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RADAR ALTIMETRY SYSTEMS COST ANALYSIS

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RADAR ALTIMETRY SYSTEMS COST ANALYSIS

Prepared for

NASA/WALLOPS FLIGHT CENTER

By

COMPUTER SCIENCES CORPORATION

Under

Contract NAS 6-2369

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ABSTRACT

This report discusses the application and cost of two types of altimeter systems (spaceborne (satellite and shuttle) and airborne) to twelve user requirements. The overall design of the systems defined to meet these requirements is predicated on an unconstrained altimetry technology; that is, any level of altimeter or supporting equipment performance is possible.

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SECTION 1 - INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

The effort described in this report has been carried out as part of the Wallops Flight Center Radar Altimeter User Research Program. Systems employing either a spaceborne (satellite or shuttle) or airborne altimeter have been specified and costed for each of 12 user requirements generated in a separate study for the Wallops Flight Center. Under the ground rules of this study, altimetry technology is unconstrained, that is, it is assumed that any level of altimeter or supporting equipment performance is possible. Furthermore, the user requirements must be satisfied using a system employing a radar altimeter, even if it is apparent that other sensors are more applicable. This is because the overall objective of this effort is not to produce viable systems for satisfying the user requirements. The overall objective of this effort is, however, to provide scientific and cost data for input into an economic management decision model that is currently being evaluated by the Wallops Flight Center to refine their techniques for allocation of scarce research funds. As such, the necessary scientific data on altimeter systems and the associated costs and confidence levels have been generated in a format suitable for input into the model. As part of the Wallops Flight Center Radar Altimeter User Research Program, the model will be applied to identify the accuracy, precision, resolution, and data reduction requirements of various sectors of the user community and to determine the economics of satisfying these requirements.

The state of the art of the various components (platforms, altimeters, auxiliary equipment, positioning equipment, and data processing) of operational altimeter systems is discussed in Section 2. The techniques and methods used to cost the altimeter system are described in Section 3. Section 4 contains a list of the user requirements, a description of the altimeter system conceptualized to satisfy each requirement, and the life-cycle cost of implementing each system.

1.2 COST ANALYSIS SUMMARY

Altimetry systems were conceptually defined for 11 of 12 altimetry user requirements (the twelfth was unfeasible using a radar altimeter) by structuring separate component cost elements, specifying effectiveness measures, providing cost estimates, specifying variance and confidence factors as defined in the economic decision model, and computing total life-cycle costs for each. Operating effectiveness parameters (accuracy, resolution, repetition rate, etc.) were specified by NASA. Where these effectiveness parameters could not be met with existing hardware, expert opinion was consulted to determine the additional costs required to modify equipment effectiveness to satisfy the user requirement. All cost estimates were based on current equipment costs, costs relating to similar projects, current administrative rates (per diem, transportation, communications, etc.), and the basic operating environment and parameters defined in the system required by the altimetry user requirement. The system cost analysis provides input parameters to be used in the economic decision model and provides estimated annual and life-cycle costs for 11 systems conceptualized to satisfy 11 altimetry user requirements. A comparison of costs for satellite versus aircraft is provided where both modes are applicable. These total annual and life-cycle cost estimates, when compared with the anticipated benefits for each of the 11 user requirements, should enable the selection of candidate systems that would be cost effective and provide a suitable demonstration of the use of the economic decision model in management decisions.

Although the function of this work was to provide input to the economic model, not to make general conclusions concerning the applicability of radar altimetry to satisfying user requirements, the following observation should nevertheless be made. From the analysis, it is apparent that satelliteborne altimeters are more cost effective when synoptic observations are desired whereas airborne altimeters are more cost effective for repeated observations of limited geographical areas.

Table 1-1. Altimeter System Cost Analysis Summary

SYSTEM COMPONENTS	GRAVITY ANOMALIES	WAVE STATISTICS FOR OFFSHORE STRUCTURE DESIGN	HURRICANE ANALYSIS	COASTAL SURGE STORM-DRIVEN RUN-UP	STATIC WATER HEIGHT IN COASTAL MARSHLAND, SHORELINE DELINEATION	OVERFLOW PATTERNS OF MAJOR RIVERS	BEACH MONITORING, WAVE CLIMATE MAPS, ETC.	TSUNAMI WARNING	OPEN OCEAN TIDES	MONITORING HEIGHT FOR SHIPPING PURPOSES	PRE-FLOOD ASSESSMENT	NEAR SHORE · DE AND SEA LEVEL INFORMATION, ETC.
PLATFORM			WAY BEYOND THE STATE OF THE ART									
SPACECRAFT	•	•		•				•	•	•	•	•
AIRCRAFT DEDICATED		•		•	•	•	•	•			•	•
AIRCRAFT COMMERCIAL										• •		
ALTIMETER												
SPACEBORNE	•	•		•				•	•	•	•	•
AIRBORNE		•		•				•			•	•
AUXILIARY EQUIPMENT												
INFRARED SCANNER						•						
IMAGER, VISIBLE OR RADAR						•						
RADAR SCATTEROMETER							•			•		
POSITIONING												
NAVSTAR TRACKING SYSTEM OR NAVSTAR RECEIVER	•	•		• •	•	•		• •	•		• •	• •
RADAR TRACKING STATION				•	•	•					•	•
INERTIAL NAVIGATION SYSTEM		•		•	•	•	•	•		•	•	•
VERTICAL ACCELEROMETER		•					•	•		•		
LORAN, ETC.												
DATA RELAY SYSTEMS												
STDN	•	•		•					•	•		
COMMUNICATION SATELLITE								• •		•	•	•
RF LINK				•	•	•	•				•	
MAIL		•			•				•			
TWX, TELEPHONE				•	•	•					•	•
DATA PROCESSING												
MAXIMUM-LIKELIHOOD PROCESSOR		• •					•			•		
SOFTWARE DEVELOPMENT NECESSARY	•	• •		• •	•	•	•	• •	•	• •	• •	• •
COMPUTERS, SUCH AS ILLIAC CDC STAR	•											
CALCOMP PLOTTER	•			• •	•	•	•			• •	• •	• •
COMPUTER		• •		• •	•	•	•	• •	•	• •	• •	• •
DATA DISTRIBUTION												
FACSIMILE				• •		•				• •	• •	• •
TELEPHONE				• •		•					• •	• •
TELETYPE						•						
MAIL	•	• •			•		•		•			• •
TEN-YEAR COST ($\times 10^6$): SPACECRAFT	NOTE 1	581.3		185.3				278.3	98.5	NOTE 2	559.6	82.5
AIRCRAFT		6.7		9.2	15.7	26.1	54.8	510.1		281.8	11.8	10.6

NOTES:

[1]CASE A $ 36.8
CASE B 209.2
CASE C 12.6

[2]SIX SATELLITES $286.9
TWELVE SATELLITES 573.3

Table 1-1 is a summary matrix indicating the major system components (e.g., platforms, altimeters, positioning, etc.) required to satisfy each of the 12-user requirements. A dot (.) indicates that a particular component is included in the altimetry system.

SECTION 2 - STATE OF THE ART OF ALTIMETER SYSTEM COMPONENTS

This section discusses the state of the art of the various components used in the altimeter systems described in Section 4.

The state of the art of the various components used in the altimeter systems designed to meet the user requirements of Section 4 are briefly described below. As discussed in Section 3, in many cases, improvements are needed to the altimeter itself, as well as to the other components, to satisfy the user requirements. In some cases, the requirements can be satisfied using current state-of-the-art equipment. The following system components are discussed: platforms (spacecraft and aircraft), radar altimeters, auxiliary equipment, tracking and positioning equipment, data processing software and hardware, and data relay and distribution facilities.

2.1 PLATFORMS

2.1.1 Spacecraft

Skylab, GEOS-3, and SEASAT-A are spacecraft platforms that have carried or are planned to carry a radar altimeter. Skylab weighs over 8200 kilograms, GEOS-3 weighs about 350 kilograms, and SEASAT-A will weigh approximately 1000 kilograms.

2.1.2 Aircraft

Airborne altimeters weighing over 200 kilograms have been flown aboard C-54 aircraft. The desirable aircraft characteristics for altimeter mounting are a load capability of greater than 500 pounds; space for two 19-inch racks; power requirements on the order of 3 kilovoltamperes (kva); and sufficient space in which to mount a 1-meter antenna. In addition, the aircraft should be relatively insensitive to turbulence in the vertical direction because the altimeter requires a stable platform from which to make measurements. An aircraft with a high lift-to-weight ratio will experience large fugoid oscillations. The converse is true for aircraft with a low lift-to-weight ratio. Furthermore, a long aircraft will experience smaller, low-frequency oscillations than will a short aircraft. These oscillations must be accounted for by the positioning equipment and distinguished from the surface oscillations that are being detected by a radar altimeter.

2.2 ALTIMETERS

The altimeters that have been or will be flown aboard spacecraft and aircraft are listed below, with the nominal observational precision of each instrument.

Spacecraft Altimeters	Range Precision (meters)	Seastate Accuracy
GEOS-3	0.6	±25 percent of the wave height for waves of 1 to 10 meters in height[1]
SEASAT-A	0.1	±0.5 meter or 10 to 25 percent of the wave height values of 1 to 10 meters in height[2]
Aircraft Altimeters		
NANOSECOND	0.1	±0.5 meter
AAFE	0.1	±0.5 meter or ±25 percent of the wave height for waves of 1 to 20 meters in height[1]

2.3 SPACECRAFT AND AIRCRAFT TRACKING SYSTEMS

2.3.1 Spacecraft

Factors affecting the state of the art of the tracking system are the quality of the gravity field representations, uncertainty regarding the positions of the tracking network stations, uncertainty in specifying the atmospheric density, and uncertainty in defining the solar radiation pressure.

[1] Reference 2.

[2] Reference 3.

Current satellite tracking networks are capable of specifying satellite position to less than ±5 meters. The necessary data for such accuracy are observations over a 2- to 5-day period (Reference 4).

A global positioning system (NAVSTAR) is in the planning stage. This system will be capable of fixing station positions, using 2 weeks of data, with a standard deviation of 3 to 10 centimeters. Satellites therefore will be able to be tracked with the same accuracy.

Currently, atmospheric density models can correct for microwave propagation errors to within ±1 centimeter. The quality of the atmospheric density and solar radiation pressure models used by Anderle and Tanenbaum (Reference 4), Black, et al. (Reference 5), and Lerch, et al. (Reference 6), are clearly adequate to satisfy the previously quoted tracking accuracies; however, improvement will probably be necessary to match the capability of the NAVSTAR tracking system.

2.3.2 Aircraft

Aircraft positioning is accomplished by radar tracking, laser tracking, an inertial navigation system, or the NAVSTAR tracking system. The range precision of radar and laser trackers is a few centimeters. If three tracking stations are used, the resulting position accuracy is less than 10 centimeters. If one tracker is used, however, the position accuracy is a few meters because of the use of angle measurements (whose uncertainty is much greater than the range measurements) with the range. The horizontal accuracy of the inertial navigation system depends on the drift rate, which may be 0.1 degree azimuth per hour. State-of-the-art vertical precision is approximately 10^{-6} g (the acceleration of gravity) and accuracy is approximately 10^{-5} g. NAVSTAR is expected to be capable of aircraft position determination to ±10 meters. It is conceivable that this could be reduced to ±1 meter when used in conjunction with an inertial navigation system.

2.4 COMPUTER PROCESSING

2.4.1 Software

A set of currently operating programs exists within NASA that is capable of generating geoidal heights and gravity anomalies from altimeter observations. These programs have been developed in support of the GEOS-3 program. Additional software is being developed by instrument developers to support SEASAT-A. The software contains models for atmospheric transmission, ocean tides, atmospheric density, and solar radiation pressure to enable altimeter range measurement correction for the effects of these factors. Tidal models can predict tides to ± 5 centimeters where observational data exist, and atmospheric transmission models can reduce refraction errors to less than ± 1 centimeter.

2.4.2 Hardware

An IBM S/360-95 computer, or similar configuration, is adequate for all data reductions except for extremely high-resolution gravity anomaly surveys. Part of the Advanced Applications Flight Experiment (AAFE) and SEASAT-A altimeter systems is a computer called a maximum-likelihood processor, which enables the onboard computation of the seastate. Many plotting machines exist for displaying the computer output in a digital grid format.

2.5 DATA DISTRIBUTION

Data can be transmitted and distributed in many ways, depending on reporting time requirements and the availability of transmission facilities. Means of transmitting data between various points of the data stream are described below.

2.5.1 Real-Time Transmission

Telephone, teletype, cable, microwave, and satellites (INTELSAT, WESTAR, etc.) are used for data transmission. The type of transmission selected depends somewhat on information content (data rate). Telemetry data from satellites will generally be transmitted via the STDN network to a computer center.

2.5.2 Non-Real-Time Transmission

Data may be transmitted by any of the non-real-time methods (mailed, hand carried, etc.)

SECTION 3 - SYSTEM COST ANALYSIS

3.1 GENERAL

This section discusses the method used in developing costs for the altimetry systems proposed to meet the user requirements. The method permits the identification of input parameters that are compatible for use with the economic decision model. Operating parameters (precision, range, resolution, etc.) were specified for each of the user requirements. When the operating parameters could not be satisfied with existing hardware, an improved unit cost was included as a part of the total system cost, accounting for any additional research and development effort that would be required. In every case, component cost estimates include a percent variance, which indicates a high and low range through which a cost estimate might vary and a confidence factor on a scale from 1 to 10, which indicates how confident an expert is of the component cost estimate. The variance and confidence factors relate directly to the source from which the estimate was obtained and rely heavily on historic pricing and inflationary trends. For example, experience shows that it is doubtful that postal rates will ever decrease, but it is certain that they will continue to increase with inflationary trends. A detailed description of the variance and confidence factors is given in the economic model for estuarine evaluation.

3.2 METHODOLOGY

An altimetry system package has been developed for each user requirement, which reflects the hardware requirements (altimeter, accelerometer, maximum-likelihood processor, etc.), platform (spacecraft or aircraft), processing equipment, means of data distribution, overhead, planning, and other associated administrative costs (transportation, per diem, etc.). Each component is costed at present operational capabilities and an improvement factor is applied where current systems cannot satisfy the operating requirements specified in the user requirement. Total life-cycle costs are then computed on a 10-year life cycle. All user requirements can be satisfied by airborne or spaceborne systems. Airborne systems include the use of aircraft purchased specifically to house and transport the altimeter package, and spaceborne systems make use of satellites. In each case, the individual system (aircraft with altimeter package or satellite with altimeter package) is costed and then total costs are derived from the total number of required systems. The following assumptions were made in developing the altimetry system costs:

- Technology is available to attain the operating parameters (precision, range, resolution, etc.) needed to meet user requirements
- Life-cycle costs are over a period of 10 years
- Satellite systems mean time to failure is 3 years
- All electronic components (excluding satellite-installed equipment) have a useful life of 10 years
- Existing tracking stations can be used for tracking satellite altimetry systems and for receiving telemetry data

In addition, specific steps were followed to define each user requirement in terms of its cost elements. These steps include:

- Developing a system and operational scenario for each user requirement so that geographical limits are defined, within reason, and operating and maintenance costs can be derived
- Addressing each individual user requirement in terms of its functional requirements and technical specifications (accuracy, resolution, repetition rate, data format, distribution, etc.)
- Identifying current state-of-the-art altimeter systems and associated subsystems and peripheral equipment. Included are such things as

the altimeter, the inertial navigation system, the maximum-likelihood processor, communications equipment, a minicomputer, and so forth

- Researching component costs
- Applying equipment packages to satisfy each user requirement. Where current operational capability does not match the user requirement, an improvement factor is applied to derive the additional required development costs
- Reviewing initial project planning and startup requirements

Total system costs based on a 10-year-life-cycle, where applicable, were derived for each of the specified user requirements using the methodology outlined above. The following subsections define in greater detail the basic cost categories and associated rationale that apply to this cost analysis.

3.3 COST CATEGORIES

The basic cost categories applicable to this cost analysis are discussed below.

3.3.1 Life-Cycle Costs

These costs include all expenditures associated with the system life cycle and include nonrecurring costs; those costs that are incurred up to system startup on a nonrecurring basis; and annual recurring costs associated with operating and maintaining the system annually for a specified life period (a given number of years). Life-cycle costs may be categorized in many different ways, depending on the type of system and the sensitivities desired in cost-effectiveness measurement. For the purposes of this altimeter system cost analysis, all estimates are based on known or estimated hardware costs to achieve the stated user requirement operating effectiveness. No costs have been inflated or discounted to present values. Discounting refers to applying a selected rate of interest to a cost stream such that each future cost is adjusted to the time when the decision is made. It is understood that discounting will be accomplished by NASA during use of the economic model when applied against the altimeter user requirements.

The life-cycle costs for this cost analysis are based on a 10-year life cycle except for the equipment used on the satellites. This equipment will assume the life expectancy of the satellite, which is 3 years.

3.3.2 Nonrecurring Costs

These costs relate to the research, development, test, and evaluation (RDT&E) phase to a point in which the user requirement system has an initial operating capability. Included are installation, aircraft retrofit, flight test and evaluation, and initial acquisition costs for such things as spare parts, test and maintenance equipment, initial training, housing, and any other one-time expenditures. For this cost analysis, nonrecurring costs are as defined below.

3.3.2.1 Initial Acquisition Costs

These costs are associated with the initial buy of equipment required to achieve system startup.

3.3.2.2. Improvement Costs

Those costs associated with the additional outlay of funds that are required to achieve greater system effectiveness than is currently possible. Four of the altimeter systems conceived to address the 11 user requirements require a twofold to a fivefold improvement over current altimeter capabilities. It was learned from the General Electric Corporation (who engineered and built the GEOS altimeter) that a twofold to fivefold improvement with GEOS would require only an additional expenditure equal to 10 percent of the current GEOS altimeter research and development costs, and a thirtyfold improvement could be accomplished for approximately 100 percent of the current GEOS altimeter research and development costs. A three-hundredfold improvement required by case B, user requirement 1 (Table 1-1), would require a new-technology approach because the bandwidth of the information would be greater than the carrier frequency of the radar. In consideration of this, an estimated $100 million was allocated to achieve a three-hundredfold improvement with a variance of ±50 percent and a confidence factor of 1.

3.3.2.3 Software Development Costs

These costs are associated with the personnel and machine time requested to develop the software programs for processing data collected by the altimeter user requirement systems. Costs are reflective of the software sophistication.

3.3.2.4 Launch Costs

These costs include those associated with launching the satellite. The estimated cost for the Atlas booster was $7 million and was obtained from the GPS project manager's office.

3.3.2.5 Repair Parts (Operating)

These costs are associated with repair parts required to maintain the system in operation. Costs were calculated at 10 percent of the initial acquisition costs.

3.3.2.6 Installation, Flight Test, and Evaluation Costs

These costs are computed on the basis of the flight time required to check out equipment and to familiarize a flight crew with operational procedures. Installation costs are based on both the time and the extent of aircraft modifications that are required to install the equipment aboard the aircraft. These costs were estimated at approximately $10,000 per aircraft installation plus hourly flying costs for equipment familiarization and checkout.

3.3.2.7 Initial Training (Per Diem, Transportation, Etc.)

These costs are associated with system training, and are based on a 2-week course at $50 per day per diem and $400 administrative costs per individual.

3.3.2.8 Test/Maintenance Equipment

These costs are associated with the purchase of test hardware for maintaining the equipment. Costs were derived on the basis of the specific configuration of each user requirement.

3.3.2.9 Personnel Displacement Costs

These costs are associated with the movement of personnel and household effects, and are based on current moving rates in the transportation industry: 8000 pounds of household goods and an average stage length of 1500 miles. Per diem was charged at $50 per day. Automobile mileage was costed at a rate of $0.15 per mile.

3.3.2.10 Land and Building Purchase

These costs are associated with the outright purchase of either a building or land. No purchases were contemplated in any of the user requirements.

3.3.2.11 Program Planning Costs

These costs are associated with the preplanning required to plan for and start up a project. These costs were computed at 2 percent of the nonrecurring costs and then added as a part of the total nonrecurring costs. The 2-percent factor is based on expenditures from other similar projects (SEASAT and Viking). This factor will, however, vary with the complexity of the project.

3.3.3 <u>Annual Recurring Costs</u>

These are costs incurred after acceptance of the altimetry system package and are associated with the operation of the system and the ongoing maintenance of the equipment and facilities. Included are (1) operating costs incorporating data acquisition, processing and analysis, technical management and engineering, communications, tracking costs, and flight crew members; and (2) maintenance costs, which include labor and materials for maintenance of facilities and equipment. For this cost analysis, annual recurring costs are as defined below.

3.3.3.1 Personnel Costs

These are costs associated with the manpower requirements to operate and maintain the system. Salary schedules are as follows: pilots, $30,000 annually; technical personnel, $25,000 annually; maintenance and crew chiefs, $18,000 annually; and administrative personnel $10,000 annually.

3.3.3.2 Rents/Lease Costs

These costs are associated with renting or leasing office or maintenance space. Rates used represent a mean rate based on current office and hangar rental rates throughout the United States.

3.3.3.3 Data Processing Costs

These costs are based on the data processing time multiplied by an hourly machine rate. For this analysis, two hourly rates were used: $500 per hour for standard requirements and $1000 per hour for higher order data processing requirements.

3.3.3.4 Transportation Costs

These costs include all transportation requirements, both air and land. In some instances, automobiles were assumed to be leased; in those cases where it was more economical, they were assumed to be purchased.

3.3.3.5 Per Diem Costs

These costs are computed at $50 per day per person.

3.3.3.6 Retraining Costs

These costs are computed at 10 percent of the initial training costs per annum with a personnel attrition rate of 10 percent per year.

3.3.3.7 Overhead and Administrative Costs

These are based on 50 percent of the personnel salaries and account for personnel benefit and administrative costs.

3.3.3.8 Data Distribution Costs

These costs are associated with distribution of data via facsimile, mail, etc., to the user and in some cases represent just nominal costs.

3.3.3.9 Facility Costs

These costs are associated with facility maintenance and are included in rental rates.

