NASA TECHNICAL
MEMORANDUM

NASA TM X- 64517

# CRATER SIZE AND IMPACT FLASH PREDICTED FOR THE S-IV B STAGE LUNAR IMPACT ON APOLLO 13 FLIGHT

By David W. Jex and Geoffrey Hintze
Space Sciences Laboratory

December 10, 1970



NASA

*George C. Marshall Space Flight Center*
*Marshall Space Flight Center, Alabama*

MSFC - Form 3190 (September 1968)

## ACKNOWLEDGMENTS

The work performed by Charles MacKay, Billy Joe Taylor, and Byron R. Yance is greatly appreciated in accomplishing this study.

TECHNICAL REPORT STANDARD TITLE PAGE

| 1. REPORT NO. | 2. GOVERNMENT ACCESSION NO. | 3. RECIPIENT'S CATALOG NO. |
|---|---|---|
| TM X-64517 | | |

4. TITLE AND SUBTITLE

Crater Size and Impact Flash Predicted for the S-IVB Stage Lunar Impact on Apollo 13 Flight

5. REPORT DATE

December 10, 1970

6. PERFORMING ORGANIZATION CODE

7. AUTHOR (S)

David W. Jex and Geoffrey Hintze

8. PERFORMING ORGANIZATION REPORT #

9. PERFORMING ORGANIZATION NAME AND ADDRESS

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS

National Aeronautics and Space Administration
Washington, D. C. 20546

13. TYPE OF REPORT & PERIOD COVERED

Technical Memorandum

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by the Space Sciences Laboratory, Science and Engineering Directorate

16. ABSTRACT

Marshall Space Flight Center has the responsibility to direct the impact of the S-IV B stage on the lunar surface during the Apollo 13 flight.

The Space Sciences Laboratory conducted an investigation to determine the diameter of the crater expected and the intensity of the associated impact flash.

Both theory and empirical relationships were used to obtain a meaningful conclusion.

17. KEY WORDS

Lunar Impact Flash
Crater Size
S-IV B Stage
Apollo 13 Flight

18. DISTRIBUTION STATEMENT

ANNOUNCE IN STAR.

| 19. SECURITY CLASSIF. (of this report) | 20. SECURITY CLASSIF. (of this page) | 21. NO. OF PAGES | 22. PRICE |
|---|---|---|---|
| Unclassified | Unclassified | 23 | $3.00 |

MSFC - Form 3292 (May 1969)

# TABLE OF CONTENTS



## LIST OF ILLUSTRATIONS



## LIST OF TABLES

TECHNICAL MEMORANDUM X-64517

# CRATER SIZE AND IMPACT FLASH PREDICTED FOR THE S-IV B STAGE LUNAR IMPACT ON APOLLO 13 FLIGHT

## SUMMARY


An attempt was made to predict the crater size and impact flash created by the impact of the S-IV B stage of Apollo flight 13 on the lunar surface. Both theory and empirical relations were used to obtain a meaningful conclusion.

The crater diameter for the S-IV B stage impact was determined to be approximately 40 meters.

It was concluded that very small chances exist for observation of the impact flash from earth-based stations. The maximum flash expected would be on the order of a 16th magnitude star.

In the soil of two of the six laboratory impact craters glassy spheres were found similar to the spheres found in the Apollo 11 lunar soil sample.


## INTRODUCTION

Marshall Space Flight Center has the responsibility to direct the impact of the S-IV B stage on the lunar surface during the Apollo 13 flight. The impact coordinates will be 3 degrees South, 30 degrees West, and impact time is predicted for 7:02 p.m. CST, on April 14, 1970.

Two questions connected with this impact arise: (1) What is the expected diameter of the crater that will be formed? and (2) Will the impact flash be observable from earth-based stations?

In order to answer these questions the Space Sciences Laboratory conducted the following investigations. To predict the diameter of the crater formed, an empirical explosive formula, missile impacts into different soils, and empirical tests in the light gas gun facility were employed. To determine if the flash generated by impact will be observable by earth-based stations, the impact of an aluminum projectile into a simulated lunar soil was monitored and analyzed.

