N 62 13290

NASA TN D-1366

CASE FILE COPY

TECHNICAL NOTE

D-1366

THE ORBITAL BEHAVIOR OF THE ECHO I SATELLITE AND ITS ROCKET CASING DURING THE FIRST 500 DAYS

By Gertrude C. Westrick and Katherine G. Johnson

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON June 1962

ERRATA

NASA Technical Note D-1366

By Gertrude C. Westrick and Katherine G. Johnson
June 1962

Page 8: In the first paragraph under the heading "CONCLUDING REMARKS," line 9, the number 0.80 should be 0.08. The line will then read as follows:

has been changing, with the eccentricity varying between zero and 0.08.

1H

L
2
0
5
7

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-1366

THE ORBITAL BEHAVIOR OF THE ECHO I SATELLITE AND ITS ROCKET CASING DURING THE FIRST 500 DAYS

By Gertrude C. Westrick and Katherine G. Johnson

SUMMARY

The orbital behavior of the Echo I satellite (1960 Iota 1) and its rocket casing (1960 Iota 2) is presented in both time-history and cross-plot forms for the period covering the first 500 days of their lifetime. The orbit of the inflated sphere, Echo I, is the first to be markedly perturbed by solar radiation pressure, whereas that of the rocket casing is relatively unaffected. The basic data were made available by the Smithsonian Astrophysical Observatory and the Goddard Space Flight Center.

The orbital characteristics of the rocket casing (1960 Iota 2) are included for comparison, since the ratio of weight to the mean drag area of 1960 Iota 2 is about 900 times that of 1960 Iota 1. Included also are derived data on the location of Echo I's perigee with reference to the sun and its percentage of time spent in the earth's shadow.

INTRODUCTION

The long-term orbital behavior of Echo I (a 100-foot-diameter inflatable sphere) and its rocket casing has been of particular interest inasmuch as Echo I is the first satellite whose orbit is markedly affected by solar pressure, whereas the orbit of its rocket casing is relatively unaffected. Echo I, designated by the Harvard Observatory as 1960 Iota 1, was developed by the NASA Langley Research Center. It was launched from Cape Canaveral, Florida, on August 12, 1960. The sphere and the third-stage rocket casing (1960 Iota 2) were injected into a near-earth circular orbit (about 1,000 statute miles in altitude).

Both 1960 Iota 1 and 1960 Iota 2 have been tracked extensively by the Smithsonian Astrophysical Observatory (SAO) using the worldwide Baker-Nunn photographic stations. In addition, 1960 Iota 1 (Echo I) has been tracked by the NASA Goddard Space Flight Center (GSFC) using Minitrack and camera stations which are primarily located north and south in the western hemisphere (ref. 1). The results of this worldwide surveillance have been made available by SAO and GSFC in the form of orbital elements for specified reference times. Additional data in the form of predictions and darkness tabulations have also been supplied.

The purpose of this report is to present these basic data in a form useful for the analysis of the gross orbital behavior of satellites of very low ratios of weight to mean drag area which are appreciably affected by solar pressure. This report covers the period of 500 days from launch and includes the physical and orbital characteristics of both 1960 Iota 1 and 1960 Iota 2. Data for 1960 Iota 2 are included because it is believed that they provide a reference or base line for the behavior of 1960 Iota 1. The ratio of weight to mean drag area of the rocket casing is about 900 times that of the Echo I sphere, and its orbit should be affected much less by both drag and solar pressure.

L
2
0
5
7

Information is included on the location of Echo I's perigee with reference to the sun. Also included is Echo I's percentage of time per period spent in the earth's shadow.

The data originally received from SAO and GSFC are plotted without correction. Except for comments on areas of special interest, no attempt is made herein to analyze the results or to evaluate apparent discrepancies in the data.

SYMBOLS

e	eccentricity of the orbit
i	inclination, angle between the orbital plane and the equatorial plane
N	north celestial pole
p	perigee
RA	right ascension, arc measured eastward along the celestial equator from the vernal equinox
S	south celestial pole
T	time from launch, days
UT	Universal time, identical with Greenwich civil time, counted from 0 to 24 hours, beginning with Greenwich midnight

δ declination, angular distance north or south of the celestial equator

γ Aries

DEFINITIONS

L
2
0
5
7

Anomalistic period: interval between successive passes of the satellite through perigee of its orbit.

Argument of perigee: the angle between the ascending node and perigee, measured in the orbit plane, positive in the direction of the satellite's motion.

Ascending node: the intersection of the orbit plane and the celestial equator where the satellite crosses from south to north.

Epoch: arbitrary instant of time for which the elements of an orbit are valid.

Regression: westward motion of the satellite's ascending node.

Vernal equinox: the point of intersection of the celestial equator with the ecliptic (path) through which the sun crosses the equator from south to north.

DESCRIPTION AND COMPARISON OF DATA

The orbital elements transmitted by SAO and GSFC are not listed in the same form, as may be seen from the samples in tables I and II. The main differences in listing and derivation (as applicable to the contents of this report) are as follows:

(1) The reference time of the SAO modified orbital elements is the particular day, hour, and minute UT that the satellite happens to be passing through perigee (ref. 2). (Mean anomaly is, by definition, zero at perigee.) The reference time called epoch in the GSFC orbital elements is usually given at 00:00 (hours and minutes) UT, and the location of the satellite in the orbit is expressed as an angle (mean anomaly).

(2) The SAO reference time is 3 days ahead of the calendar, whereas the GSFC epoch (reference time) is from 1 to 2 weeks behind it. This results from the use of different theory in the machine programs that compute the satellite ephemeris. SAO uses a Differential Orbit

Improvement Program (ref. 3) for the entire period of the observations to predict the orbit and to update the elements to a reference time ahead of the date of issue. GSFC on the other hand, has a differential correction program which has been modified especially for satellite orbits affected by solar pressure (ref. 4). The program uses the observations from a period of about 11 days to redefine the orbit and to compute the mean elements for an epoch at the middle at that interval.

(3) SAO lists geographic longitude of the ascending node west of Greenwich as well as the right ascension of the node (measured east of the vernal equinox in the plane of the celestial equator). GSFC gives only the right ascension of the ascending node. Both SAO and GSFC give the longitude and altitude of the equator crossings in the form illustrated in table II.

L
2
0
5
7

(4) The SAO elements list radial distance of the satellite from the center of the earth at perigee and apogee, whereas the GSFC elements give perigee and apogee heights in miles above the mean surface of the earth which is represented by a Hough ellipsoid (ref. 5). However, the SAO daily predictions which accompany their modified orbital elements list heights of the nodes, perigee, and apogee in statute miles above the earth which is represented by the International ellipsoid. (See ref. 5.) For the sake of uniformity in the data plotted herein, orbital distances are expressed in statute miles. For convenience in converting these units to kilometers, the relationship 1 statute mile = 1.609344 kilometers may be used.

(5) The weekly darkness tabulations, provided only by GSFC, list Echo I's time in continuous sunlight as well as its time of entry into and its time of exit from the earth's shadow for all the passes. Only GSFC lists velocities at perigee and apogee.

Results from both programs for Echo I were found to be erratic during the 2 weeks following launch (August 1960) and also during June 1961 (the period between 310 and 340 days) when the eccentricity of the orbit approached zero. Both the SAO and GSFC programs for converting available Echo I satellite observations into orbital parameters became ill-behaved at very low values of eccentricity ($e < 0.01$). At $e = 0.01$, the semimajor and semiminor axes of the Echo I orbit differ by 0.2 statute mile.

PHYSICAL CHARACTERISTICS

Echo I has an effective cross-sectional area of 7,854 square feet. The launch weight of 157 pounds decreased to 124 pounds with the loss of 33 pounds of benzoic acid and anthraquinone which were used to maintain inflation for the first few weeks in orbit. Thus, the initial ratio of the weight to mean drag area for Echo I was 0.020 pound per square foot and reduced to 0.016 pound per square foot after several weeks in orbit.

The satellite 1960 Iota 2 contains a rocket motor, a section of staging, and a telemeter tray, and its total weight is estimated to be 79.5 pounds. The shape of the assembly is essentially that of a cylinder 52 inches long and 18 inches in diameter. The total length of Iota 2 is 61 inches. However, when the shape of the rocket nozzle is considered, the cross-sectional area is effectively that of a 52-inch cylinder. When one-fourth of the outside surface area is used as the mean effective cross-sectional area, Iota 2 has a ratio of weight to mean drag area of about 13.3 pounds per square foot.

L
2
0
5
7

The separation velocity between Echo I and the rocket casing was between 4 and 6 feet per second. One year after separation, the rocket casing trailed Echo I by about 2 days or 25 orbits. Both satellites continue to circuit the earth 12 to 13 times daily. Radar observations indicate that the sphere rotates about its axis (or changes shape) at varying rates.