3.3.3.10 Flight Hour Costs

These costs include maintenance, fuel, insurance, depreciation, etc., for flying a specified aircraft (excluding crew). Flight cost for a Lockheed Electra is $535 per hour.

3.3.3.11 Satellite Replacement Costs

Satellite replacement is assumed every 3 years and includes both launch and satellite costs.

3.3.3.12 Satellite Tracking and Stationkeeping Costs

These costs are based on the amount of tracking and satellite monitoring necessary for a user requirement. It is assumed that a STDN tracking facility would be used at an average rate of $1000 per hour.

3.3.3.13 Replenishment Repair Parts

These costs are based on a 50-percent turnover of the initial repair parts package.

3.4 USER REQUIREMENT COST WORKSHEET

A user requirement cost worksheet (Table 3-1) was developed, which identifies by user requirement the operating effectiveness required; all cost elements including hardware, operating, processing, and maintenance requirements; unit costs; improvement costs; a variance and confidence factor for each cost element; required numbers of each cost element; and a total cost. The primary

Table 3-1. Sample Blank User Requirement Cost Worksheet

ACCURACY:
RESOLUTION:
REPETITION RATE:
REPORT TIME:
FORMAT:
DISTRIBUTION:
DURATION OF DATA GATHERING:

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR. (1–10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			

purpose of this user requirement cost worksheet is to provide input data by cost element in a format that can be used with the economic model for estuarine evaluation. It further provides an altimetry systems package from which estimated annual and life-cycle altimetry user requirement costs can be calculated.

3.5 USER REQUIREMENT COST SUMMARY

A user requirement cost summary (Table 3-2) is included for computing annual and life-cycle costs for each of the altimetry user requirements. This cost summary sheet identifies applicable nonrecurring and annual recurring costs for each user requirement, specifies the type of system (satellite or aircraft), and allows for computation and comparison of total life-cycle costs of the satellite versus the aircraft system. All cost elements contained in Table 3-2 are defined in Section 3.3. Life-cycle costs are calculated by the following expression:

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

where LCC = life-cycle costs

NRC = nonrecurring costs

ARC = annual recurring costs (N = number of life-cycle years)

No costs have been inflated or discounted to present values as this will be accomplished in the execution of the economic decision model.

The total life-cycle costs present values from which a preliminary cursory judgment can be made as to the overall cost effectiveness of the system and whether further efforts should be exerted to conduct a detailed cost benefit analysis. It was observed that in most instances, the use of satellites prove to be more expensive than utilizing aircraft because they are costly to launch and require replacement every 3 years. However, in the case of user requirement 1, gravity anomalies, a satellite could be used effectively because the life cycle of the project was less than 3 years and thus required no replacement.

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Table 3-2. Sample Blank User Requirement Cost Summary[a]

COST	PLATFORM	
	SATELLITE	AIRCRAFT
NONRECURRING:		
INITIAL ACQUISITION (EXISTING HARDWARE)		
IMPROVEMENT		
SOFTWARE DEVELOPMENT		
LAUNCH		
REPAIR PARTS (OPERATING)		
INSTALLATION, FLIGHT TEST AND EVALUATION		
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)		
TEST/MAINTENANCE EQUIPMENT		
PERSONNEL DISPLACEMENT		
LAND AND BUILDING PURCHASE		
PROGRAM PLANNING		
TOTAL NONRECURRING COSTS		
ANNUAL RECURRING:		
OPERATING		
PERSONNEL		
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC.; INCLUDES UTILITIES)		
DATA PROCESSING		
TRANSPORTATION		
PER DIEM		
RETRAINING (10 PERCENT ANNUAL TURNOVER)		
OVERHEAD AND ADMINISTRATIVE		
DATA DISTRIBUTION		
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)		
SATELLITE REPLACEMENT		
TRACKING AND STATIONKEEPING		
REPAIR PARTS (REPLENISHMENT)		
TOTAL ANNUAL RECURRING COSTS		
TOTAL COSTS FOR [10] YEARS = $		

[a] LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

SECTION 4 - ALTIMETER SYSTEM COST ANALYSIS

This section describes the system proposed to meet the user requirements along with an associated cost analysis. For each requirement, the information is presented as follows:

- User requirement
- Narrative describing system components and operation
- Illustration depicting system operation
- User requirement cost summary
- User requirement cost worksheets

4.1 USER REQUIREMENTS FOR INFERRING GRAVITY ANOMALIES

The user requirements for inferring gravity anomalies from satellite altimetry measurements are as follows:

- Accuracy: Case A 2 to 3 milligal
  B 1 milligal
- Resolution: Case A 3 by 3 kilometers
  B 1 by 1 kilometer
- Repetition rate: Not critical
- Report time: Not critical
- Format: Data tapes and gravity anomaly maps
- Distribution: Worldwide via special publication
- Duration of data acquisition: To completion of global coverage

To satisfy these requirements, a system incorporating a radar altimeter aboard a satellite is required (Figure 4-1). The satellite should be in a polar orbit (90-degree inclination) to achieve global coverage with a nominal 2-hour period. Because the orbit is polar, its ascending node does not precess; thus, to sample every point for cases A and B on the Earth in the shortest possible time the orbit chosen must be such that successive equatorial crossings are no closer than 1 or 3 kilometers, respectively. For a satellite orbital period of about 2 hours, the satellite will cross the equator 24 times, 12 ascending nodes and 12 descending nodes, each 24 hours. Because the Earth rotates 15 degrees per hour, if the system begins at an ascending node at zero hour, all ascending nodes will occur at or near even hours and all descending nodes at or near odd hours. To achieve global coverage at 1- or 3-kilometer intervals, a nonintegral number of nodal crossings per day is necessary and a suitable orbit period must be determined. An orbital rate slightly greater than 2 hours is required, such that the thirteenth revolution crosses the equator on the ascending node 1 or

3 kilometers from the initial orbit. The correct orbital period, τ_{sat}, to achieve the foregoing requirements is determined by the following equation:

$$\tau_{sat} = 2\pi \frac{\left[1 \pm \frac{\delta}{2\pi R_0}\right]}{12\,\omega_e}$$

where δ = resolution (1 or 3 kilometers)

R_0 = Earth's semimajor axis (6378.1 kilometers)

ω_e = Earth's rotation rate (7.29211585 radians per second)

At the orbital periods necessary to achieve the 3- and 1-kilometer resolution, the time, T , necessary for one satellite to map the whole Earth is equal to

$$T = \frac{2\pi R_0}{24\,\delta}$$

555 days and 1670 days, respectively.

It is assumed that the lifetime of a satellite for case B is 5 years, an improvement of 2 years over current-generation satellites. Because of the high duty rate assumed for this mission (100 percent), however, this improvement may be difficult to achieve. Furthermore, because of the small surface region (1 kilometer) being observed, multiple passes will probably be needed to filter out transient conditions on the sea surface. However, both of these factors are being ignored in this analysis because this requirement is difficult to meet, even with unconstrained technology.

To determine gravity anomalies to within the specified values, the geoidal height uncertainty may not exceed 0.3 centimeter for case A and 0.03 centimeter for case B. These values are inferred from the requirements of 3 milligal and

and 1 milligal using Kaula's Rule.[1] They are statistical estimates representing the expected variance in the geoid height for area elements of 3 by 3 kilometers and 1 by 1 kilometer for cases A and B, respectively. In practice, the requirements can be expected to be more stringent because the theory used to estimate geoidal heights from gravity anomalies is imprecise. Dr. M. A. Khan used gravity models with 3-milligal uncertainty averaged over 1-degree-by-1-degree squares to generate geoidal heights having a 1-meter uncertainty. In performing the inverse calculation, i.e., generating gravity anomalies from geoidal heights and, in particular, using the ±1-meter geoidal heights, an uncertainty in gravity anomalies of the order of 15 to 20 milligal was realized. Thus, the current theory requires an increase in altimeter precision by a factor of five to seven.

To meet these user accuracy requirements, all errors must be less than 0.3 centimeter or 0.03 centimeter. The uncertainty in geoidal height arises from satellite tracking and attitude errors, atmospheric propagation errors, and altimeter errors. As stated in Section 2, these factors cannot presently be corrected to this accuracy. Thus, the theory must be developed further.

Data must be recorded in the units of time it takes for the radar pulse to travel from the antenna and be reflected by the sea and return to the detector. A time tag is applied to each piece of data that may be an average of many reflections. The time tag is used to pick out the satellite position from the ephemeris and the elapsed transmission time is used to estimate the range to the surface. A multitude of these range data after correcting for atmospheric effects and other factors is averaged over a selected square and, successively, geoidal height and gravity anomaly determinations are made over the area of interest. A simulation performed in support of the GEOS-C satellite can be used as an

[1] This rule may not be strictly valid for degrees of this magnitude (case A, n = 6,000; case B, n = 18,000).

example of the computer time required to produce a worldwide gravity map. In this case, geoidal heights and gravity anomalies over a region 24 degrees longitude and 17 degrees latitude were determined. In this simulation, 1500 1-second range averages were processed in 5 minutes on the IBM S/360-95 computer to produce 2-degree-by-2-degree maps.

The GEOS-C altimeter is used to study regions 100 kilometers by 100 kilometers and has a repetition rate of 10 pulses per second. Thus, for the same number of samples per 1-by-1-kilometer resolution element, a pulse repetition rate of 1000 pulses per second is required.

Computation time for each resolution element is 3 seconds and there are approximately 8 by 10^8 elements on the Earth's surface for case B. The amount of computer time required to produce a worldwide gravity anomaly map of the ocean with a 1-kilometer resolution is 35 to 40 years. This figure takes into account that the Earth is 30 percent land and the distance between the meridians decreases with increasing latitude. For case A, this time would be reduced by a factor of 9. The IBM S/360-95 is a third-generation machine, and existing fourth-generation machines (Illiac, CDC Star, etc.) are at least an order of magnitude faster. Case B data, therefore, can probably be processed in 4 years whereas case A data can be processed in approximately 6 months. If data from only certain regions of the Earth must be processed, much less computing time is required. Once processed, gravity anomaly maps can be mailed to users.

The costs of the system required for cases A and B are $36,794,514 and $209,241,403, respectively. The following pages contain a detailed breakdown of these costs.

A less stringent set of user requirements for inferring gravity anomalies is as follows:

- Accuracy: Case C 40 milligal
- Resolution: 30 by 30 kilometers
- Repetition rate: Not critical

- Format: Data tapes and gravity anomaly maps
- Distribution: Worldwide via special publication
- Duration of data gathering: To completion of global coverage

To satisfy these requirements, a system employing an altimeter similar to that onboard the GEOS-3 satellite is required. Forty-milligal accuracy over a 30-kilometer region corresponds to an altimeter accuracy of 0.40 meter, well within the current capability of GEOS-3. The equation used is as follows:

$$\sigma_L(N) = \frac{R_E \, L}{\gamma \, (2 \times 10^{+4} - L)} \, \sigma_L(\Delta g)$$

where $\sigma_L(N)$ = expected deviation in geoid height, N, over an area L kilometers on a side (meters)

R_E = mean Earth radius, 6,370,000 meters

γ = mean gravity on the geoid, 980,000 milligal

$\sigma_L(\Delta g)$ = expected deviation in mean free air gravity anomaly over an area L kilometers on a side (milligal)

Data should be collected over a 3-year period with a duty cycle of 4 hours of data collected per day. If the orbit is chosen such that it precesses 1/3 degree per day, two independent sets of data for each point on the Earth (separated by 111 kilometers = 1 degree) will be collected. This will facilitate identification and removal of transient topographic features. The satellite needs to be tracked globally using the existing STDN network, which should be able to locate the satellite sufficiently accurately over a short, slowly varying arc to detect gravity anomalies to within 0.40 meter.

The costs for the three satellite systems are as follows: case A, $36,795,514 (2 years); case B, $209,241,403 (9 years); and case C, $12,674,324 (1 year). Tables 4-1 and 4-2 present detailed cost information.

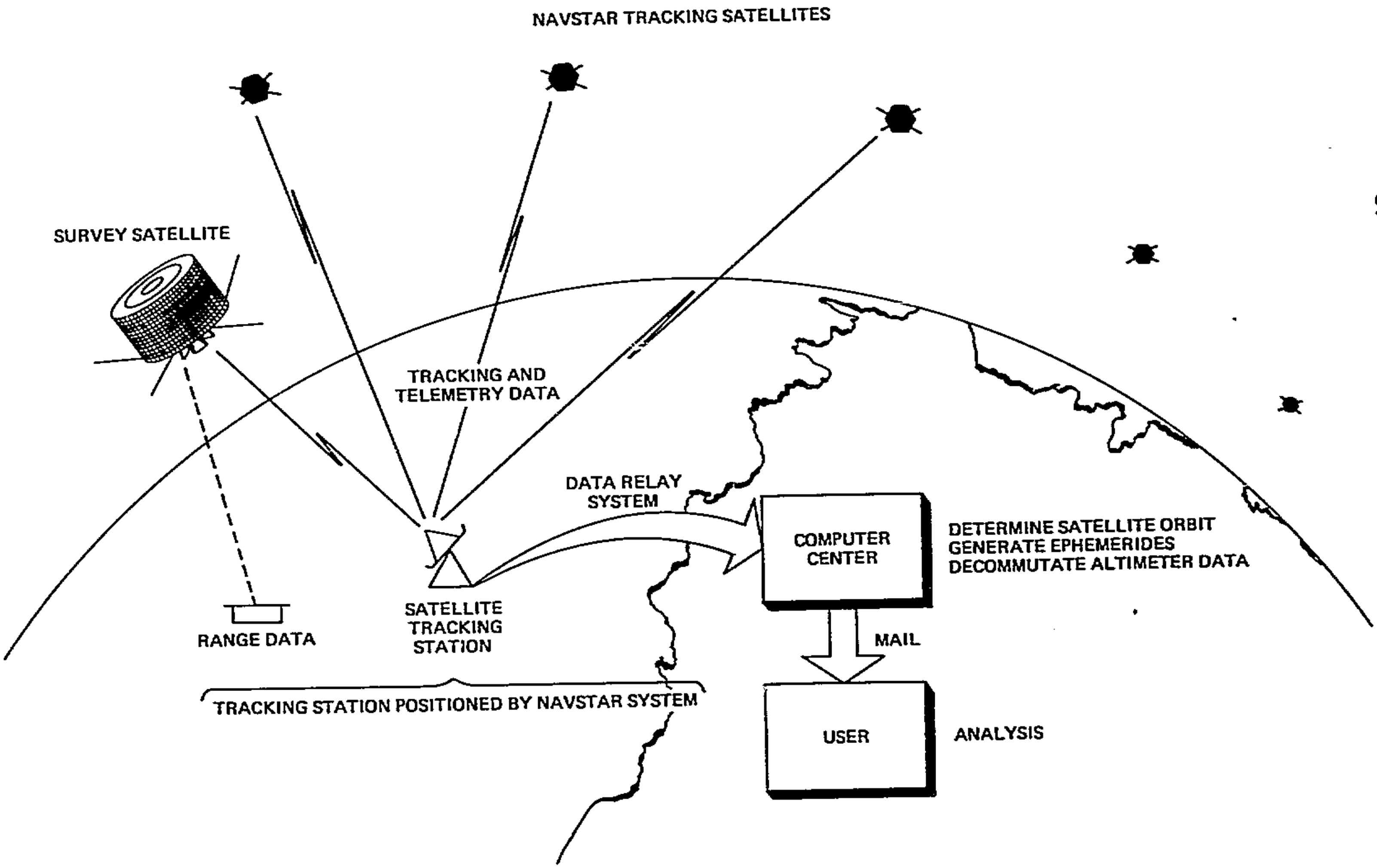

Figure 4-1. Inferred Gravity Anomalies--Spacecraft

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Table 4-1. User Requirement Cost Summary for Inferring Gravity Anomalies[a]

TYPE OF COST	PLATFORM COST (DOLLARS)		
	CASE A SATELLITE	CASE B SATELLITE	CASE C SATELLITE
NONRECURRING			
INITIAL ACQUISITION (EXISTING HARDWARE)	4,500,000	4,500,000	4,500,000
IMPROVEMENT	4,500,000	112,500,000	
SOFTWARE DEVELOPMENT	1,500,000	3,000,000	100,000
LAUNCH	7,000,000	7,000,000	7,000,000
REPAIR PARTS (OPERATING)	N/A	N/A	N/A
INSTALLATION, FLIGHT TEST AND EVALUATION	N/A	N/A	N/A
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)	N/A	N/A	N/A
TEST/MAINTENANCE EQUIPMENT	N/A	N/A	N/A
PERSONNEL DISPLACEMENT	N/A	N/A	N/A
LAND AND BUILDING PURCHASE	N/A	N/A	N/A
PROGRAM PLANNING	357,000	2,590,800	236,640
TOTAL NONRECURRING COSTS	17,857,000	129,590,800	11,836,640
ANNUAL RECURRING			
OPERATING			
PERSONNEL	8,750	35,000	35,000
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC., INCLUDES UTILITIES)	1,184	1,184	1,184
DATA PROCESSING	8,760,000[b]	8,760,000[c]	53,000
TRANSPORTATION	N/A	N/A	
PER DIEM	N/A	N/A	
RETRAINING (10 PERCENT ANNUAL TURNOVER)	N/A	N/A	
OVERHEAD AND ADMINISTRATIVE	4,375	17,500	17,500
DATA DISTRIBUTION	1,036	36,383	1,000
MAINTENANCE			
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)	N/A	N/A	
FLIGHT HOUR (AIRCRAFT)	N/A	N/A	N/A
SATELLITE REPLACEMENT	N/A	N/A	N/A
TRACKING AND STATIONKEEPING	8,760,000[d]	8,760,000[e]	730,000
REPAIR PARTS (REPLENISHMENT)	N/A	N/A	N/A
TOTAL ANNUAL RECURRING COSTS	9,468,757	8,850,067	837,684
TOTAL COSTS	36,794,514 (2 YEARS)	209,241,403 (9 YEARS)	12,674,324 (1 YEAR)

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

[b]FOR 6 MONTHS.
[c]FOR 4 YEARS.
[d]FOR 565 DAYS.
[e]FOR 1670 DAYS.

Table 4-2. User Requirement Cost Worksheet for Inferring Gravity Anomalies (1 of 5)

ACCURACY: CASE A, 2 TO 3 MILLIGAL; CASE B, 1 MILLIGAL
RESOLUTION: CASE A, 3 BY 3 KILOMETERS; CASE B, 1 BY 1 KILOMETER
REPETITION RATE: NOT CRITICAL
REPORT TIME: NOT CRITICAL
FORMAT: DATA TAPES AND GRAVITY ANOMALY MAPS
DISTRIBUTION: WORLDWIDE VIA SPECIAL PUBLICATION
DURATION OF DATA GATHERING: TO COMPLETION OF GLOBAL COVERAGE

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE (SEASAT ALTIMETER) (CASE A)	4,500,000	30	4,500,000	25	25	7	1	9,000
SATELLITE (SEASAT ALTIMETER) (CASE B)	4,500,000	300	108,000,000	50	50	1	1	112,510,000
SOFTWARE DEVELOPMENT COSTS (CASE A)	N/A	30	500,000/ YEAR	15	15	3	3	1,500,000
SOFTWARE DEVELOPMENT COSTS (CASE B)	N/A	300	1,000,000/ YEAR	15	15	1	3	3,000,000
LAUNCH COSTS	7,000,000	N/A	N/A	15	15	8	1	7,000,000
PROGRAM PLANNING COSTS (CASE A)	357,000	N/A	N/A	30	5	6	N/A	357,000
PROGRAM PLANNING COSTS (CASE B)	2,590,800	N/A	N/A	30	5	6	N/A	2,590,800
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	1	25,000

Table 4-2. User Requirement Cost Worksheet for Inferring Gravity Anomalies (2 of 5)

SATELLITES A AND B (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1–10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
PERSONNEL (ADMINISTRATIVE)	10,000/YEAR	N/A	N/A	10	10	9	1	10,000
OFFICE RENT (10 BY 15 FEET)	7.89 FEET^2/	N/A	N/A	15	15	8	150	1,184
DATA PROCESSING SYSTEM (CASE A)	1,000/HOUR	N/A	N/A	15	15	4	4,380	4,380,000
DATA PROCESSING SYSTEM (CASE B)	1,000/HOUR	N/A	N/A	15	15	4	35,040	35,040,000
OVERHEAD COSTS (CASE A)	0.5 X PER-SONNEL COSTS	N/A	N/A	15	5	8	N/A	4,375
OVERHEAD COSTS (CASE B)	0.05 X PER-SONNEL COSTS	N/A	N/A	15	5	8	N/A	17,500
DATA DISTRIBUTION (CASE A)	1.12/POUND	N/A	N/A	30	0	9	1,460 YEAR	1,635
DATA DISTRIBUTION (CASE B)	1.12/POUND	N/A	N/A	30	0	9	32,485 YEAR	36,383

Table 4-2. User Requirement Cost Worksheet for Inferring Gravity Anomalies (3 of 5)

SATELLITES A AND B (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE TRACKING	1,000/HOUR	N/A	N/A	15	15	9	8,760	8,760,000

Table 4-2. User Requirement Cost Worksheet for Inferring Gravity Anomalies (4 of 5)

SATELLITE C

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE (SEASAT ALTIMETER)	4,500,000		4,500,000	15	15	9	1	4,500,000
SOFTWARE DEVELOPMENT COSTS	N/A	N/A	N/A	15	15	3	1	100,000
LAUNCH COSTS	7,000,000	N/A	N/A	15	15	8	1	7,000,000
PROGRAM PLANNING COSTS	236,640	N/A	N/A	30	5	6	N/A	236,640
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	1	25,000
PERSONNEL (ADMINISTRATIVE)	10,000/YEAR	N/A	N/A	10	10	9	1	10,000
OFFICE RENT (10 BY 15 FEET)	7.89 FEET^2/ YEAR	N/A	N/A	15	15	8	150	1,184
DATA PROCESSING	500/HOUR	N/A	N/A	15	15	4	106	53,000

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Table 4-2. User Requirement Cost Worksheet for Inferring Gravity Anomalies (5 of 5)

SATELLITE C

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
OVERHEAD COSTS	0.5 X PER-SONNEL COSTS	N/A	N/A	15	5	8	N/A	17,500
DATA DISTRIBUTION	NOMINAL							1,000
SATELLITE TRACKING COSTS[a]	1,000/HOUR	N/A	N/A	15	15	9	730	730,000

[a]TWO HOURS PER DAY FOR 365 DAYS.