## CRATER SIZE

It has been observed that hypervelocity impact craters are similar to craters formed by explosives. An empirical expression [1] relating the size of the crater and energy is:

$$r^3 = k E \qquad (1)$$

where r is the radius in feet, E is the energy of the explosive in pounds of TNT, and K is a constant which satisfies: $0.5 \leqslant k \leqslant 1.5$.

In the MKS system (International System of Units) r is the radius in meters, E is the energy in kilograms of TNT and k satisfies: $0.0312 \leqslant k \leqslant 0.0636$.

It has been found that one pound of TNT is equal to 1130 calories [2] or $2.14 \times 10^{13}$ ergs of energy. The S-IV B stage will impact the moon at a velocity of 2.58 km/sec, with a mass of 13 925 kg, therefore having an energy of $4.635 \times 10^{17}$ ergs or $9.809 \times 10^3$ kg of TNT. Substituting these values into equation (1) results in a crater diameter of 13.48 meters for $k = 0.0312$ and 19.44 meters for $k = 0.0636$.

The United States Geological Survey studied the size of craters formed by missile impacts on various soils in 1966. In their report [3] 19 cases were published. Assuming that impact craters scale as the cube root of the energy, the 19 cases were scaled up to the energy of the S-IV B stage for the lunar impact. The scaled results are listed in Table 1.

The light gas gun facility performed six test shots using a solid aluminum cylinder to impact a simulated lunar soil sample of basalt made available by Dr. Costes of the Space Sciences Laboratory. A comparison of this soil to lunar soil is shown in Figure 1. The mass and velocity of the projectile were known and the depth and diameter of the crater were measured after impact. Using energy scaling to predict the size of the crater formed by the S-IV B impact into a similar soil, Table 2 was compiled.

Limited time in which to predict the crater size necessitated use of previously manufactured hardware. Therefore, the available area in which to conduct the experiments was restricted to 4 inches square. This may have contributed to the higher energy tests resulting in smaller craters. The restricted area prevented ejected soil from following a normal trajectory, causing some of it to refill the crater after initial processes had ceased.

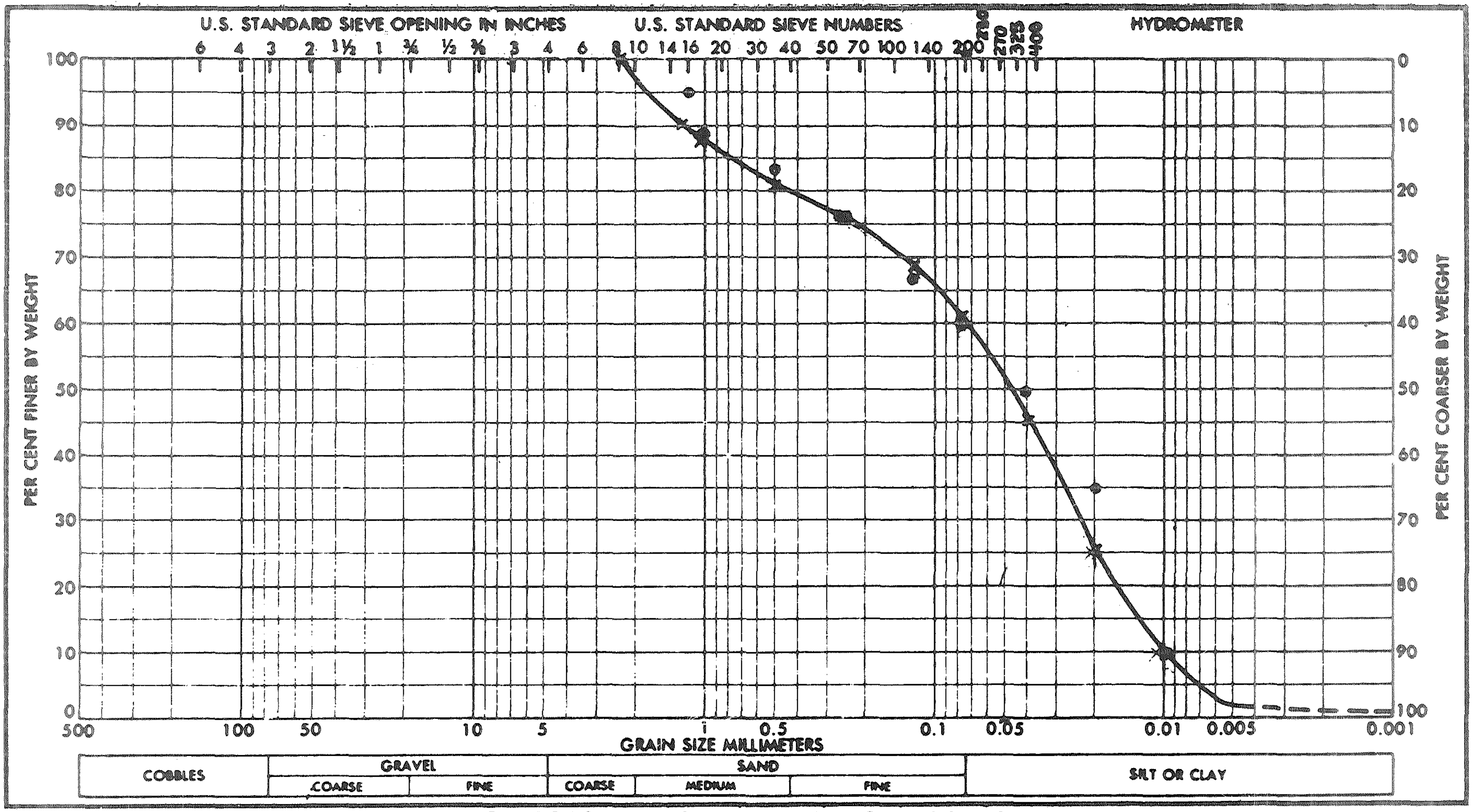
The three independent methods of predicting the impact crater for the S-IV B impact on the lunar surface give the following results:

