GOODYEAR AEROSPACE
CORPORATION

AKRON 15, OHIO

AN INDICATED SPECULAR DEGRADATION RATE FOR ALUMINIZED MYLAR SURFACES IN NEAR-EARTH ORBIT FROM RECENT PHOTOMETRIC OBSERVATIONS OF THE ECHO I SATELLITE

by
Richard H. Emmons
Goodyear Aerospace Corporation

(A paper presented before the 116th meeting of the American Astronomical Society in Flagstaff, Ariz., 24-27 June 1964.)

GER-11521, Rev A

17 June 1964

ABSTRACT OF

AN INDICATED SPECULAR DEGRADATION RATE FOR ALUMINIZED MYLAR SURFACES IN NEAR-EARTH ORBIT FROM RECENT PHOTOMETRIC OBSERVATIONS OF THE ECHO I SATELLITE

by
Richard H. Emmons
Goodyear Aerospace Corporation

Photometric measurements were made of the Echo I satellite with a visual comparison photometer on 1 March 1964 (Universal Time).

The data, taken over a wide range of phase angles (143 to 32 deg) and normalized for slant range, are best fitted in illuminance versus Russell's phase function by a surface model that is 96 percent specular and 4 percent diffuse. This indicates that the actual specular degradation rate for aluminized Mylar surfaces in a near-earth orbit, due to the combined effects of all environmental factors, is less than 1 percent per year.

If a reflectivity coefficient of 0.83 is assumed, the Echo I photometric observations yield a mean radius of curvature of 47 ft with a probable error of 3 ft. Several surface anomalies were observed having local radii of curvature ranging from 39 to 66 ft.

Together with the results from laboratory hypervelocity impact tests of very small particles on aluminized Mylar, the present indications may prove of value in further defining the micrometeoroid environment at Echo I's orbital height, either with respect to the flux in the vicinity of the mass cutoff or the mass cutoff itself. The present indications should also prove of value in predicting the useful life in nearby space of exposed optical and thermal balance surfaces.

The photometric studies of Echo I are being extended at Goodyear Aerospace Corporation under NASA-Langley Research Center Contract NAS 1-3114, monitored by William J. O'Sullivan. While final results from these additional visual and photoelectric measurements are not available at this time, the preliminary results appear to support the conclusion herein that Echo I's surface remains highly specular.

ABSTRACT

Photometric measurements were made of the Echo I satellite with a visual comparison photometer on 1 March 1964 (Universal Time).

The data, taken over a wide range of phase angles (143 to 32 deg) and normalized for slant range, are best fitted in illuminance versus Russell's phase function by a surface model that is 96 percent specular and 4 percent diffuse. This indicates that the actual specular degradation rate for aluminized Mylar surfaces in a near-earth orbit, due to the combined effects of all environmental factors, is less than 1 percent per year.

If a reflectivity coefficient of 0.83 is assumed, the Echo I photometric observations yield a mean radius of curvature of 47 ft with a probable error of 3 ft. Several surface anomalies were observed having local radii of curvature ranging from 39 to 66 ft.

Together with the results from laboratory hypervelocity impact tests of very small particles on aluminized Mylar, the present indications may prove of value in further defining the micrometeoroid environment at Echo I's orbital height, either with respect to the flux in the vicinity of the mass cutoff or the mass cutoff itself. The present indications should also prove of value in predicting the useful life in nearby space of exposed optical and thermal balance surfaces.

The photometric studies of Echo I are being extended at Goodyear Aerospace Corporation under NASA-Langley Research Center Contract NAS 1-3114, monitored by William J. O'Sullivan. While final results from these additional visual and photoelectric measurements are not available at this time, the preliminary results appear to support the conclusion herein that Echo I's surface remains highly specular.

AUTHOR

TABLE OF CONTENTS

SECTION I - INTRODUCTION

To obtain photometric data for bright artificial satellites, a hand-held, polarizing, visual-comparison photometer was designed and constructed at Goodyear Aerospace Corporation in January, 1964[a] (see Figure 1). The digital readouts (polarizing filter rotations) are converted to stellar magnitudes by means of the calibration determined from repeated observations of stars of known visual magnitude.[1,b] Allowances are made for atmospheric extinction according to the instantaneous zenith distances (z) of the reference stars and target.