4.2 USER REQUIREMENTS FOR DETERMINING WAVE STATISTICS

The user requirements for determining wave statistics for offshore structure design are as follows:

- Accuracy: ±10 centimeters (seastate)
- Resolution: 1 by 1 kilometer
- Repetition rate: 2 hours (during storm)
- Report time: Not critical
- Format: Data tape only
- Distribution: Specific users (small number)
- Duration of data gathering: Permanent task

The altimeter provides statistics on wave height distribution; wave directional spectra, of primary importance in tower design, cannot be obtained. To gather the wave statistics via a satellite system, 12 satellites, each carrying a radar altimeter, are required (Figure 4-2(a)), and such a system would be extremely expensive. Each satellite, about the size of GEOS-3, must be in a polar orbit (90-degree inclination) at an altitude of 480 kilometers, with successive right ascensions of the ascending node differing by 30 degrees. This will enable observations over the region of interest every 2 hours. The satellite altimeter must be able to provide seastate data to within ±10 centimeters. The altimeter currently under development for SEASAT-A has a precision of ±10 centimeters and can provide seastate to within ±50 centimeters. Thus, a fivefold improvement in altimeter precision to ±2 centimeters is expected to be able to meet the ±10-centimeter seastate requirement.

The satellite trajectory must also be known to within ±2 centimeters as it passes over the region of interest so that vertical excursions can be filtered out of the range data. With a slight improvement in the ±3-centimeter precision, the planned NAVSTAR system can satisfy this requirement. The data-handling requirements are not excessive, for 1 year of data can be readily processed by the anticipated SEASAT-A data processing system.

The altimeter data rate will not exceed the SEASAT-A 300-bit-per-second rate if a maximum-likelihood processor is deployed on the satellite. On the assumption that there will be 12 observations per day, the computer time required for 1 year of data is a few minutes. The processed data (seastate versus time) can be mailed to the user for input into Texas Tower design models.

An alternative to a 12-satellite system is one employing an aircraftborne radar altimeter (Figure 4-2(b)). The altimeter should be a fivefold improved version of the NRL nanosecond radar, which has a range quantization of 0.625 nanosecond = 9.37 centimeters. The improved version should have a range quantization of 0.125 nanosecond = 0.187 centimeters. Such an improvement can be achieved by decreasing the pulse duration by a factor of five. An instrumented Electra aircraft could be sent to the offshore region of interest whenever a severe storm is forecast. Such an aircraft would traverse the region of interest every 2 hours and collect wave-height data. If the duration of the storm exceeds 6 hours (the nominal aircraft loiter time), as it frequently does, at least two aircraft will be required. For example, to reduce turbulent motions, an aircraft flying at 500 kilometers per hour at an altitude of over 20,000 feet can travel 1000 kilometers in 2 hours (overfly a 100-kilometer-by-100-kilometer region 10 times with flight lines spaced every 10 kilometers). For each 10-kilometer region, 18 seconds of seastate data should be recorded.

A vertical accelerometer is needed to correct for aircraft vertical motions resulting from turbulence during the time data is being collected. The aircraft should also be equipped with a NAVSTAR receiver to update its inertial navigator so that it can determine its position to within 1 kilometer. The seastate data may be processed onboard the aircraft using a maximum-likelihood processor, the output of which can be stored on tape. Once the aircraft has landed, the tape can be stored until all data has been collected. These tapes can then be mailed to the users for processing to determine wave statistics.

The costs of the spaceborne and airborne systems over a 10-year period are $581,380,270 and $6,789,331, respectively. Tables 4-3 and 4-4 contain detailed cost information.

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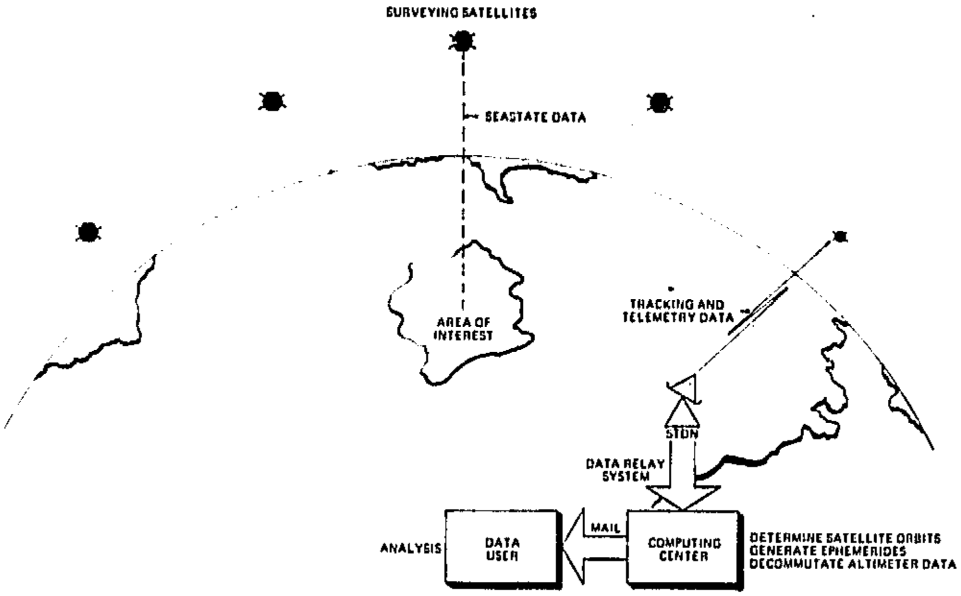
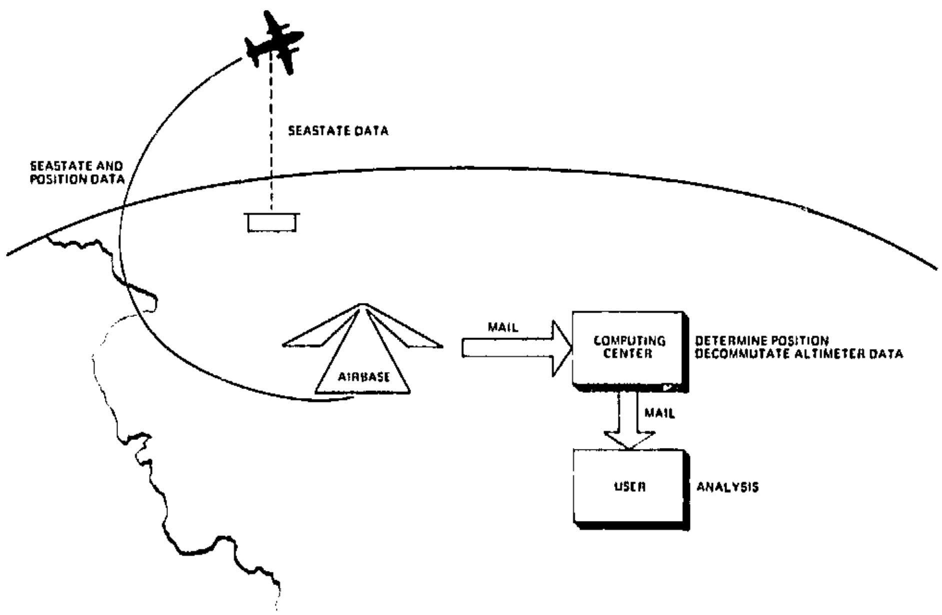


(a) Satellites



(b) Aircraft

Figure 4-2. Offshore Wave Statistics--Satellites and Aircraft

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Table 4-3. User Requirement Cost Summary for Determining Wave Statistics[a]

TYPE OF COST	PLATFORM COST (DOLLARS)	
	SATELLITE	AIRCRAFT
NONRECURRING		
INITIAL ACQUISITION (EXISTING HARDWARE)	54,300,000	1,453,000
IMPROVEMENT	5,400,000	7,500
SOFTWARE DEVELOPMENT	20,000	10,000
LAUNCH	84,000,000	N/A
REPAIR PARTS (OPERATING)	N/A	25,650
INSTALLATION, FLIGHT TEST AND EVALUATION	N/A	38,050
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)	N/A	6,600
TEST/MAINTENANCE EQUIPMENT	N/A	7,896
PERSONNEL DISPLACEMENT	N/A	2,400
LAND AND BUILDING PURCHASE	N/A	N/A
PROGRAM PLANNING	2,874,000	31,441
TOTAL NONRECURRING COSTS	146,594,000	1,572,641
ANNUAL RECURRING		
OPERATING		
PERSONNEL	2,083	216,000
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC., INCLUDES UTILITIES)	N/A	4,932
DATA PROCESSING	500	500
TRANSPORTATION	N/A	1,000
PER DIEM	N/A	18,230
RETRAINING (10 PERCENT ANNUAL TURNOVER)	N/A	660
OVERHEAD AND ADMINISTRATIVE	1,042	108,000
DATA DISTRIBUTION	NOMINAL	NOMINAL
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)	N/A	160,500
SATELLITE REPLACEMENT	43,110,000	N/A
TRACKING AND STATIONKEEPING	365,000	N/A
REPAIR PARTS (REPLENISHMENT)	N/A	12,825
TOTAL ANNUAL RECURRING COSTS	43,478,627	522,609
TOTAL COSTS FOR (10) YEARS = $	581,380,270	6,79[illegible]

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

Table 4-4. User Requirement Cost Worksheet for Determining Wave Statistics (1 of 5)

SATELLITE

ACCURACY: ±10 CENTIMETERS (SEASTATE)
RESOLUTION. 1 BY 1 KILOMETER
REPETITION RATE: 2 HOURS DURING STORM
REPORT TIME: NOT CRITICAL
FORMAT: DATA TAPE ONLY
DISTRIBUTION: SPECIFIC USERS (SMALL NUMBER)
DURATION OF DATA GATHERING: CONTINUOUS, PERMANENT

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE (SEASAT ALTIMETER)	4,500,000	5	4,950,000	37	0	9	12	59,400,000
MAXIMUM-LIKELIHOOD PROCESSOR	25,000	N/A	N/A	15	15	7	12	300,000
SOFTWARE DEVELOPMENT	2,500/MONTH	N/A	N/A	5	5	8	8 MONTHS	20,000
LAUNCH COSTS	7,000,000	N/A	N/A	15	15	8	12	84,000,000
PROGRAM PLANNING COSTS	2,874,000	N/A	N/A	30	5	6	N/A	2,874,000
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	1 MONTH	2,083
DATA PROCESSING SYSTEM	500/HOUR	N/A	N/A	15	15	8	1 HOUR	500
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	1,042

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Table 4-4. User Requirement Cost Worksheet for Determining Wave Statistics (2 of 5)

SATELLITE (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
DATA DISTRIBUTION (MAIL)	1.12/POUND	N/A	N/A	30	0	9	1	2
SATELLITE TRACKING COSTS	1000/HOUR	N/A	N/A	50	20	7	365	365,000

Table 4-4. User Requirement Cost Worksheet for Determining Wave Statistics (3 of 5)

AIRCRAFT

ACCURACY: ±10 CENTIMETERS (SEASTATE)
RESOLUTION: 1 BY 1 KILOMETER
REPETITION RATE: 2 HOURS DURING STORM
REPORT TIME: NOT CRITICAL
FORMAT: DATA TAPE ONLY
DISTRIBUTION: SPECIFIC USERS (SMALL NUMBER)
DURATION OF DATA GATHERING: CONTINUOUS, PERMANENT

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
AIRCRAFT (LOCKHEED ELECTRA)	600,000	N/A	N/A	10	10	8	2	1,200,000
NANOSECOND RADAR ALTIMETER	75,000	5	82,500	25	25	6	2	165,000
VERTICAL ACCELEROMETER	10,000	N/A	N/A	10	10	7	2	20,000
SATELLITE RECEIVER (NAVSTAR)	10,000	N/A	N/A	25	25	5	2	20,000
MAXIMUM-LIKELIHOOD PROCESSOR	25,000	N/A	N/A	15	15	7	2	50,000
SOFTWARE DEVELOPMENT	2,500/MONTH	N/A	N/A	5	5	8	4 MONTHS	10,000
AUXILIARY EQUIPMENT[a]	1,500 EACH	N/A	N/A	5	5	9	1	1,500
EQUIPMENT INSTALLATION, FLIGHT TEST AND EVALUATION	535/HOUR	N/A	N/A	10	10	8	30 FLIGHT HOURS	36,050

[a]THE INSTALLATION COST FOR EACH AIRCRAFT IS $10,000

Table 4-4. User Requirement Cost Worksheet for Determining Wave Statistics (4 of 5)

AIRCRAFT (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
TRAINING (2-WEEK COURSE)	1,000/PER	N/A	N/A	10	10	7	6 PER	6,600
AIR TRAVEL	300/TICKET (ROUND TRIP)	N/A	N/A	15	0	9	8	2,400
PROGRAM PLANNING COSTS	31,441	N/A	N/A	30	5	6	N/A	31,441
FLIGHT PERSONNEL (PILOT)	30,000/YEAR	N/A	N/A	10	10	9	4	120,000
FLIGHT PERSONNEL (CREW)	18,000/YEAR	N/A	N/A	10	10	9	2	36,000
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	2	50,000
PERSONNEL (ADMINISTRATIVE)	10,000/YEAR	N/A	N/A	10	10	9	1	10,000
OFFICE RENT	7.89 FOOT^2	N/A	N/A	10	10	8	1 YEAR	4,932

Table 4-4. User Requirement Cost Worksheet for Determining Wave Statistics (5 of 5)

AIRCRAFT (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 - 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
DATA PROCESSING SYSTEM	500/HOUR	N/A	N/A	15	15	8	1 HOUR	500
CAR PURCHASE	4000/CAR	N/A	N/A	10	10	9	1	4,000
PER DIEM	50/DAY	N/A	N/A	5	5	9	365 DAYS	18,250
OVERHEAD COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	108,000
DATA DISTRIBUTION MAIL	1.12/POUND	N/A	N/A	30	0	9	1 POUND	2
AIRCRAFT OPERATING COSTS	535/HOUR	N/A	N/A	10	10	8	300	160,500

4.3 USER REQUIREMENTS FOR PREDICTING HURRICANE/STORM PATHS

The user requirements for predicting hurricane/storm paths are as follows:

- Accuracy: ±10 centimeters
- Resolution: 0.5 by 0.5 kilometer
- Repetition rate: 1 hour
- Report time: 2 hours after reading
- Format: Digital grid for wave heights
- Distribution: Regional (area affected)
- Duration of data gathering: Permanent task

It is doubtful that a spacecraft could meet this requirement because a hurricane path is irregular, making observation by a satellite on a continuing basis extremely improbable. Furthermore, multiple satellite passes over the hurricane in a short period of time is next to impossible even given the premise of unconstrained technology. An alternative method is that of mounting an altimeter aboard a hurricane hunter aircraft.

A hurricane is typically 600 kilometers across, and the speed of a hurricane hunter aircraft is 500 kilometers per hour. This alternative, therefore, will enable only one pass to be made across the hurricane in 1 hour. In addition, turbulence within the hurricane would probably preclude the P-3 hurricane hunters from penetrating at 500 kilometers per hour. Thus, a fleet of aircraft would be needed if hourly seastate data are desired. This requirement, and the fact that seastate would be of only marginal value in predicting the path of a hurricane (current models only require sea surface temperature, wind, and pressure versus altitude) leads to the conclusion that a system employing a radar altimeter to predict the path of a hurricane would be extremely cost in-effective.

4.4 USER REQUIREMENTS FOR COASTAL SURGE, STORM-DRIVEN RUNUP

The user requirements for coastal surge, storm driven runup are as follows:

- Accuracy: ±10 centimeters
- Resolution: 10 by 10 kilometers
- Repetition rate: 6 hours
- Report time: 3 hours after reading
- Format: Analog or digital grid displayed on map of specific coastal areas of interest
- Distribution: Regional (area affected)
- Duration of data gathering: Permanent task

Satisfaction of this requirement with a satellite-based altimeter system is possible (Figure 4-3(a). However, four satellites in polar orbit would be needed to interrogate some general region on a 6-hour basis. The SEASAT-A altimeter has sufficient precision to meet the ±10-centimeter accuracy, provided that the satellite can be tracked to within ±10 centimeters. This accuracy should be possible using either the planned NAVSTAR navigation system or one with its accuracy. Also needed are local tide tables so that the oscillations in surface height due to tides can be subtracted for altitude range measurements during storm periods. Data from the altimeter can be telemetered to a STDN ground receiving station and subsequently to the National Oceanic and Atmospheric Administration (NOAA) or some other agency for processing. Altimeter data can be quickly processed using SEASAT algorithms for input into the storm surge models. A telefax link between the processing center and the user must be established for rapid data distribution of digital grid maps.

A system employing an aircraftborne altimeter can be employed as an alternative (Figure 4-3(b)). The aircraft must be tracked continuously and its vertical position must be known to within ±10 centimeters. Three tracking stations employing all-weather radar trackers are needed. The station coordinates can be located to within ±10 centimeters using the planned NAVSTAR system. The aircraft used should be a Lockheed Electra, outfitted with a radar transponder to facilitate radar tracking. Both the NRL nanosecond radar and the Wallops AAFE altimeter have sufficient precision to measure the range to the surface to within ±10 centimeters. Surface profiles can be taken on both the outbound and inbound flight legs. Data should be telemetered to the aircraft base and then sent by telephone line to a central processing facility. A telephone line to the user will enable the facsimilies to reach the user within 3 hours.

The cost of such a satelliteborne altimeter system for a 10-year period is estimated to be $185,301,403; an aircraftborne system is estimated to cost $9,255,832. Tables 4-5 and 4-6 include detailed cost information for each system.

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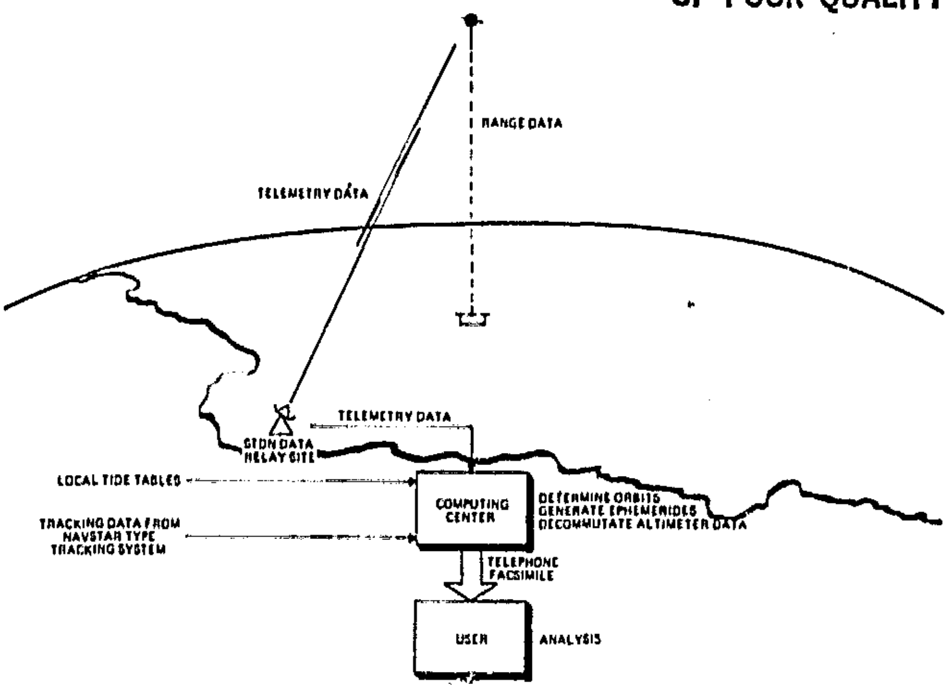
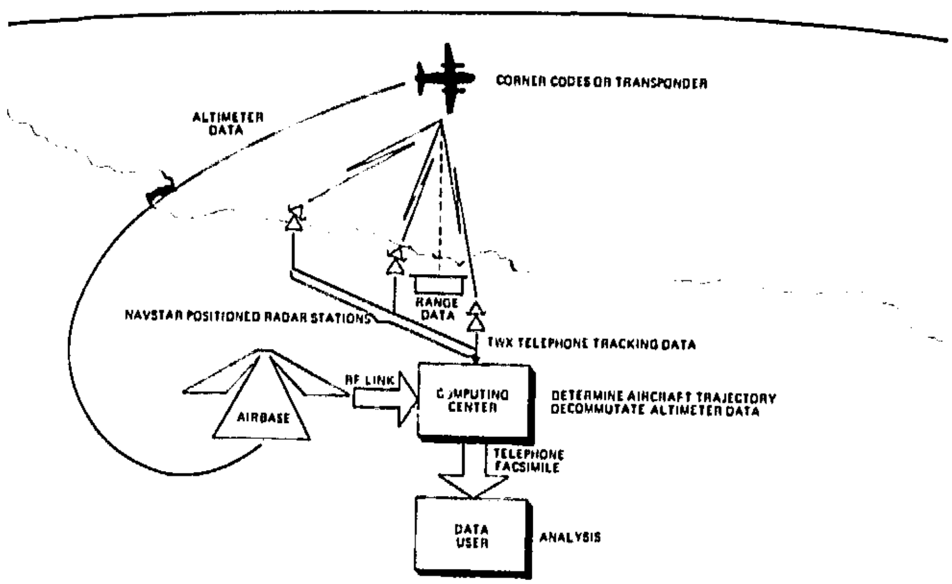


(b) Spacecraft



(b) Aircraft

Figure 4-3. Coastal Surge--Spacecraft and Aircraft

Table 4-5. User Requirement Cost Summary for Coastal Surge Storm-Driven Runup[a]

