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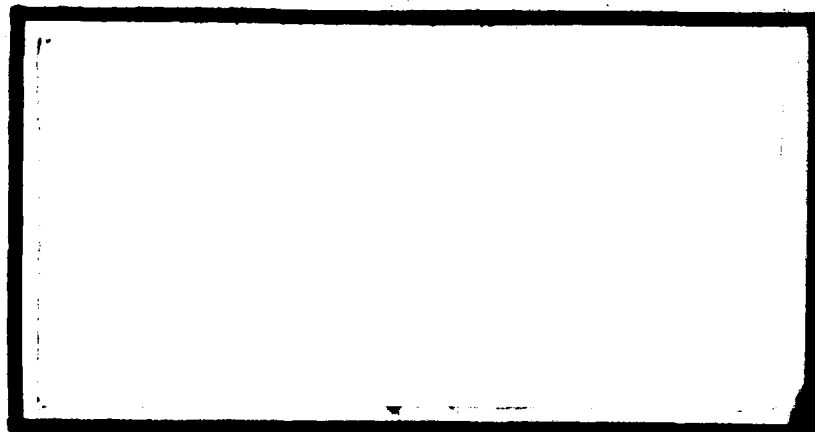
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AN EVALUATION OF THE EFFECTIVENESS OF
DEPLOYING ELECTRO-OPTICAL TELESCOPES
FOR SATELLITE TRACKING ON HIGH
ALTITUDE POWERED PLATFORMS

THESIS

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DEPLOYING ELECTRO-OPTICAL SATELLITE

TRACKING TELESCOPES ON HIGH ALTITUDE

ALTITUDE POWERED PLATFORMS

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirement for the Degree of

Master of Science

by

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Capt.   USAF

Graduate Space Operations

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Preface

This research was performed to determine the potential of developing electro-optical satellite tracking telescopes on board high altitude powered platforms. A computerized simulation model was developed to conduct a comparative analysis of a hypothetical system of air based telescopes with the Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) System. Some effort was also devoted to assessing the feasibility of an air based satellite tracking telescope.

Thanks go to Professor Edward Dunne for his guidance in the analysis procedures, Professor James Lange for his assistance in electro-optics, and Capt. Charles Ruberson for his help in obtaining cloud cover data.

Richard T. Salmon

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Abstract

The purpose of this research was to evaluate the possible benefits of an air based system of electro-optical satellite tracking telescopes. A computerized simulation model was developed to conduct a comparative analysis of a hypothetical system of air based telescopes with the Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) System. The simulation includes a first order optimization process for selecting a satellite surveillance system and a many-on-many engagement model to test the effectiveness of the surveillance system selected. In addition, the user can input a preselected surveillance system and test its effectiveness.

The user specifies the characteristics of the surveillance system and the basing locations, if they are preselected. Cloud cover data can be entered with preselected ground sites. Target satellites included four sets of representative satellite systems. The user selects the targets, defines the mission time, and determines the percentage of each target system which must be tracked.

Preliminary results indicate that an air based surveillance system with three dispersed telescope platforms could outperform a system of five candidate GEODSS sites.

AN EVALUATION OF THE EFFECTIVENESS OF DEPLOYING ELECTRO-OPTICAL TELESCOPES FOR SATELLITE TRACKING ON HIGH ALTITUDE POWERED PLATFORMS

I Introduction

Background

Optical sensors provide an important input to the Space Detection and Tracking System (SPADATS), a network of sensors maintained by the Air Force to monitor all man-made objects in space (Ref 1:Ch 2). Unlike radar, optical sensors can with relative ease track a satellite in deep space. The Baker-Nunn camera, classified as a modified Schmidt telescope, is currently SPADATS' primary deep space sensor. This telescope can track an object the size of a basketball at 35,000 nautical miles (Ref 1:Ch 2, 20).

Unfortunately, the presence of the atmosphere limits the utility of these sensors. The atmosphere limits telescopes in five ways (Ref 1:Ch 5, 31-32). The first limitation is due to weather. Clouds, fog, and rain severely degrade atomospheric transmission. The second limitation is that the atmosphere is not transparent to all regions of the electromagnetic spectrum. The atmosphere is actually opaque in some regions of the spectrum. The third problem is that the atmosphere scatters light. Thus an astronomical telescope cannot detect faint objects in daylight, and at night even city lights limit the depth that can be probed by a telescope. The fourth problem is caused by variations in the density of the atmosphere. It is these variations which cause the stars to twinkle. Finally, the fifth limitation is that under s____

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conditions the atmosphere can emit light. The auroras illustrate this ability. As a result of these limitations, it is desirable to locate optical telescopes at remote sites at high altitudes. This creates severe complications in choosing sites for SPADATS' optical sensors.

Airborne electro-optical telescopes have been proposed as a means of circumventing some of the atmospheric limitations. In 1967, Nortronics (Palos Verdes Peninsula, California) conducted a design study for an airborne electro-optical surveillance system (Ref 2). Since then, the feasibility of using airborne optical sensors for satellite tracking has been demonstrated. In 1970, a long-wavelength infrared search/track radiometer, mounted on a U-2 aircraft, successfully acquired and tracked Pegasus satellites up to a range of 720 nautical miles (Ref 3:81-94).

Most experience with airborne optical sensors has been gained by astronomers using infrared telescopes. Because the atmosphere absorbs infrared radiation, celestial observations from the earth's surface are limited to views from high altitudes through narrow "atmospheric windows" at 1 to 2.5, 3 to 5, 8 to 12, 20, and less clearly at 350 microns (Ref 4). At sea level, most atmospheric absorption of the infrared is due to water vapor and carbon dioxide; however, the water content of the atmosphere decreases rapidly with altitude, and above 40,000 feet, the water content of the air is negligible (Ref 5:118). The two types of vehicles which astronomers have used most successfully as airborne observatories are balloons and airplanes. The balloon has the advantage of high operating altitudes. For example, a 40-inch far-infrared telescope has been carried to 95,000 feet several times by balloon (Ref 6), and the NASA Ames Research Center has sent a

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balloon-borne 28-inch telescope to 100,000 feet (Ref 4). The Ames Center also operates a Learjet carrying a 12-inch telescope and a C-141 carrying a 36-inch telescope (Ref 7). Although these aircraft can operate only up to 45,000 feet, they can carry equipment operators in a shirt sleeve environment, the flight path is controlled, and the payload is not at risk. In addition, the C-141 can carry a large payload.

But neither the balloon nor the airplane are practical for satellite surveillance (Ref 8:Sec B.2). Balloons have little station-keeping ability. This imposes a serious constraint since sensor data must be sent to the ground where it can be processed. Airplanes, on the other hand, would be too expensive. Due to expected aircraft availability, at least three planes would be required at each station to assure 16 hours/day operation.

A third kind of high altitude sensor platform is still under development. Both the Air Force (Ref 9) and the Navy (Ref 10) have sponsored programs for the development of an unmanned high altitude airship (or aerostat).

This concept combines some of the advantages of the airplane and the free balloon since the vehicle should be able to maintain a stationary position above the ground at 70,000 feet. The Air Force sponsored program has demonstrated that such an airship can be built. In May of 1970, High Platform II, a solar powered airship, was flown. This vehicle had a design speed of 10.3 meters/seconds at 20 kilometers above sea level. In spite of two attempts, the Navy has not yet sponsored a successful flight, but their effort is perhaps more ambitious. The Navy's High Altitude Superpressured Powered Aerostat

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(HASPA) program has built an ?'ship which is designed to maintain a payload of 4,000 pounds at 70,000 feet for 1 year.

The development of a practical high altitude airship has been slowed by two serious problems (Ref 11). The most serious of these problems is developing a suitable hull fabric. The high operating altitudes impose a severe strength to weight ratio requirement. Materials exist which can meet this requirement; but finding a material which also resists abrasion, tolerates temperature extremes, and tolerates ultraviolet light is a problem. The second problem is that the high altitude airship requires a lightweight power system for payload operation and propulsion. Several types of power systems are being studied as alternatives. Perhaps the most probable candidate for long duration flights is a regenerative power source utilizing solar arrays (Ref 11). However, NASA is evaluating the feasibility of powering an aerostat or even an unmanned lightweight airplane with a microwave power system (Ref 12). This should also be suitable for long duration flights. For short duration flights, up to 30 days or more, technology is currently available to assemble a gasoline fueled, turbocharged, reciprocating engine capable of providing sufficient power (Ref 13).

The latest effort to build a practical high altitude airship is a concept called Hi-Spot for high altitude surveillance platform for over-the-horizon targeting (Ref 14). Hi-Spot could hover at 60,000 to 80,000 feet for as long as 155 days. It would be 504 feet long and 154 feet in diameter, would carry a 550-pound payload, and would be propelled by a 27 meter diameter propeller powered by a hydrogen fueled, air breathing engine(s). The Hi-Spot concept is being studied for the

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Navy by Lockheed Missile & Space Company for applications including air/sea surveillance, communications relay, remote sensors readout, and signal intelligence (SIGENT) collection missions. The Lockheed design is being considered for a Fiscal 1984 start of a technical risk reduction program and scale model demonstration.

Objective of the Study

In the past (Ref 8:Sec B.2), the high altitude airship has been summarily dismissed as a viable platform option for satellite surveillance because of the relatively high development risk associated with finding a suitable hull fabric and because of the limited station-keeping ability of the proposed designs. However, interest in developing a high altitude airship has continued, and Hi-Spot may soon demonstrate the feasibility of such a vehicle. Furthermore, NASA is now investigating the feasibility of a High Altitude Powered Platform (HAPP) which would be either an unmanned airship or airplane utilizing a microwave power system. The results of their cost/feasibility study appear promising (Ref 15). In addition, NASA has funded user surveys in various areas of application (Ref 16). These surveys suggest that the HAPP system would have the attributes of a low attitude geostationary satellite. It would be particularly useful as a communications relay, and it would also be attractive in some remote sensing applications where very frequent coverage is required.

Since the implementation of a high altitude airship concept in some form appears likely, the practical value of an aerostat for satellite surveillance should be reassessed. The first step in that process should be to determine what practical value the aerostat would

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have in operational terms. The problem of interest here is to estimate
the effectiveness of a system of airship-based optical sensors
in performing the deep space surveillance mission and to compare this
to a system of ground-based sensors. Thus the objective of this study
is to assess the gain in mission performance due to three major
operational advantages conferred by the airship:

1. The optical sensor would be relatively insensitive to weather
   limitations.

2. The optical sensor could be stationed almost anywhere.

3. The infrared portion of the spectrum would be more readily
   available to the sensor.

Modeling Approach

The comparison between the different modes of sensor basing, airship
versus ground basing, can be made by using a computer program derived
from HELBASE, a computer simulation model for the investigation of high
energy laser applications in the antisatellite role (Refs 17 and 18).
The purpose of HELBASE is (given specific mission requirements) to
determine the optimal configuration and number of laser weapons re-
quired to "shoot" a given number of satellites with a given probability
of success. The program can make these selections regardless of
whether the laser weapons are ground-, air-, or spacebased. To deter-
mine if a particular system design (number and location of weapons)
will meet the mission requirements, the program simulates several
battles. If the system is unsatisfactory, the program selects the next
"best" weapon/location combination to add to the system. This ensures
that the weapons system selected can meet the mission requirements.

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Obviously HELBASE needed to be adapted for this thesis. HELBASE has been revised to do the following:

1. Allow the input of selected ground sites with predefined coordinates (latitude, longitude, and altitude) and associated sky cover probabilities.

2. Account for the effect of weather on a ground-based sensor's performance by utilizing sky cover probabilities in Markov chain model.

3. Determine if a target satellite can be tracked based upon the sun/earth shadow, target, and sensor configuration as well as the type of sensor involved.

The output from the model is the average time required to track all of the simulated target satellites. For this study, target satellite orbits were selected which emphasized the ability to detect and track injections from parking orbits into highly elliptical, 12-hour orbits and to detect maneuvers.

Scope, Limitations, and Assumptions

Scope. This effort is limited to comparing the performance of the aerostat-based versus ground-based optical sensors in the role of deep space surveillance and tracking. No comparison of investment and operating costs has been made. The ground-based system against which the aerostat-based system was compared was the Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) system which is now in the process of being deployed.

Limitations and Assumptions. Since there has been only moderate interest, an aerostat-based electro-optical telescope has yet to be built that could meet the requirements for deep space satellite

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surveillance. It is somewhat uncertain how such a system would
perform. For the purposes of this study, however, it has been assumed
that an aerostat based electro-optical telescope can track objects in
geosynchronous orbit and that the expected problems with pointing
accuracy, position fixing, and weight limits can be overcome at a
reasonable cost.

Sites for the aerostat-based system were selected from 13 evenly
spaced latitudes from 60 degrees north through 60 degrees south. No
other limits were placed upon deployment. This is somewhat unrealistic,
however, it is possible that configuration of the aerostat-based
systems could be approximated in the real world. The aerostat based
optical sensors were assumed to be operating at 70,000 feet and without
weather interference. Sites for the ground-based system were placed in
the same configuration as those sites selected for the GEODSS system.
The sky cover (weather interference) for each of the ground sites was
estimated using a model which assumed that the sky cover conditions
persisted for at least a 3-hour interval.

The orbital mechanics used in the model assume a simple two body
problem with the satellites acting as point masses. The Earth is
regarded as a simple sphere of radius 6378.145 kilometers.

Sequence of Presentation

Chapter II provides an overview of the computer simulation model.
In addition, some of the basic physical principles used in the model
are described. Chapter III contains an explanation of the concepts
employed in each of the model's subprograms. Chapter IV gives the
results of the basing mode analysis. Chapter V, the conclusion,
includes a summary of this thesis, some conclusions derived from this
work, and recommendations for further study.

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II Model Overview

This chapter presents a general overview of the program EOBASE.
The user inputs, the submodels, and some of the basic physical
principles which are used in the program are described. The program
EOBASE was derived from HELBASE (Refs 17 and 18), and it is analogous
to HELBASE in as much as one of its purposes is to select "the most
efficient" sensor system. However, EOBASE can also be used to evaluate
a system of sensors with user selected sites.

Definition of Terms

1. Basing Mode: This refers to the possible sensor locations.
    The three alternative locations are the surface of the
    earth, in an aircraft or aerostat, and in a circular orbit
    around the earth.

2. Sensor: One electro-optical sensor which either detects
    visible or infrared radiation from a specific sensor
    type.

3. Sensor Type: A specific combination of specific electro-
    optical sensor characteristics.

4. Sensor System: A collection of sensors selected from the
    available sensor types.

5. Target: A single specific satellite which a sensor may
    track.

6. Target Type: A group of targets which are related by a
    common set of mission and orbital parameters.

7. Target System: The collection of all selected targets.

8. Mission: The operational capabilities around which the
    sensor system is to be defined.

9. Most Efficient: Like HELBASE, EOBASE selects a system which
    is a first cut approximation of the optimal system. The term
    "most efficient" is viewed in this sense.

User Inputs

The EOBASE program allows the user two distinct options. The
program can be used to select the most efficient sensor system, or it
can be used to evaluate a user selected system. Each of these options
requires somewhat different input formats. Appendix A illustrates
these input formats and provides a description of the various inputs.

However the user chooses to use the program, the following
categories of user inputs are required: general, sensor types, target
types, and mission data. Table I provides a summary of these inputs.

Up to five sensor types may be input. As illustrated in Table I,
both the basing mode and the sensor characteristics are needed to
specify a sensor type. One of three basing modes can be chosen for
each sensor type, the ground mode, the air mode, or the space basing
mode. If the user elects to have the EOBASE program select the sensor
system; selection of the ground mode, Mode 1, limits deployment to the
latitudes on the surface of the earth; selection of the air mode,
Mode 2, limits deployment 21.3 kilometers above latitudes on the
surface of the earth; and selection of the space basing mode, Mode 3,

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TABLE I

User Inputs: General, Sensor Data, and Mission Data

Input Category	Variable	Dimension
General	SEED	----*
	JCOUNT	----
	NOWT	----
	ICOUNT	----
	DT	Minutes
	P	----
	INPUT	----
	INPUTS	----
	SUNTYP	----
Sensor Data	Basing mode	----
	Sensor	----
	Cutoff/angular resolution	Visual magnitudes/steradians
	Altitude	Kilometers
	Minimum tracking time per cycle	Seconds
	Dwell time	Seconds
Target Type Selection	Del	----
Mission Data	Target type	----
	Target type tracking percentage	----
	Mission time	Minutes
	Target type tracking priority	----

*Dimensionless parameter.
Note: Several sets of sensor and/or mission data are possible.

limits deployment to circular orbits around the earth at an altitude specified by the user.

The EOBASE program provides the user with the selection of any combination of four target types. These target types are permanently stored in EOBASE, and they are intended to be reasonable representations of real world target possibilities. See Table II for a description of the four types.

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TABLE II

Target Type Descriptions

Target Type	I	II	III	IV
Semimajor axis (kilometers)	22,260.0	22,260.0	42,164.0	42,165.0
Orbital eccentricity (dimensionless)	.7	.7	0	0
Orbital inclination (radians)	1.1340	.7854	1.5708	0
Argument of perigee (radians)	4.0143	4.5379	0	0
Longitude of the ascending node (radians)	Random*	Random	Random	0
Mean anomaly	Random*	Random	Random	Random
Number of targets	3	4	3	4

*Each set of targets is evenly spaced over 360 degrees.

A set of mission data inputs must be provided by the user with each target type selection. These inputs define the minimum mission requirements for tracking each type of target, and they are particularly relevant when EOBASE is used to select the most efficient sensor system. The target type tracking percentage is the percentage of a particular type of target which must be tracked to ensure mission accomplishment. The mission time is the maximum time a selected sensor system is allowed to accomplish the mission. This input must be the

same for all target types. A target type tracking priority is assigned to each target type (one is the highest). The tracking priority is used to determine which target is tracked first if two targets can be tracked at the same time. A secondary criterion is the target's range from the sensor. The target with the shortest range, within a particular priority group, is tracked first.

A fifth input category, ground site locations, is used when the user wishes to input previously selected sites for sensors in the ground mode. As shown in Table III, the user enters the latitude, longitude, altitude, and sensor type of each ground-based sensor. Associated with each of these site locations is a sixth input

TABLE III

User Inputs: Ground Site Locations and Air and Space

Based Sensor Location Parameters

Input Category	Variable	Dimension
Ground site locations	Latitude	Radians
	Longitude	Radians
	Altitude	Kilometers
	Sensor type	---*
Sky cover probabilities (see Table IV)	Conditional	---
	Unconditional	---
Air and space-based sensor location parameters	Orbital radius or coordinate theta	Kilometers or radians
	Eccentricity	---
	Inclination or coordinate theta	Radians or radians
	Longitude of ascending node	Random
	Argument of perigee	0

*Dimensionless parameter

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TABLE IV

User Inputs: Sky Cover Probabilities

Initial Time	Starting Condition	Array # 0 hours	Array # +3 hours	Array # +6 hours	Array # +9 hours	Array # +12 hours
1700 L	0-3/8	1	2	4	6	8
	4-8/8		3	5	7	9
2000 L	0-3/8	10	11	13	15	
	4-8/8		12	14	16	
2300 L	0-3/8	17	18	20		
	4-8/8		19	21		
0200 L	0-3/8	22	23			
	4-8/8		24			
0500 L	0-3/8	25				
	4-8/8					

category, sky cover probabilities. These are the probabilities for the occurrence of less than or equal to 3/8 total cloud cover. These probabilities are used to determine whether or not the sensor has a cloud free line of sight. As shown in Table IV, the sky cover probabilities for each site are inserted into an array which requires 25 inputs for each site. The probabilities are used to simulate cloud cover conditions from 1700 hours to 0700 hours local time. The input values under the 0 hours column are the unconditional probabilities of less than or equal to 3/8 sky cover at the initial time. The remaining

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inputs are the conditional probabilities of less than or equal to 3/8 sky cover given the initial sky cover condition and starting time.

Finally, the seventh input category is the air-and space-based sensor location parameters. These inputs are used if the user wishes to evaluate a user selected sensor system which includes air-or space-based sensors. As shown in Table III, there are six inputs in this category. These include the sensor type and the orbital parameters for a space-based sensor or the latitude (coordinate theta) for an air-based sensor.

Basic Physical Principles

The fundamental aspects of orbital mechanics and sensor operation as used in EOBASE are described below.

Orbital Mechanics. The EOBASE program employs the same techniques and principles of orbital mechanics as utilized in the HELBASE simulation (Refs 17 and 18). As stated in Chapter I as an assumption, the techniques used here assume a simple two body problem with the satellite acting as a point mass, and the earth is regarded as a simple sphere of radius 6378.145 kilometers.

The coordinate reference system employed in the model is the geocentric-equatorial system. This system has its origin at the earth's center, and it is essentially fixed with respect to the stars. Figure 1 depicts this reference system.

Sensor Operation. Both of the two classes of electro-optical sensors which can be evaluated with EOBASE have to have two conditions satisfied before they can be used for satellite tracking. First, the sensors have to be located either in space or on the night side of the

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∽   LONGITUDE OF ASCENDING NODE

ν   TRUE ANOMALY AT EPOCH

ω   ARGUMENT OF PERIGEE

ι   INCLINATION
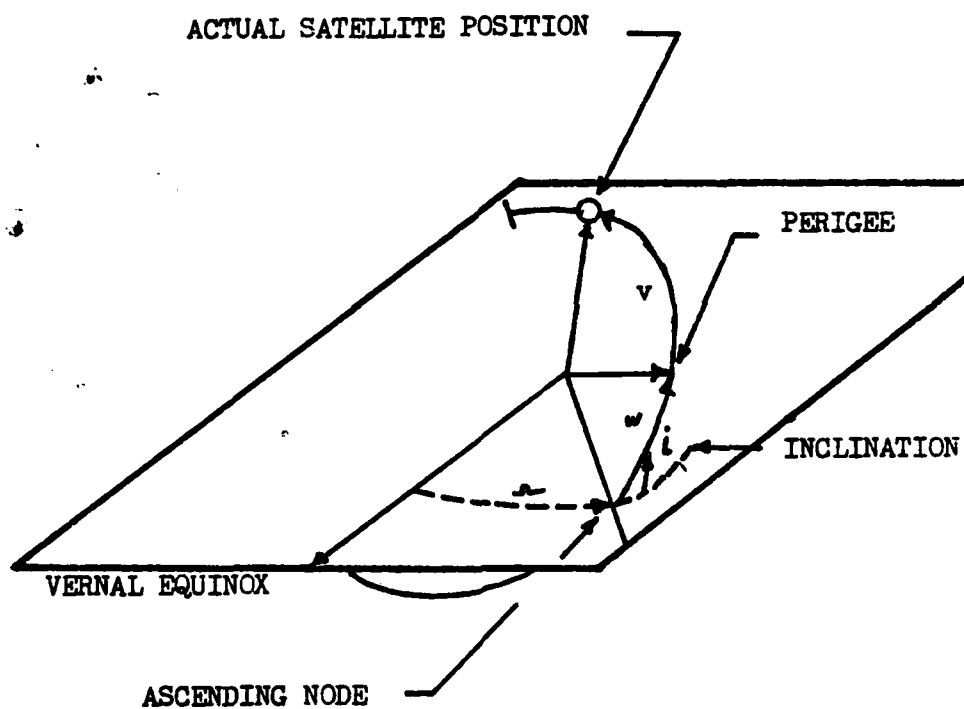
Figure 1. Geocentric equitorial reference.

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clear line of sight to the target. Second, the sensor cannot operate in the presence of cloud cover or with the earth between it and its target.