With this instrument 21 photometric measurements were made of Echo I from North Canton, Ohio, (Smithsonian Astrophysical Observatory satellite tracking station No. 8544) in a 13.6-min period, during a high pass of this satellite on 1 March 1964 Universal Time (U. T.). Figure 2 was drawn from a one-minute exposure photograph taken at 0 hr 37 min U. T., 1 March 1964, showing Echo I's path left of the planets Venus and Jupiter as the first photometric observations were made. Also shown are selected star and constellation locations, right ascension/declination reference grid, and time tics.

Calibration observations of stars were made before and after the satellite date was taken, yielding a total of 39 measurements at 18 different elevations of 17 different reference magnitudes throughout the photometer's range. A least squares reduction was made of this data, providing a mean extinction coefficient of 0.207 and the instrument's calibration equation:

---

[a]This photometer was first tried in its automatic record mode to measure Echo II's optical characteristics during its first week in orbit. The measurements obtained were consistent with predicted values that would result from a successful deployment of this satellite.

[b]Superior numbers in the text refer to items in the List of References.

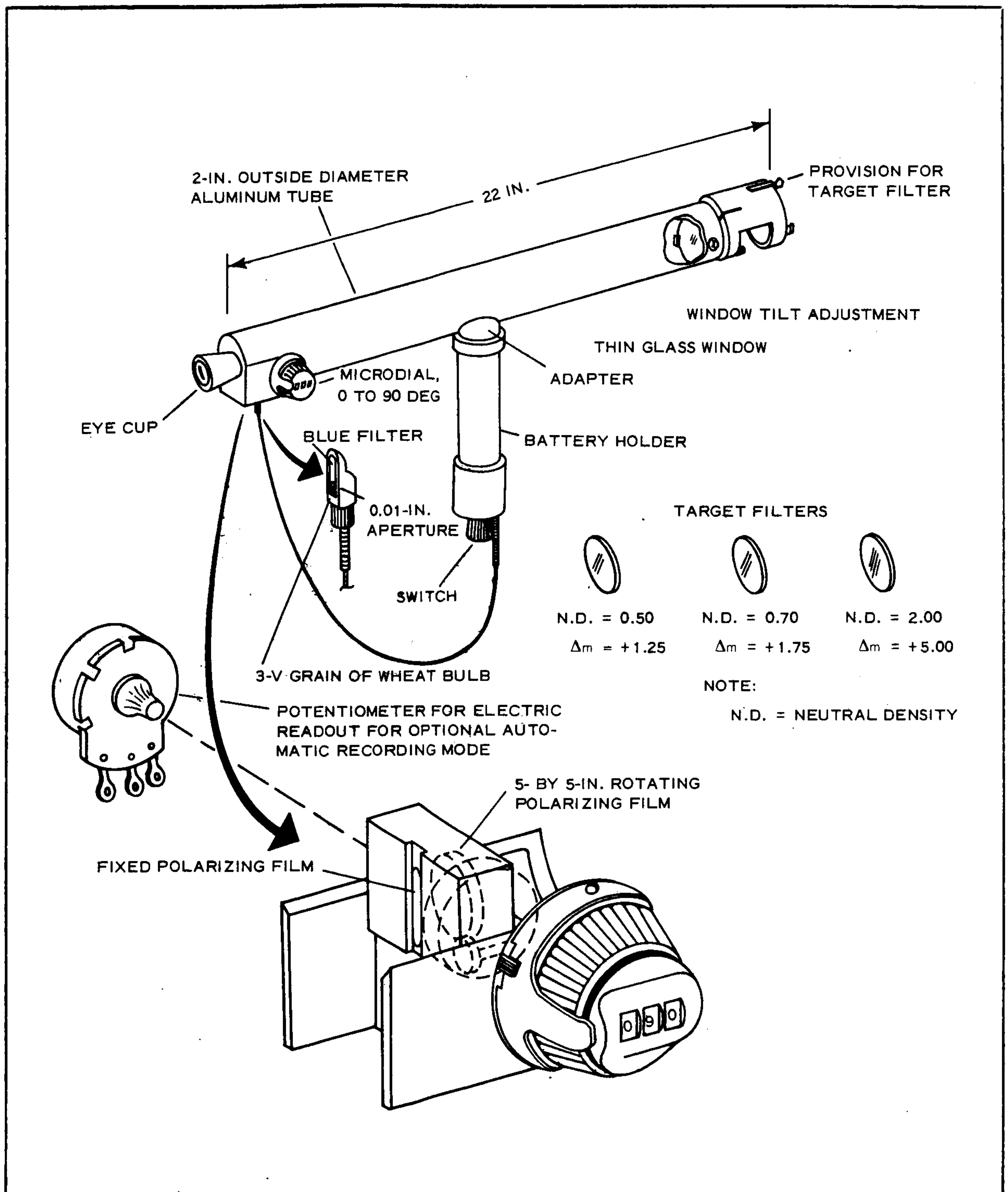

Figure 1 - Visual Comparison Photometer for Bright Satellites

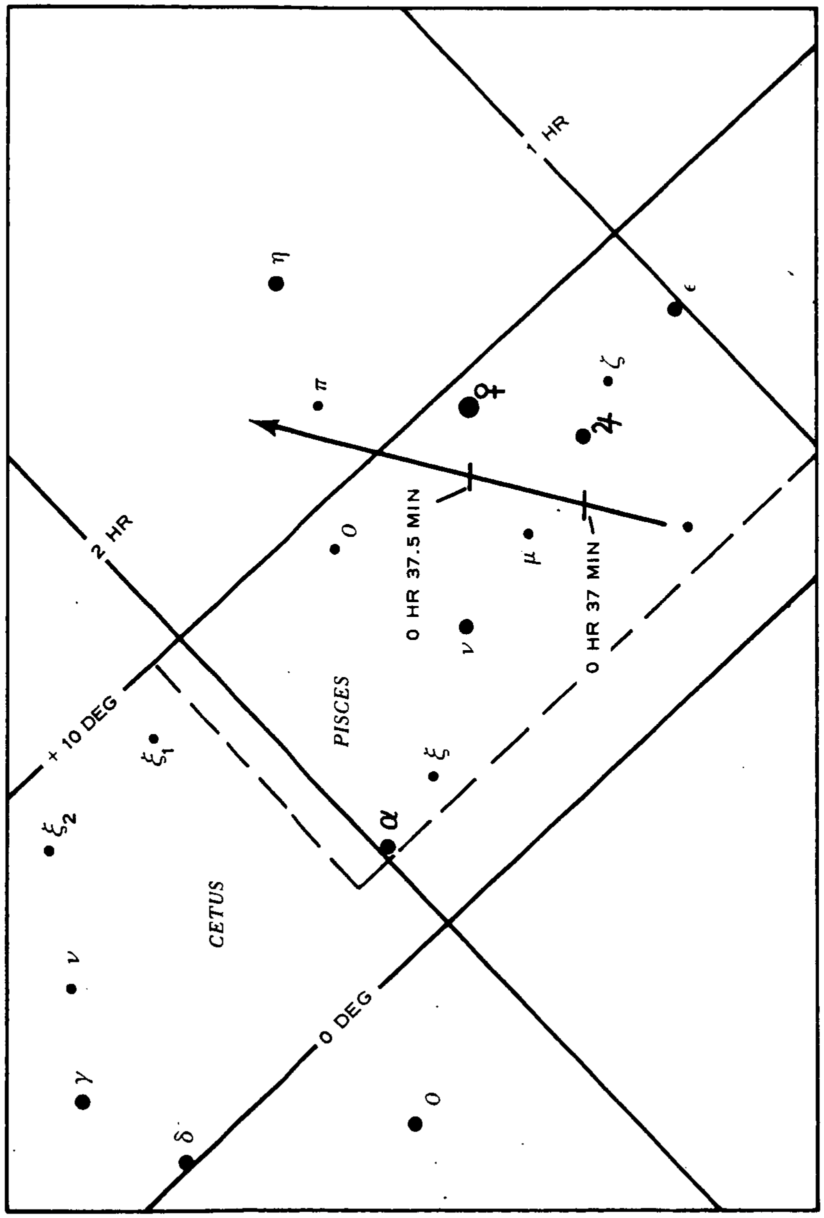

Figure 2 - Echo I's Apparent Path Past Jupiter and Venus

