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IMPROVEMENTS AND MODIFICATIONS OF THE AIRS PERFORMANCE
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TECHNICAL REPORT

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IMPROVEMENTS AND MODIFICATIONS OF
THE AIRS PERFORMANCE MODEL

Submitted to:

Mr. Albert Knobloch
Naval Air Development Center
Johnsville, Warminster, Pennsylvania

27 February 1970

Contract No. N62269-69-C-0532

Prepared by the Staff of Analytics

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ABSTRACT

This report describes improvements which have been made in the Airborne Integrated Reconnaissance System (AIRS) Performance Model. Specifically, the report includes:

- . An algorithm for analyzing the observability of target complexes.
- . Methodology for evaluating the effectiveness of slewing optical sensors.
- . A technique for examining why sensors perform as they do, on a micro-level.
- . Improvements in the performance models of individual sensors by inclusion of additional equipment, environmental, and operational parameters.
- . Improvements in the method of data presentation to the AIRS user.

In addition, the prospective AIRS user is provided with instructions on the use of the several computer programs which make up the overall model.

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Albert Knobloch of NAVAIRDEVCEN-Johnsville supervised the contract and contributed to the improvements described. Jay Goldfarb, also of NAVAIRDEVCEN, was the Project Manager for the overall program under which this work was done.



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SECTION I

INTRODUCTION

1.1 BACKGROUND

Under NAVAIRDEVCCEN contract number N62269-68-C-0441, Analytics developed a simulation model for studying the performance of future tactical airborne reconnaissance systems. This simulation model, called the AIRS Model (for Airborne Integrated Reconnaissance System), was documented in the following report to NAVAIRDEVCCEN:

Analytics Incorporated, Final Report 1004-1, Simulation of Advanced Integrated Reconnaissance Systems (AIRS), Volumes I, II, and III. Submitted to Naval Air Development Center, Johnsville, under Contract N62269-68-C-0441, 4 April 1969.

Under a subsequent contract, Analytics was tasked to make improvements in the AIRS Model. This report documents these improvements.

It is assumed that the reader has a detailed knowledge of the three AIRS report volumes, this report cannot be effectively used unless this is the case. The AIRS report will be cited frequently throughout this report, and will be referred to simply as "AIRS", with, of course, the appropriate volume and paragraph number.



It would be good to redefine here certain key concepts of the AIRS Model (see AIRS, Volume I, paragraph 1.1). The four primary measures of performance for tactical airborne reconnaissance systems used by AIRS are:

- 1) Target detectability.
- 2) Target identifiability.
- 3) Localizability of the target (expressed as a CEP).
- 4) Time-late statistics (defined as the time that elapses between collection and processing of reconnaissance data).

Values of these performance parameters are computed for each of four data processing levels. The levels are:

- 1) Real-time and near-real-time processing of reconnaissance data on board the aircraft.
- 2) Keying (flagging) of data which contains relevant target information and transmission of this keyed data to the ground support station for early interpretation.
- 3) Keying of relevant data but no transmission of this data to ground support station.
- 4) Conventional processing (that is, no keying of relevant data and no transmission to ground support station.)

Thus the model user can analyze increased system performance as a function of the type of data processing used by the reconnaissance system.



1.2 OVERVIEW OF IMPROVEMENTS

Analytics was tasked to make improvements in the AIRS Model in five major areas, as follows:

- 1) Develop mathematical techniques for measuring the ability of a reconnaissance system to provide detectable, identifiable, and localizable information concerning target complexes as well as individual targets. (Before this improvement, the model considered only targets, not target complexes.)
- 2) Develop mathematical techniques which can be used to measure the effectiveness of slewing optical sensors aboard reconnaissance aircraft.
- 3) Improve the sensor models by inclusion of additional equipment, environmental, and operational parameters.
- 4) Develop algorithms that can be used to reduce the outputs of the AIRS performance simulation to meaningful measures of system performance.
- 5) Make such additions and changes as are necessary to provide additional AIRS outputs which will enable the user to examine why sensors behave as they do on a micro-level.



Task (1) is the topic of Section II, task (2) is considered in Section III. Section IV discusses work performed under task (4). Tasks (3) and (5) are covered in Sections V and VI, respectively. Section VII provides the AIRS user with instruction for the use of the main computer programs which comprise the AIRS Model.



SECTION II

ANALYSIS OF TARGET COMPLEXES

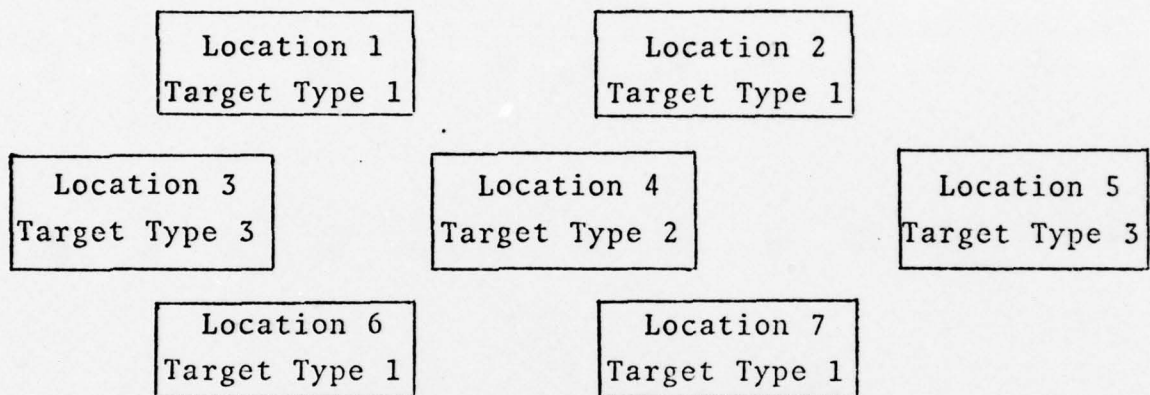
2.1 INTRODUCTION

The "Target Complex" problem is treated in response to a question highly relevant to air reconnaissance. The problem is to determine how additional information about specific targets can be inferred from observed data provided by the reconnaissance system on other targets in the surrounding area. The approach pursued in this project is logically analogous to the thought processes of the human interpreter. Namely, if it is concluded that each element of a group of targets is functionally related as a member of a target complex to the other elements of that group (on the basis of a priori knowledge of the nature of target



complexes), inferences can be made about the identity of more obscure targets which, by virtue of proximity, are also members of the complex. The following example illustrates this more clearly:

Suppose it is known that a given type of complex always consists of targets arranged in the following geometric pattern (a priori knowledge):



Now, suppose a photo-interpreter could identify as well as detect targets at locations 1,2,3,5, and 6, but could only detect (i.e., could not identify) targets at locations 4 and 7. Once he realized he was examining a known pattern (i.e., observes the complex) he can make reasonable decisions about the types of targets at locations 4 and 7 (i.e., make inferences about their identities).

Thus, the objectives of this project are necessarily two-fold. The first is to determine whether a target complex is observed, and the second is to use this information to upgrade the identifiability for each target-member of the complex.



2.1.1 Definition of a Complex

A target complex is defined to consist of one or more types of targets; however, there may be one or more targets within a type. Three kinds of complexes have been studied: (1) Anti-aircraft artillery (AAA) sites, (2) Surface-to-Air Missile (SAM) sites, and (3) truck convoys.

AAA and SAM sites are modeled as consisting of up to four target types (the sum of the number of targets in the four types is constrained to be less than 21). For example, an AAA site might be modeled as consisting of artillery, radar, power vans, and computer vans -- there might be 4 artillery emplacements, 2 radars, 2 power vans, and 1 computer van.

Convoys are modeled as consisting of only one target type -- trucks. There may be up to 20 trucks in a convoy.

AAA and SAM sites are modeled as being "compact" complexes. This means that all targets comprising the complex are considered close enough in geographical proximity that at any time the probability that any target is obscured by terrain or clouds is the same as the probability that any other target in the complex is obscured by terrain or clouds.

On the other hand convoys are modeled as "dispersed" complexes. This means that the trucks which comprise the convoy are considered to be separated geographically to a degree sufficient to allow each truck to be considered independent of the other trucks with respect to clouds and terrain blocking.

2.1.2 Definition of Complex Observability

A complex is considered observed when sufficient data is developed by the system on the targets which



constitute the complex to verify that a complex really exists. Since information is supplied in a probabilistic sense (i.e., detectabilities and identifiabilities of the individual targets), a complex can be observed only with some probability; this probability is called the observability of the complex.

2.1.2.1 Compact Complexes. Surface-to-Air Missiles (SAM) and anti-aircraft artillery (AAA) complexes are similar in that they: (1) consist of several target types, (2) may contain several targets of each type, (3) are arranged in geographical areas. A complex of this category will contain g (from one to four) target types, and there will be N_h targets in type T_h .* $I_{h,j}$ is defined as the probability (conjoined with, not conditional on, detection) of identifying the j th target of type T_h , where j ranges from 1 to N_h and h ranges from 1 to g .

A decision rule, shown in the following form, has been established by the user for determining whether or not the complex is observed.

| Decision Function | TARGET TYPE | | | |
|-------------------|-------------|-----------|-----|-----------|
| | T_1 | T_2 | ... | T_g |
| 1 | $V_{1,1}$ | $V_{1,2}$ | ... | $V_{1,g}$ |
| 2 | $V_{2,1}$ | $V_{2,2}$ | ... | $V_{2,g}$ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| l | $V_{l,1}$ | $V_{l,2}$ | ... | $V_{l,g}$ |

* $\sum_{i=1}^g N_i$ is constrained to be no more than 20 because of practical limitations.



Under the decision rule, a complex is observed if any decision function is satisfied. Decision function 1 is satisfied if at least $V_{1,1}$ targets of type T_1 and $V_{1,2}$ targets of type T_2 and ... and $T_{1,g}$ targets of type T_g are identified; the other decision functions are analogous.

Let $D_{k,h}$ be the probability of identifying at least k targets of type T_h (k ranges from 0 to N_h) for a given decision function. The method for computing the $D_{k,h}$'s is given in Paragraph 2.2.2.1. The general expression for satisfying decision function ℓ is:

$$\prod_{h=1}^g D_{k,h} \quad (2.1)$$

where k is $V_{\ell,h}$. The method used for computing whether the complex is observed, that is, whether any decision function is met, is presented in Paragraph 2.3.

2.1.2.2 Dispersed Complexes. In a convoy (the only dispersed complex modeled) there is only one target type, namely, trucks. Therefore, the decision rule for the complex consists of a single decision function, and that function has only one element, $V_{1,1}$. That is, if at least $V_{1,1}$ trucks are identified, the complex is considered to be observed. The value of $V_{1,1}$ is a user established parameter.

2.2 TREATMENT OF COMPACT COMPLEXES

The EXECUTIVE program of AIRS treats each target independently; in particular, each target at a given time has a probability of being masked by terrain and a probability of being obscured by clouds which is independent of



any other target, no matter how close they may be geographically. As already pointed out, compact complexes assume dependence of terrain and clouds for all targets within the complex. Hence, a method was devised which allows recomputing the identifiabilities of each target in the complex assuming dependence and using as input only the independent identifiabilities as computed by EXECUTIVE. Paragraph 2.2.1 shows how this is accomplished.

Once these new identifiabilities are computed, the observability of the complex can be computed by using the decision function for that complex. The exact methods used to compute the observability are given in Paragraph 2.2.2.

Once the observability of the complex is known, the identifiabilities of each of the targets that comprise the complex can be upgraded. This is discussed in detail in Paragraph 2.2.3.

2.2.1 Recomputation of Target Identifiabilities

For each target and each processing level, EXECUTIVE produces the probability of detection given that there is no terrain shadowing, weather is perfect, and the equipment is functioning properly. Let this probability be denoted by $BDET_{i,j}$, where i is the processing level and j is an index for all targets in the complex. EXECUTIVE also computes a total probability of detection which takes terrain, weather, and equipment into consideration. This quantity, for the j^{th} targets in the complex, at processing level i is noted as $TDET_{i,j}$. For target j , level i , the ratio

$$\frac{TDET_{i,j}}{BDET_{i,j}}$$



is a degrading factor which is the fraction of times that terrain, weather and equipment parameters do not interfere with detection.

For compact complexes it is assumed that there is dependence among these parameters for each target in a given complex. Consequently, an average degrading factor applicable over all levels and targets is needed. This average, denoted as \overline{DF} , is found as the average of the individual ratios:

$$\overline{DF} = \frac{\sum_{i=1}^4 \sum_{j=1}^{N_T} \frac{TDET_{i,j}}{BDET_{i,j}}}{4N_T} \quad (2.2)$$

where N_T is the total number of targets in the complex.

The quantity \overline{DF} is now used to calculate the modified total identifiability $TIDENT_{i,j}$ for target j , level i ($i = 1, \dots, 4$; $j = 1, \dots, N_T$) in the following manner. EXECUTIVE computes the conditional identifiability $CIDENT_{i,j}$, the probability of identification given detection, not taking into account terrain, weather, and equipment conditions. Clearly,

$$(CIDENT_{i,j}) (BDET_{i,j})$$

gives the probability of identification conjoined with detection and assuming no terrain blocking, adverse weather conditions or equipment failure. The overall probability of identification, conjoined with detection and degraded by \overline{DF} is expressed by:

$$TIDENT_{i,j} = (CIDENT_{i,j}) (\overline{DF}) (BDET_{i,j}) \quad (2.3)$$



Similarly, $TDET_{i,j}$ is modified by the following equation (the modified value of $TDET_{i,j}$ being denoted by $TDET'_{i,j}$):

$$TDET'_{i,j} = (\overline{DF}) (BDET_{i,j}) \quad (2.4)$$

2.2.2 Computation of Complex Observability

The first step in computing the complex observability is to compute, for each target type, the probability that at least k targets of that type are identified, where k ranges from zero to the number of targets of that type. This is accomplished in the manner described in Paragraph 2.2.2.1. Paragraph 2.2.2.2 then gives the method for computing the probability that at least one of the decision functions for the complex is met, i.e., the observability of the complex.

2.2.2.1 Computation of the Probability of Identifying at Least k Targets out of a Total of N_h for a Given Target Type. This problem can be reworded as: Compute the probability of realizing at least k out of N_h events given that the events do not occur with the same probabilities.

This cannot be computed in a straightforward manner* because the computations are exceedingly long and many intermediate computations are required, thus the accuracy is lost when they are combined.

In order to accurately calculate by computer the probability of realizing k of N_h events, a short

See the discussion in:

Feller, William, An Introduction to Probability Theory and Its Applications, Volume I, 2nd Edition, 1965, Wiley and Sons, New York, New York, pp. 88-100.



algorithm was developed. This algorithm may be represented by the two general equations shown below. The calculations are performed iteratively, where:

- j = the iteration index
- k = the number of targets identified
- $P(E_j)$ = the probability of occurrence of the j th event
- $1-P(E_j)$ = the probability that the j th event does not occur
- $P(E_{k,j})$ = the j th iteration of the probability that exactly k events occur
- N_h = the maximum number of events possible.

$$P(E_{0,j+1}) = P(E_{0,j}) (1-P(E_{j+1})) \quad (2.5)$$

$$P(E_{k,j+1}) = P(E_{j+1}) P(E_{k-1,j}) + (1-P(E_{j+1})) P(E_{k,j}) \quad (2.6)$$

k ranges from 0 to $j+1$

j ranges from 0 to $N_h - 1$

and $P(E_{k,0})$ is set to $\begin{cases} 1 & \text{when } k = 0 \\ 0 & \text{when } k > 0 \end{cases}$

A formal proof of this algorithm is given in Appendix A.

Applying this technique to each target type in the complex leads to a set of probabilities:

$$P_{k,h} \begin{cases} k = 0, 1, \dots, N_h \\ h = 1, 2, \dots, g \end{cases}$$



where

- $P_{k,h}$ = the probability that k targets of type h are identified
- N_h = the number of targets of type h
- g = the number of target types

Another useful statistic can now be computed in a straightforward manner; namely, $D_{k,h}$, the probability that at least k targets of type h are identified. It can easily be seen that:

$$D_{k,h} = \prod_{\eta=k}^{N_h} P_{\eta,h} \quad \begin{matrix} (k = 0,1, \dots, N_h) \\ (h = 1,2, \dots, g) \end{matrix} \quad (2.7)$$

2.2.2.2 Probability That at Least One of the General Criteria Sets is Satisfied. Suppose for a given complex, the following decision rule is given:

| Decision Function | TARGET TYPE | | | |
|-------------------|--------------|--------------|-----|--------------|
| | T_1 | T_2 | ... | T_g |
| 1 | $V_{1,1}$ | $V_{1,2}$ | ... | $V_{1,g}$ |
| 2 | $V_{2,1}$ | $V_{2,2}$ | ... | $V_{2,g}$ |
| ⋮ | ⋮ | ⋮ | | ⋮ |
| ⋮ | ⋮ | ⋮ | | ⋮ |
| ⋮ | ⋮ | ⋮ | | ⋮ |
| ℓ | $V_{\ell,1}$ | $V_{\ell,2}$ | ... | $V_{\ell,g}$ |

where $V_{\ell,h}$ is as defined in Paragraph 2.1.2.1. Reiterating, decision function 1 says that at least $V_{1,1}$ of target type T_1 and $V_{1,2}$ of target type T_2 and ... and $V_{1,g}$ of target type T_g must be detected for the complex to be



observed under that decision function. The other decision functions are analogous. The complex observability then becomes the probability that the complex is observed under decision function 1, or decision function 2, ... or decision function ℓ .

Suppose the probability of observing the complex under each rule is known, how does one compute the overall observability? The answer is not clear. Let W_ℓ be the probability that the complex is observed under decision function ℓ . At first glance, it would seem that the observability, denoted by OB would simply be

$$OB = 1 - \prod_{i=1}^{\ell} (1 - W_i) \quad (2.8)$$

However, closer inspection reveals that this is not the case, the reason being that the rules are not independent. An example might show this dramatically; consider a two-target type, two-decision-function rule:

| Decision Function | TARGET TYPE | |
|-------------------|----------------|----------------|
| | T ₁ | T ₂ |
| 1 | 4 | 2 |
| 2 | 3 | 1 |

Further, assume that $W_1 = 0.6$ and $W_2 = 0.9$. The formula given above would give OB as 0.96. But notice, decision function 1 is subsumed in decision function 2; i.e., if decision function 1 is met, decision 2 must also be met. In this example, the observability is clearly only 0.9,



the probability that the least stringent decision function is met.

Another approach would be to let OB be found as:

$$OB = \text{MAX} [W_1, W_2, \dots W_\ell] \quad (2.9)$$

Though this does not have the problem discussed above, it tends to understate the observability by not taking into account the fact that the complex could be observed under a non-redundant decision function.

Many alternatives were considered, but the one chosen was an iterative technique developed by Analytics which yields exact answers. It is quite involved mathematically, and if the reader wishes to examine the mathematical development and proof of exactness, refer to Appendix B. It is sufficient here to specify that the observability of the complex in level i will be denoted throughout the remainder of this paragraph by OB_i .

2.2.3 Upgrading the Identifiability of the Individual Targets

This paragraph illustrates, once the observability of a complex is known, how the identifiabilities of the individual targets which comprise that complex are upgraded. In order to show these computations, several factors are needed which have already been computed, namely:

The total identifiability, $PI_{i,j}$, of target j level i . (This is just $TIDENT'_{i,j}$ as computed in Paragraph 2.2.1).

The total detectability, $PD_{i,j}$, of target j level i . (This is just $TDET'_{i,j}$ as computed in paragraph 2.2.1).



