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INTERIM REPORT

SATELLITE SURVEILLANCE AVOIDANCE FOR NAVAL COMMANDERS

DECISIONS AND DESIGNS INCORPORATED

Thomas W. Keelin, III

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INTERIM REPORT

**SATELLITE SURVEILLANCE
AVOIDANCE FOR NAVAL COMMANDERS**

by

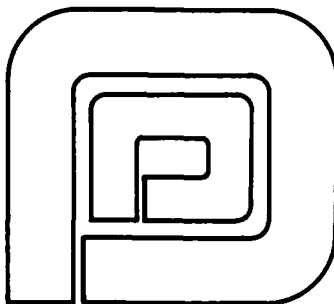
Thomas W. Keelin, III

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DECISIONS and DESIGNS, INC.

Suite 600, 8400 Westpark Drive
McLean, Virginia 22101
(703) 821-2828

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SATELLITE SURVEILLANCE AVOIDANCE FOR NAVAL COMMANDERS

1.0 INTRODUCTION

Adversary surveillance has long been a concern of naval commanders at sea. Not only can it identify a naval task force as a possible military target, but it may also lead to an unwanted confrontation with possibly far greater military and political consequences.

Ships at sea are potentially subject to many kinds of surveillance. Traditionally, the important components of a surveillance system have been aircraft, shipping, submarines, and land-based radar and communications sensors. Future surveillance systems can be expected to include land-based acoustic sensors and earth-orbiting satellites with varied sensing capabilities.

It is possible to avoid some of these surveillance systems by careful pre-transit planning. In many cases, the task force commander may plan to avoid areas of the ocean in which he is likely to be detected by land-based sensors, merchant traffic, aircraft, or submarines. In addition, he may plan to follow a deceptive route so that, if he is detected, his intentions and

destination will be difficult to infer. The result of this planning would be a track plan, which consists of a specified transit route. A hypothetical track plan from Norfolk, Virginia to the Straits of Gibraltar is illustrated in Figure 1-1.

The presence of satellites with surveillance capabilities would greatly diminish the effectiveness of a track plan, which is intended to circumnavigate areas of the ocean where surveillance is likely. Since surveillance satellites can cover all areas of the ocean at regular time intervals, a track plan by itself would be an ineffective countermeasure for satellite surveillance.

The task force commander can, however, predict a satellite's motion and use that information to his advantage. The ephemeris data for an adversary satellite is either known or can be calculated by using observations. The ground track, which is traced out by movement of the satellite's sub-orbital point across the earth's surface, can then be predicted with precision. The satellite's ground track will usually intersect the commander's track plan at regular, predictable intervals.

One pass of a satellite over the track plan is represented by the ground track segment A in Figure 1-2. The dotted lines on either side of A represent the satellite's effective field of vision. If, at the time of this pass, the task force is in the