$$m_o + 0.207X = 6.446 - 3.802 \log(\text{instrument reading}) \quad ,$$

where

m_o = the extra atmosphere magnitude, and

X = number of atmospheres ($\cong$ sec z).[a]

The standard deviation of the calibration data was 0.196 stellar magnitude, which includes the effect of possible extinction changes. The correlation coefficient was 0.9836.

Table I gives the Universal Times (obtained via short-wave radio from CHU and tape recorded together with the photometer readings), the instrument readings, the phase angle, the reduced stellar magnitudes normalized to a 1000-stat-mi zenith range, and the indicated radius of curvature. The stellar magnitudes have been corrected for earthshine.[2,3] At the tracking station where these data were taken, the longitude was 81 deg 24 min 42 sec west, the latitude was 40 deg 52 min 45 sec north, and the elevation was 350 m above sea level.

The phase angles and geometrical circumstances of these observations were reduced from orbital elements provided by the Smithsonian Astrophysical Observatory, which were found to conform to observed times and positions obtained during the pass. The solar coordinates at this time were: right ascension, 22 hr, 48 min; declination, -7 deg 39 min.

The normalized stellar magnitudes given in Table I are plotted versus phase angle in Figure 3. Upon inspection of the data it was judged that the three unnumbered photometric values were the result of surface macrotexture anomalies, and they were therefore excluded from the microtexture analysis. The remaining 18 numbered data points, used in the subsequent microtexture analysis, yield a mean normalized stellar magnitude of +0.22.

