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GRUMMAN RESEARCH DEPARTMENT MEMORANDUM RM-297

PHOTOMETRIC MEASUREMENTS OF SIMULATED LUNAR SURFACES

by

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Quarterly Progress Report on NASA Contract No. NAS 9-3182

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SUMMARY

This report is in partial fulfillment of the reporting requirements on Contract No. NAS 9-3182. It is the first quarterly progress report on the extension of the work on "Photometric Measurements of Simulated Lunar Surfaces" and covers the work performed in the period from July 1, 1965 to September 30, 1965.

Work accomplished to date includes a number of important modifications on the Photometric Analyzer which were necessitated by the nature of the contractual experiments. Preliminary test runs show significant improvements in the quality of the test data, particularly near the critical, zero-degree phase area where the "opposition effect" on the moon has been recently observed.

Actual experimental and analytical work has just begun and is now under way.

TABLES OF CONTENTS

INTRODUCTION

In this first quarterly progress report on the extension to the Contract on "Photometric Measurements of Simulated Lunar Surfaces," we present an account of the redesign, modification and calibration of the Grumman Photometric Analyzer that had to be made prior to the performance of the contractual experiments. We also present some preliminary measurements and discuss briefly our approach to the analytical phase of the program.

Work accomplished under the original contract is reported in detail in Ref. 1. This work consisted essentially of the laboratory measurements of "natural," "artificial," and "controlled" models in an attempt to reproduce the lunation curves of the moon (measured with integrated visible light) and infer certain physical properties of the lunar surface. Work to be performed in the extension to the original contract is as defined in "Proposal B" of Ref. 2 and consists of three parts, namely, "spectral" brightness vs. phase angle measurements of some of the natural specimens that passed the photometric test under integral lighting, analytical and/or experimental assessment of "suspended particles" as a lunar photometric model and finally, investigations of "contrived" models in an attempt to formulate the reflection laws of the moon in terms of the geometry and albedo of its surface elements and to account for some of the photometric peculiarities recently reported in the literature.

PROJECT STATUS

A number of important instrumental modifications and improvements necessitated by the new photometric and polarimetric experiments have been successfully completed after considerable analysis, rework and calibration. Some of this work is described in the next section of this report, but the major portion of it will be presented in a separate Grumman report (Ref. 3) to be released soon.

Test runs to assess the "improved" beam splitter have been made on Hawaiian volcanic cinder No. 1. The results are clearly superior to those obtained with the old beam splitter and show striking similarity to Gehrels' lunar observation of the "opposition effect." Actual work on the contractual experiments and analysis has begun and is currently proceeding satisfactorily. Barring major instrumental setbacks, which are possible but not likely, we expect to complete the "spectral" measurements phase of the contractual experiments during the next reporting period.

MODIFICATIONS AND IMPROVEMENTS OF THE GRUMMAN PHOTOMETRIC ANALYZER

Considerable time and effort has been spent during the period covered by this report to modify and improve the Grumman Photometric Analyzer. Although this work was necessitated by the nature of the experiments to be performed under this contract and the "Polarimetric" contract, No. NAS 9-4942, it has been carried through under in-house funding and is described in detail in a Grumman non-contractual report (Ref. 3). Briefly, the analysis and rework of the experimental set-up described in the above referenced report include the following items:

1. Light source analysis and comparison to solar source; correction by filters
2. Filter analysis and comparison to Gehrels, UGI, and UBV systems
3. Photomultiplier comparative spectral responses
4. Photomultiplier spectral characteristics
    a) at room temperature
    b) as a function of applied voltage
    c) at dry ice temperature
    d) at liquid nitrogen temperature
    e) as a function of various photomultipliers of the same type
5. Filter transmission characteristics and comparison to manufacturers' data

6. Filter temperature characteristics and instrumental heating characteristics

7. Astronomical data photometric systems and comparison to the Grumman system

8. Comparison of filters among themselves

9. Opti-mechanical modifications of the Photometer/Polarimeter

An equally important improvement of the photometric analyzer that is not discussed in Ref. 3 is the widening of the beam splitter to enable a more meaningful simulation and study of the "opposition effect" recently reported in the literature. As has been explained in a previous report (Ref. 1), the Grumman Photometric Analyzer makes use of a beam splitter to generate photometric functions which pass through zero phase angle. Furthermore, this beam splitter is mounted in such a way that it can be replaced readily with a complete first-surface mirror of the same size for use at phase angles greater than about 6°. A second first-surface mirror inclined 45° about an axis normal to the source axis and also normal to the axis of the first mirror is provided to de-polarize the source for other than zero phase region.