The observability OB_i , the complex at level i .
(Computed in Paragraph 2.2.2.2).

In addition, a quantity called $OB'_{i,j}$, must be computed. This quantity is the probability of observing the complex given that target j is not identified (i.e., given $PI_{i,j} = 0$) at level i . $OB'_{i,j}$ is found for each target ($j = 1, \dots, N_T$) at each level ($i = 1, \dots, 4$) by temporarily letting $PD_{i,j}$ equal zero and recomputing the observability by the algorithm discussed in Paragraph 2.2.2.2.

Suppose the complex has been flown over (or near) some number of times. Then $(1 - PI_{i,j})$ represents the percentage of times the target was not identified through its own signature. This percentage should decrease by precisely the number of times the target could be identified through examination of other targets in the complex when the target itself could not be identified. In other words, the upgraded identifiability of a target is the sum of two factors: (1) the target's own identifiability without regard to whether the complex was observed, and (2) a term which gives the identifiability of the target due to the complex observability when it is not identifiable by its own signature.

The first factor above, for target j level i is $PI_{i,j}$.

To develop the second factor, it is assumed that a target's identifiability can be upgraded whenever the complex has been observed and the target itself is detected with some non-zero probability.



Drawing these factors together and expressing the results mathematically, $PI'_{i,j}$, the upgraded identifiability of target j level i is:

$$PI'_{i,j} = PI_{i,j} + (PD_{i,j} - PI_{i,j}) \cdot OB'_{i,j} \quad (2.10)$$

2.3 TREATMENT OF DISPERSE COMPLEXES

Since all targets within a disperse complex are considered as independent with respect to terrain and weather considerations, the identifiabilities computed by the EXECUTIVE program for each truck in the complex can be used without modification to ascertain whether the convoy (the only modeled disperse complex) was observed. Paragraph 2.3.1 discusses how the observability is computed.

Once the observability of the complex is known, the identifiabilities of the targets (i.e., trucks) which comprise the complex can be upgraded. The procedures for accomplishing this is discussed in Paragraph 2.3.2.

2.3.1 Computation of the Observability of the Complex

The EXECUTIVE program provides the probabilities for (total) identifying, by level, each of the targets in the complex. Let $PI_{i,j}$ be the probability of identifying the j th target ($j = 1, 2, \dots, N_T$; N_T = the number of targets) at level i . Using the technique given in Paragraph 2.2.2.1 the probability of detecting at least k targets out of the N_T in the complex is found for level i ; denote this quantity by $D_{k,i}$ ($k = 0, 1, \dots, N_T$; $i = 1, \dots, 4$). Now the decision rule for whether a disperse complex is observed consists of a single number, namely, the minimum number of targets that must be identified before the complex can be observed. Let this number be k_{Min} . Then, the



probability of observing the complex at level i , OB_i is just the probability that at least k_{Min} targets are identified:

$$OB_i = D_{k_{Min},i} \quad (i = 1, \dots, 4) \quad (2.11)$$

2.3.2. Upgrading the Identifiabilities of the Targets

The upgrading algorithm for disperse targets functions in the same way as that for the compact complexes (see Paragraph 2.2.3). Let

$PI_{i,j}$ = the total identifiability of target j level i *

$PD_{i,j}$ = the total detectability of target j level i *

OB_i = the observability of the complex at level i .

Using the technique discussed in Paragraph 2.2.3, $OB'_{i,j}$, the observability of the complex given that the identifiability of target j is zero, at level i , is computed.

Finally $PI'_{i,j}$ the upgraded identifiability for target j , level i , can be written as:

$$PI'_{i,j} = PI_{i,j} + (PD_{i,j} - PI_{i,j}) OB'_{i,j} \quad (2.12)$$

* Since disperse complexes assume independence, their quantities are not modified as in the case of compact complexes.



2.4

COMPUTER IMPLEMENTATION

The program which implements the complex model consists of:

- (1) A main program, COMPLEX, which reads in user parameters and data from the AIRS EXECUTIVE routine and rearranges the data for use by the COMPLEX subroutines.
- (2) A subroutine, SAMAAA, which computes the observability of compact complexes.
- (3) Utility subroutines PREPAR and OBS called in by SAMAAA.
- (4) A utility routine, MULTI, called in by PREPAR and CONVOY.
- (5) Utility function, PALST, called in by OBS.
- (6) A subroutine, CONVOY, which is used for the only disperse complex, the convoy. CONVOY also utilizes MULTI.

Figure 2-1 presents a general flow diagram of COMPLEX.

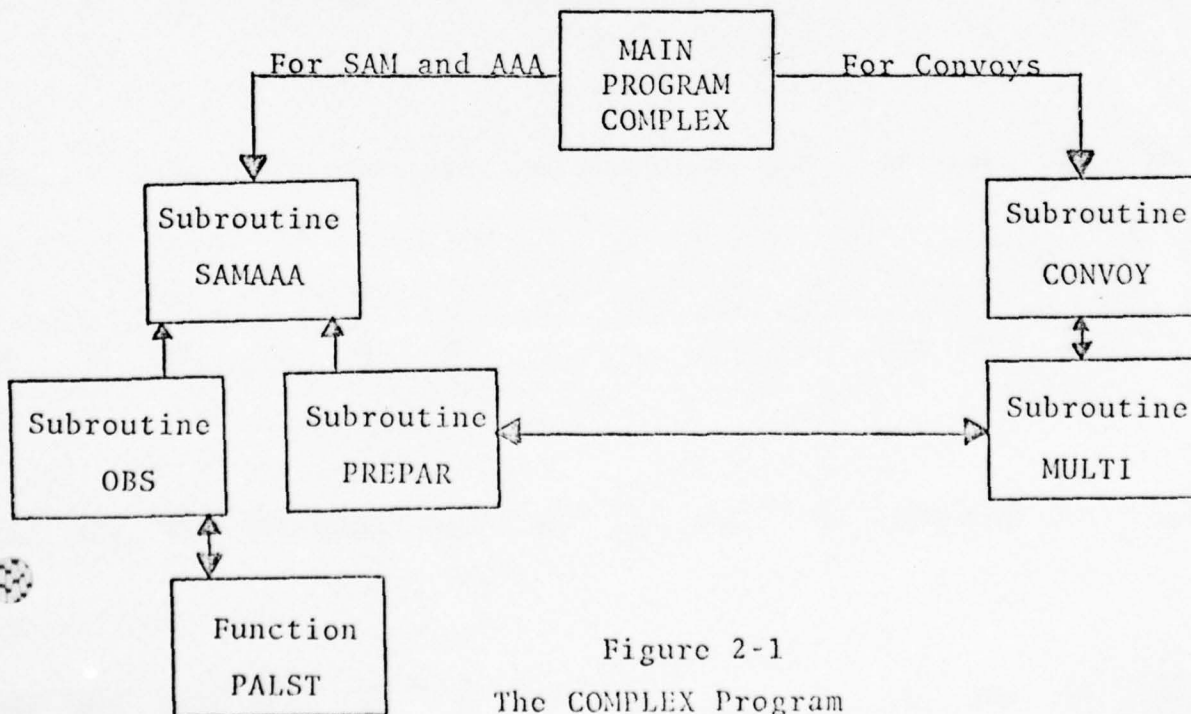


Figure 2-1
The COMPLEX Program



2.4.1 The Main Program, COMPLEX

The purpose of the main program is to:

- (1) Read the decision rules for SAM, AAA, and convoy complexes.
- (2) Read the target types which comprise the SAM, AAA, and convoy Complexes.
- (3) Read, for each complex to be analyzed, the complex type number.
- (4) Read, for each complex, the target number of the targets which comprise the complex.
- (5) For each target in the complex, determine by level:
 - (a) The basic detectability
 - (b) The total detectability
 - (c) The conditional identifiability
 - (d) The total identifiability

The main program develops these statistics before (1) they are modified to take into account correlation of terrain and cloud cover for targets in compact complexes, and (2) before they are upgraded as a function of the observability of the complex of which the targets are members.

Decision functions are read-in via card input. The following illustrates a decision rule consisting of two decision functions for three target types.

| DECISION FUNCTION | TARGET TYPE | | |
|----------------------|-------------|---|----|
| | 23 | 4 | 12 |
| 1 | 0 | 3 | 2 |
| 2 | 5 | 1 | 0 |



Decision function 1 requires that at least 0 of type 23 and at least 3 of type 4 and at least 2 of type 12 must be detected for observation to occur. Decision function 2 is similarly interpreted. For overall complex observability, decision function 1 or decision function 2 must be met.

In the case of a convoy the decision rule is simple -- a single number. The probability that this number (or more) of trucks are identified is the probability that the convoy is observed.

The target types which comprise a given complex are found from the SCENARIO input deck. For example, in the SCENARIO input, target type 19 might be defined as power vans, target type 1 as SAM launchers, etc.

The complex type and the targets which make up the complex are also user inputs. Complex type 1 is defined to be a SAM site; type 2 an AAA site, and type 3 a convoy. Target numbers of the targets which comprise a complex are also read in from cards. The way the user determines the target number is to count the position of the target card (for the relevant target) in the SCENARIO input deck; thus, the first target card is for target number 1, the second for target number 2, and so on.

For each target in the complex, the main program reads the tape (Output Tape #1) prepared by EXECUTIVE. Since the main concern is in how well the overall aircraft system did for a given target, all records on the tape relating to how a particular sensor performed against that target are skipped.

The EXECUTIVE tape is organized on a pass/target basis; therefore, the main program must aggregate identifiabilities and detectabilities over all passes. Consider the



basic detectability at level i of target j , pas k ; call this $B_{i,j,k}$; further, let $B'_{i,j}$ represent the probability of (basic) detecting target j over all passes, then:

$$B'_{k,j} = 1 - \prod_{p=1}^{p_T} (1 - B_{i,j,p})$$

where there are p_T passes. This reflects the fact that for a target to be detected, it must be detected only on 1 of the p_T passes. The total detectability, conditional identifiability, and total identifiability are computed in an analogous manner.

Figure 2-2 is a detailed flowchart of the function of the main program, COMPLEX.



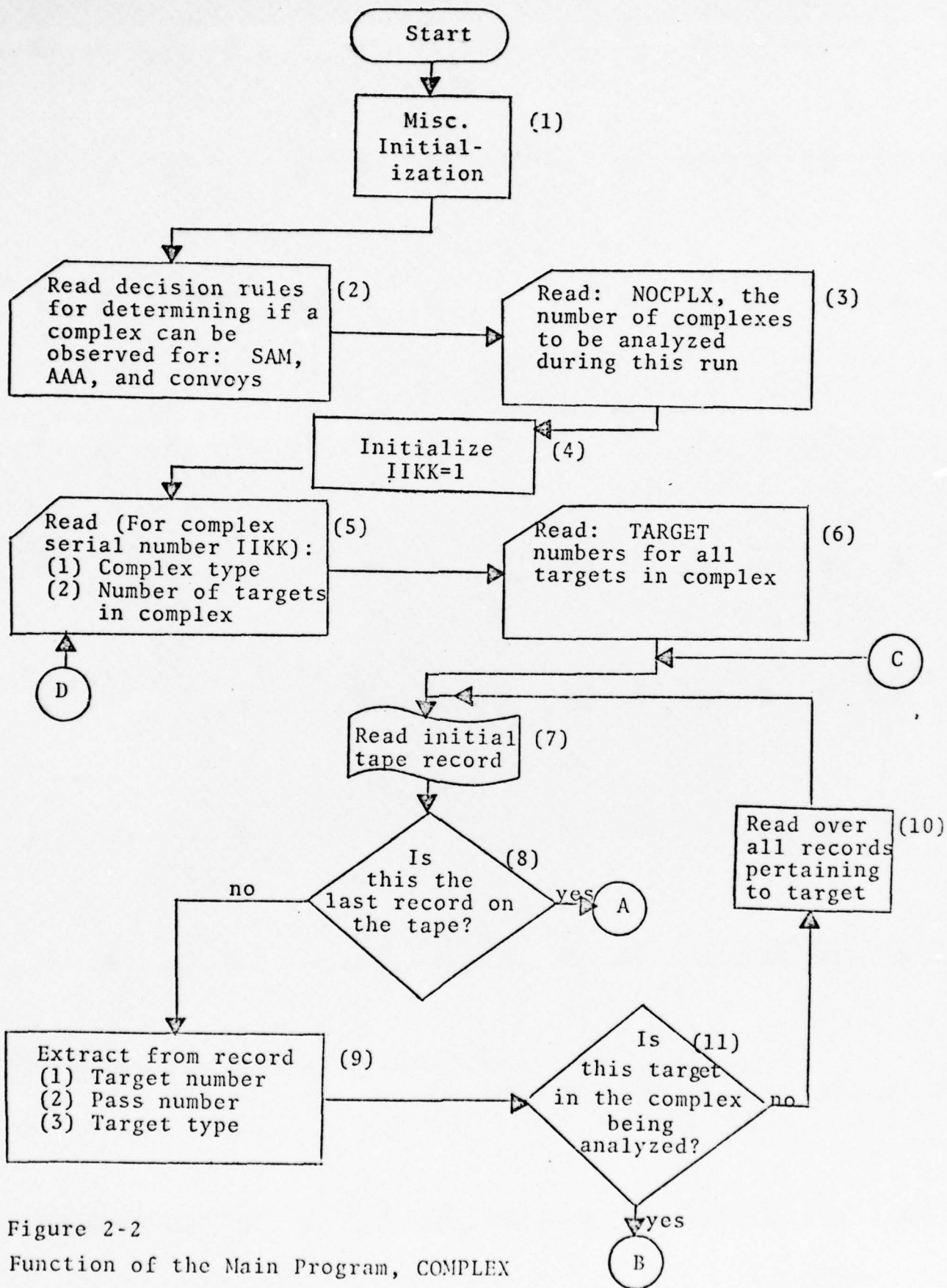


Figure 2-2
Function of the Main Program, COMPLEX



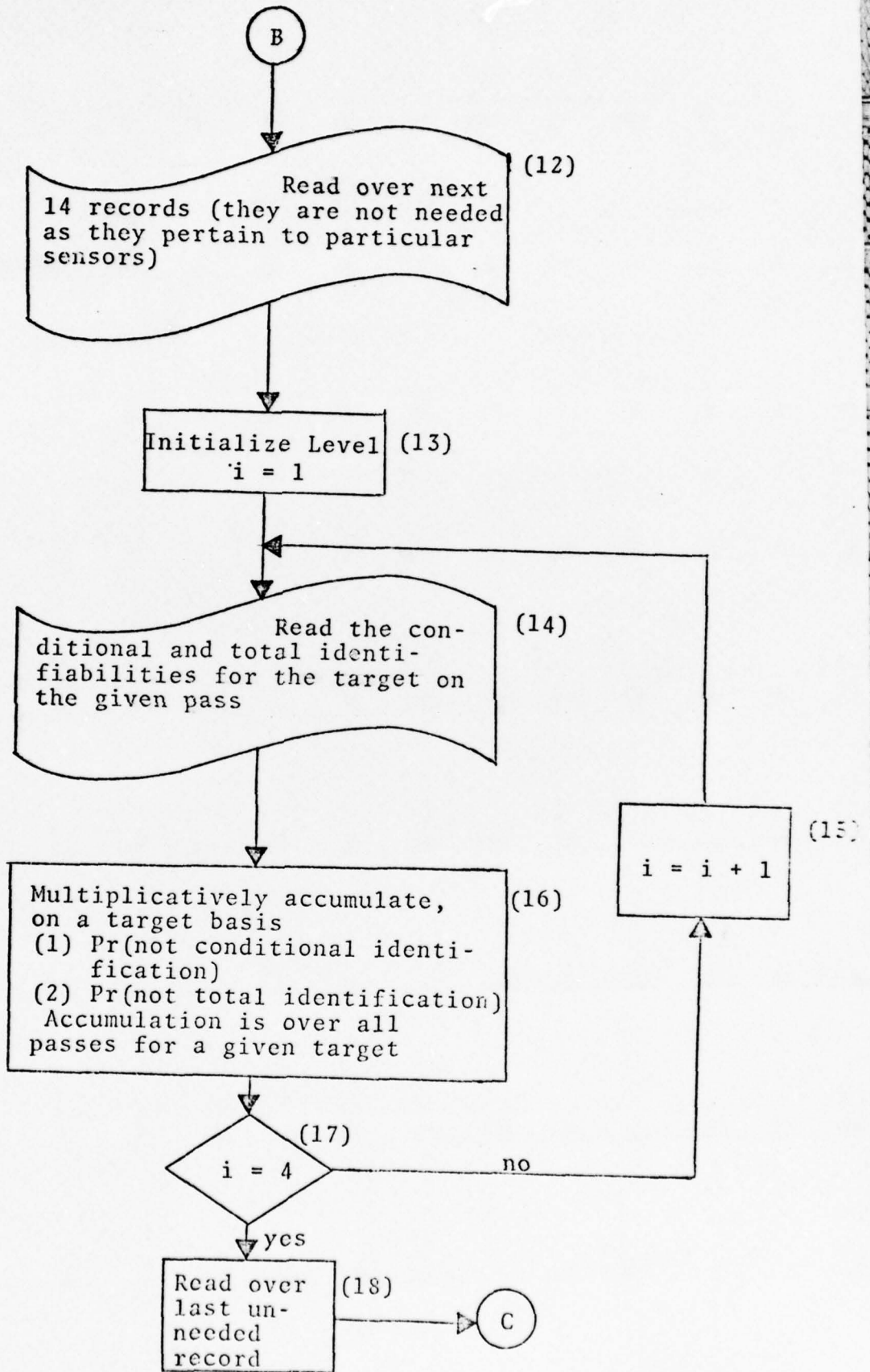


Figure 2-2
(Continued)



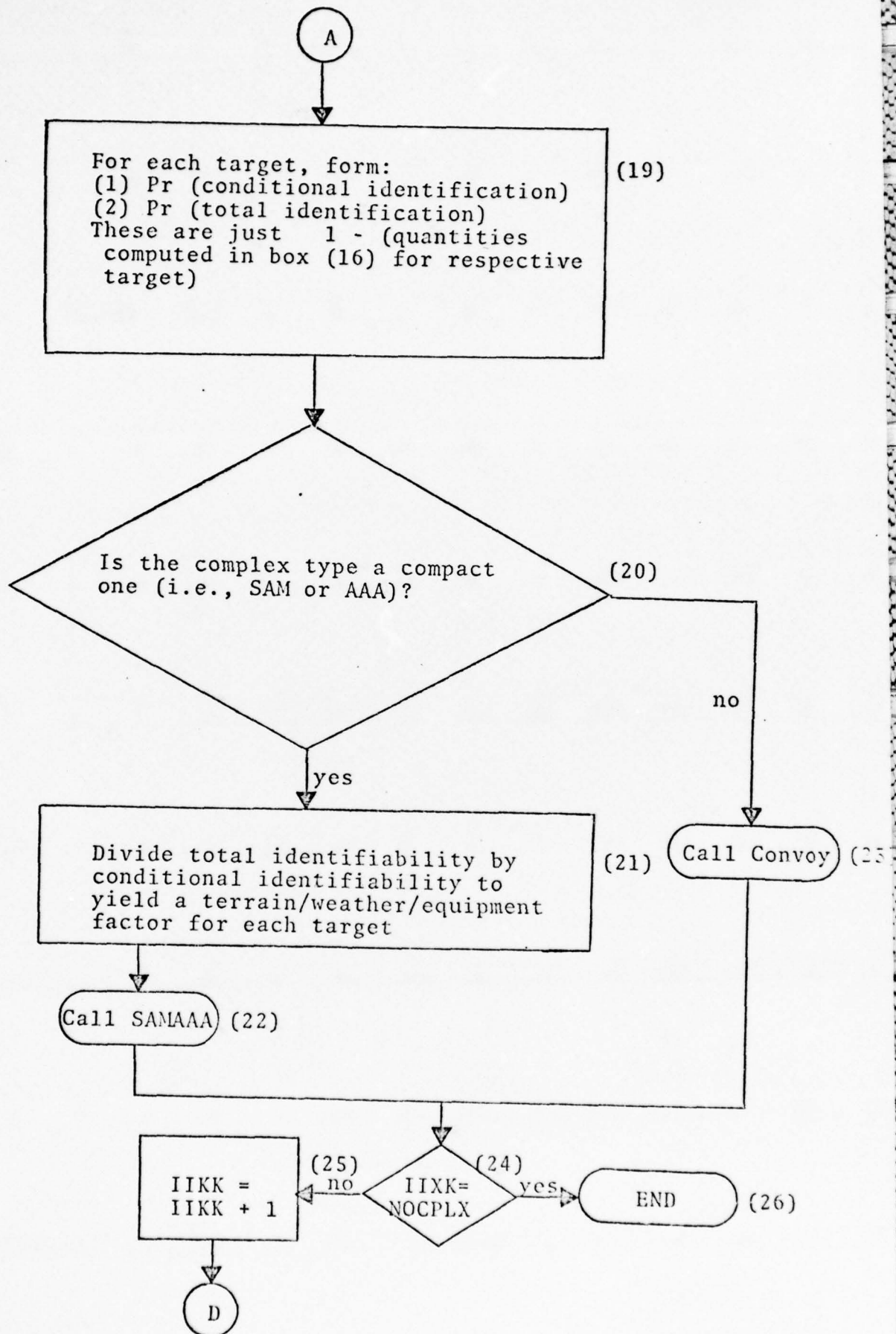


Figure 2-2
(Continued)



2.4.2 SAMAAA

The SAMAAA subroutine is called in by COMPLEX whenever the complex being analyzed is either a SAM or AAA (Complex Type 1 or 2). The complex type is used as an argument of the subroutine while all other inputs are through common statements.

