GEOS-C RADAR ALTIMETER CHARACTERISTICS

18

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I. INTRODUCTION

GEOS-C is the third in a series of spacecraft to be designed and built by the Applied Physics Laboratory for NASA. The first two of these spacecraft, GEOS-A and B, have successfully operated in orbit for a number of years and have become important components of the National Geodetic Satellite Program. The GEOS-C spacecraft will fulfill a dual mission; it will carry on the work of the GEOS series in satellite geodesy, and it will also carry equipment to gather data of significance in earth physics research. A primary experiment of GEOS-C will be a K-band radar altimeter, employed to gather data for both of these research areas. This paper will describe the characteristics of this radar altimeter and will discuss the rationale behind the choice of its operating parameters.

An artist's concept of the multi-purpose GEOS-C spacecraft is shown in Figure 1. The octagonally shaped body will carry solar cells arranged in an array designed for maximum efficiency in the collection of solar power. Gravity gradient stabilization will be employed in order to keep the flat face of the satellite facing the earth at all times. The weight of the spacecraft will be approximately 600 pounds. Present plans call for launch during the last quarter of 1973.

As with previous GEOS spacecraft, several of the equipments carried will provide precision data for determining the shape of the earth. These include the doppler beacon, the unified S-band transponder, the range and range rate transponder, the ATS relay experiment, the flashing lights, and the laser reflectors. All of these experiments, with the exception of the ATS relay, will have their antennas located on the earth-facing side of the satellite.

II. EXPERIMENT OBJECTIVES

Two general objectives guide the design of GEOS-C radar altimeter experiment. It is a requirement that height measurements and other supporting data necessary to evaluate the feasibility and value of altimetry on a global basis be obtained. It is also a design goal that data be obtained on which the design of a dedicated altimetry spacecraft can be based. It is necessary that a design approach be chosen such that mission objectives be met within the constraints imposed by the previous spacecraft design effort and by the dual nature of the mission itself.

III. SPACECRAFT CONSTRAINTS

As in most unmanned spacecraft, power represents a major constraint in the design of the on-board experiments. In GEOS-C, weight and volume also represent less stringent but still important constraints. In addition, all electronic packages must meet orbital temperature restrictions, and certain specific constraints, such as radiated peak power and magnetic compatibility.

Figure 2 is a cross sectional drawing of the GEOS-C spacecraft structure. Space reserved for the radar altimeter is indicated on this drawing. The antenna is visualized as either a paraboloid or a phased array; in either case, it can occupy a volume bounded by a 24 inch diameter cylinder 4.6 inches high. Two electronic packages have also been allowed for. One of these, attached directly to the antenna itself, would contain the altimeter transmitter and receiver. A volume of 6" x 6" x 7" has been set aside for this package. A second package, having a volume of 5" x 9" x 10", has been set aside for additional remote electronics which will be used to process the radar signals as they return from the earth.

Two basic operating modes are visualized for the altimeter. One of these, the global mode, will be used in gathering data over substantial portions of a satellite orbit. In this mode the altimeter experiment can consume a maximum of 40 watts for a duration of two hours. Six non-operating hours are then required to recharge the spacecraft batteries associated with the altimeter experiment. In the intensive mode, ground truth experiments and other data gathering experiments of use in determining some of the characteristics of the ocean surface, will be obtained. In this mode, a maximum of 80 watts can be consumed for a one hour period; seven hours are then required for recharge.

A weight of 60 pounds is allowed for the required global mode altimeter system. The intensive mode system, which is intended to satisfy the design goals of the program, is allowed 25 pounds additional. In order to keep rf interference at a minimum, a maximum radiated peak power of 10 kW is allowed in either the global or the intensive mode. Since the spacecraft will be gravity gradient stabilized, residual magnetic moments must be kept small in order to minimize overturning forces. A maximum of 100 pole-centimeters residual moment is allowed for each altimeter package. In addition, the use of nonmagnetic materials is suggested to keep in-orbit magnetization of the altimeter components to a minimum.