---

[a]Actually used $X = \sec z - 0.0018167(\sec z - 1) - 0.002875(\sec z - 1)^2 - 0.0008083(\sec z - 1)^3$ (see Reference 4).

TABLE I - PHOTOMETRIC OBSERVATIONS

Number	Universal time	Instrument reading	Elevation (deg)	Slant range (stat mi)	Phase angle (deg)	Normalized stellar magnitude*	Radius of curvature (ft)+
1	0 hr 36 min 13 sec	13.0	17.54	1810	142.8	0.280	45.8
2	0 hr 37 min 17 sec	18.5	23.32	1606	138.0	0.106	49.7
3	0 hr 37 min 56 sec	22.0	27.37	1486	134.5	0.052	50.9
4	0 hr 39 min 02 sec	25.7	35.43	1298	127.3	0.171	48.1
5	0 hr 39 min 46 sec	27.1	41.80	1184	121.3	0.320	44.8
6	0 hr 40 min 04 sec	30.0	44.67	1142	118.6	0.247	46.3
7	0 hr 40 min 30 sec	30.0	49.07	1085	114.3	0.378	43.5
8	0 hr 41 min 15 sec	35.0	57.31	1002	105.9	0.324	44.4
. . .	0 hr 42 min 18 sec	55.5	68.65	928	92.2	-0.247‡	57.8
9	0 hr 42 min 49 sec	39.8	72.26	913	85.0	0.344	43.5
10	0 hr 43 min 19 sec	39.7	72.65	912	77.9	0.349	43.2
11	0 hr 43 min 46 sec	36.5	70.18	924	71.7	0.457	40.8
. . .	0 hr 44 min 19 sec	53.2	64.97	953	64.5	-0.242‡	57.1
. . .	0 hr 44 min 45 sec	61.0	60.22	987	59.3	-0.553‡	66.2
12	0 hr 45 min 13 sec	39.8	55.04	1033	54.2	0.040	49.6
13	0 hr 45 min 38 sec	35.7	50.57	1081	50.2	0.105	47.9
14	0 hr 46 min 28 sec	28.7	42.40	1194	43.6	0.211	45.2
15	0 hr 47 min 00 sec	28.3	37.77	1276	40.2	0.060	48.7
16	0 hr 48 min 05 sec	17.3	29.68	1458	35.4	0.503	38.7
17	0 hr 49 min 22 sec	16.95	21.92	1693	32.3	0.073	48.4
18	0 hr 49 min 49 sec	16.5	19.57	1779	31.7	-0.048	51.2