RESULTS

Time History of Echo I

Initial orbital elements of 1960 Iota 1 obtained from reference 6, are given in table III. Except for a small separation velocity, these elements also apply to the rocket casing.

In figure 1, time variations of the orbital parameters of Echo I are presented. Time is given as lifetime of the satellite in days with zero corresponding to the launch date, August 12, 1960. The first days of alternate months are also indicated.

The parameters which define the orbit are presented in figure 1(a). At the top of the figure is the anomalistic (perigee to perigee) period, which began at 118.3 minutes and decreased gradually during the first 150 days. It leveled off for the next 180 days and decreased again gradually for the last 170 days. The net change during the 500 days since launch was a decay of 2.091 minutes. During the first 140 days, the apogee radius increased 320 miles while the perigee radius decreased 380 miles. During the next 170 days, these variations reversed. This variation of apogee and perigee is clearly reflected in the eccentricity curve which varies from zero to 0.08. It therefore appears that the variation in apogee radius and perigee radius is periodic.

The orbital parameters which relate the orbit to the earth are shown in figure 1(b). The right ascension of the ascending node is shown at the top of the figure, and it may be seen that the rate of regression is virtually constant. Irregularities in the argument of perigee are noted during the first 20 days and in the interval from 310 to 340 days when the orbit is again near circular. Such irregularities occur in both of the present SAO and GSFC programs since argument of perigee is difficult to define for very small values of eccentricity and is not defined for zero eccentricity. The latitude of perigee, which has a period of approximately 100 days, bears the same irregularity in the two intervals where the eccentricity was close to zero. Oscillations may be discerned in the orbital inclination curve. A marked decrease in inclination is seen during the 120-day period from 240 to 360 days. However, the total spread in angle of inclination amounts to only 0.11°.

L
2
0
5
7

Pertinent parameters involving nonconservative forces are given in figure 1(c). The velocity at perigee and apogee is shown at the top of the figure. Time in the earth's shadow was computed from GSFC darkness reports for the orbit nearest 00:00 UT for the epoch given and is shown as a percentage of the anomalistic period. Shown also is the decrease in the semimajor axis of the orbit, which is an indication of the amount of atmospheric drag. The two intervals which show a marked decrease in semimajor axis appear to correspond to similar intervals (fig. 1(a)) of increasing eccentricity. It is interesting to note that starting at T = 230 days there appears to be a small region where the semimajor axis is increasing, which denotes an increase in energy.

Time History of 1960 Iota 2

To provide comparison with Iota 1, the orbital elements of the rocket casing, 1960 Iota 2, are shown in figure 2. The data show that the orbital elements of Iota 2 have been relatively stable since launch. The period is virtually constant at 118.06 minutes. Apogee and perigee radii oscillate in periods of 121 days with a maximum change of approximately 10 miles. The eccentricity undergoes like oscillations with a total change of only 0.002. No irregularities are apparent in the regression of the ascending node, and the slope of the argument of perigee curve is nearly constant. The latitude of perigee curve in figure 2(b) also has a period of 121 days. It is of interest to note that the data show that Iota 2's perigee moves faster in the orbit when it is south of the equator. During the first 500 days after launch, the number of days when perigee remained north of the equator was constant at about 63 days, while the intervals spent south of the equator were recorded at 58 days. The inclination of the orbit plane remained relatively constant at 47.24°.

Cross Plots and Special Variations

In figure 3, the variation of anomalistic period in minutes with the eccentricity of the orbit is shown for both Iota 1 and Iota 2. It may be noted that from August 12, 1960 to December 31, 1960 and from July 8, 1961 to December 6, 1961 Echo I's orbital eccentricity increases as the period decreases. This trend differs from that of the rocket casing where the two parameters oscillate without decreasing perceptibly. Other satellites in decaying orbits show a period decrease accompanied by a decrease in eccentricity. These two intervals of increasing eccentricity are concomitant with the two periods of decreasing radius of perigee and semimajor axis of the orbit shown on figures 1(a) and 1(c), respectively. It is expected that this pattern of behavior is cyclic and that it will be repeated throughout Echo I's lifetime.

The time history of the altitude at perigee, apogee, and nodal points is presented in figure 4. The solid outer-envelope lines represent the apogee and perigee altitudes. Inside these boundaries are the altitudes at equator crossings as given by SAO and GSFC. The points of tangency of the nodal curves with the perigee altitude curves indicate the dates on which perigee is located on the equator, except in the interval between 310 and 340 days where the orbit of Echo I is nearly circular. The days at which the ascending and descending node curves cross coincide with the days of alternating maximum north and south latitudes of perigee of the orbits as shown on figures 1(b) and 2(b).

Figure 5 shows the correlation between the geocentric position of the Echo I orbit and the sun. The upper solid curve of the plot represents the declination of the sun, and the data points represent the latitude of perigee of the Echo I orbit for various epochs. Values for the apparent declination and right ascension of the sun are taken from the American Ephemeris and Nautical Almanacs of 1960 and 1961. Right ascension of perigee is computed from known formulas of spherical trigonometry by using both SAO and GSFC data. Appreciable differences in the two calculations occurred only in the area identified by the data points.

In the lower plot, the right ascension of the sun, ascending node, and perigee are shown. The times of maximum and minimum eccentricity are shown by arrows. The GSFC data show that the right ascension of perigee increased with small superimposed oscillations until perigee was 90° to the earth-sun line at which time the data indicate that the orbit became circular and perigee shifted approximately 160°. It may be observed that perigee always lies between 180° and 360° in right ascension.

The positions of Aries γ, the sun, the earth, the orbit of Echo I, and its ascending node are shown schematically in figure 6 for the times designated. In figure 6(a) these parameters are shown in the <u>equatorial</u>

plane, as seen from the north pole. In this figure, the earth-sun line is held constant and the relative motions of the other reference points at three 30-day intervals (approximately) are given. It may be noted that the satellite, Echo I, moves counterclockwise in its orbit while the semimajor axis of the orbit moves clockwise with respect to the earth-sun line. A projection on the meridian plane is given in figure 6(b). To facilitate other interpretations, the directions and rates of rotation of lines of reference as seen from the north and measured in the equatorial plane are given in the accompanying table.

The orientation of the sun with respect to the orbit plane is shown in figure 7. The time history of the angle between the earth-sun line and the orbit plane derived from figure 5 is shown in figure 7(a). The times when the curve crosses the zero line indicate times when the sun is directly in the orbit plane. The times of maximum and minimum eccentricity are indicated by arrows. The sketches in figure 7(b) show the position of the sun with respect to perigee and the ascending node at four specified times when the earth-sun line is in the orbit plane. With the ascending node held constant, the relative positions and motions of the other parameters are shown as seen from the north side of the orbit plane. It is noted that both Echo I and the semimajor axis rotate in the same direction with respect to the ascending node.

L
2
0
5
7

In figure 8, measured values of velocity and altitude at perigee and apogee are plotted to indicate the changes in kinetic and potential energy of the Echo I orbit.

CONCLUDING REMARKS

The orbital elements of the Echo I (1960 Iota 1) satellite and its rocket casing (1960 Iota 2) are compiled for 500 days from data provided by the Smithsonian Astrophysical Observatory and the Goddard Space Flight Center. The main objective is to present these data in a form useful for the analysis of the behavior of satellites with low ratios of weight to drag. Information is included on the orientation of the Echo I orbit with respect to the sun and on the percentage of time per period spent in the earth's shadow. The data indicate that the shape of the orbit of Echo I has been changing, with the eccentricity varying between zero and 0.80. The changes in the parameters which define the orbit appear to be periodic with similar conditions recurring at approximately 310 to 340 days. It also appears that the orientation of the satellite orbit with respect to the sun is a factor in the changes in eccentricity and energy.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 19, 1962.

REFERENCES

1. Thomas, Paul D.: Use of Near-Earth Satellite Orbits for Geodetic Information. Tech. Bull. No. 11, Coast and Geodetic Survey, U.S. Dept. Commerce, Jan. 1960.

2. Cormier, Leonard N., Goodwin, Norton, and Squires, Reginald K.: Simplified Satellite Prediction From Modified Orbital Elements. IGY Satellite Rep. Ser. No. 7, Nat. Acad. Sci., Jan. 1, 1959.

L 2 0 5 7

3. Mechau, D. V. (Compiler): Satellite Orbital Data. Special Rep. No. 40(R), Smithsonian Institution Astrophysical Observatory, May 24, 1960, rev. June 30, 1960.

4. Musen, Peter: A Modified Hansen's Theory as Applied to the Motion of Artificial Satellites. NASA TN D-492, 1960.

5. Burkard, Richard K.: Geodesy for the Layman. Aero. Chart and Information Center, U.S. Air Force, Oct. 1959.

6. Zadunaisky, Pedro E., Shapiro, Irwin I., and Jones, Harrison M.: Experimental and Theoretical Results on the Orbit of Echo. Special Rep. No. 61, Smithsonian Institution Astrophysical Observatory, Mar. 20, 1961.

