

SATELLITE HEIGHT DETERMINATION USING SATELLITE-TO-SATELLITE TRACKING AND GROUND LASER SYSTEMS

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The height of the GEOS-C spacecraft is one of the more important parameters for earth and ocean dynamics and geodesy. It is the intent to utilize this parameter, as measured by the onboard radar altimeter, for an improved determination of the earth's gravitational field and for the determination of the variation of the physical surface of the oceans.

Two tracking system approaches to accurately determine the spacecraft height (orbit) are described and their results stated. These are satellite-to-satellite tracking (SST) and ground-laser tracking (GLT). Height variations can be observed in the dm - regions using SST and in the m-region using present GLT.

1. INTRODUCTION

The GEOS-C spacecraft will be the first one to make a connection between the National Geodetic Satellite Program and hopefully a new program, namely the Earth and Ocean Dynamics Satellite Applications Program.

The major difference between GEOS-C and the two previous spacecraft, GEOS-A and -B, is that this one carries a radar altimeter and a satellite-to-satellite tracking system.¹ Both are major experiments needed for future applications programs in the area of earth and ocean dynamics.²

Altimeter data with errors of, say, ± 3 to ± 5 m will be used for a more rigorous analysis, as done in the past, of the earth gravity field and the variations of the physical surface of the sea (gravity anomalies, geostrophic equilibrium of the sea, wind loading, storm surges, etc.). One of the main advantages of height information for orbit and thus gravity field analysis is the large number of data points

obtainable (2 per second), their high accuracy and extremely good along track distribution. For the determination of the ocean height and its variations, the altimeter is at present the only capable instrument.

As is the case for all measurements made, a zero adjustment or an initial calibration will have to be performed by each of the pertinent experimenters. The SST and GLT for altimeter calibration and along track evaluation will be briefly discussed.

II. ATS-F AND GEOS-C SATELLITE TO SATELLITE TRACKING

The ATS-F spacecraft will track, as shown in figure 1, the GEOS-C using a ~2000 MHz SST which measures range and range rate sums.¹ With such a system, the orbits of ATS-F and GEOS-C can be determined simultaneously with a high degree of accuracy. In addition, after an initial independent determination of the GEOS-C height (using, say, a radar, or a laser ground or shipborne station), the SST will be able to "follow" the GEOS-C spacecraft in a phase-locked fashion over half the earth. Thus a constant "watch" can be kept on the altimeter independent of any ground support. This is important if the height is to be used to check the variation of the physical surface of the ocean, say from the U.S. to Europe. The SST, as presently configured, should be able to "detect" satellite height variations in the submeter level, figure 2. Please note that only systems errors are included which are of primary importance at this time. It is clear that these system errors have to be smaller by a factor of 5 to 10 as compared to those expected from the eventual experiments.

Figure 3 shows the height differences of GEOS-C orbit due to different gravity fields as used in present day accurate orbit determination. The fields used are the NWL and the SAO fields.^{3 4} Variations in the order of tens of meters

do occur. Improvements made in the meantime may reduce these values by a factor of 3 to 5. Nevertheless this indicates that for the GEOS-C, at least at the beginning of the flight evaluation period, only relative height variations in the submeter level will be detectable.⁵ In other words, one can only determine these variations consistent with one particular gravity field used in the orbit determination process.

These considerations do not hold for the variation of the physical sea surface. A trench (5 to 10 m over 100 to 200 km) can and will be fairly easy to detect. This holds true for other variations in the height of the ocean surface (tides, storm surges). Figure 4 shows a mathematically simplified trench profile (Puerto Rico trench) and the expected height variations ($\Delta h = 15$ m, $\dot{\Delta h} = 1.6$ m/s).¹ Since the satellite orbit will certainly not follow this kind of a profile and the altimeter can be "watched" from the ATS for any eventual drifts, such profiles should be fairly easy detectable with the GEOS-C altimeter system as configured.

The contribution of the SST to the analysis of the gravity field, and in particular to the determination of anomalies, is out of the content of this paper and is discussed in references 5, 6, and 7.

III. GEOS-C LASER GROUND TRACKING

In addition to the SST approach, precision GLT systems will be used as an additional method of determining the "real" height of the GEOS-C spacecraft independent of the dynamics of the orbit.