SAMAAA performs three functions:

- (1) An average terrain-shadowing, equipment-up, and weather-degradation factor for all levels is computed and used to find the total identifiability and the total detectability for each target in the complex.
- (2) The probability of observing the complex is computed for each level and the results are printed.
- (3) The targets are grouped by type and, for each level, the original probability of identification is printed along with the augmented probability of identification.

SAMAAA calls in PREPAR and OBS for functions (2) and (3), respectively, to calculate the probability of observing the complex at each level. A flowchart of the SAMAAA routine is shown in Figure 2-3.

2.4.2.1 PREPAR. This subroutine prepares data for the OBS, which implements the decision function algorithm (Paragraph 2.2.2.2) to determine the probability of observing the complex at each level. PREPAR has no arguments; all input and output is through common.



For each level, PREPAR uses the total identifiability of each target and computes the probability of identifying at least k ($k = 0, 1, 2, \dots, N_k$) targets of each type.

PREPAR calls MULTI once for each level for each target type. A flowchart of PREPAR is given in Figure 2-4.

2.4.2.2 MULTI. This subroutine has as inputs N_h , the total number of targets of a given type in the Complex, and PD, an array that comprises the probabilities of identification of each of the N_h targets. The probability of identifying at least k , ($k = 0, 1, \dots, N_h$) of the N_h targets is generated as an array called PATLST. The computation is based on the iterative technique described in Paragraph 2.2.2.1. Figure 2-5 is a flowchart of MULTI.

2.4.2.3 OBS. Subroutine OBS implements the decision function algorithm (Paragraph 2.2.2.2). OBS uses the results of PREPAR to calculate the probability of observing the complex. The type of complex, T_C , is the input. PROBS(i) is an output array of the probability of complex observation at each level, i . OBS utilizes the function PALST to compute PROBS(i). A flowchart of OBS is given in Figure 2-6.

2.4.2.4 PALST. This is a utility function used by OBS to implement the decision function algorithm.

2.4.3 CONVOY

The CONVOY subroutine is called in whenever the complex being analyzed is a convoy. This subroutine is



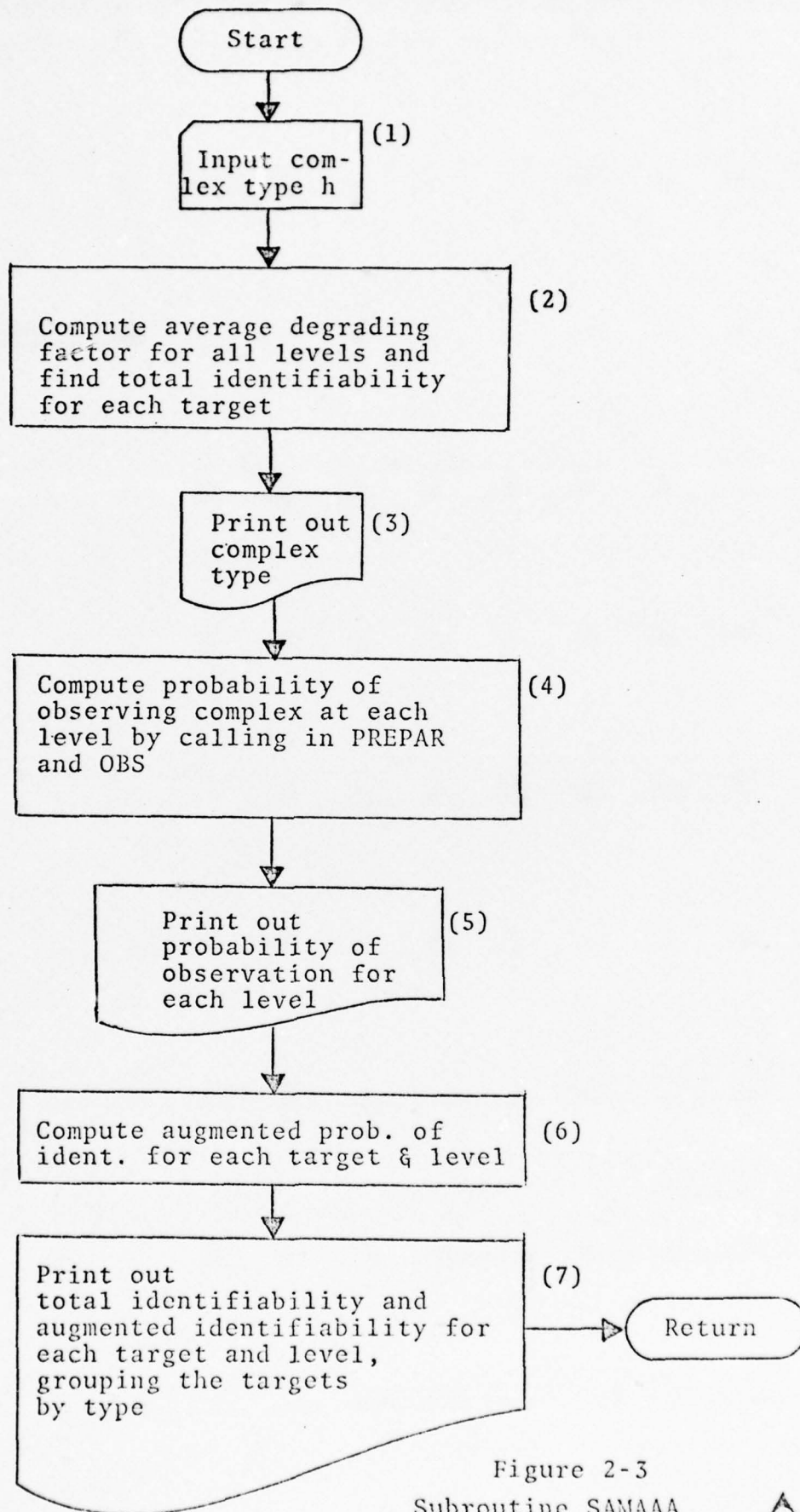


Figure 2-3
Subroutine SAMAAA



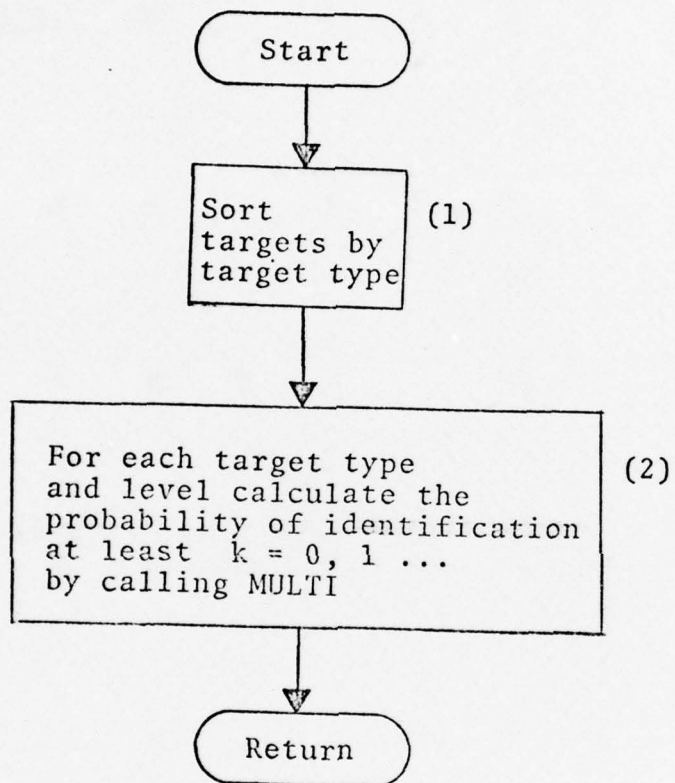


Figure 2-4
Subroutine PREPAR



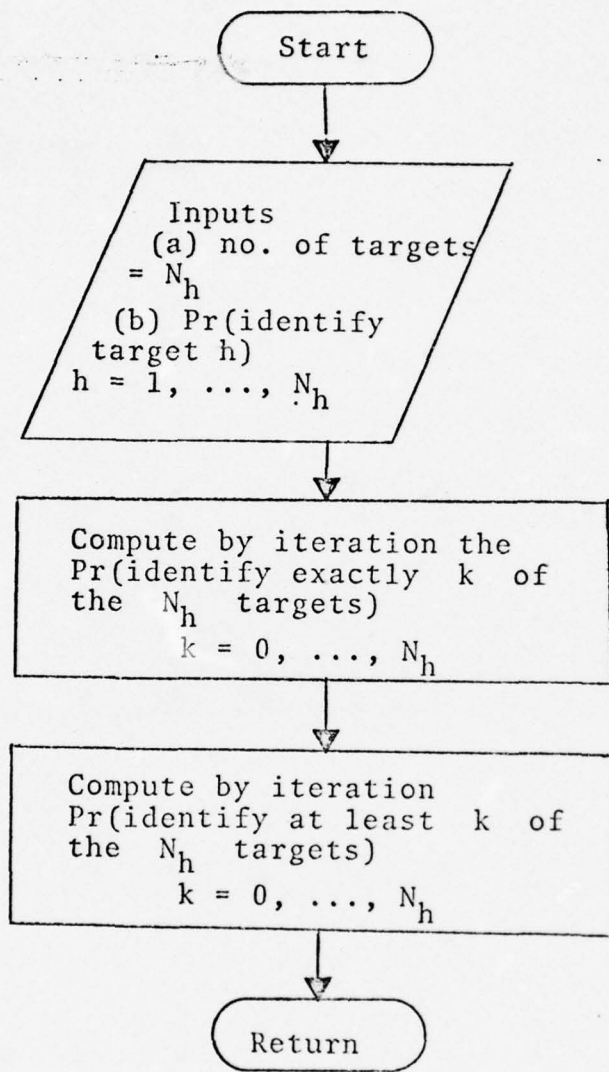


Figure 2-5
Subroutine MULTI



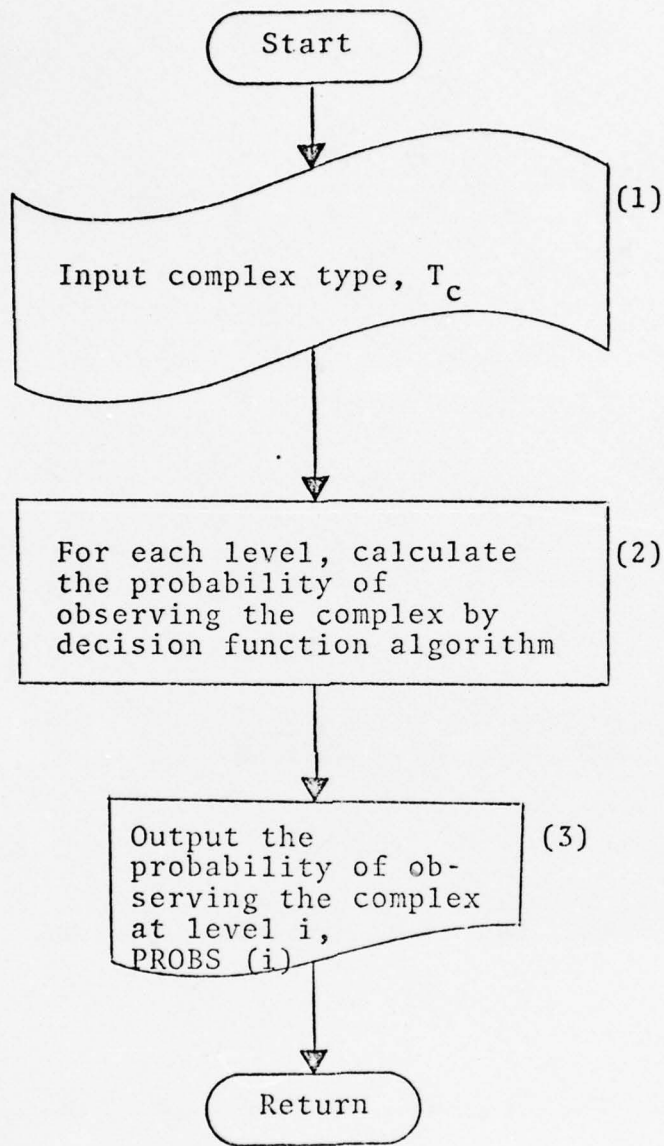


Figure 2-6
Subroutine OBS



provided the total identifiability and total detectability at each processing level for each truck in the convoy.

For each level, CONVOY calls upon MULTI (Paragraph 2.4.2.2) to compute the probability that at least k trucks are identified, where k is the minimum number of trucks, k_{Min} , that must be identified before the complex can be considered as observed (k_{Min} is specified by the decision rule $V_{1,1}$ for convoys). Thus, the observability of the complex is found for each level.

Next, again on a processing level basis, CONVOY considers each truck in turn. It sets, temporarily, the identifiability of the truck being considered to zero and, via MULTI, computes the probability that the complex is observed given that the identifiability of the truck is zero. Using this probability, the upgraded identifiability for the truck is computed.

A flowchart of the functions performed by CONVOY in analyzing convoy complexes is presented in Figure 2-7.

2.5 INPUTS

The following paragraphs discuss the form of the card and tape input to the program.

2.5.1 Card Inputs

Table 2-1 gives the form of the card input deck. Cards 1 to 4 define a decision matrix for a SAM complex and cards 5 to 8 define an AAA complex decision matrix. The following matrix is an example of a decision rule for a SAM Complex; AAA is analogous.



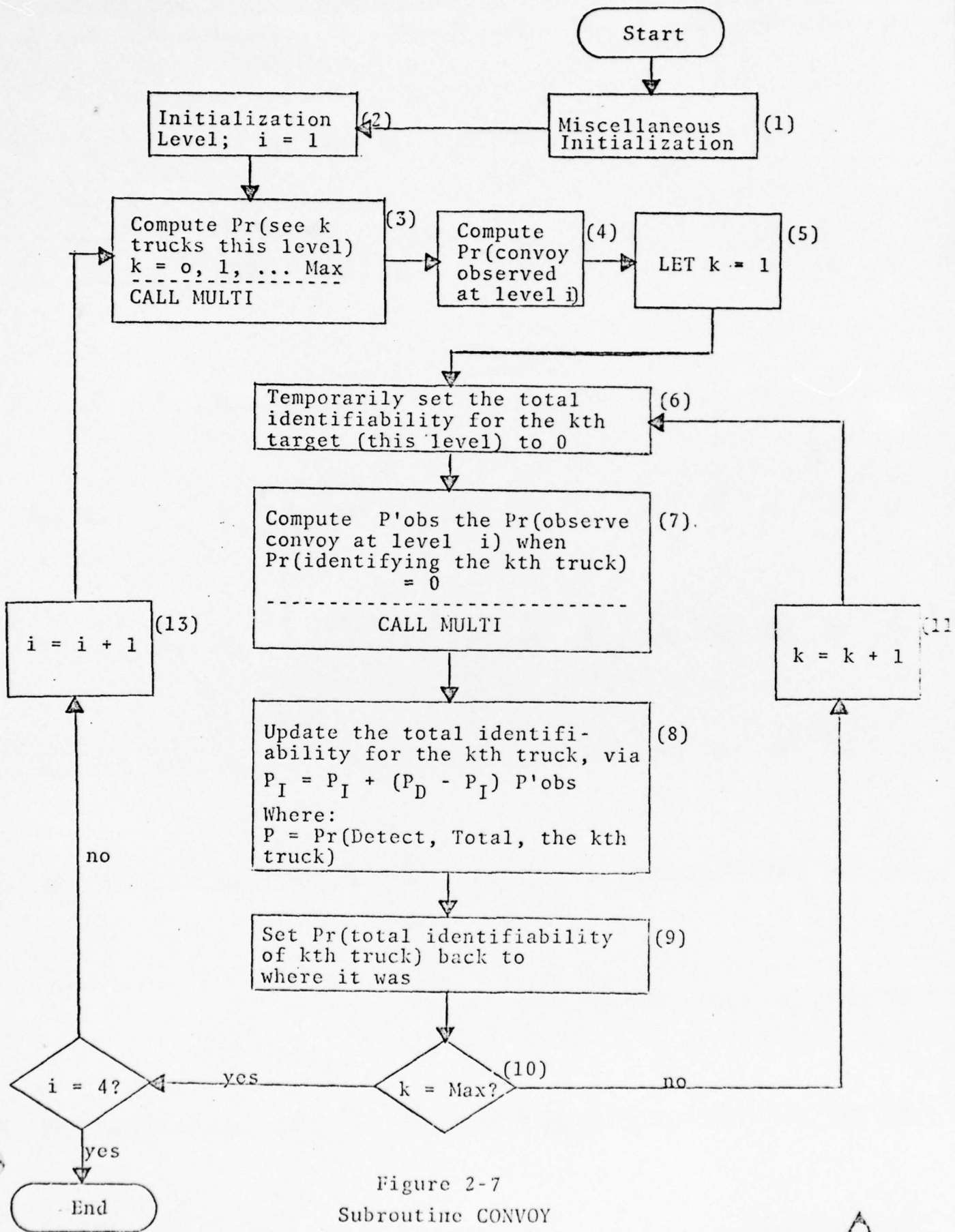


Figure 2-7
Subroutine CONVOY

TABLE 2-1
INPUT CARD DECK

| Card | Variable Name | Definition | Format |
|------|--------------------------------|---|--------|
| 1 | MAXTAR(1) | The number of target types in a SAM complex (maximum of four). | I4 |
| 2 | TARTYP(1,I) I=1,MAXTAR(1) | For a SAM complex, the target type number that appears is the Ith column of the SAM decision matrix. | 4I4 |
| 3 | NRULES | The number of logically "OR" connected decision functions for observing a SAM complex, i.e., the number of rows in SAM decision matrix (maximum of four). | I4 |
| 4a | DECMAT(1,I,1) I=1,MAXTAR(1) | For a SAM site, decision function 1, the min. number which must be identified of target type in col. I of SAM decision matrix. | 4I4 |
| 4b | DECMAT(1,I,2) I=1,MAXTAR(1) | For a SAM site, decision function 2, the min. number which must be identified of target type in col. I of SAM decision matrix. | 4I4 |
| 5 | MAXTAR(2) | The number of target types in an AAA complex (maximum of four). | I4 |
| 6 | TARTYP(2,I) | For an AAA complex, the target type number that appears in the Ith column of the AAA decision matrix. | 4I4 |
| 7 | NRULES | NRULES now becomes the number of logically OR-connected decision rules. For observing an AAA complex, i.e., the number of rows in the AAA decision matrix (max. of four). | I4 |

NRULES OF THESE
CARDS



Table 2-1 - continued

| | | | | |
|-----------------------|------------------------|---|--|-----|
| NRULES OF THESE CARDS | 8 a | DECMAT(2, I, 1) | For an AAA site, decision function 1, the min. number which must be identified of the target type in column I of AAA decision matrix. | 4I4 |
| | 8b . . | DECMAT(2,I,1) | For an AAA site, decision function 2, min. number which must be identified of the target type in column 1 of AAA decision matrix. | 4I4 |
| | 9 | IDECON | The min. number of trucks that must be identified for the convoy to be observed. | I4 |
| | 10 | NOCPLX | The number of complexes which are to be analyzed on this run. (No limit on this number.) | I4 |
| | 11 † | ICPXT NOTARG | The complex type 1 = SAM, 2 = AAA, 3 = convoy The number of targets (not types in complex (maximum of 20 targets spread over up to 4 types)* | 2I4 |
| 12 † | ITAR(I) I=1, NOTARG | The target numbers of those targets in the complex. | 20I4 | |

* Targets should be drawn only from the type specified in the element decision matrix. Targets of inappropriate type will not affect observation of the complex, but their identifiabilities will be adjusted and this is not warranted.