Astrophysical data reported by Gehrels et al (Ref. 4) have shown a very pronounced "opposition" effect, much sharper near zero phase angle than earlier data. These new data are based on measurements of the lunation photometric function much closer to zero degrees phase angle than had been reported previously. By comparison with the Grumman Photometric analyzer data taken on many models it can be seen that this trend toward a sharp peak exists in the laboratory data also, but because the valid data taken through the beam splitter are effectively confined to about $1\frac{1}{2}$ degree phase angle, the exact shape of the curve over a range of $\pm 6°$ phase angle cannot be verified. Furthermore, the interval of time the beam splitter takes to travel this narrow angular distance is not sufficient to allow the recorder to respond in time to the actual brightness sensed by the photometer. To increase the Grumman capability of reading out the slope and peak of this significant part of the photometric signature of a model, a large beam splitter has been built-up especially for this range. The large beam splitter is used solely for readings near zero phase angle and is removed and replaced with a mirror for readings at larger phase angles. The approximate range which this beam splitter will cover is -7° to +13° as can be seen from sample reaordings, Fig. 3c. A photograph of the unit attached to the rotating collimated source arm is shown as Fig. 1.

The rotating source of the Analyzer has also been provided with accommodation for 6 filters or 5 filters and a clear space, manually selectable from floor level as shown in Fig. 2. The filters are inserted between the diffuser disks and the field stop. The source radiance has been improved by a large factor by use of a 1 KW tungsten-iodine lamp and two quartz diffuser disks in series whereas flashed opal diffusers of greater density had been used previously.

Although the filters are shielded by the diffuser disks and a certain amount of structural shielding, the thermal problem resulting from the use of a 1 KW lamp is severe. Trial of a dense red filter showed a temperature of about 200° F at the surface of this filter. This particular filter cracked. Temperature fluctuations of such a degree can result in color changes as well as mechanical failure. The design has been reviewed from a thermal standpoint and improved by providing high absorptivity radiation heat sink surfaces for the filter and improving the conduction transfer paths. A blower has been used throughout to circulate air through the source assembly. The filters have been placed adjacent to the source rather than the photometer phototube for reasons of convenience and timesaving in operation. The filter problem could also be alleviated by the use of filters which have low radiation absorption.

DISCUSSION OF TEST RESULTS

To evaluate the performance of the new, improved, beam splitter, a test run was made on the Hawaiian volcanic cinder No. 1 at 0°, 30° and 60° viewing angles as shown in Fig. 3a to c.

A comparison with similar curves on the same specimen obtained by the old, narrower beam splitter as presented in Fig. 17 of Ref. 1, indicates a significant improvement in the quality of the data obtained. The brightness peak, at zero degree phase, measured by the old beam splitter was only about 10 per cent greater than the 1.0 normalization point on the ordinate of the curve whereas the corresponding value measured by the new beam splitter is in excess of 30 per cent not counting the fact that at the normal viewing position the brightness surge at zero degree phase was so intense that the recording pen went off the paper, as may be seen in Fig. 3a.

In addition to measuring the brightness peak more accurately, the new beam splitter reveals the change in the slope of the photometric curve in the region where the opposition effect takes place and thus, permits direct comparison with the measured lunar data in this region. The similarity of Gehrels' data (Ref. 4) with our new measurements is more striking than with the previous measurements obtained through the old beam splitter.

The demonstration of the new beam splitter illustrates again the importance of adequate or refined instruments in lunar model-matching experiments. Judging from the preliminary results, the time and effort spent in improving this particular aspect of our photometric analyzer appear to have been justified.