Once these preconditions have been satisfied, the differences between the sensors become important. The sensor class of primary interest here (like the GEODSS system) uses the sunlight reflected by the target satellites to detect them. The amount of sunlight which the targets reflect is dependent upon the relative positions of the sun, the target, and the sensor. This relationship is illustrated in Figure 2. For the sake of simplicity, all of the targets in the EOBASE simulation are modeled as cylinders with an earth center orientation. In addition, the irradiance of the sun (Ho) is assumed to be constant throughout the orbits of the target satellites. In this case, the irradiance of the light reflected by the target at the sensor can be calculated if the following is known (Ref 19:12, 15, and 84-86): the distance between the target and the sensor (R), the sensor aspect angle (α), the solar aspect angle (β), the phase angle (ϕ), the reflectivity of the cylinder (ρc) and the endplate (ρp), and the projected area of the cylinder (Ac) and the endplate (Ap). The following formulas are employed.

$$Hp = \frac{Ho \; \rho p \; Ap \cos \alpha \cos \beta}{\pi \; R^2}$$

$$Hc = \frac{Ho \; \rho \; Ac \sin \alpha \sin \beta \; (\sin \theta + [\pi - \theta] \cos \theta)}{4 \; \pi \; R^2}$$

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LOCAL VERTICAL
IS ALSO
CYLINDER LONG
AXIS

SENSOR LINE

TO
SUN

β

α

ϕ

SENSOR

EARTH CENTER
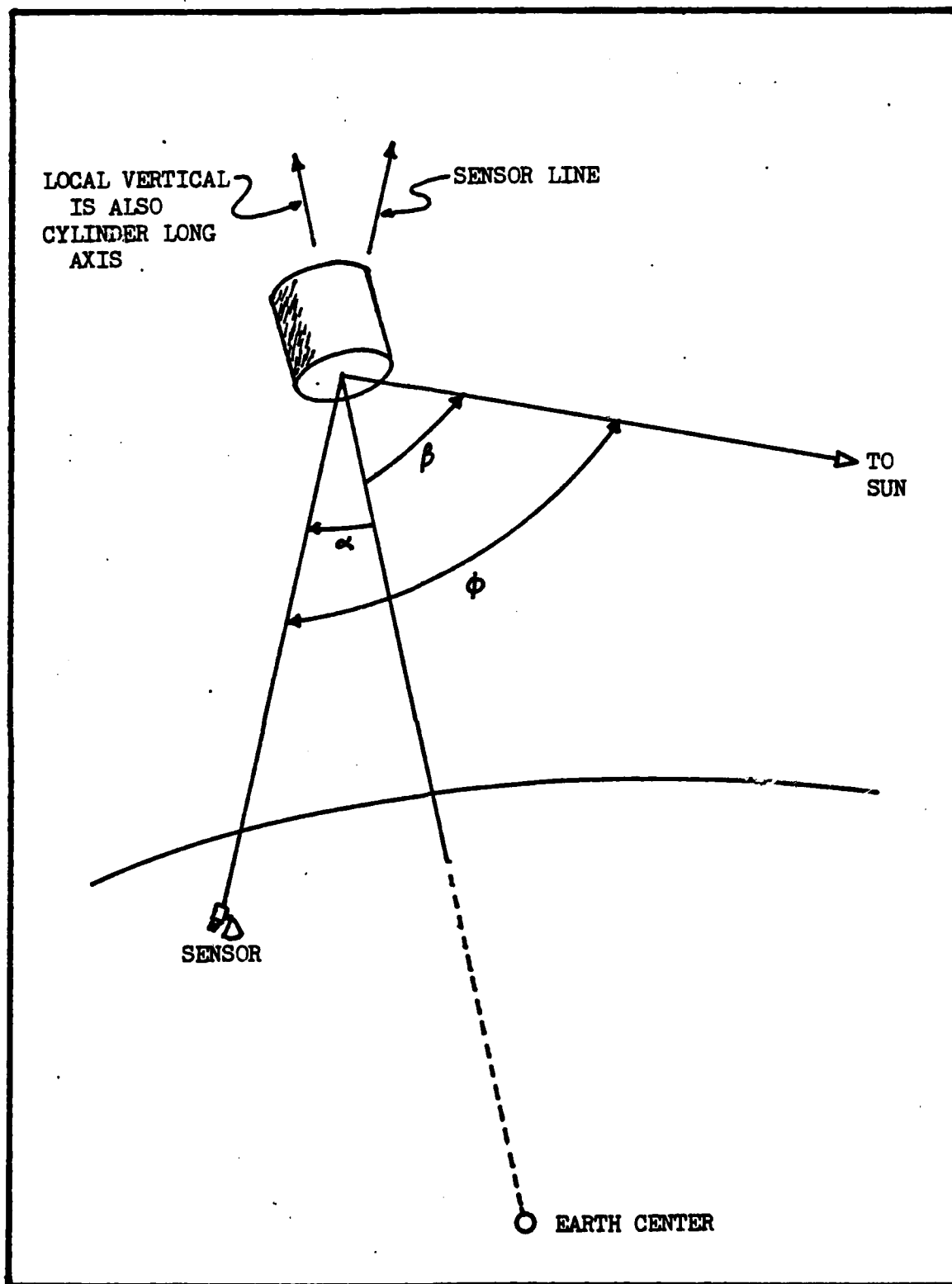
Figure 2.   Sunlight reflection geometry.

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where

H_p = the irradiance at the sensor due to the end plate

H_c = the irradiance at the sensor due to the cylinder

$\theta = \cos^{-1} (\cos \phi - \cos \alpha \cos \beta \sin \alpha \sin \beta)$

The final value is computed in units of visual magnitudes of light.

$$MAG = M_{v\odot} - 2.5 \log_{10} \left[\frac{H_p + H_c}{H_o} \right]$$

where

MAG = the visual magnitude of the target at the sensor number

$M_{v\odot}$ = the visual magnitude of the sun at the target

$= -26.78 \; M_v$

The visual magnitude of light from the target can then be compared with the amount of light that the sensor needs to detect the target. If the number is low enough (the smaller the number the more light), then the sensor can detect the target.

The second sensor which can be considered using EOBASE detects satellites from their thermal emissions in the long wavelength infrared (LWIR) range of 8 to 14 micrometers. Unlike the reflected sunlight employed by the previous sensor, the emissions come directly from the satellite itself, and their intensity and wavelength are primarily

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dependent upon the temperature of the satellite. The emissions can be modeled using Planck's Blackbody Radiation Law (Ref 20:Ch 1).

As indicated in Chapter I in the introduction, some experimental work has been done with this kind of sensor using a U-2 aircraft (Ref 3). However, the sensitivity of this system was not great enough to detect deep space satellites (Ref 3:Ch 3). The system ultimately was limited by background infrared emissions from the atmosphere and the telescope itself. Nonetheless, this type of sensor has been included as an EOBASE sensor option since it is conceivable that further improvements in detector technology could make it feasible to use it for deep space satellite tracking. Such a breakthrough, the development of the vidicon imaging tube, has been extremely important in the development of visible wavelength sensors for satellite tracking (Ref 21). The extremely small image cell diameters or detector spot sizes which can be achieved with these tubes are to a great extent responsible for the high sensitivity of the GEODSS system.

So, the long-wavelength infrared sensor is included in EOBASE with two assumptions. First, the sensor will be either in a space-based or air-based mode. The ground-based mode will be excluded because of the relatively much higher sky background at lower altitudes and because the presence of water vapor prohibits cooling the optics to liquid nitrogen temperatures. Second, it will be assumed that the sensor has sufficient sensitivity to track target satellites in geosynchronous orbits in a reasonable time frame.

Because of the effect that the earth's atmospheric radiance has upon the LWIR Air-Based Sensor, an effort has been made to have EOBASE account for the loss of sensitivity as the zenith angle increases with

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respect to the sensor's line of sight to the target satellite. Therefore, EOBASE calculates the irradiance at the sensor due to both the target satellite and the atmosphere. The formula used to determine the irradiance at the sensor (ε_T) from the target is based upon the point source approximation (Ref 22:App 5)

$$\varepsilon_T = \frac{L\lambda\ (\bar{\lambda})\ a^2\ \tau A\ \Delta\lambda}{r^2}$$

where

$L\lambda_T\ (\bar{\lambda})$ = the radiance of the target at the middle of the sensor's spectral band

a = the radius of the target

τ_A = the average atmospheric transmittance

$\Delta\lambda$ = the bandwidth of the sensor

r = slant range to the target

The irradiance at the sensor on a single detector field of view due to the atmosphere (ε_β) is calculated by (Ref 20):

$$\varepsilon_\beta = \Omega_1\ L\lambda_A\ \tau A$$

where

Ω_1 = the field of view of a single detector

$L\lambda_A$ = the radiance of the atmosphere over the spectral band of the sensor

Once the irradiance at the sensor is known, the current response both due to the target irradiance and due to the atmosphere can be calculated (Ref 20). The current (i_T) produced by the target can be calculated by:

$$i_T = \frac{S_R \; \eta(\overline{\lambda}) \; \varepsilon_T \; e}{hc/\overline{\lambda}}$$

where

S_R = the area of the receiving optics

$\eta(\overline{\lambda})$ = quantum efficiency of the detector at the mean wavelength of the sensor's spectral band

h = Planck's constant

= 6.63×10^{-34} Watts second^{+2}

c = speed of light

= 3.00×10^{8} meters second^{-1}

$\overline{\lambda}$ = the mean of the sensor's spectral band

e = the charge on an electron

= 1.6×10^{-19} Coulombs

The current response (i_β) due to the atmospheric irradiance is:

$$i_\beta = \frac{S_R \; \eta(\overline{\lambda}) \; \varepsilon_B \; e}{hc/\overline{\lambda}}$$

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Once the current response is known, the signal to noise ratio (S/N),
assuming there is no source of noise other than atmospheric radiance,
can be calculated by:

$$S/N = \frac{i_T/e \sqrt{tD}}{\sqrt{i_T/e + i_B/e}}$$

If the signal to noise ratio is sufficiently large, then the target can
be tracked.

Submodel Descriptions

The ten major subroutines associated with the program EOBASE are
SPHERE, CART, TARGET, SUNPOS, SIGHT, VISBLE, SLWIR, SIDEN, CLOUD, and
TRACK. Each is briefly described in this section. Expanded
descriptions of underlying models for these subroutines are found in
the next chapter.

SPHERE and CART. When EOBASE is used to select the most efficient
sensor system, SPHERE and CART are called to generate a sphere of
operations for each sensor type. Together these subroutines calculate
and store 410 points that are spread uniformly over this sphere of
operations which is fixed in the geocentric equatorial coordinate
system. Note that the radius of each sphere is defined by the altitude
of the sensor for which it is calculated. See Figure 3 for a
functional flow of SPHERE.

TARGET and SUNPOS. TARGET is used to randomly place all selected
targets into their proper orbits and store the cartesian coordinates of
their locations. The TARGET algorithm uses a random selection from a
uniform $(0, 2\pi)$ distribution for the mean anomaly, a root solution

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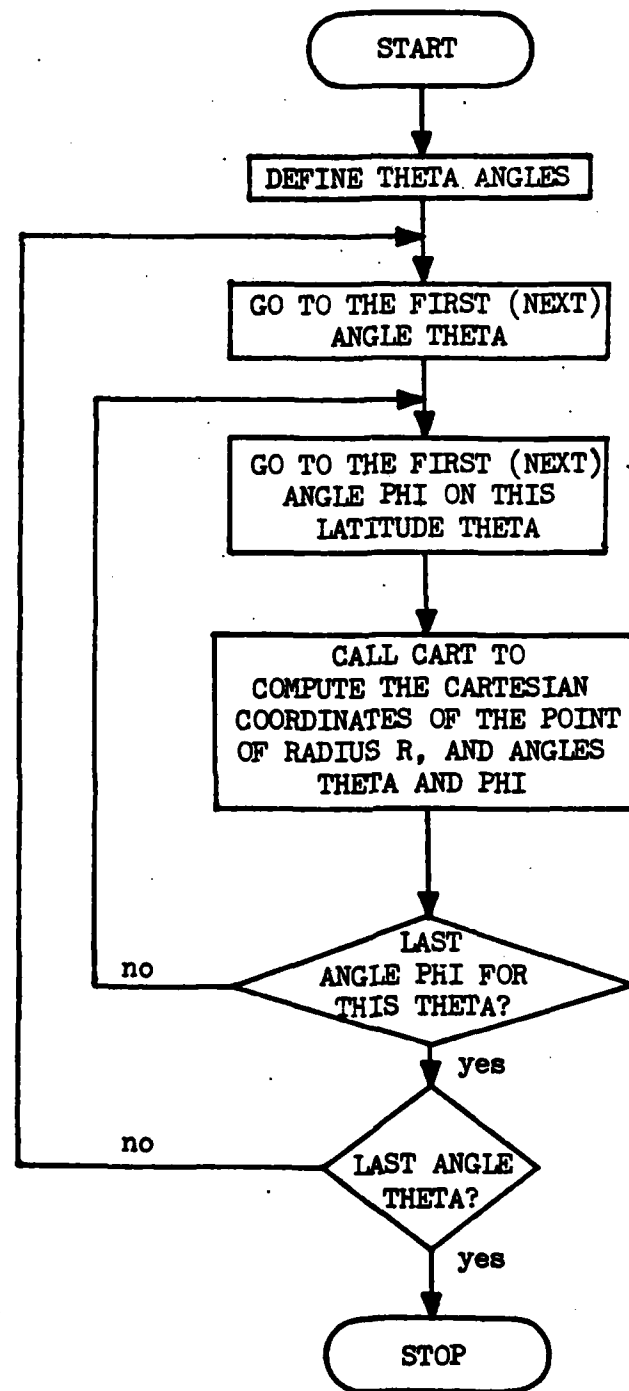
Figure 3. Submodel SPHERE logic diagram

to Kepler's equation for the eccentric anomaly, and a conversion to the true anomaly. In addition, TARGET calls subroutine SUNPOS to randomly place the position of the sun with respect to the latitude and longitude that is oriented over the earth. See Figure 4 for the functional flow of TARGET.

SIGHT. The purpose of SIGHT is to determine whether or not a target can be tracked by a particular sensor from a given location. SIGHT's answer is yes or no. If the target cannot be tracked, SIGHT returns the calling program a score of 0.0. Conversely, if the target can be tracked, SIGHT returns a value of 1.0. SIGHT uses the subroutine VISBLE or the subroutine LWIR. See Figure 5 for the functional flow of SIGHT.

VISBLE. Subroutine VISBLE is used to determine if the amount of visible radiation from the sun reflected to a particular sensor is sufficient for the target to be detected. For the sake of simplicity, the algorithm used in VISBLE assumes that the target is a simple earth center oriented cylinder. See Figure 6 for the functional flow of VISBLE.

SLWIR. The purpose of subroutine SLWIR is to determine if a LWIR sensor can track a target satellite. SLWIR assumes the target is a Lambertian surface at 300 degrees Kelvin with one square meter of surface area presented to the sensor. See Figure 7 for the functional flow of LWIR.

SIDEN. Subroutine SIDEN uses the subroutines TARGET and SIGHT to generate an "average target system sighting efficiency" value for each point on each sensor type's sphere of operations. Subroutine SIDEN

25
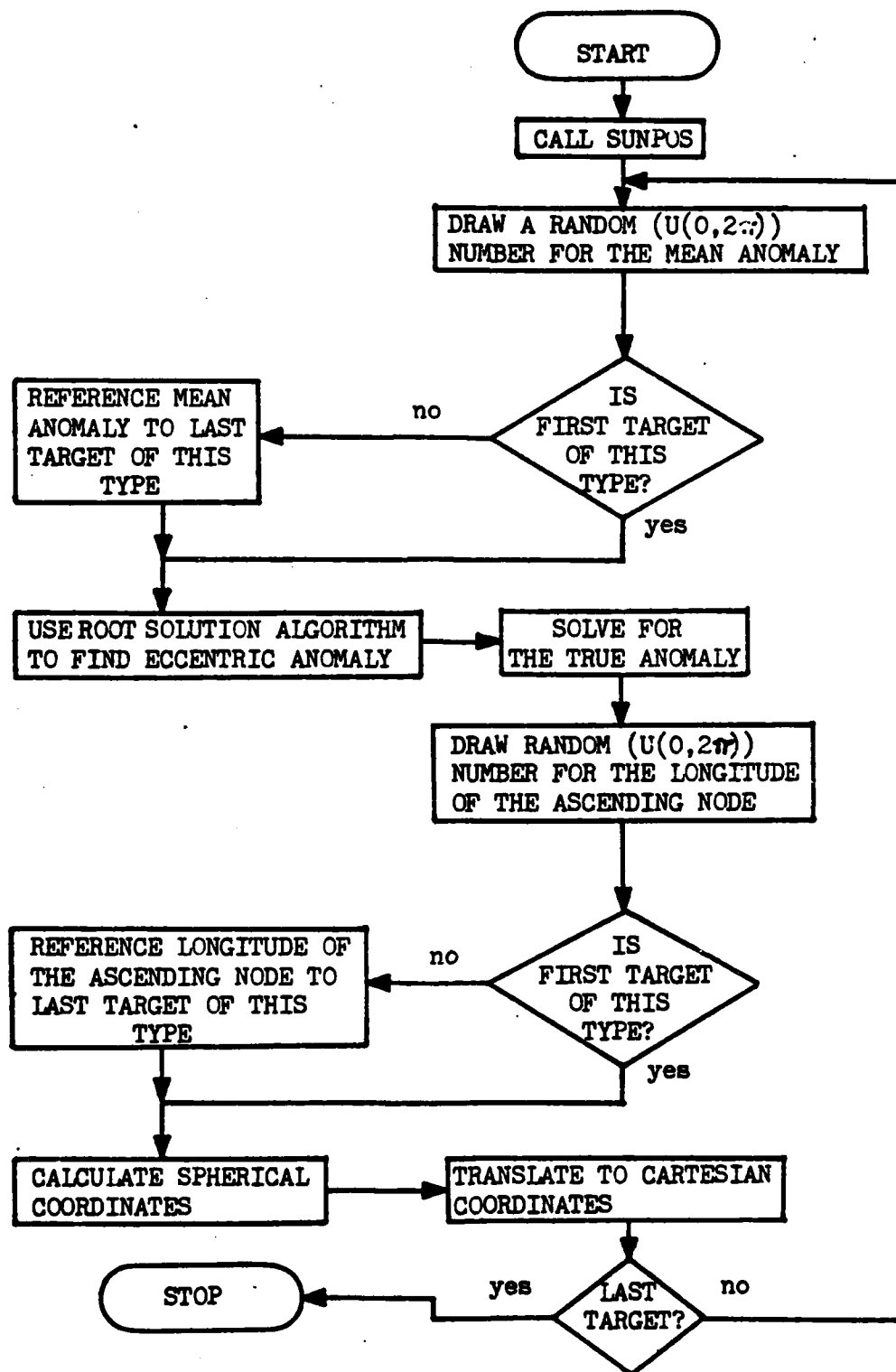
Figure 4. Submodel TARGET logic diagram.

26
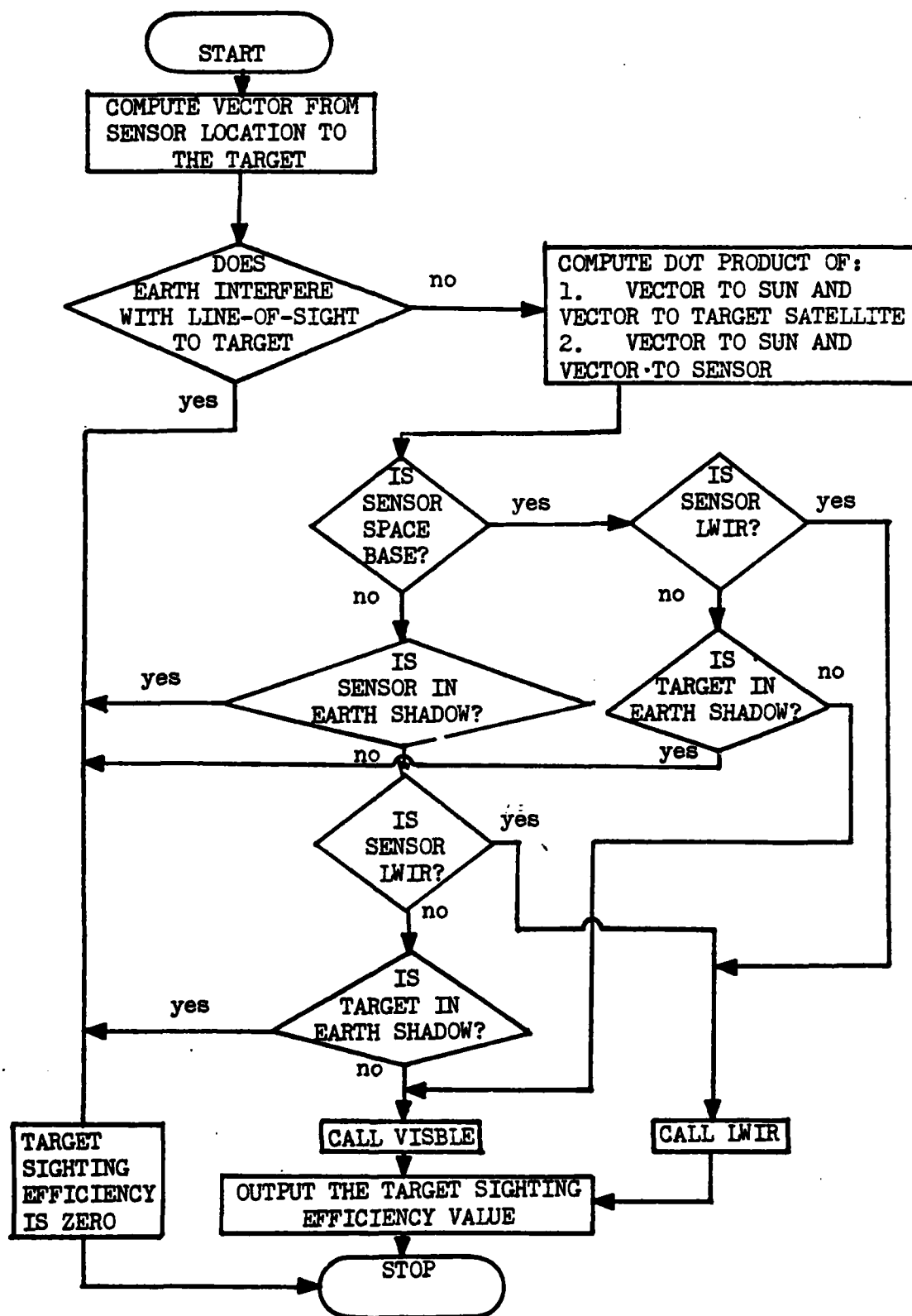
Figure 5. Submodel SIGHT logic diagram.
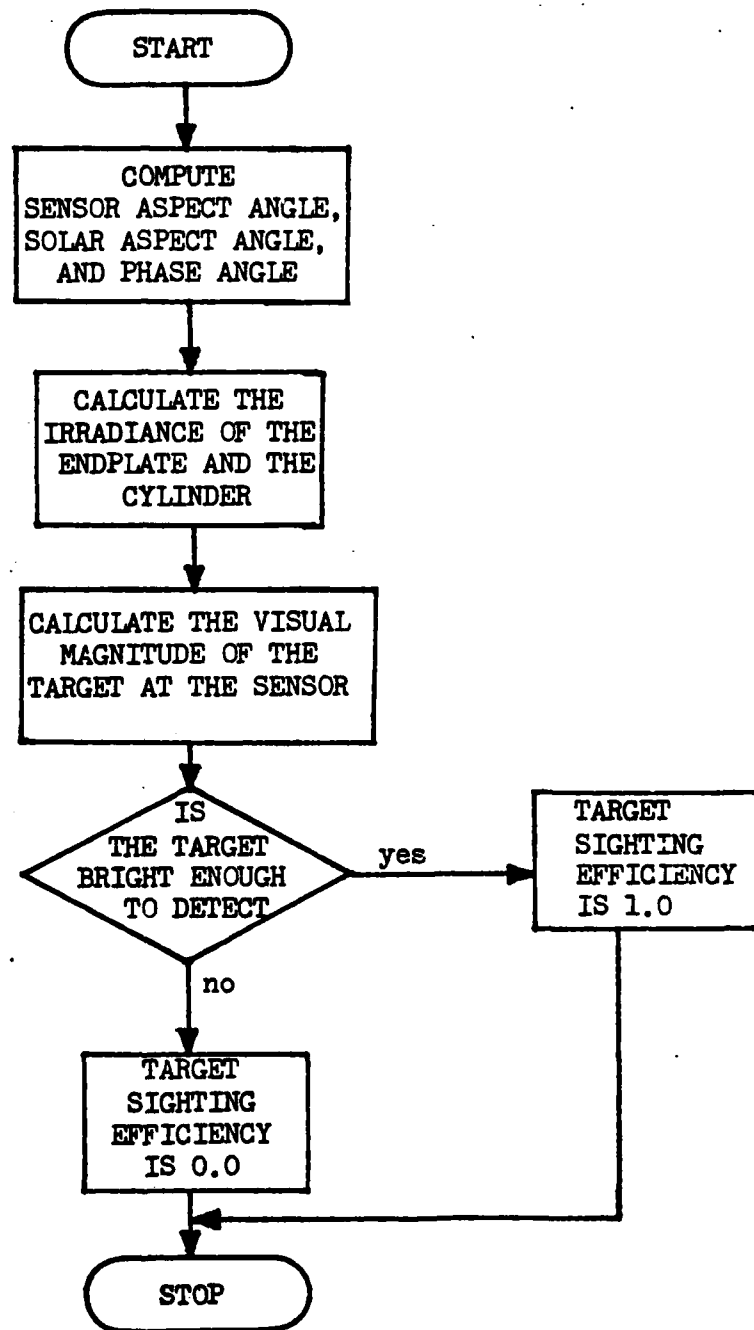
Figure 6. Submodel VISBLE logic diagram.