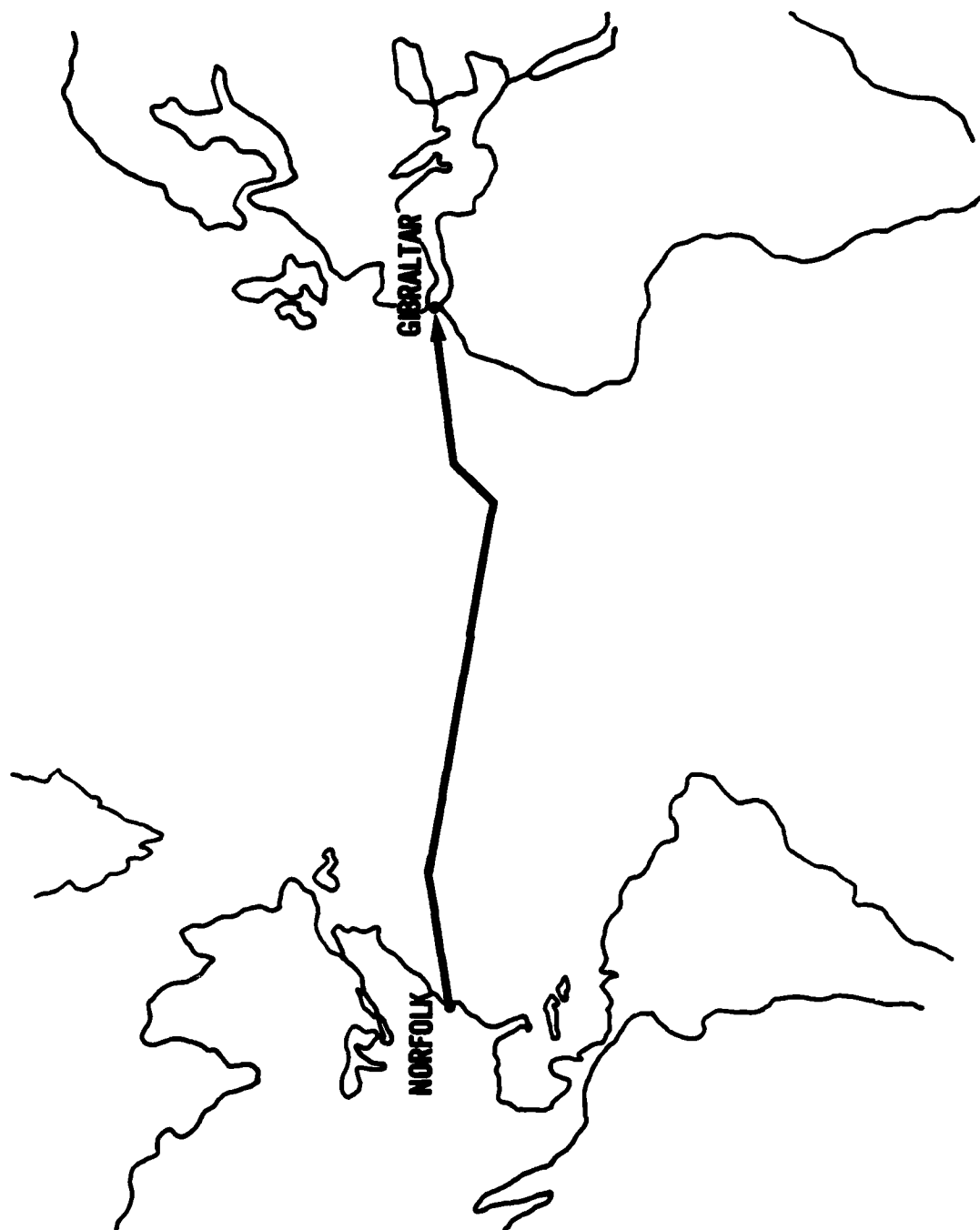


Figure 1-1
A HYPOTHETICAL TRACK PLAN FROM NORFOLK TO GIBRALTAR

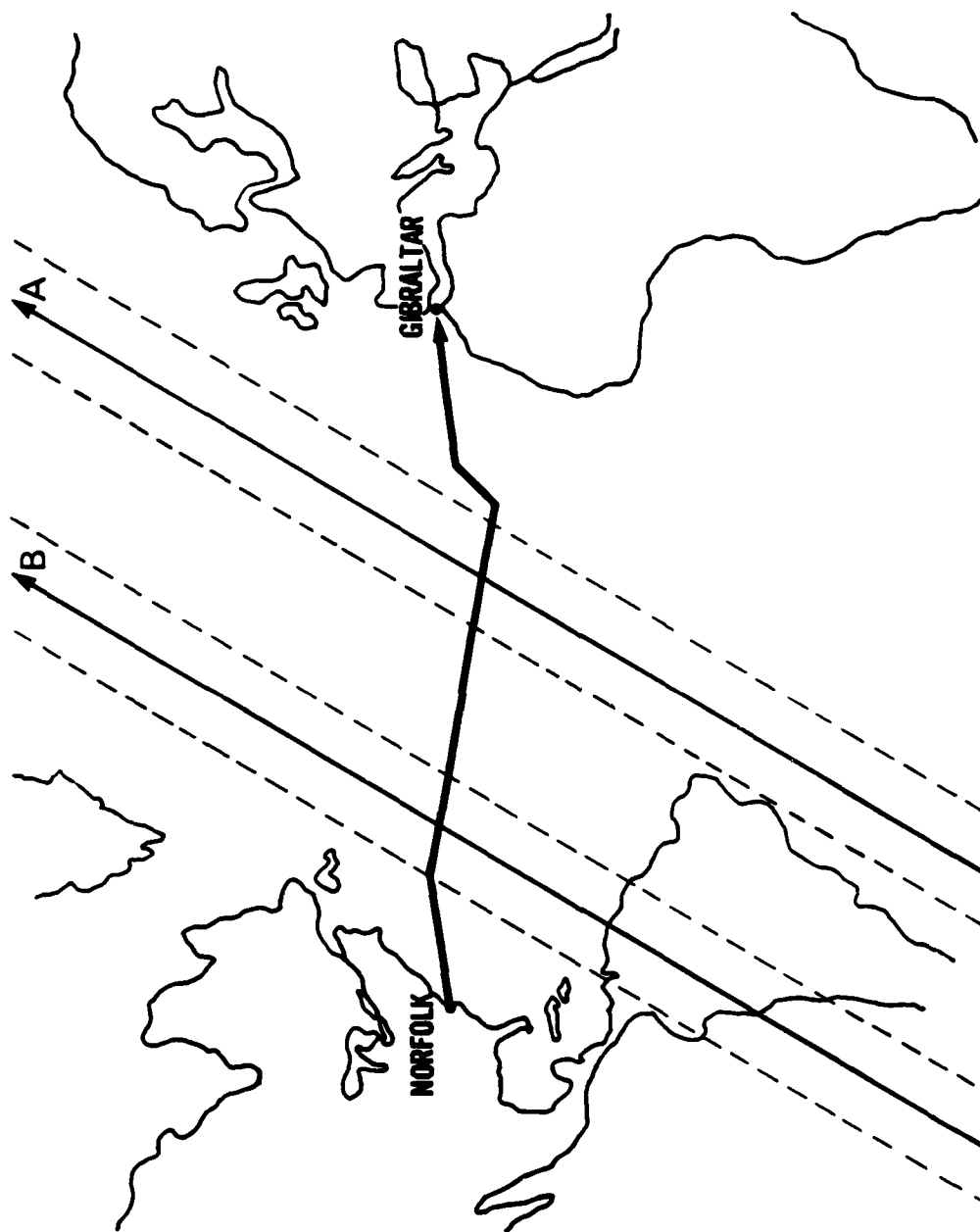


Figure 1-2
TWO SATELLITE PASSES OVER A HYPOTHETICAL TRACK PLAN

segment of its track plan within this field of vision, then detection is possible.