TABLE I.- SAMPLE LISTINGS OF ORBITAL ELEMENTS OF

EARTH SATELLITE ECHO I (1960 IOTA 1)

(a) Modified orbital elements issued by SAO

Reference time, UT	1961yr 8mo 19da 1hr 23.89min
Inclination, deg	47.26
Ascending node, deg west longitude	183.53
Prime sweep interval	1 day - 16.43 min
Argument of perigee, deg	38.44
Rate of change, deg per period	0.31943
Anomalistic period, min	116.984
Rate of change, min per period	-0.00023
Eccentricity	0.03216
Radius of perigee, statute miles	4764.6
Radius of apogee, statute miles	5081.3
Rate of change, miles per day	-0.16
Ascending node (RA), deg	164.48
Rate of change, deg per day	-3.16810
Latitude of perigee, deg	27.17

L
2
0
5
7

(b) Orbital elements computed from optical tracking data by the NASA computing center and issued on August 25, 1961 by the Goddard Space Flight Center

Epoch, 00:00 UT	19 Aug. 1961
Anomalistic period, min	116.94965
Minus, min per day	0.00479
Inclination, deg	47.259
RA of ascending node, deg	164.648
Motion minus, deg per day	3.172
Argument of perigee, deg	40.785
Motion plus, deg per day	3.041
Latitude of perigee, deg	28.669
Mean anomaly, deg	99.863
Eccentricity	0.03402
Semimajor axis, earth radii	1.24201
Perigee, statute miles	791.7
Apogee, statute miles	1126.7
Velocity at perigee, mph	16,417
Velocity at apogee, mph	15,337

TABLE II.- SAMPLE LISTING OF PREDICTED DATA ON EQUATOR CROSSINGS OF ECHO I (1960 IOTA 1)

(a) Data issued for August 19, 1961 by the Smithsonian Astrophysical Observatory on August 16, 1961

Equator		Other latitudes								
South-North		South-North					North-South			
Time, UT	Longitude, deg west	Latitude, deg	Time correction, min	Longitude correction, deg	Height, statute miles	Bearing, deg northeast	Time correction, min	Longitude correction, deg	Height, statute miles	Bearing, deg northeast
1 12.2	180.55	47.5	27.6	-83.00	865	90.0	27.6	-83.06	865	90.0
3 9.1	210.11	45.0	22.5	-60.92	835	72.3	32.7	-105.12	902	107.8
5 6.0	239.67	40.0	18.5	-45.68	818	60.7	36.8	-120.32	935	119.3
7 2.9	269.23	35.0	15.6	-36.05	809	54.0	39.9	-129.91	960	126.1
8 59.8	298.79	30.0	13.0	-28.70	805	49.4	42.7	-137.21	982	130.7
10 56.7	328.35	20.0	8.4	-17.38	806	43.7	47.7	-148.43	1,021	136.4
12 53.5	357.91	0	0	0	834	39.9	57.0	-165.60	1,082	140.2
14 50.4	27.46	-20.0	-8.6	17.34	893	43.7	-50.4	147.73	1,117	136.4
16 47.3	57.02	-30.0	-13.4	28.61	933	49.4	-45.2	136.56	1,121	130.7
18 44.2	86.58	-35.0	-16.1	35.92	957	53.9	-42.3	129.30	1,118	126.1
20 41.1	116.14	-40.0	-19.2	45.50	985	60.6	-39.0	119.77	1,111	119.4
22 38.0	145.70	-45.0	-23.5	60.66	1,021	72.2	-34.6	104.65	1,094	107.8
		-47.5	-29.0	82.64	1,062	90.0	-29.0	82.70	1,062	90.0

(b) Data issued August 15, 1961 by Goddard Space Flight Center for August 19, 1961

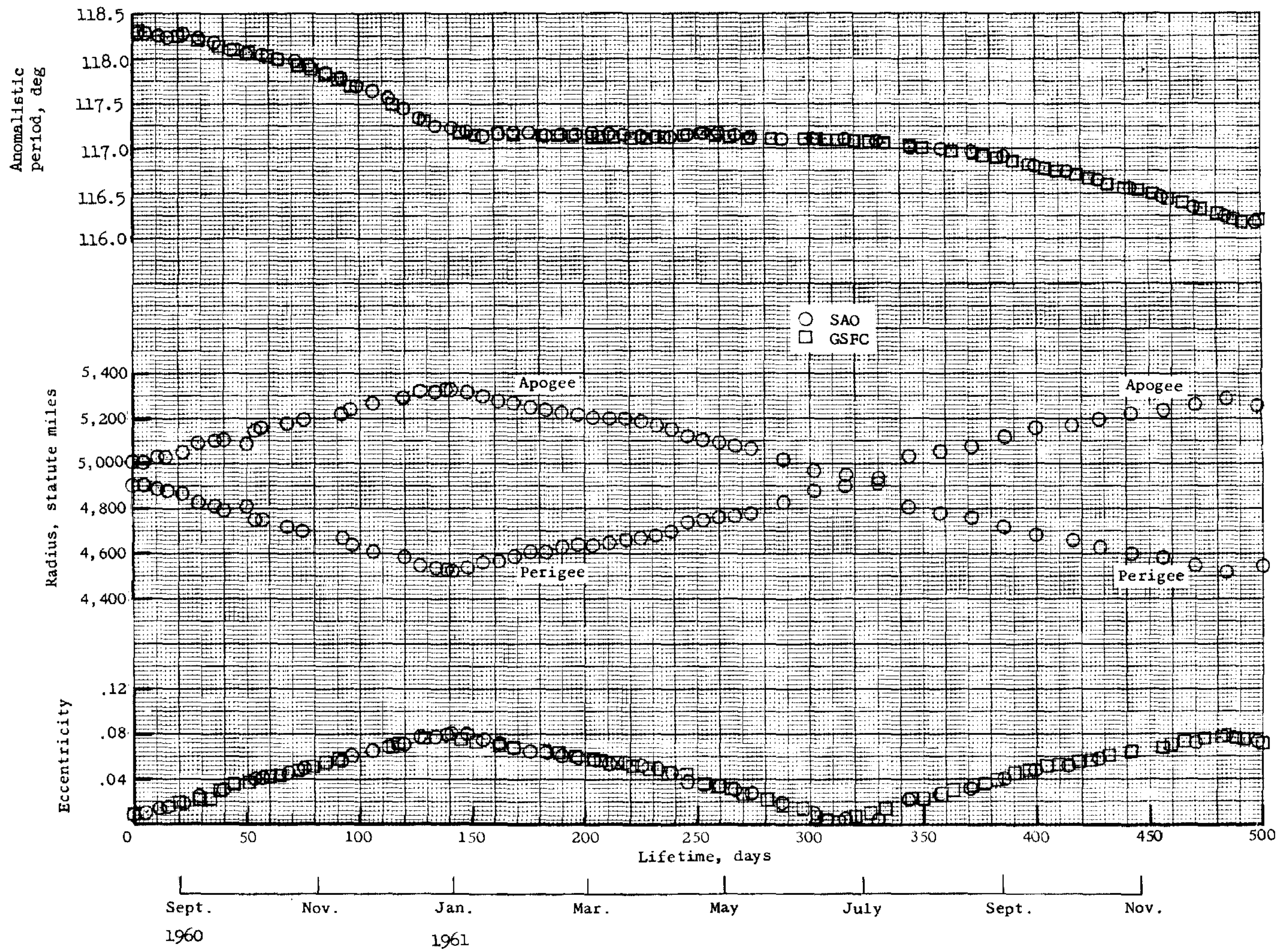
Day Hr Min Sec	Longitude, deg min sec	Revolution	Height, km
19 01 12 29	179 12 37	4,563	1,305
19 03 09 23	149 38 58	4,564	1,305
19 05 06 16	120 05 19	4,565	1,305
19 07 03 10	090 31 40	4,566	1,305
19 09 00 03	060 58 01	4,567	1,305
19 10 56 57	031 24 22	4,568	1,306
19 12 53 51	001 50 44	4,569	1,306
19 14 50 44	-027 42 53	4,570	1,306
19 16 47 38	-057 16 30	4,571	1,306
19 18 44 31	-086 50 07	4,572	1,307
19 20 41 25	-116 23 44	4,573	1,307
19 22 38 18	-145 57 21	4,574	1,307