28
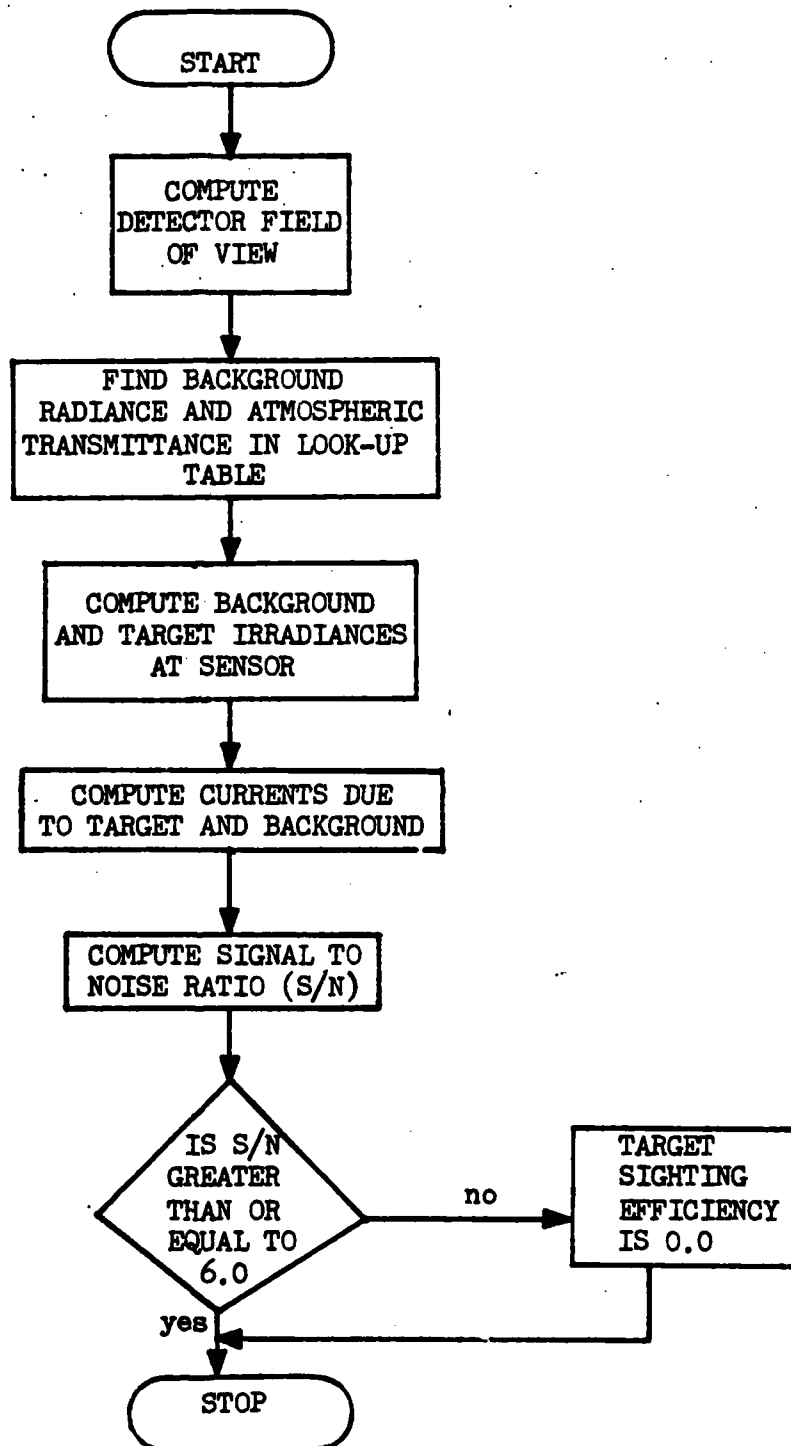
Figure 7. Submodel SLWIR logic diagram.

does this by having TARGET randomly place the targets into their orbits and then it uses SIGHT to score each point on each sphere of operations with respect to each target. See Figure 8 for the functional flow of SIDEN.

CLOUD. The purpose of subroutine CLOUD is to simulate the amount of cloud cover at ground-based sensor site locations and then determine if the sensor is still functional. CLOUD is called only when preselected ground-based sensor site locations have been entered into the program. See Figure 9 for the functional flow of CLOUD.

TRACK. Subroutine TRACK is the portion of the EOBASE model in which the simulation takes place. TRACK uses either the user supplied sensor system or the sensor system selected by EOBASE to attempt tracking the target system within the mission completion time. TRACK uses subroutines TARGET, SIGHT, and CLOUD. See Figure 10 for the functional flow of TRACK.

Main Program EOBASE

The main program, EOBASE, acts as a controlling program. EOBASE is divided into three sections, an input section, an optimization section, and a confidence section. The optimization and confidence sections of EOBASE, together with its various subroutines, provide the EOBASE with the capability to select the most efficient sensor system from the input sensor types to accomplish a given mission. In the event the user wishes to evaluate a preselected weapons system, the optimization section is bypassed and TRACK is called the number of times requested. See Figure 11 for a functional flow of EOBASE.

30
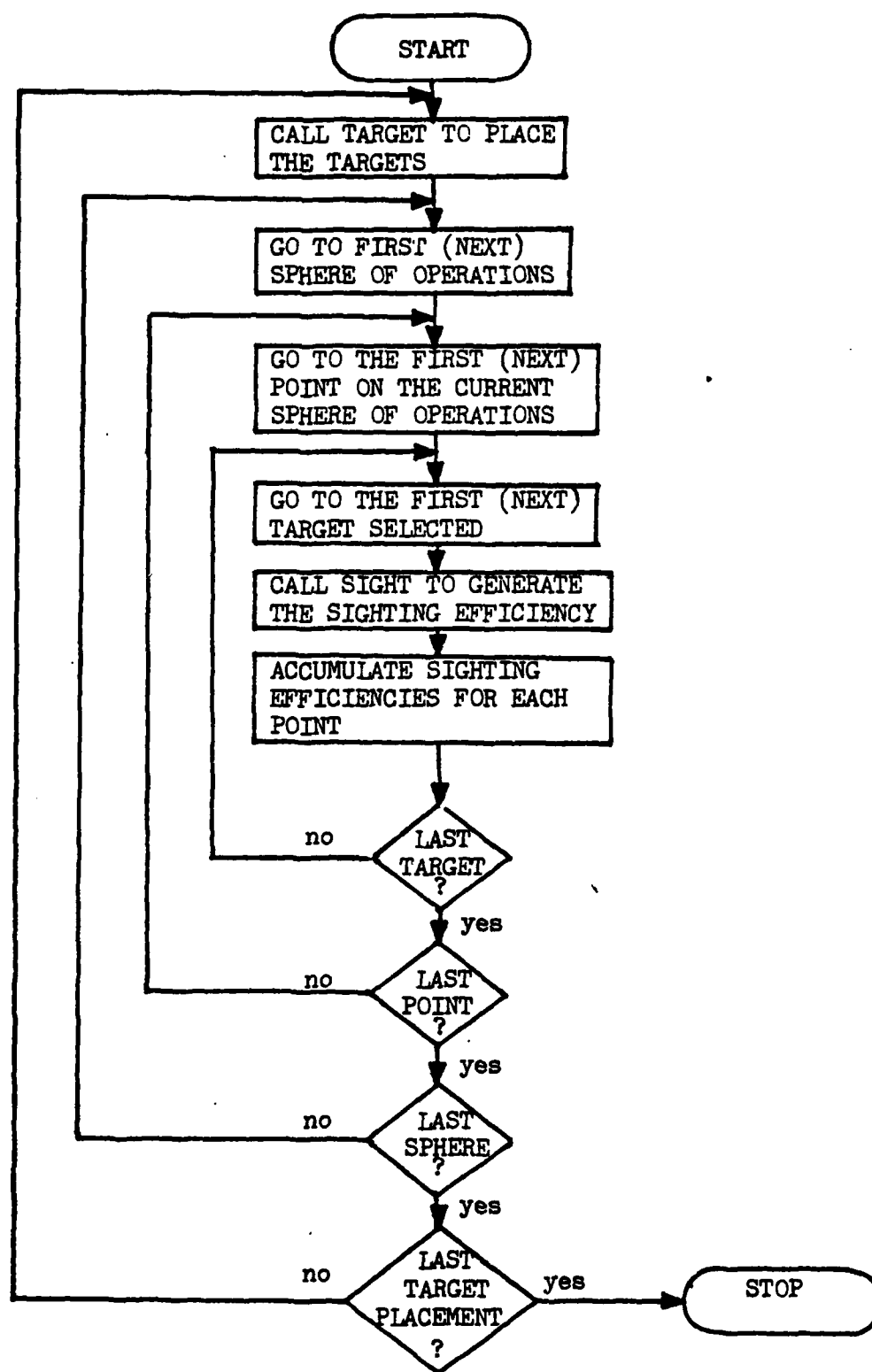
Figure 8. Submodel SIDEN logic diagram.

31
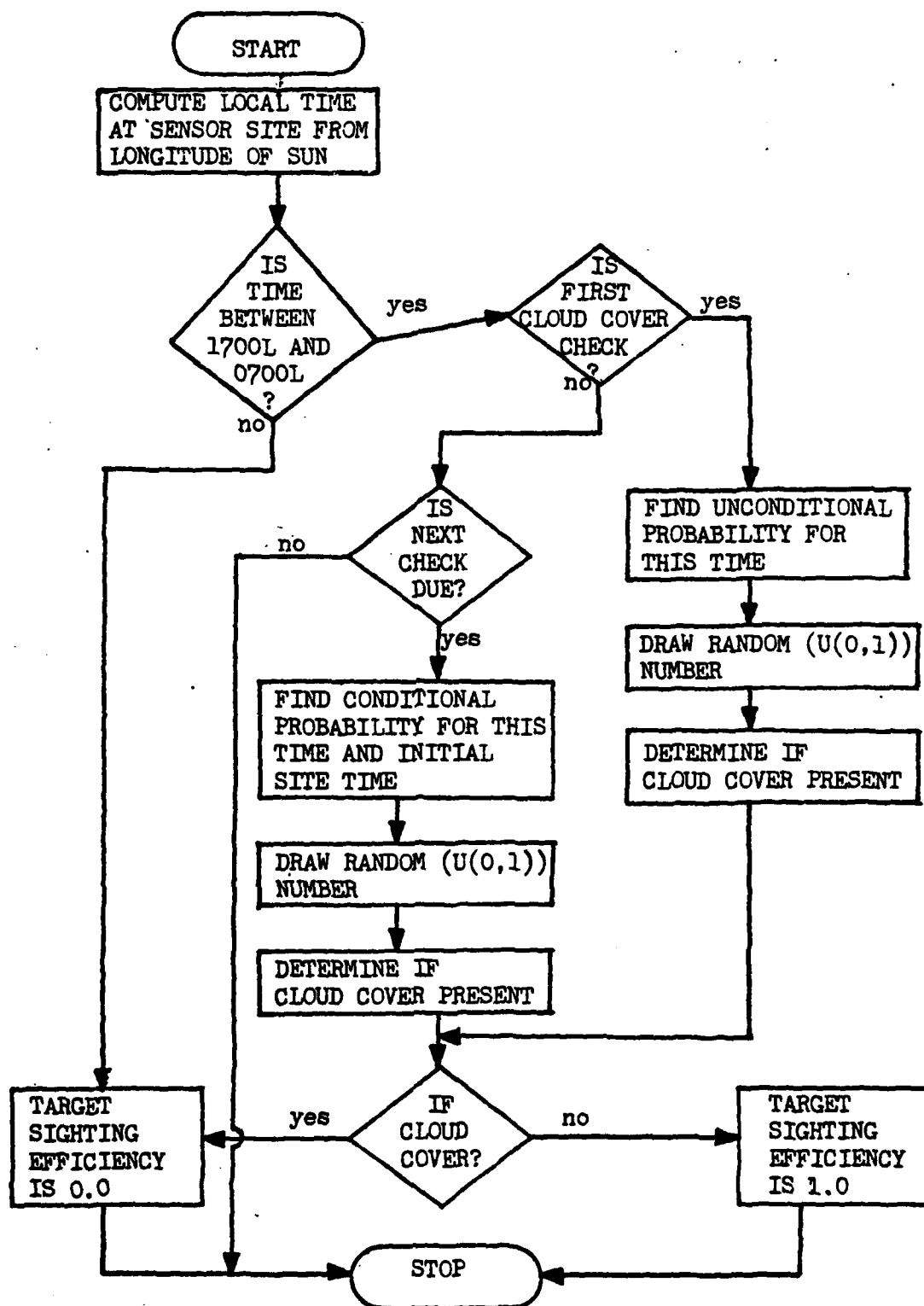
Figure 9. Submodel CLOUD logic diagram.
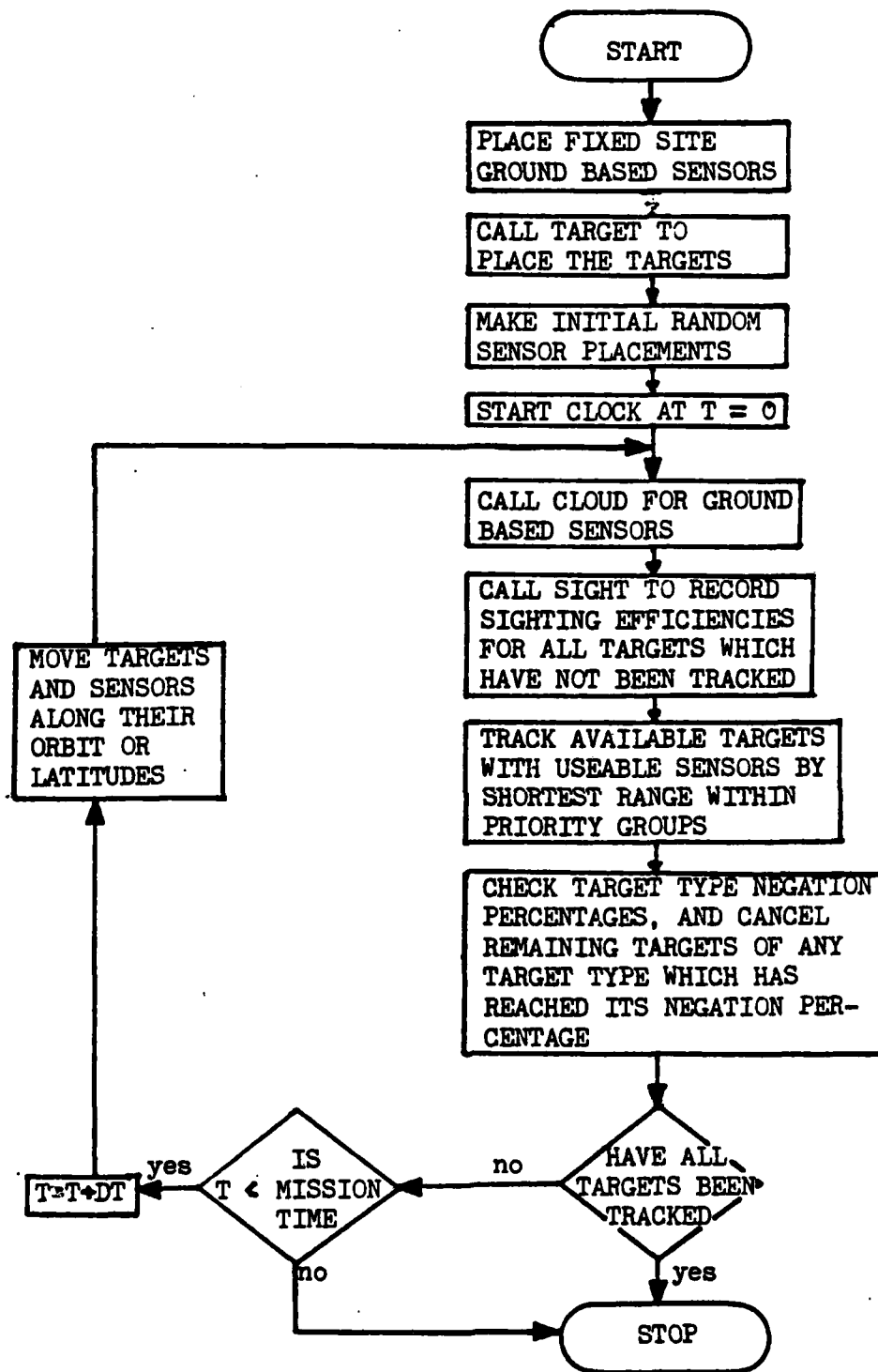
Figure 10. Submodel TRACK logic diagram.

33
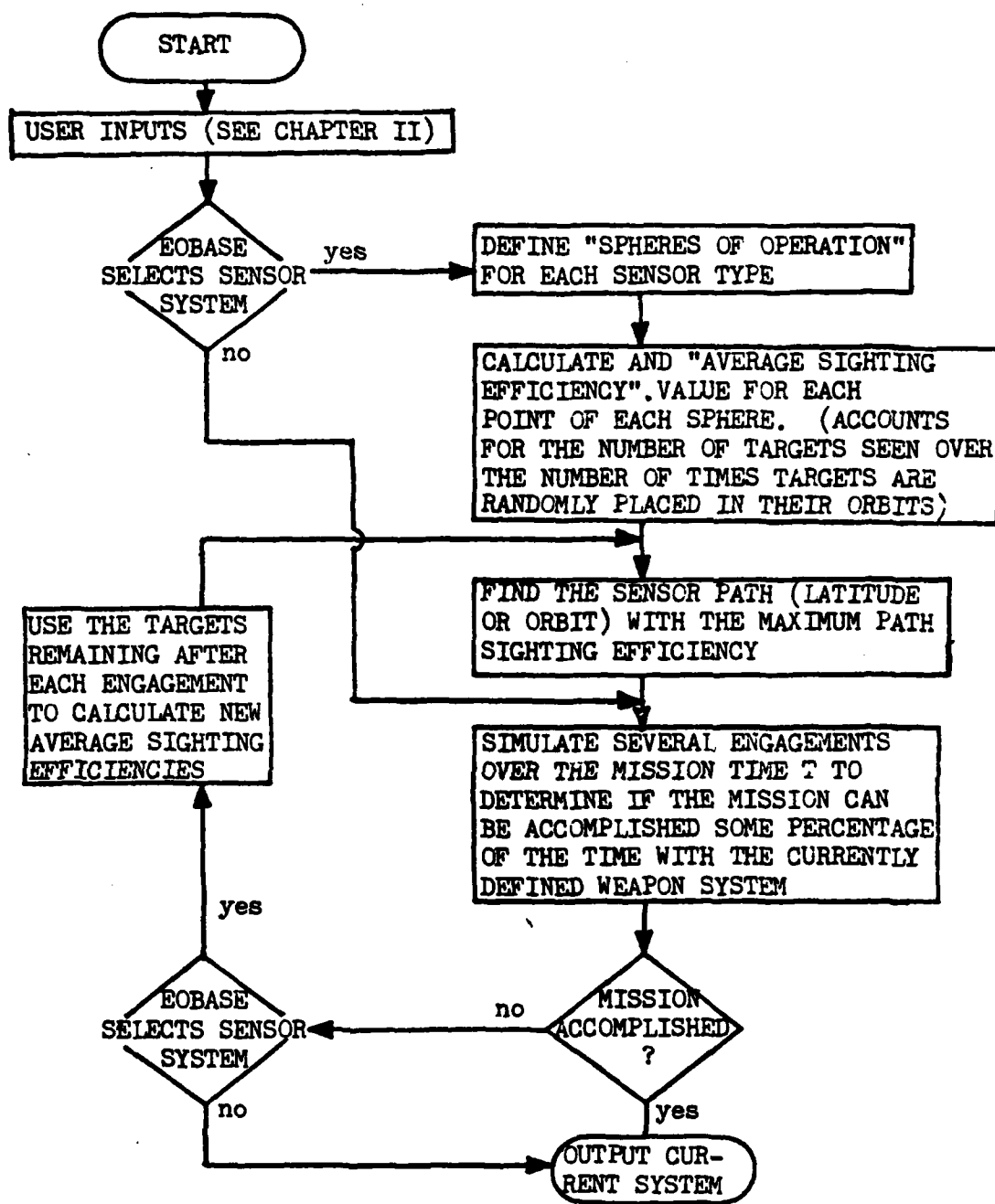
Figure 11. EOBASE function flow.

Input Section. This section of EOBASE reads in all user inputs
and writes them back for verification. In addition, SPHERE is called
to generate the sphere of operations for each sensor type when the
user directs EOBASE to select the most weapons system.

Optimization Section. The purpose of this section of the program
is to place the first (next) best sensor in the most efficient orbit or
latitude. The average target system sighting efficiencies, generated
by SIDEN, are used to decide the first (next) best sensor/path choice.
SIDEN is called each time a sensor is placed.

Confidence Section. The confidence section of the program runs
TRACK several times to determine if the selected sensor system can meet
mission requirements. If EOBASE is being used to select the most
efficient sensor system, the percentage of time the selected sensor
meets mission requirements is compared with some user selected
percentage. In the event that the user selected percentage is higher,
SIDEN is called, and then control is passed to the optimization section
and another sensor is added to the sensor system. Otherwise, EOBASE
writes out the final selected sensor system. If the user wishes to use
EOBASE to evaluate a preselected sensor system, the confidence section
is used to run TRACK the requested number of times.

Summary. The purpose of the EOBASE simulation program is twofold;
the program can be used to select the most efficient sensor system
which will meet mission requirements given no knowledge of the time of
the tracking sequence initiation, or the program can be used to
evaluate a preselected system. This chapter has included a functional
description of EOBASE and its submodels, and it is concluded with a

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table summarizing these submodels, their functions, inputs, and outputs
see Table V). Chapter III provides an explanation of the concepts
employed by each of the EOBASE submodels, and it describes the efforts
which were made to validate the EOBASE program.

TABLE V

Summary of Submodel Functions

Submodel	Function	Inputs	Outputs
SPHERE	Calculate and store cartesian coordinates of points on a sphere of operations	Radius	Cartesian coordinates of a sphere of operation
TARGET	Place targets randomly into orbits	Target type selections	Cartesian coordinates of all targets
SUNPOS	Place sun above earth	Sun type selection	Unit vector to and longitude of sun
SIGHT	Determines feasibility of sighting target	Target, sun, and sensor locations, sensor type, and target type	Target sighting efficiency
VISBLE	Calculates visual magnitude of target at sensor	Sensor type, vectors to target from origin and sensor, vector to sun, and range to target	Target sighting efficiency
SLWIR	Calculates signal to noise ratio for target irradiance versus background irradiance	Sensor type, zenith angle, range to target	Target sighting efficiency
SIDEN	Establishes the target system sighting efficiency for each point on each sphere of operations	Sensor type, target type, sun type, and spheres of operation	Values of target system sighting efficiency

(continued)

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TABLE V (continued)

Summary of Submodel Functions

Submodel	Function	Inputs	Outputs
CLOUD	Simulates effect of cloud cover on ground based sensor	Longitude of sun, longitude of sensor, sky cover probabilities	Target sighting efficiency
OPTIMIZE	Select most efficient sensor orbit or latitude to place first (next) sensor	Average target system sighting efficiencies	Sensor system locational parameters
TRACK	Engage targets in accordance with mission data	Sensor system, target system, mission data	Number of targets tracked and target system tracking time

III   Model Development

The previous chapter provided a functional description of EOBASE
and its submodels. This chapter contains a description of the concepts
employed by each of the various submodels described in Chapter II. In
addition, the efforts made to validate EOBASE are presented.

Sphere of Operations (Subroutine SPHERE)

A "sphere of operations" is a stationary sphere in the celestial
reference system, and it is used to represent all of the possible
basing locations for a particular sensor type (see Refs 17 and 18 for a
more complete explanation).

Placement of Points. EOBASE uses 410 points to define a sphere
of operations. This number is the same as chosen for HELBASE
(Ref 18:Ch 2, 29), and it was chosen as a tradeoff between accuracy run
time and computer core memory requirements. The 410 points are
distributed among 19 latitudes starting with the equator and heading
north and south in 10 degree increments. The number of points on each
latitude is the number of points required to achieve the closest
approximation to a 10 degree arc spacing (see Table VI). Subroutine
SPHERE calculates the cartesian coordinates for each of the 410 points
for each sphere of operations.

Ground and Air Basing Modes. The sphere of operations for ground
based sensors is the mean surface of the earth. For air-based sensors,

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TABLE VI

Number of Points on Each 10 Degrees of Latitude

True Latitude (degrees)	Number of Points
0	36
10	35
20	34
30	31
40	27
50	23
60	18
70	12
80	6
90	1

Note: The southern hemisphere is a mirror image of the northern hemisphere.

the sphere of operations is 21 kilometers (70,000 feet) above the mean surface of the earth. The choice of this altitude is due to the existence of a minimum wind velocity at this altitude (Refs 11 and 23). A typical example of this minimum is shown in Figure 12. As noted by Petrone and Wessel (Ref 11), although a considerable penalty in weight and complexity is exacted at this altitude, the required power is much less (except of course at altitudes near sea level). As a first approximation, drag (power consumption) and lift (power available) are proportional to density while power consumption increases as the cube of the velocity; thus a minimum in the velocity altitude curve represents an optimal point for operations.

