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THE DECLINE AND FALL OF IMP 3: A PRELIMINARY REPORT

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ABSTRACT

Data from the IMP 3 satellite is used to establish an orbit which can be extrapolated until re-entry. The re-entry time is predicted to be the midnight between July 4 and 5, within 1/2 an hour. It is concluded that it is feasible to prepare experiments to observe the satellite re-entry in advance. Further work is in progress to establish a definitive orbit and to increase the accuracy of the decay trajectory.

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INTRODUCTION

The IMP series of satellites are launched into highly eccentric orbits, with large semimajor axes. ($e \sim .95$, $a \sim 20$ earth radii). Currently, 4 satellites in this series have been put into orbit (not including A-IMP's); of these, it seems certain that IMP 1 and 2 are no longer in orbit (Ref. 1). IMP 4 went into orbit relatively recently - in May, 1967. IMP 3, which this paper is concerned with, was launched on May 25, 1965 and will terminate its lifetime due to the combined action of solar and lunar gravitational forces in July of 1968.

The IMP 3 satellite presents an unusual opportunity to predict the re-entry time and position with sufficient accuracy to enable positioning observers with equipment in advance of the occurrence. There are two factors which make this satellite especially opportune for re-entry observations:

1) The lifetime is dominated by a very intense lunar perturbation which keeps the satellite above the earth's atmosphere until the final re-entry trajectory. The gravitational

forces acting on the orbit are easily predictable, while the density of the earth's atmosphere is a function of the solar activity, which cannot be predicted accurately. The next-to-last orbit of the satellite is hundreds of kilometers above the earth's surface where the atmospheric drag on the satellite is negligible. During the final orbit, the satellite's perigee is lowered over 1000 kilometers by the moon, bringing the perigee well below the ground. This results in a steep re-entry trajectory, much like a meteor's.

2) There are 2 years of tracking data on this satellite. Because $\frac{2}{3}$ of its total lifetime is spanned with data, it is possible to extrapolate ahead to the fall time. In particular, an initial value of the semimajor axis may be found which will allow the time of perigee passage to match the data over the 2 year period. When this data is matched with good accuracy, it is reasonable to expect that the predicted decay time will not deviate greatly from the actual fall time.

Because of these two factors, it is possible to give a prediction of the subsatellite point of the decay with some accuracy. This is a rare opportunity; the satellite is reasonably heavy - 120.46 lbs - and the prediction is made almost a year in advance.

While it is difficult to estimate the error in an <u>extrapolated</u> quantity, it is felt that the predicted decay time is not worse than

$\frac{1}{2}$ hour in error. Further work is in progress to improve the accuracy of the orbit and to obtain a better estimate of the error in the re-entry prediction. However, because the event will occur in the not-too-distant future, and because the results obtained to date are significant, it was decided to issue a preliminary report at this time and to present the refined results when the study is completed.

PROCEDURE

In order to predict a fall time and location accurately enough to station an observer, even though there is no tracking data for the final year of the lifetime, it is necessary to know the orbital period with extreme precision. For example, if there is an error of one minute on the satellite's orbital period, which is about 140 hours, or 3360 minutes, the error in the time to perigee will accumulate with every orbit. After an extrapolation one year ahead, during which the satellite will have made about 60 orbits, the error in the decay time would be about an hour. This temporal uncertainty might be tolerable for a patient observer, but the earth will have also rotated 15° underneath the satellite orbit, displacing the location of fall by 15° in longitude. The further from the zenith, the more difficult the observations would be, and if very far, the satellite's re-entry would be unobservable. Therefore, the orbital period of the satellite must be determined with precision in order to be able to project forward a year accurately enough to plausibly station observers. However, this stringent requirement on the orbital period can be used to find one which will fit the two years of data available.

The procedure used is to compare the computed time of perigee passage with the observed times. Essentially, the difference between the observed perigee times can be taken, and the difference divided by the number of orbits occuring between the times, which yields the orbital period. In order to obtain the most accuracy, the time interval between the two times of perigee passage should be as large as possible.