For the approximate orbit of the GEOS-C spacecraft, the temperature extremes of the three altimeter packages have been calculated. The antenna must meet its design characteristics over a range from -130 to +90°F. The attached electronics package must meet its specifications over a temperature range from +20 to +105°F. The remote electronics package will be subjected to a temperature ranging from +10 to +104°F.

IV. OPERATIONAL CONSTRAINTS

In addition to the constraints on the radar altimeter imposed by the spacecraft design itself, a number of operational constraints exist. For example, the orbit must be chosen to maximize both the geodetic and the earth sciences data gathering capabilities of the spacecraft. Tentatively, the following orbit parameters have been chosen; spacecraft eccentricity, .005 maximum; spacecraft inclination, between 40° and 65° retrograde; spacecraft altitude, between 750 and 950 km. Inclination and altitude figures will be refined and finalized in the near future. The radar altimeter frequency is limited by international agreement; in our case, an operating frequency of 13.9 GHz has been chosen. The altimeter will be designed to survive 1500 hours of on-time over an 18 month satellite lifetime. In order to meet its objectives over a wide range sea-state conditions, the altimeter must be designed to operate for sea surface reflectivities between +3 to +16dB. In addition to this, a small amount of satellite libration is expected. With the orbit parameters mentioned above, the maximum value of this libration is not expected to exceed one degree. Therefore, all the objectives of the altimeter experiment must be met for off-vertical librations up to one degree maximum.

V. FEASIBILITY CALCULATIONS

The design of a useful radar altimeter meeting these constraints is an exacting task. The first phase of this task will result in an extremely detailed design study, in which the feasibility of the design will be examined from all aspects. At present, a number of simplified calculations have been completed in an attempt to provide guidance for the detailed study. As an example of one of these calculations, it is interesting to examine the effect of various combinations of radar pulse length, peak power, pulse repetition frequency, average power, and received signal-to-noise ratio on the rms error in the altitude measurement. Figures 3 and 4 indicate the results of such calculations. The first equation in Figure 3 expresses the rms noise of the altitude measurement in terms of pulse length, received signal-to-receiver noise ratio, and the number of pulse integrated, for a three gate range tracker. A Raleigh-type sea return is assumed. The second equation in Figure 3 is the receiver signal-to-noise ratio given by the standard radar range equation. In this equation, the constants have been adjusted to be consistent with the units given below the equation. To make meaningful use of these two equations, we also impose the spacecraft peak power constraint of 10 kW and a maximum PRF constraint which results if one demands complete decorrelation between successive received pulses, as the spacecraft moves over the earth's surface. The results of some sample calculations are shown in Figure 4. The first set of data assumes a maximum peak transmitted power of 2 kW, and varies the pulse length from 100 to 50 nanoseconds. The value of n given corresponds to zero correlation between successive received pulses, in accordance with the Van Cittert-Zernike theorem, and can be thought of as the limiting PRF for the altimeter footprint represented by the pulse. An averaging time of one second has been assumed. The average power level, the signal-to-noise ratio at the front end of the radar receiver, and the rms noise level of the resulting altitude measurement, are shown in the three remaining columns. It is interesting to note that with the parameters employed, a minimum in the noise level occurs at a pulse length of approximately 70 nanoseconds. The noise level of 0.82 meters obtained under these conditions is the noise due to the statistical character of the reflecting surface; it does not take into account either sources of noise within the altimeter tracking loops, or digitizing noise which may result from the range measurement process itself.

It is interesting to see what happens as the peak power is varied and an optimum pulse length is sought for each value of peak power. This calculation is shown in the bottom part of Figure 4. The second column, τ_{opt}, is the pulse length for which the noise level in the measured altitude is a minimum. For example, if one were to choose a 10 kW peak power, the optimum pulse length would be approximately 30 nanoseconds, and the resulting statistical noise in the received altitude measurement for a one second averaging time would be approximately 0.45 meters. The signal-to-noise ratio for each pulse arriving at the front end of the radar receiver would be approximately 2.85, and the average radiated power under this condition would be 0.36 watts.