*Extra atmosphere magnitude normalized to a slant range of 1000 stat mi and corrected for earthshine.

+Assumes a coefficient of reflectivity of 0.83.

‡Excessive brightness attributed to a gross surface anomaly (macrotexture) and therefore is omitted from the microtexture analysis.

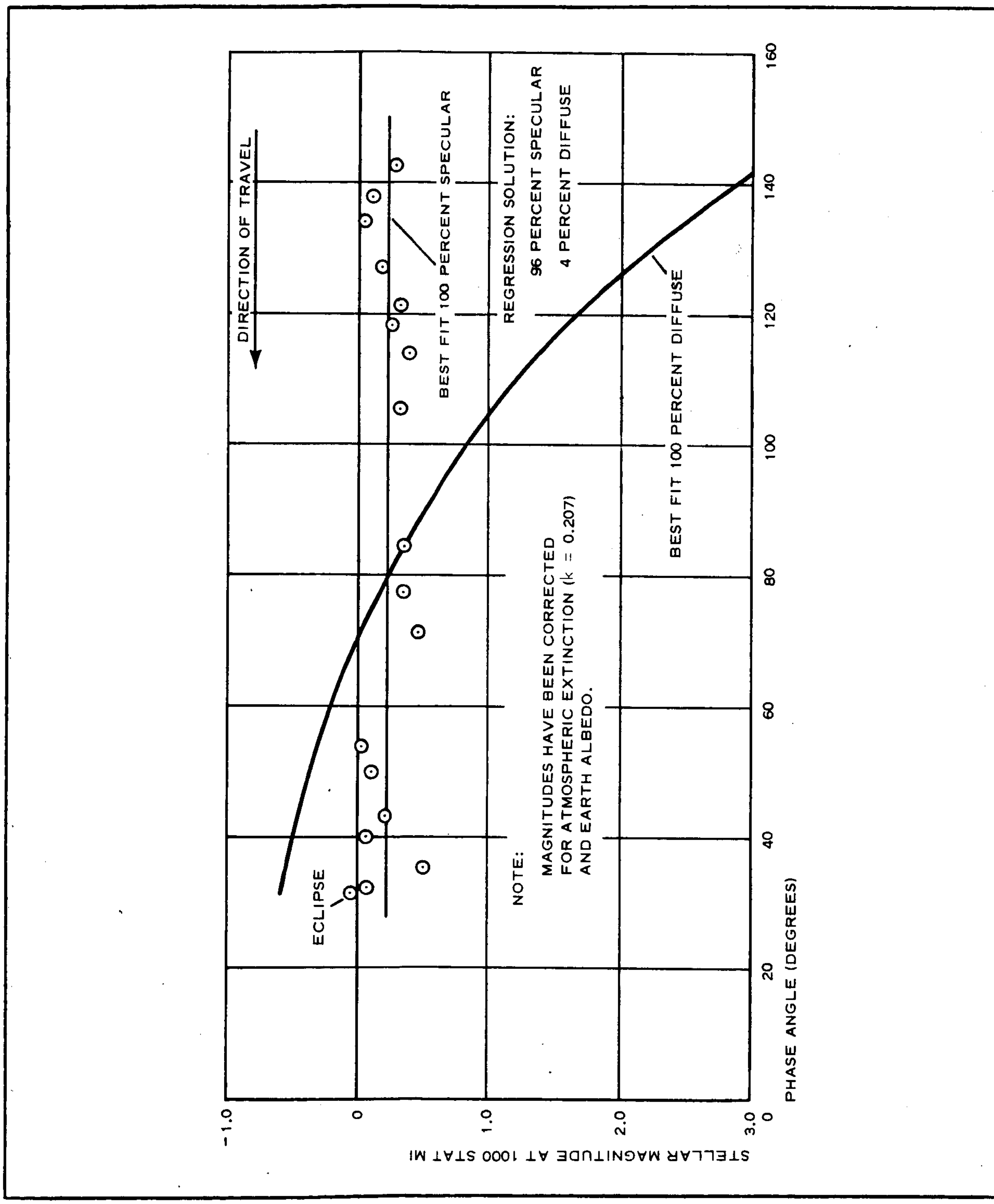

Figure 3 - Echo I normalized Magnitudes versus Phase Angle

SECTION II - SURFACE MICROTEXTURE ANALYSIS

A regression analysis was performed on the 18 normalized magnitudes (m) with a IBM 1410 computer. The dependence of their corresponding illuminances (E) on the Russell[5] phase function $\left[F(\psi)\right]$, was investigated for a diffusely reflecting sphere that obeys Lambert's law. This analysis was based on the following regression equation:

$$\frac{E}{E_o} = \text{antilog}(-0.4\ m)$$

$$= \frac{A}{4} + \frac{2}{3} BF(\psi) \quad ,$$

where

E/E_o = illuminance ratio,

A = weighting factor for optically specular reflection,

B = weighting factor for optically diffuse reflection,

$F(\psi) = \frac{1}{\pi}\left[\sin\psi + (\pi - \psi)\cos\psi\right]$, and

ψ = phase angle (0 deg when satellite is opposite sun).

A least squares best-fit solution of this regression equation for the normalized data yields:

$A = 3.13621$,

$B = 0.14424$,

correlation coefficient = 0.27,

and

standard deviation, $\sigma = \pm 0.15$.

This solution, transformed to stellar magnitudes, is plotted in Figure 3, together with curves for best-fit solutions where A = 0 (surface 100 percent diffuse), and B = 0 (surface 100 percent specular).

The present optical specularity (P_s), not to be confused with the coefficient of reflection, is indicated by:

$$P_s = \frac{A}{A + B} = 96 \text{ percent} .$$

If the presently indicated optical specularity (96 percent) of Echo I is compared with its initial specularity at the time of deployment in orbit (12 August 1960), an actual rate of specular degradation of aluminized Mylar due to the simultaneously combined effects of all environmental factors in a near-earth orbit is inferred. The initial optical specularity (P_{s_o}) of Echo I was close to 98 percent. On this basis the actual rate of specular degradation for aluminized Mylar in a near-earth orbit is indicated to be less than 1 percent per year:

$$1 - \text{antilog}\left(\frac{\log P_s - \log P_{s_o}}{3.55 \text{ years}}\right) \cong 0.6 \text{ percent per year} .$$

The photometric studies of Echo I are being extended at Goodyear Aerospace Corporation under NASA-Langley Research Center Contract NAS 1-3114, monitored by William J. O'Sullivan. While final results from these additional visual and photoelectric measurements are not available at this time, the preliminary results appear to support the conclusion herein that Echo I's surface remains highly specular.

SECTION III - SURFACE MACROTEXTURE ANALYSIS

The photometric data were also used to determine mean and local radii of curvature of Echo I's surface. The radius of curvature of a spherical specular surface having a coefficient of reflectivity of 0.83 (typical for aluminized Mylar) can be found from the relation:[6]

$$R_c = \text{antilog}(1.71806 - 0.2m_{sp}) ,$$

where

R_c = radius of curvature in feet, and

m_{sp} = stellar magnitude at a 1000-stat-mi zenith range for spherical surface of 100 percent specularity, 83 percent reflectivity.