The possible alternatives for positioning a sensor in these modes are limited to the set of latitudes from 60 degrees north through 60 degrees south spaced in 10 degree intervals. The position of both ground-and air-based sensors is considered fixed with respect to the
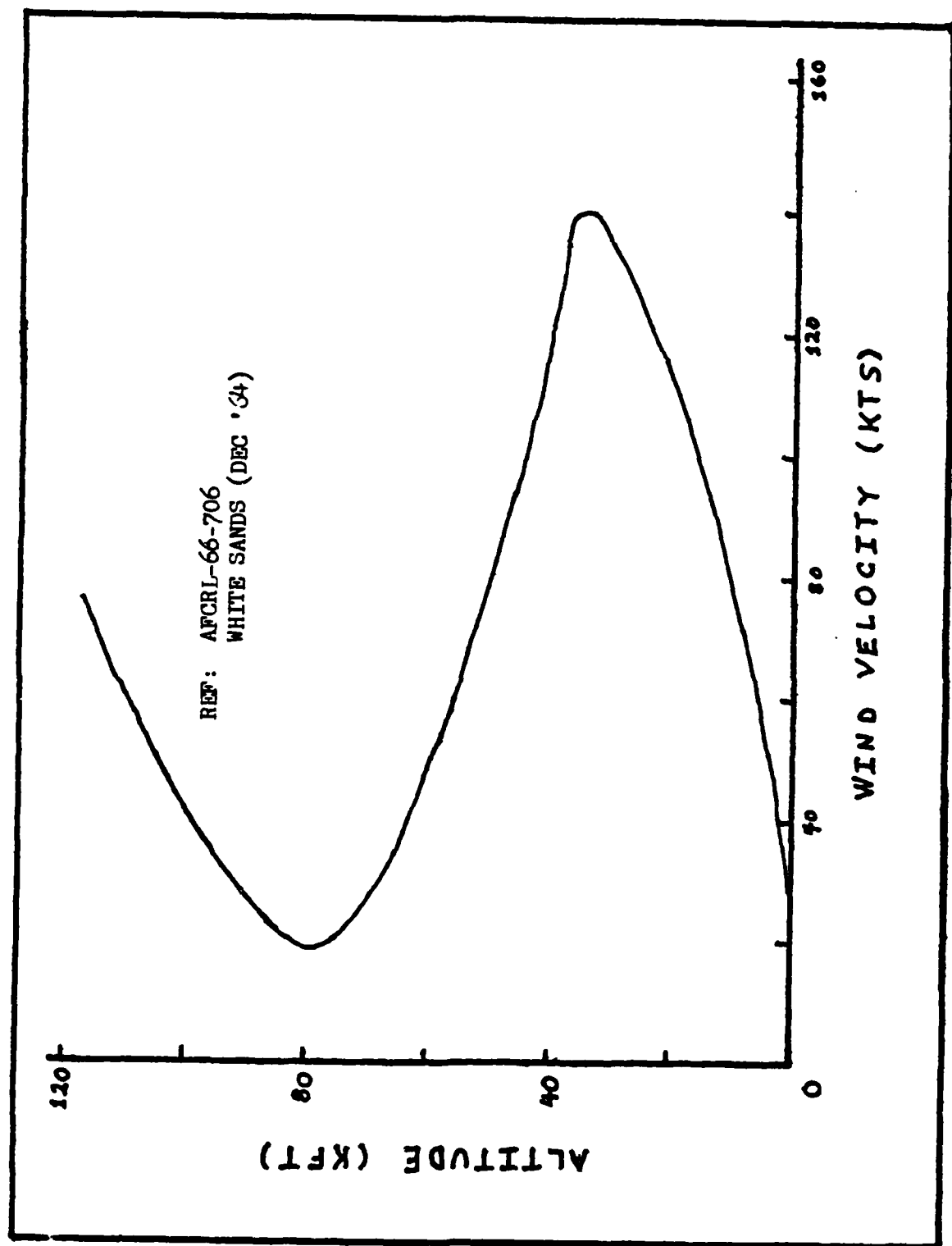
Figure 12. Typical wind velocity profile.

earth, however, since the earth rotates over time, selection of a particular longitude is not necessary. So, the sighting efficiency for a latitude is approximated using the average sighting efficiency of the set of evenly spaced points at that latitude.

Space-Basing Mode. The space-basing mode is also available in EOBASE. The sphere of operations for a sensor type in the space-based mode is defined by a sphere at some given radius from the earth's center. Since orbits precess at different rates based upon their altitude, inclination, and eccentricity, the longitude of the ascending mode for a sensor is randomly chosen by EOBASE. The inclination of an orbit is the only parameter which must be selected. The inclinations considered are 0, 15, 25, ..., 85, and 90 degrees. Each inclination alternative is defined by the points which lie over a latitude which is less in degrees from the equator than the inclination of the orbit. These points are used to model the band swept out by an orbit as it precesses around the earth in time. The average of the sighting efficiencies for all the points which fall within the band is used to describe the sighting of the orbit.

TARGET and SUNPOS

Subroutine SUNPOS, when called by TARGET, uses the user input SUNTYP to determine how to place the sun over the earth. SUNTYP can have the values 1, 2, 3, or 4. With the values 1, 2, or 3, the latitude over which the sun is oriented is fixed. The value 1 causes the sun to be placed over the equator, 2 at 23 degrees north, and 3 at 23 degrees south. The value of 4 causes the sun to be randomly placed between 23 degrees north and 23 degrees south. The procedure for

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randomly placing the sun assumes a circular orbit for the earth around

the sun so that the number of days since the last vernal equinox can

be randomly chosen from a uniform (0,365.25) distribution. Then the

angle between the earth at its randomly chosen position and its

position at the vernal equinox (relative to the sun) can be calculated

by:

$$\theta = \frac{2\pi \text{ rad.}}{365 \text{ days/year}} \quad \text{number of days since last vernal equinox}$$

From θ the declination angle (δ) to the sun, that is the angle

between the earth's equatorial plane and the vector to the sun, can be

calculated as shown below (Ref 24).

$$\delta = \sin^{-1} (\sin \varepsilon \sin \theta)$$

where

   ε = the angle between the earth's equatorial plane and the

      ecliptic plant

   = 23 degrees

If a spherical earth is assumed, this last calculation provides the

latitude over which the sun resides since latitude and declination

angle then become equivalent concepts. In all four cases or sun

types, the longitude is randomly selected from a uniform (0,2π)

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distribution. Once the latitude and longitude are chosen, SUNPOS then calculates a unit vector to the sun.

Subroutine TARGET itself uses the orbital parameters of the selected target satellites to randomly place them into their orbits. Two orbital parameters are randomly selected, mean anomaly (M) and the longitude of the ascending mode (Ω). Both are randomly drawn from a uniform $(0,2\pi)$ distribution. In order to position the satellite, the mean anomaly is converted to the true anomaly using the "mean anomaly to true anomaly technique" (Ref 25:185). M is related to the eccentric anomaly by:

$$M = E - e \sin E$$

where

e = the orbital eccentricity

A numerical technique is used to find E. Then E is used to calculate the true anomaly, V, by:

$$V = \cos^{-1} \left[\frac{e - \cos E}{e \cos E - 1} \right]$$

Note that the numerical solution procedure is not necessary where e = 0, since in this case M = E = V.

SIGHT

Subroutine SIGHT is used to determine the feasibility of tracking a target at one point by a sensor at another given location. Several

checks are made by Subroutine SIGHT. The first check is for line-of-sight interference with the earth. Next, in the case of ground and air based sensors, a check is made to determine if the sensor is on the dark side of the earth. Then, in the case of sensors employing visible light, a check is made to determine if the target is in the earth's shadow. Finally, Subroutines VISBLE (for visible light detecting sensors) and SLWIR (for LWIR detecting sensors) are used to determine if the quantity of light from the target reaching the sensor is sufficient for detection of the target to occur. If any of these checks are violated, the subroutine returns a sighting efficiency value of 0.0 for negative acquisition. However, if all the checks are passed, a value of 1.0 is returned which indicates that tracking of the target is feasible.

All of these checks are made with vector algebra using the appropriate vectors. For example, whether or not ground and air-based sensors are on the earth's dark side is determined using the inner dot product of the vector to the sensor and the unit vector to the sun. A negative value indicates that the sensor is in the earth's shadow.

VISBLE and SLWIR

The basic principles employed in VISBLE and SLWIR have been previously explained as part of sensor operations in Chapter II.

In the case of the visible light detecting sensors, Subroutine VISBLE is used to calculate the required angles: α, β, and ϕ. These angles together with the target's range from the sensor, and the target's plate and cylinder areas (these areas are stored with the target's orbital parameters) are used by VISBLE to calculate the visual

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magnitude of the target at the sensor. The value must be less than the maximum required by the sensor for detection to occur.

Subroutine SLWIR is used in the case of the air-based LWIR sensor. SLWIR is supplied with the angular resolution of the telescope, which it converts to the detector field of view, and the detector dwell time as user inputs under sensor type. Subroutine SIGHT provides the angle from the zenith and the range to the target. Also, SLWIR uses two permanently stored arrays which contain the values for the atmospheric radiance and transmittance for a standard U.S. atmosphere (Ref 26) looking into space from 21 kilometers at zenith angles from 0 to 80 degrees at intervals of 10 degrees. In addition, SLWIR contains the assumptions that the target is a Lambertian surface 1.0 meter in diameter, at 300 degrees Kelvin, with a radiance of $(44/\pi)$ Watts meter^{-2} steradran^{-1} (over the spectral range from 10.5 micrometers to 12 micrometers); that the receiving optics are 1.0 meter in diameter; that the detector efficiency is .25; and the sensor has a bandpass 10.5 micrometers to 12 micrometers. With these assumptions and inputs, SLWIR calculates a signal to noise ratio. If the ratio is greater than or equal to 6.0, the sensor is considered capable of detecting the target satellite.

SIDEN

Subroutine SIDEN is used to calculate an average sighting efficiency for each point on the sphere of operations for each sensor type. These sighting efficiencies are used by the OPTIMIZE to generate path sighting efficiencies for all possible paths for each sensor type.

For one point looking at a target, Subroutine SIGHT returns with S, the sighting efficiency, with a value of 0.0, target not sighted, or

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1.0, target sighted. With n targets, the target system sighting
efficiency is calculated by:

$$\overline{S} = \sum_{k=1}^{n} S_k$$

where

S_k = the sighting efficiency of the k_{th} target

Since the targets and the sun are randomly placed, the system sighting
concept can be extended for m iterations to achieve greater accuracy by
calculating an average target system sighting efficiency (EFF). EFF is
calculated by:

$$EFF = \sum_{j=1}^{m} \sum_{k=1}^{n} S_{jk}$$

where

S_{jk} = the sighting efficiency of the k_{th} target at the
j_{th} iteration

The input variable JCOUNT is equal to j and determines the number of
iterations used to calculate EFF.

CLOUD

Subroutine CLOUD is called by Subroutine TRACK to simulate the
interference of cloud cover with ground-based sensor operations. The

major assumptions demonstrated in this submodel are: (1) a ground based sensor is relatively ineffectual at greater than 3/8 sky cover and effective at less than or equal to 3/8 sky cover, (2) the percentage of total sky cover tends to be either extremely low or extremely high, and (3) the amount of total sky cover does not tend to change radically in less than 3 hour intervals. The basis for the first assumption is the Air Defense Comand's (ADCOM) criteria for site selection for the GEODSS sites (Ref 27). ADCOM has used the decimal fraction of less than or equal to 3/10 sky cover over the tracking period (1800 hours to 0600 hours) as one measure of effectiveness for the candidate GEODSS sites. Previous experience with the Baker-Nunn camera system has found that the average number of tracks submitted is approximately equal to the square of the probability of less than or equal to 3/10 sky cover times the number of scheduled tracks. The 3/8 sky cover figure was used in this study for two reasons: (1) sky cover is usually reported in eighths and (2) GEODSS is expected to do 30 to 40 percent better than the Baker-Nunn system (Ref 27). The second assumption is based upon existing data and observations. For example, Lund and Shanklin (Ref 28) report that, of over 12,000 observations, 57 percent were either 0/10 sky cover or 10/10 sky cover. The third assumption is also based upon observation. Lund and Shanklin (Ref 29) indicate that initial conditions for a line of sight will on the average persist, whether cloud free or cloudy, for a greater than 3 hour period more than 50 percent of the time

CLOUD operates in the following sequence. First, CLOUD determines the local site time relative to the longitude over which the sun

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resides. Then, if the time falls between 1700 hours and 0700 hours local, CLOUD checks the appropriate (see Table IV in Chapter II) unconditional probability for that time relative to a random number selected from a uniform (0,1.0) distribution. Thereafter, based upon the results of the comparison, the initial sky cover condition is established and the appropriate conditional probability is checked at 3-hour intervals.

OPTIMIZE

OPTIMIZE, a section of the main program EOBASE, is used when the user wishes to have EOBASE identify the most efficient sensor system. OPTIMIZE uses the output from SIDEN to search all the allowable paths for the path with the highest "path sighting efficiency." For ground and air-based sensors, a "path sighting efficiency" at each latitude from 60 degrees north to 60 degrees south at 10 degree intervals is calculated. For space-based sensors, there are ten orbital "bands" which are defined by the inclinations of the orbits. As noted in the first section of this chapter, "Spheres of Operation," the coordinates supplied by Subroutine SPHERE are used to model these orbital and latitudinal paths (see Refs 17 and 18 for further details).

TRACK

Subroutine TRACK is used by the confidence section of EOBASE to simulate, at some random starting time, a tracking engagement between the selected sensor and target systems over the mission time. TRACK has dual purposes. If the sensor system is supplied by the user, TRACK merely simulates the number of tracking engagements indicated. If,

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however, the sensor system is supplied by EOBASE, then the confidence

section of EOBASE uses TRACK to check the adequacy of the sensor system

in terms of meeting the mission requirements. If the sensor system is

found to be inadequate, then OPTIMIZE is used to select another sensor

for the sensor system.

Sensor Placement. Several methods are used to place sensors.

These methods differ according to the basing mode of the sensors and

according to whether or not the sensor system is user or EOBASE

selected. In the case of user selected ground-based sensors, the

sensor's coordinates are already specified, latitude, longitude, and

altitude. So, TRACK merely converts these coordinates to cartesian

coordinates. In the case of air- and space-based sensors, only the

latitude or the inclination and the altitude respectively are supplied

by the user. Therefore, TRACK must calculate the remaining positioning

coordinates. Air-based sensors are placed so that the sensors occupy

equally spaced longitudes around the globe. The basing longitude of

the first sensor to be placed is randomly chosen, and all the other

air-based sensors are located with respect to it. The sensors on the

latitude on which the most sensors are located are placed first to

prevent a large number of sensors from being clumped together on the

same latitude on the same side of the globe. Then the latitude with

the next largest number of sensors is considered, and so forth.

Space-based sensors are arranged by giving sensors which share the same

inclination equally spaced values for the mean anomaly and the same

value for the longitude of the ascending mode. EOBASE selected

ground-based sensors are placed in the same way as air-based sensors.

It should be emphasized that TRACK does not consider geographical features as part of the sensor placement process. Sensors, therefore, may be placed at unrealistic locations such as broad ocean areas or even the Soviet land mass. Nonetheless, the system configuration selected by EOBASE is a good indication of what the relative positions of the sensors should be.

Target and Sensor Movement at Each Δt. All sensors and targets are assigned initial locations at the beginning of each tracking sequence. For targets and space sensors, the initial position in orbit is determined by a random selection of the mean anomaly and the longitude of the ascending mode. At each time increment (Δt), the mean anomaly advances (ΔM). This effect is given by:

$$\Delta M = (\mu/a^3)^{1/2} (\Delta t)$$

where

$\mu = 3.986 \times 10^5 \text{ km}^3/\text{sec}^2$

a = semimajor axis of the orbit

The new mean anomaly is then calculated and converted to the true anomaly, and from this, the new position is found.

The movement of ground and air-based sensors is due to the rotation of the earth with respect to the fixed geocentric coordinate frame. The effect of the earth's rotation can be determined by adding the rotation of the earth to the previous location; thus moving the sensor to a new longitude L. The new L is calculated by:

$$L = Lo + 2\pi (\Delta t/1440)$$

where

Lo = the previous longitude

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EOBASE Validation

The "Towards Validation" methodology proposed by Haley and Ghelber (Ref 30) was used as a guideline for the EOBASE validation process. The process is divided into four parts: (1) conceptualization, (2) verification, (3) credibility, and (4) confidence.

Conceptualization. The purpose of this step is to determine if the early stages of model development are reasonable and valid. This includes a statement of the model's purpose, degree of accuracy, assumptions, limitations, and a structural framework. These items are contained in Chapters I and II and in this chapter and have been coordinated with experts in the areas of operations research, physics, and astrodynamics.

Verification. There are four parts to the verification process: (1) structural walk-through, (2) verification of technical processes, (3) simulation of predictable states, and (4) testing of stochastic events. The structured walk-through was accomplished for all subroutines as well as the overall EOBASE simulation. See Chapter II for descriptions of the event-path logic flow diagrams for all subroutines. The technical processes associated with EOBASE are discussed in detail in this chapter. Proper coding of these processes was checked by comparing subroutine outputs with hand calculations. In some cases the set of predictable states was chosen based upon extremes of what could occur in the real world. For all experiments, a basic scenario was chosen and the parameters were identical to those in Table VII unless otherwise specified. Table VIII provides the experiments (variations from Table VII) and Table IX provides a

TABLE VII

Basic Scenario

_____

Initialization

SEED	421.	—
JCOUNT	40	—
NOWT	1	—
ICOUNT	40	—
DT	5.	minutes
P	.899	
INPUT	3	
INPUT2	0	
SUNTYP	1	

Sensor

Mode	1.	
Type	1.	
Cutoff/detector field of view	16.	visual magnitudes
Altitude	0.	kilometers
Cycle time	120	seconds
Dwell time	0.	seconds

Target Selection and Mission Data

Target type	4	
Negation percentage	100	
Negation time	1440	minutes
Tracking priority	1	

Ground Site Data*

Latitude	1.5708	radians
Longitude	0.	radians
Altitude	0.	kilometers
Sensor type	1.0	—
Sky cover probabilities	.5#	

_____

* Three sites are entered separated by (2π/3) radians of
  longitude.

All elements of the sky cover probabilities array are set
  equal to .5.

TABLE VIII

Experiment Descriptions

1. Three sensors: on the equator, 120 degrees apart
   Four sensors: on the equator, 90 degrees apart

2. Make one run with Target Type 4 only
   Make one run with Target Types 3 and 4

3. Three sensors: sensitivity cutoff equal to 13.5 visual magnitudes
   Three sensors: sensitivity cutoff equal to 16 visual magnitudes

4. Make one run with sky cover probabilities all equal to .5
   Make one run with sky cover probabilities all equal to 1.0

5. Three sensors: equally spaced around the globe at 30°N, 0°,
                   and 30°S, SUNTYP = 2
   Three sensors: equally spaced around the globe at 30°N, 0°,
                   and 30°S, SUNTYP = 3

TABLE IX

Experiment Results

Experiment	Predicted results	Actual results
1	Target system negation times shorter with four sensors	*
2	Target system negation times longer with second target type	*
3	Sensor system with lower sensitivity cut-off has longer target system negation times	*
4	Run with sky cover probabilities equal to 1.0 has shorter target system negation times	*
5	Sensors in summer hemisphere track fewer targets than sensor in winter hemisphere	*

* Actual results matched predictions.

comparison of expected results to the actual results. Testing of
stochastic events was unwarranted since all random numbers were
selected from a uniform distribution using Fortran IV's random number
generator.

Credibility. The third phase, credibility, deals with intuitive
(face validation) and statistical (sensitivity analysis) appeal of
EOBASE. Face validation of EOBASE was accomplished by consultation
with experts in operations research and physics concerning the physical
processes modeled and the structure of the model. Sensitivity analysis
was performed on two variables to determine their effect on accuracy
and processing time. JCOUNT was varied to determine how large it has
to be to get consistent path selections from EOBASE for an air-based
visible light detecting sensor. The same inputs described in Table VII
were used except INPUT was set equal to zero, Target Types 2 and 3 were
selected, and the sensor location and sky cover probability inputs
were deleted. A STOP was inserted into the program so that only the
first sensor path choice was output. Ten trials each of JCOUNT were
made at values of 5, 10, 20, 40, and 80. The results indicate that
JCOUNT must be at least 20 to obtain consistent path selections.
Target Type 2 appears to have the most influence upon path selection in
this case and causes the most northern latitudes to be favored. The
simulation time step Δt was also subjected to sensitivity analysis.
The same inputs as shown in Table VII were used except Target Types 2
and 3 were selected and ICOUNT was set equal to 10. As shown in
TABLE X, Δt was varied from 5 through 80. The results confirmed that
the number of successful missions increases as Δt decreases until Δt

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equals 10 minutes. Then there is essentially no difference in the average target system tracking time using 5 minutes versus using 10 minutes for Δt.

Confidence. Further confidence in the ability of the EOBASE model was built by examining the cost/benefit of additional information and

TABLE X

Δt Experiment Results

Δt	Number of successful missions*
5	9
10	9
20	8
40	7
80	6

* Out of 10 trials.

by proper documentation of the model. Analysis of the sensitivity of EOBASE to JCOUNT and Δt indicated the cost of further information. Each iteration of JCOUNT with one sensor and six targets requires 0.3 seconds of execution time. Each time increment in TRACK with three sensors and six targets averages 0.03 seconds of execution time.

The documentation of EOBASE is fairly thorough. A "documentation list" described by Shannon (Ref 31, 262) requires the following:

Flow diagrams of each module and the overall model
--Chapter II

Description of inputs necessary for executing the program
--Chapter II, Appendix A, and Appendix B

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Definitions of the program variables not used as inputs

--Appendix B

Verbal description of the purpose and function of all modules

--Chapter II and Chapter III

Input deck set up to run

--Provided separately

Listing of program

--Appendix B

The validation results indicate EOBASE is performing as described. The conceptual validity of the underlying physical processes and techniques described in this chapter and Chapter II has been coordinated with experts in physics, operations research, and astrodynamics. Chapter IV will present analysis results comparing the ability of ground- and air-based sensors.

IV   Sensor System Basing Mode Analysis

The purpose of this analysis is to compare the Ground-based Electro-Optical Deep Space Surveillance (GEODSS) system with a hypothetical system of air-based sensors. The GEODSS system is a military project, built for the Air Force to replace the quartet of Baker-Nunn photographic telescopes (Refs 32 and 33). The first GEODSS station began operations in May of this year at White Sands Missile Range southeast of Socorro, New Mexico, and three other installations are expected to take shape during the next two years on Mount Haleakala, Hawaii; at Taeger, Korea; and at the naval base on Diego Garcia in the Indian Ocean. A fifth site is planned for either Ascension Island or the Iberian Peninsula.

Each of the GEODSS sites houses three tracking instruments. Two of the three have 1-meter apertures and a 2.1-degree field of view. Three telescopes can detect objects as faint as magnitude 18.5, however, in normal operation, the cutoff is 16.0. The third telescope has a 0.4-meter aperture, a 6.0-degree field of view, and its magnitude cutoff is 14.5. The wider field of view and faster slow rate of the small instrument make it better suited to the study of lower altitude, brighter satellites.

The principle advantage of the GEODSS system is that the data analysis is rapid. The time required per track is about one minute.

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Unlike the Baker-Nunn cameras which use photographic film, a GEODSS sensor uses a SIT vidicon imaging tube, an advanced television camera, so that data processing can be computer assisted. Thus the time consuming process of photographic development required for the Baker-Nunn camera is avoided.

The characteristics of the hypothetical air-based sensor are less easily defined. But, it is obvious that it should be like a GEODSS sensor in that it would use a vidicon tube and computer assisted data processing. Unfortunately it is also apparent that the sensor will have to weigh much less and that both this lower weight and the sensor' mode of basing would contribute to less pointing stability in the telescope. The reduced pointing stability would reduce the image stability in the focal plane; hence, the sensitivity of the telescope could be reduced. Fortunately, high pointing accuracy is possible with an air-based telescope. The 36-inch aperture telescope which NASA has on board a C-141 can maintain a line of sight stability of 2 arc seconds root mean square while in flight for at least 30 minutes (Ref 34). So, it is possible that the pointing stability problem can be solved.

Also, the air-based telescope has several relevant advantages. The air-based telescope receives a satellite's image with much less loss in intensity due to atmospheric absorbency. This is critical at high line of sight angles to the zenith. The LOWTRAN program was used to estimate this loss using the program's model for a standard rural atmosphere (Ref 27). The transmittance to the air-based sensor at 23 kilometer above sea level was found to be virtually 100 percent at the zenith and 38.8 percent at 90 degrees to the zenith. However, the

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transmittance to the ground-based sensor was much less, only 44.6 percent at the zenith, and the transmittance dropped off as the zenith angle increased. At 60 degrees to the zenith the transmittance begins to drop off rapidly, and at 80 degrees, a sensor with a magnitude 16.0 cutoff receives too little light from a target presenting 1.0 square meters of surface area to detect it even when haze conditions are favorable. The other advantage of the air-based sensor is that the image which it receives does not suffer significantly from the atmospheric effect "seeing," which is caused by small fluctuations in the index of refraction of the atmosphere (Ref 19:26). Seeing causes a blurring of the image and thus reduces the sensitivity of the telescope.

Since these advantages may just about make up for the pointing stability problem, the sensitivity of the hypothetical air-based telescope will be treated here as equal to that of the ground-based telescope.

Methodology

The analysis was conducted in two stages. First the ability of the GEODSS system to detect the target system was characterized using the EOBASE program and then EOBASE was used to choose an air-based sensor system and assess its ability to detect the target system relative to the GEODSS system.

The data required to characterize the GEODSS system came from several sources. The literature was consulted (Refs 32 and 33) to get estimates of the sensitivity of the sensor and the rate at which data from it could be processed. The coordinates of the GEODSS system used

in this study are from a list provided by DODR, NORAD Headquarters, Colorado Springs, Colorado. Table XI provides a list of the five sites selected for this study. While this list does not necessarily represent the final configuration of the GEODDS system, it is a viable one. The sky cover probabilities for each of these sites was provided by the USAF Environmental Technical Applications Center using data from their nearest reporting station (see Table XII). Unfortunately the proximity of the weather station and GEODSS site was not always as close as desired. Thus, the data for the GEODSS site at Mount Haleakala, Hawaii, is not as accurate as desired. This GEODSS site is 3000 meters above sea level whereas the weather station is near sea level. Nevertheless, the sky cover probabilities for this site still indicates predominately clear skies. Also, as indicated in the earlier part of this chapter, LOWTRAN (Ref 27) was used to assess the atmospheric transmittance at sea level and at 23 kilometers above sea level. As a result, the SIGHT subroutine was modified to score a line of sight with a zenith angle of greater than 70 degrees as 0.0 for ground-based sensors, and thus not a clear line of sight. As indicated in the first part of this chapter, the transmittance at zenith angles above 70 degrees tends to drop off rapidly.