TABLE 1. RESULTS SCALED TO AN ENERGY OF 4.635 × $10^{17}$ ERGS FROM THE U. S. GEOLOGICAL SURVEY FOR CRATER SIZE[a]

| Target | Diameter (meters) | |
|---|---|---|
| | min | max |
| 1. Sand, noncohesive | 30.29 | 33.06 |
| 2. Sandstone, large cohesion | 31.90 | 36.15 |
| 3. Gypsiferous Sediments, weakly cohesive | 19.57 | 29.41 |
| 4. Aluvium, weakly cohesive | 29.46 | 36.80 |
| 5. Gravelly Sands, weakly cohesive | 25.28 | 29.21 |
| 6. Alluvium, weakly cohesive | 32.35 | 41.58 |
| 7. Gypsum Lake Beds, cohesive, 20 percent water, density 1.2 - 1.6 g/cm$^3$ | 64.11 | 66.22 |
| 8. Alluvium, weakly cohesive | 21.92 | 27.40 |
| 9. Colluvium, weakly cohesive | 24.63 | 29.56 |
| 10. Gypsum Lake Beds, cohesive, 5 - 10 percent water, density 1.98 g/cm$^3$ | 31.03 | 40.04 |
| 11. Alluvium, weakly cohesive | 20.90 | 31.35 |
| 12. Sand, weakly cohesive | 24.11 | 28.93 |
| 13. Alluvium, weakly cohesive | 35.77 | 36.61 |
| 14. Colluvium, weakly cohesive | 37.08 | 37.55 |
| 15. Gypsum, cohesive | 42.96 | 44.69 |
| 16. Gypsum Sand, cohesive | 39.38 | 41.56 |
| 17. Clayie Silt, weakly cohesive[b] | 39.66 | 43.35 |
| 18. Clayie, weakly cohesive | 43.75 | 47.63 |
| 19. Soil and Colluvium Overlaying Clay and Siltstone, weakly cohesive | 40.31 | 50.90 |
| Average | 21.59 | 38.58 |

a. The angle of impact from the U. S. Geological Survey was normalized while the S-IV B impact was only 5 degrees from normal so that normalization was ignored.

b. The clayie silt would probably approximate the lunar soil more closely from grain size considerations than the other soils listed.




• OFFICIAL LUNAR SOIL SPECIFICATION

× GRL SIMULANT

Figure 1. Lunar soil model GRL 11/16 versus official.