TYPE OF COST	PLATFORM COST (DOLLARS)	
	SATELLITE	AIRCRAFT
NONRECURRING		
INITIAL ACQUISITION (EXISTING HARDWARE)	18,016,150	1,412,650
IMPROVEMENT	N/A	N/A
SOFTWARE DEVELOPMENT	15,000	12,000
LAUNCH	28,000,000	N/A
REPAIR PARTS (OPERATING)	N/A	62,575
INSTALLATION, FLIGHT TEST AND EVALUATION	N/A	23,375
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)	N/A	7,700
TEST/MAINTENANCE EQUIPMENT	N/A	26,817
PERSONNEL DISPLACEMENT	N/A	18,095
LAND AND BUILDING PURCHASE	N/A	N/A
PROGRAM PLANNING	920,623	30,955
TOTAL NONRECURRING COSTS	46,951,773	1,665,732
ANNUAL RECURRING		
OPERATING		
PERSONNEL	4,167	181,000
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC.; INCLUDES UTILITIES)	N/A	4,932
DATA PROCESSING	2,[illegible]	10,500
TRANSPORTATION	N/A	N/A
PER DIEM	3,000	4,900
RETRAINING (10 PERCENT ANNUAL TURNOVER)	N/A	770
OVERHEAD AND ADMINISTRATIVE	2,084	90,500
DATA DISTRIBUTION	N/A	N/A
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)	N/A	445,120
SATELLITE REPLACEMENT	13,804,845	N/A
TRACKING AND STATIONKEEPING	18,700	N/A
REPAIR PARTS (REPLENISHMENT)	N/A	31,288
TOTAL ANNUAL RECURRING COSTS	13,834,963	769,010
TOTAL COSTS FOR (10) YEARS = $	185,301,403	9,255,832

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

Table 4-6. User Requirement Cost Worksheet for Coastal Surge Storm-Driven Runup (1 of 5)

SATELLITE
ACCURACY ±10 CENTIMETERS
RESOLUTION 10 BY 10 KILOMETERS
REPETITION RATE 6 HOURS
REPORT TIME 3 HOURS AFTER READING
FORMAT ANALOG OR DIGITAL GRID (MAP DISPLAY)
DISTRIBUTION REGIONAL (AREA AFFECTED)
DURATION OF DATA GATHERING PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1–10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE (SEASAT ALTIMETER)	4,500,000	N/A	N/A	15	15	7	4	18,000,000
DATA DISTRIBUTION (FAC)	TX AND RX 16,150	N/A	N/A	10	5	10	1	16,150
SOFTWARE DEVELOPMENT COSTS	2,500/MONTH	N/A	N/A	5	5	8	6 MONTHS	15,000
LAUNCH COSTS	7,000,000	N/A	N/A	15	15	8	4	28,000,000
PROGRAM PLANNING COSTS	920,623	N/A	N/A	30	5	6	N/A	920,623
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	2 MONTHS 1 YEAR	4,167
DATA PROCESSING SYSTEM	5 MINUTE/DAY 500/HOUR	N/A	N/A	30	30	6	4.33	2,167
PER DIEM	50/DAY	N/A	N/A	5	5	9	60	3,000

Table 4-6. User Requirement Cost Worksheet for Coastal Surge Storm-Driven Runup (2 of 5)

SATELLITE (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 - 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PER-SONNEL COSTS	N/A	N/A	15	5	8	N/A	2,084
STDN COSTS	1,040/HOUR	N/A	N/A	50	20	7	18	18,720

Table 4-6. User Requirement Cost Worksheet for Coastal Surge Storm-Driven Runup (3 of 5)

AIRCRAFT
ACCURACY: ± 10 CENTIMETERS
RESOLUTION: 10 BY 10 KILOMETERS
REPETITION RATE: 6 HOURS
REPORT TIME: 3 HOURS AFTER READING
FORMAT: ANALOG OR DIGITAL GRID (MAP DISPLAY)
DISTRIBUTION: REGIONAL (AREA AFFECTED)
DURATION OF DATA GATHERING: PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
AIRCRAFT (LOCKHEED ELECTRA)	600,000	N/A	N/A	10	10	8	1	600,000
NANOSECOND RADAR ALTIMETER	75,000	N/A	N/A	10	10	8	1	75,000
INERTIAL NAVIGATION SYSTEM (LTN 51)	110,000	N/A	N/A	5	5	10	1	110,000
SATELLITE RECEIVER (NAVSTAR)	10,000	N/A	N/A	25	25	5	1	10,000
RADAR TRACKING STATION (FPQ-6)	200,000	N/A	N/A	5	5	8	3	600,000
AUXILIARY EQUIPMENT (POWER UNIT INSTALLATION)	1,500 EACH	N/A	N/A	5	5	9	1	1,500
DATA DISTRIBUTION (FAC)	TX AND RX 16,150	N/A	N/A	10	5	10	1	16,150
SOFTWARE DEVELOPMENT COSTS	12,000	N/A	N/A	5	5	8	1	12,000

Table 4-6. User Requirement Cost Worksheet for Coastal Surge Storm-Driven Runup (4 of 5)

AIRCRAFT (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1- 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
FLIGHT TEST AND EVALUATION	535/HOUR	N/A	N/A	15	15	7	25	23,375
TRAINING (2-WEEK COURSE)	1,100/EACH	N/A	N/A	10	10	7	7	7,700
PERSONNEL DISPLACE-MENT COSTS	2,585/PERSON	N/A	N/A	10	10	9	7	18,095
PROGRAM PLANNING COSTS	30,955	N/A	N/A	30	5	6	N/A	30,955
FLIGHT PERSONNEL (PILOTS)	30,000/YEAR	N/A	N/A	10	10	9	4	120,000
FLIGHT PERSONNEL (CREW)	18,000/YEAR	N/A	N/A	10	10	9	2	36,000
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	3	1	25,000
OFFICE RENT (25 BY 25 FEET)	7.89/FOOT^2	N/A	N/A	10	10	8	1	4,932

Table 4-6. User Requirement Cost Worksheet for Coastal Surge Storm-Driven Runup (5 of 5)

AIRCRAFT (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
DATA PROCESSING SYSTEM	500/HOUR	N/A	N/A	15	15	8	21	10,500
PER DIEM	50/DAY	N/A	N/A	5	5	9	98	4,900
G&A COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	90,500
AIRCRAFT OPERATING COSTS	535/HOUR	N/A	N/A	10	10	8	832	445,120

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4.5 USER REQUIREMENTS FOR STATIC WATER HEIGHT

The user requirements for static water height in coastal marshlands, shoreline delineation, and identification are as follows:

- Accuracy: ±5 centimeter
- Resolution: ±100 meters
- Repetition rate: 24 hours (not critical)
- Report time: 24 hours (not critical)
- Format: Digital grid displayed on map of specific area of interest
- Distribution: Local (state)
- Duration of data gathering: 1 year

This requirement can be more easily satisfied with the aid of an aircraftborne altimeter system than by a satelliteborne altimeter system (Figure 4-4) because of the relatively small dimensions of marshlands and because it would require many satellites to crisscross the entire swamp in 100-meter increments. For estimation purposes, a typical marshland is assumed to measure 50 by 50 kilometers. Two Electra-type aircraft flying 500 kilometers per hour can each cover 12,000 kilometers in 25 hours of continuous flying and thus can traverse the necessary 25,000 kilometers of swamp in the prescribed 24 hours. Each aircraft must be continuously tracked by 3 all-weather radar tracking stations such that their positions are known to within ±5 centimeters. Each station can be located to within ±5 centimeters using the planned NAVSTAR navigation system. The Electra-type aircraft should be equipped with radar transponders to facilitate radar tracking. The present version of the NRL nanosecond radar, and the AAFE altimeter require improved precision by a factor of 2. The aircraft should fly straight lines perpendicular to the shore at altitudes below 6750 feet to present a radar spot size of less than 100 meters. The radar return should change in intensity as the aircraft passes from dry land to wet land because of the difference in the reflective properties of wet and dry land, which also vary depending on surface wind conditions. Thus, the shoreline crossing can be detected. Once over wet land, the range is recorded for each 100-meter cell. The aircraft is kept on course to within ±100 meters with the aid of a NAVSTAR inertial navigation system updated at the beginning of each pass across the marshland. Data recorded can be stored on the aircraft and mailed to a central computing facility for batch processing. Digital maps may be prepared on a CalComp plotter and subsequently mailed to users.

The cost of the airborne system described is estimated to be $15,730,276 for the 1-year operation required. Detailed cost information is presented in Tables 4-7 and 4-8.

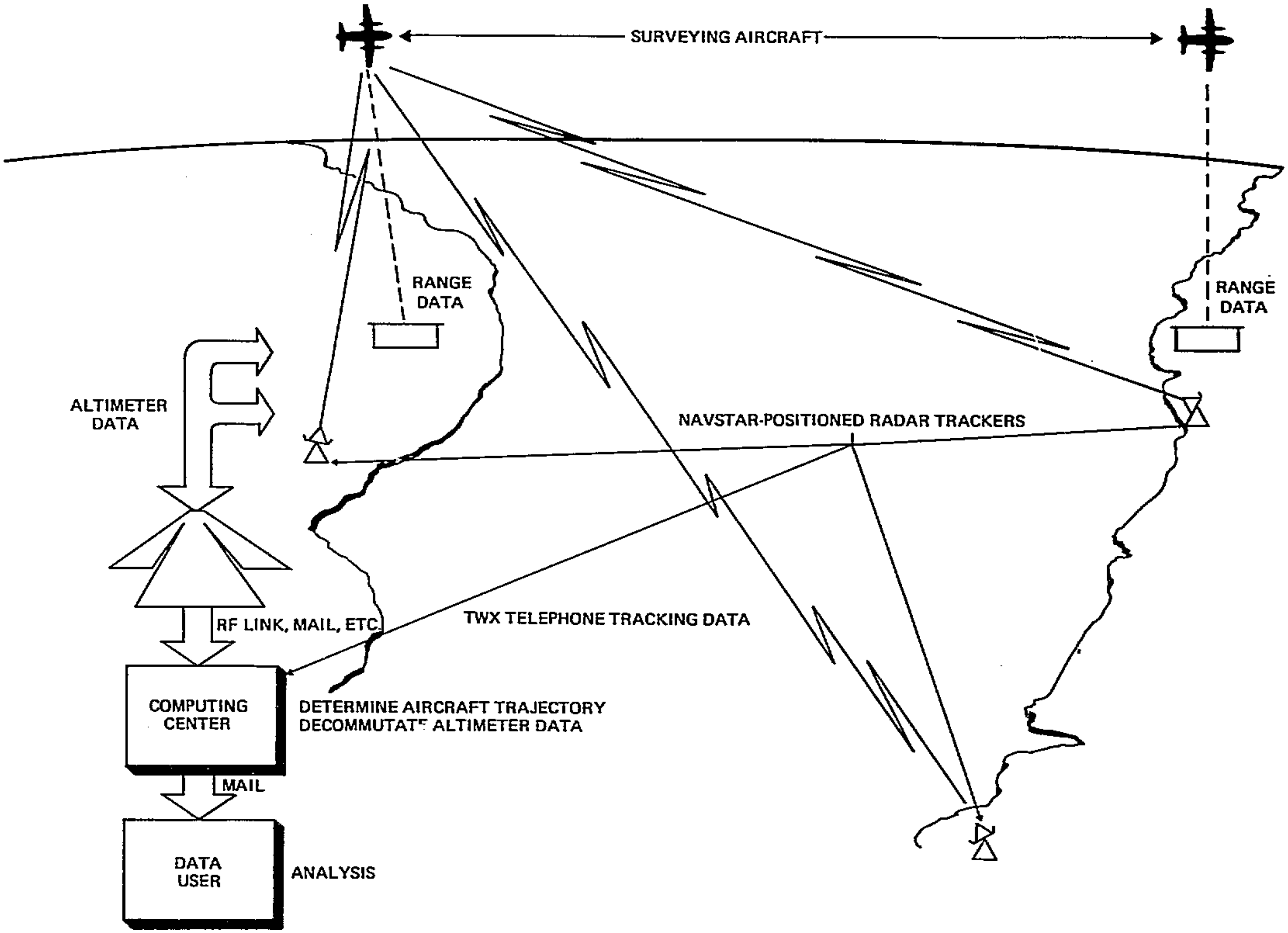

Figure 4-4. Coastal Marshland Static Water Height--Aircraft

Table 4-7. User Requirement Cost Summary for Static Water Height in Coastal Marshlands[a]

TYPE OF COST	PLATFORM COST (DOLLARS)	
	SATELLITE	AIRCRAFT
NONRECURRING:		
INITIAL ACQUISITION (EXISTING HARDWARE)		4,536,000
IMPROVEMENT		37,500
SOFTWARE DEVELOPMENT		15,000
LAUNCH		
REPAIR PARTS (OPERATING)		109,585
INSTALLATION, FLIGHT TEST AND EVALUATION		90,125
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)		21,000
TEST/MAINTENANCE EQUIPMENT		
PERSONNEL DISPLACEMENT		9,287
LAND AND BUILDING PURCHASE		N/A
PROGRAM PLANNING		97,219
TOTAL NONRECURRING COSTS		4,967,416
ANNUAL RECURRING:		
OPERATING		
PERSONNEL		535,000
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC.; INCLUDES UTILITIES)		6,312
DATA PROCESSING		182,500
TRANSPORTATION		N/A
PER DIEM		401,500
RETRAINING (10 PERCENT ANNUAL TURNOVER)		N/A
OVERHEAD AND ADMINISTRATIVE		267,500
DATA DISTRIBUTION		1,635
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)		9,373,200
SATELLITE REPLACEMENT		N/A
TRACKING AND STATIONKEEPING		N/A
REPAIR PARTS (REPLENISHMENT)		N/A
TOTAL ANNUAL RECURRING COSTS		1,768,647
TOTAL COSTS FOR [1] YEAR = $		6,736,063

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

Table 4-8. User Requirement Cost Worksheet for Static Water Height in Coastal Marshlands (1 of 3)

ACCURACY ±5 CENTIMETERS
RESOLUTION +100 METERS
REPETITION RATE 24 HOURS (NOT CRITICAL)
REPORT TIME 24 HOURS (NOT CRITICAL)
FORMAT DIGITAL GRID DISPLAYED ON MAP OF SPECIFIC AREA OF INTEREST
DISTRIBUTION LOCAL (STATE)
DURATION OF DATA GATHERING 1 YEAR

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 - 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
AIRCRAFT (LOCKHEED ELECTRA)	600,000	N/A	N/A	10	10	8	5	3,000,000
NANOSECOND RADAR ALTIMETER	75,000	2	82,500	20	20	7	5	412,500
INERTIAL NAVIGATION SYSTEM	110,000	N/A	N/A	5	5	10	5	550,000
RADAR TRACKING STATION (FPQ-6)	200,000	N/A	N/A	5	5	8	3	600,000
AUXILIARY EQUIPMENT (POWER UNITS)	1,500 EACH	N/A	N/A	5	5	9	2	3,000
CAR PURCHASE	4000/CAR	N/A	N/A	10	10	9	2	8,000
SOFTWARE DEVELOPMENT COSTS	2,500/MONTH	N/A	N/A	5	5	8	6	15,000
INSTALLATION, FLIGHT TEST, AND EVALUATION	535/HOUR	N/A	N/A	10	10	8	75	90.125

Table 4-8. User Requirement Cost Worksheet for Static Water Height in Coastal Marshlands (2 of 3)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 - 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
TRAINING (2-WEEK COURSE)	50 EACH	N/A	N/A	10	10	7	420	21,000
PERSONNEL DISPLACEMENT COSTS	2,585/ PERSONNEL	N/A	N/A	10	10	9	20	51,700
PROGRAM PLANNING COSTS	97,219	N/A	N/A	30	5	6	N/A	97,219
FLIGHT PERSONNEL (PILOTS)	30,000/YEAR	N/A	N/A	10	10	9	10	300,000
FLIGHT PERSONNEL (CREW)	18,000/YEAR	N/A	N/A	10	10	9	5	90,000
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	5	125,000
PERSONNEL (ADMINISTRATIVE)	10,000/YEAR	N/A	N/A	10	10	9	2	20,000
OFFICE RENT (40 BY 20 FEET)	7.89 FEET^2/ YEAR	N/A	N/A	10	10	8	800	6,312

Table 4-8. User Requirement Cost Worksheet for Static Water Height in Coastal Marshlands (3 of 3)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
DATA PROCESSING SYSTEM	500/HOUR	N/A	N/A	15	15	8	365	182,500
PER DIEM	50/DAY	N/A	N/A	5	5	9	12,775	638,750
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	267,500
DATA DISTRIBUTION (MAIL)	1.12/POUND	N/A	N/A	30	0	9	1,460	1,635
AIRCRAFT OPERATING COSTS	535/HOUR	N/A	N/A	10	10	8	17,520	9,373,200

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4.6 USER REQUIREMENTS FOR MEASURING RIVER OUTFLOW PATTERNS

The user requirements for measuring outflow patterns of major rivers are as follows:

- Accuracy: ±5 centimeters
- Resolution: 100 by 100 meters
- Repetition rate: 12 hours
- Report time: 12 hours
- Format: Analog profile across specific sections
  Digital tapes
  Digital grid displayed on maps of specific areas
  Height contours on maps of specific areas
- Distribution: Local
- Duration of data gathering: Permanent task

A system employing an airborne radar altimeter alone cannot satisfy this requirement. If, however, it is complemented by an infrared scanner, or a visible imager, a significant amount of information about the outflow patterns of major rivers can be provided. The altimeter can measure both changes in the height of water and the stream velocity via range measurements and application of the theory of geostrophic flow. The infrared scanner or the imager can give data on the spatial extent of the river water as it enters a bay or ocean by either delineating temperature differences or differences in turbidity.

However, in this case (±5-centimeter altimeter accuracy requirement) the stream velocity cannot be measured because the change in stream height due to the coriolis force is only about 2 centimeters for a typical river 1 kilometer wide, flowing at a rate of 6 to 8 knots. Nevertheless, height profiles for specific areas of the river can be readily obtained. The radar altimeter should be mounted on an Electra-type aircraft and flown repeatedly across the river at intervals of 100 meters (Figure 4-5). An inertial navigation system updated by NAVSTAR is needed to position the aircraft horizontally. Location of the aircraft vertical position to within ±5 centimeters in all kinds of weather can be obtained from continuous tracking with the aid of three FPQ-6 type tracking radars located by NAVSTAR and an airborne transponder. On completion of each flight, altimeter and imager data can be taken to a local processing center and processed in a few minutes and contour maps of outflow prepared. The maps can be transmitted via a facsimile device to users.

The estimated cost for such a system over a 10-year period is $26,170,119. Detailed cost information is presented in Tables 4-9 and 4-10.

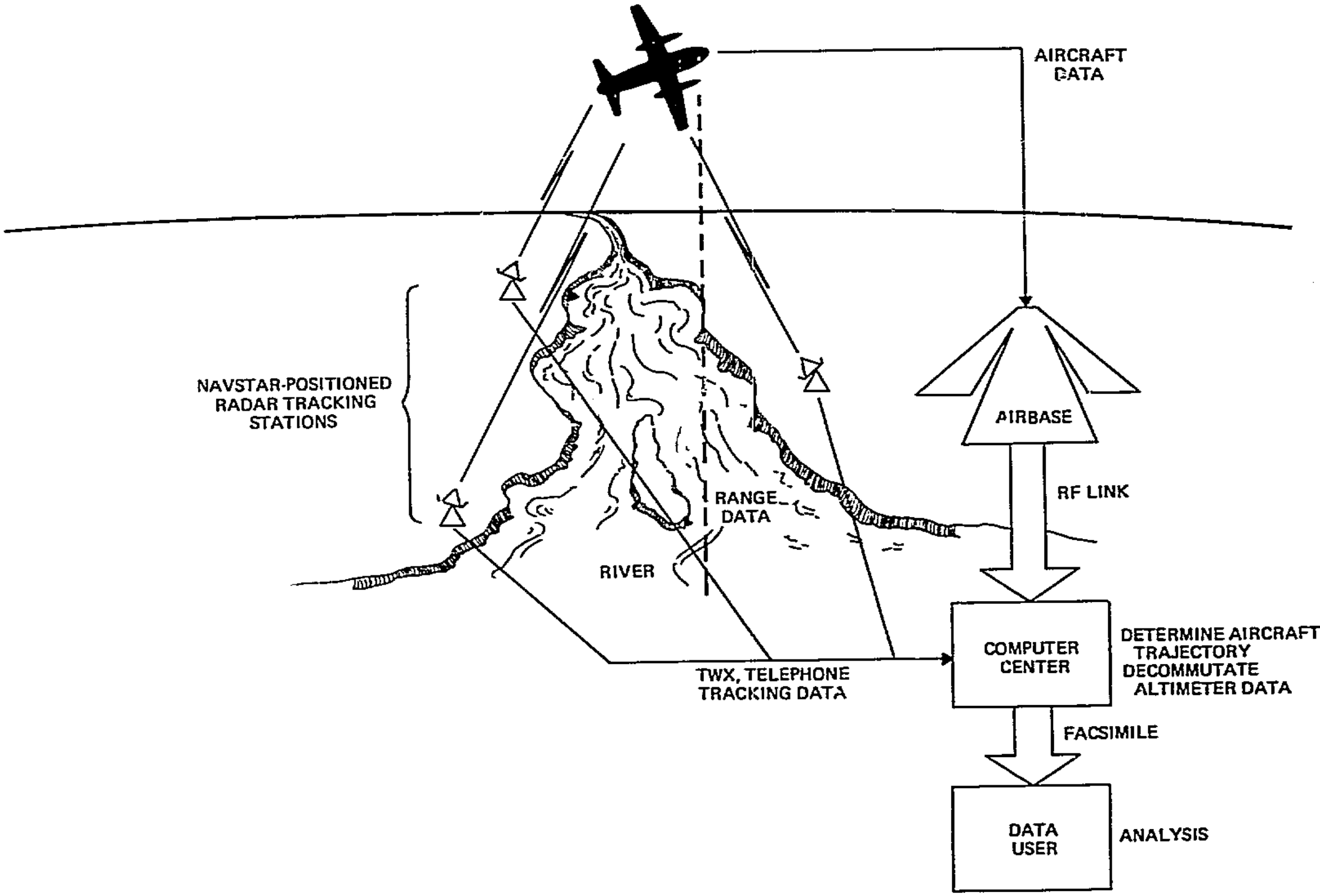

Figure 4-5. Outflow Patterns of Major Rivers--Aircraft

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Table 4-9. User Requirement Cost Summary for Measuring River Outflow Patterns[a]