† Cards 11 and 12 are repeated NOCPLX times, once for each Complex.



| Decision Function | TARGET TYPE | | | |
|----------------------|-------------|---|----|---|
| | 23 | 4 | 12 | 9 |
| 1 | 0 | 3 | 2 | 1 |
| 2 | 5 | 1 | 0 | 0 |
| 3 | 2 | 2 | 2 | 2 |

MAXTAR(1) = 4, i.e., there are four target types. TARTYP(1,1) = 23, i.e., target type 23 appears in the first column of the matrix; likewise TARTYP(1,2) = 4; TARTYP(1,3) = 12; TARTYP(1,4) = 9. Decision function 1 says that in order for the complex to be observed, at least 0 of type 23 and 3 of type 4 and 2 of type 12 and 1 of type 9 must be identified; decision functions 2 and 3 are analogous. In this example for the DECMAT array, the first subscript is 1 if considering a SAM complex and 2 if an AAA complex; the second subscript is the column number, while the third index is the row (i.e., decision rule number) number. Note that for a complex to be observed, Rule 1, Rule 2, or Rule 3 must hold, not some combination of them.

2.5.2 Tape Inputs

The tape input is on Output Tape #1 of the EXECUTIVE routine. This tape is discussed in detail in Paragraph 3.6.1 of the cited AIRS report.

2.6 OUTPUTS

The first page of output presents the decision matrix (i.e., the decision rule) for SAM complexes; page 2 is the AAA decision matrix. Similarly, page 3 presents the decision rule for observing convoys. Sample outputs are given in Figure 2-8.



ON FIRST PAGE:

DECISION MATRIX FOR SAM COMPLEX

| | | TARGET TYPE | | |
|-----------------|---|-------------|----|----|
| DECISION RULE * | | 22 | 21 | 20 |
| ***** | | | | |
| 1 | * | 4 | 1 | 1 |
| 2 | * | 2 | 2 | 2 |
| 3 | * | 5 | 0 | 0 |

ON SECOND PAGE:

DECISION MATRIX FOR AAA COMPLEX

| | | TARGET TYPE | | |
|-----------------|---|-------------|---|---|
| DECISION RULE * | | 3 | 6 | 7 |
| ***** | | | | |
| 1 | * | 2 | 0 | 1 |
| 2 | * | 2 | 1 | 0 |

ON THIRD PAGE:

FOR CONVOYS, AT LEAST 3 TRUCKS MUST BE
IDENTIFIED FOR THE COMPLEX TO BE OBSERVED

Figure 2-8
Sample Outputs -- Decision Rules



For each complex analyzed, header information is generated consisting of the complex number (the first complex analyzed is complex #1, the second is complex #2, etc.) and the type of the complex. Then, for each of the four processing levels the probability of observing the complex is given, appropriately labeled. Within each level individual targets are grouped by type (in the case of SAM and AAA complexes -- this is not done for convoys, which consists of only one target type). The identifiability of each target before consideration of whether a complex is observed is given, as in the new target identifiability computed once the probability of observing the complex of which the target is a member is known. Sample outputs for SAM, AAA, and Convoy Complexes are given in Figure 2-9.



COMPLEX NUMBER 4

COMPLEX TYPE 1
 LEVEL
 1 2 3 4
 PROB OF OBS COMP .962071 .066065 .888146 .891153

| TYPE | TAR NO. | WITHOUT | WITH |
|------|---------|---------------------|---------------------|
| 3 | 4 | .932 .663 .779 .779 | .955 .665 .911 .913 |
| 3 | 5 | .926 .398 .808 .808 | .932 .407 .914 .915 |
| 22 | 71 | .937 .297 .936 .936 | .957 .308 .918 .918 |
| 22 | 72 | .937 .285 .932 .936 | .957 .297 .914 .918 |
| 22 | 73 | .937 .285 .932 .936 | .957 .297 .914 .918 |

LEVELS 1 - 4

LEVELS 1 - 4

Figure 2-9a
 Sample Output For a SAM Complex



COMPLEX NUMBER 3

COMPLEX TYPE 2

LEVEL 1 2 3 4
PROB OF OBS COMP .919503 .154245 .838469 .946163

| TYPE | TAR NO. | WITHOUT | WITH |
|------|---------|---------------------|---------------------|
| 6 | 20 | .911 .719 .863 .921 | .841 .723 .894 .933 |
| 6 | 22 | .822 .484 .598 .921 | .722 .498 .786 .904 |
| 22 | 74 | .921 .280 .916 .920 | .948 .319 .909 .908 |
| 22 | 71 | .921 .291 .920 .920 | .948 .328 .913 .908 |
| 22 | 75 | .921 .686 .920 .921 | .962 .694 .950 .970 |

LEVELS 1 - 4

LEVELS 1 - 4

Figure 2-9b
Sample Output For an AAA Complex



COMPLEX NUMBER 1
COMPLEX TYPE 3

THE PROBABILITY OF OBSERVING COMPLEX NO. 1 AT LEVEL 1 IS .9994

FOR LEVEL 1

| TARGET NO. | WITHOUT OBSERVING COMPLEX | WITH OBSERVING COMPLEX |
|------------|------------------------------|---------------------------|
| 3 | .9127 | .9127 |
| 4 | .8963 | .8963 |
| 5 | .9622 | .9622 |
| 8 | .9342 | .9342 |
| 9 | .0000 | .2909 |
| | .0000 | .0000 |

NOTE: A similar table is prepared for each of the other three processing levels

Figure 2-9c

Sample Output For a Convoy Complex



SECTION III. PHOTO-SLEWING

3.1 INTRODUCTION

The term photo-slewing indicates the process of directing the orientation of reconnaissance photographic devices with respect to specific geographical points of interest. The original AIRS* model conceptualizes fixed photo-sensors, i.e., the orientation of the projected field-of-view with respect to the aircraft is fixed, for a given mission, according to the designation of the user.

* Reported in Volumes I, II, and III of "SIMULATION OF ADVANCED INTEGRATED RECONNAISSANCE SYSTEMS," submitted to Systems Analysis and Engineering Department, U.S. Naval Air Development Center, Johnsville, Warminster, Pennsylvania by Analytics, Inc., under Contract No. N62269-68-C-0441; April 4, 1969.



In future reconnaissance systems slewing capabilities will become increasingly important, as more targets can be detected by a slewable camera than by an otherwise identical fixed-position camera. Analytics was tasked to improve the AIRS models to allow slewable cameras to be modeled.

The modeling technique chosen to implement this slewing capability was to retain the concept of a camera fixed in orientation. By modifying only relevant film dimensions and, in the case of the side-looking frame camera, the depression angle of the center beam, the modified camera can be made to "see" the entire area over which its real-life counterpart could be pointed. The field of view of this modified camera is called the "expanded field of view"; the field of view of the original, non-modified camera is referred to as the "rest field of view."

Detectability and identifiability are then computed using the expanded field of view, without regard to whether or not the camera is actually slewed. These detectabilities and identifiabilities are then modified according to the following algorithms:

- (1) If the target would have passed through the field of view of the camera in its unslewed mode (a deterministic computation), slewing gains nothing, and the detectabilities and identifiabilities remain as computed.
- (2) If the target would not have passed through the field of view of the camera in its unslewed mode, the detectability (identifiability) must be modified by multiplying the computed detectability (identifiability) by the probability that slewing occurred for the target.

The forward-looking and side-looking frame cameras are modeled as being capable of direction by preplanning or



by real-time signals from the ECM, MTIFLR, or FLIR sensors. The choice of these three sensors as sources of slewing is discussed in Paragraph 3.4.3. The computer implementation has been effected by additions to the existing AIRS SCENARIO and EXECUTIVE programs.

Paragraph 3.2 discusses those parts of the slewing model which are implemented in SCENARIO.

Paragraph 3.3 discusses the changes effected in the EXECUTIVE program.

3.2 SCENARIO

Paragraph 3.2.1 presents a discussion of the geometry of the field-of-view, in slewed versus unslewed mode, for the forward-looking frame camera and an explanation of the means employed to achieve the larger field of view. Paragraph 3.2.2 provides a similar treatment of the side-looking frame camera.

3.2.1 Forward-Looking Frame Camera

In the original AIRS model, forward-looking frame cameras were not modelled as being slewable by other sensors. The model has now been modified to allow slewable forward-looking frame cameras to be considered within the model. The modeling technique chosen was to continue representing the camera as fixed in orientation, but to enlarge the field of view of the camera to correspond to the entire area over which the slewed camera could be directed. However, resolution and other performance characteristics of the slewed camera are the same as those of its unslewed counterpart.

The problem as appraised is to find the ratio of the area of coverage in the slewable mode to the non-slewable



mode. Since the forward camera sweeps a strip under the aircraft, this is equivalent to finding the ratio of the length* of the swaths swept out. This ratio can then be used to find an effective film length, i.e., the film length which would yield the path the slewable camera could cover.

Let f be the focal length and λ the film length. Then α , the half angle of the beam spread parallel to the wing is given by:

$$\alpha = \arctan (\lambda/2f) \quad (3.1)$$

Let d be half the swath length of the field swept out:

$$d = X \tan \alpha, \quad (3.2)$$

where X is the slant range to the ground. X is given by:

$$X = H/\cos \theta. \quad (3.3)$$

Where H is the aircraft height above mean ground level and θ is the angle between the vertical and the uppermost ray of the beam. Equations (3.1), (3.2), and (3.3) are taken from Figures 3-1a, 3-1b, and 3-2.

Let ψ be the half angle through which the camera can be slewed, as shown in Figure 3-1b. Referring to this figure, the effective film length, λ' , can be found in the following manner.

From equations (3.1) and (3.2):

$$d = X\lambda/2f \quad (3.4)$$

From equation (3.4) and Figure 3-1b:

$$d' = (X + \epsilon) \tan (\alpha + \psi) \quad (3.5)$$

* Length is measured as parallel to the a/c wing axis.

It can be assumed that * $\epsilon \ll X$.

Therefore:

$$d/d' = \lambda/f \tan (\alpha + \psi) \quad (3.6)$$

By similar triangles:

$$\begin{aligned} d'/d &= \tan (\pi/2 - \beta)/\tan \alpha \\ &= 2f \tan (\alpha + \psi)/\lambda \\ &= \cot \beta/\tan \alpha \end{aligned} \quad (3.7)$$

$$\cot \beta = 2f \tan (\alpha + \psi)(\tan \alpha)/\lambda \quad (3.8)$$

Then:

$$\begin{aligned} \lambda' &= 2f/\tan \beta \\ &= 2f \cot \beta \\ &= [(2f)^2/\lambda] \tan (\alpha + \psi) \tan \alpha \end{aligned} \quad (3.9)$$

which, by inspection, has the correct unit of distance.

Equation (3.9) can be simplified to yield

$$\begin{aligned} \lambda' &= (2f)^2/\lambda \tan [\arctan(\lambda/2f) + \psi] \cdot \tan (\arctan \lambda/2f) \\ &= 2f \tan (\alpha + \psi) \end{aligned} \quad (3.10)$$

Empirical data indicates that within a certain number of degrees, γ , from the horizon (usually γ is about 6°), optical sensors are not productive. Therefore, we shall constrain δ to be not greater than the slew angle which would allow the camera to see within γ degrees of the horizon. This angle can be found by referring to Figure 3-3.

* Exactly, $\epsilon = f - \epsilon'$; $\epsilon' = \frac{1}{2}\lambda \sin (\frac{\pi}{2} - \alpha) / \sin(\psi - \alpha)$
For a typical case $\alpha = 4^\circ$, $\psi = 60^\circ$, $\lambda = 2.5$ inches,
 $f = 16$ inches, $\epsilon' = 1.5$ inches, and $\epsilon = 14.5$ inches
compared to X which is several miles.