In practice, a numerical integration program must be used to compute the times of perigee passage, because the moon introduces a large variation in the orbital period. The ITEM program (Ref. 2) a N-Body program utilizing a modified Encke method, was employed to compute orbits until initial conditions were obtained which satisfactorily matched the data. The computation was then extrapolated forward by numerical integration until the decay point was reached. In order to get an idea of how accurate the extrapolation might be, two separate sets of data were used and the predicted fall times were compared. Data points from the first 25 orbits were used in the orbit improvement; the initial conditions were extrapolated forward for three years to get the decay time. (This will be termed Run 1). Since there are a total of 115 orbits for which there are observations of the time of perigee, the extrapolation may be compared with observations for 90 orbits. Fig. 1 shows the residuals; that is, the difference between the observation and the computation. Since the observed time of perigee passage is only accurate to within $\frac{1}{2}$ minute (due to the method of obtaining the data), the residuals would be expected to scatter within this range.

The data shows a sinusoidal trend in the residuals which has an amplitude of $1\frac{1}{2}$ minutes. This was unexpected; work is underway to identify the source of this discrepancy. It may be due to radiation pressure, which was not included in the computation. What is pertinent in determining the decay time is that there is no discernible secular trend. If the orbital period were slightly incorrect, the residuals would deviate from zero in a linear fashion.

The residuals on the height of perigee are shown in Fig. 2. The discrepancy is again larger than the error in the observed perigee height; however, this discrepancy is not large enough to affect the time of fall significantly. The inclusion of radiation pressure may reduce the residual.

A second set of data was used to give another decay time (Run 2). Seventeen orbits beginning in December, 1966, were used to find another set of orbital elements which were extrapolated forward. Fig. 3 shows the residuals obtained when this set of data was reduced. The residuals are scattered, with no evidence of a secular trend; however, this represents a forced solution of the data and not an extrapolation as above. For this reason, this solution represents a less satisfactory solution than above, particularly when Fig. 1 indicates that data during a short span may be biased. Therefore, forcing a solution from this data to show no secular trend may in fact cause the period obtained to be slightly incorrect. However, this solution is extrapolated forward in order to give a maximum estimate of the error in decay time.

The mathematical model used in these runs includes the gravitational force of the moon, sun and earth, including the J_2, J_3 and J_4 harmonics. The effects of radiation pressure are presently being included and may reduce the size of the residuals. However, the predicted decay time will not be altered markedly because the lunar gravitational force dominates the lifetime prediction.

RE-ENTRY CONDITIONS

The time of fall is determined to be July 4, 1968 at 23:35 U.T. by extrapolating Run 1 forward until re-entry. The location of re-entry is near the Maldive Islands in the Indian Ocean southwest of Ceylon, (Fig. 4). The re-entry trajectory is in an east-southeast direction (120° measured counterclockwise from north). The angle of re-entry with respect to the local horizon is 17°.

The re-entry obtained from Run 2 is also indicated on Fig. 4. It occurs on July 5, 00:03 U.T.

In either case, the local time of re-entry is between 4:45 and 5:00 a.m. (The uncertainty in the universal time is <u>not</u> reflected in the local time but rather in the longitude.) Local sunrise on this date occurs at 6:01 a.m. and local civil twilight at 5:38; thus the satellite re-entry will occur under nighttime conditions.

The earth-fixed velocity is 10.5 km/sec. The atmosphere was not included in computing the re-entry trajectory so that the actual trajectory will not penetrate quite as far southward as indicated.

CONCLUSION

The decay time of the IMP orbit is predicted to be July 4 or 5 at about midnight. The prediction is estimated to be accurate to within $\frac{1}{2}$ hour U.T. The longitudes along the decay path can therefore be established within $7\frac{1}{2}^{\circ}$. The latitudes, which do not depend on establishing a correct orbital period, are correct to within less than a degree. The re-entry will occur near the Maldive Islands in the Indian Ocean.

Further work is in progress to establish a definitive orbit, that is, one which will match the data within the accuracy of the data. However, this will not alter the predicted decay time in a practical sense of preparing for observations of it.