TYPE OF COST	PLATFORM COST (DOLLARS)	
	SATELLITE	AIRCRAFT
NONRECURRING		
INITIAL ACQUISITION (EXISTING HARDWARE)		2,307,650
IMPROVEMENT		N/A
SOFTWARE DEVELOPMENT		20,000
LAUNCH		N/A
REPAIR PARTS (OPERATING)		90,135
INSTALLATION, FLIGHT TEST AND EVALUATION		36,050
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)		8,800
TEST/MAINTENANCE EQUIPMENT		38,629
PERSONNEL DISPLACEMENT		23,265
LAND AND BUILDING PURCHASE		N/A
PROGRAM PLANNING		50,490
TOTAL NONRECURRING COSTS		2,575,019
ANNUAL RECURRING		
OPERATING		
PERSONNEL		216,000
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC.; INCLUDES UTILITIES)		6,312
DATA PROCESSING		30,500
TRANSPORTATION		N/A
PER DIEM		N/A
RETRAINING (10 PERCENT ANNUAL TURNOVER)		880
OVERHEAD AND ADMINISTRATIVE		108,000
DATA DISTRIBUTION		N/A
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)		1,952,750
SATELLITE REPLACEMENT		N/A
TRACKING AND STATIONKEEPING		N/A
REPAIR PARTS (REPLENISHMENT)		45,068
TOTAL ANNUAL RECURRING COSTS		2,359,510
TOTAL COSTS FOR (10) YEARS = $		26,170,119

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

Table 4-10. User Requirement Cost Worksheet for Measuring River Outflow Patterns (1 of 3)

ACCURACY ±5 CENTIMETERS
RESOLUTION 100 BY 100 METERS
REPETITION RATE 12 HOURS
REPORT TIME 12 HOURS
FORMAT ANALOG PROFILE ACROSS SPECIFIC STATIONS, DIGITAL TAPES, GRID DISPLAYS, HEIGHT CONTOURS
DISTRIBUTION LOCAL
DURATION OF DATA GATHERING PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
AIRCRAFT (LOCKHEED ELECTRA)	600,000	N/A	N/A	10	10	8	2	1,200,000
NANOSECOND RADAR ALTIMETER	75,000	2	82,500	10	10	8	2	175,000
INERTIAL NAVIGATION SYSTEM (LTN-51)	110,000	N/A	N/A	5	5	10	2	220,000
SATELLITE RECEIVER (NAVSTAR)	10,000	N/A	N/A	25	25	5	2	20,000
RADAR TRACKING STATION (FPQ-6)	200,000	N/A	N/A	5	5	8	3	600,000
DATA DISTRIBUTION (FAC)	8,075 EACH	N/A	N/A	5	5	9	2	16,150
AUXILIARY EQUIPMENT (POWER UNIT)	1,500 EACH	N/A	N/A	5	5	9	1	1,500
INFRARED LINE SCANNER	50,000 EACH	N/A	N/A	25	25	6	2	100,000

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Table 4-10. User Requirement Cost Worksheet for Measuring River Outflow Patterns (2 of 3)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SOFTWARE DEVELOPMENT COSTS	2,500/MONTH	N/A	N/A	10	10	7	8	20,000
INSTALLATION, FLIGHT TEST, AND EVALUATION	535/HOUR	N/A	N/A	15	15	7	30	36,050
TRAINING (2-WEEK COURSE)	1,100 EACH	N/A	N/A	10	10	7	8	8,800
PERSONNEL DISPLACEMENT COSTS	2,585/PERSON	N/A	N/A	10	10	9		23,565
PROGRAM PLANNING COSTS	50,490	N/A	N/A	30	5	6	N/A	50,490
FLIGHT PERSONNEL (PILOTS)	30,000/YEAR	N/A	N/A	10	10	9	4	120,000
FLIGHT PERSONNEL (CREW)	18,000/YEAR	N/A	N/A	10	10	9	2	36,000
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	2	50,000

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Table 4-10. User Requirement Cost Worksheet for Measuring River Outflow Patterns (3 of 3)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
PERSONNEL (ADMINISTRATIVE)	10,000/YEAR	N/A	N/A	10	10	9	1	10,000
OFFICE RENT (40 BY 20 FEET)	7.89 FEET^2/YEAR	N/A	N/A	10	10	8	800	6,312
DATA PROCESSING SYSTEM	500/HOUR	N/A	N/A	15	15	4	61	30,500
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	103,000
AIRCRAFT OPERATING COSTS	535/HOUR	N/A	N/A	10	10	8	3,650	1,952,750

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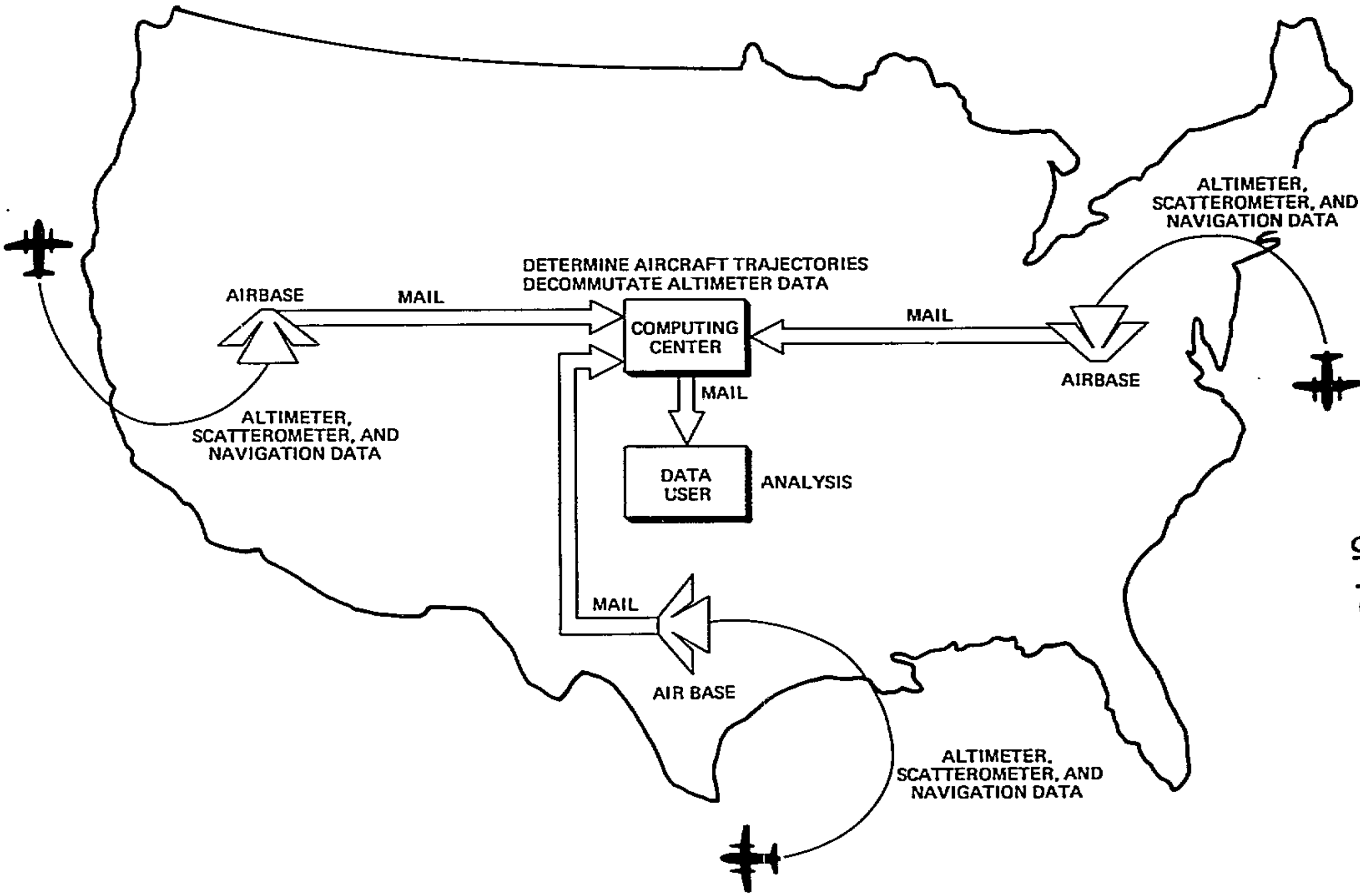
4.7 USER REQUIREMENTS FOR BEACH MONITORING AND WAVE FORECASTING

The user requirements for beach monitoring, wave climate maps, update of wave refraction maps, and improved wave height hindcast and forecast are as follows:

- Accuracy: ±10 centimeters
- Resolution: 0.5 by 0.5 kilometer
- Repetition rate: 24 hours
- Format: Digital grid on maps; geographic coverage for all U. S coast; length of recordkeeping; permanent record must include catastrophic and unusual events (hurricane, etc.)
- Report time: Unspecified, analog profile sections needed for beach monitoring (in addition to above)
- Distribution: Local/regional, specific areas
- Duration of data gathering: Permanent task

This task can only be partially satisfied by an aircraftborne radar altimeter system (Figure 4-6). Only seastate (wave height) data can be gathered directly from altimeter readings. (If a radar scatterometer can be employed to sense the wind direction at the sea surface and if no swell is present, wave height may be related to wave length and a one-dimensional wave spectra may be obtained from the altimeter data.) Wave refraction patterns can only be obtained from a wave directional spectrometer-type instrument or with an imaging radar. Three Electra-type aircraft, for segments of the Atlantic, Pacific, and Gulf coasts, equipped with an improved version of the NRL nanosecond radar, can provide daily measurements of seastate along the coastal regions of interest. These aircraft have a range in excess of 3000 miles and can therefore follow meanderings of the coastline for considerable distances. Flight speed should be over 400 miles per hour so that flight time will be less than 7 hours to permit turnaround of the aircraft for the next day's flight. Flight altitude should be about 20,000 feet. The radar spot size should be 300 meters and an integration interval of 1 second for measurements should be used. A vertical accelerometer is needed to record aircraft motions during this time. Traveling at 300 miles per hour, the aircraft will cover about 125 meters in 1 second and thus overlap of successive regions will not occur. The radar system should be equipped with a maximum-likelihood processor to compute seastate and decrease the amount of data recorded. The aircraft flying along the coast can use a NAVSTAR receiver to update their inertial navigation system to keep their position known to within ±0.5 kilometer. Except when required for forecast purposes, data can be mailed to a central data processing facility (such as at NOAA in Silver Spring, Maryland) and processed and used in NOAA wave height hindcast and forecast models. Specific users can also receive data for their individual regions through the mail.

Over a 10-year period, it is estimated that such a system will cost $54,851,623. Detailed cost information is presented in Tables 4-11 and 4-12.



PLANES NAVIGATE WITH INERTIAL NAVIGATORS AND CHECK WITH LORAN, ALTIMETER ABOARD PLANES MEASURES SEASTATE, AND SCATTEROMETER MEASURES WIND DIRECTION.

Figure 4-6. Beach Monitoring--Aircraft

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Table 4-11. User Requirement Cost Summary for Beach Monitoring and Wave Forecasting[a]

TYPE OF COST	PLATFORM COST (DOLLARS)	
	SATELLITE	AIRCRAFT
NONRECURRING:		
INITIAL ACQUISITION (EXISTING HARDWARE)		3,097,600
IMPROVEMENT		22,500
SOFTWARE DEVELOPMENT		20,000
LAUNCH		N/A
REPAIR PARTS (OPERATING)		92,400
INSTALLATION, FLIGHT TEST AND EVALUATION		68,470
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)		22,000
TEST/MAINTENANCE EQUIPMENT		39,600
PERSONNEL DISPLACEMENT		51,700
LAND AND BUILDING PURCHASE		N/A
PROGRAM PLANNING		68,083
TOTAL NONRECURRING COSTS		3,482,253
ANNUAL RECURRING:		
OPERATING		
PERSONNEL		535,000
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC.; INCLUDES UTILITIES)		14,794
DATA PROCESSING		60,833
TRANSPORTATION		N/A
PER DIEM		108,000
RETRAINING (10 PERCENT ANNUAL TURNOVER)		2,200
OVERHEAD AND ADMINISTRATIVE		267,500
DATA DISTRIBUTION		1,635
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)		4,100,775
SATELLITE REPLACEMENT		N/A
TRACKING AND STATIONKEEPING		N/A
REPAIR PARTS (REPLENISHMENT)		46,200
TOTAL ANNUAL RECURRING COSTS		5,136,937
TOTAL COSTS FOR (10) YEARS = $		54,851,623

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

Table 4-12. User Requirement Cost Worksheet for Beach Monitoring and Wave Forecasting (1 of 3)

ACCURACY: ±10 CENTIMETERS
RESOLUTION: 0.5 BY 0.5 KILOMETER
REPETITION RATE: 24 HOURS
REPORT TIME: UNSPECIFIED
FORMAT: DIGITAL GRID ON MAPS (ALL U.S. COAST) PERMANENT RECORD OF CATASTROPHIC AND UNUSUAL EVENTS
DISTRIBUTION: SPECIFIED AREAS (LOCAL, REGIONAL)
DURATION OF DATA GATHERING: PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 – 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
AIRCRAFT (LOCKHEED ELECTRA)	600,000	N/A	N/A	10	10	6	3	1,800,000
NANOSECOND RADAR ANTENNA	75,000	5	82,500	25	25	6	3	247,500
INERTIAL NAVIGATION SYSTEM (LTN-51)	110,000	N/A	N/A	5	5	10	3	330,000
VERTICAL ACCELEROMETER	10,000	N/A	N/A	10	10	7	3	30,000
SATELLITE RECEIVER (NAVSTAR)	10,000	N/A	N/A	25	25	5	3	30,000
MAXIMUM LIKELIHOOD PROCESSOR	25,000	N/A	N/A	15	15	7	3	75,000
AUXILIARY EQUIPMENT (POWER UNITS)	1,500 EACH	N/A	N/A	5	5	9	5	7,500
SCATTEROMETER WAVE SPECTROMETER	200,000	N/A	N/A	25	25	6	3	600,000

Table 4-12. User Requirement Cost Worksheet for Beach Monitoring and Wave Forecasting (2 of 3)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SOFTWARE DEVELOPMENT	2,500/MONTH	N/A	N/A	10	10	7	8	20,000
INSTALLATION, FLIGHT TEST, AND EVALUATION	535/HOUR	N/A	N/A	10	10	8	42	58,470
TRAINING (2-WEEK COURSE)	1,100/PERSON	N/A	N/A	10	10	8	20	22,000
PERSONNEL DISPLACEMENT COSTS	2,585/PERSON	N/A	N/A	10	10	9	20	51,700
PROGRAM PLANNING	68,083	N/A	N/A	30	5	6	N/A	68,083
FLIGHT PERSONNEL (PILOTS)	30,000/YEAR	N/A	N/A	10	10	9	10	300,000
FLIGHT PERSONNEL (CREW)	18,000/YEAR	N/A	N/A	10	10	9	5	90,000
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	5	125,000

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Table 4-12. User Requirement Cost Worksheet for Beach Monitoring and Wave Forecasting (3 of 3)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 - 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
PERSONNEL (ADMINISTRATIVE)	10,000/YEAR	N/A	N/A	10	10	9	2	20,000
OFFICE RENT (3 OFFICES)	7.89 $FEET^2$/ YEAR	N/A	N/A	10	10	8	1,875	14,794
DATA PROCESSING SYSTEM	500/HOUR	N/A	N/A	15	15	4	122	60,833
PER DIEM	50/DAY	N/A	N/A	5	5	9	2,160	108,000
OVERHEAD AND ADMINISTRATIVE COSTS	267,500	N/A	N/A	15	5	8	N/A	267,500
DATA DISTRIBUTION (MAIL)	1.12/POUND	N/A	N/A	30	0	9	1,460	1,635
AIRCRAFT OPERATING COSTS	535/HOUR	N/A	N/A	10	10	8	7,665	4,100,775

4.8 USER REQUIREMENTS FOR TSUNAMI WARNING

The user requirements for tsunami warning are as follows:

- Accuracy: ±10 centimeters
- Resolution: 10 by 10 kilometers
- Repetition rate: 4 hours
- Report time: 2 hours
- Format: Digital tape; wave location map
- Distribution: International
- Duration of data gathering: Permanent task

Six polar orbiting satellites separated in ascending node by 4 hours can satisfy this requirement. The spacecraft must be tracked to within ±10 centimeters using tracking stations positioned by the proposed NAVSTAR system. Tsunamis, in the Pacific (the principal area of occurrence) arise from earthquakes taking place in the very active ring of fire surrounding the Pacific Ocean. As a result, the waves can be traveling in all compass directions, which imposes a requirement of at least six more satellites with nonpolar inclination. The waves are thought to have amplitudes on the order of 50 centimeters or less in midocean, so the SEASAT-A altimeter should be capable of detecting them. As the satellites traverse the Pacific, they can constantly measure the range to the surface. Altimeter and tracking data should be relayed via satellite to the tsunami warning center for processing (Figure 4-7(a)). Data on tides and geoidal undulations, storm surges, and so forth, in the suspected area are required also for input into the data processing programs. When a tsunami is detected, the warning can be sent in the usual manner.

An alternative to the satellite system is one employing an aircraftborne altimeter (Figure 4-7(b)). Either the NRL nanosecond radar or the AAFE altimeter can meet the precision requirements. Because tsunamis travel over 500 miles per hour the open sea, an SR-71 class aircraft capable of traveling 500 to 2000 miles per hour is required. At 500 miles per hour, a tsunami can reach

Hawaii from Alaska in 7 hours or less. The aircraft must be tracked such that its vertical position is known to within ±10 centimeters. Even the currently planned NAVSTAR system, augmented by an airborne accelerometer, will not be able to determine the vertical position to better than a few meters. Thus, a more advanced navigation system must be developed. Altimeter and position data should be telemetered via a satellite link to the tsunami warning center for processing. As with the satellite system tides, geoidal undulations and meteorological factors must be accounted for. Once a tsunami has been detected, an alert can be sounded using the existing warning system.

The estimated 10-year costs for the satelliteborne system is $278,380,837 and $503,063,935 for the airborne system. Detailed cost information is presented in Tables 4-13 and 4-14.

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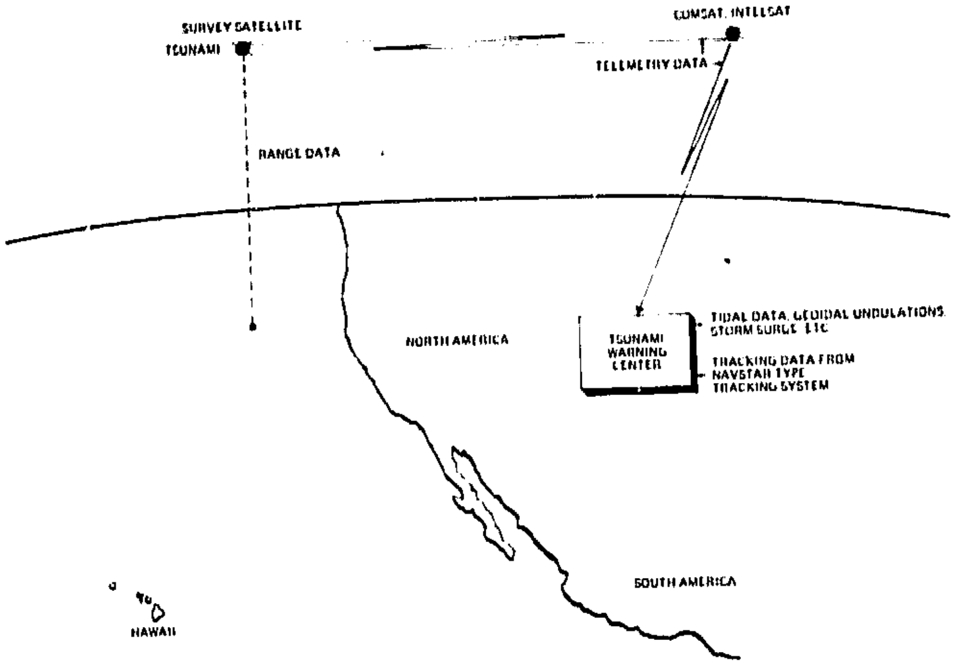
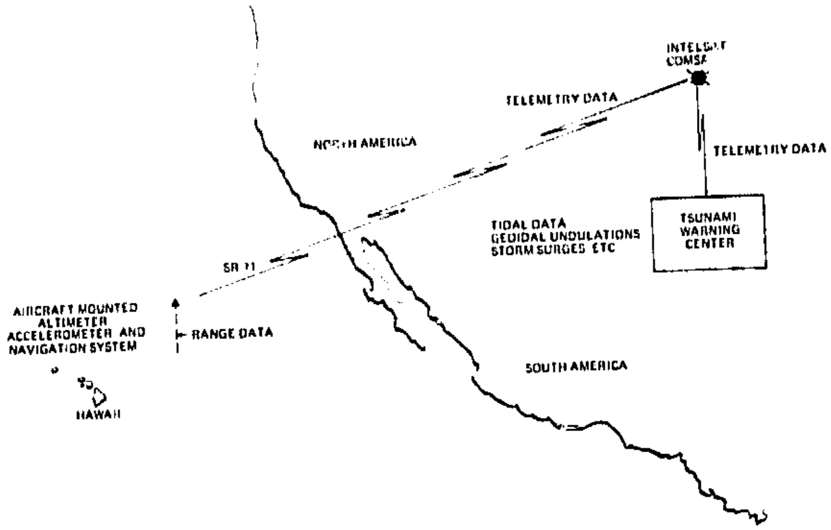