PRELIMINARY ANALYTICAL APPROACH TO PHASES II AND III

While experimental models are being constructed the analytic work associated with Phases II and III was initiated during the first reporting period and will continue throughout the remaining portion of the present contract. The role of shadowing is being investigated for various suspended particle configurations within which multiple scattering and diffraction effects are neglected. For purposes of generality the individual particles being considered are assumed, as in Ref. 5, to be opaque, macroscopic, generalized surfaces of revolution of uniform albedo. Also, for simplicity, each elementary surface element is assumed to exhibit the diffusive reflective behavior of a "Lambertian" surface. The utility of the analysis developed in Ref. 5 resides in the fact that it lends itself to computer analyses in which the pertinent parameters can be varied. Furthermore, results for specific well-known geometries (cylinders, spheres, planar surfaces) are easily obtained and can be readily compared to other more complicated shapes. For the spherical case the individual particle scattering function reduces to the result previously obtained by Schoenberg (Ref. 6) and later used by Hapke (Ref. 7) who considered the scattering of light from a medium comprised of randomly oriented opaque particles with rough surfaces. Owing to the increased difficulties encountered in the geometrical analysis for these models as one increases the number of layers, it appears at this point that it will probably be necessary to limit the number of layers to just a few.

With reference to Phase III of the present study, the dominant role of shadowing is being studied for various contrived tridimensional models. Preliminary numerical results have been obtained for the configuration consisting of a series of suspended horizontal "Lambertian" elements of uniform albedo, separated by a fixed distance. The brightness vs. phase curve for one case (viewing angle E, equal to zero) bears a remarkable resemblance to one recently suggested in the Interim Report of the original contract (Ref. 1). Though the analysis for this model has been completed for all viewing angles as well as variable linear dimensions, no numerical results have been obtained for cases other than $E = o$. Analytical work along these lines will be extended to include as many of the contrived configurations as is possible and in particular the T or "thumb tacks" model. "Composite" albedo effects will also be considered for certain cases. In this connection, the "improved" beam splitter, described above, will be particularly useful in assessing the analytical results.

ACKNOWLEDGEMENT

It is a pleasure to thank again H.B. Hallock, J. Grusauskas and D.R. Lamberty of Servo Engineering for their valuable contribution and painstaking efforts in rebuilding and recalibrating the Photometric Analyzer and performing the experiments.

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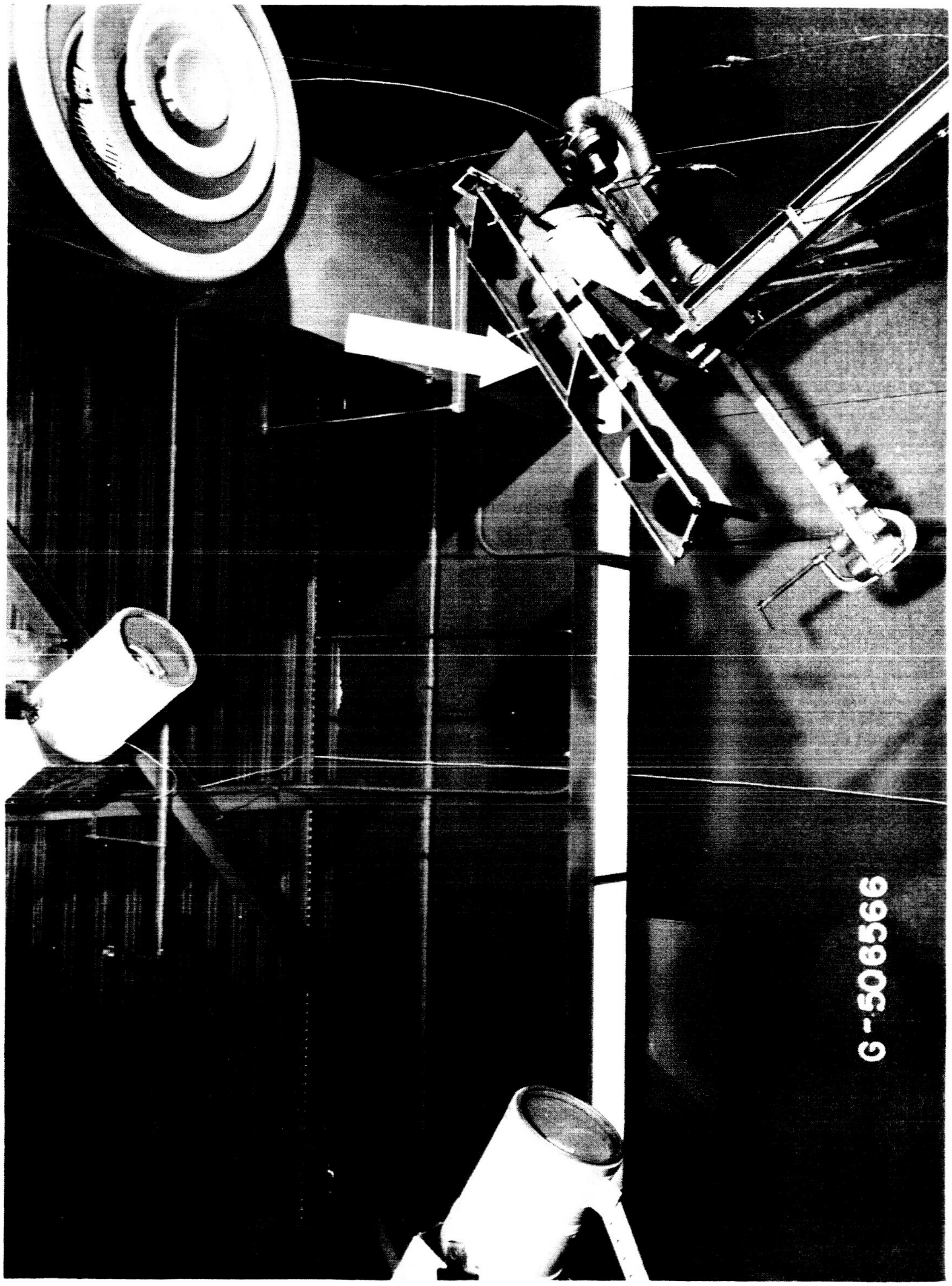