The capabilities of the GEODSS system were characterized in the following way. First, the ability of the system to detect each target type in a 24 hour tracking period was determined. A separate program run was used to determine the capability of the GEODSS system to track each target type, and the results of these runs were used to set the mission inputs for each target type in all of the subsequent runs.

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TABLE XI

Locations of GEODSS sites

Site	Name	Latitude	Longitude
1	Faro, Portugal	37.00N	7.92W
2	White Sands Missile Range, New Mexico	33.82N	106.66W
3	Mount Haleakala, Hawaii, AFB	20.71N	156.26W
4	Taeger, Korea	35.74N	231.39W
5	Diego Garcia	7.20S	287.75W

TABLE XII

Locations of Weather Stations

Site	Name	Latitude	Longitude
1	not substituted		
2	Holloman AFB, New Mexico	32.87	106.10
3	Kahuli, Hawaii	20.78	15.47
4	Taeger ARTCC, Korea	35.74	231.38
5	not substituted		

Next, the ability of the GEODSS system to track all four target types simultaneously was evaluated. The average annual ability of the GEODSS system to track the target system was estimated using the average annual sky cover probabilities with the position of the sun with respect to its latitudinal position over the earth randomly chosen. The impact of the seasonal variation of the sun's position and weather patterns was estimated in separate program runs using the sky cover probabilities at the winter solstice (month of December) and at the summer solstice (month of June) with the sun at its appropriate latitudinal position. In addition, the extent to which the cloud cover diminishes the effectiveness of the GEODSS system was estimated by setting the sky cover probabilities all to 1.0. the GEODSS system experiments required eight computer runs.

The capabilities of the air-based sensor were modeled around those of the GEODSS sensor. Like the GEODSS sensors, tracks for the air base sensors were limited to those with a line of sight less than or equal to 70 degrees to the zenith. This cutoff was again chosen since the intensity of the night sky background can be significantly larger beyond this point (Ref 19:19-23). For example, night airglow emission increases with increasing zenith angle because the telescope looks through a larger emitting air mass.

The first step in evaluating the air-based system was to use EOBASE to choose an air-based system sufficient to match or better the performance of the GEODSS system in tracking all four target types simultaneously. This system was chosen with the longitudinal position of the sun randomly chosen. Then this system was evaluated in

separate computer runs with the sun in its winter and summer solstice positions. Next EOBASE was used to choose a sensor system with five air-based sensors as opposed to five GEODSS sensors. Then the ability of this system to track the target system was evaluated to determine how well five air-based sensors could track the target system as opposed to five GEODSS sensors.

Results and Discussion

As indicated in the previous section, the first step in characterizing the ability of the GEODSS system to track the target system was to assess its ability to track each individual target type. The purpose of this step was to determine the maximum percentage of each target type that the GEODSS system could reasonably be expected to track in a 24-hour period. So, the GEODSS system was run against each target type with the tracking negation percentage set to 100 percent, the mission time to 1440 minutes, and the tracking priority to 1. The initialization and sensor type inputs used for these experiments and the remaining GEODSS characterizations are shown in Table XIII unless otherwise specified. Also, the average annual sky cover probabilities were used unless otherwise indicated.

The ability of the GEODSS system to track the first target type, a satellite in the highly eccentric Molynia orbit, was never 100 percent in a 24-hour period. Apparently, the apogee of at least one target satellite of this type is always oriented toward the sun where it could not be sighted by any earth based sensor. Note that if the angle between the sun and the sensor (with the target at the vertex) is greater than 90 degrees, very little sunlight, if any, is

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TABLE XIII

Basic Initialization and Sensor Inputs
for GEODSS System Simulation

Initialization

SEED	151	- -
JCOUNT	0	- -
NOWT	1	- -
ICOUNT	40	- -
DT	10.	minutes
P	.5	- -
INPUT	5	- -
INPUT 2	0	- -
SUNTYP	4	- -

Sensor

Mode	1.0	- -
Type	1.0	- -
Cutoff	16.0	visual magnitudes
Altitude	0.0	kilometers
Cycle time	120.0	seconds
Dwell time	0.0	seconds

---

reflected by the target to the sensor by an earth oriented cylinder. This problem is not remedied by placing a target (of type 1) with the apogee of its orbit oriented toward the sun in another part of its orbit because the very small portion of its orbit which is not oriented to the sun is mostly in the earth's shadow where there is no sunlight to reflect. The perigee of target type one is only 300 kilometers high. Nevertheless, since the longitude of the ascending mode of this target type is always 120 degrees apart, the GEODSS system can track at least two targets. In only three cases out of 40 trials was only one target tracked, and two targets were tracked in all other cases. As a result the GEODSS system could be expected to track two

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targets of this type, and so a tracking percentage of 65 percent was used in all subsequent runs.

Target type 2 produced similar results, and it is also in a high eccentric orbit. However, the longitude of the ascending modes for this target type are separated by only 90 degrees. So, in this case two targets could be oriented toward the sun. In 10 of 40 trials only two targets were tracked. In the remaining trials, three targets were tracked. So, the mission negation percentage was again set to 65 percent in all subsequent runs.

Target types 3 and 4 produced similar results because both use geosynchronous orbits. With target type 3, 28 out of 40 trials resulted in all targets tracked; and with target type 4, 27 out of 40 trials resulted in all targets tracked. Thus, in both cases, the mission negation percentage was set to 100 percent in all subsequent computer runs.

The next step in evaluating the GEODSS system was to test its ability to track all the target types simultaneously. The results of these runs are shown in Table XIV. These four experiments suggest that cloud cover has an important effect in reducing the effectiveness of the GEODSS system. The number of successful runs increases quite significantly when the sky cover probabilities are all set to 1.0. The latitudinal position of the sun is also important. All but one of the GEODSS sites is in the northern hemisphere, and Diego Garcia, the site in the southern hemisphere, is very close to the equator. Thus, the latitudinal position of the sun can significantly alter the number of hours the sites spend in daylight and are therefore not functional.

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TABLE XIV

Results of GEODSS System Encounters with the
Four Target Type Target System

Experiment	Number of Successful Trials
1. Average Environment	15
- Annual sky cover probabilities	
- Random sun	
2. Winter Solstice Environment	26
- December sky cover probabilities	
- Sun at winter solstice	
3. Summer Solstice Environment	12
- June sky cover probabilities	
- Sun at summer solstice	
4. Cloudless environment	34
- Sky cover probabilities all set to 1.0	
- Random sun	

* Out of 40 trials.

This effect is important because the sun spends considerable time near its latitudinal extremes, hence the name solstice. The seasonal variation in cloud cover may also be important. Although the sites are widely dispersed, with one exception, they all experience the same seasons at the same time. Since the unconditional probability of less than or equal to 3/8 sky cover varies with the time of year (see Table XV), the probability of good weather at the sites may vary as a whole

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TABLE XV

Average Nighttime Probability of Less than or Equal to 3/8 Sky Cover

Site	Annual	June	December
1	.70	.75	.55
2	.70	.78	.73
3	.64	.65	.66
4	.52	.72	.35
5	.33	.38	.34

Note: These nighttime probabilities are defined by observations taken at the weather stations between 2,000 hours and 0400 hours local time.

so that the system performance may be dependent upon the time of year. Table XV indicates that better weather occurs in June at most of the GEODSS sites than in December.

The air-based system was chosen using the inputs shown in Table XVI. This resulted in the selection of three sensors. The sensors were located on lines of longitude separated by 120 degrees. Two sensors were located 10 degrees north, and one sensor was located 10 degrees south.

This system was able to track the target system (all 4 target types) 27 out of 40 times during a 24-hour period. In all cases the target satellites in geosynchronous orbits were target within 24 hours. The satellites in subsynchronus orbits limited the mission success rate. The system was also evaluated with the sun at the winter and summer solstices. With the sun in the winter position, 40 out of 40 trials were successful in meeting the mission requirements. Twenty-five trials were successes with sun in the summer position.

These runs strongly indicate that if all other aspects of the air- and ground-based modes are equal, that is sensor performance and reliability, three air-based sensors can match or exceed the performance of the GEODSS system which includes five sensors.

EOBASE was also used to choose an air-based system composed of five sensors. The same inputs shown in Table XVI were used except the sensor system was required to track the target system in 1200 minutes with a probability of .99. The program was allowed to run until it ran out of CPU time. At this point five sensors had been chosen.

TABLE XVI

Inputs Used To Choose The Air Based System

Initialization

SEED	151	- -
JCOUNT	40	- -
NOWT	1	- -
ICOUNT	40	- -
DT	10.	minutes
P	.375	- -
INPUT	0	- -
INPUT 2	0	- -
SUNTYP	4	- -

Sensor

Mode	1.0	- -
Type	1.0	- -
Cutoff	10.0	visual magnitudes
Altitude	23.0	kilometers
Cycle time	120.0	seconds
Dwell time	0.0	seconds

Note: The same target selection and mission inputs used to characterize the GEODSS system were used to select the air-based system.

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These five sensors were located as shown in Table XVII. This system was able to track the target system 37 out of 40 times in 24 hours. The target satellite located in geosynchronous orbit were always tracked within 24 hours. The performance of this system was about as good as the GEODSS system in the absence of cloud cover.

The experiments with the air-based sensors indicate air basing could significantly increase the frequency deep space satellites are tracked. Three air-based sensors could conceivably match or surpass the performance of the GEODSS system. In addition, a reliable air-based system could assure that all geosynchronous satellites would be tracked within any 24-hour period. This comparative analysis of the GEODSS system with a system of hypothetical air-based sensors was conducted in two phases. First, the capabilities of the GEODSS system to track all four target types was determined, and the position of the sun and cloud cover conditions were varied so that their effect upon the capabilities of the GEODSS system could be estimated. The results of these experiments showed that it was possible for an earth based sensor to consistently track only two of the three type 1 targets and three of the four type 4 targets in a 24-hour period. All of the type 1 and type 4 targets could be track in a 24-hour period. These experiments also showed that cloud cover significantly reduces the effectiveness of the GEODSS system and that the latitudinal position of the sun causes the effectiveness of the GEODSS system to vary considerably. Next, a system of air-based sensors was chosen which could match the GEODSS system's capability to track the target system.

TABLE XVII

Five Sensor Air-Based System

Sensor	Latitude	Relative Longitude* (degrees)
1	1.4039	0
2	1.4039	144
3	2.1041	216
4	0.6930	288
5	1.5708	72

Note: The longitude of the first sensor is randomly chosen and the remaining sensors are placed relative to it

Only three air-based sensors were needed. When a system of five air-based sensors were chosen, it was found that this system could be tracked within 24 hours nearly 100 percent of the time.

Unfortunately it cannot be stated without reservation that these air-based systems would perform as well as indicated. As noted in Chapter III under "Sensor Placement," submodel TRACK does not consider geographic features as part of the sensor placement process. Since it is possible that the desired system configuration might not be achievable in the real world, in practice these air-based systems might not perform as well as indicated by the model.

In the next chapter, the information contained in this study will be summarized. Then some conclusions will be presented. Finally, this work will close with some recommendations for further study.

V Conclusion

The primary purpose of this thesis has been to evaluate the possible benefits of an air-based system of electro-optical telescopes. As a prerequisite, some effort has been made to show the need for and the plausibility of such a system.

Summary

The presence of the atmosphere is a serious hindrance to a ground-based astronomical telescope. Because of this, the satellite tracking telescopes of the Air Force's SPADATS network tend to be located at remote sites at high elevation. The use of air-based sensors has been suggested as a possible solution for this problem. This approach has already been adopted by astronomers who use balloons and airplanes to carry their infrared telescopes into the stratosphere.

Several efforts are currently under way to develop a high altitude airship which can remain on station for extended periods of time. The Air Force's program has already demonstrated the feasibility of this kind of vehicle with the launch of High Platform II in May of 1970, and the Navy, as demonstrated by its Hi Spot, is seriously considering the high altitude airship for operational use. On the other hand, NASA is studying the value of this kind of airship for commercial use. NASA has purposed the HAPP concept which utilizes a microwave transmitter to power a high

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concept which utilizes a microwave transmitter to power a high altitude airship or perhaps a high altitude airplane.

The program EOBASE has been developed to estimate the value of a high altitude platform for satellite tracking. The program can be used to assess the gain in performance conferred by the airship's high operating altitude and flexibility in site selection. The program simulates getting the first track on each satellite of a system of deep space satellites using either a system of user input sensors or a system of sensors selected by EOBASE.

The EOBASE program has been used here in a comparative analysis of the GEODSS system with a hypothetical system of air-based sensors. This analysis was conducted in two phases. First, the EOBASE program was used to assess the capability of the GEODSS system to track four target types, both individually and collectively. This analysis showed that the affect of weather is quite detrimental to the GEODSS system, and that the changing position of the sun can cause its performance to vary considerably. Second, EOBASE was used to choose an air-based sensor system based upon its ability to track all four target types simultaneously at least as well or better than the GEODSS system. Only three air-based sensors were needed to match the performance of the GEODSS system. The performance of this system was also found to be dependent upon the position of the sun. EOBASE was also used to select an air-based system of five air sensors. This system was able to track the target system within 24 hours nearly 100 percent of the time.

Conclusions

While the results of this study with EOBASE are not sufficient grounds for launching a program to develop a system of air-based satellite tracking telescopes, they do demonstrate that such a system may have value. The possibility that three air-based sensors could match the performance of the GEODSS system means that there could be possible cost savings promising air-based sensors instead of ground-based sensors. Also, the air-based sensor could have greater value in the early warning role than the GEODSS system. The air-based system is consistently able to track all the satellites in geosynchronous orbit in less than 24 hours because unlike a ground-based system, it is unaffected by weather. However, it should be emphasized that because of the dearth of basing restrictions in the sensor placement process in practice, the air-based system may not perform quite as well as indicated.

Based upon the results of their study, the concept of using air-based satellite surveillance telescopes warrants an engineering feasibility study. This study is needed to determine if the required sensitivity can be obtained with a sensor light enough to be carried by a high altitude airship or perhaps a high altitude airplane. Also, this study is needed to establish a basis for a cost analysis.

Recommendations

Further refinements of the results obtained with EOBASE could be useful. Following is a list of recommendations which should lead to an improved understanding of the problems involved in choosing the proper basing mode.

1. Allow the user to input the target satellite orbital and shape parameters of his choice.

2. Allow different negation times for each target type.

3. Revise subroutine VISIBLE to include the effect of atmospheric transmittance.

4. Include basing restrictions in the sensor placement algorithm.

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APPENDICES

A Use of the Model

The purpose of this section is to acquaint the EOBASE user with the various input possibilities, how to interpret the data, and how to interpret the output. As an aid to explanation, specific examples will be used.

Inputs

All input is free formatted with both integer and real variables. The first input card contains nine inputs. (1) SEED - the random number generator argument (real), (2) JCOUNT - the number of times the targets are placed to calculate sighting efficiencies (integer), (3) NOWT - the number of sensor types choices to be input (integer), (4) ICOUNT - the number of times TRACK is called to build confidence in the selected sensor system (integer), (5) DT - the time increment in TRACK in minutes (real), (6) P - the probability of success required for a given mission (real), (7) INPUT - the number of preselected ground based sensors to be entered (integer), (8) INPUT2 - the number of preselected air and/or space sensors to be entered (integer), and (9) SUNPOS - this number, 1-4, indicates the way the latitudinal position is to be chosen (integer). See Table XVIII.

The next set of data cards contains sensor type information. A separate card is input for each sensor type, and contains all the information given in Table XVIII. All inputs are real.

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Table XVIII

Example Scenario

Initialization

SEED	4239.- -	
JCOUNT	50 - -	
NOWT	1 - -	
ICOUNT	10 - -	
DT	10.	minutes
P	.8 - -	
INPUT	0 - -	
INPUT 2	0 - -	
SUNTYP	4 - -	

Sensor

Basing Mode	1.0 - -	
Sensor	1.0 - -	
Cutoff	16.0	visual magnitudes
Altitude	0.	kilometers
Minimum tracking time per cycle	120.0	seconds
Dwell time	0.0	seconds

Mission Data

Target type	4 - -	
Target type tracking percentage	100 - -	
Mission time	1440	minutes
Target type tracking priority	1 - -	

The third set of data cards contain the target types selected and their associated mission data. For each target type selected, a single card with that target type number is included (real), followed by a card containing the mission data for that target type (integer). This is repeated for all target types selected, followed by a "termination" card with a 99. on it (not needed if all target types are selected). Again see Table XVIII.

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If both INPUT and INPUT2 equal zero, then the above mentioned inputs and the data are entered as shown in Table XIX, otherwise sensor location data is needed.

TABLE XIX

Input Data Format for Preselected Ground Base Sensors

Card #				Contents					
1	4239.	50	1	10	10.	.8	0	0	4
2	.1	1.	.16	0.	120.	0.			
3	4.								
4	4	.93	100	1440	1				
5	99.								

The location of ground-based sensors are entered first in the next set of cards. For each site entered, a single card containing the sensor type, the latitude, longitude, and the altitude (all real) is included in the order just given. The following cards provide the sky cover probabilities (see Table IV in Chapter II for the format). Table XX provides an example input.

Air- and space-based sensors are input next. A card is entered for each sensor and includes the sensor type, the orbital radius or coordinate theta for air-based sensors, the eccentricity, the inclination or coordinate theta, longitude of the ascending mode, and the argument of perigee in the order just given. See Table XXI.

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TABLE XX

Input Data Format for Preselected Ground Base Sensors

Card #			Contents						
1	1.	.925		6.145	0.				
2	.54	.93	.32	.93	.48	.91	.50	.83	.45
3	.65	.94	.31	.92	.37	.83	.36		
4	.72	.93	.21	.82	.28				
5	.72	.85	.18						
6	.66								

Note: This card represents the GEODSS site at Faro, Portugal located at 37.0 degrees north and 7.917 degrees west. In Card 1, degrees have been converted to radians in the geocentric coordinate referenced system. Cards 2-6 contain the annual sky cover probabilities.

TABLE XXI

Input Data Format for Preselected Air and Space Based Sensor

Card #			Contents		
1	1.	1.5708	0.	1.5708	0.0
2	1.	1000.	0.	1.5708	0.0

Note: Card 1 represents an air-based sensor located on the equator. Card 2 represents a space-based sensor in a in a 90-degree, 1000-kilometer circular orbit. Angular measurements are input in radians.

Output

All sensor types, target types, sensor location, and sky cover probabilities are printed out in an easy to read well documented format. At the start of each TRACK run, the track run is printed, followed by all the sensors selected. When a target satellite is tracked, the target number and sensor number are printed. At the completion of each successful tracking sequence, the total time and the number of targets tracked is printed. If tracking sequence is unsuccessful, only the number of targets tracked is printed. After all the tracking sequences have been completed, the number of successful sequences and the total number of sequences are printed. If the sensor system meets mission requirements, the sensor types and location parameters for all sensors in the sensor system are printed. All output is well documented.

B EOBASE Listing

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```
120-  C     CAPT RICHARD T. SALMON
130-        PROGRAM ECBASE(INPUT,OUTPUT)
140-        DIMENSION SENSOR(6,5),T(14,11),MISSION(4,4),TAROPP(14),
150-  C     SUMEFF(5,410),X(5,410),V(5,410),Z(5,410),XT(14),YT(14),
160-  C     ZT(14), EOSEL(50,6),PATH(5,19),TH(19),SITE(50,4),NU(50),
170-  C     SKYC(50,25)
180-        INTEGER SUNTYP
190-        COMMON/AIR/TRNSMT(9),BKGD(9)
200-        DATA (BKGD(I),I=1,9)/.00236,.0024,.00251,.00272,.00306,.00362,
210-  C     .00467,.00671,.0129/
220-        DATA (TRNSMT(I),I=1,9)/.9992,.9992,.9992,.9991,.9990,.9988,.9985,
230-  C     .9978,.9958/
240-  C*******************************************
250-  C
260-  C     SEED IS THE RANDOM NUMBER GENERATOR SEED (REAL).
270-  C     JCOUNT IS THE NUMBER OF TIMES THE TARGETS ARE RANDOMLY PLACED TO
280-  C     CALCULATE THE AVERAGE SIGHTING EFFICIENCY FOR EACH POINT ON A
290-  C     SPHERE OF OPERATIONS (INTEGER).
300-  C     NOUT IS THE NUMBER OF SENSOR TYPES (INTEGER).
310-  C     ICOUNT IS THE NUMBER OF TIMES TRACK  IS CALLED TO BUILD CONFIDENCE
320-  C     IN THE SELECTED SENSOR SYSTEM (INTEGER).
330-  C     DT IS THE TIME INCREMENT IN TRACK (REAL).
340-  C     P IS THE PROBABILITY OF SUCESS REQUIRED FOR THE SELECTED SENSOR SYST
350-  C
360-  C     INPUT IS THE NUMBER OF GROUND-BASED SENSORS WHOSE COORDINATES ARE TO
370-  C     ENTERED (INTEGER).
380-  C     INPUT2 IS THE NUMBER OF AIR AND SPACE BASED SENSORS (INTEGER).
390-  C     SUNTYP IS USE TO SELECT TH THETA VALUE OF THE SUN  (INTEGER)
400-  C     READX,SEED,JCOUNT,NOUT,ICOUNT,DT,P,INPUT,INPUT2,SUNTYP
410-  C     P=P-.001
420-  C
430-  C     THE FOLLOWING IS USED TO CONTROL THE NUMBER OF TIMES SIDEN IS
440-  C     IS RUN BY TRACK TO PROVIDE SIGHTING EFFICIENCIES TO CHOOSE THE
450-  C     THE NEXT BEST SENSOR PATH COMBINATION.
460-  C
470-  C     COUNT=ICOUNT
480-  C     KCOUNT=JCOUNT/ICOUNT
490-  C     IF(KCOUNT.LE.0)KCOUNT=1
500-  C     CALL RANSET(SEED)
510-  C*******************************************
520-  C
530-  C     THE FIRST SECTION IS DESIGNED TO ACCEPT USER INPUTS
540-  C     INPUTS ARE READ IN THE FOLLOWING ORDER...
550-  C     SENSOR TYPES
560-  C     TARGET TYPES
570-  C     MISSION DATA
580-  C     SITE LOCATIONS
590-  C     SKYCOVER PROBABILITIES
600-  C     AIR AND SPACED BASED SENSOR PARAMETERS
610-  C*******************************************
620-  C
630-  C     SENSOR INPUTS ARE STORED IN MATRIX SENSOR (6,5)
640-  C
650-  C     UP TO FIVE DIFFERENT SENSOR TYPES MAY BE INPUT, 1 CARD PER SENSOR TY
660-  C     EACH CARD IS FREE FORMATTED, WITH ENTRIES BEING SEPARATED BY COMMAS
670-  C     SPACES.
```

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

```
C     A "0." MAY BE INPUT WHERE ALLOWED TO ACCEPT THE DEFAULT VALUE.
C     THE VARIABLE ORDER ON EACH CARD IS AS FOLLOWS.
C            MODENO...MODE NUMBER(REAL)...(1-GROUND, 2-AIR, 3-SPACE)(MANDAT
C            TYPE.....SENSOR TYPE(REAL)...(1-VISIBLE, 2-LWIR)
C            CUTOFF...MINIMUM SIGNAL STRENGTH (VISUAL MAGNITUDES)
C                     OR LWIR SENSOR ANGULAR RESOLUTION(RADIANS)
C            ALT......SENSOR ALTITUDE (KILOMETERS)
C                     MODE  1:    0.
C                     MODE  2:   21.3 KM
C                     MODE  3.    (MANDATORY)
C            DELTRM...MINIMUM CYCLE TIME (SEC)
C            DWLTM....LWIR DETECTOR DWELL TIME(SEC)
C     *********************************************
C
C     TARGET TYPE INPUTS ARE STORED IN MATRIX T(14,7)
C     4 TARGET TYPES  14 TOTAL TARGETS
C            T(I,1) IS TARGET TYPE NUMBER.
C            T(I,2) IS SEMI-MAJOR AXIS OF ORBIT.
C            T(I,3) IS ORBITAL ECCENTRICITY.
C            T(I,4) IS ORBITAL INCLINATION.
C            T(I,5) IS LONGITUDE OF THE ASCENDING NODE.
C            T(I,6) IS ARGUEMENT OF PERIGEE.
C            T(I,7) IS MEAN ANOMALY.
C            T(I,8) IS THE PROJECTED AREA OF THE CYLINDER WRT TO THE SENSOR.
C            T(I,9) IS THE REFLECTIVITY OF THE CYLINDER.
C            T(I,10) IS THE PROJECTED AREA OF THE PLATE.
C            T(I,11) IS THE REFLECTIVITY OF THE PLATE.
C     *************************************************
C
C     MISSION DATA INPUTS ARE STORED IN MATRIX MISSION(4,4) (INTEGER)
C
C     THREE VARIABLES FOR EACH TARGET TYPE ARE ALLOWED
C     A CARD MUST BE INPUT FOR EACH TARGET TYPE SELECTED.
C     AS BEFORE, INPUT 1 CARD FOR EACH TARGET TYPE.
C     CARD FORMAT IS AGAIN FREE FIELD
C            TYPE.....TARGET TYPE (1.,2.,3.,OR 4.) (MANDATORY)
C            TYPNEG...TARGET TYPE NEGATION PERCENTAGE (MANDATORY)
C            TNEG.....TARGET SYSTEM NEGATION TIME (MINUTES) (MANDATORY),
C            NOTE.....TNEG MUST BE THE SAME FOR ALL TARGET TYPES SELECTED.
C            PRIFIR...TRACK PRIORITIES (1,2,3,4) (4 THE LOWEST) (MANDATORY)
C     ***************************************************
C
C     SITE LOCATIONS ARE STORED IN SITE(50,4)
C            SITE(I,1).....LATITUDE
C            SITE(I,2).....LONGITUDE
C            SITE(I,3).....ALTITUDE
C            SITE(I,4).....SENSOR TYPE
C     ****************************************************
C
C     SKYCOVER PROBABILITIES ARE STORED IN SKYC(50,25)
C     ARRAY ELEMENTS ARE STORED AS SHOWN BELOW.
C     INITIAL  STATE   INITIAL  +3HR  +6HR  +9HR  +12HR
C     TIME              PROB
```

60
65
70
75
80
85
90
95
100
105
110

710-
720-
730-
740-
750-
760-
770-
780-
790-
800-
810-
820-
830-
840-
850-
860-
870-
880-
890-
900-
910-
920-
930-
940-
950-
960-
970-
980-
990-
1000-
1010-
1020-
1030-
1040-
1050-
1060-
1070-
1080-
1090-
1100-
1110-
1120-
1130-
1140-
1150-
1160-
1170-
1180-
1190-
1200-
1210-
1220-
1230-
1240-
1250-
1260-
1270-