(a) Satellites



(b) Aircraft

Figure 4-7. Tsunami Warning--Satellites and Aircraft

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Table 4-13. User Requirement Cost Summary for Tsunami Warning[a]

TYPE OF COST	PLATFORM COST (DOLLARS)	
	SATELLITE	AIRCRAFT
NONRECURRING:		
INITIAL ACQUISITION (EXISTING HARDWARE)	27,000,000	105,000
IMPROVEMENT	N/A	500,000,000
SOFTWARE DEVELOPMENT	60,000	60,000
LAUNCH	42,000,000	N/A
REPAIR PARTS (OPERATING)	N/A	7,350
INSTALLATION, FLIGHT TEST AND EVALUATION	N/A	45,000
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)	N/A	2,200
TEST/MAINTENANCE EQUIPMENT	N/A	3,150
PERSONNEL DISPLACEMENT	2,585	2,585
LAND AND BUILDING PURCHASE	N/A	N/A
PROGRAM PLANNING	1,381,252	10,025,000
TOTAL NONRECURRING COSTS	70,443,837	510,250,285
ANNUAL RECURRING:		
OPERATING		
PERSONNEL	25,000	65,000
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC.; INCLUDES UTILITIES)	N/A	N/A
DATA PROCESSING	25,000	5,000
TRANSPORTATION	N/A	N/A
PER DIEM	N/A	N/A
RETRAINING (10 PERCENT ANNUAL TURNOVER)	N/A	220
OVERHEAD AND ADMINISTRATIVE	12,500	32,500
DATA DISTRIBUTION	N/A	N/A
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)	N/A	175,000
SATELLITE REPLACEMENT	20,700,000	N/A
TRACKING AND STATIONKEEPING	31,200	N/A
REPAIR PARTS (REPLENISHMENT)	N/A	3,645
TOTAL ANNUAL RECURRING COSTS	20,793,700	281,365
TOTAL COSTS FOR (10) YEARS = $	278,380,837	513,063,935

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

Table 4-14. User Requirement Cost Worksheet for Tsunami Warning (1 of 5)

SATELLITE

ACCURACY: ±10 CENTIMETERS
RESOLUTION: 10 BY 10 KILOMETERS
REPETITION RATE: 4 HOURS
REPORT TIME: 2 HOURS
FORMAT: DIGITAL TAPE; WAVE LOCATION MAP
DISTRIBUTION: INTERNATIONAL
DURATION OF DATA GATHERING: PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1–10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE (SEASAT ALTIMETER)	4,500,000	N/A	N/A	50	50	1	6	27,000,000
SOFTWARE DEVELOPMENT	30,000/YEAR	N/A	N/A	10	10	5	2	60,000
LAUNCH COSTS	7,000,000	N/A	N/A	15	15	8	6	42,000,000
PERSONNEL DISPLACEMENT COSTS	2,585/PERSON	N/A	N/A	10	10	9	1	2,585
PROGRAM PLANNING COSTS	1,381,252	N/A	N/A	30	5	6	N/A	1,381,252
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	1	25,000
DATA PROCESSING	500/HOUR	N/A	N/A	15	15	8	50	25,000
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	12,500

Table 4-14. User Requirement Cost Worksheet for Tsunami Warning (2 of 5)

SATELLITE (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE TRACKING	1040/HOUR	N/A	N/A	50	20	7	30	31,200

Table 4-14. User Requirement Cost Worksheet for Tsunami Warning (3 of 5)

AIRCRAFT

ACCURACY: ±10 CENTIMETERS
RESOLUTION: 10 BY 10 KILOMETERS
REPETITION RATE: 4 HOURS
REPORT TIME: 2 HOURS
FORMAT: DIGITAL TAPE; WAVE LOCATION MAP
DISTRIBUTION: INTERNATIONAL
DURATION OF DATA GATHERING: PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 - 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
AIRCRAFT (F-14)[a]								
NANOSECOND RADAR ALTIMETER	75,000	N/A	N/A	25	25	5	1	75,000
IMPROVED GPSS TRACKING	15,000,000/ LAUNCH	30	125,000,000	50	50	1	25	500,000,000
SOFTWARE DEVELOPMENT COSTS	30,000/YEAR	N/A	N/A	10	10	5	2	60,000
SATELLITE RECEIVER (NAVSTAR)	10,000	N/A	N/A	25	25	5	1	10,000
DATA TRANSMITTER (SATELLITE RELAY)	10,000	N/A	N/A	25	25	5	1	10,000
VERTICAL ACCELEROMETER	10,000	N/A	N/A	10	10	7	1	10,000
INSTALLATION FLIGHT TEST, AND EVALUATION	3,500/HOUR	N/A	N/A	15	15	7	10	45,000

[a]WILL TASK DOD.

Table 4-14. User Requirement Cost Worksheet for Tsunami Warning (4 of 5)

AIRCRAFT (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1–10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
TRAINING (2-WEEK COURSE)	1,100/PERSON	N/A	N/A	10	10		2	2,200
PERSONNEL DISPLACEMENT COSTS	2,585/PERSON	N/A	N/A	10	10	9	1	2,585
PROGRAM PLANNING COSTS	10,025,000	N/A	N/A	30	5	6	N/A	10,025,000
PERSONNEL (PILOT)	25,000/YEAR (MILITARY)	N/A	N/A	10	10		1	25,000
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10		1	25,000
PERSONNEL (MECHANIC)	15,000/YEAR (MILITARY)	N/A	N/A	10	10		1	15,000
DATA PROCESSING	500/HOUR	N/A	N/A	15	15	8	10	5,000
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	32,500

Table 4-14. User Requirement Cost Worksheet for Tsunami Warning (5 of 5)

AIRCRAFT (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
AIRCRAFT OPERATING COSTS	3,500/HOUR	N/A	N/A	40	40	5	50	175,000

4.9 USER REQUIREMENTS FOR OPEN OCEAN TIDES

The user requirements for open ocean tides are as follows:

- Accuracy: ±10 centimeters
- Resolution: 10 by 10 kilometers
- Repetition rate: 24 hours
- Report time: Not critical
- Format: Digital grid
- Distribution: International, publication of special tables
- Duration of data gathering: 10 years

Daily measurement of ocean tides (Figures 4-8) for a particular region of ocean can be accomplished with one polar-orbiting satellite carrying an instrument such as the SEASAT-A altimeter. The repetition rate specified allows for detecting the relatively small amplitude diurnal and greater period tides. But the larger amplitude semidiurnal tides would be undetectable. The use of two polar-orbiting satellites displaced by 180 degrees of right ascension of the ascending node would yield data from which the semidiurnal tide could be discerned; that is, they would enable observations to be made at 12-hour intervals. The two satellites must be tracked such that either vertical position is known to within ±10 centimeters, which can be accomplished with the aid of the planned NAVSTAR system. The satellite data can be telemetered to Earth and reduced for analysis using the SEASAT-A or GEOS-C data processing system. Only a few minutes of computer time are required for a particular point of interest. Tide tables can be prepared and mailed to users as requested. The estimated 10-year cost for the satelliteborne altimeter system is $98,512,809. Detailed cost information is presented in Tables 4-15 and 4-16.

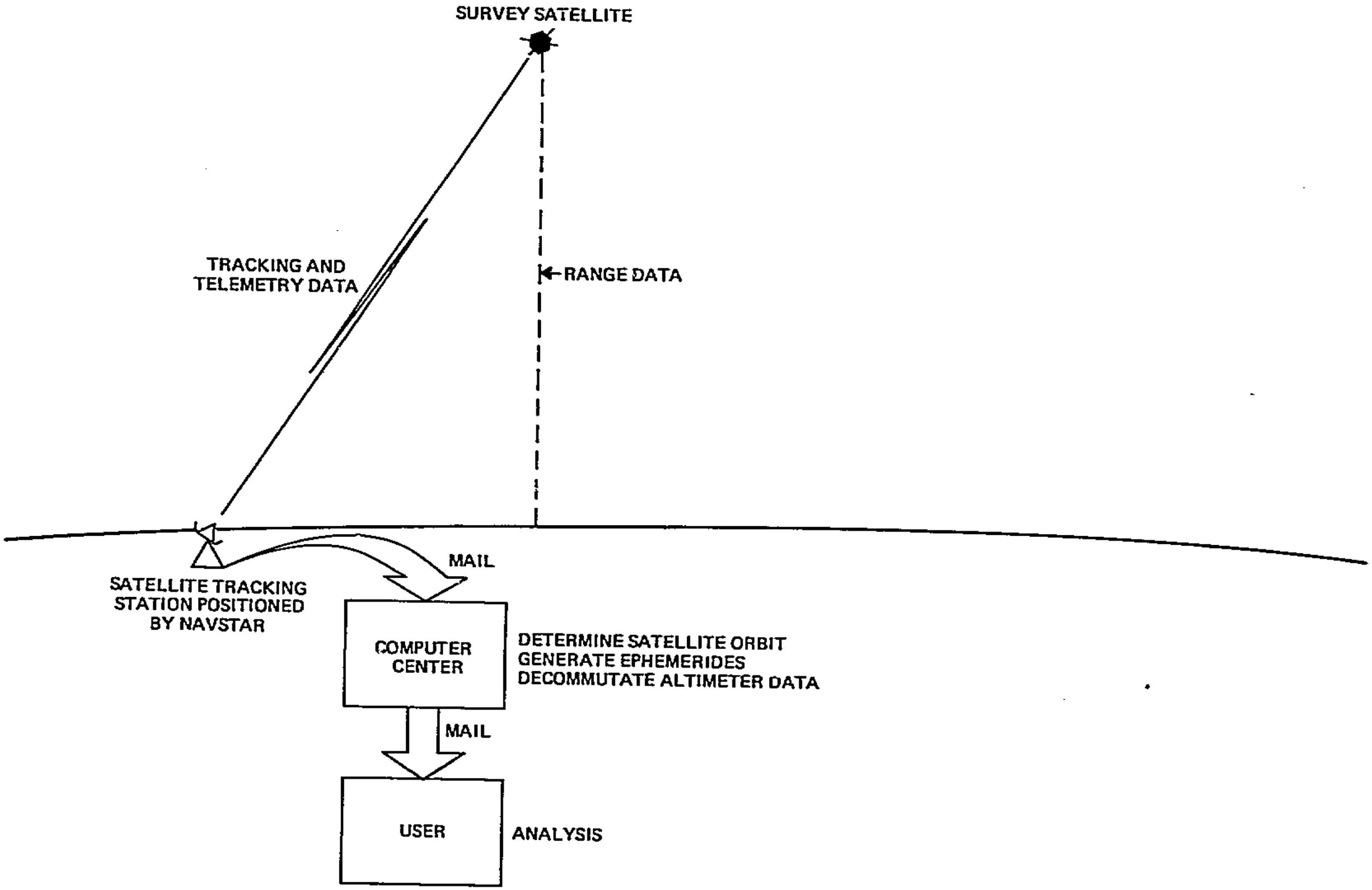

Figure 4-8. Measurement of Ocean Tides--Satellites

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Table 4-15. User Requirement Cost Summary for Open Ocean Tides[a]

TYPE OF COST	PLATFORM COST (DOLLARS)	
	SATELLITE	AIRCRAFT
NONRECURRING:		
INITIAL ACQUISITION (EXISTING HARDWARE)	9,010,000	
IMPROVEMENT	N/A	
SOFTWARE DEVELOPMENT	60,000	
LAUNCH	14,000,000	
REPAIR PARTS (OPERATING)	N/A	
INSTALLATION, FLIGHT TEST AND EVALUATION	13,200	
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)	N/A	
TEST/MAINTENANCE EQUIPMENT	N/A	
PERSONNEL DISPLACEMENT	31,020	
LAND AND BUILDING PURCHASE	N/A	
PROGRAM PLANNING	463,208	
TOTAL NONRECURRING COSTS	23,577,428	
ANNUAL RECURRING:		
OPERATING		
PERSONNEL	300,000	
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC.; INCLUDES UTILITIES)	N/A	
DATA PROCESSING	91,500	
TRANSPORTATION	N/A	
PER DIEM	N/A	
RETRAINING (10 PERCENT ANNUAL TURNOVER)	1,320	
OVERHEAD AND ADMINISTRATIVE	150,000	
DATA DISTRIBUTION	18	
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)	N/A	
SATELLITE REPLACEMENT	6,900,000	
TRACKING AND STATIONKEEPING	50,700	
REPAIR PARTS (REPLENISHMENT)	N/A	
TOTAL ANNUAL RECURRING COSTS	7,493,538	
TOTAL COSTS FOR (10) YEARS = $	98,512,809	

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

Table 4-16. User Requirement Cost Worksheet for Open Ocean Tides (1 of 2)

ACCURACY ±10 CENTIMETERS
RESOLUTION 10 BY 10 KILOMETERS
REPETITION RATE 24 HOURS
REPORT TIME NOT CRITICAL
FORMAT DIGITAL GRID
DISTRIBUTION INTERNATIONAL PUBLICATION (TABLES)
DURATION OF DATA GATHERING 10 YEARS

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 - 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE (SEASAT ALTIMETER)	4,500,000	N/A	N/A	15	15	7	2	9,000,000
SATELLITE RECEIVER (NAVSTAR)	10,000	N/A	N/A	25	25	5	1	10,000
SOFTWARE DEVELOPMENT COSTS	30,000/YEAR	N/A	N/A	10	10	5	2	60,000
LAUNCH COSTS	7,000,000	N/A	N/A	15	15	8	2	14,000,000
TRAINING (2-WEEK COURSE)	1,100 EACH	N/A	N/A	10	10	7	12	13,200
PERSONNEL DISPLACEMENT COSTS	2,585 EACH	N/A	N/A	10	10	9	12	31,020
PROGRAM PLANNING COSTS	463,208	N/A	N/A	30	5	6	N/A	463,208
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	12	300,000

Table 4-16. User Requirement Cost Worksheet for Open Ocean Tides (2 of 2)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 - 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
DATA PROCESSING SYSTEM	500/HOUR	N/A	N/A	30	30	5	183	91,500
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	150,000
DATA DISTRIBUTION (MAIL)	1.12/POUND	N/A	N/A	30	0	9	16	18
SATELLITE TRACKING	1,040/HOUR	N/A	N/A	50	20	7	50	50,700

4.10 USER REQUIREMENTS FOR MONITORING SEA HEIGHT

The user requirements for monitoring sea height for shipping purposes are as follows:

- Accuracy: ±10 centimeters
- Resolution: 10 by 10 kilometers (in open sea)
5 by 5 kilometers (near shore)
- Repetition rate: 6 hours (in open sea)
3 hours (near shore)
- Report time: 3 hours
- Format: Facsimile maps with wave heights in feet and wave direction arrows
- Distribution: International/regional/local
- Duration of data gathering: Permanent task

This task can be partially satisfied with the aid of a radar altimeter which only measures wave height. It cannot provide wave directional spectra unless it is operated in the off-nadir wave directional spectrometer mode. If the altimeter is operated in conjunction with a wind-sensing scatterometer and no swell is present, a one-dimensional wave spectrum may be obtained. The number of satelliteborne altimeters necessary to satisfy this user requirement is on the order of hundreds because of the vast geographic region to be covered and the 3- to-6-hour repetition rate. (A less severe requirement can be satisfied using a constellation of satellites.) However, it may be possible, using a concept proposed by Drs. E. Walsh, G. Swift, and D. Weissman (Reference 7), to obtain reasonably good coverage of the shipping lanes by taking advantage of the hundreds of commercial and military aircraft that traverse the oceans and coastlines of the continents (Figure 4-9). These aircraft could be equipped with radar altimeters that are capable of continuously measuring seastate to within

±10 centimeters over a 5-by5-kilometer or a 10-by-10 kilometer sea lane resolution cell. An inertial navigation system for positioning the aircraft is already available. A vertical accelerometer for recording vertical motions to within ±10 centimeters over a few seconds is also needed. The instrument required should be a fivefold improved version of the NRL nanosecond radar. The package onboard the aircraft must include a maximum-likelihood processor to produce seastate data, which can be relayed via a synchronous satellite to a central processing and data dissemination facility that puts out facsimile maps of wave heights. The facsimile maps should be transmitted via the telefax network to the users upon request.

The estimated 10-year cost for a 100-aircraft system is $281,841,640.

A less stringent set of requirements (Figure 4-10) for monitoring sea height for shipping purposes is as follows:

- Accuracy: ±10 centimeters
- Resolution: 600 kilometers
- Repetition Rate: 6 hours
12 hours
- Report Time: 6 hours
12 hours
- Format: Facsimile maps with wave heights in feet and wave direction arrows
- Distribution: International/regional/local
- Duration of Data Gathering: Permanent task

This requirement can be only partially satisfied with the aid of satelliteborne altimeters because the altimeter can measure wave height but not wave direction, unless it is operated in the off-nadir wave directional spectrometer mode. Six satellites are required to cover the globe in 600-kilometer increments every 12 hours and 12 satellites are required to cover the globe every 6 hours.

Each satellite should be equipped with a radar altimeter capable of measuring seastate to within ±10 centimeters. The instrument required should be a five-fold improved version of the SEASAT-A altimeter and its associated maximum-likelihood processor to produce seastate data. The data can be telemetered to the STDN network and on to a central processing and data dissemination facility, which puts out facsimile maps of wave heights. The facsimile maps should be transmitted via the telefax network to the users upon request. The estimated 10-year cost for the 6-satellite system is $286,995,492 and for the 12-satellite system is $573,321,492. Detailed cost information is presented in Tables 4-17 through 4-20.

C-2

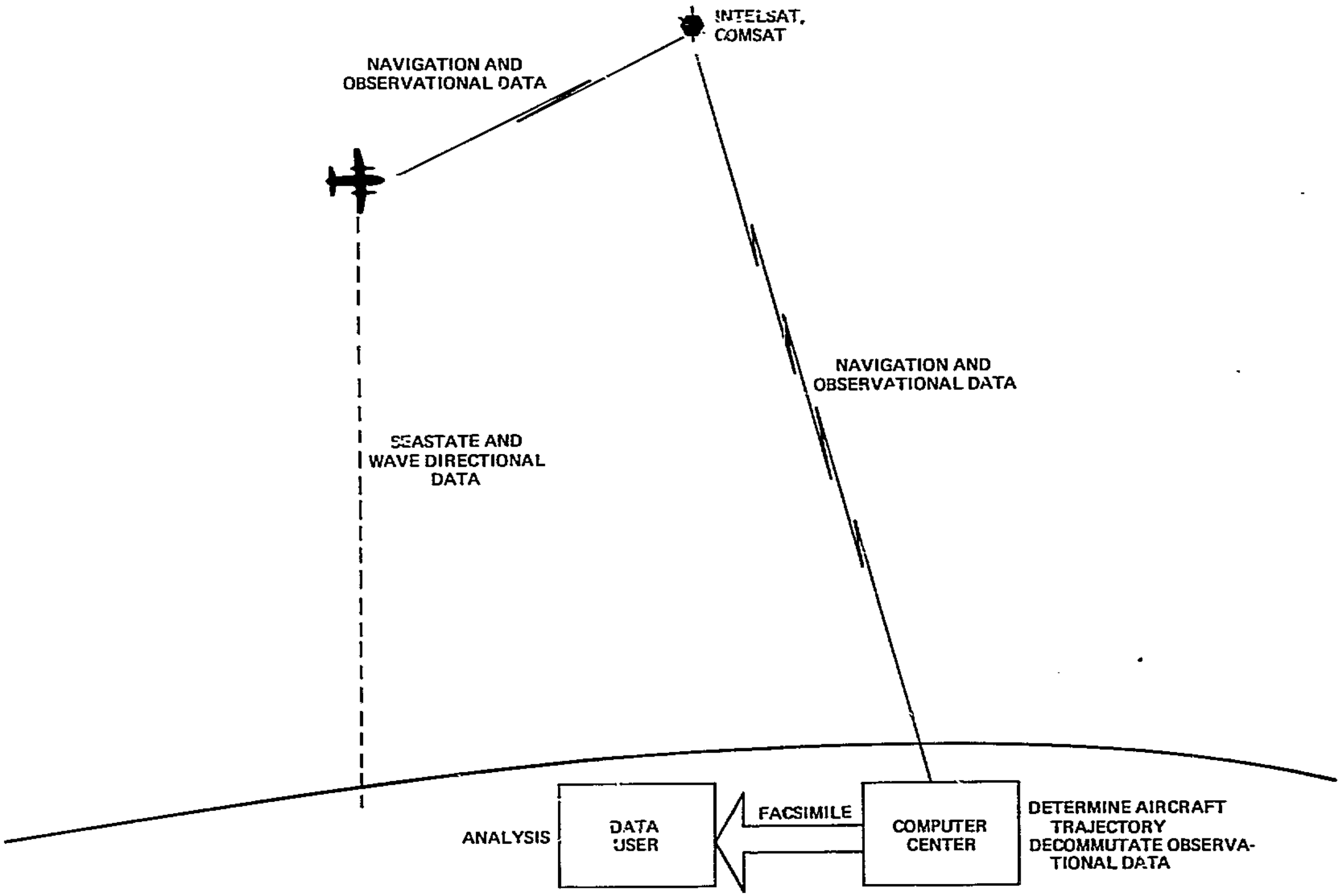

Figure 4-9. Monitoring Shipping Wave Seastate--Aircraft

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Table 4-17. User Requirement Cost Summary for Monitoring Sea Height[a] (Aircraft Case)

TYPE OF COST	PLATFORM COST (DOLLARS)	
	SATELLITE	AIRCRAFT[b]
NONRECURRING:		
INITIAL ACQUISITION (EXISTING HARDWARE)		33,750,000
IMPROVEMENT		750,000
SOFTWARE DEVELOPMENT		1,100,000
LAUNCH		N/A
REPAIR PARTS (OPERATING)		N/A
INSTALLATION, FLIGHT TEST AND EVALUATION		1,000,000
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)		N/A
TEST/MAINTENANCE EQUIPMENT		N/A
PERSONNEL DISPLACEMENT		N/A
LAND AND BUILDING PURCHASE		N/A
PROGRAM PLANNING		746,640
TOTAL NONRECURRING COSTS		37,346,640
ANNUAL RECURRING:		
DATA PROCESSING		608,500
TRANSPORTATION (AIR FREIGHT CHARGE)		17,666,000
OPERATING AND MAINTENANCE COSTS		5,175,000
SATELLITE COMMUNICATIONS COST		1,000,000
TOTAL ANNUAL RECURRING COSTS		24,449,500
TOTAL COSTS FOR (10) YEARS = $		281,841,640

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

[b]ASSUME 100 AIRCRAFT MAKING 2 FLIGHTS PER DAY.