To apply the above relation in the macrotexture analysis, it was first necessary to eliminate the contribution of diffuse reflectivity, $2/3\,BF(\psi)$, from the normalized magnitudes. From the previous regression analysis it can be seen that the representative specular normalized magnitude is:

$$\frac{\log \frac{A}{4}}{-0.4} = +0.264 ,$$

which yields a mean R_o of 46.3 ft.

The normalized magnitudes at phase angles of 92.2, 59.3, and 35.4 deg were selected for local radii of curvature determinations because they corresponded to independent data extremes, each at least 2 σ from the best-fit and adopted regression curve. These magnitudes were reduced in illuminance by the amount $2/3\,BF(\psi)$ to yield m_{sp} = -0.22, -0.51, and +0.65, respectively, indicating independent local curvatures with radii of 58, 66, and 39 ft.

SECTION IV - SIGNIFICANCE OF RESULTS

The measurements reported herein have provided the first available indication of the actual degradation rate of a specular surface in a near-earth orbit and represent a significant advance over the estimates previously available for the design of solar energy collectors, thermal balance surfaces, etc. Repeated observation and analysis would undoubtedly narrow the present range of uncertainty. Together with the results from laboratory hypervelocity impact tests of very small particles on aluminized Mylar, these data should also prove useful in further defining the micrometeoroid environment at Echo I's orbital height, either with respect to the flux in the vicinity of the particle mass cutoff or the mass cutoff itself.

These measurements of Echo I can also serve as a cross check on measurements made by other methods of observation, such as by photoelectric or photographic photometry and high-resolution photography. With reference to the latter, Goodyear Aerospace with the cooperation of RCA Service Corporation personnel at the Kennedy Space Center, made some "quick-try" attempts in 1962 to obtain high-resolution optical and electro-optical photographs of Echo I, with uncertain results.[7] The tentative conclusion was that one (or more) specular highlights were being photographed repeatedly, and that Echo I was then still predominantly specular, with some macrotexture variation. This conclusion is entirely compatible with the recent and more definitive photometric indications.

Because Echo I (and now also Echo II) is continually immersed in the near-earth space environment and is continuing to integrate the effects of all the environmental parameters as encountered throughout the course of the earth's annual motion around the sun, it is increasing in its value both as a large-scale test specimen in an existing ideal test for the technology of space materials and as a large-scale scientific probe of the near-earth micrometeoroid environment. It is suggested that Echo I and Echo II will continue to be sources of vital information for the astronautics engineer and space scientist and deserve the serious investigations that traditional astronomy would demand and pursue for natural satellites. Artificial satellites tend to become "naturalized citizens" of space.

LIST OF REFERENCES

1. MacRae, D. A.: "The Brightest Stars," The Observer's Handbook, 1964. Toronto, The Royal Astronomical Society of Canada. (Based on Johnson, H. L.; and Morgan, W. W.: "Fundamental Stellar Photometry for Standards of Spectral Type on the Revised System of the Yerkes Spectral Atlas," Astrophysical Journal, 1953; 117:113.)

2. Schneider, L. J.: "Determination of the Stellar Magnitude Increment of the Echo I Satellite Due to the Earth's Albedo." SP-3225. Akron, Ohio, Goodyear Aerospace Corporation, 28 May 1964.

3. Ginter, R. L.: "Albedo Radiation on a Sphere or Planet-Oriented Flat Plate." GER-11618. Akron, Ohio, Goodyear Aerospace Corporation. June 1964.

4. Hardie, R. H.: "Photoelectric Reductions." Chapter 8 of Astronomical Techniques (W. A. Hiltner, ed.). Chicago, Ill., University of Chicago Press, 1962.

5. Russell, H. N.: Astrophysical Journal, 1916; 43:173.

6. Baker, R. M., Jr.; and Makemson, M. W.: An Introduction to Astrodynamics. New York, Academic Press, 1960, p. 252.

7. GAP-1566: A Program for the Purpose of Determining the Geometry, Surface Characteristics, and Reflectance Degradation Rate of the Echo I Satellite from Ground Observational Data. Akron, Ohio, Goodyear Aircraft Corporation, 6 June 1962.