Fig. 1 New Improved Beam Splitter Mounted in Front of Light Source

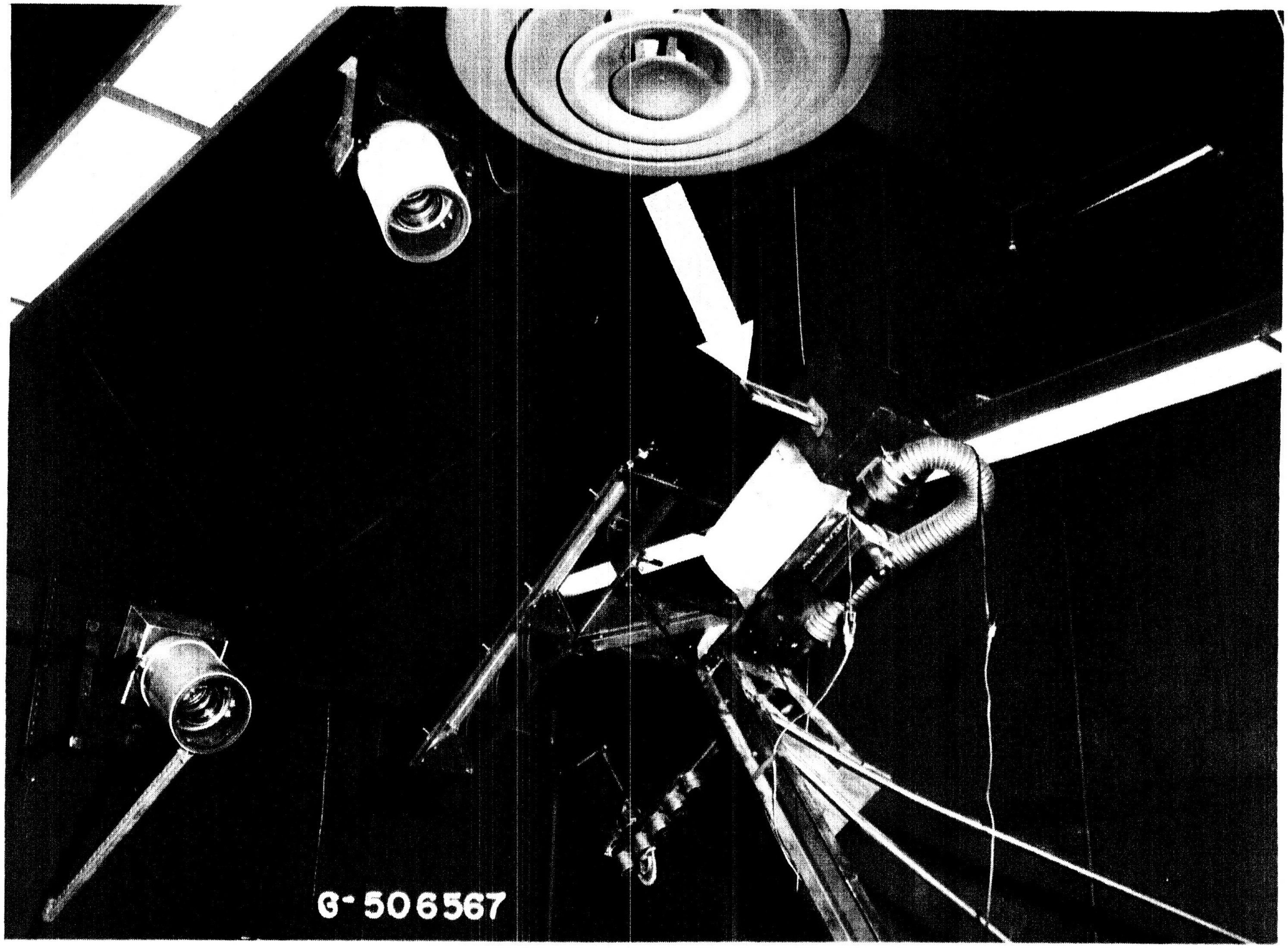