As shown in figure 5, three precision ground laser stations are planned to be used in the Caribbean area. The stations will be near the sea (for ease of level determination) at Key West, Canal Zone, and Antigua to form a good three-dimensional triangle (station distances commensurate with satellite height) of near optimum conditions. It is assumed that the uncertainty of the sea surface over this area is

approximately two meters. Using these three stations, the height of the spacecraft can be determined completely independent of the orbital dynamics earth gravity field and its rather large uncertainties, as shown in figure 3. Figure 6 depicts the height errors of the spacecraft as a function of the ground track.⁸ Please see also for comparison figure 5 showing the ground track and the position of the spacecraft (time ticks) relative to the three ground stations. It can be seen (fig. 6) that over a rather large subsatellite track (500 to 1000 km), the spacecraft height can be determined with these laser systems to within two to three meters. Please note that this assumes that the relative errors are ± 5 to 10 m in longitude and latitude, and ± 2 m in height for Key West and Antigua and zero (arbitrary reference) for the Canal Zone.

The present (10 cm in the future) tracking system's capabilities of 30 cm (noise, bias) of the laser systems are far below the errors considered, so they do not constitute a limit. On the contrary, they enable one to determine relative intersite distances from 30 to 50 cm. This result was obtained during the recent Goddard Polar Motion Experiment as reported in reference 9. Thus, the errors of five meters, as shown in figure 6, for the error of the intersite distances can be reduced considerably by the method used for the Polar Motion Experiment which in turn will reduce the depicted height errors. This, of course, assumes that the problems associated with the reflection from the sea surface have been solved to a compatible accuracy.

In conclusion it can be stated: Both methods, the SST as well as the GLT can be used, under the conditions stated, to determine the height of the GEOS-C spacecraft with errors commensurate of the radar altimeter. It should be noted that both methods are rather independent of the final choice of the orbit.

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TRACKING GEOMETRY FOR ATS-F AND GEOS-C