TABLE 2. TABLE OF CRATER SIZE USING ENERGY SCALING OF EACH OF SIX SHOTS, CONDUCTED BY THE LIGHT GAS GUN FACILITY

| Shot Ref No. | Mass of Projectile $m_p$ $X10^{-3}$ gm | Velocity of Projectile $v_p$ $X10^5$ cm/sec | Kinetic Energy of Projectile $E_p$ $X10^7$ ergs | Scaling Factor $\left(\frac{E_{IV}}{E_p}\right)^{1/3}$ | Diameter of Crater Measured $D_p$ cm | Diameter of Crater Expected $D_{IV}$ meters |
|---|---|---|---|---|---|---|
| E-1-023 | 7.21 | 3.26 | 38.31 | 1065.56 | 4.44 | 47.31 |
| E-1-024 | 7.22 | 3.40 | 41.73 | 1038.62 | 4.44 | 46.11 |
| E-1-025 | 7.24 | 3.85 | 53.66 | 952.36 | 4.20 | 40.00 |
| E-1-022 | 7.14 | 4.10 | 60.01 | 917.51 | 3.18 | 29.18 |
| E-1-026 | 6.14 | 4.29 | 56.50 | 936.12 | 3.88 | 36.32 |
| E-1-027 | 6.00 | 4.33 | 56.25 | 937.51 | 3.88 | 36.38 |

The average diameter of the three shots in 3 to 4 km/sec range is 44.47 meters.

The average diameter of the three shots in the 4 to 5 km/sec range is 33.96 meters.

| | | min | max |
|---|---|---|---|
| (1) Explosive formula | | 13.48 | 19.44 |
| (2) Missile impacts | (avg) | 21.59 | 38.53 |
| | (clayie silt) | 39.66 | 43.35 |
| (3) Light gas gun experiments | | 29.18 | 47.31 |

The low prediction of the explosive formula may possibly be attributed to the lack of momentum consideration in the empirical development. That is, a traveling projectile has a given energy and momentum, while an explosive has only energy.

It was therefore concluded that the crater diameter formed by the S-IV B stage impact on the moon would approximate the physical impacts conducted under the other two studies. The predicted crater diameter is approximately 40 meters.

## IMPACT FLASH

To determine if the impact flash could be observed from earth-based stations, the six light gas gun shots listed in Table 2 were monitored by two photomultiplier tubes. The viewing area of the tubes was 2.323 $cm^2$ at a distance of 10.95 cm from the impact point.

The maximum output voltage recorded by the photomultiplier tubes corresponded to a current of $2 \times 10^{-5}$ amperes. The sensitivity of the photomultiplier tubes under the test conditions was 10 amperes/lumen, so that the luminosity recorded was $2 \times 10^{-6}$ lumens. The total luminosity of the impact event is therefore:

$$L_p = \frac{(2 \times 10^{-6} \text{ lumens})\,(10.95 \text{ centimeters})^2}{(2.323 \text{ cm}^2)\text{ steradians}} \; \frac{4\,\pi \text{ steradians}}{\text{unit sphere}}$$

$$= 1.297 \times 10^{-3} \text{ lumens}$$

Three approaches were made, using this empirical information, to predict the maximum intensity of the flash to be generated by the S-IV B stage impact and find the magnitude.

1. Assume area scaling:

It was assumed that luminosity is directly proportional to the area of the impacting body.

The diameter of the base of the S-IV B stage (660 cm) was used, because a maximum flash would be generated in this orientation. The scale factor $a$ is:

$$a = \frac{A_{IV}}{A_p} = \frac{\frac{\pi d_{IV}^2}{4}}{\frac{\pi d_p^2}{4}} = \frac{d_{IV}^2}{d_p^2} = \frac{(660\ \text{cm})^2}{(0.165\ \text{cm})^2} = 1.60 \times 10^7$$

$$L_{IV} = a L_p = 2.075 \times 10^4 \text{ lumens}$$

At earth distance, the intensity is:

$$I = \frac{L_{IV}}{4\pi r_E^2} = 1.12 \times 10^{-18} \text{ lumens/cm}^2$$

where $r_E$ is the distance between the earth and the moon ($3.84 \times 10^{10}$ cm).

To determine the magnitude we use the equation [4]

$$-2.5 \log_{10} \left( \frac{I}{I_o} \right) = M_V$$

where $I_o$ is the intensity of a zero magnitude star ($2.65 \times 10^{-10}$ lumens/cm$^2$).