L
2
0
5
7

TABLE III.- INITIAL ORBITAL ELEMENTS OF ECHO I AND ITS ROCKET CASING

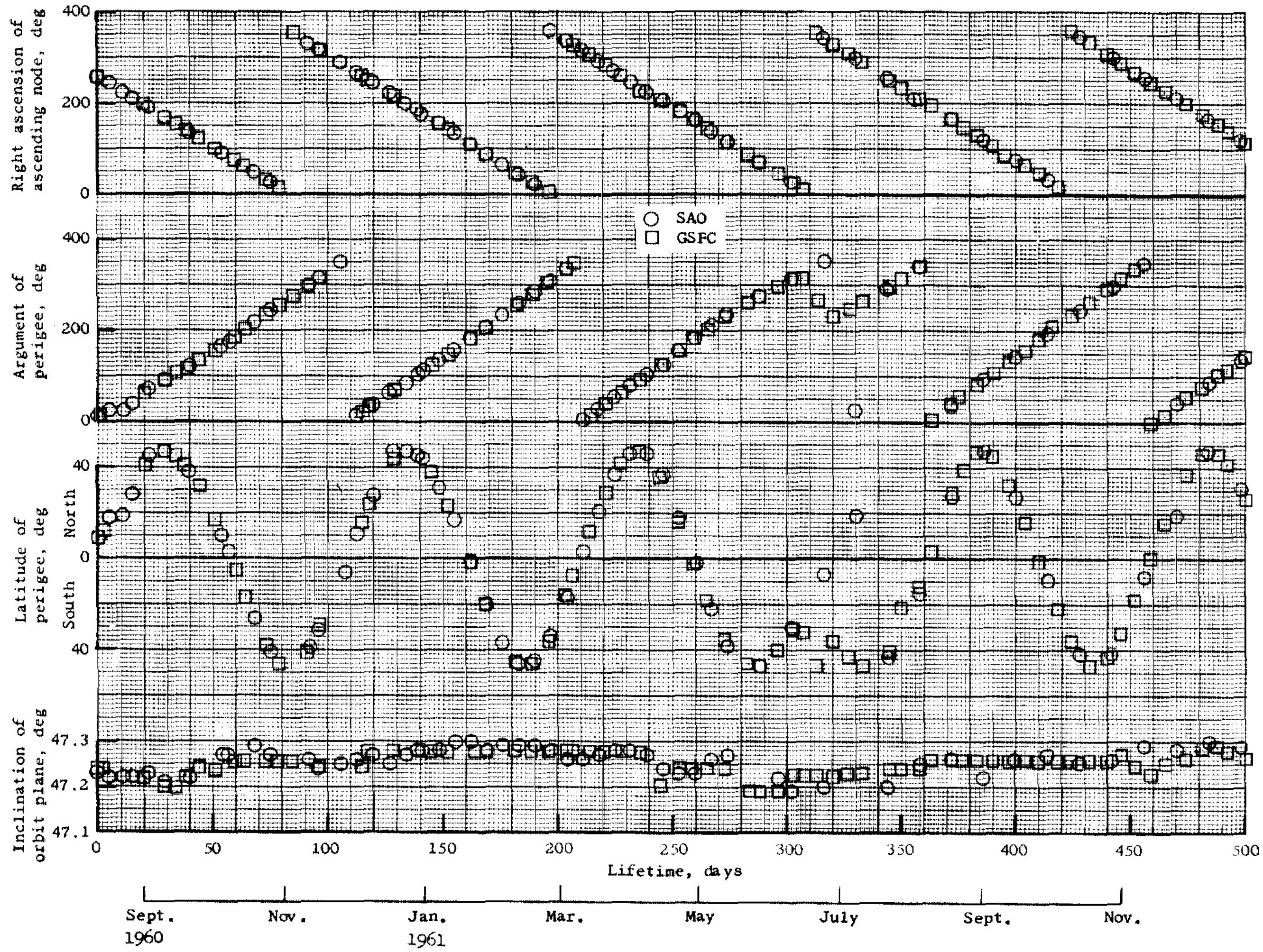
(1960 IOTA 2) REFERENCED TO AUGUST 12, 1960 (SUPPLIED BY SAO)

Reference time, UT	1960yr 8mo 12da 12hr 00min
Inclination, deg	47.232
Ascending node (RA), deg east	254.644
Argument of perigee, deg	14.00
Anomalistic period, min	118.3
Eccentricity	0.01029
Radius of perigee, statute miles	4907.8
Radius of apogee, statute miles	5011.5
Latitude of perigee, deg	9.308



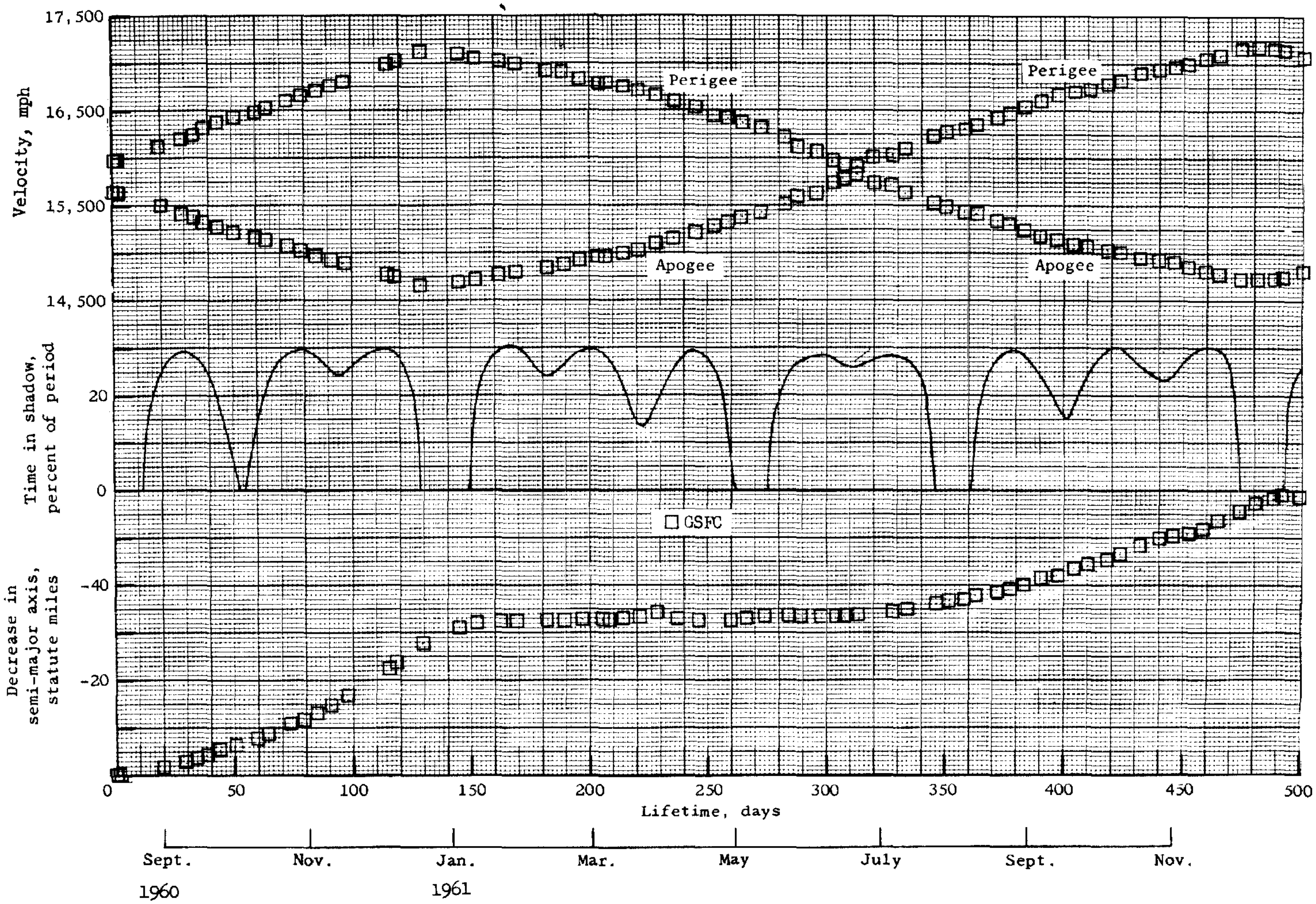
(a) Orbital elements.

Figure 1.- Time history of orbital parameters of 1960 Iota 1 (Echo I).