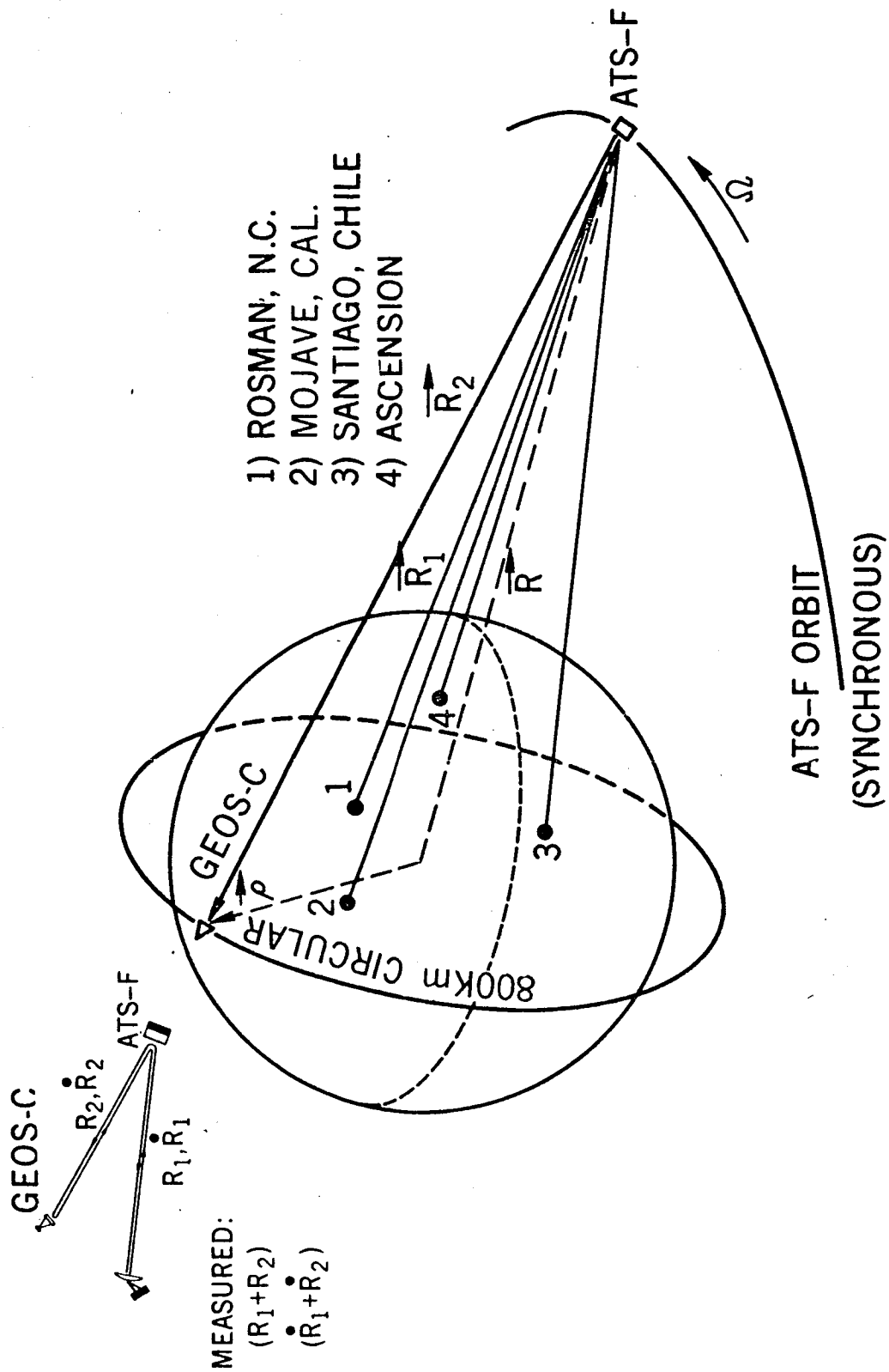


Figure 1

ATS-F AND GEOS-C SYSTEM HEIGHT ERRORS vs. ROSMAN STATION ERRORS

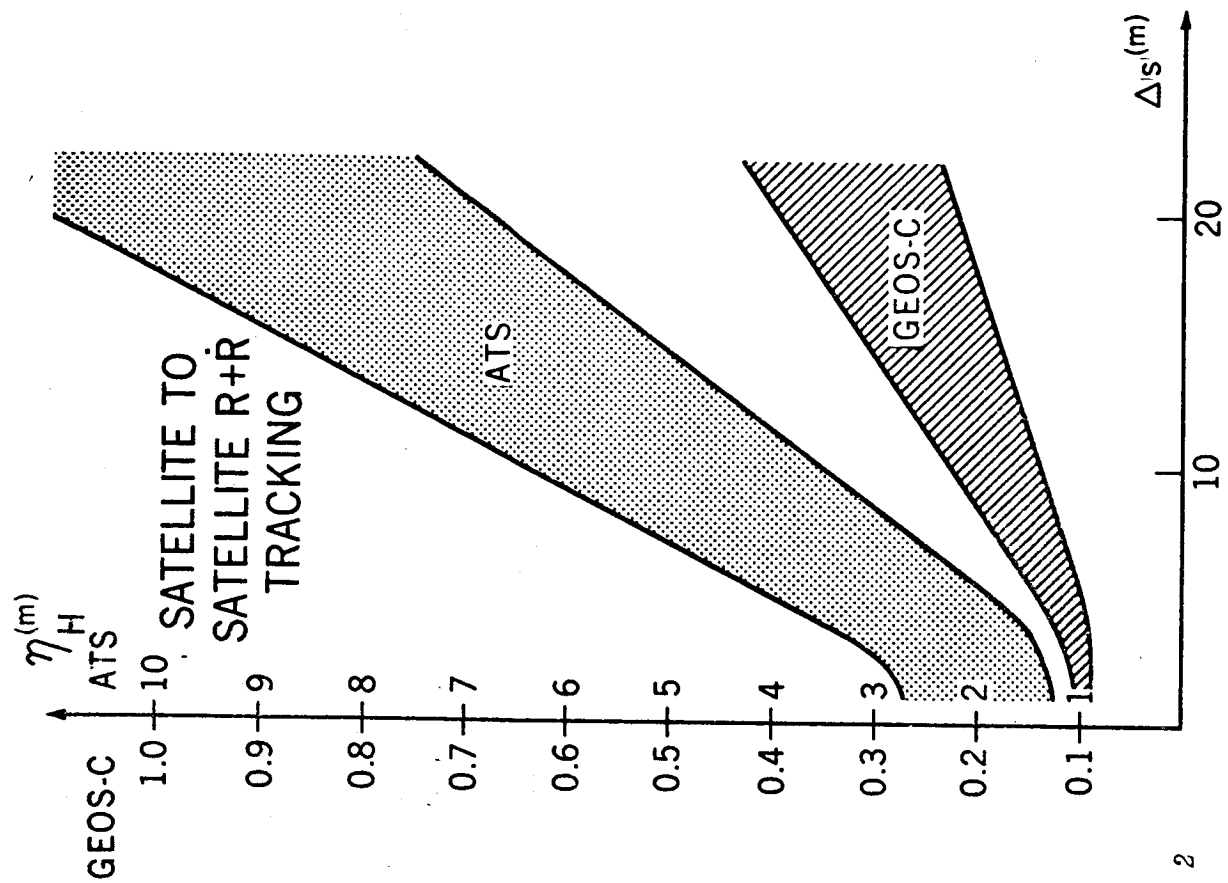


