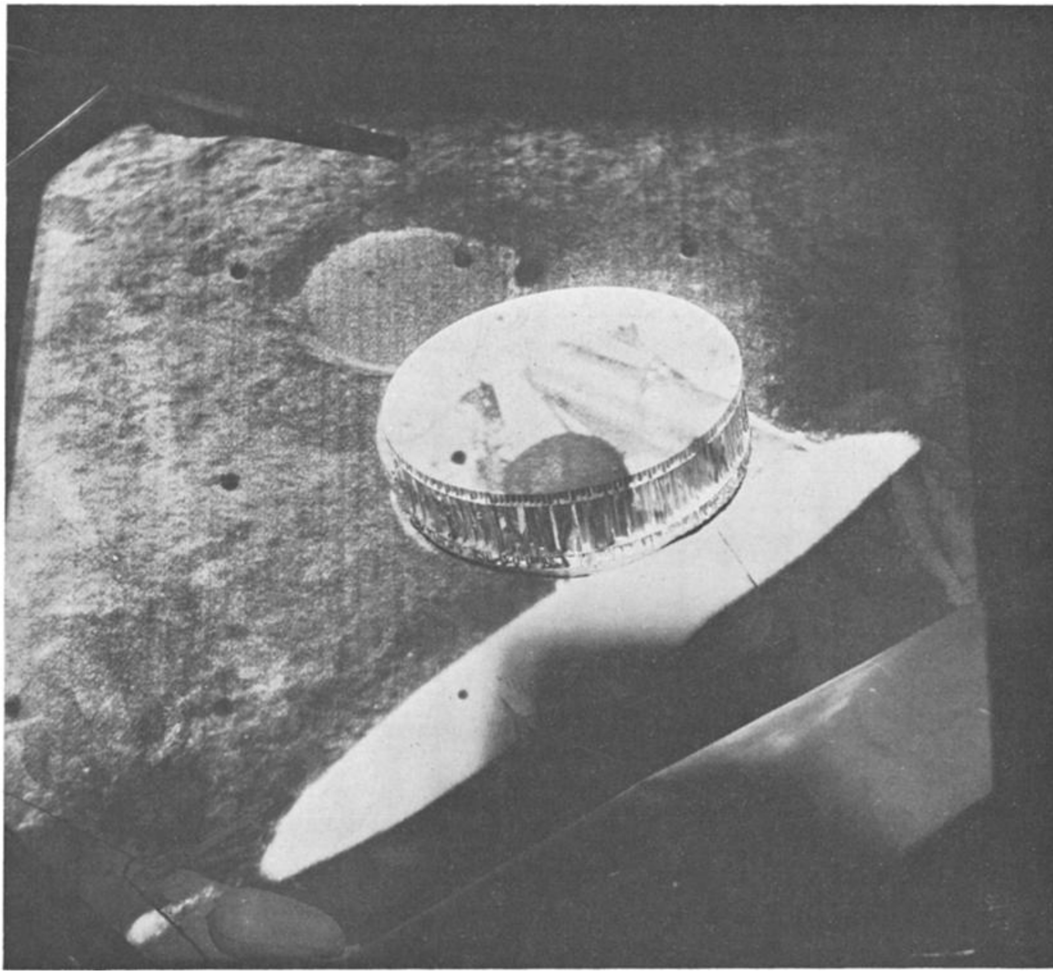

Fig. 6*b*. Photograph of projection of Figure 1 on footpad and soil arrangement of Figure 6*a* in the laboratory.

CONCLUSIONS

It is tentatively concluded that the Surveyor 3 spacecraft moved, probably as a result of a sudden failure of the leg 3 shock absorber, between May 1967 and November 1969. The movement at footpad 2 was in the amount of 5° of tilt and 3 inches of lateral translation in the form of a rotation about footpad 1, which is imbedded in the lunar soil.

Because a number of fairly close views of the Surveyor spacecraft and surface sampler appear on the Apollo 12 roll of film before the photograph of Figure 6 appears, the possibility arose that the spacecraft may have been moved by the astronauts. Post-mission questioning of Conrad and Bean indicated that this was not the case.

The time at which the movement occurred can only be estimated from the comparison of the shielded and unshielded parts of footpad 3 and a knowledge of the mechanism and rate of the process that tans the painted surface. The nature and magnitude of the spacecraft movement are pertinent to studies of the possible movement of lunar surface particles adjacent to Surveyor 3 [*Jaffe*, 1970]. They also have significance for any spacecraft examinations in which its orientation is important.