```
         1720HR   0-3/8     1         2       4   6    7      8
          200HR   4-8/8    10        11      13  14   15     9
          230HR   0-3/8    17        18      19  20   16
          020HR   4-8/8    22        23      21
          050HR   0-3/8    25        24

C    USER SELECTED AIR- AND SPACE-BASED SENSORS ARE STORED IN
C    EOSEL(50,6) AS SHOWN LATER IN THE OPTIMIZE SECTION.  THE
C    SAME FORMAT IS USED FOR BOTH EOBASE AND USER SELECTED
C    SENSORS.
C
C    ZERO ALL INPUT STORAGE LOCATIONS
C
         DO 5 I=1,6
         DO 7 J=1,5
         SENSOR(I,J)=0.
    7    CONTINUE
    5    CONTINUE
C
         DO 90 I=1,14
         DO 91 J=1,11
         T(I,J)=0.
   91    CONTINUE
   90    CONTINUE
C
         DO 175 I=1,4
         DO 174 J=1,4
         MISSION(I,J)=0
  174    CONTINUE
  175    CONTINUE
         DO 797 I=1,50
         DO 797 J=1,25
         SKYC(I,J)=1.
  797    CONTINUE
C
         DO 706 I=1,50
         DO 706 J=1,4
         SITE(I,J)=0.
  706    CONTINUE
C
         DO 348 I=1,50
         DO 341 J=1,6
         EOSEL(I,J)=0.
  341    CONTINUE
  348    CONTINUE
C
C    INPUT SENSOR TYPE SELECTIONS
C
         DO 10 I=1,MOUT
         READ,(SENSOR(IU,I),IU=1,6)
         IF(SENSOR(3,I).EQ.0.)SENSOR(3,I)=16.
         IF((SENSOR(4,I).EQ.0.).AND.(SENSOR(1,I).EQ.2.))SENSOR(4,I)=21.3
```

```
10    CONTINUE
C
C     INPUT TARGET TYPE SELECTIONS AND MISSION DATA.
C
      J999=0
      DO 50 J=1,4
      READX,DEL
      IF(DEL.EQ.99.)GO TO 60
      IF(DEL.EQ.2.)GO TO 150
      IF(DEL.EQ.3.)GO TO 155
      IF(DEL.EQ.4.)GO TO 160
C
C     TYPE 1 IS 3 TARGETS IN MOLYNIA ORBITS
C
      DO 110 I=1,3
      T(I,1)=1.
      T(I,2)=2260.
      T(I,3)=.7
      T(I,4)=1.134
      T(I,6)=4.8143
      T(I,8)=.00001
      T(I,9)=.5
      T(I,10)=.00001
      T(I,11)=.50
110   CONTINUE
      READX,(MISSION(1,IM),IM=1,4)
      J999=J999+3
      GO TO 50
C
C     TYPE 2 IS 4 TARGETS IN SUBSYNCHRONOUS ORBITS
C
150   DO 120 I=4,7
      T(I,1)=2.
      T(I,2)=2260.
      T(I,3)=.7
      T(I,4)=.7854
      T(I,6)=4.5379
      T(I,8)=.00001
      T(I,9)=.5
      T(I,10)=.00001
      T(I,11)=.50
120   CONTINUE
      READX,(MISSION(2,IM),IM=1,4)
      J999=J999+4
      GO TO 50
C
C     TYPE 3 IS 3 TARGETS IN POLAR GEOSYNCHRONOUS ORBIT
C
155   DO 130 I=8,10
      T(I,1)=3.
      T(I,2)=42164
      T(I,4)=1.5708
      T(I,8)=.00001
      T(I,9)=.5
      T(I,10)=.00001
      T(I,11)=.50
130   CONTINUE
```

```
2480-          READX,(MISSION(3,IM),IM=1,4)
2490-          J999=J999+3
2500-          GO TO 50
2510-C
2520-C    TYPE 4 IS 4 TARGETS IN EQUATORIAL SYNCHRONOUS ORBITS
2530-C
2540-  160     DO 140 I=11,14
2550-          T(I,1)=4.
2560-          T(I,2)=42164.
2570-          T(I,3)=.00001
2580-          T(I,5)=.5
2590-          T(I,10)=.000001
2600-          T(I,11)=.50
2610-  140     CONTINUE
2620-          READX,(MISSION(4,IM),IM=1,4)
2630-          J999=J999+4
2640-  50      CONTINUE
2650-  60      CONTINUE
2660-C
2670-C    INPUT SITE LOCATIONS AND SKY COVER PROBABILITIES
2680-C
2690-          IF(INPUT .EQ.0)GO TO 704
2700-          DO 793 I=1,INPUT
2710-          READX,(SITE(I,IU),IU=1,4)
2720-          READX,(SKYVC(I,IU),IU=1,9)
2730-          READX,(SKYVC(I,IU),IU=10,16)
2740-          READX,(SKYVC(I,IU),IU=17,21)
2750-          READX,SKYVC(I,25)
2760-  793     CONTINUE
2770-  704     CONTINUE
2780-C
2790-C    INPUT AIR AND SPACE  BASED SENSOR LOCATION PARAMETERS
2800-C
2810-          IF (INPUT2.EQ.0)GO TO 787
2820-          J=INPUT +1
2830-          I=INPUT2+INPUT
2840-          DO 788 IN=J,I
2850-          READX,(EOSEL(IN,IU),IU=1,6)
2860-  788     CONTINUE
2870-  787     CONTINUE
2880-C
2890-C    THIS ENDS THE INPUT SECTION OF EOBASE.
2900-C
2910-C    xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
2920-C
2930-C    THE FOLLOWING COMMANDS ARE USED AS A VALIDATION OF PROPER INPUTS
2940-          PRINT3,'xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx'
2950-          PRINT3,'xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx'
2960-          PRINT3,'SEED..........................',SEED
2970-          PRINT3,'JCOUNT........................',JCOUNT
2980-          PRINT3,'NOUT..........................',NOUT
2990-          PRINT3,'ICOUNT........................',ICOUNT
3000-          PRINT3,'DT............................',DT
3010-          PRINT3,'P.............................',P
3020-          PRINT3,'INPUT.........................',INPUT
3030-          PRINT3,'INPUT2........................',INPUT2
3040-          PRINT3,'SUNTYP........................',SUNTYP
```

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```
                PRINTX, 'XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX'
                PRINTX, 'XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX'
                PRINTX, 'XXXXX SENSOR TYPES XXXXX'
                PRINTX, ' '
3070-           DO 300 I=1,NOUT
3080-           PRINTX, 'XX SENSOR TYPE ',I,' XX'
3090-           PRINTX, 'MODENO.............',SENSOR(1,I)
3100-  292      PRINTX, 'TYPE...............',SENSOR(2,I)
3110-           IF(SENSOR(2,I).EQ.2.0)GO TO 867
3120-           PRINTX, 'CUTOFF.............',SENSOR(3,I)
3130-           GO TO 868
3140-  867      PRINTX, 'ANGRES.............',SENSOR(3,I)
3150-  868      CONTINUE
3160-           PRINTX, 'ALT................',SENSOR(4,I)
3170-  295      PRINTX, 'DELTRM.............',SENSOR(5,I)
3180-           PRINTX, 'DULTM..............',SENSOR(6,I)
3190-  300      CONTINUE
3200-           PRINTX, 'XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX'
3210-           PRINTX, 'XXXXX TARGET TYPES SELECTED XXXXX'
3220-  300      PRINTX, ' '
3230-           DO 310 I=1,14
3240-           TAROPP(I)=T(I,1)
3250-           IF(T(I,1).EQ.0.0)GO TO 310
3260-           PRINTX, 'XX TARGET TYPE ',T(I,1),', TARGET NUMBER ',I,' XX'
3270-  305      PRINTX, ' '
3280-           PRINTX, 'SEMI/MAJOR AXIS.........  ',T(I,2),' KILOMETERS'
3290-           PRINTX, 'ECCENTRICITY............  ',T(I,3)
3300-           PRINTX, 'INCLINATION.............  ',T(I,4),' RADIANS'
3310-  310      PRINTX, 'ARGUEMENT OF PERIGEE....  ',T(I,6),' RADIANS'
3320-           PRINTX, ' '
3330-  310      CONTINUE
3340-           PRINTX, 'XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX'
3350-           PRINTX, 'XXXXX MISSION DATA XXXXX'
3360-  315      PRINTX, ' '
3370-           DO 320 I=1,4
3380-           IF((I.EQ.1).AND.(T(1,1).EQ.0.0))GO TO 320
3390-           IF((I.EQ.2).AND.(T(4,1).EQ.0.0))GO TO 320
3400-           IF((I.EQ.3).AND.(T(8,1).EQ.0.0))GO TO 320
3410-  320      IF((I.EQ.4).AND.(T(11,1).EQ.0.0))GO TO 320
3420-           PRINTX, 'XX TARGET TYPE ',MISSION(I,1),' XX'
3430-           PRINTX, 'TARGET TYPE NEGATION PERCENTAGE ',MISSION(I,2),'%'
3440-           PRINTX, 'TARGET SYSTEM NEGATION TIME.... ',MISSION(I,3),' MINUTES'
3450-  325      PRINTX, ' '
3460-  320      CONTINUE
3470-           PRINTX, 'XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX'
3480-           IF(INPUT.EQ.0)GO TO 701
3490-           PRINTX, 'XXXXXXSITE LOCATION DATAXXXXX'
3500-  330      PRINTX, ' '
3510-           DO 700 I=1,INPUT
3520-           PRINTX, 'SITE NUMBER.............',I
3530-  335
3540-  340
```

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```
      PRINT*,'LATITUDE...............',SITE(I,1),'RADIANS'
      PRINT*,'LONGITUDE..............',SITE(I,2),'RADIANS'
      PRINT*,'ALTITUDE...............',SITE(I,3),'KILOMETERS'
      PRINT*,'SKY COVER PROBABILITIES'
      PRINT 111,(SKYC(I,IU),IU=1,9)
      PRINT 111,(SKYC(I,IU),IU=10,16)
      PRINT 111,(SKYC(I,IU),IU=17,21)
      PRINT 111,(SKYC(I,IU),IU=22,24)
      PRINT 111,SKYC(I,25)
111   FORMAT(F8.2,F8.2,F8.2,F8.2,F8.2,F8.2,F8.2,F8.2,F8.2)
790   CONTINUE
791   CONTINUE
      IF(INPUT2.EQ.0)GO TO 785
      PRINT*,'##### AIR AND SPACE BASED SENSOR LOCATION PARAMETERS #####'
C
      PRINT*,' '
      I=INPUT2+INPUT
      J=INPUT +1
      DO 786 IOUT=J,I
      PRINT*,'SENSOR TYPE............',EOSEL(IOUT,1)
      PRINT*,'ORBITAL RADIUS.........',EOSEL(IOUT,2),'KILOMETER'
      PRINT*,'ECCENTRICITY...........',EOSEL(IOUT,3)
      PRINT*,'INCLINATION............',EOSEL(IOUT,4),'RADIANS'
      PRINT*,'ASCENDING NODE.........',EOSEL(IOUT,5),'RADIANS'
      PRINT*,'ARGUEMENT OF PERIGEE...',EOSEL(IOUT,6),'RADIANS'
      PRINT*,' '
786   CONTINUE
785   CONTINUE
      PRINT*,'#######################################################'
      PRINT*,'#######################################################'
C
C     ZERO THE SUMEFF MATRIX.
C
      DO 337 I=1,NOUT
      DO 339 J=1,410
      SUMEFF(I,J)=0.
339   CONTINUE
337   CONTINUE
C
      IC=1
      IF((INPUT.GT.0).OR.(INPUT2.GT.0))IC=0
      IF((INPUT.GT.0).OR.(INPUT2.GT.0))GO TO 922
C     CALL SPHERE FOR EACH SENSOR TYPE.
C
      DO 340 I=1,NOUT
      R=SENSOR(4,I) +6378.145
      CALL SPHERE(R,I,X,V,Z,TH)
340   CONTINUE
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     THIS SECTION IS SUB-MODEL 'OPTIMIZE'
C
C     THE PURPOSES OF 'OPTIMIZE' ARE TO PLACE THE FIRST (OR NEXT) SENSOR I
C     THE 'MOST EFFICIENT' ORBIT OR LATITUDE, AND TO DETERMINE WHEN THE
C     DEPLOYED SENSOR SYSTEM BECOMES ENOUGH TO SATISFY THE MISSION
```

```
C     REQUIREMENTS.
Cxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
C     PLACE THE NEXT SENSOR IN THE 'MOST EFFICIENT' ORBIT OR LATITUDE.
C
C     THERE ARE 37 LATITUDINAL PLACEMENT POSSIBILITIES FOR EACH SENSOR TYP
C     IN BASING MODES 1 OR 2.
C
C     THERE ARE 324 ORBITAL PLACEMENT POSSIBILITIES FOR EACH SENSOR
C     TYPE IN BASING MODE 3.
C
      CALL SIDEN(IT,XT,YT,ZT,SENSOR,X,Y,Z,SUREFF, EOSEL,TAROPP,JCOUNT
     C,NOUT,SUNTYP)
C
C     SO SUREFF NOW CONTAINS VALUES OF THE AVERAGE SIGHTING EFFICIENCY WIT
C     A PRESCRIBED CONFIDENCE INTERVAL.
C
343   CONTINUE
C
      DO 500 I=1,NOUT
C
C     FIND THE 'MOST EFFICIENT' LATITUDE FOR EACH MODE 1 OR 2 SENSOR TYPE.
C     THE ATTRIBUTE OF EFFICIENCY USED IS THE 'PATH AVERAGE TARGET SYST
C     SIGHTING EFFICIENCY', PTHEFF.
C
      PTHEFF=0.
      DO 415 J=1,36
      PTHEFF=PTHEFF+SUREFF(I,J)
415   CONTINUE
      PATH(I,1)=PTHEFF/36.
C
      PTHEFF=0.
      DO 417 J=37,71
      PTHEFF=PTHEFF+SUREFF(I,J)
417   CONTINUE
      PATH(I,2)=PTHEFF/35.
C
      PTHEFF=0.
      DO 419 J=72,105
      PTHEFF=PTHEFF+SUREFF(I,J)
419   CONTINUE
      PATH(I,3)=PTHEFF/34.
C
      PTHEFF=0.
      DO 421 J=106,136
      PTHEFF=PTHEFF+SUREFF(I,J)
421   CONTINUE
      PATH(I,4)=PTHEFF/31.
C
      PTHEFF=0.
      DO 423 J=137,163
      PTHEFF=PTHEFF+SUREFF(I,J)
423   CONTINUE
      PATH(I,5)=PTHEFF/27.
C
      PTHEFF=0.
      DO 425 J=164,185
      PTHEFF=PTHEFF+SUREFF(I,J)
```

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425    CONTINUE
       PATH(I,6)=PTHEFF/23.
C
       PTHEFF=0.
       DO 427 J=187,204
       PTHEFF=PTHEFF+SUMEFF(I,J)
427    CONTINUE
       PATH(I,7)=PTHEFF/18.
C
       PTHEFF=0.
       DO 429 J=205,216
       PTHEFF=PTHEFF+SUMEFF(I,J)
429    CONTINUE
       PATH(I,8)=PTHEFF/12.
C
       PTHEFF=0.
       DO 431 J=217,222
       PTHEFF=PTHEFF+SUMEFF(I,J)
431    CONTINUE
       PATH(I,9)=PTHEFF/6.
C
       PATH(I,10)=SUMEFF(I,223)
C
       PTHEFF=0.
       DO 434 J=224,258
       PTHEFF=PTHEFF+SUMEFF(I,J)
434    CONTINUE
       PATH(I,11)=PTHEFF/35.
C
       PTHEFF=0.
       DO 436 J=259,292
       PTHEFF=PTHEFF+SUMEFF(I,J)
436    CONTINUE
       PATH(I,12)=PTHEFF/34.
C
       PTHEFF=0.
       DO 438 J=293,323
       PTHEFF=PTHEFF+SUMEFF(I,J)
438    CONTINUE
       PATH(I,13)=PTHEFF/31.
C
       PTHEFF=0.
       DO 440 J=324,350
       PTHEFF=PTHEFF+SUMEFF(I,J)
440    CONTINUE
       PATH(I,14)=PTHEFF/27.
C
       PTHEFF=0.
       DO 442 J=351,373
       PTHEFF=PTHEFF+SUMEFF(I,J)
442    CONTINUE
       PATH(I,15)=PTHEFF/23.
C
       PTHEFF=0.
       DO 444 J=374,391
       PTHEFF=PTHEFF+SUMEFF(I,J)
444    CONTINUE
```

```
515          PATH(I,16)=PTHEFF/18.
      C
             PTHEFF=0.
             DO 446 J=392,403
             PTHEFF=PTHEFF+SUMEFF(I,J)
446          CONTINUE
520          PATH(I,17)=PTHEFF/12.
      C
             PTHEFF=0.
             DO 448 J=404,409
             PTHEFF=PTHEFF+SUMEFF(I,J)
525   448    CONTINUE
             PATH(I,18)=PTHEFF/6.
      C
             PATH(I,19)=SUMEFF(I,410)
             DO 2 J=1,19
             PRINT3,I,PATH(I,J)
530   2      PRINT3,
      CCC
      CCC    THIS COMPLETES THE FINDING OF THE 'PATH EFFICIENCIES' FOR EACH
      CCC    SENSOR TYPE OF MODES 1. AND 2.
535          IF(SENSOR(1,1).LT.2.5)GO TO 500
      CCCCC
      CCCCC  CALCULATE 'PATH AVERAGE TARGET SYSTEM SIGHTING EFFICIENCY' FOR THE
      CCC    VARIOUS ORBITAL INCLINATIONS
      C
540          DO 481 N=2,10
             EFF=0.0
             DO 490 J=2,N
             EFF=EFF+PATH(I,J)
             N=J+9
545          EFF=EFF+PATH(I,N)
490          CONTINUE
             PATH(I,N)=(EFF+PATH(I,1))/(((N-1)*2)+1)
             PRINT3,I,PATH(I,N)
550   491    CONTINUE
      500    CONTINUE
      CCCCCC
      CCCCC  THE PATH MATRIX NOW CONTAINS 'PATH SIGHTING EFFICIENCY' VALUES
      CCC    FOR ALL POSSIBLE PATHS OF ALL SENSOR TYPES.
555   CCCCC
      CCCCC  MODES 1 AND 2 SENSOR TYPES WILL HAVE 19 VALUES IN A ROW.
      CCC    HOWEVER, LATITUDES MORE THAN 60 DEGREES FROM THE EQUATOR
      CCC    WILL NOT BE CONSIDERED AS POSSIBLE BASING LOCATIONS.
      CCC    MODE 3 SENSOR TYPES WILL HAVE 10 VALUES IN A ROW.
560   CCCCC
      CCC    CHOOSE THE PATH WITH THE MAXIMUM EFFICIENCY.
      CCCCC
      CCC    LET IMAX BE THE SENSOR TYPE (INTEGER), AND JMAX THE LATITUDE OR ORBI
      C
565          XMAX=0.
             DO 540 I=1,NOUT
             L=10
             IF(SENSOR(I,1).LT.3)L=19
570          DO 530 J=1,L
             IF((SENSOR(I,1).LT.2.5).AND.(J.GT.7).AND.(J.LT.11))
```

```
C     PATH(I,J)=0.
      IF((SENSOR(1,I).LT.2.5).AND.(J.GT.16))PATH(I,J)=0.
      IF(PATH(I,J).GT.XMAX)IMAX=I
      IF(PATH(I,J).GT.XMAX)JMAX=J
      IF(PATH(I,J).GT.XMAX)XMAX=PATH(I,J)
550   CONTINUE
540   CONTINUE
      PRINT3,.
      PRINT2,I,J,XMAX,IMAX
C
C     SO THE SENSOR SELECTED BY OPTIMIZE TO BE ADDED TO THE SENSOR SYSTEM
C     SENSOR IMAX IN LATITUDE OR ORBIT JMAX.
C
C*******************************************************************
C
C     THE MATRIX SUMEFF HAS NOW SERVED ITS PURPOSE, AND IS ZEROED.
C
      DO 650 I=1,NOUT
      DO 640 J=1,410
      SUMEFF(I,J)=0.
640   CONTINUE
650   CONTINUE
C
C     THE PARAMETERS OF THE SELECTED SENSOR ARE STORED IN EOSEL(50 BY 6)
C     USE BY TRACK  AND FOR OUTPUT AS THE FINAL SENSOR SYSTEM.
C     EOSEL(IC,1) IS THE SENSOR TYPE (REAL).
C
      EOSEL(IC,1)=IMAX
C
C     EOSEL(IC,2) IS THE ORBITAL RADIUS (MODE 3), OR THE SPHERICAL COORDI
C     THETA (MODES 1 OR 2).
C
      IF(SENSOR(1,IMAX).EQ.3.) EOSEL(IC,2)=SENSOR( 4,IMAX)+6378.145
      IF(SENSOR(1,IMAX).LT.3.) EOSEL(IC,2)=TH(JMAX)
C
C     EOSEL(IC,3) IS THE ORBITAL ECCENTRICITY, AND IS ZERO.
C
C     EOSEL(IC,4) IS THE ORBITAL INCLINATION
C     OR THE SPHERICAL THETA (MODES 1 AND 2)
C
      RINC=(JMAX-1)*10+5
      EOSEL(IC,4)=(RINC/180.)*3.14159
      IF(JMAX.EQ.1) EOSEL(IC,4)=0.0
      IF(JMAX.EQ.18) EOSEL(IC,4)=1.570796
C
C     EOSEL(IC,5) IS THE LONGITUDE OF THE ASCENDING NODE (RANDOM).
C
C     EOSEL(IC,6) IS THE ARGUEMENT OF PERIGEE, AND IS ZERO.
C
      DO 20 J=1,IC
      NU(J)=0
      DO 30 I=1,IC
      IF(( EOSEL(I,1).EQ. EOSEL(J,1)).AND.( EOSEL(I,4).EQ. EOSEL(J,4)))
C                                                NU(J)=NU(J)+1
30    CONTINUE
20    CONTINUE
B22   CONTINUE
```

```
C      THIS COMPLETES THE STORAGE OF THE SELECTED SENSOR PARAMETERS IN EOS
C
Cxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
C
C      THIS SECTION OF SUBMODEL OPTIMIZE RUNS TRACK ENOUGH TIMES
C      TO DEVELOP A CONFIDENCE OF .9 THAT THE CURRENT SENSOR SYSTEM (SENSOR
C      SELECTED BY OPTIMIZE AND STORED IN EOSEL) EITHER CAN OR CANNOT
C      MEET THE MISSION REQUIREMENTS SPECIFIED BY THE USER.
C
       SUCESA=0.
       DO 700 II=,ICOUNT
       PRINT8,' '
       PRINT8,'         TRACK RUN NUMBER ',II
       PRINT8,' '
       CALL TRACK( MISSION,EOSEL,T,SENSOR,TAROPP,XT,YT,ZT,J9,IC,NU,NOUT,
     C DT,TB,INPUT,INPUT8,SUNTVP,SITE,SKVC)
       J9=J9-(14-J999)
       IF((INPUT.GT.0).OR.(INPUT2.GT.0))GO TO 888
       IF(J9.LT.J999)CALL SIDEN(T,XT,YT,ZT,SENSOR,X,Y,Z,SUNEFF,EOSEL,
     C TAROPP,KCOUNT,NOUT,SUNTVP)
C
C      J9 IS THE NUMBER OF TARGETS NEGATED DURING THIS RUN OF TRACK.
C
888    PRINT8,' '
       PRINT8,J9,' TARGETS TRACKED FOR TRACK RUN NUMBER',II
       PRINT8,'xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx88'
       SUCESS=0.
       IF(J9.EQ.J999)SUCESS=1.
       SUCESA=SUCESA+SUCESS
700    CONTINUE
       PRINT8,' '
       PRINT8,SUCESA,' OUT OF ',ICOUNT,' TRACK RUNS WERE SUCCESSFUL'
       PRINT8,'xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx'
       PRINT8,'xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx'
       PRINT8,'xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx'
       SUCESA=SUCESA/COUNT
C
C      IF THIS IS ONLY A SIMULATION RUN, THEN DO NOT GET ANOTHER SENSOR.
C
       IF((INPUT.GT.0).OR.(INPUT2.GT.0))GO TO 1000
C
C      IF THE AVERAGE OF SUCESS IS .GE. TO P, THE CURRENT SENSOR SYSTEM
C      MEETS THE MISSION REQUIREMENTS, AND THE SENSOR SYSTEM MAY BE OUTPUT
C
       IF(SUCESA.GE.P)GO TO 1000
C
C      IF THE AVERAGE OF SUCESS IS .LT. P, ANOTHER SENSOR IS NEEDED.
C
       IC=IC+1
       GO TO 343
1000   CONTINUE
C
C      OUTPUT THE FINAL SENSOR SYSTEM WHICH MEETS MISSION REQUIREMENTS.
C
1015   CONTINUE
```

```
      PRINT*,' '
685   PRINT*,'         xxxxx SENSORS SELECTED xxxx'
      PRINT*,' '
C
C     MSEN IS THE INTEGER SENSOR TYPE.
C
690   IF((INPUT.GT.0).OR.(INPUT2.GT.0))IC=INPUT+INPUT2
      DO 1020 I=1,IC
      PRINT*,'   SENSOR SELECTION NUMBER ',I
      MSEN= EOSEL(I,1)
      PRINT*,'          SENSOR TYPE ',MSEN
695   PRINT*,'          MODE NUMBER ',SENSOR(1,MSEN)
      IF(SENSOR(1,MSEN).LT.3.)PRINT*,'      LATITUDE IS ',
     C EOSEL(I,2)
      IF(SENSOR(1,MSEN).LT.3.)GO TO 1020
700   PRINT*,'          ORBITAL RADIUS ',EOSEL(I,2),' KILOMETERS'
      ALT=EOSEL(I,2)-6378.145
      PRINT*,'          ORBITAL ALTITUDE ',ALT,' KILOMETERS'
      PRINT*,'          ORBITAL INCLINATION IS ',EOSEL(I,4)
1020  CONTINUE
705   STOP
      END
```

```
      SUBROUTINE SPHERE(R,RC,X,Y,Z,TH)
      DIMENSION X(5,410),Y(5,410),Z(5,410),TH(19)
      INTEGER RC
C
C     PROVIDES 3-D CARTESIAN COORDINATES OF ALL 410 POINTS ON THE
C     SPHERE OF OPERATIONS FOR A SINGLE RADIUS
C     CALL STATEMENT MUST SPECIFY WHICH RADIUS AND ENUMERATOR IS TO BE USE
      TH(1)=1.5708
      TH(2)=1.4039
      TH(3)=1.2359
      TH(4)=1.0374
      TH(5)=.8693
      TH(6)=.6930
      TH(7)=.5236
      TH(8)=.3546
      TH(9)=.1675
      TH(10)=.0
      TH(11)=1.7276
      TH(12)=1.9057
      TH(13)=2.1041
      TH(14)=2.2723
      TH(15)=2.4485
      TH(16)=2.6180
      TH(17)=2.7870
      TH(18)=2.9741
      TH(19)=3.1416
C
C     POINTS 1 THRU 36
C
      XC=0.
      DO 1 I=1,36
      PHI=XC*6.2831/36.
      CALL CART(R,RC,TH,PHI,1,1,X,Y,Z)
      XC=XC+1.
    1 CONTINUE
C
C     POINTS ON LAT. 2 AND 11
C
      XC=0.
      DO 3 I=37,71
      PHI=XC*6.2831/35.
      CALL CART(R,RC,TH,PHI,I,2,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+187,11,X,Y,Z)
      XC=XC+1.
    3 CONTINUE
C
C     POINTS FOR LAT. 3 AND 12
C
      XC=0.
      DO 5 I=72,105
      PHI=XC*6.2831/34.
      CALL CART(R,RC,TH,PHI,I,3,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+187,12,X,Y,Z)
      XC=XC+1.
    5 CONTINUE
```