As the satellite follows its orbital trajectory, the earth precesses from west to east underneath it. Thus, after one orbital revolution, the same satellite may again cross the track plan with ground track B, which is to the west of A.

A typical non-synchronous satellite with surveillance capabilities may have an orbital period of about 90 minutes. The time interval between successive detection zones, like those associated with A and B, is roughly equal to one orbital period, depending to some extent on the angle of inclination between the ships' track plan and the satellite's ground track. Furthermore, from the vantage point of the task force commander, each detection zone lasts for only a few minutes because the satellite moves so quickly; for a satellite having a 90-minute orbital period and an effective swath diameter of 1,000 miles, the ships' exposure time to surveillance would be less than four minutes.

Thus, each detection zone in Figure 1-2 occurs at a particular time and lasts for only a few minutes. Even if the commander must depart from his origin and arrive at his destination at specified times, he may be able to avoid surveillance from satellite passes A and B entirely by changing his speed at appropriate points in route.

If the transit requires several days, however, a given satellite would normally pass over the track plan many times, and selecting the appropriate speed to use at various times may become rather complex. The problem would be further complicated if there were many surveillance satellites, each with different orbital characteristics and sensing capabilities.

The methodology discussed below was developed to help the naval commander understand during transit planning exactly what satellite surveillance he faces and what he can do to avoid it.

2.0 A GRAPHICAL REPRESENTATION

The satellite surveillance zones along a track plan and some possible ways to avoid them can be represented graphically. For illustration, assume that a commander is ordered to leave Norfolk at 4 P.M. on November 27 (Greenwich mean time) and is expected to arrive at Gibraltar nine days later, at 4 P.M. on December 6.

He first selects a track plan, which may be a great circle, a rhumb line, or a more complicated route. Helping the commander select a track plan is beyond the scope of this paper since that decision depends on many transit-specific factors such as the location of land masses, shipping lanes, and land-based adversary surveillance.

Suppose that a track plan like that in Figure 1-1 has been selected and that the length of the transit according to this plan is 3,240 nautical miles. Figure 2-1 represents the distance along the track plan on the vertical axis. Time after departure is represented on the horizontal axis.

Each vertical line segment in Figure 2-1 represents a satellite passing over a portion of the track plan. Assume, for example, that pass A in Figure 1-2 occurs 16 hours after the departure from Norfolk. That pass is then represented by line segment A in Figure 2-1. The length and vertical position of this line