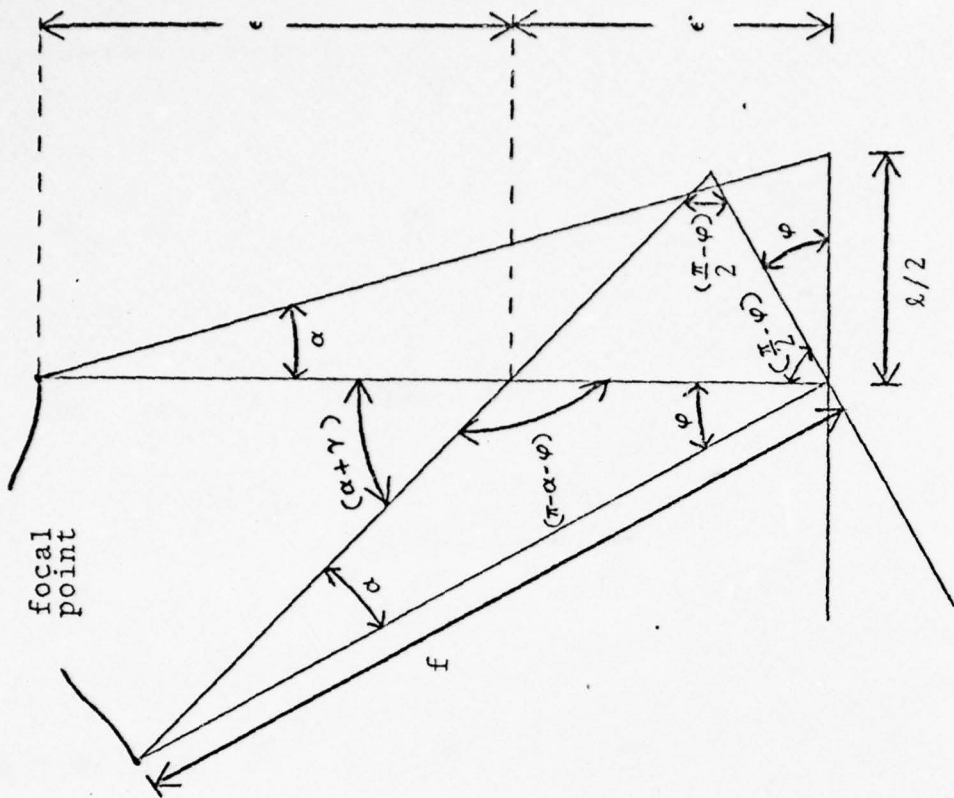


Figure 3-1b

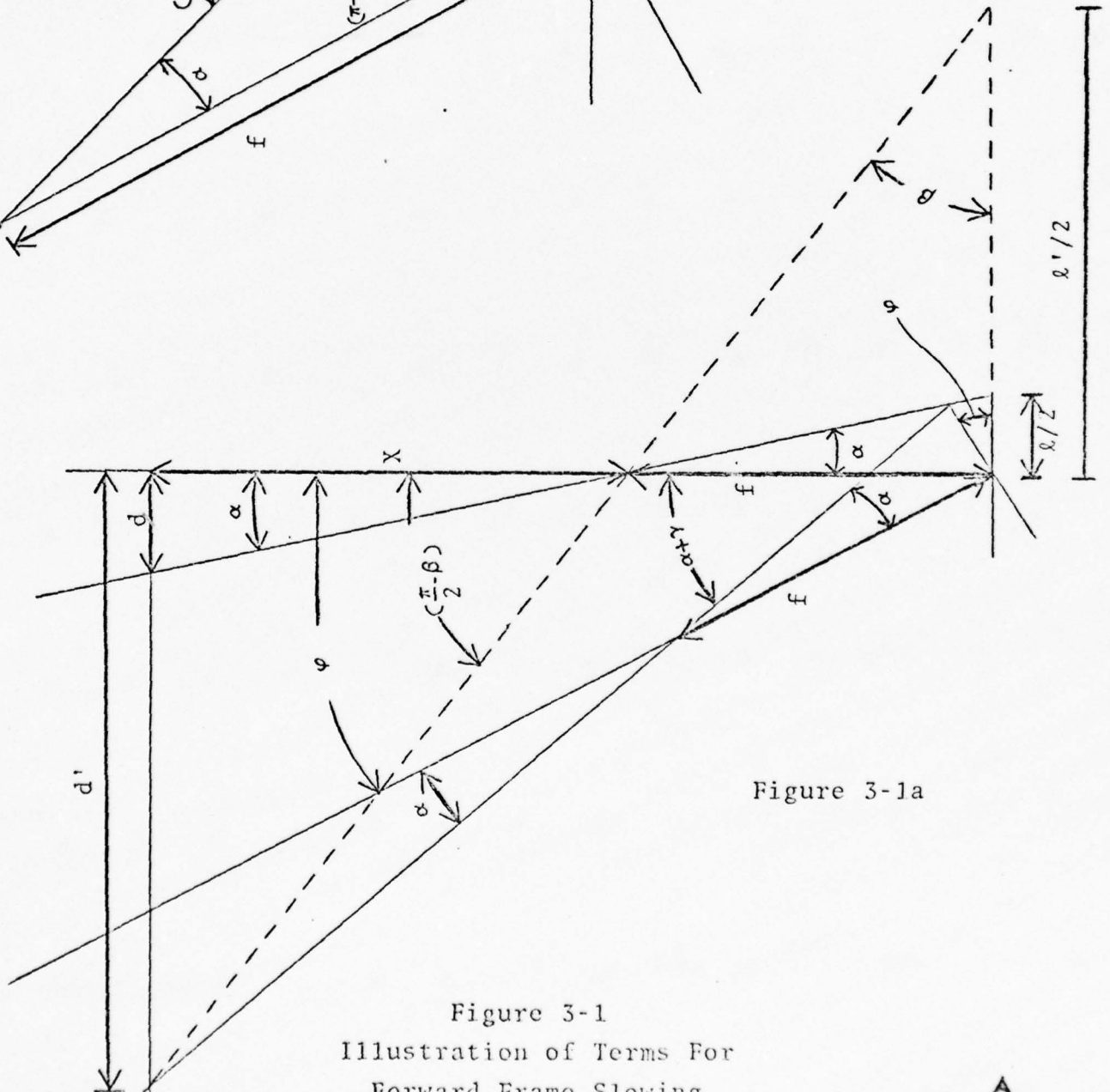


Figure 3-1a

Figure 3-1
Illustration of Terms For
Forward Frame Slewing



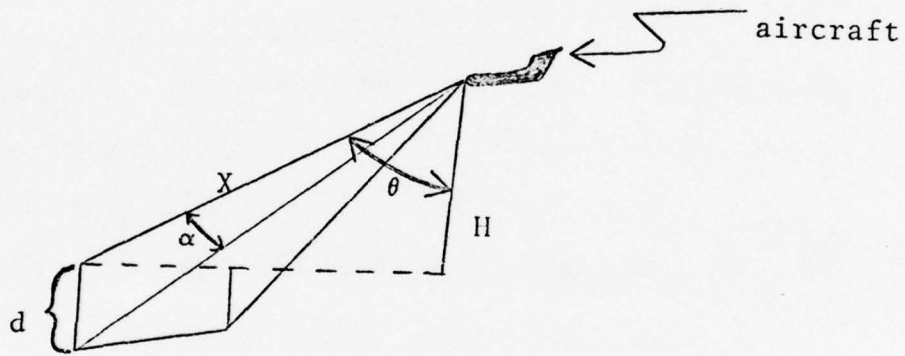


Figure 3-2
Illustration of Terms For
Forward Frame Slewing



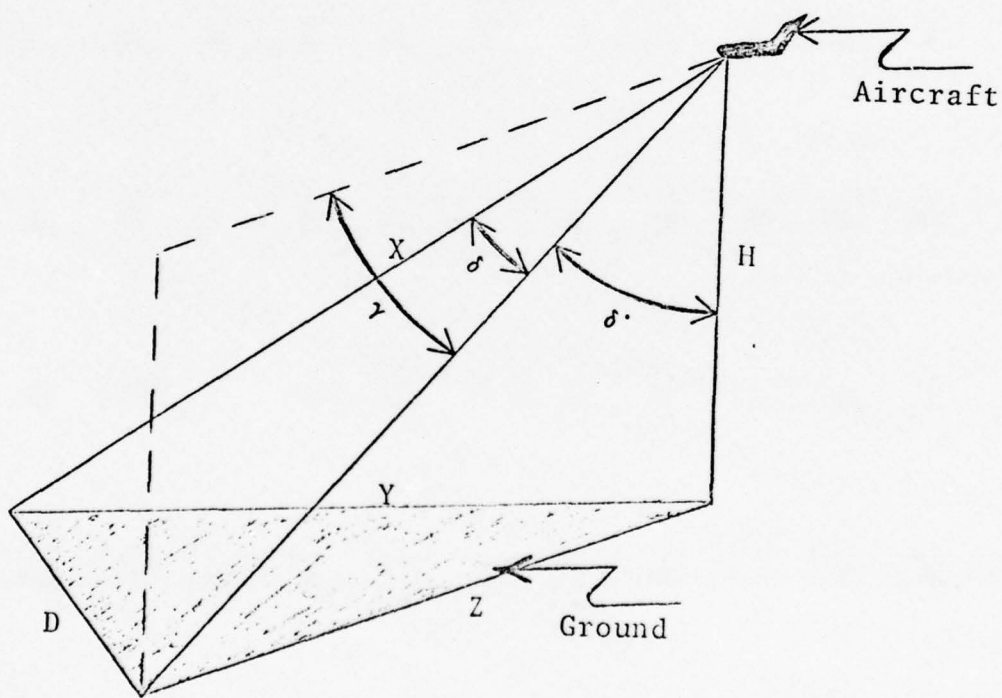


Figure 3-3
 Illustration of Maximum Slew Angle



As before, θ is the angle from the vertical to the top edge of the beam. δ' , as defined in Figure 3-3 is:

$$\delta' = \pi/2 - \gamma \quad (3.11)$$

Note that:

$$\tan \delta = D/X = (H/X)(D/H) = (\cos \theta) D/H \quad (3.12)$$

where

$$\begin{aligned} D/H &= (Z^2 - Y^2)^{1/2}/H = (Z^2/H^2 + Y^2/H^2)^{1/2} \\ &= [\tan^2(\pi/2 - \gamma) - \tan^2 \theta]^{1/2} \end{aligned} \quad (3.13)$$

Therefore:*

$$\delta = \arctan \left[\cos \theta \{ \tan^2(\pi/2 - \gamma) - \tan^2 \theta \}^{1/2} \right] \quad (3.14)$$

And finally:

$$\psi' = (-\alpha) + \min[\alpha + \psi, \delta], \quad (3.15)$$

* For a limit of 6° from the horizon, δ becomes $\arctan [(\cos^2 \theta / .0109) - 1]^{1/2}$



where ψ is the user input value of the half angle of the slew. Equation (3.10) is then rewritten simply as:

$$\lambda' = 2f \tan (\alpha + \psi') \quad (3.16)$$

3.2.1.1 Computation of the Target Offset Distance. One of the statistics that must be provided to the EXECUTIVE program for each look at a given target is the offset distance from the target to the heading axis at the time of that look.

Let:

F = offset distance

ζ = heading angle measured clockwise from north (i.e., x axis)

(Y_T, X_T) = the coordinates of the target

(Y_A, X_A) = the coordinates of the aircraft

Then, with the aid of Figure 3-4:

Ground distance to target, G_R , is:

$$G_R = [(X_T - X_A)^2 + (Y_T - Y_A)^2]^{\frac{1}{2}}$$

Angle from north to target, ρ , is:

$$\rho = [\pi/2 - \arctan ((X_T - X_A)/(Y_T - Y_A))]$$

Angle from heading to target = $\rho - \zeta$

Then:

$$F = G_R \sin (\rho - \delta) \quad (3.17)$$



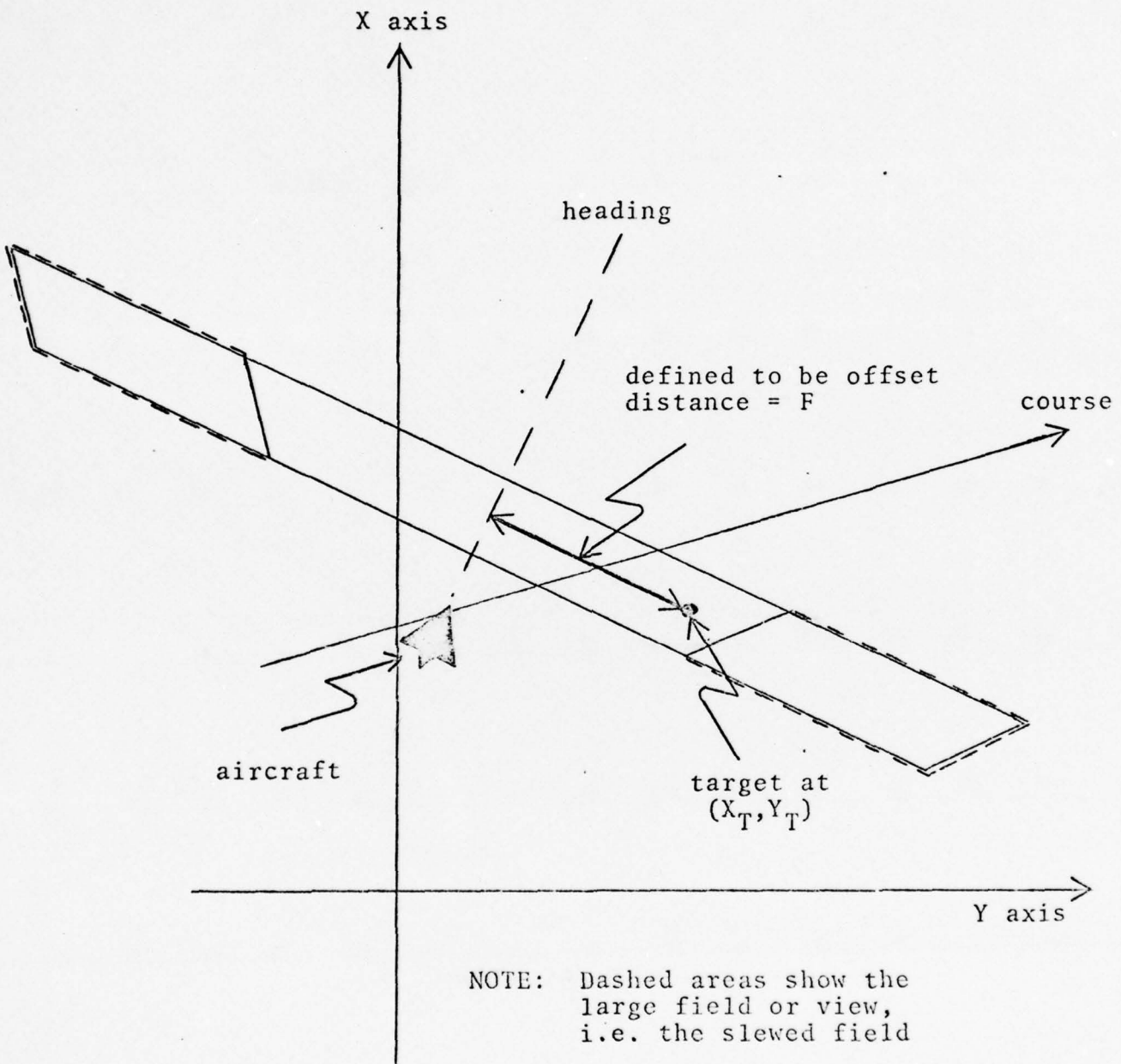


Figure 3-4
Target Offset Distance



3.2.1.2 Computation of the Average Length of Rest Field of View. The rest field of view is a trapezoid; however, for reasons which will be discussed in Paragraph 3.3.1, a necessary parameter is the average width of the rest field of view, denoted by \bar{D} .

The length of the longer side of the trapezoid is:

$$D_L = 2X \tan \alpha \quad (3.18)$$

Where X is computed by equation (3.3) as:

$$X = H / \cos \theta$$

Let ξ be the angle between the aircraft vertical and the center of the focal beam. Since θ equals $\xi + \omega$, from Figure 3-1c, \bar{D} becomes:

$$\bar{D} = 2H \tan (\alpha) \sec (\xi) \quad (3.19)$$

3.2.1.3 Input for Forward-Looking Frame Camera Slewing. One new parameter must be provided the SCENARIO program to allow for slewing of forward-looking frame cameras, namely, the half angle of slewing capability (in degrees). Paragraph 7.2.1 gives the new form of the SCENARIO input deck, including this parameter.

3.2.1.4 Output Related to Forward-Looking Frame Camera Slewing. The modeling of the slewing capability of the forward-looking frame camera produces no changes in the form of the SCENARIO output, either hard copy or tape.



3.2.2 Side-Looking Frame Camera

Side-looking frame cameras were not modeled as being slewable in the original AIRS model; this capability has now been added. As in the case of the forward-looking frame camera (Paragraph 3.2.1), the modeling technique chosen is to consider the slewable camera as a fixed-orientation, non-directable camera having a field of view which encompasses the entire area over which the slewable camera could actually be directed. This is accomplished by modifying only physical parameters (e.g., film lengths) of the camera; performance characteristics (e.g., resolution) remain unchanged.

As in the case of the forward-looking camera, it is also assumed here that when all other parameters are held constant the length of the field of view is proportional to film length. The augmented film length, denoted by λ' (see Figure 3-5) is computed by equations (3.22) and (3.23) where:

λ = the original film length

f = the focal length

T = the angle between the focal axis and the aircraft vertical. When the user wishes the camera to point to the right, relative to the direction in which the aircraft is pointed, T is positive. When the camera should be pointed to the left (when looking along the flight path) T is input as a negative value.

θ_{MIN} = the minimum depression angle of slewing

θ_{MAX} = the maximum depression angle of slewing.

θ_{MIN} and θ_{MAX} are always positive. The angles are measured relative to the horizon of interest depending on whether the camera



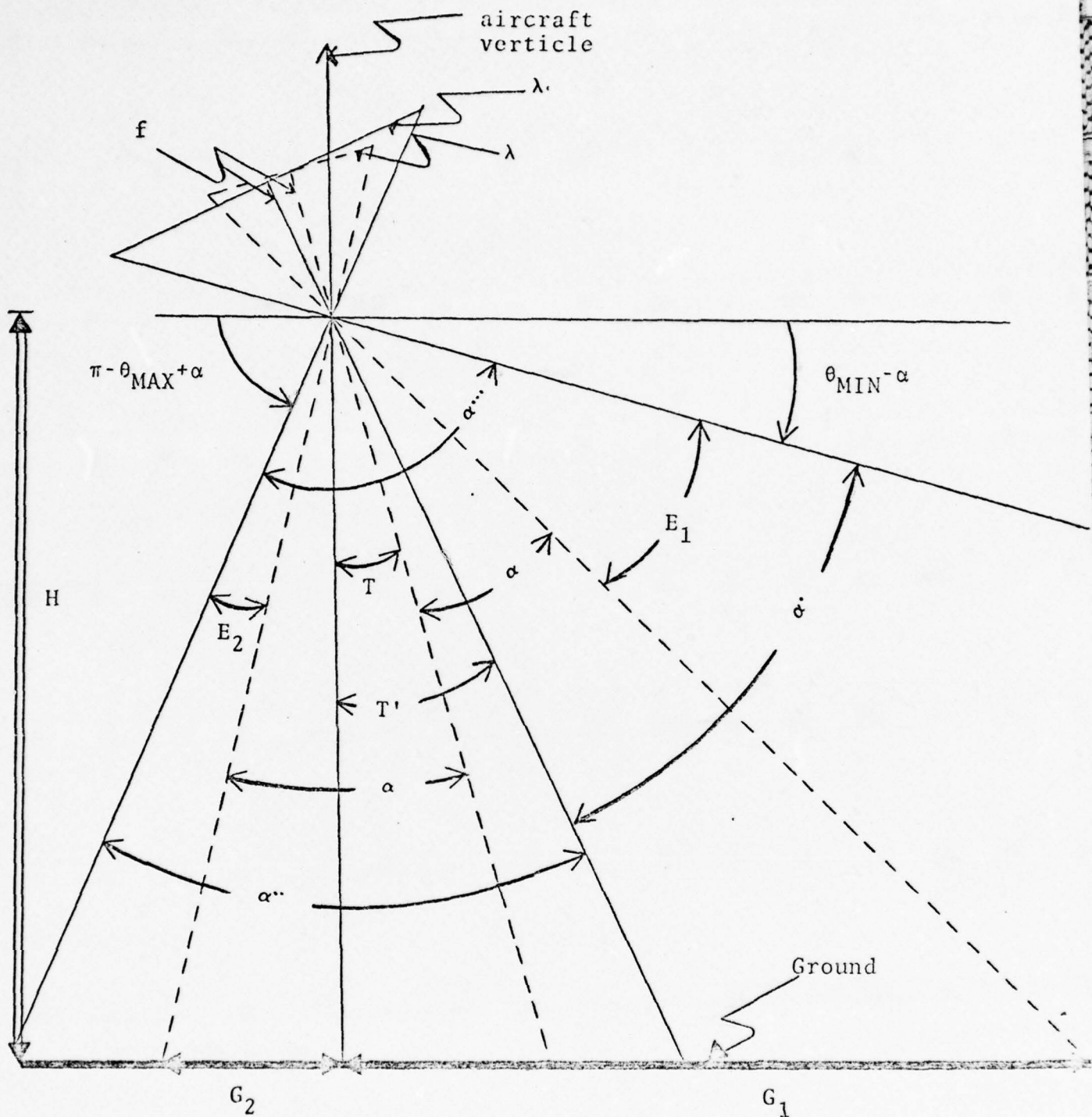


Figure 3-5
Side-Looking Photo Slewing

TABLE:

$$\lambda = 2f \arctan(\alpha)$$

$$\alpha = \tan(\lambda/2f)$$

$$\alpha' = \tan(\lambda'/2f)$$

$$\lambda' = 2f \arctan(.5(E_1 - E_2) + \alpha)$$

$$G_1 = H \tan(T + \alpha)$$

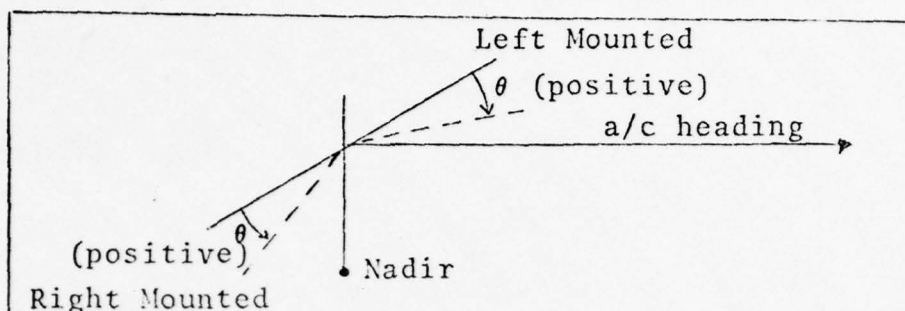
$$G_2 = H \tan(T - \alpha)$$

$$E_1 = \text{magnitude of } \pi/2 - \theta_{\text{MIN}}$$

$$E_2 = \text{magnitude of } \pi/2 - \theta_{\text{MAX}}$$



is right-mounted or left-mounted on the aircraft.



E1 = the signed magnitude of the quantity

$$\pi/2 - \theta_{\text{MIN}}$$

E2 = the signed magnitude of the quantity

$$\pi/2 - \theta_{\text{MAX}}$$

$$\alpha = \text{beam spread} = \arctan (\lambda/2f)$$

In order for the upper edge of the expanded focal beam to remain 6° below the horizon, E1 must not exceed $(84^\circ - \alpha)$. For the reverse edge of the expanded focal beam to remain 6° below the horizon, E2 must not be more negative than $(-84^\circ + \alpha)$. When E1 and E2 are set equal to either their original values or, where they exceed the computed limits, the focal axis is repositioned to bisect E1 + E2 by equation (3.20): this repositioned focal axis is at an angle denoted by T' from the aircraft vertical. Hence,

$$T' = 0.5(E1 + E2) \quad (3.20)$$

From Figure 3-5 it can be seen that the portion of augmented beam angle, α' , above the aircraft vertical will be:

$$\alpha' = T' + \alpha + 0.5(E1 - E2)$$



and the part of the new beam angle α'' below the aircraft vertical is:

$$\alpha'' = -T' + \alpha + 0.5(E1 - E2)$$

and the total beam angle is α''' , given by:

$$\alpha''' = \alpha' + \alpha'' = 2\alpha + E1 - E2 \quad (3.21)$$

and, since λ' is perpendicular to the bisector of the total beam angle (see Figure 3-5):

$$\lambda' = 2f (\tan 0.5\alpha''') \quad (3.22)$$

$$= 2f (\tan (\alpha + 0.5(E1 - E2))) \quad (3.23)$$

3.2.2.1 Computation of the Target Offset Distance. The target offset distance is computed using equation (3.17) in Paragraph 3.2.1.1.