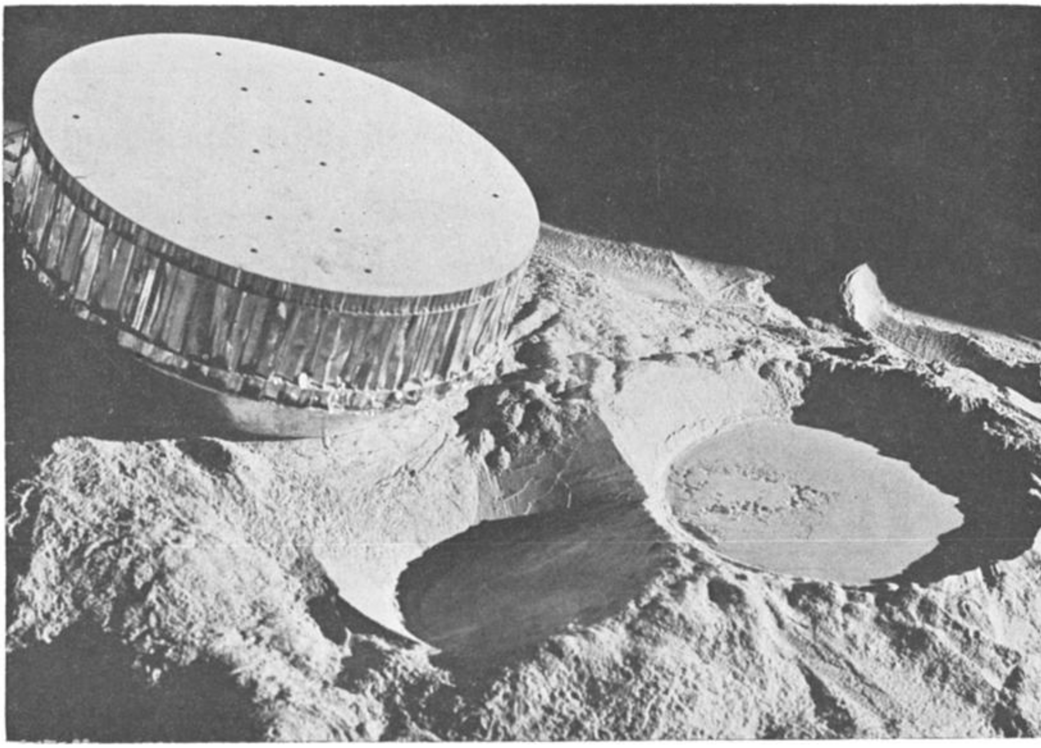

Fig. 7. Laboratory photograph of footpad 2 in original Surveyor 3 location. Compare with Figure 5.