Using the intensity calculated from the empirical work, we find:

$$M_V = 20.94$$

Therefore, the impact flash generated by the S-IV B stage impact on the lunar surface, based on the laboratory data and area scaling, would be equivalent to approximately a 21st magnitude star.

2. Assume mass scaling:

$$a = \frac{M_{IV}}{M_p} = \frac{13.925 \times 10^6 \text{ gms}}{6.825 \times 10^{-3} \text{ gms}} = 2.04 \times 10^9$$

$$L = 2.646 \times 10^6 \text{ lumens}$$

$$I = 1.428 \times 10^{-16} \text{ lumens/cm}^2$$

and

$$M_v = 15.67$$

3. Assume energy scaling:

$$a = \frac{E_{IV}}{E_p} = \frac{4.635 \times 10^{17} \text{ ergs}}{5.366 \times 10^8 \text{ ergs}} = 8.638 \times 10^8$$

$$L = 1.12 \times 10^6 \text{ lumens}$$

$$I = 6.05 \times 10^{-17} \text{ lumens/cm}^2$$

and

$$M_v = 16.60$$

## CONCLUSIONS

An attempt was made to predict the crater size and impact flash created by the Apollo 13 S-IV B stage impact on the lunar surface. Both theory and empirical results were used to obtain a meaningful result.

The crater size is predicted to be approximately 40 meters in diameter. This prediction is based on results obtained using an explosive formula, missile impacts on various soils, and experiments conducted using a light gas gun facility.

The maximum flash expected is based on the empirical information gained in the light gas gun experiments and scaling. The three scaling factors and the calculated results are:

| Scaling Factors | Equivalent Order Magnitude Star |
|---|---|
| area scaling | 21 |
| mass scaling | 16 |
| energy scaling | 17 |

Therefore the maximum flash expected would be equivalent to a 16th magnitude star.

On two of the six laboratory impacts some glassy spheres were found that are similar to the spheres found in the Apollo 11 lunar soil sample. Details of soil examination after impact experiments are contained in the Appendix.

## APPENDIX

At the beginning of the experiments in the light gas gun facility it was decided that after each crater had been measured and photographed, the top layer of soil that surrounded and lined the crater would be sifted and examined to determine if remains of the projectile could be found.

While examining the first sample some spheres were found. These spheres, shown in Figure A-1, show evidence of melting and fusion. They are similar to spheres found in the actual lunar soil from Apollo 11 shown in Figure A-2, and the soil material when examined under a microscope is very similar to the actual moon soil sample. There are irregular shaped fragments of basalt ranging from clear fragments, similar to the one to which one of the spheres in Figure A-1 is fused, to dark opaque fragments.

The sieves used for separating the soil sample had been examined before this part of the experiment to be sure that they contained no foreign material; however, it was concluded that this examination was not so rigorous as to preclude all possibilities of contamination. The sieves had been used to separate and obtain uniform glass spheres in other experiments. Therefore, the possibility that the spheres were a result of this form of contamination was considered; although it was unlikely that a sphere of this size would be missed in the preliminary examination.

The top four inches of the remaining sample was examined and produced no additional spheres. Communication with Dr. Costes of Space Sciences Laboratory, from whom the sample was obtained, gave assurance that there were no such objects introduced into the soil by the manufacturer.

The next three shots were examined in an identical manner. No spheres were found. However, during the examination of the fifth shot three more spheres, shown in Figure A-3, were found. Again the spheres came from the soil which surrounded and lined the crater. No spheres were found on the sixth shot. The shot reference number associated with the two tests in which spheres were found are E-1-022 and E-1-026. From Table 2 it was noted that these two shots were adjacent in the velocity and energy variations of the test series. The range used for this test series had a 10.16 cm square free flight path, 182.88 cm in length, to check the velocity of the primary projectile. The range was vertical and examination of the inside of the range showed that many of the soil fragments ejected from the crater area had traveled a vertical height of greater than 1 meter. This allowed approximately 1 second of free fall for molten ejecta to solidify.