VI. ALTIMETER CHARACTERISTICS

The desired characteristics of the GEOS-C radar altimeter are given in Figure 5. Based on simplified feasibility calculations of the type outlined above, the characteristics of the global mode appear to represent a consistent set, achievable within the spacecraft and operational constraints of the program. The intensive mode design goals also appear to be achievable, although greater circuit and system sophistication will obviously be required.

The GEOS-C radar altimeter represents an important first step in the design of dedicated altimetry spacecraft. As such, it can supply information of great importance to geodesists. It can supply some information of interest to oceanographers and can provide a means for establishing design criteria useful in future altimeters.

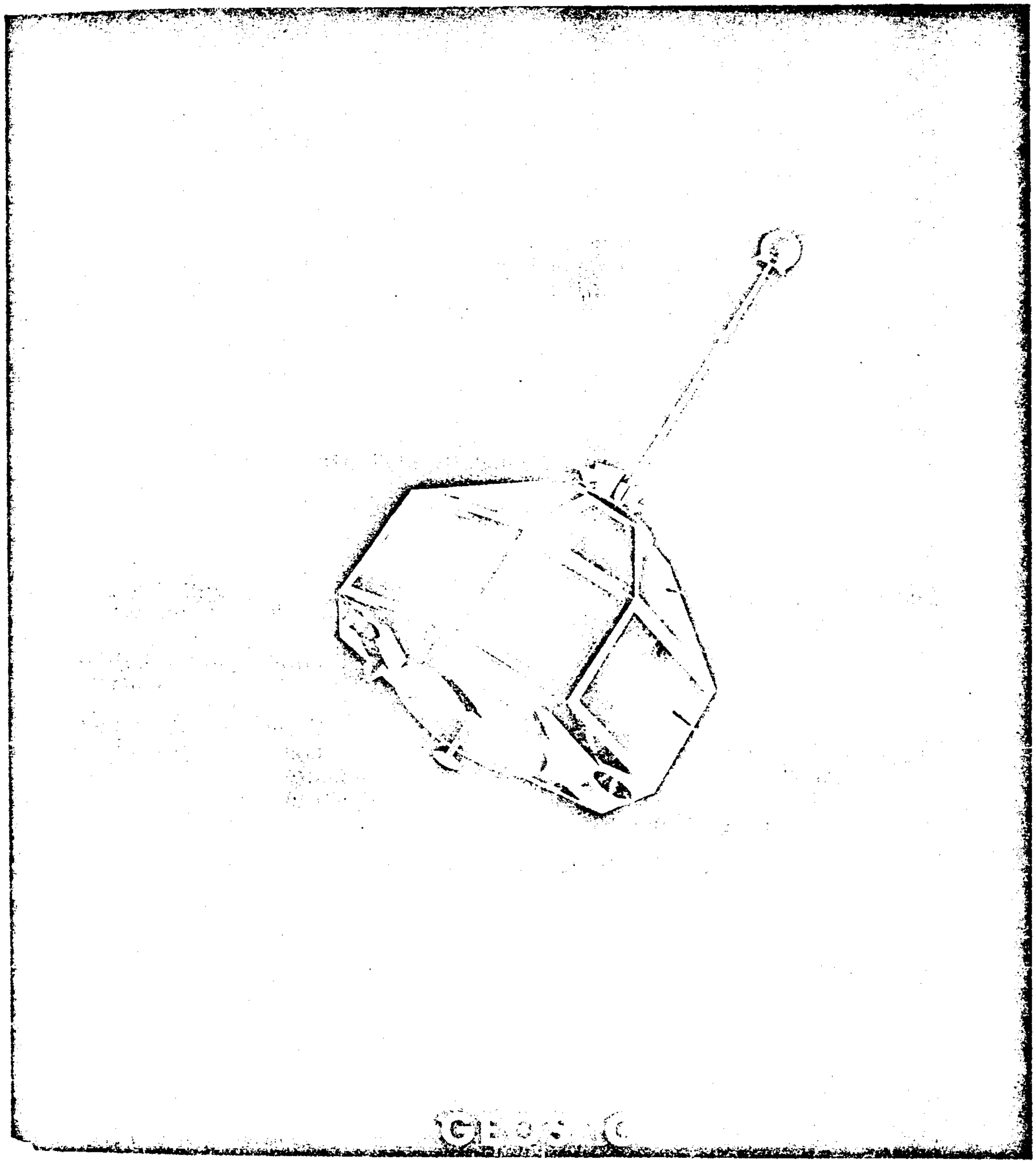
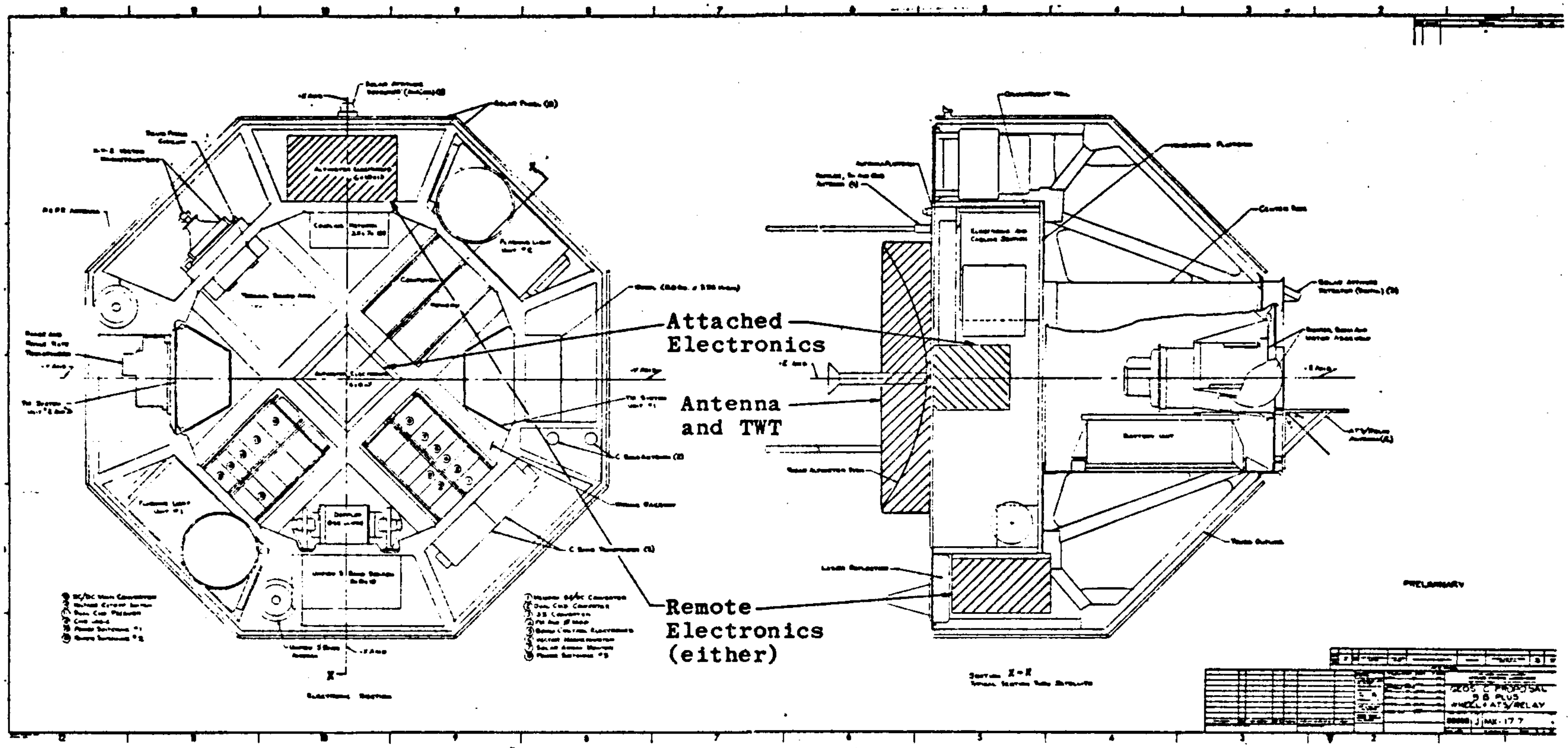