Table 4-18. User Requirement Cost Worksheet for Monitoring Sea Height (Aircraft Case) (1 of 2)

ACCURACY: 15 CENTIMETERS
RESOLUTION:
REPETITION RATE: 6 HOURS BEST CASE; 12 HOURS WORSE CASE
REPORT TIME: 6 HOURS BEST CASE; 12 HOURS WORSE CASE
FORMAT: FACSIMILE MAPS WITH WAVE HEIGHTS IN FEET WITH WAVE DIRECTION ARROWS
DISTRIBUTION: INTERNATIONAL/REGIONAL/LOCAL
DURATION OF DATA GATHERING: PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
NANOSECOND RADAR ALTIMETER	75,000	5	82,500	25	25	6	100	9,000,000
VERTICAL ACCELEROMETER	10,000	N/A	N/A	10	10	7	100	1,000,000
SCATTEROMETER	200,000	N/A	N/A	25	25	3	100	20,000,000
MAXIMUM-LIKELIHOOD PROCESSOR	25,000	N/A	N/A	15	15	7	100	2,500,000
COMSAT TRANSMITTER	20,000	N/A	N/A	10	10	3	100	2,000,000
SOFTWARE DEVELOPMENT COSTS	2,500/MONTH	N/A	N/A	15	5	8	40	1,100,000
INSTALLATION, FLIGHT TEST, AND EVALUATION	10,000	N/A	N/A	5	5	9	100	1,000,000
PROGRAM PLANNING COSTS	746,640	N/A	N/A	30	5	[illegible]	N/A	746,640

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Table 4-18. User Requirement Cost Worksheet for Monitoring Sea Height (Aircraft Case) (2 of 2)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 - 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
DATA PROCESSING	500/HOUR	N/A	N/A	10	10	8	100	2,000,000
AIR FREIGHT CHARGE (700 POUNDS PER AIRCRAFT)	242/FLIGHT	N/A	N/A	15	5	8	73,000	17,666,000
OPERATING AND MAINTENANCE COSTS (15 PERCENT HARD-WARE COSTS)	51,750/ AIRCRAFT	N/A	N/A	15	15	7	100	5,175,000
COMMUNICATIONS COSTS VIA SATELLITE (COMSAT)	10,000	N/A	N/A	20	20	6	100	1,000,000

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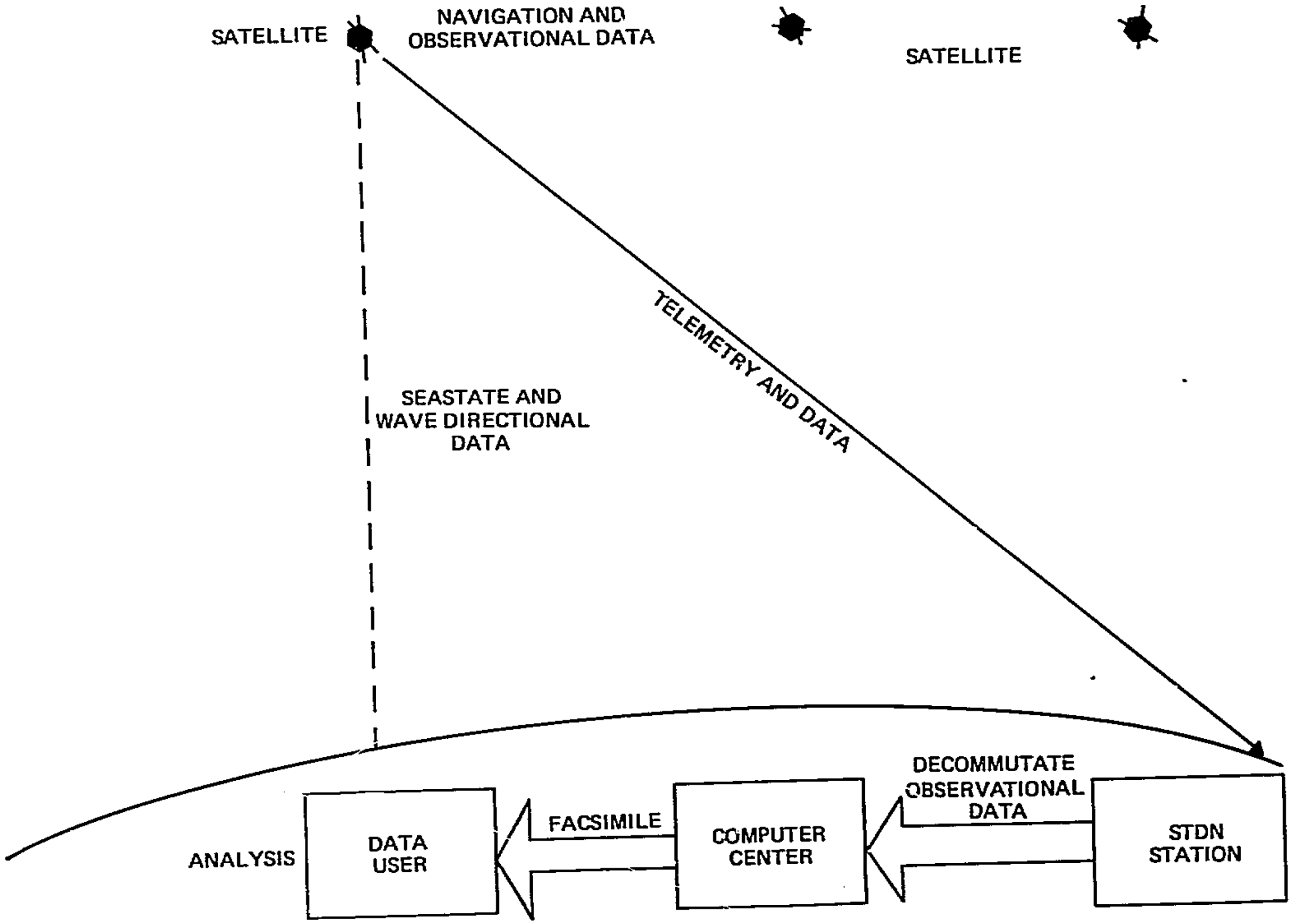

Figure 4-10. Monitoring Shipping Wave Seastate--Satellites

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Table 4-19. User Requirement Cost Summary for Monitoring Sea Height[a] (Six and 12 Satellite Cases)

TYPE OF COST	PLATFORM COST (DOLLARS)	
	6 SATELLITES	12 SATELLITES
NONRECURRING:		
INITIAL ACQUISITION (EXISTING HARDWARE)	27,000,000	54,000,000
IMPROVEMENT	N/A	N/A
SOFTWARE DEVELOPMENT	20,000	20,000
LAUNCH	42,000,000	84,000,000
REPAIR PARTS (OPERATING)	N/A	N/A
INSTALLATION, FLIGHT TEST AND EVALUATION	N/A	N/A
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)	2,200	2,200
TEST/MAINTENANCE EQUIPMENT	N/A	N/A
PERSONNEL DISPLACEMENT	N/A	N/A
LAND AND BUILDING PURCHASE	N/A	N/A
PROGRAM PLANNING	1,380,444	2,760,444
TOTAL NONRECURRING COSTS	70,402,644	140,782,644
ANNUAL RECURRING:		
OPERATING		
PERSONNEL	35,000	35,000
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC.; INCLUDES UTILITIES)	1,184	1,184
DATA PROCESSING	15,500	31,000
TRANSPORTATION	N/A	N/A
PER DIEM	N/A	N/A
RETRAINING (10 PERCENT ANNUAL TURNOVER)	220	220
OVERHEAD AND ADMINISTRATIVE	17,500	17,500
DATA DISTRIBUTION		
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)	N/A	N/A
SATELLITE REPLACEMENT	207,000,000	414,000,000
TRACKING AND STATIONKEEPING	730,000	1,460,000
REPAIR PARTS (REPLENISHMENT)	N/A	N/A
TOTAL ANNUAL RECURRING COSTS	799,404	1,544,904
TOTAL TRIANNUAL COSTS	69,000,000	138,000,000
TOTAL COSTS FOR (10) YEARS = $	286,996,492	573,321,492

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

Table 4-20. User Requirement Cost Worksheet for Monitoring Sea Height (Six and 12 Satellite Cases) (1 of 2)

ACCURACY: ±50 CENTIMETERS
RESOLUTION: 1,000 KILOMETERS
REPETITION RATE: 6 HOURS (BEST CASE); 12 HOURS (WORSE CASE)
REPORT TIME: 6 HOURS (BEST CASE); 12 HOURS (WORSE CASE)
FORMAT: FACSIMILE MAPS WITH WAVE HEIGHTS IN FEET WITH WAVE DIRECTION ARROWS
DISTRIBUTION: INTERNATIONAL/REGIONAL/LOCAL
DURATION OF DATA GATHERING: PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1–10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE (SEASAT ALTIMETER)	4,500,000	N/A	N/A	15	15	9	6 12	27,000,000 54,000,000
SOFTWARE DEVELOP-MENT COSTS	2,500/MONTH	N/A	N/A	15	5	8	8	20,000
LAUNCH COSTS	7,000,000	N/A	N/A	15	15	9	6 12	42,000,000 84,000,000
TRAINING (2-WEEK COURSE)	1,100/ PERSONNEL	N/A	N/A	10	10	7	2	2,200
PROGRAM PLANNING COSTS	1,380,444 2,760,444	N/A	N/A	30	5	6	N/A	1,380,444 2,760,444
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	1	25,000
PERSONNEL (ADMINISTRATIVE)	10,000/YEAR	N/A	N/A	10	10	7	1	10,000
OFFICE RENT (10 BY 15 FEET)	7.89 FEET^2/ YEAR	N/A	N/A	15	15	8	150	1,184

Table 4-20. User Requirement Cost Worksheet for Monitoring Sea Height (Six and 12 Satellite Cases) (2 of 2)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1–10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
DATA PROCESSING	500/HOUR	N/A	N/A	15	15	5	31	15,500
							62	31,000
OVERHEAD COSTS	0.5 X PER-SONNEL COSTS	N/A	N/A	15	5	8	N/A	17,500
SATELLITE TRACKING COSTS	1,000/YEAR	N/A	N/A	15	15	9	730	730,000
							1460	1,460,000

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4.11 USER REQUIREMENTS FOR PREFLOOD ASSESSMENT

The user requirements for preflood assessment (e.g., at the Bay of Bengal) are as follows:

- Accuracy: ±10 centimeters
- Resolution: 0.5 by 0.5 kilometer
- Repetition rate: 2 hours
- Reporting time: 2 hours
- Format: Digital tapes, facsimile maps
- Distribution: Local/regional
- Duration of data gathering: Permanent task

To meet this requirement, 12 satellites in polar orbits are required because of the 2-hour repetition rate (Figure 4-11). These satellites can carry radar altimeters and can be tracked to within ±10 centimeters with a system similar to the planned NAVSTAR navigation system. During the monsoon season, the water level within the Bay of Bengal can be measured. Data could be transmitted to a ground processing station (located in Hooghly, for example) for rapid processing. Knowledge of local tides is necessary because tidal effects must be subtracted for the altimeter data. Data should be transmitted via telephone lines to users along the east coast of India.

An alternative system would incorporate an aircraftborne altimeter (Figure 4-12). Electra type aircraft, based at Hooghly, could be launched every 2 hours and fly southward along the Bay of Bengal, telemetering data via a satellite link to the central computer facility at Hooghly. The position of the aircraft must be determined to within ±10 centimeters. Three low-frequency radar tracking stations are needed to get an accurate fix in rainy weather so that clusters of three stations must be constructed at 100-kilometer intervals along the coast. Stations can be located using the NAVSTAR positioning system. Facsimile maps of water levels can be produced after geoidal undulations and the effects of tides have been subtracted from the data. They can be sent via telephone link to local and regional users.

The estimated 10-year costs for the spaceborne and airborne systems are $559,660,770 and $11,918,022, respectively. Detailed cost data is presented in Tables 4-21 and 4-22.

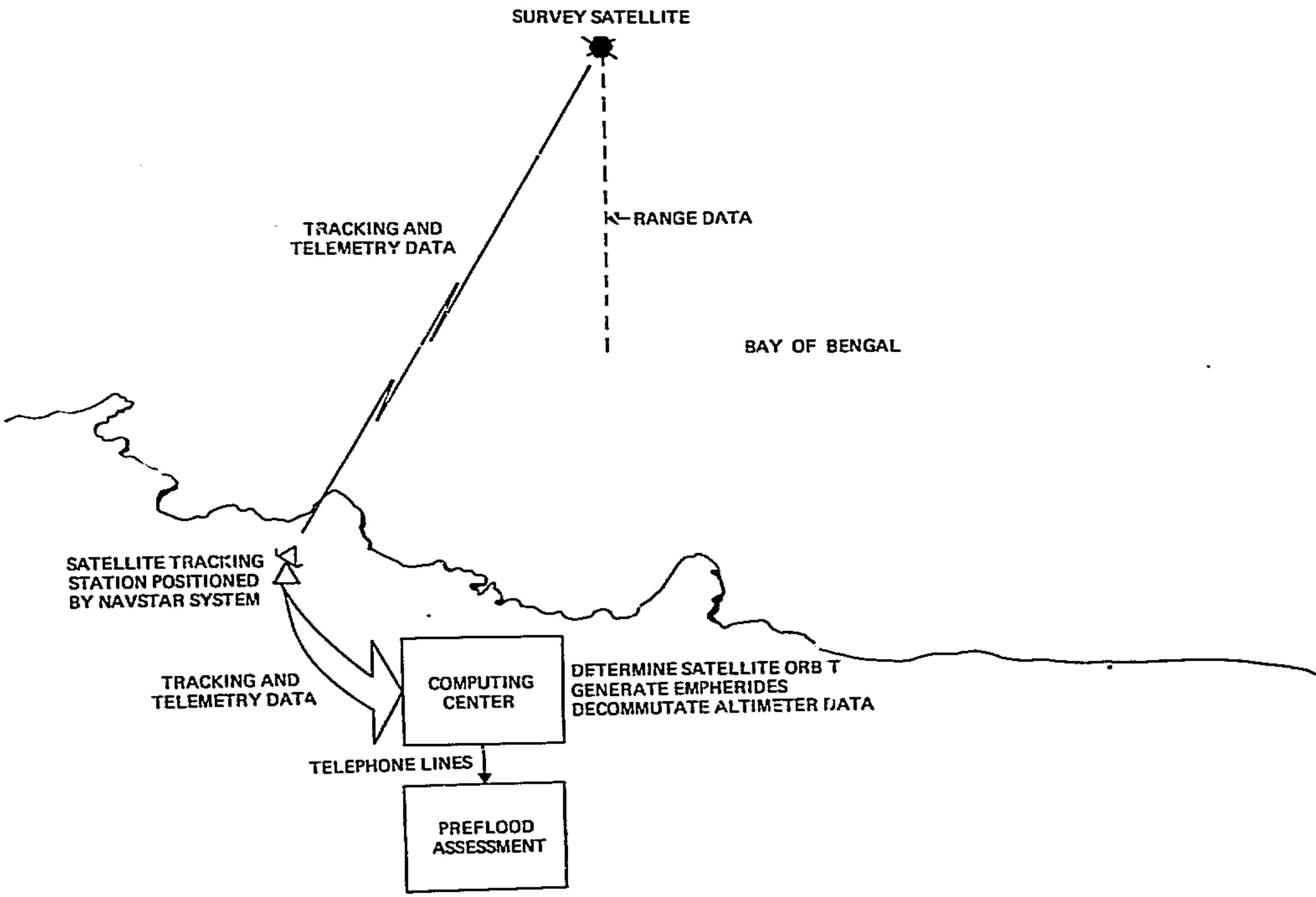

Figure 4-11. Preflood Assessment--Satellites

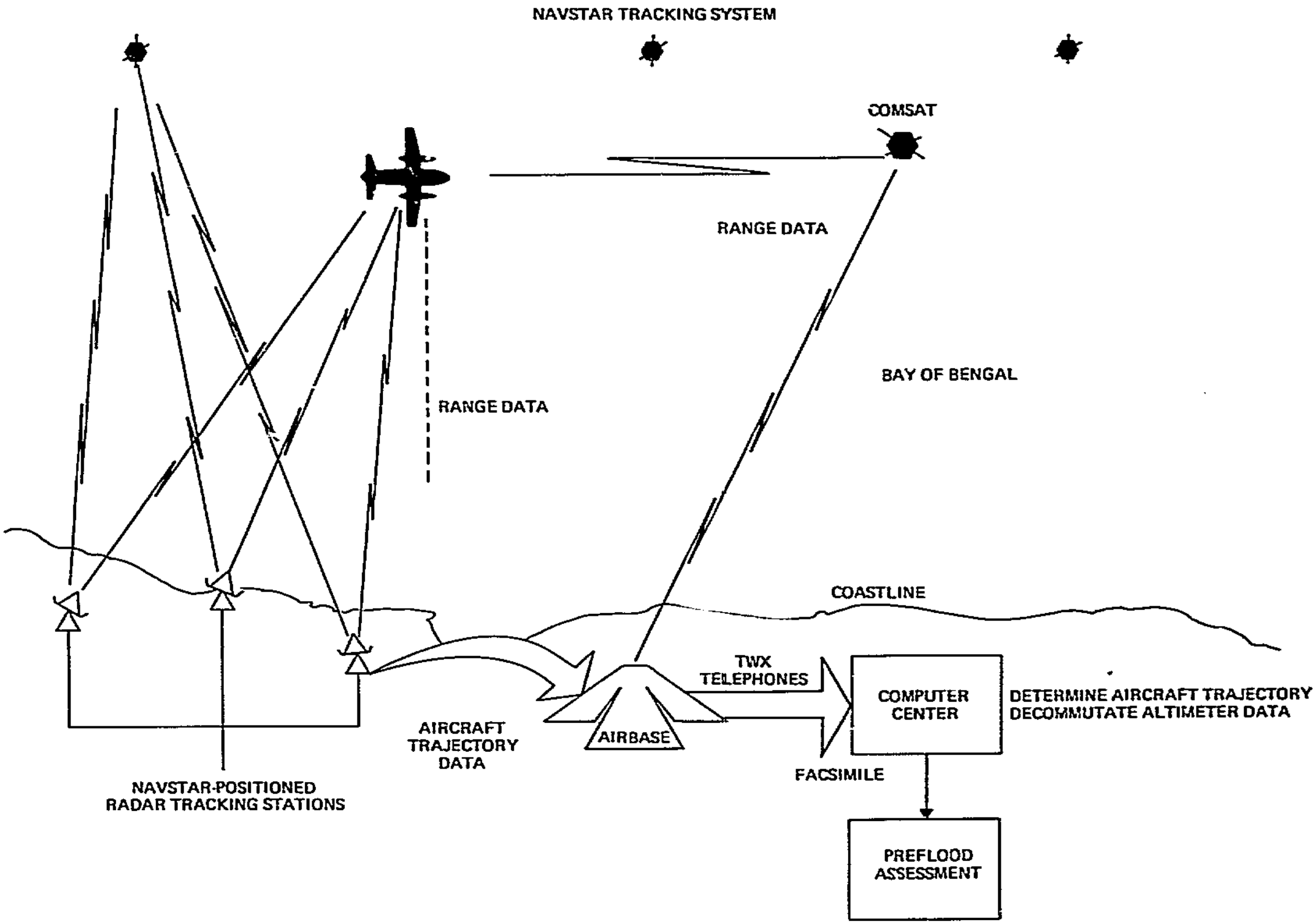

Figure 4-12. Preflood Assessment--Aircraft

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Table 4-21. User Requirement Cost Summary for Preflood Assessment[a]

TYPE OF COST	PLATFORM COST (DOLLARS)	
	SATELLITE	AIRCRAFT
NONRECURRING		
INITIAL ACQUISITION (EXISTING HARDWARE)	54,016,150	3,620,650
IMPROVEMENT	N/A	N/A
SOFTWARE DEVELOPMENT	15,000	15,000
LAUNCH	84,000,000	
REPAIR PARTS (OPERATING)	N/A	126,185
INSTALLATION, FLIGHT TEST AND EVALUATION	N/A	42,840
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)	2,200	8,800
TEST/MAINTENANCE EQUIPMENT	N/A	54,079
PERSONNEL DISPLACEMENT	N/A	N/A
LAND AND BUILDING PURCHASE	N/A	N/A
PROGRAM PLANNING	2,816,880	78,889
TOTAL NONRECURRING COSTS	140,849,230	3,946,452
ANNUAL RECURRING:		
OPERATING		
PERSONNEL	50,000	284,000
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC.; INCLUDES UTILITIES)	1,184	1,184
DATA PROCESSING	18,000	18,000
TRANSPORTATION	1,650	1,650
PER DIEM	5,500	30,250
RETRAINING (10 PERCENT ANNUAL TURNOVER)	220	880
OVERHEAD AND ADMINISTRATIVE	25,000	142,000
DATA DISTRIBUTION	N/A	N/A
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)	N/A	246,100
SATELLITE REPLACEMENT	41,400,000	N/A
TRACKING AND STATIONKEEPING	379,600	N/A
REPAIR PARTS (REPLENISHMENT)	N/A	63,093
TOTAL ANNUAL RECURRING COSTS	41,881,154	787,157
TOTAL COSTS FOR (10) YEARS = $	559,660,770	11,818,022

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

Table 4-22. User Requirement Cost Worksheet for Preflood Assessment (1 of 5)