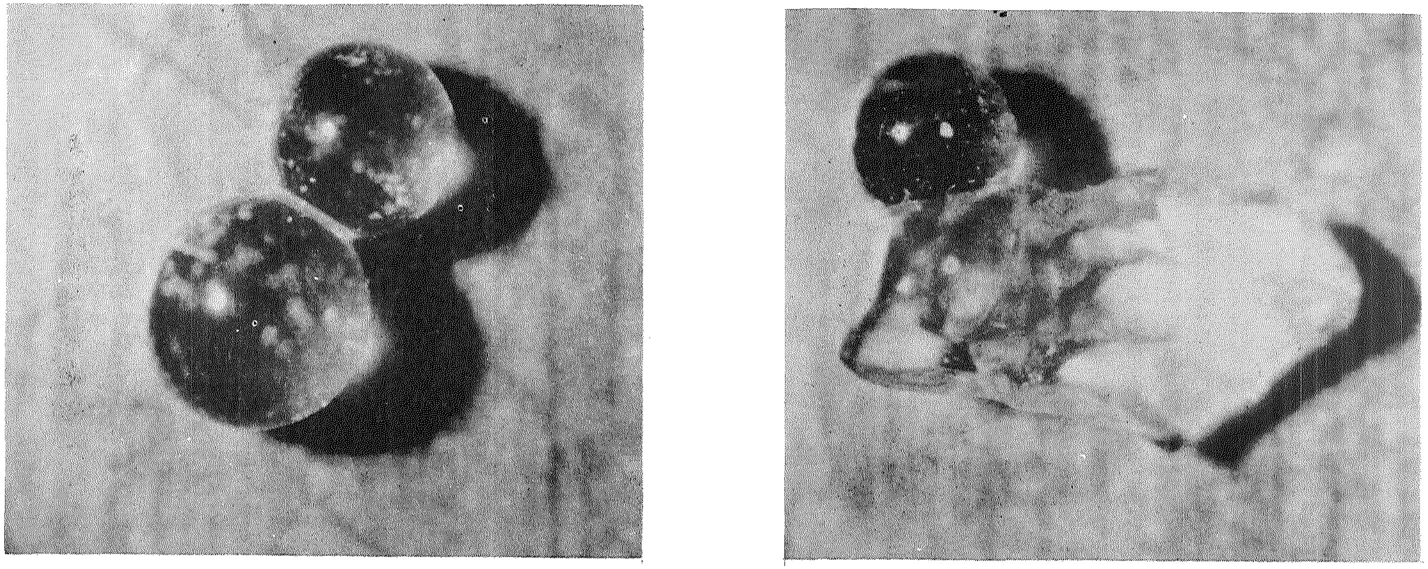


Figure A-1. Glassy spheres found on shot reference number E-2-022.

Figure A-2. Apollo 11 loose lunar soil sample (TN12, Manned Spacecraft Center).