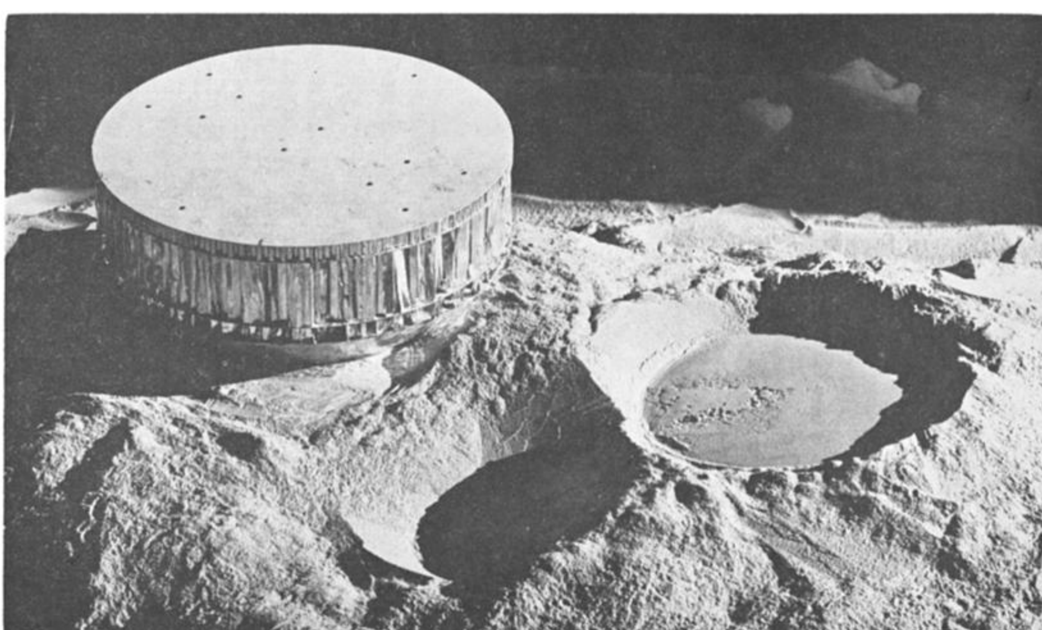

Fig. 8. Laboratory photograph of footpad 2 and imprints in position best matching astronauts' photograph (Figure 5).

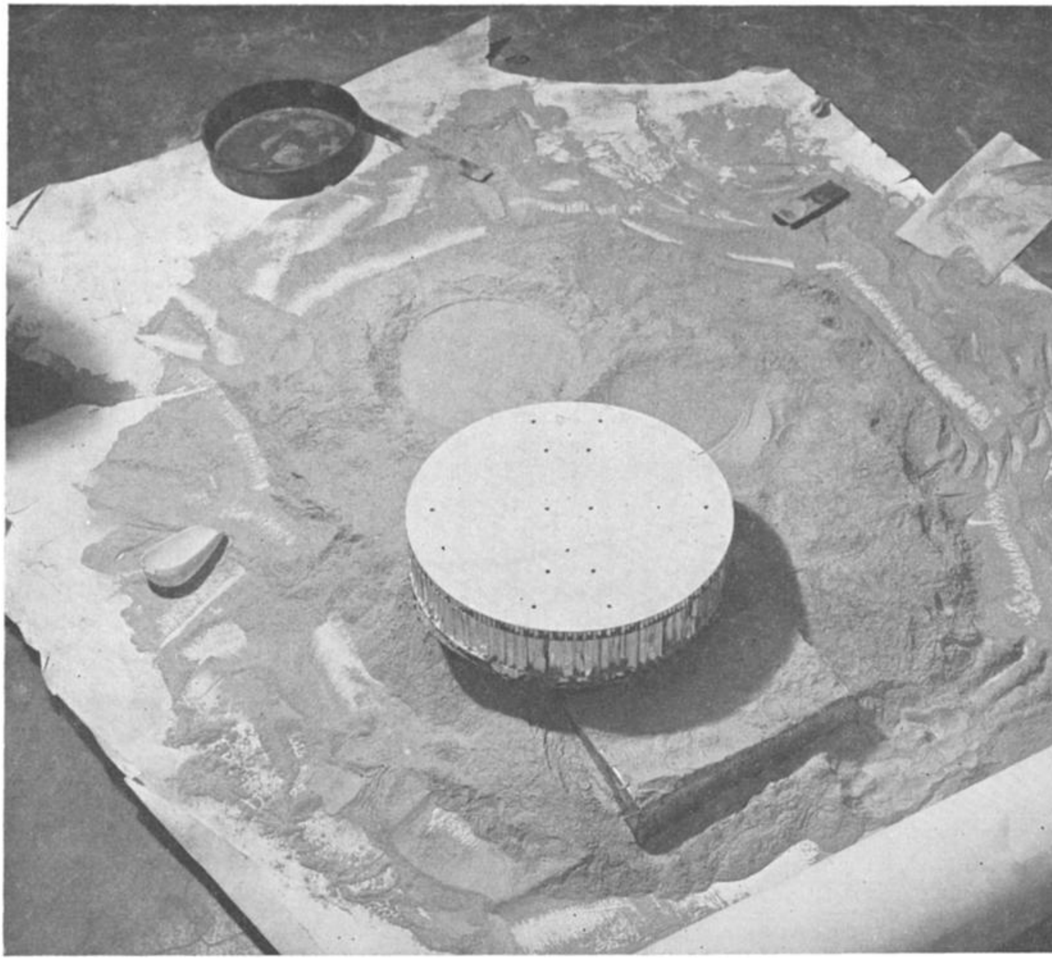

Fig. 9. Laboratory photograph from Surveyor camera position of footpad 2 and imprints in position best matching astronaut picture. The second imprint is clearly visible. Compare with Figures 1 and 6a.

Acknowledgments. Part of the work described here was supported under NASA grant NGR-05-002-118.

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(Received October 20, 1970.)