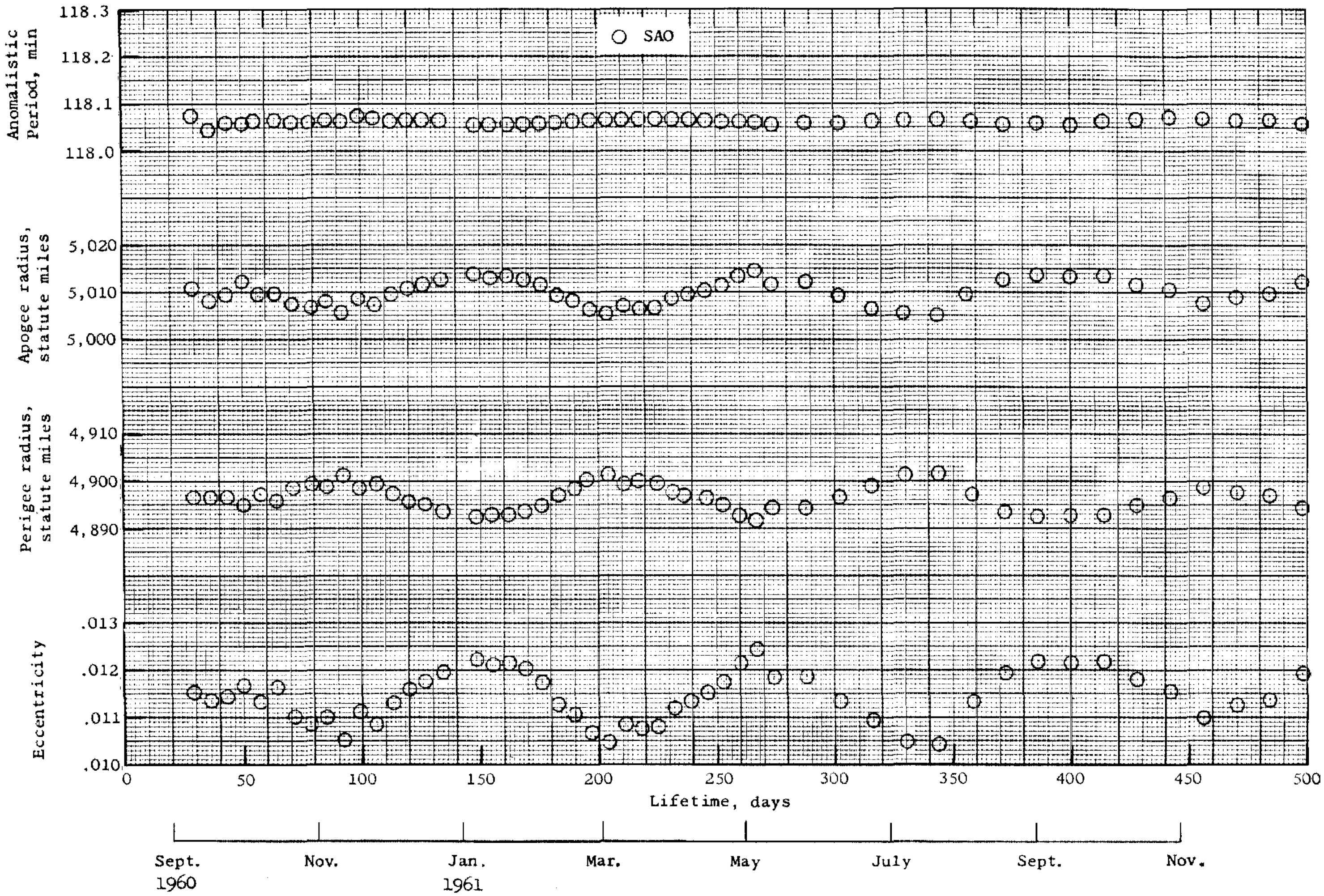
(b) Relationship between Echo I orbit and the earth.

Figure 1.- Continued.



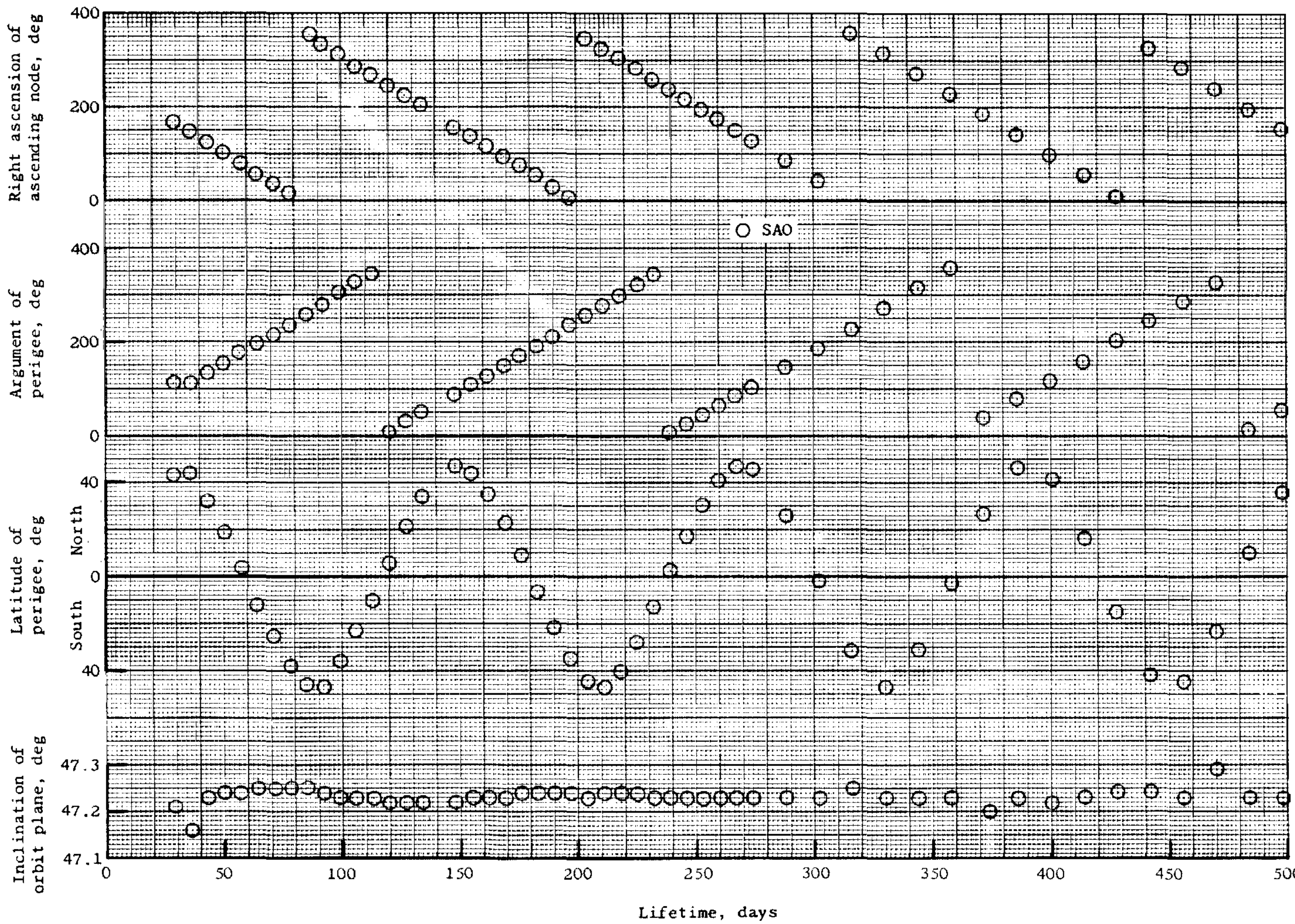
(c) Pertinent parameters involving nonconservative forces.

Figure 1.- Concluded.



(a) Orbital elements.

Figure 2.- Time history of orbital parameters of 1960 Iota 2 (Echo I rocket casing).



(b) Relationship between 1960 Iota 2 orbit and earth.

Figure 2.- Concluded.