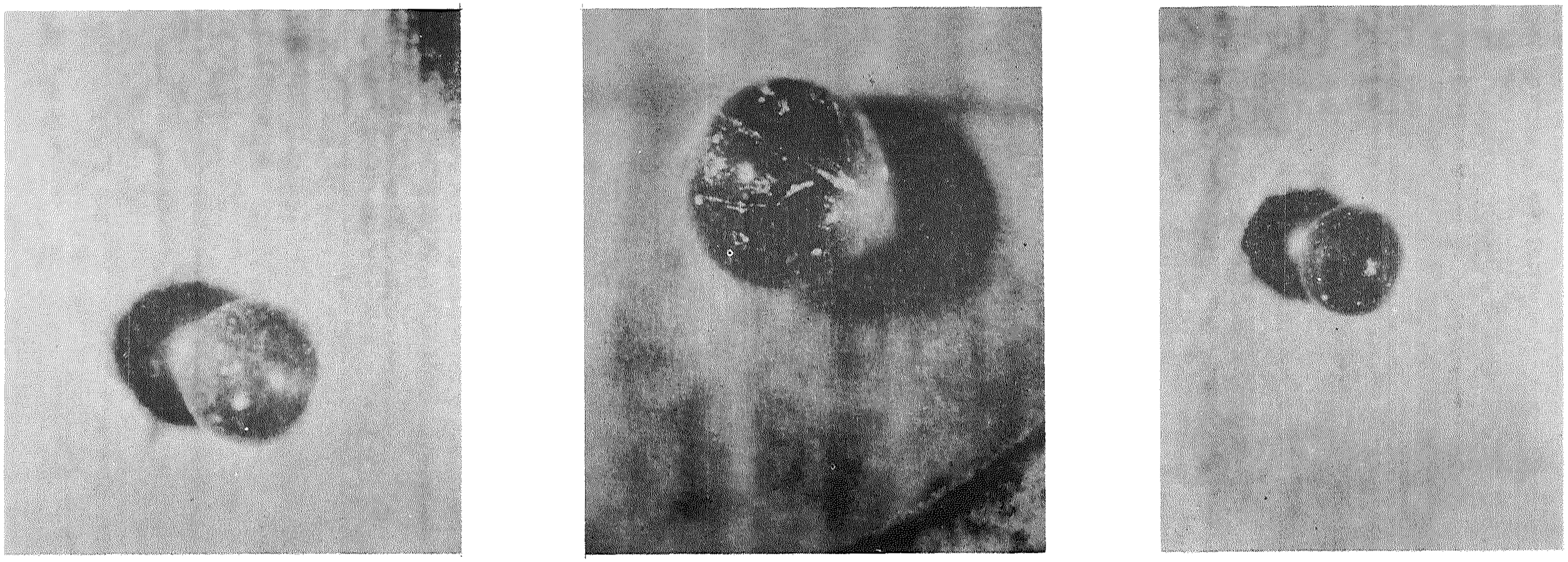


Figure A-3. Glassy spheres found on shot reference number E-2-026.

# REFERENCES

1. Kinney, Gilbert Ford: Explosive Shocks in Air. The Macmillan Co., New York, 1962, p. 7.

2. ibid, p. 2.

3. Moore, H. J.: Craters Produced by Missile Impacts. Published in Astrogeological Studies, Nov. 1966.

4. Allen, J. W.: Astrophysical Quantities. The Athlone Press, University London, 1955, p. 190.

# APPROVAL

## CRATER SIZE AND IMPACT FLASH PREDICTED FOR THE S-IV B STAGE LUNAR IMPACT ON APOLLO 13 FLIGHT

By David W. Jex and Geoffrey Hintze

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Robert J. Naumann

ROBERT J. NAUMANN
Chief, Physics and Astrophysics Division

Gerhard B. Heller

GERHARD B. HELLER
Director, Space Sciences Laboratory

MSFC—RSA, Ala

## DISTRIBUTION

INTERNAL

DIR
Dr. Rees
Mr. Foster

DEP-T

DEP-A&TS
Mr. Newby

AD-S
Dr. Stuhlinger

S&E-DIR
Mr. Weidner
Mr. Cook

S&E-AERO-DIR

S&E-AERO-T

S&E-AERO-Y
Mr. Vaughan
Mr. Dalton
Mr. Smith

S&E-ASTR-DIR
Mr. B. Moore

S&E-ASTR-IRT

S&E-ASTR-M

S&E-R-DIR
Dr. Johnson
Miss Smith

S&E-ME-DIR
Dr. Seibel

S&E-ASTN-DIR
Mr. Heimburg

S&E-SSL-DIR
Mr. Heller
Mr. Hembree

S&E-SSL-C
Mr. Bass
Reserve (20)

S&E-SSL-N
Dr. Decher
Dr. Costes

S&E-SSL-P
Dr. Naumann (10)

S&E-SSL-PA
Mr. Holland
Mr. Klingman
Mr. Hintze (10)

S&E-SSL-PM
Mr. Espy
Mr. Clifton
Mr. Jex (10)
Mr. Shriver

S&E-SSL-S
Dr. Sieber

S&E-SSL-T
Mr. Snoddy
Mr. Jones

S&E-SSL-X
Dr. Dozier
Mr. Winkler

INTERNAL (Concluded)

PA
Mr. Slattery

A&TS-PAT
Mr. L. D. Wofford, Jr.