Figure 2

GEOS-C HEIGHT DIFFERENCES DUE TO SAO AND NWL FIELDS

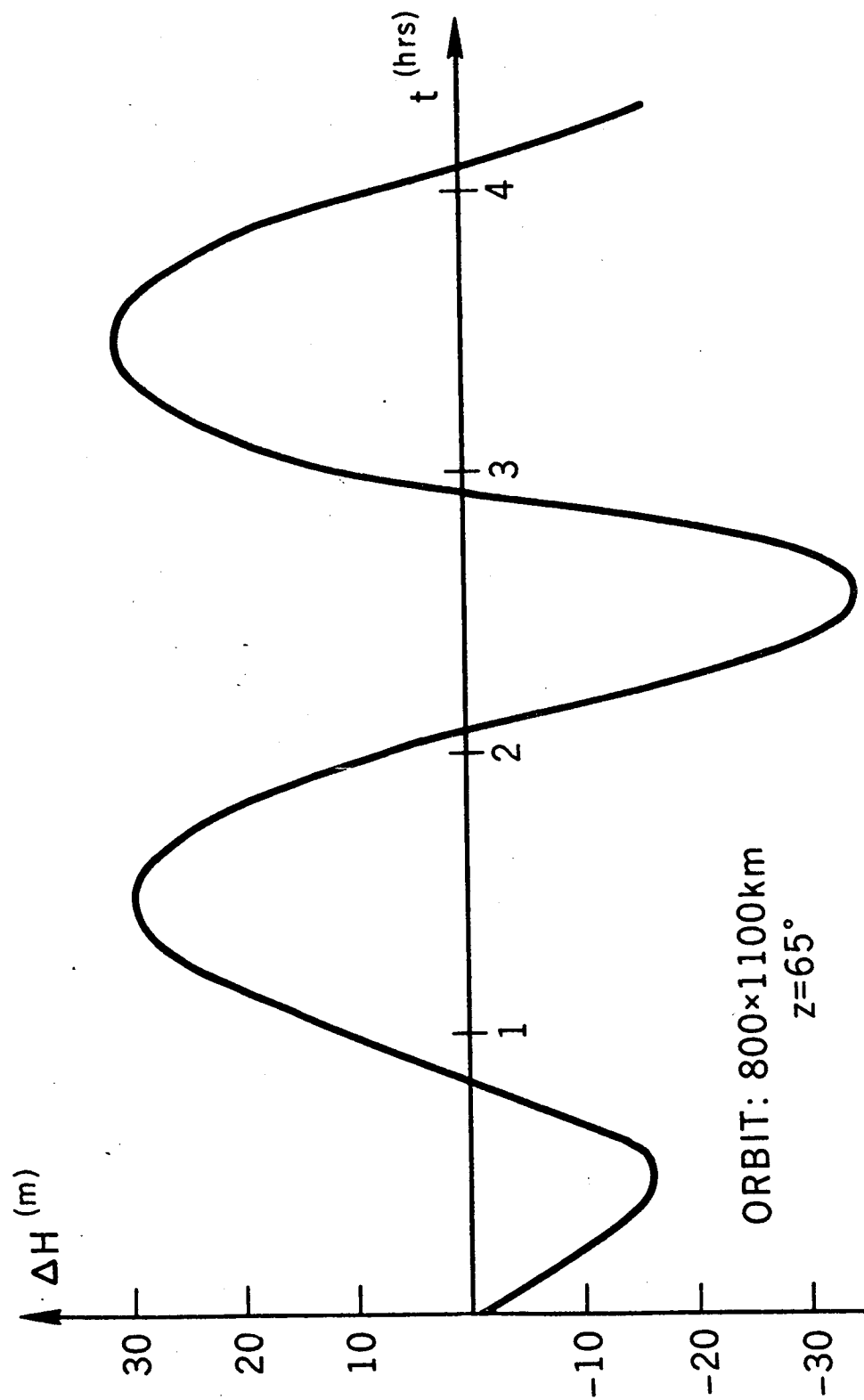
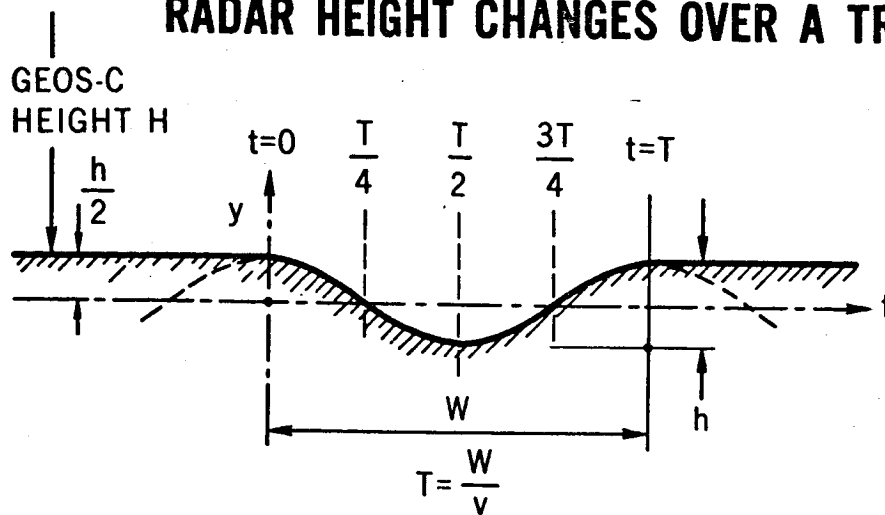