3.2.2.2 Computations of the Right and Left Edges of the Rest Field of View. As will be discussed in Paragraph 3.3.1, the EXECUTIVE program will need to know the distance from the heading axis to the right-most edge of the rest field of view and the similar distance to the left-most edge of the rest field of view. This paragraph will show how these distances are computed.

Whether or not the camera is slewed, the actual rest field of view is delimited by T (the original angle between the aircraft vertical and the focal axis) and α (the half-angle of beam width corresponding to the original, unmodified film length). For either right- or left-mounted cameras, the distance from the heading axis to the right-most edge of the rest field of view is:

$$S_d^+ = H \tan(T + \alpha) \quad (3.24)$$



The corresponding distance to the left-most edge is:

$$S_d^- = H \tan(T - \alpha) \quad (3.25)$$

3.2.2.3 Input for Side-Looking Frame Camera Slewing Model.
Two additional parameters must be input into the SCENARIO program; they are:

- (1) θ_{MIN} (in degrees); defined in Paragraph 3.2.2
- (2) θ_{MAX} (in degrees); defined in Paragraph 3.2.2

New input to SCENARIO is described in detail in Paragraph 7.2.1 of this report.

3.2.2.4 Output Related to Side-Looking Frame Camera Slewing. The modeling of the slewing capability of the side-looking frame cameras produces no changes in the form of the SCENARIO output, either hard copy or tape.

3.3 EXECUTIVE

3.3.1 Field of View

The preceding paragraph discussed how the slewing problem for forward and side oblique frame cameras was implemented in the SCENARIO program. This paragraph discusses how the outputs provided by the SCENARIO program are used in the EXECUTIVE program to compute target detectabilities, identifiabilities, and localizabilities when slewing capabilities are present.

Below are definitions of terms that will be used:

A_i = the distance of the target from the heading axis at the time of the i^{th} look. It is taken as negative if the target is to the left of the axis and positive if to the right.



B = the average distance from the heading axis to the right-most edge of the rest field of view. B is positive if the right edge of the field of view is to the right of the heading axis.

C = the average distance from the heading axis to the left-most edge of the rest field of view. C is negative if the left edge is to the left of the heading axis.

Note that for a forward-looking frame camera,

$$B = \bar{D}/2 = -C \quad (\text{Paragraph 3.2.1.2});$$

for a side-looking frame camera,

$$B = S_d^+ \quad \text{and} \quad C = S_d^- \quad (\text{Paragraph 3.2.2.2}).$$

The terms are pictorially illustrated in Figure 3-6a and 3-6b. For each look:

$$Lk_{\mu} = \begin{cases} 1 & \text{if } C \leq A_{\mu} \leq B \\ 0 & \text{otherwise} \end{cases}$$

Aggregating over τ looks at a given target:

$$E \equiv \frac{1}{\tau} \sum_{\mu=1}^{\tau} Lk_{\mu}$$

If $E \geq 0.5$, the majority of looks at the target fell within the rest field of view. If $E < 0.5$, the majority of looks fell outside the rest field of view, but within the expanded field of view. The look would not be recorded if the target were outside the expanded field of view. Figure 3-7 will illustrate different values of E. It is assumed that if $E < 0.5$ the target cannot be detected



Figure 3-6a
 Illustration of
 Terms; Forward
 Plane Camera

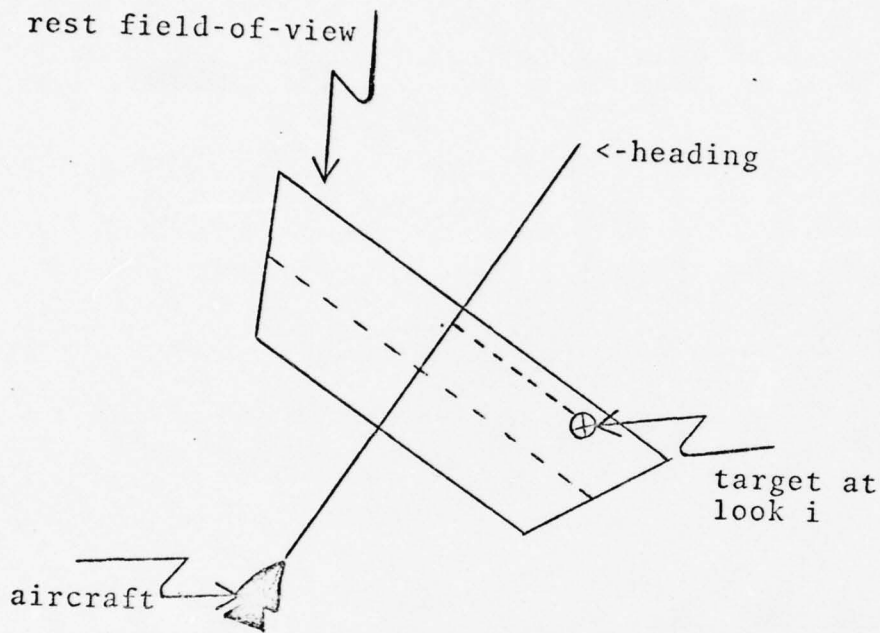
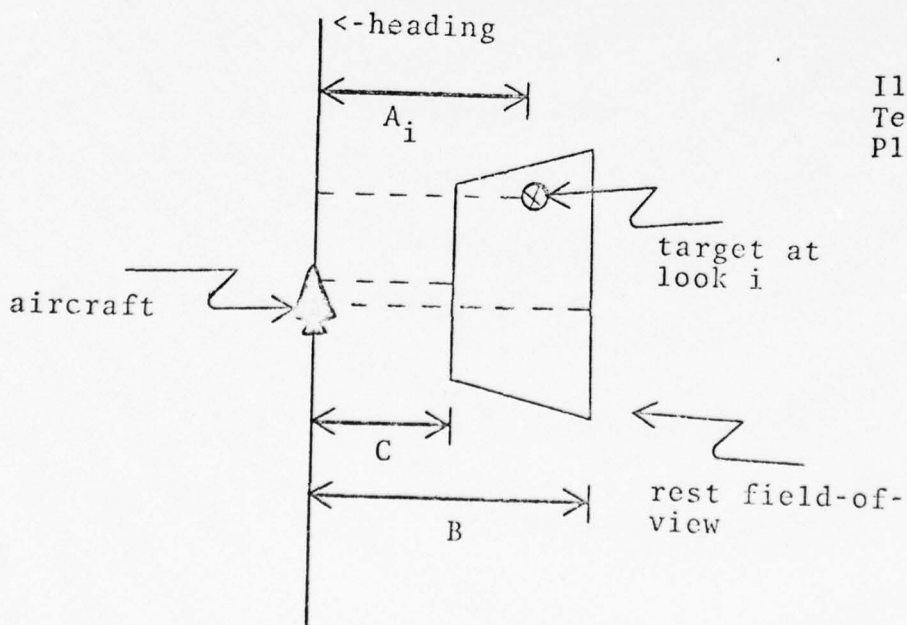


Figure 3-6b
 Illustration of
 Terms; Side
 Plane Camera



on any look unless slewing occurs; likewise, if $E \geq 0.5$ it is assumed that the target can be detected on any or all looks even if slewing does not occur.

The assumption can be justified by noting that E is usually 1 or 0 and that only in such very special cases as illustrated in Figure 3-7 will E be between these values.

3.3.2 Computation of Detectability and Identifiability

Detectability, identifiability and localizability are initially computed assuming all looks are valid, i.e., using the expanded field of view but without regard to whether slewing actually occurred. These detectabilities and identifiabilities may then be modified to take into account the probabilities that slewing did or did not occur.

If the camera would have seen the target whether or not slewing occurred (i.e., $E \geq 0.5$), then slewing provides no additional improvement. Therefore, the detectability and identifiability for the target remains unchanged.

If however, the camera cannot see the target unless slewing occurs, we have:

$$PD'_i = PD_i \cdot P_s$$

where PD'_i is the modified detectability for level i ; PD_i the initially computed detectability for level i , and P_s is the probability that the camera was slewed.

Likewise

$$PI'_i = PI_i \cdot P_s$$

where PI'_i is the modified identifiability at level i and PI the initially computed identifiability at level i .



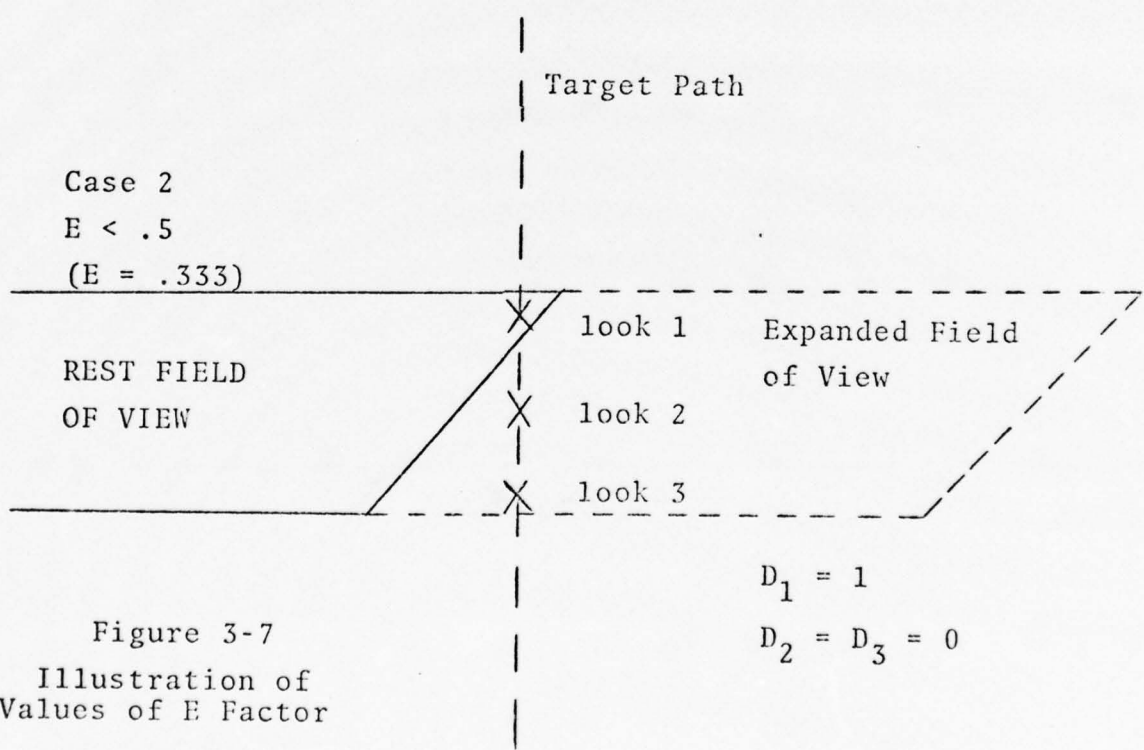
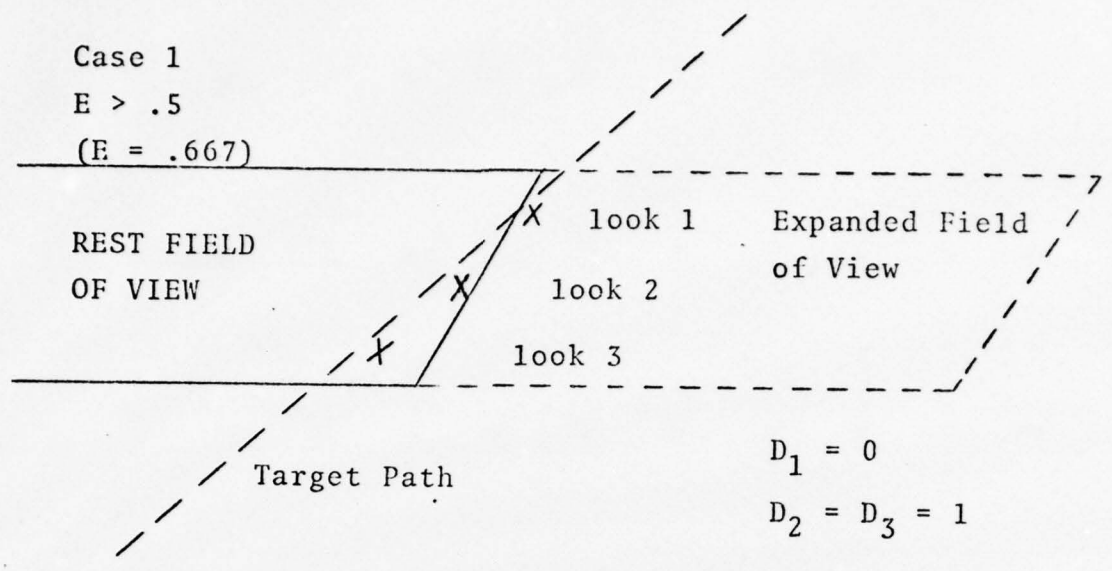


Figure 3-7
 Illustration of
 Values of E Factor

* The drawings are shown for a forward oblique frame camera; the side oblique frame camera is completely analogous.



3.3.3 Slewing Factor

Slewing can occur in one of two ways: the target can be preplanned, or the target can be sensed by another sensor which can direct the slewable cameras toward the target. In the preplanned mode, the system receives coordinates of known or suspected targets at the time of mission initiation. For the second mode the sensors must be considered which may reasonably be expected to pick up a target in time to direct the camera toward the target. The target must be sensed before it comes abreast of the aircraft, for the side oblique camera or while it is still well in front of the aircraft, for the forward oblique camera. Further, the target must be sensed in real time, i.e., Level 1 of processing. The ECM, MTIFLR, and FLIR sensors meet these criteria. Each can detect targets in front of the aircraft and each operates in Level 1. Because (see Paragraph 3.2.8.1 of AIRS Volume I) FLIR itself is slewable by the ECM and MTIFLR sensors, if FLIR has been slewed, the cameras also have been slewed, and FLIR can add nothing.

The slewing factor P_s is then:

$$P_s = 1 - R (1-PD_x) (1-PD_y) (1-PD_z(1-P'_s))$$

Where

- R = Probability that the target was not preplanned.
- PD_x = Probability that the ECM detects the target in Level 1.
- PD_y = Probability that the MTIFLR detects the target in Level 1.
- PD_z = Probability that the FLIR detects the target in Level 1.
- P'_s = Probability that the FLIR is slewed.



and, from equation (3.150) of AIRS, Volume I.

$$P'_s = 1 - R (1-PD_x) (1-PD_y)$$

No change need be made in the CEP, because it is not conditioned on detection or slewing.

3.3.4 EXECUTIVE Program Input and Output

There is no change in the form of EXECUTIVE input* or output.

* Certain parameters are redundantly input to both SCENARIO and EXECUTIVE. The user should note the duplication of focal length on input card 16b (p. 2-34) and input card 20 (p. 3-90, Vol. I. Simulation of Advanced Integrated Reconnaissance Systems (AIRS).)



SECTION IV

EVALUATION ROUTINE

4.1 INTRODUCTION

The Evaluation (EVAL) routine is a CDC 32/3300 FORTRAN program that prints usable measures of AIRS effectiveness in a highly readable format by transforming data contained on the Target/Sensor Output Tape (Executive Output Tape #1; see Paragraph 3.6.1 of AIRS, Vol. I and paragraph 7.3.2.1 of this report). Through the use of options the user of EVAL can to some degree control the type of measures computed as well as the form of the output printed; it is through such control that EVAL gains its flexibility. Further, the user can process the same data tape repeatedly using different options each time.



The basic purpose of EVAL is to integrate the effectiveness measures of detectability, identifiability, and localizability computed by EXECUTIVE over accumulations of targets known as types, and further to integrate over collections of types known as groups. These measures are integrated by sighting unit, i.e., with each sighting of a target considered a separate entity, and also by target unit, i.e., with the measures for all sightings of a particular target conjoined into single target measures before any integration takes place.* Both target unit and sighting unit data are useful in evaluating the effectiveness of AIRS systems, although sighting unit measures are especially meaningful when considering individual sensor performance, as are target unit measures when examining the system as a whole.**

Considering each target type in turn, the program outputs effectiveness measures accumulated by type (type measures) in both target and sighting units. These measures are given for each sensor and also combined over sensors. In

* In a multiple pass mission, the reconnaissance system is exposed to each physical target more than once. Each such exposure we call a target sighting or, simply a sighting.

** This is actually a deep point. When target unit measures are considered, the system performance is not adversely affected if a target is poorly detected (or identified, etc.) on one leg of the mission as long as it has been well detected on another. This is as it should be, after all, the purpose of a reconnaissance flight is to detect targets, and less concern should be given to performance against individual sightings. On the other hand, when the performance of separate sensors is being examined, sensor's effectiveness measure is based on how well it does at every opportunity; this is affected if a sensor does poorly on one sighting of a target even if it does well on another.



addition, some break out by processing level is given. A complete integration over all targets (both by sighting and target units) is then presented. Next, data for targets of the appropriate types are accumulated into target group data; however, far fewer group measures are given - only summary data are tabulated - and there is no break out by sensors. Lastly, EVAL prints the beta measure of sensor redundancy both by target and sighting unit for all sensors, integrated over all targets.*

The EVAL routine as discussed above has been implemented and thereby replaces and obsoletes an earlier, more limited version of EVAL (see Section IV, AIRS, Vol I). The coding of the present EVAL is entirely new and represents a different approach to many (although not all) of the computations.

4.2 USER OPTIONS AND FLEXIBILITY

The EVAL program is quite flexible; the user has the necessary control of program flow through input options. The options are set through punch card inputs read at the start of processing. The various inputs (along with their formats) are listed in Table 4-1 and described below.

First, the user determines which target types are to be considered during the EVAL run. Types are numbered from 1 to 30; the actual grouping of targets into types is, of course, determined at the time of SCENARIO execution, but

* See Appendix F, AIRS, Vol. I, for definition of the beta measure.



the user has the option of excluding any particular target type from the processing done by EVAL. This option is exercised by setting the input variable IHOLD(J), J = 1,30. The input values are simply IHOLD(J) = 1 if type number J should be included in the processing, and IHOLD(J) = 0 if it is to be excluded.

Second, the user specifies a maximum offset distance. If the distance from the aircraft to a particular target sighting is greater than this maximum, the sighting is not considered by EVAL. (This action does not affect other sightings of the same target, or other targets of the same type.) The input variable for this option is AMAXOF.

Last, the user may define up to five target groups, where a group, as explained above, is a collection of target types.* The input variables are:

NUM(I), I = 1, 5
NTY(I, N) I = 1, 5; N = 1, NUM(I)

where

NUM(I) is the number of target types in group I,

and

NTY (I, N) is the type number (1 to 30) of the Nth type of the Ith group.

Summary measures are computed and printed for each of the five groups.

* Unlike the previous EVAL routine, groups need not be disjoint. That is, a particular type may belong to more than one group.