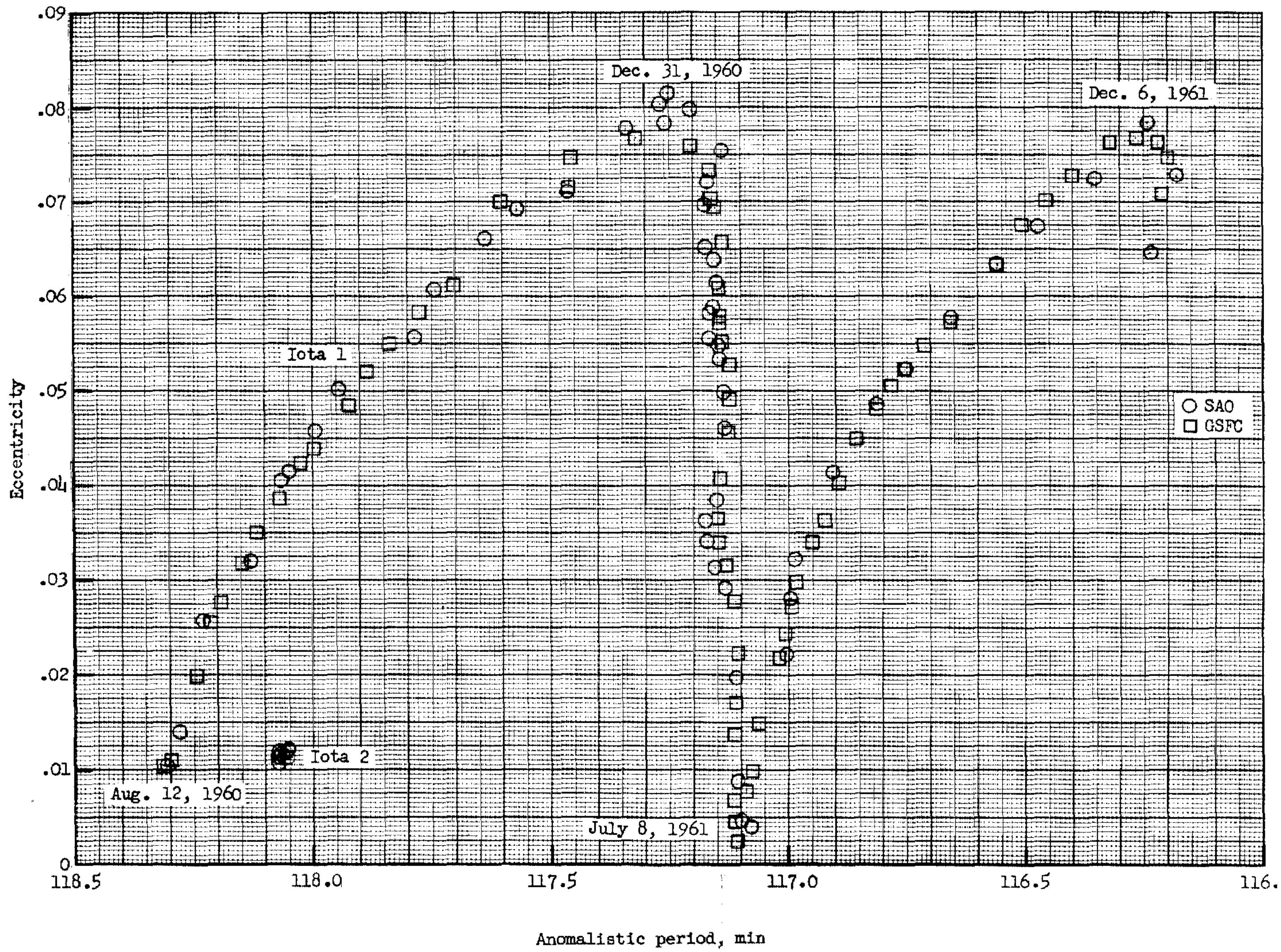


Figure 3.- Variation of eccentricity with anomalistic period.

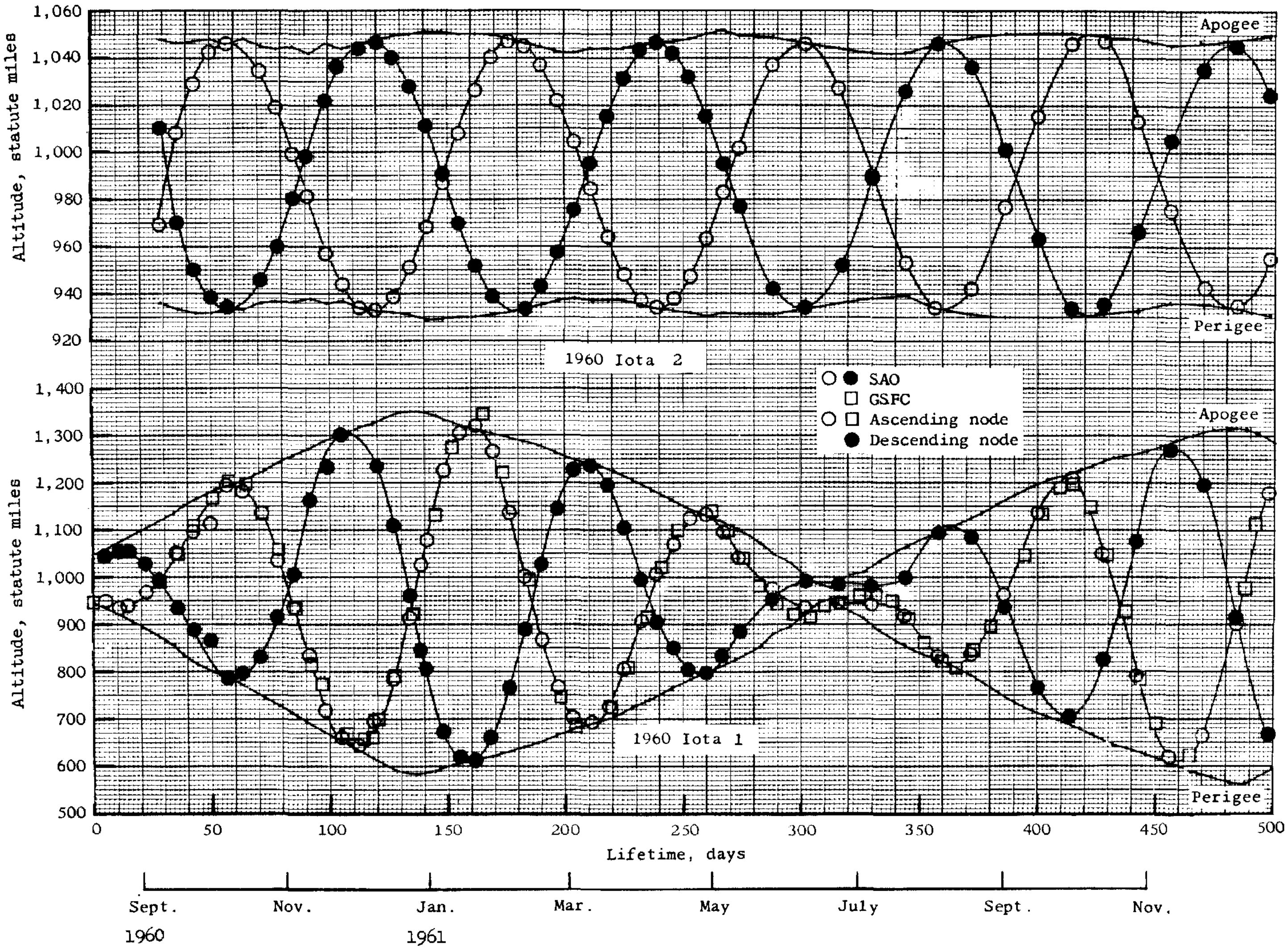


Figure 4.- Time history of altitude at perigee, apogee, and nodal points.