Figure 3

RADAR HEIGHT CHANGES OVER A TRENCH



$$\dot{H} \doteq v e \sin \eta \quad \text{GEOS-C HEIGHT VELOCITY } e \ll 1$$

$$y = \frac{h}{2} \sin \left(\frac{2\pi}{T} t + \frac{\pi}{2} \right) \quad \text{TRENCH PROFILE (Approx.)}$$

$$\dot{y} = \frac{h}{2} \left(\frac{2\pi}{T} \right) \cos \left(\frac{2\pi}{T} t + \frac{\pi}{2} \right) \quad \text{TRENCH HEIGHT VELOCITY}$$

$$\ddot{y} = - \left(\frac{2\pi}{T} \right)^2 \frac{h}{2} \sin \left(\frac{2\pi}{T} t + \frac{\pi}{2} \right) \quad \text{TRENCH HEIGHT ACCELERATION}$$

FOR GEOS-C:

WITH $h=15\text{m}$, $w=210\text{km}$, $T=30\text{ sec}$, $v \doteq 7\text{ km/s}$ $e=0.0322$

$$\begin{aligned} \dot{H}_{\text{MAX}} &\doteq 230\text{ m/s}, \quad \dot{y}_{\text{MAX}} \doteq 1.6\text{ m/s}, \quad \ddot{y}_{\text{MAX}} \doteq 0.34\text{ m/s}^2 \\ &= 3.4 \cdot 10^{-2} g \end{aligned}$$

