BELLCOMM, INC.

SUBJECT: Dust Cloud Produced by Luna-5
Impacting the Lunar Surface -
Case 211 Task 11

DATE: August 3, 1965

FROM: J. S. Dohnanyi

ABSTRACT

A dust cloud was reportedly observed when the Soviet Luna-5 impacted the moon. This study is an order of magnitude analysis of a process that would create such a cloud. It is found that the combination of the kinetic energy of Luna-5 and the chemical energy of the retro-fuel is capable of producing a marginally detectable cloud; the arguments employed are not particularly sensitive to the lunar surface materials.

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MEMORANDUM FOR FILE

I. Introduction

Shortly after the Soviet "Luna-5" impacted the surface of the moon in the Sea of Clouds, a dust cloud was reportedly observed (unsigned article, Izvestiya, p. 5, May 16, 1965) by the astronomical observatory at Rodewitsch, East Germany. This cloud was visible for about ten minutes after impact and at the time of best visibility (5.5 minutes after impact), the cloud was 230 Km and 80 Km wide. This immediately poses the question as to what information - if any - can be deduced concerning the lunar surface.

II. Origin of the Cloud

A simple analysis was undertaken to see whether the cloud could have been produced by a hard landing craft carrying explosive retro-fuel. The results indicate that this explanation is marginally consistent with the observation (see the Appendix for details). The argument assumes a simple photometric criterion, elementary ballistics, and a reasonable conversion of vehicle energy to ejecta energy. The results are consistent with a surface of basalt or some less cohesive material. While other possibilities have also been considered and dismissed the exact origin of the cloud has not been established. It is, however, believed that the assumption of a hard landing is consistent with the reported observation.

III. Comparison with Ranger

It is significant to note that none of the Ranger shots have produced an observable cloud. Since the Ranger spacecraft had a mass of less than 1/4 of Luna-5 and no retro-fuel, a typical Ranger impact will release about one order of magnitude less energy than Luna-5. If the dust cloud created by Luna-5 was barely visible, it is then possible that

Ranger might not produce such a visible dust cloud. This is consistent with the nominal calculation, and the Ranger results are not necessarily in conflict with our analysis.

IV. Conclusion

A simple analysis indicates that it is physically possible for Luna-5 to have produced a dust cloud (as reported) by cratering into basalt or a less cohesive material, and for Ranger not to do so.

V. Acknowledgements

I am particularly indebted to D. B. James, G. T. Orrok, and C. A. Pearse for valuable suggestions. Thanks are also due to E. M. Grenning and N. W. Hinners for helpful discussions.

1011-JSD-skc J. S. Dohnanyi

Attached:
Appendix

Copy to
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APPENDIX

We shall derive here an expression for the average particle size forming the dust cloud, which, coupled with simple photometric assumptions, furnishes the basis for the analysis.

We shall assume spherical nonreflecting and non-absorbing particles with index of refraction of the order of unity. For such particles (see, for example, M. Born and E. Wolf; Principles of Optics, Macmillan Co., New York, 1964) the scattering cross section is twice the geometric cross section provided that the particle size is larger than about .3 microns and is zero otherwise. Hence, the particle diameter D is

(A-1) $$2r = D > .3 \text{ micron},$$

where r is the particle radius. The particle size derived below must meet this criterion, if the impact hypothesis is tenable.

Assuming that a 1% change in visual appearance over large portions of the lunar surface is the threshold for visible detection, we have

(A-2) $$2 \times \pi r^2 \times N \times 2 \geq .01 \times \text{Area of cloud} = .01 \times 230 \times 80 \text{ Km}^2$$

where N is the number of particles present. An extra factor of 2 has been included to account for the fact that the particles scatter a light beam from the sun twice (i.e., as light reaches the lunar surface and as light leaves it).

The energy released by the spacecraft is

(A-3) $$2 \times \frac{1}{2}(\text{mass of Luna-5}) \times (\text{lunar escape speed})^2 = 8.5 \times 10^{16} \text{ergs}$$

where the reported mass of 1.5 metric tons for Luna-5 has been used; the factor 2 is included to represent the explosive energy of the retro fuel, approximately.

Letting V stand for the initial velocity (after impact) of the dust particles ejected into the cloud, one has

(A-4) $$\frac{1}{2}mV^2N = \varepsilon \times 8.5 \times 10^{16} \text{ ergs}$$

where m is the mass of the average particle and ε is the fraction of total energy expanded into creating the cloud.

In order to estimate V, we have, from elementary ballistics:

(A-5) $$V^2 = \frac{4\ R^2 + g^2\ T^4}{4T^2}$$

where V is the speed of a projectile fired into a range R and having a time of flight T; g is the lunar constant of gravity. Letting

(A-6) $$R \leq 120 \text{ km} = 1.2 \times 10^7 \text{ cm},$$

$$T = 6 \times 10^2 \text{ seconds},$$

$$g = 1.67 \times 10^2 \text{ cm/sec}^2,$$

one can solve (A-5) for V^2 and substitute into (A-3) to get

(A-7) $$N\ r^3 = \varepsilon \times 1.5 \times 10^7 \text{ cm}^3$$

where $m = \frac{4}{3}\pi\ r^3$ has been used (assuming the particles to have a density of 1 gm/cc).

Combining (A-7) and (A-2) gives

(A-8) $$r \leq \varepsilon \text{ microns}$$

or

(A-9) $$D \leq 2\varepsilon \text{ microns.}$$

The quantity ε is of the order of 50% (D. E. Gault and E. D. Heitowit, Proc. Sixth Symp. on Hypervelocity Impact, Vol. 11, part 2, p. 419, August 1963). This defines the upper limit on the particle diameter

(A-10) $D \lesssim 1$ micron.

This size limit is a factor of three above the scattering threshold (equation A-1). The nominal calculation is therefore consistent with production of a cloud by Luna-5, and, due to the smaller mass, the absence of a Ranger-produced cloud. It need not be emphasized that the calculation is approximate and should not be considered a "demonstration" of the cloud's origin.

Assumptions as to the nature of the surface do not enter strongly. The calculated cloud mass is consistent with the analysis of D. E. Gault, E. M. Shoemaker and H. J. Moore (NASA TND - 1767, April 1963) where they considered hypervelocity and explosive cratering in basalt and in less compacted materials.

In general, an initially unconsolidated material will result in ejecta of smaller size, more consistent with the assumption of particles of a uniform, small size.