The flexibility of EVAL can now be illustrated. As mentioned before, the EVAL routine is coded as a loop around the processing phase, so the user may evaluate a particular simulation result (as recorded on the Target/Sensor Output Tape) in many ways by stacking, one behind the other, sets of user option parameter cards. By using AMAXOF, the user can determine the effects of varying maximum offset distances on system performance in terms of target types and groups. Moreover, the user can evaluate system performance with respect to any collection of target types. For a quick look at system performance (i.e., total system detectability, identifiability, and localizability at each processing level), the user groups the relevant types together through the use of NTY and then reads the target group output tables. For a more detailed break out he simply "turns off" the target types he is not interested in (through the use of the IHOLD array) and receives the total EVAL output with only the right types considered.*

4.3 INPUT

EVAL uses both tape and punch card inputs. The tape input consists of the Target/Sensor Output Tape, previously referenced. The tape consists of records containing the necessary data, one record per target sighting. EVAL requires that the Target/Sensor tape be mounted on logical unit 2. The punch card input consists of 8 cards;

* The user option inputs NONPRE and IPREPL used in the previous EVAL to achieve preplanned vs. non-preplanned flexibility have been eliminated.



as many packs of 8 data cards as the number of desired loops through the program are needed. A blank card should be placed behind the last pack of 8 to end processing; the CDC operating system requires that an end-of-file card follow this blank one. Seven of the 8 input cards are concerned with the user option variables described above; the other is a card containing an alphanumeric header. The header is printed out in addition to the header obtained from the EXECUTIVE tape; thus, the user should use a different header card in each pack of 8 (if he uses more than one pack at a time) so that the EXECUTIVE header serves as an overall job title, and the header cards serve as run subtitles. The exact form of each input card as well as their order is shown in Table 4-1.

4.4 PROCESSING

The EVAL routine produces output via the following series of steps:

Step 0:

The user input options are read from punch cards.

Step 1:

The Target/Sensor Output Tape is positioned, and all variables and accumulating arrays are initialized.

Step 2:

The first physical record of a target sighting record is read from the tape.*

* A target sighting record on the Target/Sensor Output Tape, which contains all the needed data on the sighting, consists of 20 physical tape records; see reference to the tape given earlier.



Step 3:

A check of IHOLD and AMAXOF is made against the appropriate target sighting data. If the target sighting is not to be considered, all further physical records of the sighting are skipped, the tape is positioned at the beginning of the next sighting, and control returns to Step 2. System performance data is not affected. If, on the other hand, the sighting is to be considered, processing continues with Step 4.

Step 4:

The target sighting data broken out by sensors is read from the tape.* A check is made to determine whether at least one sensor had the target sighting within its field of view (FOV). If not, all further records are skipped (as in Step 3) and control returns to Step 2 for the processing of a new sighting; if so, the data is assimilated into the proper accumulating arrays. This consists of accumulating into arrays indexed by the sighting's target type number (which will produce the effectiveness measures of types in sighting units) and by the sighting's target number (which will allow the computation of target measures conjoined from individual sightings, and eventually produce type measures in target units).

Step 5:

Overall system performance data which has been

* Next 14 physical records.



integrated over sensors by EXECUTIVE are next read in by EVAL and accumulated into arrays as in Step 4.* Control then returns to Step 2 to begin the processing of the next target sighting. If, however, no more sightings remain on the tape, control goes to Step 6.

Step 6:

With the processing of target sightings complete, the accumulating arrays indexed by target number are processed to form target measures - that is, measures conjoined over sightings of a particular target.

Step 7:

The target measures are accumulated into types. At this point then there are two kinds of arrays indexed on type -- those containing target unit data and those with sighting unit data. The latter were formed in Step 4, the former in this step.

Step 8:

All arrays of both kinds indexed on type are processed to form final type measures in both target and sighting units.

Step 9:

The type measures are then integrated to form overall system measures in both units. Note that although

* This input consists of the last five physical records.



type measures are being integrated, the integration is done in such a way that the system measures are in fact taken over targets and sightings, not over targets and sightings first averaged into types. For ease of output and internal indexing, these final measures are given the label "Target Type 31" (there are only 30 real types).

Step 10:

In accordance with the user defined NTY array, the target and sighting unit measures of the appropriate types are integrated to form the target group measures. This integration is performed similarly to that of Step 9; this results in properly averaged measures.

Step 11:

The computed measures are outputted.

Step 12:

If the next card in the user punch card data deck is blank, the EVAL program ends and control is passed to the CDC monitor. Otherwise control goes to Step 0 for another processing of the same tape with different user options.

The processing described in Steps 0 - 12 is flow-charted in Figure 4-1. During this processing, the EVAL routine uses the disk for intermediate storage and employs the NAVAIRDEVGEN disk software. All disk communications are handled by two EVAL subroutines entitled GET and PUT. The former is a two argument function subprogram, and the latter



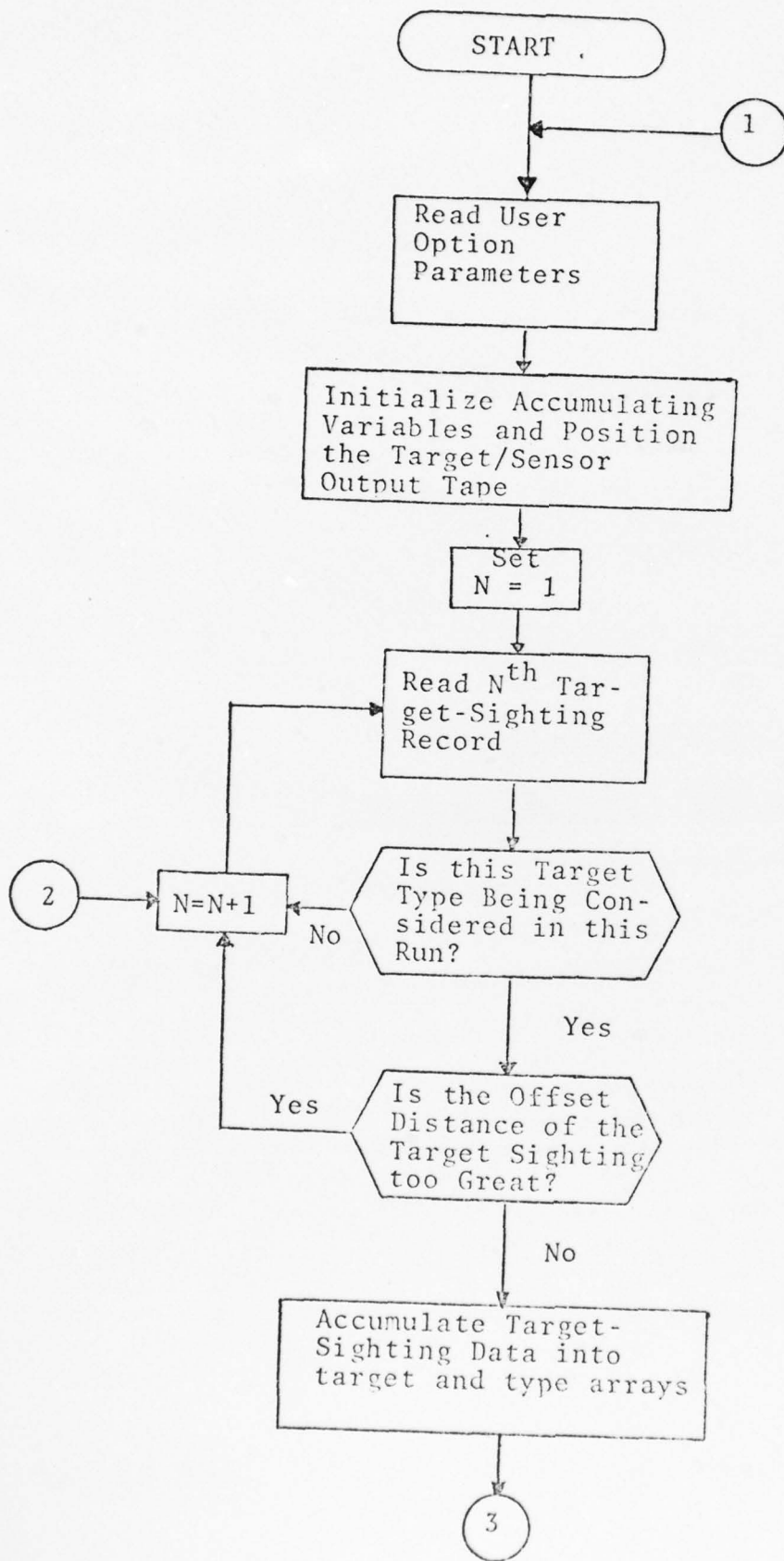


Figure 4-1. EVAL Routine



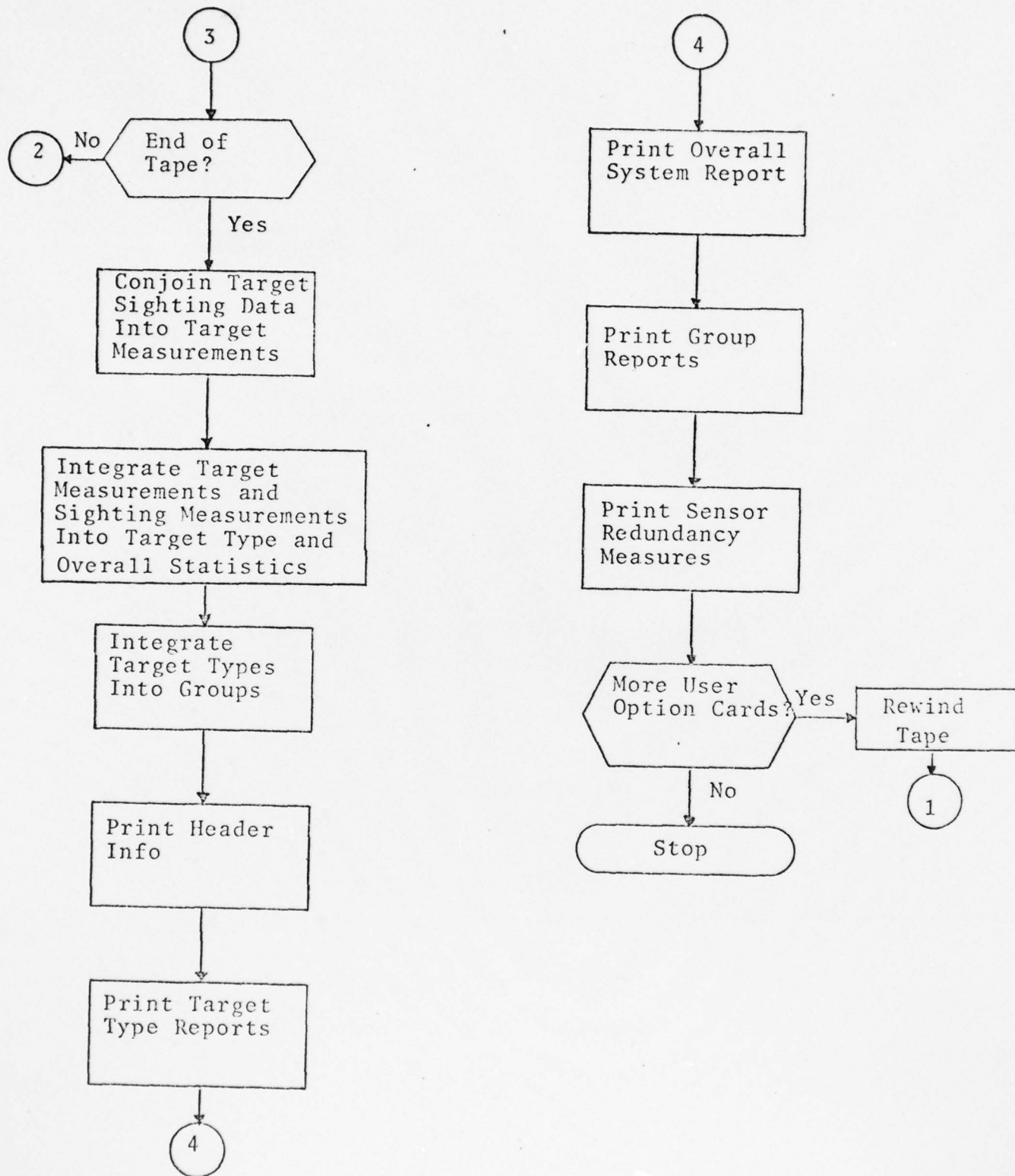


Figure 4-1. EVAL Routine



a subroutine subprogram. GET and PUT perform disk allocation, maintain a disk memory map through the use of COMMON variables, compute disk optimization, and make all calls to disk software. EVAL requires the disk to be defined as logical unit 14.

4.5 COMPUTATIONS

The following quantities are computed by the above described processing. The computations, except where indicated, are straight-forward averaging or summing of data contained on the Target/Sensor Output Tape.

Data broken out by sensor and type:

- (1a) The number of times targets of the particular type fell within the FOV of the sensor.
- (1b) The number of times target sightings of the particular type fell within the FOV of the sensor.
- (2a) The mean probability that the targets were not masked by terrain.
- (2b) The mean probability that the target sightings were not masked by terrain.
- (3a) The mean probability that the particular sensor was not non-operational when viewing the targets.
- (3b) The mean probability that the particular sensor was not non-operational for the target sightings.



- (4a) The mean probability that the targets were not obscured by clouds.
- (4b) The mean probability that the target sightings were not obscured by clouds.
- (5a) The expected number of times the targets were detected at levels 1, 2, 3, and 4.
- (5b) The expected number of times target sighting detections were made at levels 1, 2, 3, and 4.
- (6a) The expected number of times the targets were identified at levels 1, 2, 3, and 4.
- (6b) The expected number of times target sighting identifications were made at levels 1, 2, 3, and 4.
- (7a) The mean conditional CEP in feet of the targets.
- (7b) The mean conditional CEP in feet of the target sightings.
- (8a) The beta measure of sensor redundancy for targets.
- (8b) The beta measure of sensor redundancy for target sightings.



Concerning items (2a), (3a), and (4a), the probability for a single target (i.e. one of the valves averaged to form the indicated mean) is defined as the probability of success on all sightings of the target. Note that items (2a), (2b), (3a), (3b), (4a), and (4b) are means of the probabilities of non-independent events; care should be taken in using them. Concerning items (5a) and (6a), an expected detection or identification of a single target is defined as the expected detection or identification on at least one sighting of the target. Concerning items (7a) and (7b), the CEP combining algorithm (Paragraph 3.3.4, AIRS, Vol. I) is used on sighting CEP's to produce a target CEP.* Information on items (8a) and (8b) is found in Appendix F, AIRS, Vol. I; it is computed similarly for targets and sightings. Since the Target/Sensor Output Tape contains only individual sighting records, the conjoining over sightings into single target measures required by (2a), (3a), (4a), (5a), and (7a) is done by EVAL (Processing Step 6).

Data broken out by type:

- (9) Total (i.e., conjoined over the sensors)
target unit and sighting unit mean

* An investigation was made to determine how the approximation embodied in the CEP combining algorithm fared when applied to the small number of sightings of a particular target, and also the feasibility of using exact solutions in this particular case. It was concluded that although exact solutions could be employed, it would not be worth the effort because the approximation appeared quite sound. The pathological cases turn out to be not those with a small number of measurements, but rather those with grossly unequal measurements.



detectability at each of the four levels.

- (10) Total target unit and sighting unit mean identifiability at each of the four levels.
- (11) Relative target and sighting mean CEP at each of the four levels.
- (12) Total target and sighting mean CEP at each of the four levels.

Individual sighting total measures are taken from the Tape (Processing Step 5); individual target total measures are formed in the same way as (5a), (6a), and (7a).

4.6 OUTPUT

The printed reports generated by a single run of EVAL are, in order:

(a) A header page containing job title, run title, the numbers of the target types being considered, and the maximum offset distance.

(b) Pages of tables containing the target type statistics for each type considered (one page per type). The statistics consist of data items (1a) through (12)* and the additional information:

- . The number of targets being considered in the target type.
- . The number of target sightings being considered in the target type.

* At the present time, item (8) is not printed.



- . The number of targets of the type falling into the FOV of at least one sensor.
- . The number of target sightings of the type falling into the FOV of at least one sensor.

(c) A one page table containing the overall system performance measures (target type #31) in the same format as the individual type tables, with the exception of data item (8).

(d) Two pages containing the overall system redundancy measures in both sighting and target units (data item (8)).

(e) Two pages containing the group statistics, which include items (10), (11), and (12) only. These pages also list the target types included in each target group.

4.7 MISCELLANEOUS

The EVAL routine is coded in FORTRAN, well-commented, and quite readable. To aid in further understanding the code, the implementers have used certain prefixes and suffixes to designate certain kinds of variables:

| <u>Code</u> | <u>Meaning</u> |
|-------------|--|
| ____S | A variable being used to accumulate sighting unit data. |
| ____T | A variable being used to conjoin sighting data into target measures. |



| <u>Code</u> | <u>Meaning</u> |
|-------------|---|
| ___F | A variable being used to integrate over targets to form target unit data. |
| A___ | A variable containing data integrated over sensors. |
| G___ | A variable containing data integrated into groups. |

Moreover, when used as array subscripts, certain integer constants have reserved meanings: IT always refers to target type, L to level number, N to group number, I to target number, and J to sensor number.

Furthermore, the variables have been made as mnemonic as possible. For example then, the variable APDS (IT,L) would be the total (integrated over sensors) probability of detection in sighting units for level L and target type IT.



Table 4.1

EVAL CARD INPUTS

| Card Number | Columns | Variable Name | Format | Comments |
|-------------|-----------|--------------------------------|------------|---|
| 1 | 1-30 | IHOLD(IT), IT=1,30 | 3011 | User punches 30 ones and zeros. The one or zero in the j^{th} column is the value of IHOLD(j), indicating the inclusion or exclusion of type j . |
| 2 | 1-72 | LABEL | 18A4 | User punches 72 columns of free format alphanumeric to be used as job subtitle. |
| 3 | 1-10 | AMAXOF | F10.0 | User punches the maximum offset distance anywhere in first ten columns in free format. Decimal point must be included. |
| 4-8 | 1-2,11-40 | NUM(J),NTY(J,N), N=1,NUM(J) | I2,8X,30I2 | These 5 data cards represent target groups 1 to 5. For the j^{th} group, user punches the number of types in group j in the first 2 columns of the j^{th} card in I2 format (i.e., a "3" is punched "03"), and then beginning in columns 11-12 punches the type numbers (no separating commas or blanks) in I2 format, putting in as many type numbers as the number punched in the card's first two columns. |

SECTION V

SENSOR MODEL IMPROVEMENTS

5.1 INTRODUCTION

Analytics was requested to make improvements to the various sensor models reported in the AIRS, Vol. I. These improvements are discussed in this section.

Briefly, the following improvements have been made to the sensor models:

IR and FLIR: These models have been improved by allowing for image motion (i.e., improper V/H compensation) with respect to sensor motion to degrade detectabilities and identifiabilities.



SLR: This model has been improved by allowing for the use of either synthetic or real aperture processing. Also considered is the fact that only a certain range interval is recorded on film (i.e., only a certain part of the actual field of view).

MTISLR and MTIFLR: These sensor models have been improved by taking into account additional equipment parameters such as (1) the actual sensor response as a function of the doppler shift of signals received from a target, (2) the number of delay lines, and (3) other such parameters. Furthermore, other effects of the environment such as the direction and speed of rainfall are considered.

ECM: This model now explicitly considers the possibility that signals will not be detected because of the density of the EM environment.

PHOTO: The following improvements have been made and incorporated into this model

image motion may now degrade camera performance, especially the identifiability of targets.

the effects of atmospheric transmissivity and backscatter on night photography are now considered.

for night photography, the illuminator source, power, directivity, distance from target and camera, and other associated parameters are now considered.

a more realistic computation for contrast during daylight hours.

independence of cloud cover probability on successive frames has now been discarded; dependence is considered.