Figure 4

GEOS-C, PASSES OVER THE CARIBBEAN

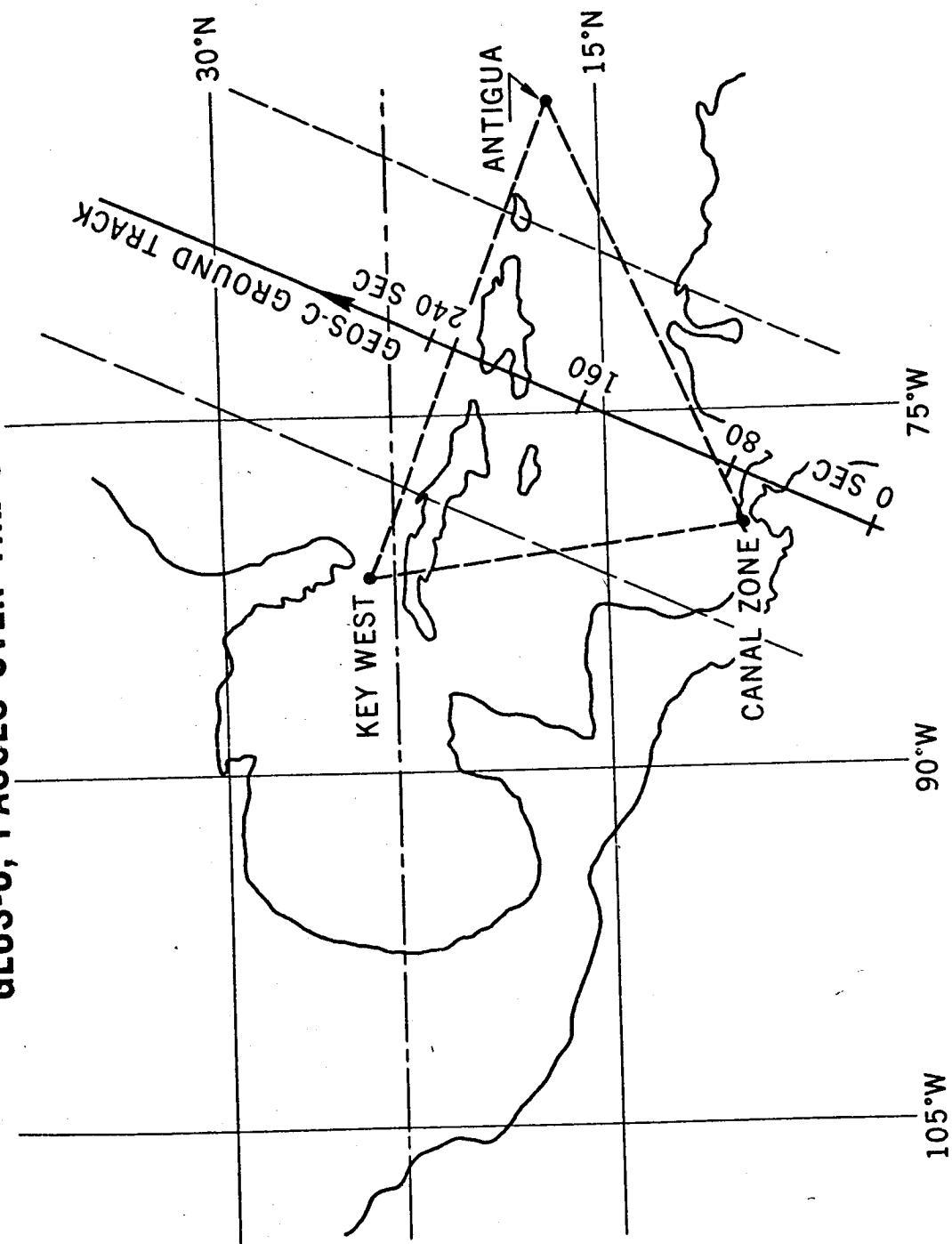


Figure 5

GEOS-C HEIGHT ERRORS USING LASER TRACKING