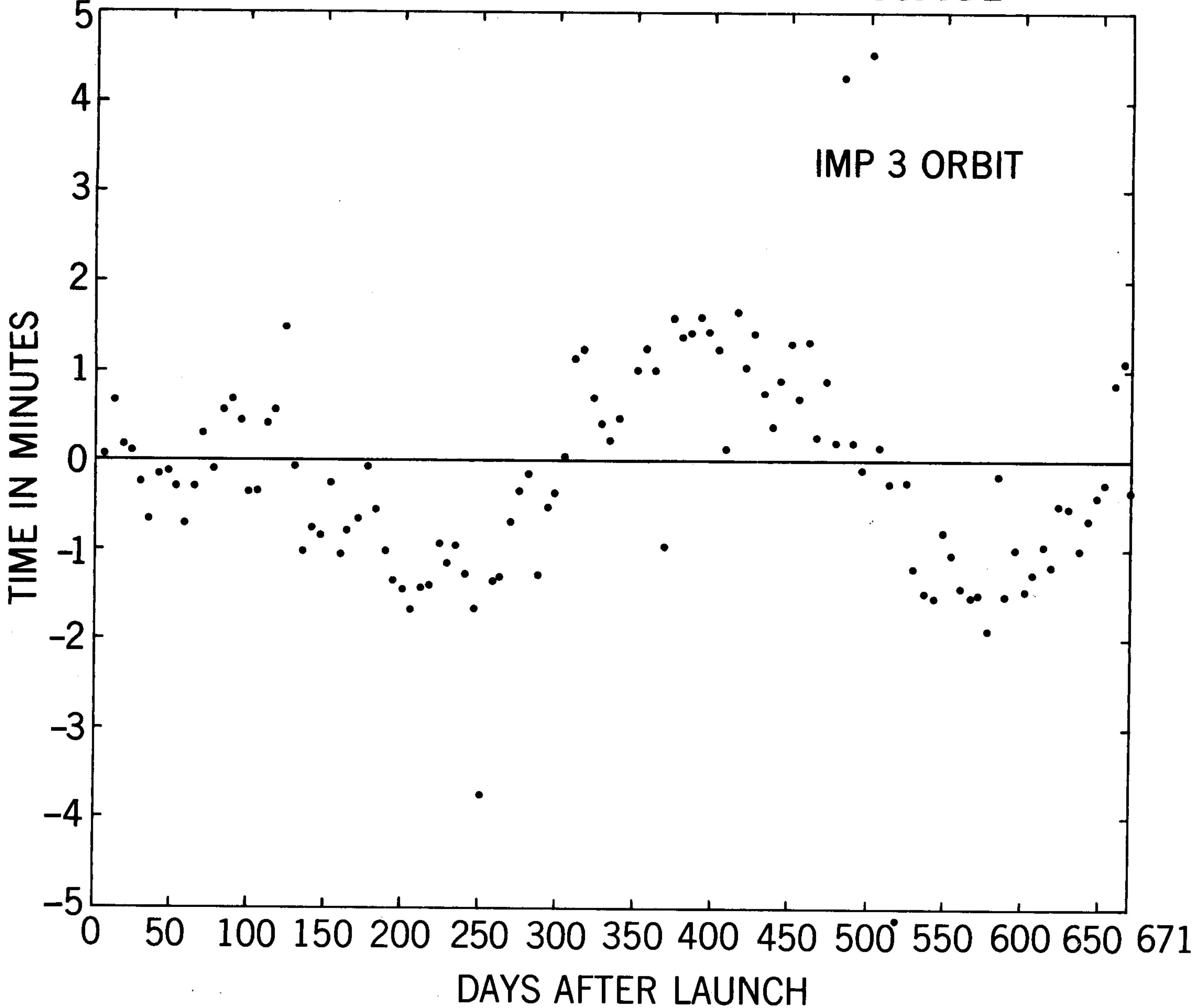
FIGURES

REFERENCES

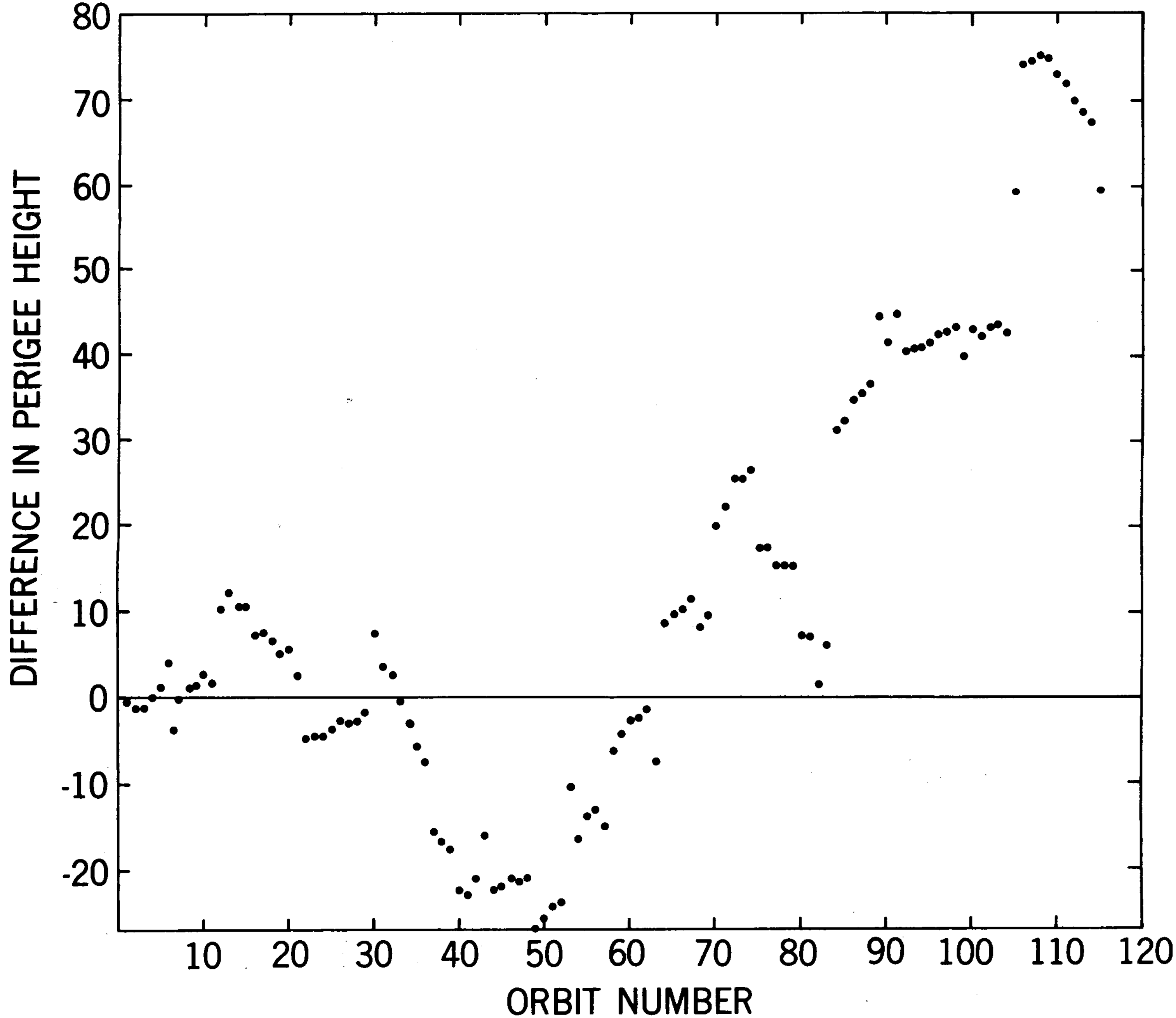
1. Shute, B. E. and Chiville, J., "The Lunar-Solar Effect on the Orbital Lifetimes of Artificial Satellites with Highly Eccentric Orbits", Planet. Space Sci., Vol. 14, pp. 361-369, (1966).

2. Wolf, H., Shaffer, F., and Squires, R. K., Interplanetary Trajectory Encke Method (ITEM) Program Manual, GSFC X-Document No. X-643-65-40, (1965).