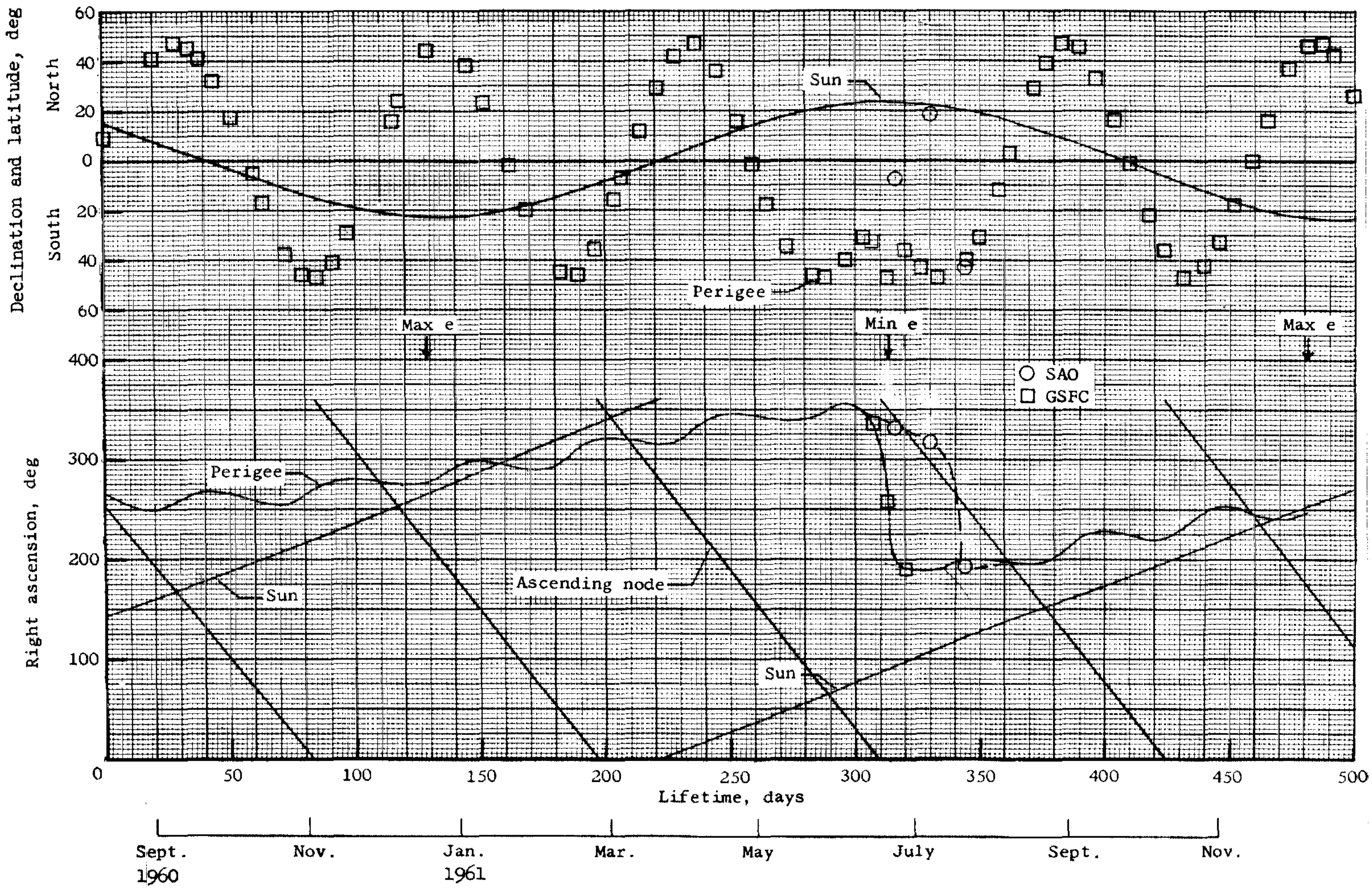
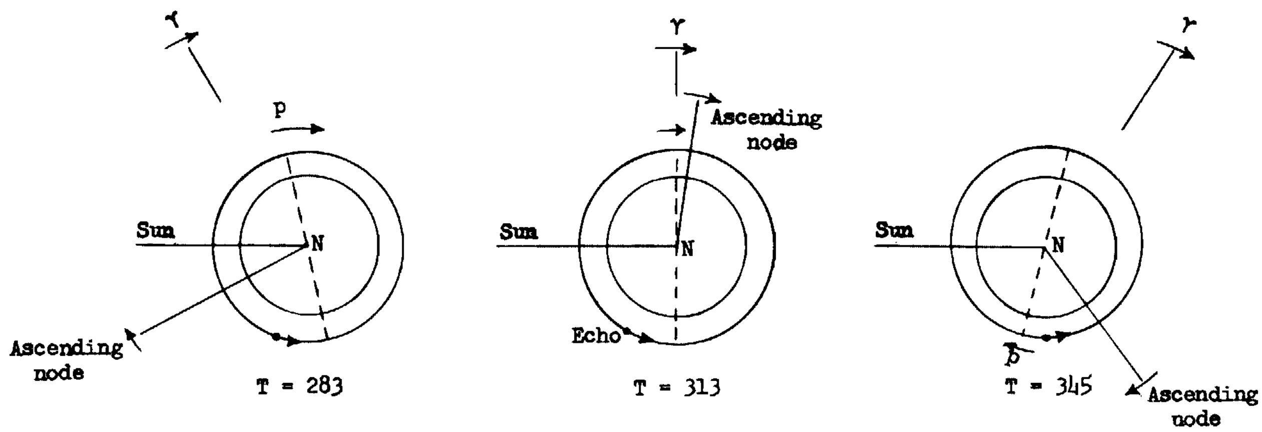
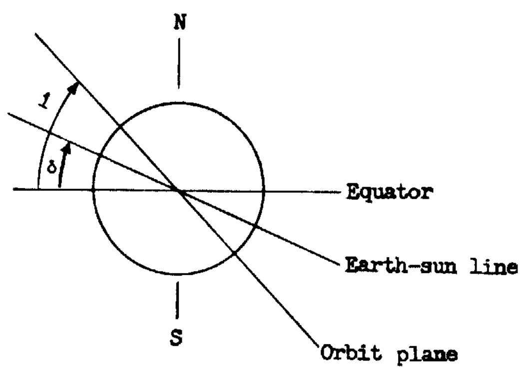


Figure 5.- Correlation between Echo I orbit and location of the sun.



(a) Projection on equatorial plane.



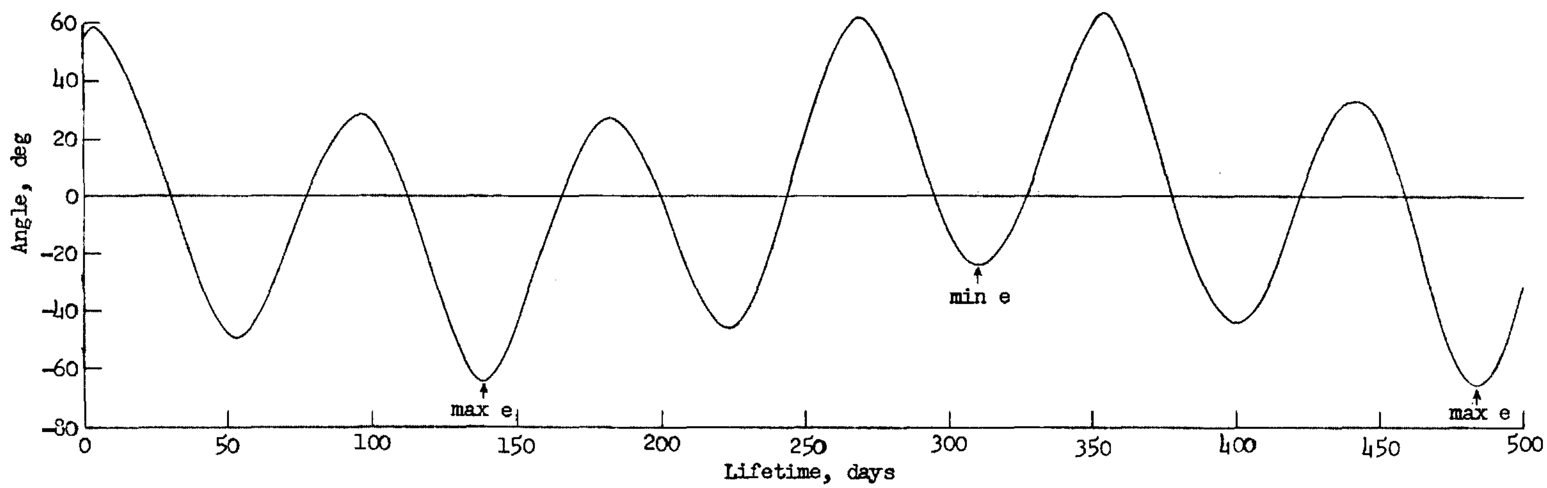
Direction and rates of rotation of lines of reference as measured in the equatorial plane

Reference line	Direction[1]	Average rate, deg/day
Aries-sun	Counterclockwise	1
Aries-semimajor axis	Counterclockwide	.35
Aries-ascending node	Clockwise	3.15
Sun-Aries	Clockwise	1
Sun-semimajor axis	Clockwise	.65
Sun-ascending node	Clockwise	4.15
Ascending node-Aries	Counterclockwise	3.15
Ascending node-sun	Counterclockwise	4.15
Ascending node-semimajor axis	Counterclockwise	3.5

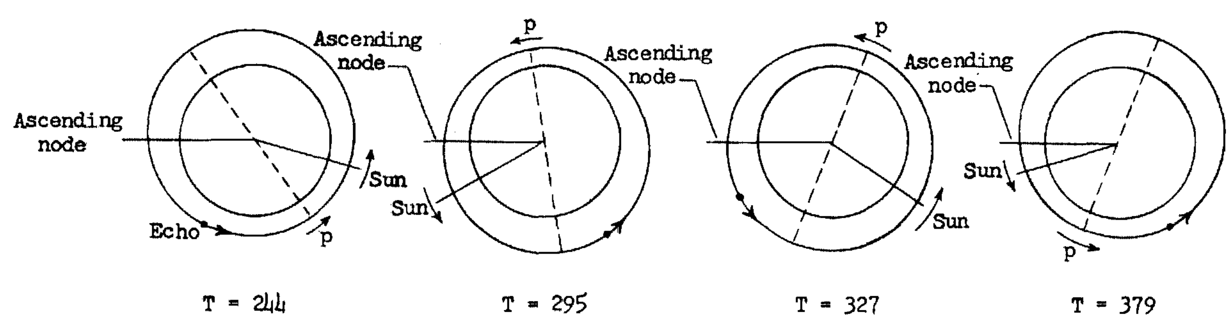
[1]Looking from the North Pole onto the equatorial plane.

(b) Projection on the meridian plane.

Figure 6.- Relative orientation of Echo orbit with respect to earth-sun line at time designated.



(a) Angle between earth-sun line and Echo I orbit plane.



(b) Projection on orbit plane. (Sun is in orbit plane.)

Figure 7.- Orientation of sun with respect to Echo I orbit plane.