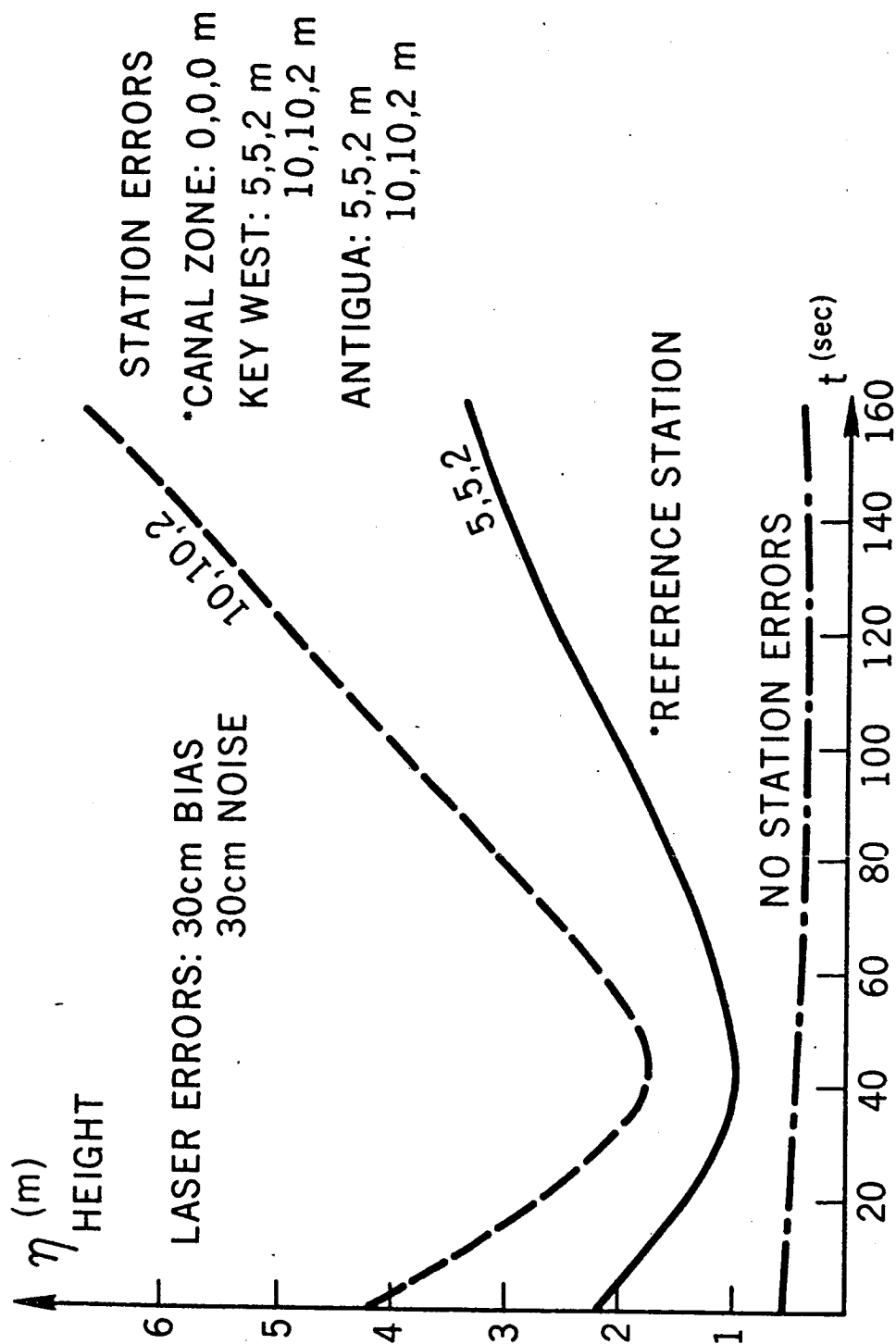


Figure 6

GEOS-C ALTIMETER HEIGHT CALIBRATION

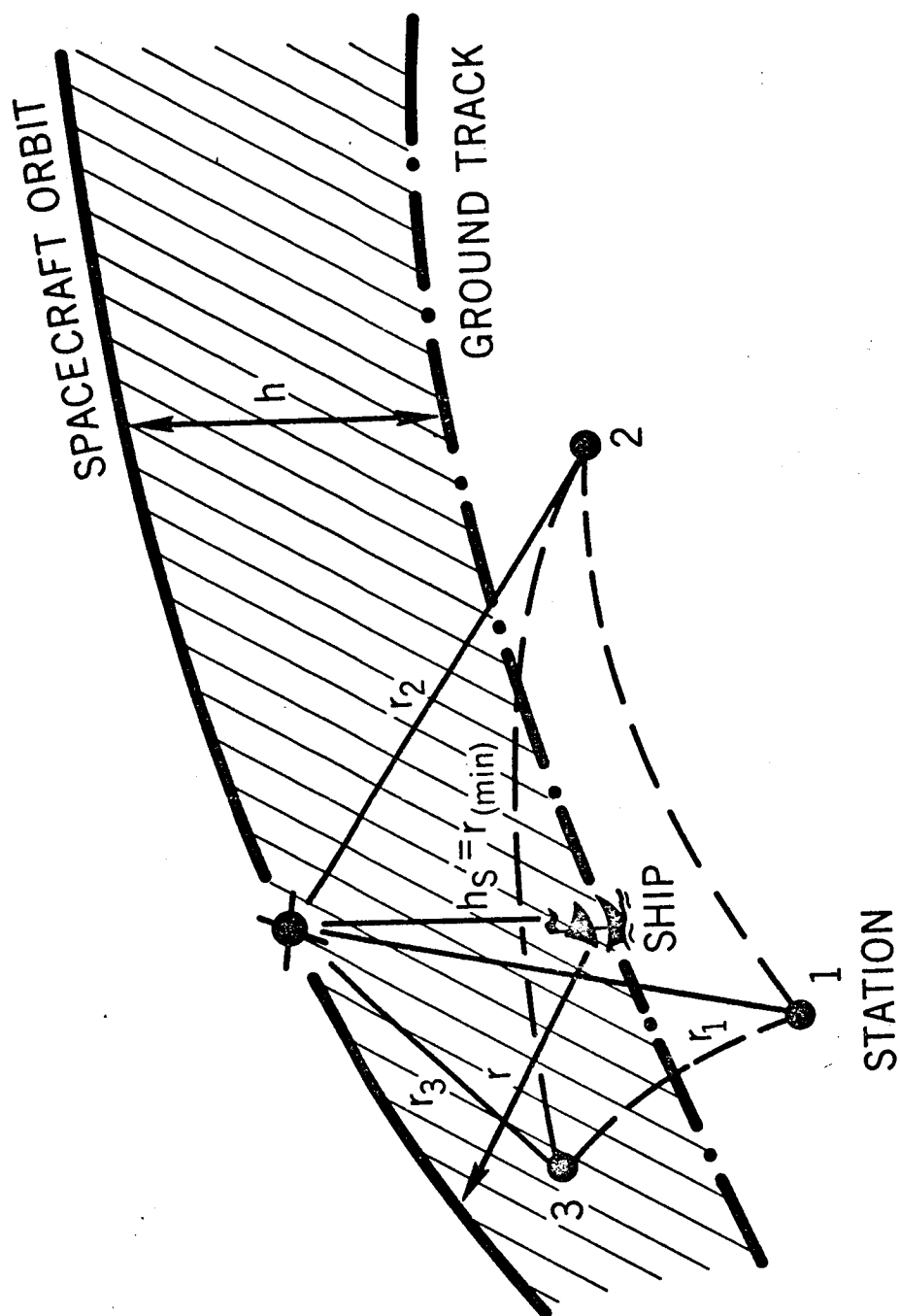