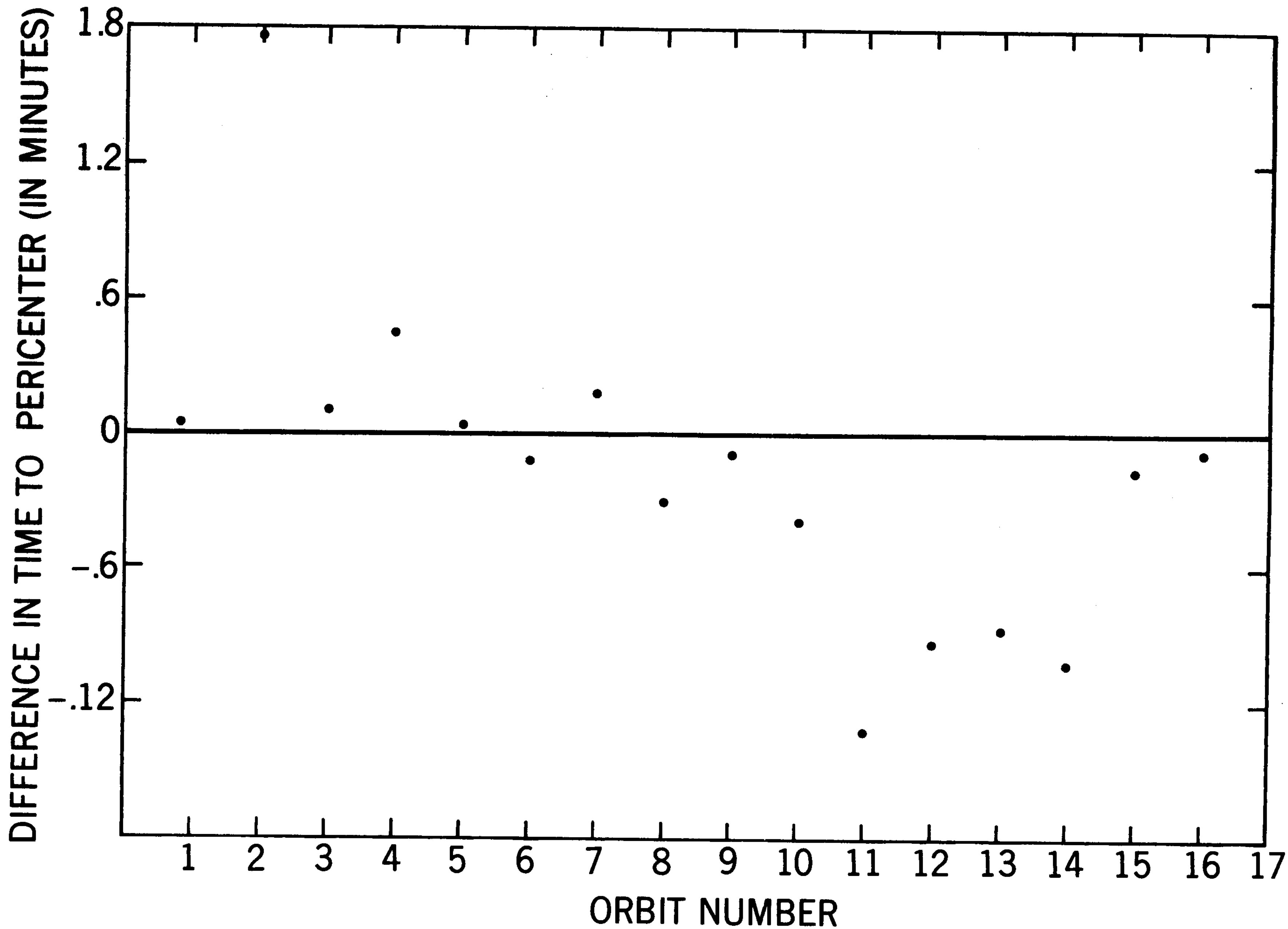
DIFFERENCE BETWEEN OBSERVED AND COMPUTED TIME OF PERIGEE PASSAGE



RUN 1: RESIDUALS IN PERIGEE HEIGHT



RUN 2 : RESIDUALS IN TIME TO PERIGEE



MAP OF REENTRY TRAJECTORY