100

```fortran
C     POINTS FOR LAT. 4 AND 13
C
      XC=0.
      DO 7 I=106,136
      PHI=XC*6.28318/31.
      CALL CART(R,RC,TH,PHI,I,4,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+187,13,X,Y,Z)
      XC=XC+1.
7     CONTINUE
C
C     POINTS FOR LAT. 5 AND 14
C
      XC=0.
      DO 9 I=137,163
      PHI=XC*6.28318/27.
      CALL CART(R,RC,TH,PHI,I,5,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+187,14,X,Y,Z)
      XC=XC+1.
9     CONTINUE
C
C     POINTS FOR LAT. 6 AND 15
C
      XC=0.
      DO 11 I=164,186
      PHI=XC*6.28318/23.
      CALL CART(R,RC,TH,PHI,I,6,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+187,15,X,Y,Z)
      XC=XC+1.
11    CONTINUE
C
C     POINTS FOR LAT. 7 AND 16
C
      XC=0.
      XC=0.
      DO 13 I=187,204
      PHI=XC*6.28318/18.
      CALL CART(R,RC,TH,PHI,I,7,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+187,16,X,Y,Z)
      XC=XC+1.
13    CONTINUE
C
C     POINTS FOR LAT. 8 AND 17
C
      XC=0.
      DO 15 I=205,216
      PHI=XC*6.28318/18.
      CALL CART(R,RC,TH,PHI,I,8,X,Y,Z)
      CALL CART(R,RC,TH,PHI,I+187,17,X,Y,Z)
      XC=XC+1.
15    CONTINUE
C
C     POINTS FOR LAT. 9 AND 18
C
      XC=0.
      DO 17 I=217,222
      PHI=XC*6.28318/6.
      CALL CART(R,RC,TH,PHI,I,9,X,Y,Z)
```

```
10170-          CALL CART(R,RC,TH,PHI,1+187.18,X,Y,Z:
10180-          XC=XC+1.
10190-   115    CONTINUE
10200- 17    C
10210-       C   POINT FOR LAT. 18
10220-       C
10230-   120    PHI=0.
10240-          CALL CART(R,RC,TH,PHI,223.18,X,Y,Z)
10250-       C
10260-       C   POINT FOR LAT. 19
10270-   125    PHI=6.28318
10280-          CALL CART(R,RC,TH,PHI, 410.19,X,Y,Z)
10290-          RETURN
10300-          END
```

```
      SUBROUTINE CART(R,RC,TH,PHI,IX,JX,X,Y,Z)
      DIMENSION TH(19),X(5,410),Y(5,410),Z(5,410)
      INTEGER RC
    1 X(RC,IX)=R*SIN(TH(JX))*COS(PHI)
      Y(RC,IX)=R*SIN(TH(JX))*SIN(PHI)
    5 Z(RC,IX)=R*COS(TH(JX))
      RETURN
      END
```

10690*
10700*
10710*
10720*
10740*
10750*
10760*

103

```fortran
      SUBROUTINE SIDE(X,XT,YT,ZT,SENSOR,X,Y,Z,SUMEFF, EOSEL,TAROPP,
     CJCOUNT,NO,T,SUNTYP)
      INTEGER SENSNO,PTNO,TGTNO,SLNTYP
      DIMENSION X(5,410),V(5,410),Z(5,410),T(14,11),XT(14),
     CYT(14),ZT(14),SENSOR(6,5), SUMEFF(5,410), EOSEL(50,6),TAROPP(14)

C     THE PURPOSE OF THIS SUB-MODEL IS TO GENERATE THE 'TARGET SYSTEM
C     SIGHTING EFFICIENCY' VALUES FOR EACH POINT ON EACH SPHERE OF OPERATI
C     (STORED IN MATRIX SUMEFF)

      DO 10 I=1,JCOUNT

C     CALL TARGET TO INITIALLY PLACE THE TARGETS

      CALL TARGET(T,XT,YT,ZT,TAROPP,SUNTYP,SNXCOS,SNXCOS,SNZCOS,SUNPHI)

C     SENSNO- SENSOR TYPE NUMBER

      DO 20 SENSNO=1,NOUT

C     PTNO-POINT ON SPHERE OF OPERATIONS

      DO 30 PTNO=1,410

C     TGTNO - TARGET NUMBER BEING LOOKED AT

      DO 40 TGTNO=1,14

C     IF THE TARGET WAS NOT SELECTED BY THE USER OR WAS SEEN
C               DON'T CALL SIGHT

      IF(TAROPP(TGTNO).EQ.0.0)GO TO 40
      CALL SIGHT(SENSNO,TGTNO,SENSOR,T,X(SENSNO,PTNO),
     C Y(SENSNO,PTNO),Z(SENSNO,PTNO),XT(TGTNO),YT(TGTNO),ZT(TGTNO),S,
     C SNXCOS,SNYCOS,SNZCOS,RANGE)
      SUMEFF(SENSNO,PTNO)=SUMEFF(SENSNO,PTNO)+S
   40 CONTINUE
   30 CONTINUE
   20 CONTINUE
   10 CONTINUE
      RETURN
      END
```

104

```
              SUBROUTINE TARGET (T,XT,YT,ZT,TAROPP,SUNTYP,SNXCOS,SNYCOS,SNZCOS,
             C SUNPHI)
              DIMENSION T(14,11),XT(14),YT(14),ZT(14),TAROPP(14)
              INTEGER SUNTYP

      C       THIS SUBROUTINE PLACES THE SUN OVER THE EARTH, AND IT
      C       GENERATES CARTESIAN COORDINATES FOR RANDOM POSITIONS OF ALL SELECTED
      C       TARGETS

              PI=ACOS(-1.)
              TWOPI=2.*PI

      C       CALL SUNPOS TO PLACE THE SUN OVER THE EARTH.

      C       CALL SUNPOS(SUNTYP,SNXCOS,SNYCOS,SNZCOS,SUNPHI)

      C       PLACE THE TARGETS

              DO 100 I=1,14

      C       CHECK WHETHER TARGET HAS BEEN SELECTED

              IF(TAROPP(I).EQ.0.)GO TO 100

      C       FOLLOWING RANDOM SELECTION OF THE TRUE ANOMALY (ETA) IS DONE IN 3 ST
      C       STEP 1- A MEAN ANOMALY (XM) IS DRAWN FROM A UNIFORM (0,2PI) DISTR

              RN=RANF(DUM)
              XM=RN*TWOPI

      C       FOR TARGET TYPE 1, THE MEAN ANOMALIES ARE SEPARATED BY 120 DEGREES.

              IF(I.EQ.2)XM=T(1,7)*TWOPI/3
              IF(I.EQ.3)XM=T(2,7)*TWOPI/3

      C       FOR TARGET TYPE 2, THE MEAN ANOMALIES ARE SEPARATED BY 90 DEGREES.

              IF(I.EQ.5)XM=T(4,7)*TWOPI/4
              IF(I.EQ.6)XM=T(5,7)*TWOPI/4
              IF(I.EQ.7)XM=T(6,7)*TWOPI/4

      C       FOR TARGET TYPE 3, THE MEAN ANOMALIES ARE SEPARATED BY 120 DEGREES.

              IF(I.EQ.9)XM=T(8,7)*TWOPI/3
              IF(I.EQ.10)XM=T(9,7)*TWOPI/3

      C       FOR TARGET TYPE 4, THE MEAN ANOMALIES ARE SEPARATED BY 90 DEGREES.

              IF(I.EQ.12)XM=T(11,7) *TWOPI/4
              IF(I.EQ.13)XM=T(12,7) *TWOPI/4
              IF(I.EQ.14)XM=T(13,7) *TWOPI/4
              IF(XM.GT.TWOPI)XM=XM-TWOPI
              T(I,7)=XM

      C       STEP 2- THIS MEAN ANOMALY XM IS THEN TRANSFORMED TO THE ECCENTRI
      C       ANOMALY EAN BY A ROOT SOLUTION OF THE TRANSCENDENTAL EQUATION.
```

11820-
11830-
11840-
11850-   1
11860-
11870-
11880-
11890-
11900-
11910-   10
11920-
11930-
11940-
11950-   15
11960-
11970-
11980-
11990-
12000-
12010-   20
12020-
12030-
12040-
12050-
12060-   25
12070-
12080-
12090-
12100-
12110-   30
12120-
12130-
12140-
12150-   35
12160-
12170-
12180-
12190-
12200-   40
12210-
12220-
12230-
12240-
12250-   45
12260-
12270-
12280-
12290-
12300-   50
12310-
12320-
12330-
12340-
12350-   55
12360-
12370-
12380-

```
C     IF THE TARGET HAS ECCENTRICITY OF 0, THE MEAN ANOMALY, ECCENTRIC ANO
C     AND TRUE ANOMALY ARE THE SAME.
C
      IF(T(I,3).EQ.0.)ETA=XM
      IF(T(I,3).EQ.0.)GO TO 50
C
      E=T(I,3)
      A=XM-E
      B=XM+E
      CALL ROOT(E,XM,A,B,EAN)
C
C     STEP 3- THE TRUE ANOMALY ETA IS THEN CALCULATED USING THE ECCENTR
C     ANOMALY EAN
C
      ETA=ACOS((E-COS(EAN))/(E*COS(EAN)-1.))
50    CONTINUE
C
C     SELECT LONGITUDE OF THE ASCENDING NODE RANDOMLY FOR EACH TARGET TYPE
C
      RINC=I-1.
      RM=RANF(DUM)
      T(I,5)=RM*TLOOP1
      IF((I.GE.2).AND.(I.LE.3))T(I,5)=T(I,5)+2.094*RINC
      IF((I.GE.5).AND.(I.LE.7))T(I,5)=T(4,5)+1.5707*(RINC-3)
      IF((I.GE.9).AND.(I.LE.10))T(I,5)=T(8,5)+2.094*(RINC-7)
      IF(I.GE.11)T(I,5)=0.
C
C     CALCULATE R, THETA, AND PHI FROM ORBITAL PARAMETERS
C
      R=T(I,2)*(1.-T(I,3)**2.)/(1.+T(I,3)*COS(ETA))
      THETA1=ASIN(SIN(T(I,4))*SIN(ETA+T(I,6)))
      THETA=(PI/2.0)-THETA1
      IF(T(I,4).LT..0001)PHI$=ETA+T(I,6)+T(I,5)
      IF(T(I,4).LT..0001)GO TO 70
      ASP=TAN(THETA1)/TAN(T(I,4))
      ACP=COS(ETA+T(I,6))/COS(THETA1)
      PHI$=ATAN2(ASP,ACP)+T(I,5)
C
C     CALCULATE CARTESIAN COORDINATES
C
70    XT(I)=R*SIN(THETA)*COS(PHI$)
      YT(I)=R*SIN(THETA)*SIN(PHI$)
      ZT(I)=R*COS(THETA)
100   CONTINUE
      RETURN
      END
```

106

```
13300:        SUBROUTINE ROOT(E,XM,A,B,EAN)
13310:        F(E,XM,EAN)=EAN-E*SIN(EAN)-XM
13320:        F1=F(E,XM,A)
13330:        IF(F1.GT.-.001)EAN=A
13340:        IF(F1.GT.-.001)GO TO 100
13350:        F2=F(E,XM,B)
13360:        IF(F2.LT..001)EAN=B
13370:        IF(F2.LT..001)GO TO 100
13380:        IF((F1.GE.-.01).AND.(F2.LE..01))EAN=(A+B)/2.0
13390:        IF((F1.GE.-.01).AND.(F2.LE..01))GO TO 100
13400:        C=(A+B)/2.0
13410:   50   F3=F(E,XM,C)
13420:        IF(F3.GT.0.001)F2=F3
13430:        IF(F3.GT.0.001)B=C
13440:        IF(F3.GT.0.001)GO TO 50
13450:        IF(F3.LT.-.001)F1=F3
13460:        IF(F3.LT.-.001)A=C
13470:        IF(F3.LT.-.001)GO TO 50
13480:        EAN=C
13490:  100   RETURN
13500:        END
```

107

```
      SUBROUTINE SIGHT(N,TGTNO,SENSOR,T,XS,VS,ZS,XTS,VTS,ZTS,S,SNXCOS,
     C SNVCOS,SNZCOS,RANGE)
      DIMENSION T(14,11),SENSOR(6,5)
      REAL MCDENO
      REAL KX,KV,KZ ,KTGT,LXTS,LVTS,LZTS,LDOTTS,LSOTS
      INTEGER TGTNO
C
C*** THE FOLLOWING ARE INPUT VARIABLES TO SIGHT***
C
C N= CURRENT WEAPON NUMBER  (INTEGER)
C T= TARGET CHARACTERISTICS MATRIX
C TGTNO= CURRENT TARGET NUMBER  (INTEGER)
C XS,VS, AND ZS ARE COORDINATES OF SENSOR POINT
C XTS,VTS, AND ZTS ARE COORDINATES OF TARGET
C SNXCOS,SNVCOS, AND SNZCOS ARE THE DIRECTION COSINES TO THE SUN
C
C*** THE OUTPUT IS S THE TARGET SIGHTING EFFICIENCY FOR THIS ONE
C ON ONE, ONE-TIME SIGHTING ATTEMPT *****
C S IS EITHER 0 OR 1.
C SUBROUTINE 'SIGHT' IS USED BY BOTH 'SIDEN' AND 'TRACK'
C
C 'SIGHT' IS PROVIDED A SENSOR AND ITS INSTANTANEOUS POSITION, AND
C THE POSITION OF A SPECIFIC TARGET
C
C THE PURPOSE OF 'SIGHT' IS TO DETERMINE WHETHER THAT TARGET COULD
C BE TRACKED BY THAT SENSOR WITH THE GEOMETRY IMPLIED
C
C COMPUTE VECTORXL, VL, ZL FROM THE SENSOR (OR POINT) TO THE TARGET.
C
      XL=XTS-XS
      VL=VTS-VS
      ZL=ZTS-ZS
C
C COMPUTE RANGE FROM SENSOR OR POINT TO TARGET
C
      RANGE=SQRT(XL**2+VL**2+ZL**2)
C
C COMPUTE DIRECTION COSINES OF VECTOR FROM SENSOR OR POINT
C TO TARGET
C
      XLCOS=XL/RANGE
      VLCOS=VL/RANGE
      ZLCOS=ZL/RANGE
C
C COMPUTE DIRECTION COSINES OF VECTOR TO SENSOR OR POINT
C
      R=SQRT(XS**2+VS**2+ZS**2)
      XSCOS=XS/R
      VSCOS=VS/R
      ZSCOS=ZS/R
C
C COMPUTE ANGLES COR AND PSI.
C
      COSCOM=XLCOS*XSCOS+VLCOS*VSCOS+ZLCOS*ZSCOS
      COR=ABS(ACOS(COSCOM))
      COSCOR=ABS(COSCOM)
      MCDENO=SENSOR(1,N)
```

```
C
C     TO TRACK IT.

        CALL VISBLE(SENSOR,N,TGTNO,T,XTS,YTS,ZTS,S,SNXCOS,
115    C SNYCOS,SNZCOS,RANGE,XL,YL,ZL)
        RETURN
799     S=1.
        RETURN
120    
300     S=0.0
        RETURN
100     END
```

14970-
14980-
14990-
15000-
15010-
15020-
15030-
15040-
15050-
15060-

```fortran
      SUBROUTINE VISBLE(SENSOR,N,"GTNO,",XTS,YTS,ZTS,S,SNXCCS,
     C SNYCCS,SNZCOS,RANGE,XL,YL,ZL)
      DIMENSION SENSOR(6,5),T(14,11)
      REAL IRCYL,IRPLT,MAG
      INTEGER TGTNO

C     THIS SUBROUTINE CALCULATES THE VISUAL MAGNITUDE OF AN EARTH-CENTER
C     STABLE CYLINDER WITH ENDPLATES AND DETERMINES IF THE SENSOR CAN
C     SEE THE SATELLITE.
      AREAC=T(TGTNO,8)
      REFC =T(TGTNO,9)
      AREAP=T(TGTNO,10)
      REFP =T(TGTNO,11)
C     AS SHOWN LATER IN THE OPTIMIZE SECTION.
      CUTOFF=SENSOR(3,N)

C     COMPUTE BETA

      RTGT=ABS(SQRT(XTS**2+YTS**2+ZTS**2))
      TGTSUM=SNXCOS*(-XTS)+SNYCOS*(-YTS)+SNZCOS*(-ZTS)
      BETA=ACOS(TGTSUM/RTGT)

C     COMPUTE ALPHA

      RANGE=ABS(RANGE)
      TGTSEN=(-XL)*(-XTS)+(-YL)*(-YTS)+(-ZL)*(-ZTS)
      ALPHA=ACOS(TGTSEN/(RANGE*RTGT))

C     COMPUTE PHIO

      SENSUM=SNXCOS*(-XL)+SNYCOS*(-YL)+SNZCOS*(-ZL)
      PHIO=ACOS(SENSUM/RANGE)

C     COMPUTE THTA
      THTA=((COS(PHIO)-(COS(ALPHA)*COS(BETA)))/(SIN(ALPHA)*
     C SIN(BETA)))
      IF(ABS(THTA).GT.1.0)GO TO 901
      THTA=ACOS(THTA)
      GO TO 902
901   CONTINUE
      THTA=0.
902   CONTINUE
C     CALCULATE IRRADIANCE OF CYLINDER AND ENDPLATES, IRCYL AND IRPLT.

      IRCYL=REFC*AREAC*SIN(ALPHA)*SIN(BETA)*(SIN(THTA)+(ACOS(-1.0)
     C -THTA)*COS(THTA))/(4.0*(ACOS(-1.0))*RANGE**2)

C     IRPLT=REFP*AREAP*COS(ALPHA)*COS(BETA)/(ACOS(-1.0)*RANGE**2)

C     CALCULATE VISUAL MAGNITUDE OF TARGET AT SENSOR.

      IF(COS(BETA).LE.0.)IRPLT=0.
      IF((IRPLT.GT.0.).OR.(IRCYL.GT.0.))GO TO 866
      S=0.
      RETURN
866   MAG=-26.78-2.5*ALOG10(IRCYL+IRPLT)
```

```
C
C       CHECK IF TARGET IS SEEN
C
        IF(MAG.LE.CUTOFF)S=1.0
        IF(MAG.GT.CUTOFF)S=0.0
        RETURN
        END
```

16140:
16150:
16160:   60
16170:
16180:
16190:
16200:

111

```
      SUBROUTINE SLWIR(N,COM,RANGE,SENSOR,S)
C
C     THIS SUBROUTINE COMPUTES THE SIGNAL TO NOISE RATIO OF A
C     LWIR SENSOR'S TARGET CURRENT(IT) TO ITS BACKGROUND CURRENT(IB)TO
C     DETERMINE IF THE TARGET CAN BE TRACKED.
C     INPUTS TO THE PROGRAM ARE THE ZENITH ANGLE(COM),THE RANGE
C     (RANGE), THE SENSOR TYPE(N),AND THE SENSOR ARRAY.
C     THE ANGULAR RESOLUTION AND THE DETECTOR DWELL TIME
C     ARE EXTRACTED FROM THE SENSOR ARRAY.
C
      REAL IT,IB,IRADB,IRADT,LB
      DIMENSION SENSOR(6,5)
      COMMON/AIR/TRNSMT(9),BKGD(9)
      PI=ACOS(-1.)
C
C     COMPUTE DETECTOR FIELD OF VIEW (SOLID) FROM ANGULAR RESOLU-
C     TION.
C
      SOLID=((SENSOR(3,N)*PI/180.)**2)*PI/4
C
C     FIND THE APPROPRIATE VALUES FOR THE ATMOSPHERIC RADIANCE(LB)
C     AND THE ATMOSPHERIC TRANSMITTANCE(TAO) BASED ON THE ZENITH
C     ANGLE.
      DO 10 I=1,9
      ANG=(10.*FLOAT(I)-5)*PI/180.
      IF(ANG.GE.COM)GO TO 10
      LB=BKGD(I)
      TAO=TRNSMT(I)
10    CONTINUE
C
C     COMPUTE TARGET AND BACKGROUND IRRADIANCES.
C
      IRADB=SOLID*LB*TAO
      IRADT=(PI*46.5*(1/PI**2)/RANGE**2)*TAO
C
C     COMPUTE TARGET AND BACKGROUND CURRENTS
C
      IT=.8*.25*IRADT/2.8E-20
      IB=.8*.25*IRADB/2.8E-20
C
C     COMPUTE SIGNAL TO NOISE RATIO(STON).
C
      STON=IT*SQRT(SENSOR(6,N))/SQRT(IT+IB)
C
      IF STON GT 6, THEN S = 1.
      IF(STON.LT.6.)S=0.
      RETURN
      END
```

```fortran
      SUBROUTINE SUNPOS(SUNTYP,SNXCOS,SNYCOS,SNZCOS,SJNPHI)

C     THIS SUBROUTINE LOCATES THE SUN ON A RANDOM LONGITUDE AND AT A
C     LATITUDE CHOSEN ACCORDING TO SUNTYP.

C     INTEGER SUNTYP

C     SUNTYP IS USE TO LOCATE THE SUN IN ONE OF THREE POSITIONS
C     1..........ON THE EQUATOR
C     2..........MOST EXTREME NORTHERN LATITUDE
C     3..........MOST EXTREME SOUTHERN LATITUDE
C     4..........RANDOM POSITION

      IF(SUNTYP.EQ.1)THETA=1.5708
      IF(SUNTYP.EQ.2)THETA=1.1694
      IF(SUNTYP.EQ.3)THETA=1.972
      IF(SUNTYP.NE.4)GO TO 747
      RN=RANF(DUM)

C     CHOOSE RANDOM DAY AND FIND ANGLE FROM VERNAL EQUINOX(ANGLE).

      DAY =RN*365.25
      ANGLE=2.*ACOS(-1.)*DAY/365.25
C     DETERMINE LATITUDE OF SUN BASED ON TIME OF YEAR

      THETA=ASIN(SIN(.40)*SIN(ANGLE))
      IF(THETA.GT.0.)THETA=1.5708-THETA
      IF(THETA.LE.0.)THETA=1.5708+THETA
747   CONTINUE

C     CHOOSE RANDOM LONGITUDE

      RN=RANF(DUM)
      PHI=2.0*RN*ACOS(-1.0)
      SJNPHI=PHI

C     CALCULATE DIRECTION COSINES

      SNXCOS=SIN(THETA)*COS(PHI)
      SNYCOS=SIN(THETA)*SIN(PHI)
      SNZCOS=COS(THETA)
      RETURN
      END
```