Figure 7

HEIGHT ERROR VS PERPENDICULAR SHIP LOCATION ERROR

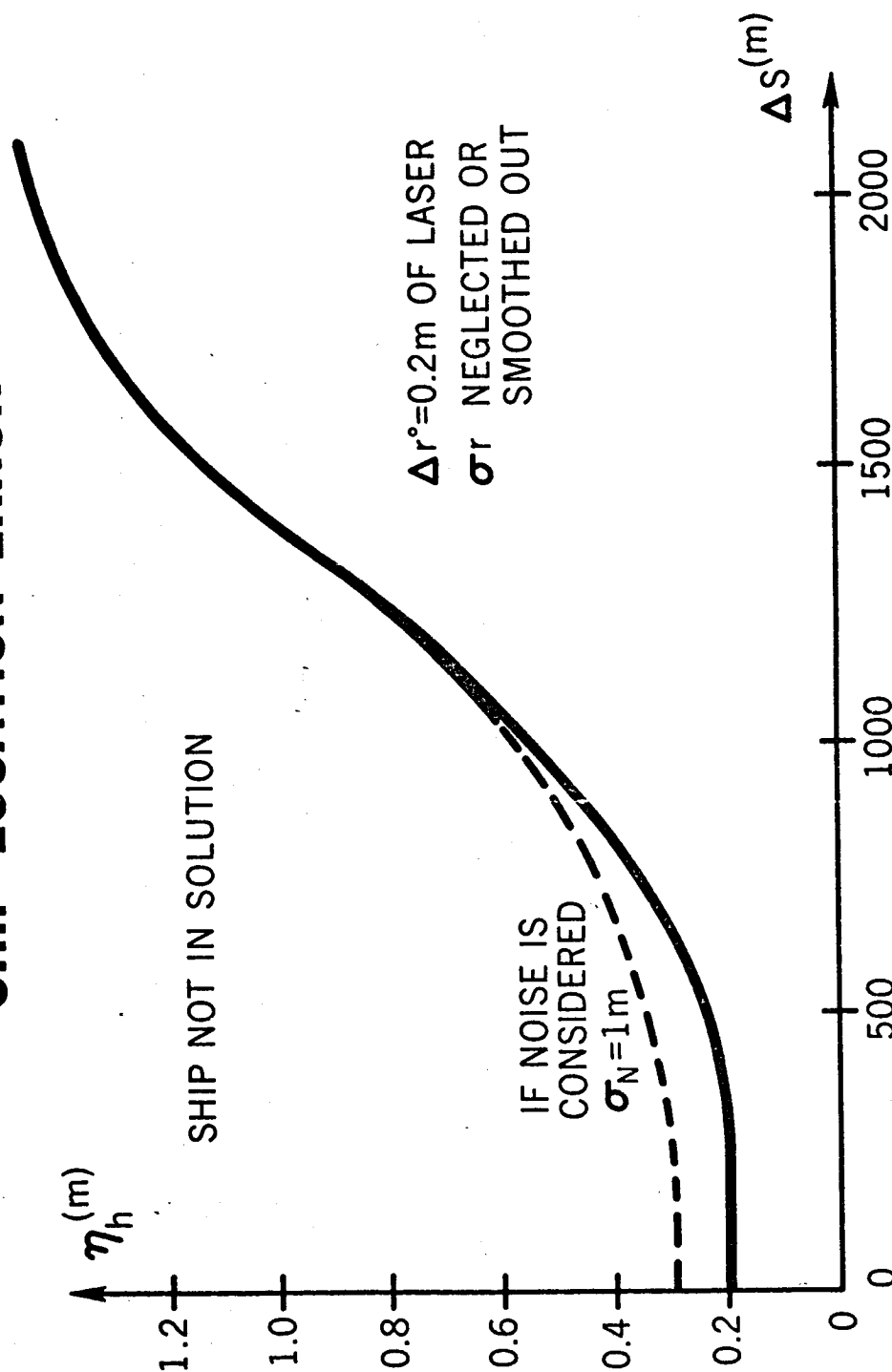


Figure 8