Fig. 2 Filter Sliders (arrow) Mounted at Light Source

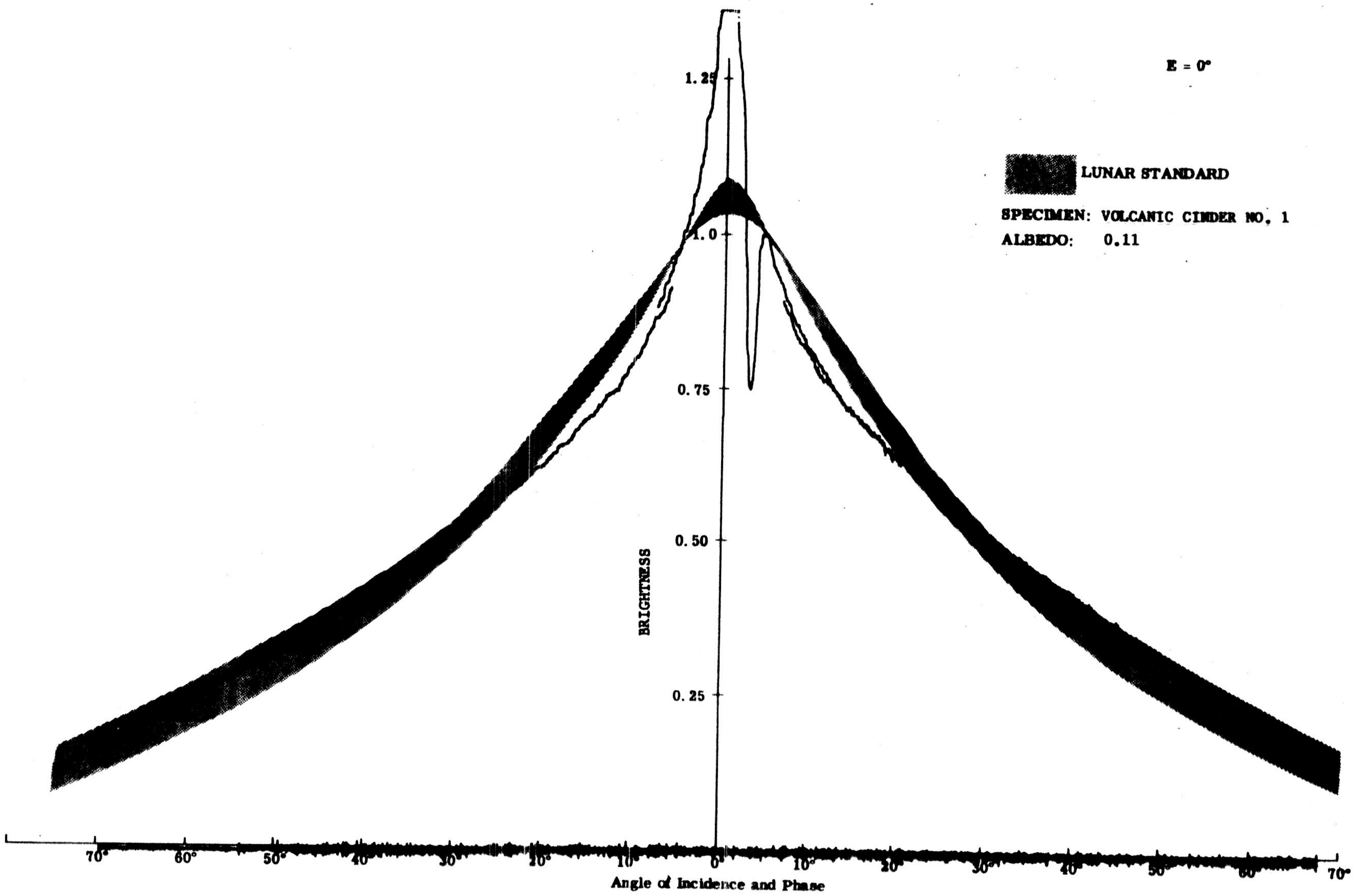

Fig. 3a Hawaiian Volcanic Cinder