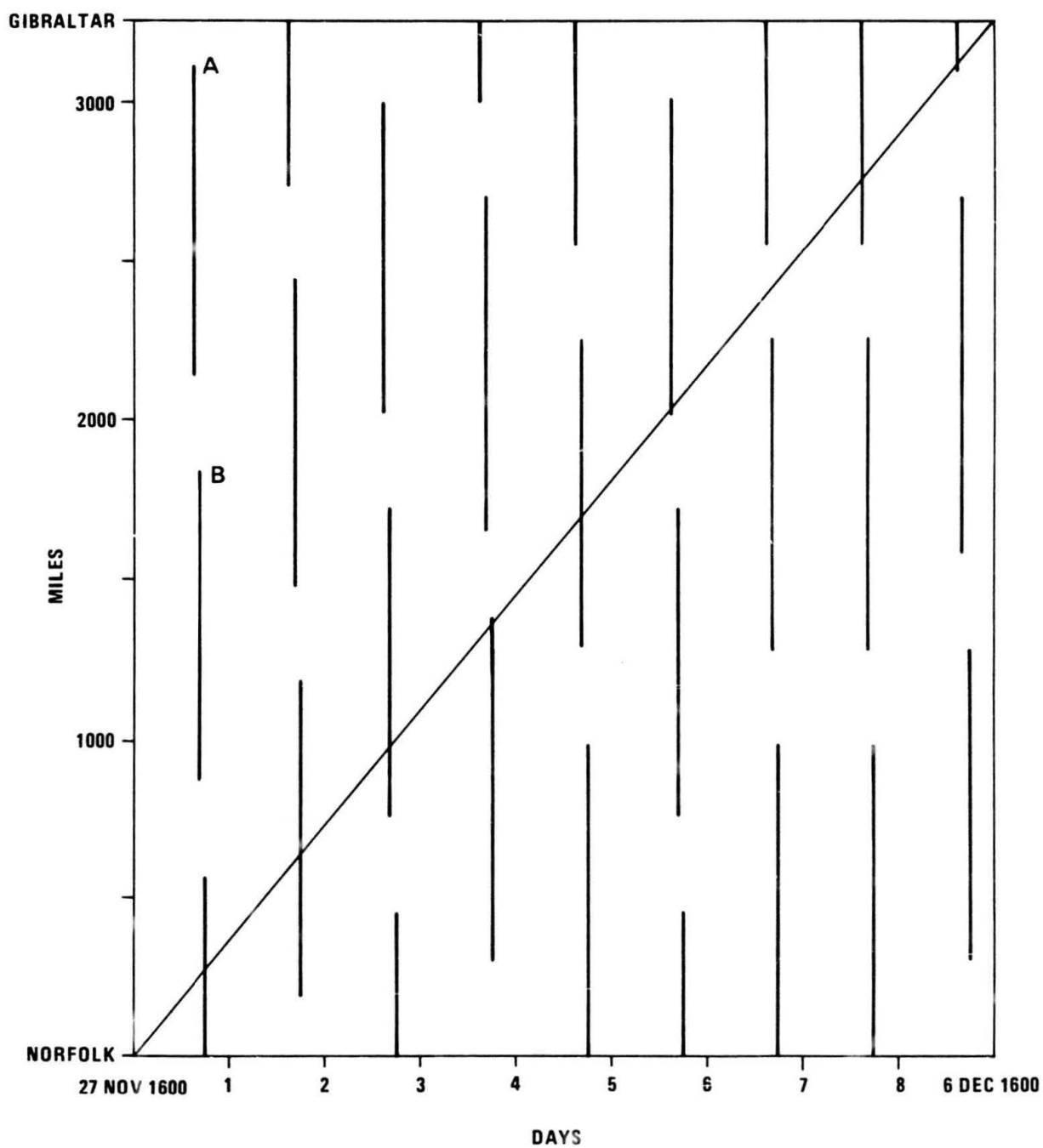


Figure 2-1
A GRAPHICAL REPRESENTATION OF SATELLITE DETECTION ZONES

segment specify the portion of the track plan that is within the satellite's effective field of vision. The horizontal position of the segment shows the time when this pass occurs (16 hours after departure), and its width is the exposure time. As indicated above, since the exposure time would be just a few minutes for a non-synchronous satellite, the line segment is very thin when plotted on a time scale measured in days.

After one orbital period, the satellite again passes over the track plan and generates another line segment B. In a similar fashion, each pass of the satellite over the track plan during the 9 day period can be represented.¹ Note that these line segments can be calculated and plotted by computer for any given departure and arrival times, track plan, and satellite ephemeris data.

The ships' position along the track plan at any point in time can also be represented on this graph. As the task force moves from Norfolk to Gibraltar, it traces out a path from the lower-left to the upper-right corner of the graph. A task force that moves with a steady 15-knot speed, for example, makes the 3,240 mile transit in exactly 9 days and traces out the diagonal path shown. This path passes through 8 detection zones. The commander can avoid some of these

¹Figure 2-1 was generated for a satellite with optical sensors only. Since these sensors cannot "see" at night, nighttime passes were not plotted. A similar graph for an infrared satellite, which is not affected by darkness, would show about twice as many detection zones.

detection zones by varying his speed in route. For example, if he follows the speed profile V in Figure 2-2, he will encounter only 3 detection zones.

Avoidance of detection zones would be a rather simple matter if ships could move at any desired speed. Realistically, however, there would be constraints within which the commander would have to operate. For example, he may wish to arrive on schedule and to use speeds that are between 5 and 25 knots. These requirements limit his possible speed profiles to those within the parallelogram in Figure 2-2. If the task force travels at the minimum speed of 5 knots for the first 4.5 days, it will trace out boundary a. Then, in order to arrive on time, it would have to use maximum speed for the rest of the way, following boundary b. Boundaries c and d may be similarly interpreted. If all detection zones are assumed to have equal importance, the speed profile V is an optimal solution within these constraints.

If there are several surveillance satellites, however, the task of avoiding detection zones becomes more complex. The detection zones for five hypothetical surveillance satellites are plotted in Figure 2-3. By using a steady 15-knot speed in this case, the commander would face 42 detection zones during his 9 day transit. It may still be possible to find graphically