FIGURE 1



OUTLINE DRAWING

Figure 2

FEASIBILITY CALCULATION

GLOBAL MODE ALTIMETER

$$\sigma_{h_{meters}} = \frac{\tau}{6}\sqrt{\frac{4 + \frac{18}{(S/N)} + \frac{9}{(S/N)^2}}{n}} \quad \text{- 3 Gate Tracker}$$

$$(S/N) = \frac{P_t\ G^2\ \lambda^2\ \sigma_0\ A_r}{4\ h^4\ BNL}$$

Where:

P_t = transmitted peak power, watts

G = antenna gain (= 2800 for 24" parabola 1° off center)

λ = wavelength, cm(= 2.16 for 13.9 GHz)

σ_0 = ocean reflectivity (= 2, worst case)

A_r = illuminated ocean area, m^2(= $2\pi h \times 0.3\tau$)

h = satellite altitude, n.mi. (= 513, worst case)

B = receiver IF bandwidth, Hz (= $1.2/\tau$, matched filter)

N = receiver noise figure (= 10, assumed)

L = two way plumbing loss (= 1.6, assumed)

n = number of received pulses integrated over the one second sampling time

τ = pulse length, nanoseconds

Impose the following limits:

$P_t \leq 10^4$ watts

$$n \leq \frac{1.5V}{\lambda}\sqrt{\frac{\tau}{h}} \quad \text{(Van Cittert - Zernike)}$$

Where V = orbital velocity in meters per second.

Figure 3

FEASIBILITY CALCULATION

GLOBAL MODE ALTIMETER (Continued)

RESULTS:

τ(ns)	P(w)	n	P_{av}(w)	S/N	σ_h(m)
350	2000	4003	2.8	6.9	2.18
300	2000	3706	2.22	5.1	2.09
250	2000	3383	1.69	3.5	2.04
150	2000	2621	0.79	1.3	2.16

P(w)	τ_{opt}(ns)	P_{av}(w)	S/N	σ_h(m)
2000	225	1.44	2.9	2.03
4000	160	1.73	2.9	1.57
7000	120	1.97	2.8	1.27
10000	100	2.14	2.8	1.11
20000	70	2.51	2.8	0.86

Figure 4

GLOBAL MODE REQUIREMENTS

1. ALTITUDE MEASUREMENT	
OUTPUT DATA RATE	1 DATA POINT PER SECOND
OUTPUT NOISE LEVEL	90% OF DATA POINTS LIE WITHIN ± 2 METERS OF THE MEAN
2. INSTRUMENT DRIFT RATE	LESS THAN 5 METERS PER HOUR, IN ORBITAL ENVIRONMENT
3. BUILT-IN CALIBRATION	ABSOLUTE ACCURACY ± 1 METER, IN ORBITAL ENVIRONMENT, FOR LIFE OF SPACECRAFT

INTENSIVE MODE GOALS

1. ALTITUDE MEASUREMENT	
OUTPUT DATA RATE	1 DATA POINT PER SECOND
OUTPUT NOISE LEVEL	90% OF DATA POINTS LIE WITHIN ± 0.5 METERS OF THE MEAN
2. INSTRUMENT DRIFT RATE	LESS THAN 2 METERS PER HOUR, IN ORBITAL ENVIRONMENT
3. BUILT-IN CALIBRATION	ABSOLUTE ACCURACY ± 0.5 METER, IN ORBITAL ENVIRONMENT, FOR LIFE OF SPACECRAFT
4. IMPULSE RESPONSE OF OCEAN	DATA DESIRABLE; AS A GOAL, MEASURE WAVES 2 METERS CREST-TO-TROUGH, TO A PRECISION OF 0.6 METERS rms, WITH AN AVERAGING TIME OF 10 SECONDS.
5. AMPLITUDE PROBABILITY DISTRIBUTION	DATA DESIRABLE
6. TIME CORRELATION FUNCTION OF BACKSCATTER	DATA DESIRABLE

Figure 5