113

```
      SUBROUTINE CLOUD(SKYC,I,TIME,S,ICFLAG,SUNPHI)
C
C     SUBROUTINE CLOUD MODELS THE WEATHER OF THE NIGHT SKY.
C     CLOUD IS MODELED AS HAVING A PROBABILITY OF CHANGING
C     EVERY THREE HOURS.
C
      DIMENSION SKYC(50,25),ICFLAG(50),TIME(50,5),BFLAG(50)
C
C     FIND THE POSITIVE ANGULAR DIFF BETWEEN THE LONGITUDAL POSIT-
C     OF THE SUN AND THE POSITION OF THE SENSOR TO DETERMINE THE
C     TIME OF DAY AT THE SENSOR
C
      ADD=0.
      SUNLIN=SUNPHI
      IF(SUNPHI.LE.TIME(I,4))GO TO 949
      ADD=2.*ACOS(-1.)-SUNPHI
      SUNLIN=0.
  949 SENPHI=TIME(I,4)+ADD
      DIFF=SENPHI-SUNLIN
C
C     DETERMINE IF THE SITE MUST BE IN DAYLIGHT.  THEN TARGET NOT
C     SEEN.
C
      IF((DIFF.LT.1.3089969).OR.(DIFF.GT.4.9741984))GO TO 948
C
C     IF FIRST TIME CLOUD COVER HAS BEEN DETERMINED, USE INTIAL
C     SKY COVER PROBABILITIES.
C
      IF(ICFLAG(I).GT.0)GO TO 947
C
C     SET FLAG(ICFLAG) FOR INITIAL TIME CLOUD COVER DETERMINED.
C
      IF(DIFF.GT.1.3089969)ICFLAG(I)=1
      IF(DIFF.GT.2.0943951)ICFLAG(I)=2
      IF(DIFF.GT.2.8797933)ICFLAG(I)=3
      IF(DIFF.GT.3.6651914)ICFLAG(I)=4
      IF(DIFF.GT.4.4505896)ICFLAG(I)=5
C
C     SET TIME TO NEXT WEATHER CHECK (TIME ARRAY ELEMENT FIVE).
C
      TIME(I,5)=.7853982
C
C     FIND INITIAL CLOUD COVER PROBABILITY BASED ON INITIAL TIME.
C
      IF(ICFLAG(I).EQ.1)PROB=SKYC(I,1)
      IF(ICFLAG(I).EQ.2)PROB=SKYC(I,10)
      IF(ICFLAG(I).EQ.3)PROB=SKYC(I,17)
      IF(ICFLAG(I).EQ.4)PROB=SKYC(I,22)
      IF(ICFLAG(I).EQ.5)PROB=SKYC(I,25)
      RN=RANF(DUM)
      IF(RN.GE.PROB)S=0.
C
C     BFLAG CONTAINS FLAG INDICATING CLOUD COVER STATE AT INITIAL
C     TIME.
```

114

```
            BFLAG(I)=5
            GO TO 946

C       FIND IF TIME FOR NEXT CLOUD COVER CHECK.
C
947     IF(ICFLAG(I).EQ.1)FLAG2=DIFF-1.3089969
        IF(ICFLAG(I).EQ.2)FLAG2=DIFF-2.0943951
        IF(ICFLAG(I).EQ.3)FLAG2=DIFF-2.8797933
        IF(ICFLAG(I).EQ.4)FLAG2=DIFF-3.6651914
        IF(ICFLAG(I).EQ.5)FLAG2=DIFF-4.4505896
        IF(FLAG2.LT.TIME(I,5))GO TO 926

C       FIND APPROPRIATE UNCONDITIONAL CLOUD COVER PROBABILITY.
C
        IFIND=INT(TIME(I,5)/.7853982)
        IF(ICFLAG(I).NE.1)GO TO 945
        IF(IFIND.EQ.1)K=2
        IF(IFIND.EQ.2)K=4
        IF(IFIND.EQ.3)K=6
        IF(IFIND.EQ.4)K=8
        GOTO 928
945     IF(ICFLAG(I).NE.2)GO TO 929
        IF(IFIND.EQ.1)K=11
        IF(IFIND.EQ.2)K=13
        IF(IFIND.EQ.3)K=15
929     IF(ICFLAG(I).NE.3)GO TO 927
        IF(IFIND.EQ.1)K=18
        IF(IFIND.EQ.2)K=20
        GO TO 928
927     K=23
C
C       CHECK IF THERE IS CLOUD COVER AND ADVANCE WEATHER CHECK TIME
C       BY THREE HOURS.
C
928     IF(BFLAG(I).EQ.0.)K=K+1
        RN=RANF(DUM)
        TIME(I,5)=TIME(I,5)+.7853982
        IF(RN.GT.SKYC(I,K))S=0.

C
C       STORE PRESENT SKY COVER STATUS IN TIME ARRAY 2.
C
946     TIME(I,2)=S
        GO TO 925
948     ICFLAG(I)=0
        S=0.
        TIME(I,2)=S
        GO TO 925
926     S=TIME(I,2)
925     RETURN
        END
```

```
      SUBROUTINE TRACK(MISSION,EOSEL,T,SENSOR,TARCPP,XT,VT,ZT,J9,JU,
     C NU,NCUT,ET,TB,INPUT,INPUT2,SUNTYP,SITE,SKVC)
      DIMENSION EOSEL(50,6),T(14,11),TAROPP(14),TRCTEF(50,4),NU(50),
     C SENSOR(6,5),XU(50),VU(50),ZU(50),TIME(50,5),XT(14),MISSION(4,4),
     C VT(14),ZT(14),N(50), SITE(50,4),SKVC(50,25),PUT(50),ICFLAG(50)
      INTEGER SUNTYP
      DO 15 I=1,50
      ICFLAG(I)=0
   15 N(I)=0
C
C     BY OPTIMIZE CAN MEET THE MISSION REQUIREMENTS.
C     THE PURPOSE OF TRACK IS TO DETERMINE IF THE SENSOR SYSTEM SELECTED
C
C     IN ADDITION, TRACK CAN BE USED TO TEST THE EFFECTIVENESS OF A
C     SYSTEM OF PRESELECTED SITES AND SENSORS.
C
C     A 50 BY 5 MATRIX (TIME) IS USED TO STORE THE FOLLOWING VARIABLES...
C
C     SENSOR SELECTION NUMBER.
C     PRESENT SITE SKY COVER STATUS.
C     TAVAIL (TIME UNTIL SENSOR WILL BE AVAILABLE AGAIN).
C     XM (MEAN ANOMALY OR PHI ANGLE).
C     TIME FOR NEXT CLOUD COVER CHECK AT FIXED GROUND SITES.
C
C     THE SENSOR SELECTIONS ARE TAKEN FROM THE EOSEL MATRIX GENERATED BY
C     OPTIMIZE.
C
C     ZERO THE TIME MATRIX.
C
      PI=ACOS(-1.)
      DO 10 I=1,50
      DO 5 J=1,5
    5 TIME(I,J)=0.
   10 CONTINUE
C
C     ENTER SITE DATA INTO TIME AND EOSEL ARRAYS IF INPUT .GT. ZERO
C     ALSO COMPUTE XU,VU, AND ZU SENSOR COORDINATES.
C
      IF(INPUT.LE.0)GO TO 944
      DO 943 I=1,INPUT
      TIME(I,4)=SITE(I,2)
      EOSEL(I,1)=SITE(I,4)
      EOSEL(I,2)=SITE(I,1)
      REARTH=6378.145
      R=REARTH+SITE(I,3)
      THETA=EOSEL(I,2)
      PHIS=TIME(I,4)
      XU(I)=R*SIN(THETA)*COS(PHIS)
      VU(I)=R*SIN(THETA)*SIN(PHIS)
      ZU(I)=R*COS(THETA)
  943 CONTINUE
  944 CONTINUE
C
C     THE TARGETS AVAILABLE ARE REGISTERED IN MATRIX TAROPP (TARGET OPPORT
```

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```
C     TAROPP MATRIX IS THE FIRST COLUMN OF THE T MATRIX.
C
C     GENERATE THE TAROPP MATRIX.
C
      DO 30 I=1,14
      TAROPP(I)=T(I,1)
   30 CONTINUE
C
C     CALL SUBROUTINE TARGET TO INITIALLY PLACE THE SUN AND THE
C     AND THE TARGETS.
C
      CALL TARGET(T,XT,YT,ZT,TAROPP,SUNTYP,SNXCOS,SNYCOS,SNZCOS,SUNPHI)
C
C     BEGIN PROCESS TO MAKE REMAINING SENSOR PLACEMENTS
C
      I=INPUT+1
      J=INPUT2+JU
C
C     CALCULATE NU MATRIX FOR PRESELECTED SPACE AND AIR BASED SENSORS.
C
      IF(INPUT2.LE.0)GO TO 940
      DO 942 K=1,J
      NU(K)=0
      DO 941 L=1,J
      IF((EOSEL(K,1).EQ.EOSEL(L,1)).AND.(EOSEL(K,4).EQ.EOSEL(L,4)))NU(K)
     C   = NU(K)+1
  941 CONTINUE
  942 CONTINUE
  940 CONTINUE
C
C     PLACE AIR-BASED SENSORS AND GROUND-BASED SENSORS WHICH ARE
C     NOT FIXED-POSITIONED.
C
      IF((INPUT.GT.0).AND.(INPUT2.EQ.0))GO TO 891
C
C     FIND THE NUMBER OF SENSORS INVOLVED(IONGRD) SO THE
C     SPACING(APART) CAN BE DETERMINED, AND A LONGITUDE(PUT ARRAY)
C     CAN BE DESIGNATED FOR EACH OF THESE SENSORS.
C
      IONGRD=0
      DO 801 K=1,J
      ASEN=EOSEL(K,1)
      IF(SENSOR(1,ASEN).LT.2.5)IONGRD=IONGRD+1
  801 CONTINUE
      RN=RNMF(DUM)
      APART=2.*ACOS(-1.)/IONGRD
      PUT(1)=2.*ACOS(-1.)*RN
      DO 802 K=2,IONGRD
      K2=K-1
      PUT(K)=PUT(K2)+APART
  802 CONTINUE
C
C     ARRANGE THE SENSORS STORED IN THE EOSEL ARRAY IN TERMS OF THE
C     GREATEST NUMBER ON SAME LATITUDE.
C
      DO 811 K=1,J
      DO 812 L1=K,J
```

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```
115      IF(NU(K).GE.NU(L1))GO TO 913
         DO 929 L2=1,6
         HOLD=EOSEL(K,L2)
         EOSEL(K,L2)=EOSEL(L1,L2)
         EOSEL(L1,L2)=HOLD
120  909 CONTINUE
         HOLD=NU(K)
         NU(K)=NU(L1)
         NU(L1)=HOLD
     913 CONTINUE
125  912 CONTINUE
         L3=0
         DO 904 L1=K,J
         IF((EOSEL(K,1).EQ.EOSEL(L1,1)).AND.(EOSEL(K,4).EQ.EOSEL(L1,4)))
       C .AND.(K.NE.L1))GO TO 908
         GO TO 907
130      L3=K-1
     908 DO 905 L2=1,6
         HOLD=EOSEL(L3,L2)
         EOSEL(L3,L2)=EOSEL(L1,L2)
         EOSEL(L1,L2)=HOLD
135  905 CONTINUE
         HOLD=NU(L3)
         NU(L3)=NU(L1)
         NU(L1)=HOLD
     907 CONTINUE
140  904 CONTINUE
     911 CONTINUE
       C
       C   PLACE SPACE-, AIR-, AND REMAINING GROUND-BASED SENSORS
145      K=1
         IPLACE=1
         DO 53 I=K,J
       C
       C   MSEN IS THE INTEGER SENSOR TYPE.
150      MSEN= EOSEL(I,1)
         RN=RANF(DUM)
         TIME(I,4)=RN*P188.
         IF(N(MSEN).EQ.0)GO TO 56
         M=I-1
155   58 NN= EOSEL(M,1)
         IF((NN.EQ.MSEN).AND.( EOSEL(I,4).EQ. EOSEL(M,4)))GO TO 57
         M=M-1
         IF(M.EQ.0)GO TO 56
         GO TO 58
       C
       C   SPACE BASED SENSORS WITH THE SAME INCLINATION ARE EQUALLY
       C   AROUND THE SAME ORBIT USING THE NU ARRAY WHICH HOLDS THE NUM-
165    C   NUMBER OF SENSORS OF THE SAME TYPE WHICH ARE IN THE SAME
       C
      57 RNJ=NU(I)
         TIME(I,4)=TIME(M,4)+(2.8PI/RNJ)
         EOSEL(I,5)= EOSEL(M,5)
170   56 R=SENSOR(4,MSEN)*678.145
         IF(SENSOR(1,MSEN).LT.2.5)GO TO 50
```

```
      ECSEL(I,5)=RANF(DUM)*P*22.
      THETA1=ASIN(SIN( EOSEL(I,4))*SIN(TIME(I,4)+ EOSEL(I,6)))
      THETA=PI/2.-THETA1
      IF( EOSEL(I,4).LT..0001)PHIS=TIME(I,4)+ EOSEL(I,6)+ EOSEL(I,5)
      IF( EOSEL(I,4).LT..0001)GO TO 51
      ASP=TAN(THETA1)/TAN( EOSEL(I,4))
      ACP=COS(TIME(I,4)+ EOSEL(I,6))/COS(THETA1)
      PHIS=ATAN2(ASP,ACP)+ EOSEL(I,5)
      GO TO 51
   50 THETA= EOSEL(I,2)
      IF(I.EQ.1)GO TO 914
      ISKIP=IONGRD/NU(I)
      HOP=FLOAT(IONGRD)/FLOAT(NU(I))
      IHOP=INT(HOP)
      HOP=HOP-FLOAT(IHOP)
      IF(HOP.GT..5)ISKIP=ISKIP+1
      IPLACE=IPLACE-ISKIP
  914 IF(IPLACE.GT.IONGRD)IPLACE=IPLACE-IONGRD
      IF(PUT(IPLACE).NE.0.)GO TO 916
      IPLACE=IPLACE+1
      GO TO 914
  916 PHIS=PUT(IPLACE)
      IF(PHIS.GT.(2.*ACOS(-1.))PHIS=PHIS-2.*ACOS(-1.)
      TIME(I,4)=PHIS
      PUT(IPLACE)=0.
   51 XU(I)=RSIN(THETA)*COS(PHIS)
      YU(I)=RSIN(THETA)*SIN(PHIS)
      ZU(I)=RCOS(THETA)
      PRINT8, 'SENSOR SELECTED ',I ,' TYPE ',NSEN
      PRINT8, 'THETA ',THETA,' PHIS ',PHIS
      NUMSEN)=1
   53 CONTINUE
  901 CONTINUE
      PRINT8, '
C
C     START CLOCK AT 0 MINUTES.
C
      TB=0.
      GO TO 11
   40 TB=TB+DT
C3333333333333333333333333333333333333333333333333333333333333333333333
C
C     MOVE THE TARGETS ALONG THEIR ORBITS TO CORRESPOND TO THE 5 MINUTE TI
C     INCREMENT.
C
      DO 48 I=1,14
C
C     CHECK WHETHER THE TARGET IS AVAILABLE.
C
      IF(TAROPP(I).EQ.0.)GO TO 48
C
C     ADVANCE THE MEAN ANOMALY.
C
      XMU=39001.2
      CUBEA=(TT(I,2))**3.
```

119

```
C     DELXM IS THE MEAN ANOMALY INCREMENT.
C
      DELXM=SQRT(XMU/CUBEA)*DT*60.
C
C     UPDATE THE MEAN ANOMALY IN MATRIX T.
C
      T(I,7)=T(I,7)+DELXM
      E=T(I,3)
      IF(E.EQ.0.)ETA=T(I,7)
      IF(E.EQ.0.)GO TO 46
      XM=T(I,7)
      A=XM-2.*E
      B=XM+2.*E
      CALL ROOT(E,XM,A,B,EAN)
      ETA=ACOS((E-COS(EAN))/(E*COS(EAN)-1.))
   46 CONTINUE
      R=T(I,2)*(1.-T(I,3)*T(I,3)*COS(ETA))
      THETA1=ASIN(SIN(T(I,4))*SIN(ETA+T(I,6)))
      THETA=(PI/2.0)-THETA1
      IF(T(I,4).LT..0001)PHIS=ETA+T(I,6)+T(I,5)
      IF(T(I,4).LT..0001)GO TO 47
      ASP=TAN(THETA1)/TAN(T(I,4))
      ACP=COS(ETA+T(I,6))/COS(THETA1)
      PHIS=ATAN2(ASP,ACP)+T(I,5)
   47 XT(I)=R*SIN(THETA)*COS(PHIS)
      YT(I)=R*SIN(THETA)*SIN(PHIS)
      ZT(I)=R*COS(THETA)
   48 CONTINUE
C
C     TARGET COORDINATE MATRICES XT, YT, AND ZT ARE NOW UPDATED WITH CURRE
C     TARGET POSITIONS.
C
C*****************************************************
C
C     NOW MOVE THE SENSORS ALONG THEIR ORBITS OR LATITUDES.
C
      J=INPUT+INPUT2+JU
      DO 55 I=1,J
C
C     DO GROUND- AND AIR-BASED SENSORS FIRST.
C
      IF(SENSOR(1,MSEN).EQ.3.)GO TO 68
      TIME(I,4)=TIME(I,4)+DT*.0043633*
      IF(TIME(I,4).GT.(2.*ACOS(-1.)))TIME(I,4)=TIME(I,1)-2.*ACOS(-1.)
      IF((INPUT.GT.0.0).AND.(SENSOR(1,MSEN).LT.2.5))GO TO 939
      R=SENSOR(4,MSEN)+6378.145
      GO TO 938
  939 CONTINUE
      R=REARTH+SITE(I,3)
  938 CONTINUE
      THETA=EOSEL(1,3)
      PHIS=TIME(I,4)
C
C     CALCULATE CARTESIAN COORDINATES FOR THE SENSOR LOCATION AT THE CURRE
C     TIME.
C
      GO TO 54
```

120

```
52    CONTINUE
C******************************************************************
C     FOLLOWING SECTION MOVES THE SPACE-BASED SENSORS ALONG THEIR ORBITS.
C     ADVANCE THE MEAN ANOMALY.
C
      CUBEA=(EOSEL(I,2))**3.
      DELXM=SQRT(XMU/CUBEA)*DT*DON.
C     UPDATE THE MEAN ANOMALY.
C
      TIME(I,4)=TIME(I,4)+DELXM
C     CALCULATE THE SPHERICAL COORDINATES.
C
      ETA=TIME(I,4)
      R=EOSEL(I,2)
      THETA1=ASIN(SIN(EOSEL(I,4))*SIN(TIME(I,4)+EOSEL(I,6)))
      THETA=PI/2.-THETA1
      IF(EOSEL(I,4).LT..0001)PHIS=TIME(I,4)+EOSEL(I,6)
      IF(EOSEL(I,4).LT..0001)GO TO 54
      ASP=TAN(THETA1)/TAN(EOSEL(I,4))
      ACP=COS(TIME(I,4)+EOSEL(I,6))/COS(THETA1)
      PHIS=ATAN2(ASP,ACP)+EOSEL(I,5)
C     CALCULATE THE CARTESIAN COORDINATES.
C
54    XU(I)=R*SIN(THETA)*COS(PHIS)
      YU(I)=R*SIN(THETA)*SIN(PHIS)
      ZU(I)=R*COS(THETA)
55    CONTINUE
C     SO ALL THE USEABLE SENSORS ARE MOVED ALONG THEIR RESPECTIVE PATHS.
C******************************************************************
C     ADJUST THE TIME MATRIX ELEMENT TAMAIL.
C
      K=INPUT+INPUT3+JU
      DO 70 I=1,K
      TIME(I,3)=TIME(I,3)-DT
      IF(TIME(I,3).LT.0.)TIME(I,3)=0.
70    CONTINUE
11    CONTINUE
C     ZERO THE TRCTEF MATRIX.
C
      DO 60 I=1,50
      DO 65 J=1,14
      TRCTEF(I,J)=0.
65    CONTINUE
60    CONTINUE
C******************************************************************
```

```
C     CALL SIGHT TO BUILD TRCTEF FOR ALL SURVIVING TARGETS OVER ALL
C     CURRENTLY USEABLE SENSORS.
345   M=0
      K=INPUT+INPUT2+JU
      DO 100 I=1,K
C     MSEN IS THE INTEGER SENSOR TYPE.
350   MSEN = EOSEL(I,1)
C     IF THE ITH SENSOR IS NOT CURRENTLY USEABLE, GO TO THE NEXT SENSOR.
355   IF(TIME(I,3).GT.DT)GO TO 100
      DO 90 J=1,14
C     IF THE JTH TARGET HAS BEEN TRACKED, GO TO THE NEXT TARGET.
360   IF(TAROPP(J).EQ.0.0)GO TO 90
      M=M+1
C     CALL CLOUD FOR GROUND-BASED SENSORS.
365   S=1.0
      IF(SENSOR(I,MSEN).EQ.1.)CALL CLOUD(SKYC,I,TIME,S,ICFLAG,SUNPHI)
370   IF(S.EQ.0.0)GO TO 90
C     CALL SIGHT FOR THE JTH TARGET AND THE ITH SENSOR.
375   CALL SIGHT(MSEN,J,SENSOR,T,XU(I),YU(I),ZU(I),XT(J),YT(J),ZT(J),S,
     C SNXCOS,SNYCOS,SNZCOS,RANGE)
C     RECORD THE INVERSE OF THE RANGE TO THE TARGET IN TRCTEF OR A ZERO
C     IF THE TARGET IS NOT VISIBLE.
380   TRCTEF(I,J)=S
      IF(S.GT.0.)TRCTEF(I,J)=1./RANGE
90    CONTINUE
100   CONTINUE
C     TRCTEF NOW CONTAINS ZEROS WHERE A SENSOR CANNOT SEE A TARGET DUE
C     TO ANY OF THE FOLLOWING REASONS.......
C     SENSOR IS CURRENTLY TRACKING A SATELLITE.
C     TARGET HAS ALREADY BEEN TRACKED.
390   TARGET IS NOT IN LINE-OF-SIGHT OF AN AVAILABLE SENSOR.
C     TRCTEF ALSO CONTAINS INVERSE OF THE RANGE TO THE TARGET IN ALL
C     OTHER LOCATIONS.
C======================================================================
C     TRACK THE TARGETS WITH THE SENSORS
395   DO 300 IPRIOR=1,4
```

122

```
      DO 222 J4=I1,I2
      IF(TAROPP(J4).EQ.0.)X3=X3+1.
222   CONTINUE
      PERCNT=(X3/D)*100.
      IF(PERCNT.LT.MISSION(ITYPE,2))GO TO 226
      DO 221 J4=I1,I2
      TAROPP(J4)=0.
221   CONTINUE
226   CONTINUE
C
C  COUNT THE NUMBER OF TARGETS OF ITYPE WHICH HAVE BEEN TRACKED.
C  IF ALL OF THE TARGETS ARE TRACKED, STOP TRACK BEFORE TNEG.
C
      J9=0
      DO 275 KK=1,14
      IF(TAROPP(KK).EQ.0.)J9=J9+1
275   CONTINUE
C
      IF(J9.EQ.14)PRINT3,'TRACK WAS STOPPED AT ',TB,' DUE TO MISSION AC
     CCOMPLISHMENT'
      IF(J9.EQ.14)GO TO 1000
290   CONTINUE
300   CONTINUE
C
C  IF TRACK HAS NOT BEEN RUN FOR THE MISSION NEGATION TIME, GO TO 40.
C
      JJJ=1
      DO 400 I=1,4
      IF(TB.LT.MISSION(I,3))GO TO 40
400   CONTINUE
1000  RETURN
      END
```
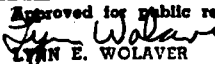
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Satellite tracking, powered balloons, airships, electro-optical telescope, astronomical telescope, remotely piloted vehicles

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The purpose of this research was to evaluate the possible benefits of an air based system of electro-optical satellite tracking telescopes. A computerized simulation model was developed to conduct a comparative analysis of a hypothetical system of air based telescopes with the Ground-Based Electro-Optical Deep Space Surveillance (GEODSS) System. The simulation includes a first order optimization process for selecting a satellite surveillance system and a many-on-many engagement model to test the

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20. effectiveness of the surveillance system selected. In addition, the user can input a preselected surveillance system and test its effectiveness.

The user specifies the characteristics of the surveillance system and the basing locations, if they are preselected. Cloud cover data can be entered with preselected ground sites. Target satellites included four sets of representative satellite systems. The user selects the targets, defines the mission time, and determines the percentage of each target system which must be tracked.

Preliminary results indicate that an air based surveillance system with three dispersed telescope platforms could outperform a system of five candidate GEODSS sites.

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