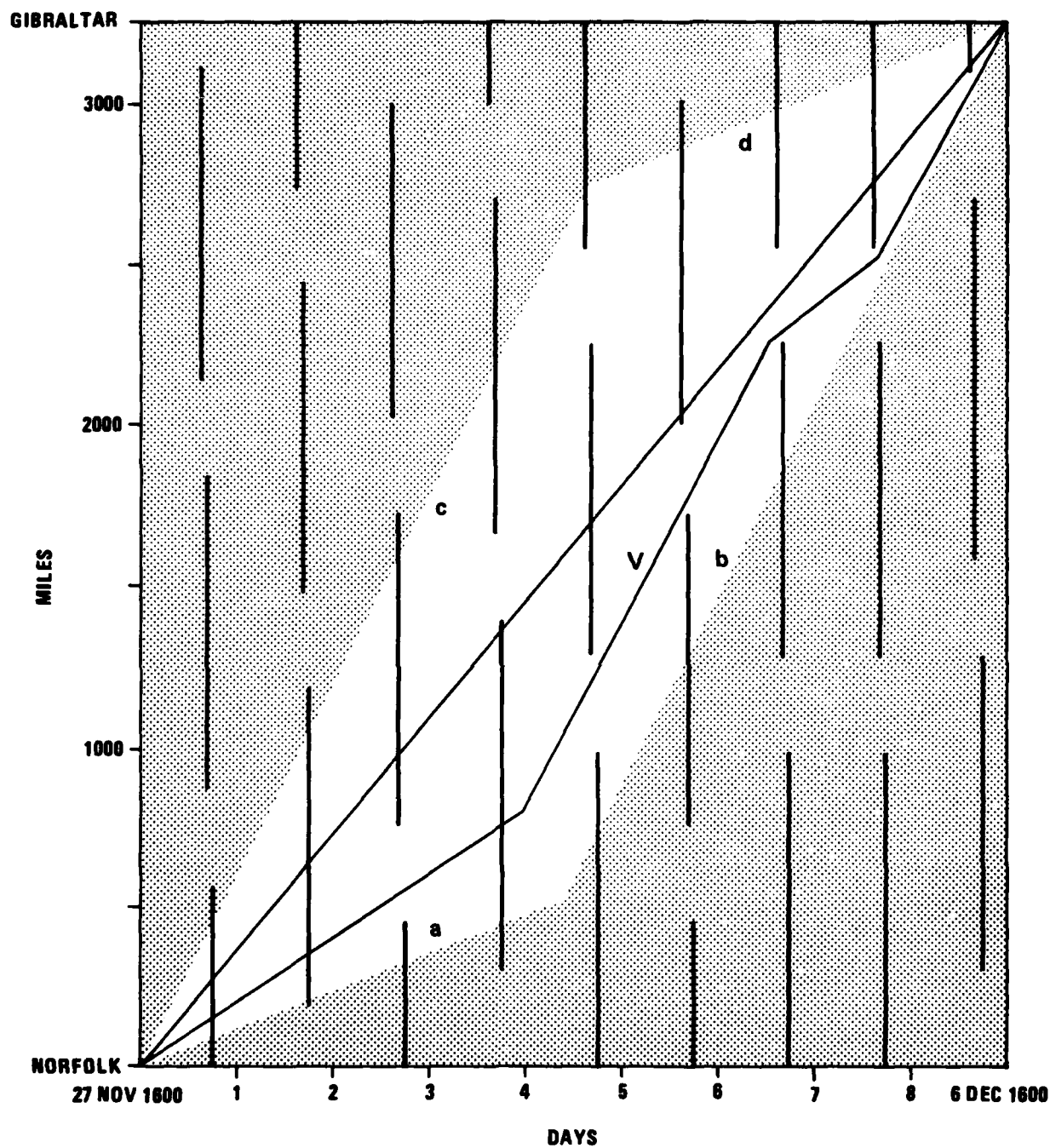


Figure 2-2
AN OPTIMAL SPEED PROFILE WITHIN VELOCITY CONSTRAINTS

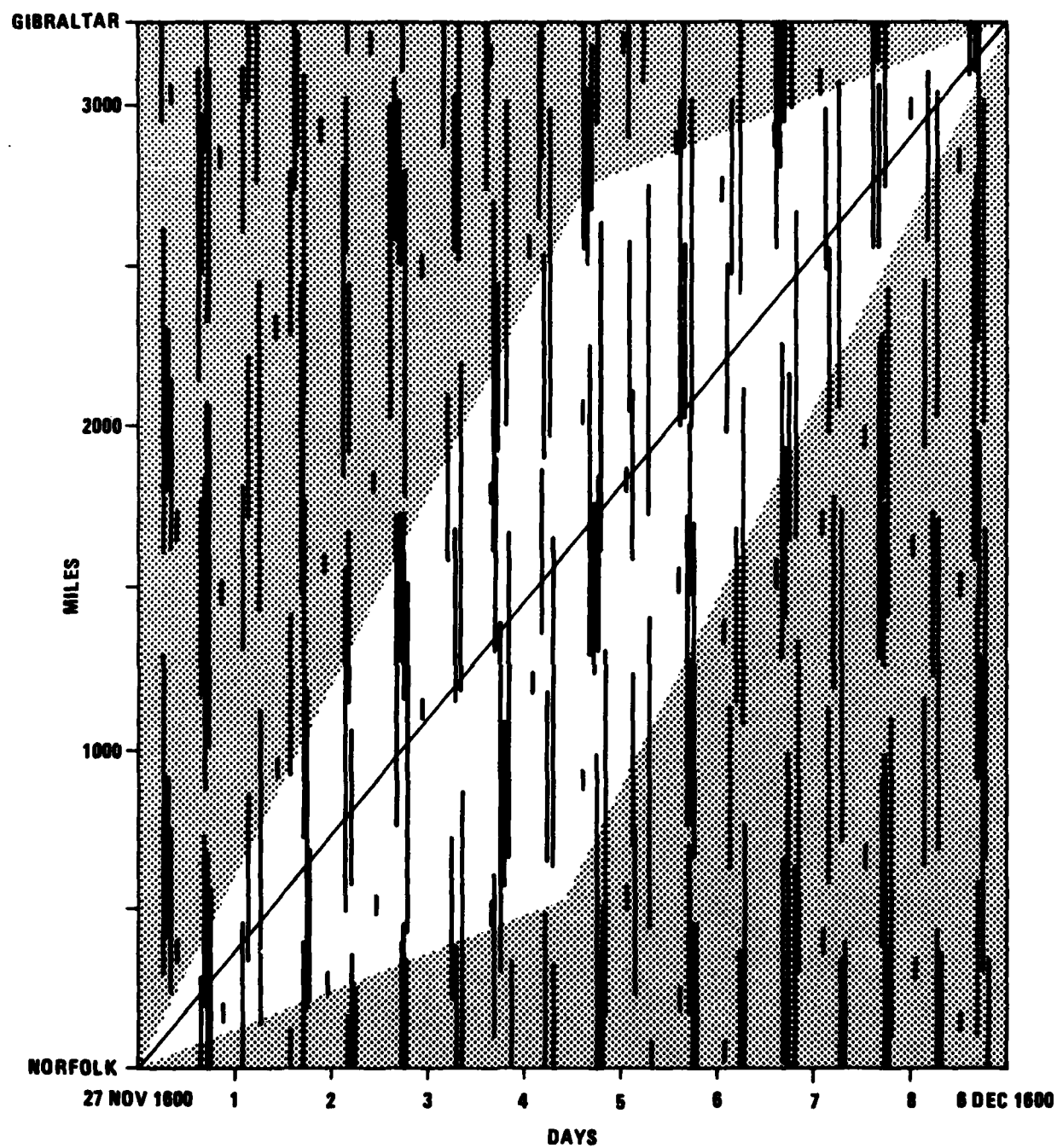


Figure 2-3
DETECTION ZONES FOR FIVE SURVEILLANCE SATELLITES

a speed profile that avoids many of these detection zones, but other factors should first be considered.

3.0 LIMITATIONS OF THE GRAPHICAL APPROACH

If all detection zones are equally important to avoid, then the solution approach suggested above is a good one: look for a speed profile that minimizes the number of detection zones.

Passing through a detection zone, however, does not necessarily mean that the task force will be detected. If cloudy weather is forecast for the first few days of the transit, for example, the probability of detection by an optical satellite during that period may be very small. At the same time, the sensing capabilities of a radar satellite would not be affected by cloud cover. Accordingly, it may be preferable to pass through two or more optical detection zones rather than a single radar detection zone. Therefore, the probability of detection within a detection zone, which is not represented in Figure 2-3, may be an important consideration in choosing a speed profile.

The cost of a detection may also be important. Are early detections more costly than later ones? Is the first detection more costly than subsequent detections?

If models for the probability of a detection and the cost of a detection within each detection zone were available, then we could select the speed profile that minimizes the expected cost of the transit. In this way, the graphical analysis could be extended.

4.0 A PROTOTYPE DECISION AID

Using the methodology discussed above, a computer-based decision aid for helping the naval commander avoid satellite surveillance is currently under development. An overview of the aid is shown in Figure 4-1.

The aid is being designed so that only a small number of parameters is required as user inputs. Important probabilistic information and current satellite ephemeris data will be supplied through a land-based computer network. Based on these inputs, the optimization procedure will supply the commander with a recommended speed profile and all relevant satellite surveillance information. Since development and integration of the components of this system are no small tasks, an operational decision aid is still years away.

A prototype aid is being built for demonstration and development purposes. Its components are briefly discussed below.

4.1 Optimization Procedure

A dynamic program searching over discrete speed options will be used to find a recommended speed profile through a pattern of detection zones. In consideration of the limitations discussed in Section 3.0, a probability model will be used to estimate the probability of detection within each