Measured with New Beam Splitter

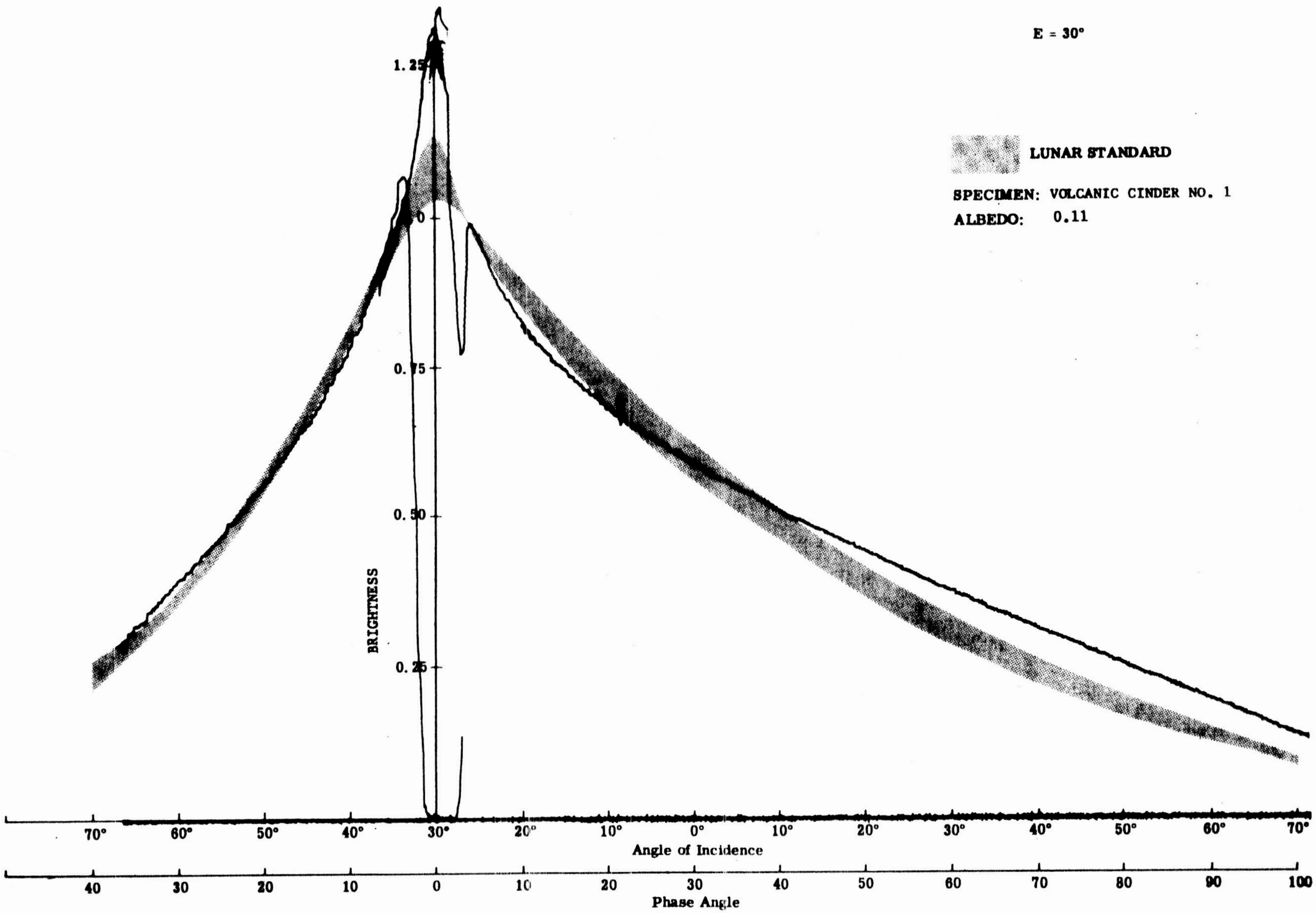

Fig. 3b Hawaiian Volcanic Cinder Measured with New Beam Splitter