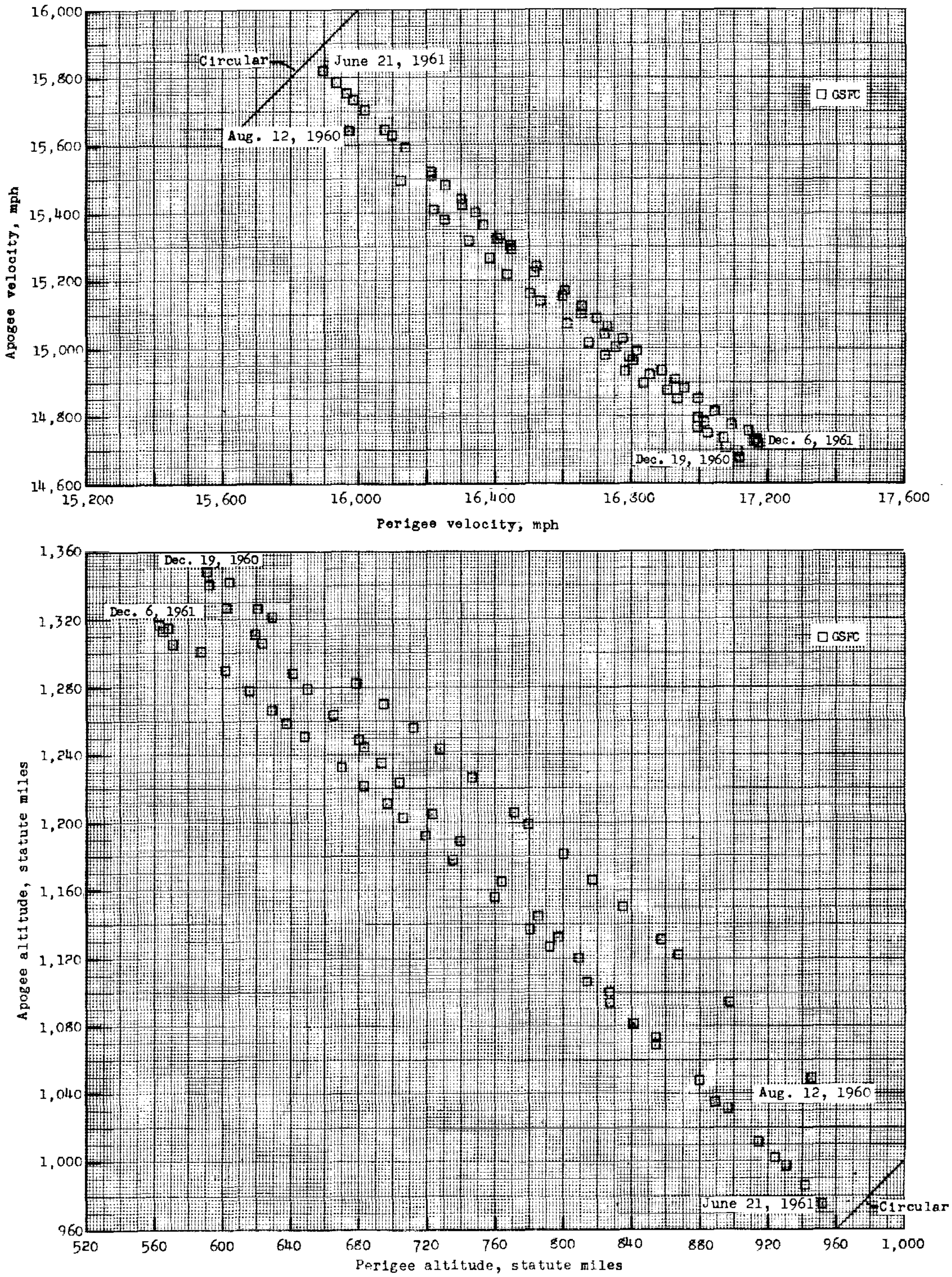


Figure 8.- Comparison of measured values with circular values of Echo I.

NASA TN D-1366
National Aeronautics and Space Administration.
THE ORBITAL BEHAVIOR OF THE ECHO I SATELLITE AND ITS ROCKET CASING DURING THE FIRST 500 DAYS. Gertrude C. Westrick and Katherine G. Johnson. June 1962. 23p. OTS price, $0.75. (NASA TECHNICAL NOTE D-1366)

The orbital behavior of Echo I (1960 Iota 1) and its rocket casing (1960 Iota 2) is presented in both time-history and cross-plot forms for the period covering the first 500 days of their lifetime. The orbit of the inflated sphere, Echo I, is the first to be markedly perturbed by solar radiation pressure, whereas that of the rocket casing is relatively unaffected. The data include orbital elements for Echo I and its percentage of time in the earth's shadow supplied by the Goddard Space Flight Center and the modified orbital elements for Echo I and its rocket casing furnished by the Smithsonian Astrophysical Observatory.

I. Westrick, Gertrude C.
II. Johnson, Katherine G.
III. NASA TN D-1366

(Initial NASA distribution:
2, Aerodynamics, missiles and space vehicles;
33, Physics, theoretical;
46, Space mechanics;
47, Satellites;
53, Vehicle performance.)

NASA

NASA TN D-1366
National Aeronautics and Space Administration.
THE ORBITAL BEHAVIOR OF THE ECHO I SATELLITE AND ITS ROCKET CASING DURING THE FIRST 500 DAYS. Gertrude C. Westrick and Katherine G. Johnson. June 1962. 23p. OTS price, $0.75. (NASA TECHNICAL NOTE D-1366)

The orbital behavior of Echo I (1960 Iota 1) and its rocket casing (1960 Iota 2) is presented in both time-history and cross-plot forms for the period covering the first 500 days of their lifetime. The orbit of the inflated sphere, Echo I, is the first to be markedly perturbed by solar radiation pressure, whereas that of the rocket casing is relatively unaffected. The data include orbital elements for Echo I and its percentage of time in the earth's shadow supplied by the Goddard Space Flight Center and the modified orbital elements for Echo I and its rocket casing furnished by the Smithsonian Astrophysical Observatory.

I. Westrick, Gertrude C.
II. Johnson, Katherine G.
III. NASA TN D-1366

(Initial NASA distribution:
2, Aerodynamics, missiles and space vehicles;
33, Physics, theoretical;
46, Space mechanics;
47, Satellites;
53, Vehicle performance.)

NASA

NASA TN D-1366
National Aeronautics and Space Administration.
THE ORBITAL BEHAVIOR OF THE ECHO I SATELLITE AND ITS ROCKET CASING DURING THE FIRST 500 DAYS. Gertrude C. Westrick and Katherine G. Johnson. June 1962. 23p. OTS price, $0.75. (NASA TECHNICAL NOTE D-1366)

The orbital behavior of Echo I (1960 Iota 1) and its rocket casing (1960 Iota 2) is presented in both time-history and cross-plot forms for the period covering the first 500 days of their lifetime. The orbit of the inflated sphere, Echo I, is the first to be markedly perturbed by solar radiation pressure, whereas that of the rocket casing is relatively unaffected. The data include orbital elements for Echo I and its percentage of time in the earth's shadow supplied by the Goddard Space Flight Center and the modified orbital elements for Echo I and its rocket casing furnished by the Smithsonian Astrophysical Observatory.

I. Westrick, Gertrude C.
II. Johnson, Katherine G.
III. NASA TN D-1366

(Initial NASA distribution:
2, Aerodynamics, missiles and space vehicles;
33, Physics, theoretical;
46, Space mechanics;
47, Satellites;
53, Vehicle performance.)

NASA

NASA TN D-1366
National Aeronautics and Space Administration.
THE ORBITAL BEHAVIOR OF THE ECHO I SATELLITE AND ITS ROCKET CASING DURING THE FIRST 500 DAYS. Gertrude C. Westrick and Katherine G. Johnson. June 1962. 23p. OTS price, $0.75. (NASA TECHNICAL NOTE D-1366)

The orbital behavior of Echo I (1960 Iota 1) and its rocket casing (1960 Iota 2) is presented in both time-history and cross-plot forms for the period covering the first 500 days of their lifetime. The orbit of the inflated sphere, Echo I, is the first to be markedly perturbed by solar radiation pressure, whereas that of the rocket casing is relatively unaffected. The data include orbital elements for Echo I and its percentage of time in the earth's shadow supplied by the Goddard Space Flight Center and the modified orbital elements for Echo I and its rocket casing furnished by the Smithsonian Astrophysical Observatory.

I. Westrick, Gertrude C.
II. Johnson, Katherine G.
III. NASA TN D-1366

(Initial NASA distribution:
2, Aerodynamics, missiles and space vehicles;
33, Physics, theoretical;
46, Space mechanics;
47, Satellites;
53, Vehicle performance.)

NASA