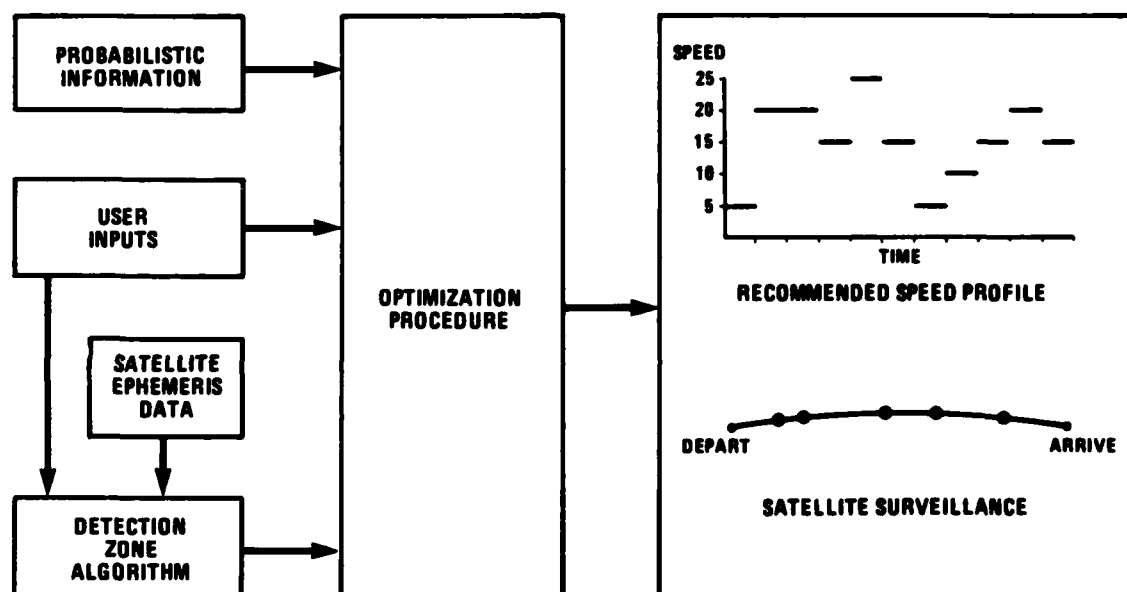


Figure 4-1
DECISION AID OVERVIEW

detection zone. Then, the recommended speed profile will be the one that minimizes the expected number of detections over the transit.

4.2 User Inputs

Required user inputs are listed in Figure 4-2. Departure point, intermediate coordinates, and destination are used to identify the commander's track plan. If no intermediate coordinates are specified, a great circle route is assumed.

Departure time and arrival time would normally be viewed as fixed in the optimization procedure; that is, the recommended speed profile will guarantee on time arrival. However, at his discretion, the user may relax these constraints; then the aid will recommend the most advantageous departure and arrival times for satellite surveillance avoidance purposes.

The user may specify speed options according to his ships' capabilities. In the example in Figure 4-2, he is willing to change his speed every 8 hours and use, for each period, one of the 5 speeds shown.

Speed constraints may also be specified at the user's discretion. If, for example, it is important to conduct under-way replenishment operations during the day on November 30, the user may require a 10 knot speed for that interval of time.

- DEPARTURE POINT
- INTERMEDIATE COORDINATES
- DESTINATION
- DEPARTURE TIME
- ARRIVAL TIME
- SPEED OPTIONS
(5, 10, 15, 20, 25 Knots @ 8 Hr. Intervals)
- SPEED CONSTRAINTS
(30 Nov. 0800 – 1600, Speed = 10 Knots)

Figure 4-2
USER INPUTS

4.3 Detection Zone Algorithm

The detection zone algorithm provides the requisite information for plotting the detection zones in Figure 2-3. In the prototype aid, it uses hypothetical orbital parameters for five surveillance satellites. In an operational decision aid, the ephemeris data for satellites would be supplied and updated regularly by a land-based computer network.

The output of the detection zone algorithm may be summarized in a table, as illustrated in Figure 4-3.

4.4 Probabilistic Information

Probabilistic information is used in the dynamic program to calculate the probability that the task force will be detected when it passes through a detection zone. In the prototype aid, the probability of detection for each detection zone is calculated as follows:

$$\begin{aligned} P [\text{Detection}] &= P[\text{Weather is O.K. for detection}] \\ &\quad \times P[\text{Satellite Operating} | \text{Weather O.K.}] \\ &\quad \times P[\text{Detection} | \text{Satellite Operating, Weather O.K.}] \end{aligned}$$

These probabilities are used to represent the commander's state of information at the time he is planning the transit.

Date	Time of Exposure	Range (Miles from Origin)	Satellite Sensors
27 NOV	1602-1607	0-560	INFRARED
27 NOV	1630-1634	3200-3240	RADAR
27 NOV	1700-1703	450-950	COMMUNICATIONS INTERCEPT
⋮			⋮
6 DEC	1530-1534	200-1200	OPTICAL

Figure 4-3
A TABLE OF DETECTION ZONES

The way in which these probabilities depend on the particular detection zone under consideration must be carefully specified.

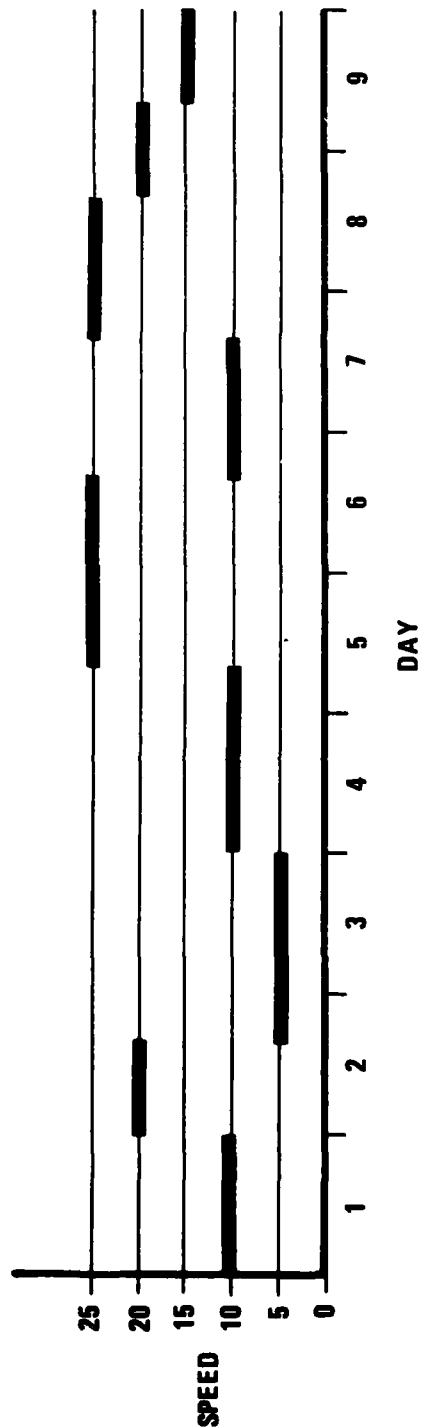
For example, the probability that weather is O.K. for detection depends on when and where the detection zone occurs and on the satellite's sensors (optical sensors would be defeated by cloud cover whereas radar sensors would not). Also, the probability of detection given that the satellite is operating and the weather is O.K. depends on what local cover and deception tactics the commander can employ (communications-intercept sensors would be defeated if the commander shuts down his communications).