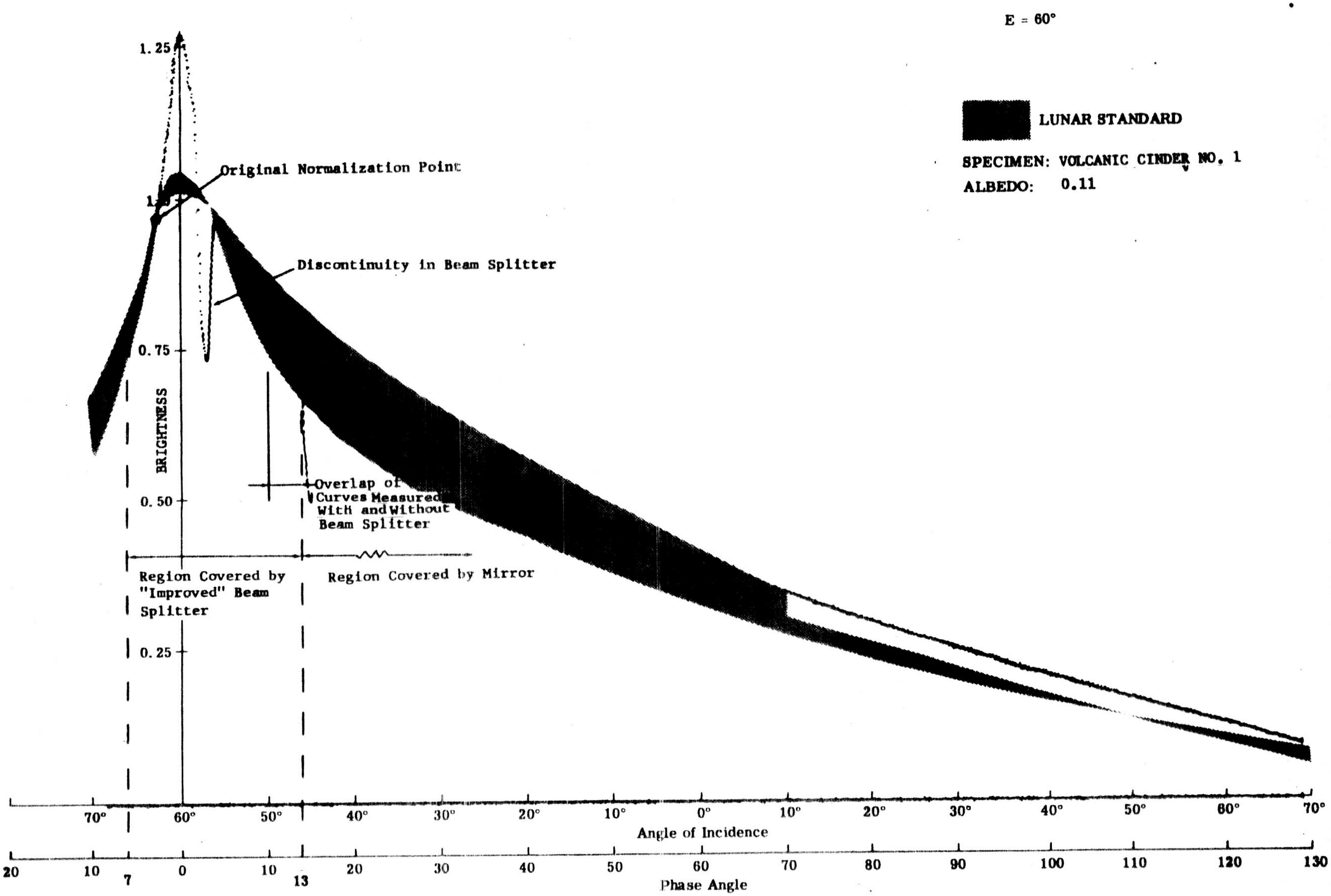

Fig. 3c Hawaiian Volcanic Cinder Measured with New Beam Splitter