A&TS-MS-H
A&TS-MS-IP (2)
A&TS-MS-IL (8)
A&TS-TU (6)
PM-PR-M

EXTERNAL

National Aeronautics and Space Administration
Washington, D. C. 20546:
Dr. George E. Mueller, M
Maj. Gen. Samuel C. Phillips, MA
Dr. Homer E. Newell, A
Dr. Maurice Dubin, SG
Mr. Jesse L. Mitchell, SG
Dr. Henry J. Smith, SG
Dr. Nancy G. Roman, SG
Mr. Bruce Lundin, R
Dr. Raymond H. Wilson, Jr., RRA
Mr. Milton B. Ames, Jr., RV
Mr. E. O. Pearson, RV-1
Mr. J. W. Keller, RV-1
Mr. C. T. D'Aiutolo, RV-1

Scientific and Technical Information Facility (25)
P. O. Box 33
College Park, Maryland 20740
Attn: NASA Representative (S-AK/RKT)

Darrell E. Munson 5163
Sandia Corporation
Albuquerque, New Mexico 87115

Robert Ratay
Structural Mechanics Section
Plt. 35, Dept. 462
Grumman Aircraft Corporation
Bethpage, New York

Basil Leftheris
Research Section
Plt. 35, Dept. 582
Grumman Aircraft Corporation
Bethpage, New York

S. Shields
LTV Aerospace
Missile and Space Division
Unit 3-52100
Grand Prairie, Texas

Verne C. Frost
Aerospace Corporation
Solid Mechanics Department
Applied Mechanics Division
2350 East El Segundo Boulevard
El Segundo, California

Prof. William Golberg
AFIT - SEB
Wright-Patterson AFB, Ohio 45433

R. K. Watanabe
The Boeing Company
P. O. Box 3999
Mail Stop 8H37
Seattle, Washington

C. Robert Nysmith
Ames Research Center
Moffett Field, California

EXTERNAL (Continued)

Dr. Benoit Jean
Computing Devices of Canada
Bell Corners
Ottawa, Ontario, Canada

Burton G. Cour-Palais
NASA-Manned Spacecraft Center
Houston, Texas

Tom Lee
NASA-Manned Spacecraft Center
Houston, Texas

Walt Turner
Brown Engineering Co.
Mail Stop 132
Huntsville, Alabama 35807

ARO, Inc.
von Karman Gas Dynamics Facility
Arnold Engineering Development Center
Arnold Air Force Station, Tennessee 37389
Attn: Jack D. Whitfield

AVCO Corporation
Research and Advanced Development Division
201 Lowell Street
Wilmington, Massachusetts 01887
Attn: W. Reinecke

Ballistics Research Laboratories
Aberdeen Proving Ground, Maryland 21005
Attn: AMXBR-EB, W. Braun

Canadian Armament Research and
Development Establishment
P. O. Box 1427
Quebec 2, P. Q., Canada
Attn: A. Lemay

Computing Devices of Canada, Ltd.
Space Sciences Laboratory
P. O. Box 508
Ottawa 4, Ontario, Canada
Attn: J. R. Murphy

Douglas Aircraft Company, Inc.
3000 Ocean Park Blvd., Loc. A-10
Santa Monica, California 90406
Attn: R. N. Teng

Denver Research Institute
University Park
Denver, Colorado 80210

General Motors Corporation
AC Electronics
Defense Research Laboratories
6767 Hollister Ave.
Goleta, California 93017
Attn: W. K. Rogers

General Motors Corporation
Manufacturing Development
G. M. Technical Center
12 Mile and Mound Road
Warren, Michigan 48090
Attn: A. R. McMillan

IIT Research Institute
10 W. 35th Street
Chicago, Illinois 60616
Attn: M. S. Nusbaum

Institut Franco-Allemand de Recherches
de Saint-Louis
12, rue de l'Industrie
Saint-Louis (Haut-Rhin)
France
Attn: C. L. Lecomte

EXTERNAL (Concluded)

Monsieur le Directeur du L. R. B. A.
Laboratoire de Recherches Balistiques
et Aerodynamiques
Vernon (EUre)
France

Lincoln Laboratory
Massachusetts Institute of Technology
Lexington, Massachusetts 02173
Attn: Dr. R. E. Slattery

Ames Research Center, NASA
Moffett Field, California 94035
Attn: Robert J. Carros, Mail Stop 237-1

U. S. Naval Ordnance Laboratory
White Oak, Silver Spring, Maryland 20910
Attn: J. N. Fedenia, Code 321

U. S. Naval Research Laboratory
Washington, D. C. 20390
Attn: J. R. Baker, Code 5186

Royal Armament Research and
Development Establishment
Fort Halstead
Sevenoaks, Kent
England
Attn: F. Smith, S/D4

University of Dayton Research Institute
University of Dayton
Dayton, Ohio 45409
Attn: H. F. Swift