A complete probability model for the prototype aid has been specified, but it requires probability assignments from weather and satellite experts, and a practical way to make these assignments must be developed before final implementation.

4.5 Decision Aid Output

The decision aid will supply the commander with a recommended speed profile and, for that profile, a listing of the satellite detection zones that will be encountered. Conceptual computer-graphic output displays are shown in Figures 4-4 and 4-5.

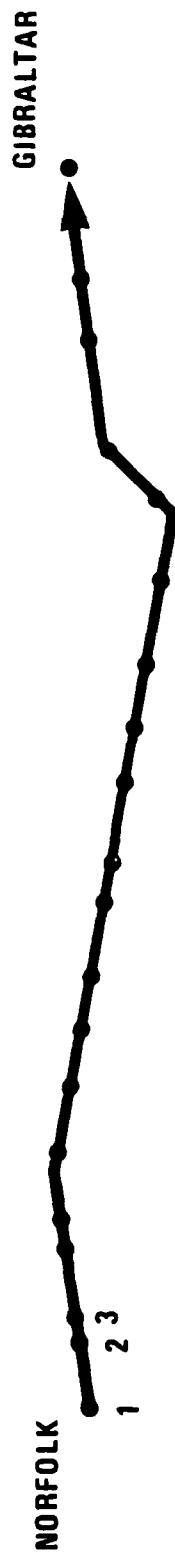
DEPART 27 NOV 1600
ARRIVE 6 DEC 1600



Date	Time	Speed	Course (T)
27 NOV	1600 - 2400	10	75
28 NOV	0001 - 0800	10	75
	0801 - 1600	10	75
	1601 - 2400	20	75
29 NOV	0001 - 0800	20	75
	0801 - 1600	5	75
			•
			•
			•

Figure 4-4
RECOMMENDED SPEED PROFILE

SHIP POSITION AT TIME OF EXPOSURE



	Date	Time of Exposure	Ship Position		Satellite Sensors	Local Cover and Deception
			Lat	Long		
1.	27 NOV	1602 - 1607	38° 40' N	76° 30' W	INFRARED	Reconfigure to Resemble Merchant Fleet
2.	28 NOV	0930 - 0934	39° 30' N	73° 50' W	RADAR	JAM
3.	28 NOV	1045 - 1049	39° 33' N	73° 24' W	COMMUNICATIONS INTERCEPT	EMISSIONS CONTROL
.						.
.						.

Figure 4-5
DETECTION ZONES UNDER RECOMMENDED SPEED PROFILE

5.0 CONCLUSION

A methodology has been presented for helping a naval commander avoid satellite surveillance. A graphical representation and some limitations of that representation have been discussed. Based on this methodology, a decision aid is being developed and some of its prototype specifications have been outlined.

A transit from Norfolk to Gibraltar was used as an example. With five hypothetical surveillance satellites, a naval commander using a steady 15-knot speed would have encountered 42 satellite detection zones (see Figure 2-3). Initial calculations have shown that an improved speed profile along with local cover and deception tactics can reduce this number of detection zones by 75%. However, no substantial claim of effectiveness can be justified unless an operational decision aid is developed and tested.

6.0 ACCOMPLISHMENTS

At the completion of the reporting period covered by this interim report, all but Task 9 of the Phase II objectives have been accomplished for the prototype decision aid designed in Phase I. The data requirements of this decision aid did not appear sufficiently intensive at this time to require the power and the generality of the Datacomputer.

Instead, additional effort was expended for the design and implementation of the optimizing decision aid proposed in the Phase I Interim Report and described in this report. Design of the optimizing aid was completed and implementation of key software modules for this aid was begun using DDI's PDP-11 and USC-ISI's DECsystem-20.

7.0 FUTURE PLANS

During the next reporting period, the optimizing decision aid will be completed in accordance with the Phase II task descriptions and it will be installed for testing on the ARPANET, at the ACCAT, and at DDI as outlined for Phase III.

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A methodology is presented for helping a naval commander avoid satellite surveillance. With known satellite orbital characteristics, the time and location of detection zones along a ship's planned route can be calculated. It is suggested that a commander can avoid many of these detection zones by varying his speed as a function of time. A graphical representation is presented and its limitations are discussed.

A decision aid based on this methodology is being developed. It uses probabilistic information, such as weather, to find the expected number of detections for any speed profile. An optimal speed profile can be found by means of dynamic programming.

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