SATELLITE

ACCURACY: ±10 CENTIMETERS
RESOLUTION: 0.5 BY 0.5 KILOMETER
REPETITION RATE: 2 HOURS
REPORT TIME: 2 HOURS
FORMAT: DIGITAL TAPES, FACSIMILE MAPS
DISTRIBUTION: LOCAL/REGIONAL
DURATION OF DATA GATHERING: PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1–10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE (SEASAT ALTIMETER)	4,500,000	N/A	N/A	50	50	1	12	54,000,000
DATA DISTRIBUTION (FAC)	TX AND RX 16,150	N/A	N/A	10	5	10	1	16,150
SOFTWARE DEVELOPMENT COSTS	2,500/MONTH	N/A	N/A	5	5	8	6	15,000
LAUNCH COSTS	7,000,000	N/A	N/A	50	50	1	12	84,000,000
TRAINING (2-WEEK COURSE)	1,100/PERSON	N/A	N/A	10	10	7	2	2,200
PROGRAM PLANNING COSTS	2,815,880	N/A	N/A	30	5	6	N/A	2,815,880
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	2	50,000
OFFICE RENT (10 BY 15 FEET)	7.89 $FEET^2$/YEAR	N/A	N/A	10	10	8	150	1,184

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Table 4-22. User Requirement Cost Worksheet for Preflood Assessment (2 of 5)

SATELLITE (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1–10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
DATA PROCESSING	500/HOUR	N/A	N/A	15	15	8	36	18,000
CAR RENTAL	30/DAY	N/A	N/A	10	10	9	55	1,650
PER DIEM	50/DAY	N/A	N/A	5	5	9	110	5,500
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	25,000
STDN COSTS	1,040/HOUR	N/A	N/A	50	20	7	365	379,600

Table 4-22. User Requirement Cost Worksheet for Preflood Assessment (3 of 5)

AIRCRAFT

ACCURACY: ±10 CENTIMETER
RESOLUTION: 0.5 BY 0.5 KILOMETERS
REPETITION RATE: 2 HOURS
REPORT TIME: 2 HOURS
FORMAT: DIGITAL TAPES, FACSIMILE MAPS
DISTRIBUTION: LOCAL/REGIONAL
DURATION OF DATA GATHERING: PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 – 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
AIRCRAFT (LOCKHEED ELECTRA)	600,000	N/A	N/A	10	10	8	3	1,800,000
NANOSECOND RADAR ALTIMETER	75,000	N/A	N/A	10	10	8	3	225,000
INERTIAL NAVIGATION SYSTEM (LTN-51)	110,000	N/A	N/A	5	5	10	3	330,000
SATELLITE RECEIVER (NAVSTAR)	10,000	N/A	N/A	25	25	5	3	30,000
RADAR TRACKING STATION (FPQ-6)	200,000	N/A	N/A	5	5	8	6	1,200,000
DATA DISTRIBUTION (FAC)	TX AND RX 16,150	N/A	N/A	5	5	9	1	16,150
AUXILIARY EQUIPMENT (POWER UNIT)	1,500 EACH	N/A	N/A	5	5	8	1	1,500
SOFTWARE DEVELOPMENT COSTS	2,500/MONTH	N/A	N/A	5	5	8	6	15,000

Table 4-22. User Requirement Cost Worksheet for Preflood Assessment (4 of 5)

AIRCRAFT (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1 10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
INSTALLATION, FLIGHT TEST, AND EVALUATION	535/HOUR[a]	N/A	N/A	15	15	8	24	42,840
TRAINING (2-WEEK COURSE)	1,100/PERSON	N/A	N/A	10	10	7	8	8,800
PROGRAM PLANNING COSTS	30,955	N/A	N/A	30	5	6	N/A	30,955
FLIGHT PERSONNEL (PILOTS)	30,000/YEAR	N/A	N/A	10	10	9	6	180,000
FLIGHT PERSONNEL (CREW)	18,000/YEAR	N/A	N/A	10	10	9	3	54,000
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	2	50,000
OFFICE RENT (10 BY 15 FEET)	7.89 FEET^2/YEAR	N/A	N/A	10	10	8	150	1,184
DATA PROCESSING SYSTEM	500/HOUR	N/A	N/A	15	15	8	36	18,000

[a]INSTALLATION COSTS: $10,000 PER AIRCRAFT.

Table 4-22. User Requirement Cost Worksheet for Preflood Assessment (5 of 5)

AIRCRAFT (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
CAR RENTAL	30/DAY	N/A	N/A	10	10	9	55	1,650
PER DIEM	50/DAY	N/A	N/A	5	5	9	605	30,250
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	142,000
AIRCRAFT OPERATING	535/HOUR	N/A	N/A	10	10	8	460	246,100

4.12 USER REQUIREMENTS FOR SHORE TIDE, SEA-LEVEL INFORMATION

The user requirements for near-shore tide and sea-level information, longshore currents, and test of local tide tables for foreign areas are as follows:

- Accuracy: ±10 centimeters
- Resolution: 0.5 by 0.5 kilometer
- Repetition rate: 12 hours
- Report time: Not critical
- Format: Digital tapes, digital display on grid, and map of specific area
- Distribution: International/regional/local
- Duration of data gathering: Permanent task

Near-shore tide and sea-level information can be obtained using a system employing two satelliteborne SEASAT-A-type radar altimeters with the spot size reduced by a factor of three. The satellites in 2-hour polar orbits must be tracked to within ±10 centimeters using a system similar to the planned NAVSTAR system (Figure 4-13). Data can be relayed from the satellite using a network similar to that proposed for SEASAT-A and then processed. Tidal fluctuations, sea-level information, and geostrophic currents can be extracted and facsimiles sent via telefax, mail, etc., to the users in the area of interest.

Aircraftborne altimetry could also be exployed where an Electra-type aircraft (Figure 4-14) would make a pass over the area of interest every 12 hours keeping on course (within ±0.5 kilometer) with the aid of an inertial navigation system. The altimeter data would be returned with the aircraft and transmitted to the computer center via data link, telephone, mail, etc. The aircraft position must be determined to ±10 centimeters. This can be satisfied using three radar tracking stations that have been located using the proposed NAVSTAR positioning system. Tracking and altimeter data can be relayed on a non-real-time basis to a central computer processing facility for processing. Digital tapes can be prepared for distribution by mail to users.

The estimated 10-year costs for the spaceborne and airborne systems are \$82,500,454 and \$10,657,002, respectively. Detailed cost data is presented in Tables 4-23 and 4-24.

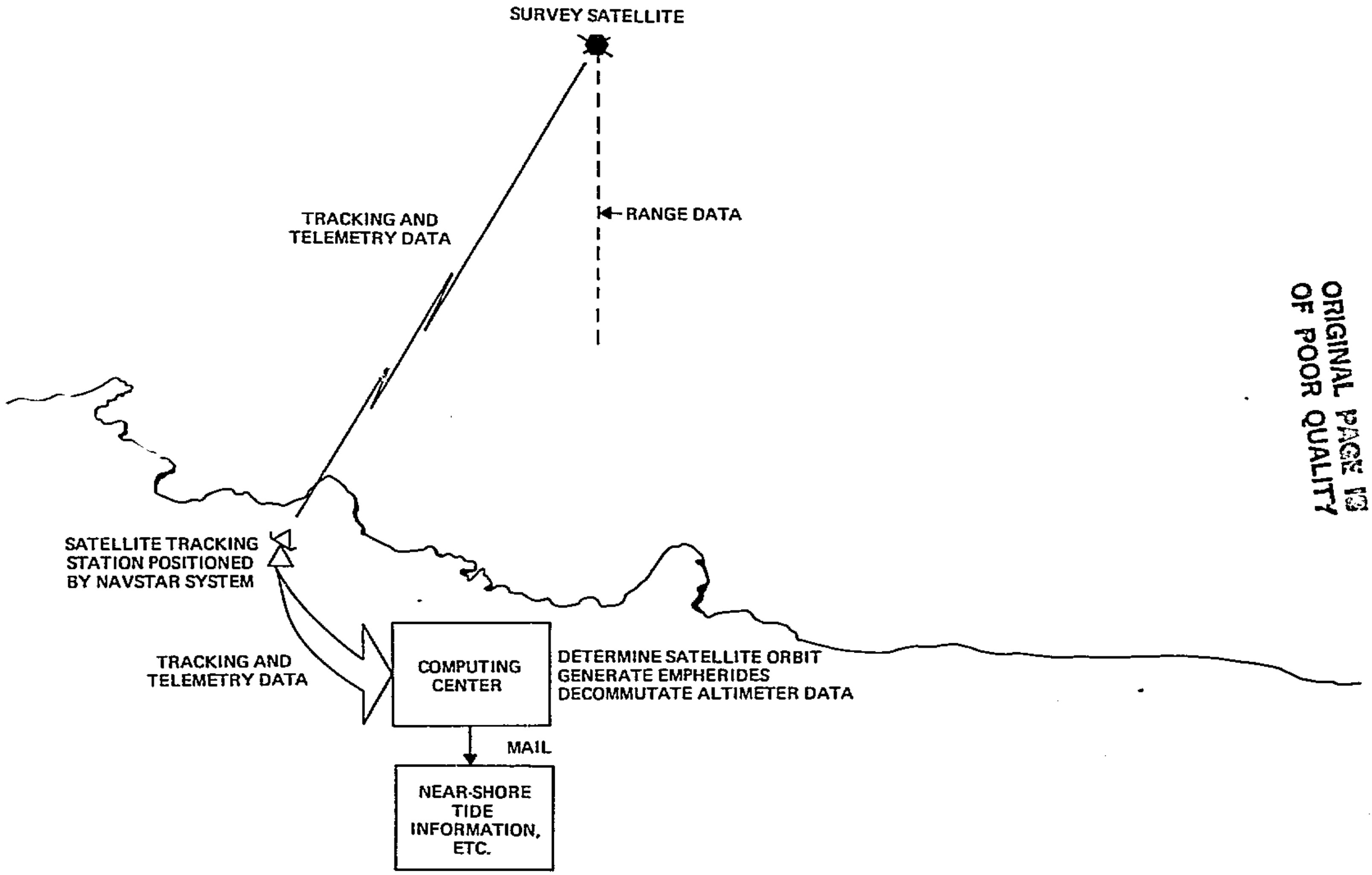

Figure 4-13. Near-Shore Tide Information--Satellites

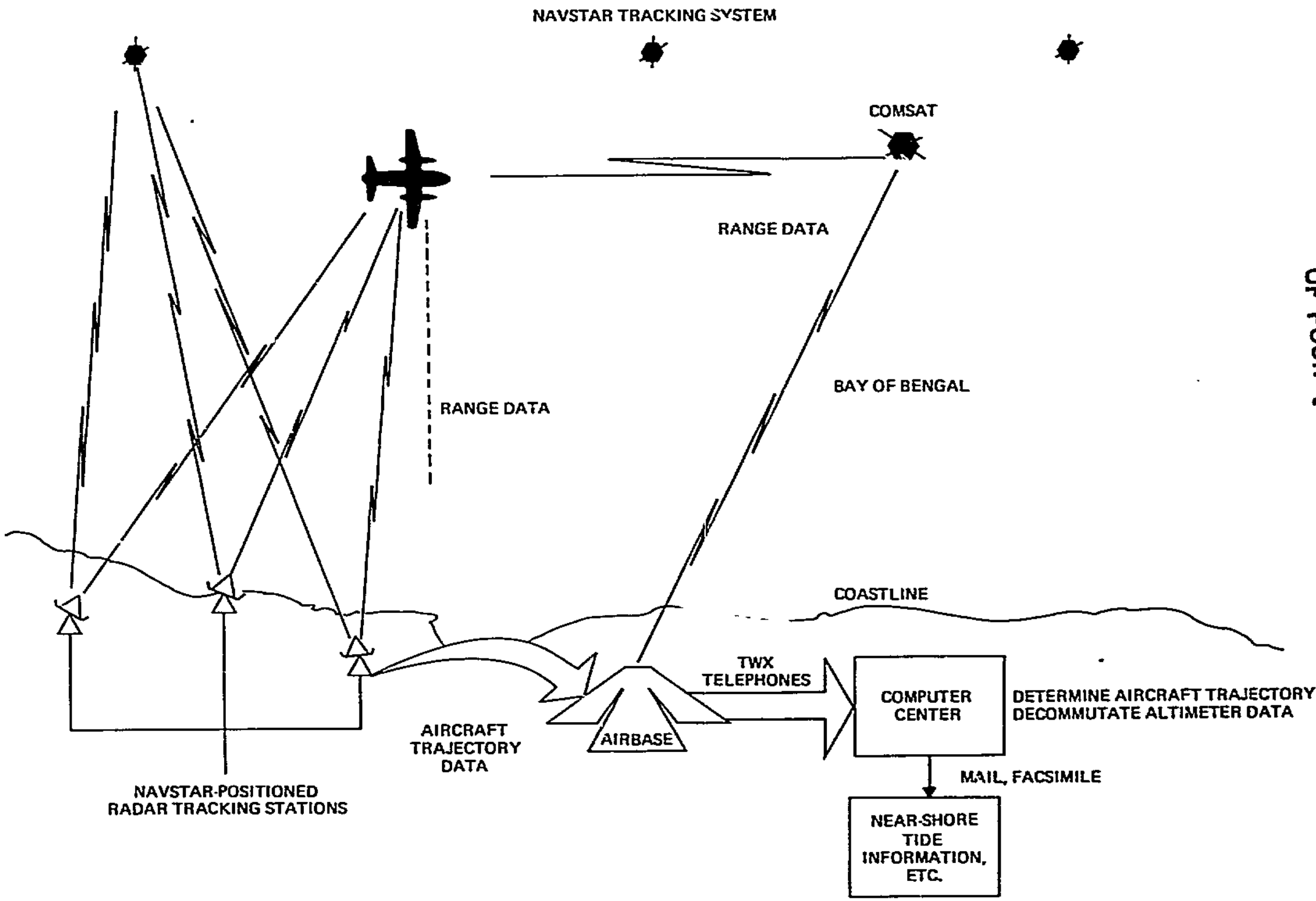

Figure 4-14. Near-Shore Tide Information/
Bay of Bengal--Aircraft

Table 4-23. User Requirement Cost Summary for Shore Tide, Sea-Level Information[a]

TYPE OF COST	PLATFORM COST (DOLLARS)	
	SATELLITE	AIRCRAFT
NONRECURRING:		
INITIAL ACQUISITION (EXISTING HARDWARE)	9,000,000	1,396,500
IMPROVEMENT	N/A	N/A
SOFTWARE DEVELOPMENT	30,000	30,000
LAUNCH	14,000,000	N/A
REPAIR PARTS (OPERATING)	N/A	61,331
INSTALLATION, FLIGHT TEST AND EVALUATION	N/A	18,026
INITIAL TRAINING (PER DIEM, TRANSPORTATION, ETC.)	1,100	6,600
TEST/MAINTENANCE EQUIPMENT	N/A	26,284
PERSONNEL DISPLACEMENT	N/A	20,680
LAND AND BUILDING PURCHASE	N/A	N/A
PROGRAM PLANNING	469,834	31,812
TOTAL NONRECURRING COSTS	23,500,934	1,591,232
ANNUAL RECURRING:		
OPERATING		
PERSONNEL	25,000	216,000
RENT/LEASING (OFFICE SPACE, BUILDINGS, ETC.; INCLUDES UTILITIES)	1,184	1,184
DATA PROCESSING	18,500	18,500
TRANSPORTATION	10,950	N/A
PER DIEM	18,250	146,000
RETRAINING (10 PERCENT ANNUAL TURNOVER)	110	660
OVERHEAD AND ADMINISTRATIVE	12,500	103,000
DATA DISTRIBUTION	NOMINAL	NOMINAL
MAINTENANCE		
FACILITIES (LABOR MATERIAL, ETC., INCLUDED IN RENT)		
FLIGHT HOUR (AIRCRAFT)	N/A	390,550
SATELLITE REPLACEMENT	5,750,000	N/A
TRACKING AND STATIONKEEPING	63,440	N/A
REPAIR PARTS (REPLENISHMENT)	N/A	30,665
TOTAL ANNUAL RECURRING COSTS	5,899,934	906,539
TOTAL COSTS FOR [10] YEARS = $	82,500,454	10,657,002

[a]LIFE-CYCLE COSTS

$$LCC = NRC + \sum_{N=1}^{N} ARC$$

WHERE LCC = LIFE-CYCLE COSTS
NRC = NONRECURRING COSTS
ARC = ANNUAL RECURRING COSTS (N = NUMBER LIFE-CYCLE YEARS)

Table 4-24. User Requirement Cost Worksheet for Shore Tide, Sea-Level Information (1 of 5)

SATELLITE
ACCURACY: ±10 CENTIMETERS
RESOLUTION: 0.5 BY 0.5 KILOMETER
REPETITION RATE: 12 HOURS
REPORT TIME: NOT CRITICAL
FORMAT: DIGITAL TAPES, DIGITAL DISPLAY ON GRID, AND MAP OF SPECIFIC AREA
DISTRIBUTION: INTERNATIONAL/REGIONAL/LOCAL
DURATION OF DATA GATHERING: PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
SATELLITE (SEASAT ALTIMETER)	4,500,000	N/A	N/A	50	50	1	2	9,000,000
SOFTWARE DEVELOPMENT COSTS	2,500/MONTH	N/A	N/A	5	5	8	12	30,000
LAUNCH COSTS	7,000,000	N/A	N/A	50	50	8	2	14,000,000
TRAINING (2-WEEK COURSE)	1,100/PERSON	N/A	N/A	10	10	7	1	1,100
PROGRAM PLANNING COSTS	469,834	N/A	N/A	30	5	6	N/A	469,834
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	1	25,000
OFFICE RENT (10 BY 15 FEET)	7.89 FEET^2/ YEAR	N/A	N/A	10	10	8	150	1,184
DATA PROCESSING	500/HOUR	N/A	N/A	15	15	8	37	18,500

Table 4-24. User Requirement Cost Worksheet for Shore Tide, Sea-Level Information (2 of 5)

SATELLITE (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
CAR RENTAL	30/DAY	N/A	N/A	10	10	9	365	10,950
PER DIEM	50/DAY	N/A	N/A	5	5	9	365	18,250
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	12,500
DATA DISTRIBUTION (MAIL)	2.50/POUND[a]	N/A	N/A	30	0	9	8	20
STDN COSTS	1,040/HOUR	N/A	N/A	50	20	7	61	63,440

[a]CONSIDERS OVERSEAS RATES.

Table 4-24. User Requirement Cost Worksheet for Shore Tide, Sea-Level Information (3 of 5)

AIRCRAFT
ACCURACY: ±10 CENTIMETERS
RESOLUTION: 0.5 BY 0.5 KILOMETER
REPETITION RATE: 12 HOURS
REPORT TIME: NOT CRITICAL
FORMAT: DIGITAL TAPES, DIGITAL DISPLAY ON GRID, AND MAP OF SPECIFIC AREA
DISTRIBUTION: INTERNATIONAL/REGIONAL/LOCAL
DURATION OF DATA GATHERING: PERMANENT TASK

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1–10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
AIRCRAFT (LOCKHEED ELECTRA)	600,000	N/A	N/A	10	10	8	1	600,000
NANOSECOND RADAR ALTIMETER	75,000	N/A	N/A	10	10	8	1	75,000
INERTIAL NAVIGATION SYSTEM (LTN-51)	110,000	N/A	N/A	5	5	10	1	110,000
SATELLITE RECEIVER (NAVSTAR)	10,000	N/A	N/A	25	25	5	1	10,000
RADAR TRACKING STATION (FPQ-6)	200,000	N/A	N/A	5	5	8	3	600,000
AUXILIARY EQUIPMENT (POWER UNIT)	1,500 EACH	N/A	N/A	5	5	9	1	1,500
SOFTWARE DEVELOPMENT COSTS	2,500/MONTH	N/A	N/A	5	5	8	12	30,000
INSTALLATION, FLIGHT TEST, AND EVALUATION	535/HOUR	N/A	N/A	15	15	7	15	18,025

Table 4-24. User Requirement Cost Worksheet for Shore Tide, Sea-Level Information (4 of 5)

AIRCRAFT (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
TRAINING (2-WEEK COURSE)	1,100/PERSON	N/A	N/A	10	10	7	6	6,600
PERSONNEL DISPLACEMENT COSTS	2,585/PERSON	N/A	N/A	10	10	9	8	20,680
PROGRAM PLANNING COSTS	31,812	N/A	N/A	30	5	6	N/A	31,812
FLIGHT PERSONNEL (PILOTS)	30,000/YEAR	N/A	N/A	10	10	9	4	120,000
FLIGHT PERSONNEL (CREW)	18,000/YEAR	N/A	N/A	10	10	9	2	36,000
PERSONNEL (TECHNICAL)	25,000/YEAR	N/A	N/A	10	10	9	2	50,000
PERSONNEL ADMINISTRATIVE	10,000/YEAR	N/A	N/A	10	10	9	1	10,000
OFFICE RENT (10 BY 15 FEET)	7.89 FEET^2/YEAR	N/A	N/A	10	10	8	150	1,184

Table 4-24. User Requirement Cost Worksheet for Shore Tide, Sea-Level Information (5 of 5)

AIRCRAFT (CONT'D)

REQUIREMENT (HARDWARE AND SUPPORT)	CURRENT UNIT COST (DOLLARS)	IMPROVEMENT		PERCENTAGE VARIANCE		CONFIDENCE FACTOR (1-10)	QUANTITY	ESTIMATED TOTAL COST (DOLLARS)
		FACTOR	UNIT COST (DOLLARS)	PLUS	MINUS			
DATA PROCESSING	500/HOUR	N/A	N/A	15	15	8	37	18,500
PER DIEM	50/DAY	N/A	N/A	5	5	9	2,920	146,000
OVERHEAD AND ADMINISTRATIVE COSTS	0.5 X PERSONNEL COSTS	N/A	N/A	15	5	8	N/A	103,000
DATA DISTRIBUTION (MAIL)	2.50/POUND[a]	N/A	N/A	30	0	9	8	20
AIRCRAFT OPERATING COSTS	535/HOUR	N/A	N/A	10	10	8	730	390,550

[a]CONSIDERS OVERSEAS RATES.

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