These improvements substantially improve the models and extend the capabilities of the AIRS Model by allowing consideration of parameters heretofore either not treated at all or treated only superficially. The IR and FLIR improvements are discussed in Paragraph 5.2 of this report, and SLR improvements are discussed in Paragraph 5.3. The MTISLR and MTIFLR improvements are the topics of Paragraphs 5.4 and 5.5, respectively. Improvements in the ECM model are discussed in Paragraph 5.6 and those in the PHOTO model in Paragraph 5.7.

5.2 IR AND FLIR

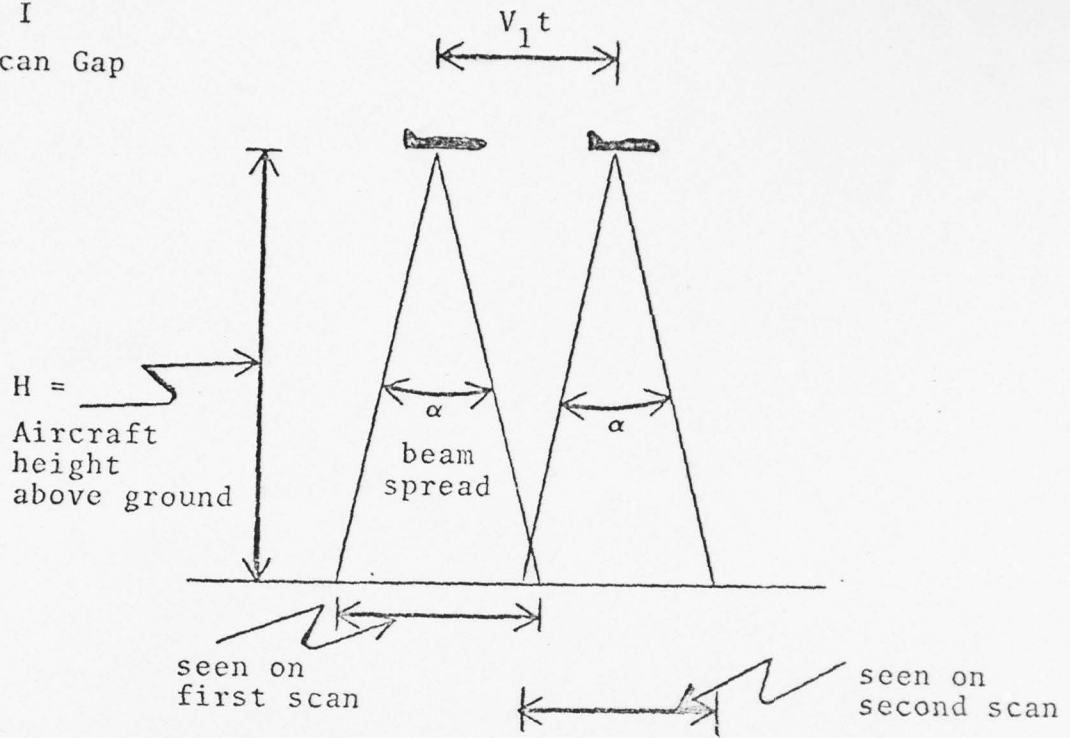
5.2.1 Introduction

An IR or FLIR sensor will occasionally miss detecting a target because the sensor has not been properly adjusted to take into account the interrelated effects of the aircraft velocity and height above ground.

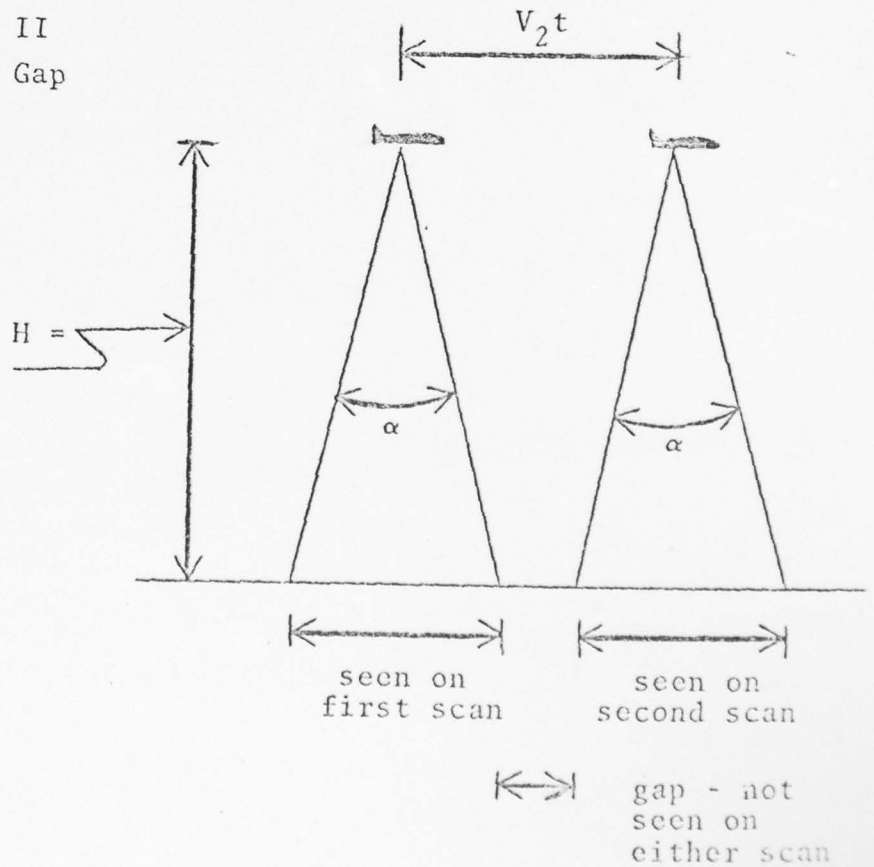
Each time the sensor's mirrors rotate, a path is traced out on the ground (the IR can, at least potentially, "see" a target that falls within this path). The thickness of this path on the ground is a function of three parameters: the aircraft height above ground, the ground offset distance from the aircraft vertical, and the angular beam spread of the detector. A short time later, as the mirrors again rotate, a second path is traced on the ground. Since the aircraft has moved forward during the time between scans, the second scan will not sweep over the same ground as the first. If the aircraft velocity is too great, the two paths do not overlap and there is a gap between successive scans which the IR does not "see". Figure 5-1 illustrates pictorially the effect of the V/H ratio.



Case I
No Scan Gap



Case II
Scan Gap



PARAMETERS

Common to both cases

H = height of aircraft

t = time between successive scans

α = beam spread

Case I

V_1 = aircraft velocity

Case II

V_2 = aircraft velocity

$V_2 > V_1$

Figure 5-1a
Illustration of Scan Gap - Vertical



AD-A039 577

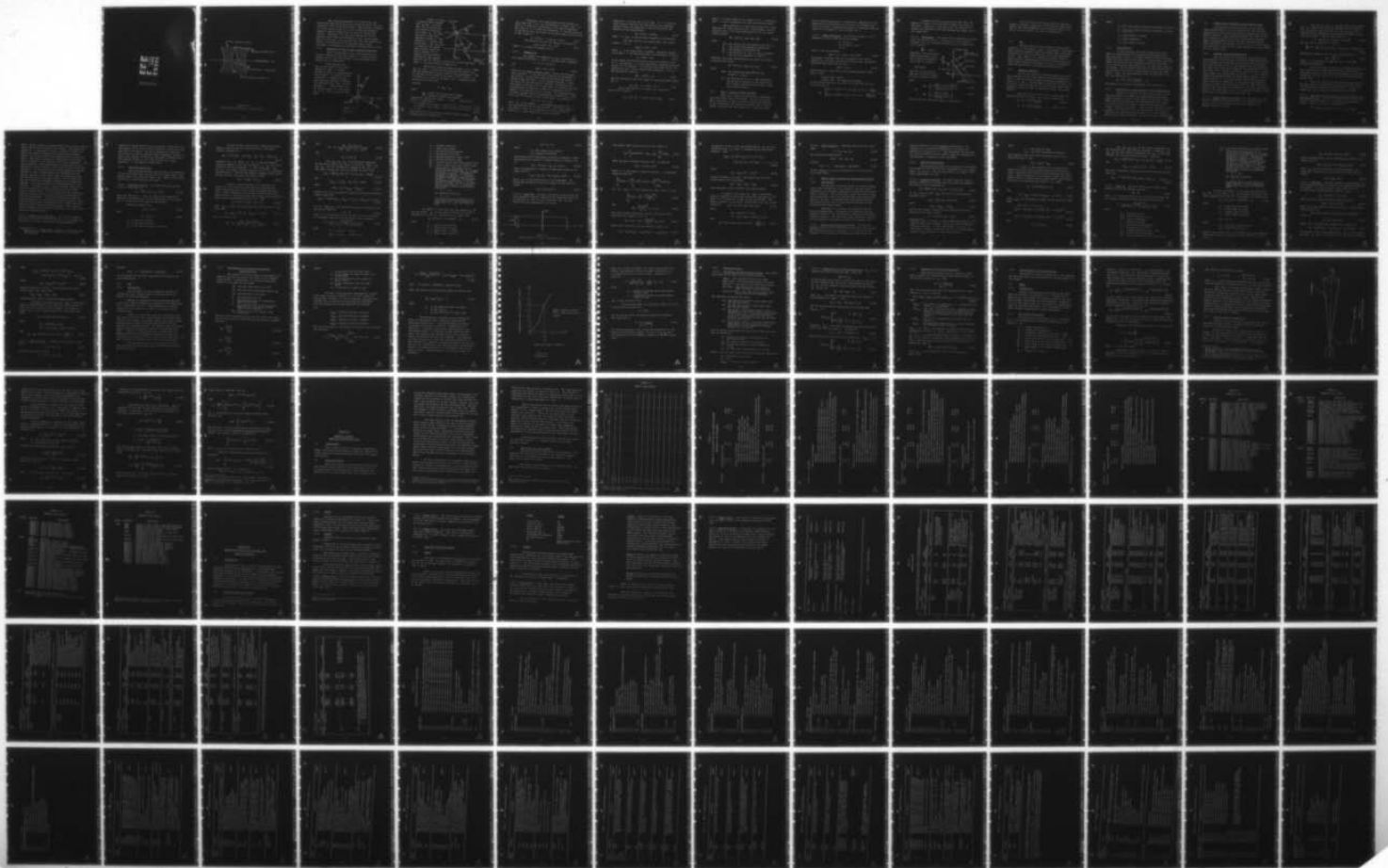
IMPROVEMENTS AND MODIFICATIONS OF THE AIRS PERFORMANCE
MODEL(U) ANALYTICS INC TINTON FALLS N J
S F MARTIN ET AL. 27 FEB 70 1010-1 N62269-69-C-0532

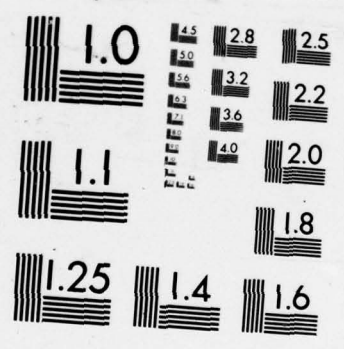
2/3

UNCLASSIFIED

F/G 15/4

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

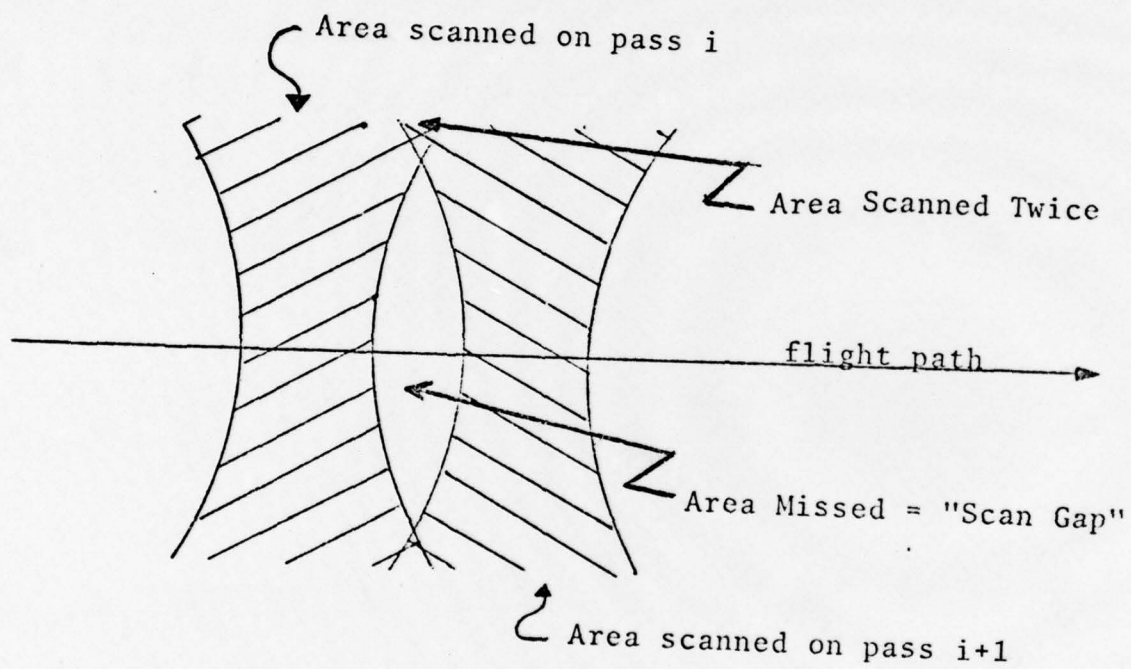


Figure 5-1b
 Illustration of Scan Gap - Ground Plane



The following paragraph will explore how this velocity/height/time-between-scans mismatch affects the performances of the IR and FLIR sensor. Specifically, Paragraph 5.2.2 will define terms to be used and develop geometric equations which are applicable to both the IR and FLIR sensors. Paragraph 5.2.3 will then develop for the IR, equations which yield the probability that a given target does not fall into a scan gap and shows how this probability affects the detectability of that particular target. Paragraph 5.2.4 presents an analogous treatment for the FLIR.

5.2.2 Definition of Terms, Basic Geometric Equations

First, an expression will be developed for the aircraft location at the time a point P on the ground is scanned by the IR or FLIR sensors. The most general case, slewed FLIR, is considered.

First consider the axis of the sensor to be slewed through an angle ψ in the horizontal plane, ψ being positive to the right. In Figure 5-2, the subscripts A denote aircraft axes and the subscripts B denote the coordinate axes after rotation through ψ . The aircraft is at the common origin O. The common Z_A or Z_B axis is positive downward.

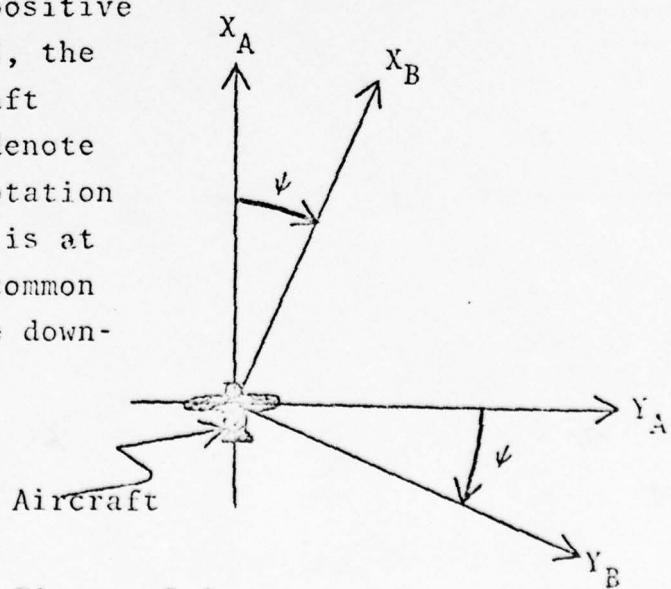


Figure 5-2

Plane View



Figure 5-3 shows a vertical plane through the X_B axis. In ordinary IR, the mirror axis of rotation is horizontal, about X_B . In FLIR, the axis is tilted up through an angle θ . The subscript C denotes the tilted axis. The Y_B axis is common to the coordinate systems before and after tilting. It is assumed that the mirrors look out at right-angles from the axis of rotation, rather than at some arbitrary angle α as shown dotted in Figure 5-3.

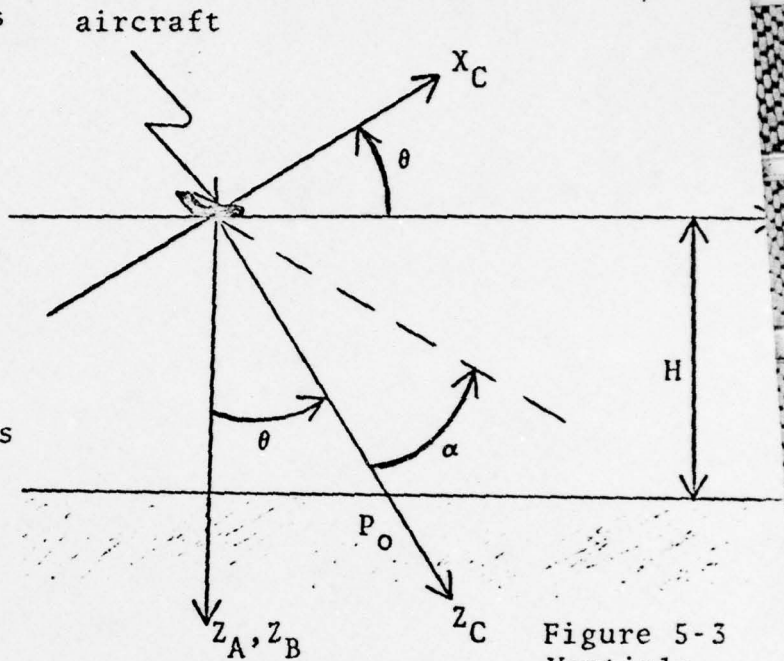


Figure 5-3
Verticle
Plane

The mirrors rotate through an angle $\phi = \omega t$ about the X_C axis. As they do, the intersection between OZ_C and the ground plane traces a path in the ground plane. This is the path of the point in the center of the "beam". P_0 in Figure 5-3 is part of the path. Let P denote an arbitrary point on this path.

Letting:

$$H = H_{AC} - H_T$$

where

H_{AC} = height of aircraft above ground

H_T = height of target above ground

resolutions through the angles θ , ϕ , and ψ give for the point P coordinates:

$$X = H(\sin \theta \cos \phi \cos \psi - \sin \phi \sin \psi) / \cos \theta \cos \phi \quad (5.1a)$$

$$Y = H(\sin \theta \cos \phi \sin \psi + \sin \phi \cos \psi) / \cos \theta \cos \phi \quad (5.1b)$$

$$Z = H, \quad (5.1c)$$

where X, Y , and Z are in the aircraft coordinate system, X being along the flight line.



Ordinarily, the target position with respect to the flight line, i.e., its Y-coordinate, is known, and it is desired to find the X-coordinate at the time of sighting. The value of X is found by eliminating ϕ between equations (5.1a) and (5.1b); the result for a point target at the center of the "beam" is:

$$X = (H \tan \theta - Y \sin \psi) / \cos \psi \quad (5.2)$$

The range at the time the target is scanned is:

$$R(Y) = (H^2 + X^2 + Y^2)^{1/2} \quad (5.3)$$

where X is given by equation (5.2).

5.2.3 Ordinary IR

In ordinary IR, equations (5.1a), (5.1b) and (5.1c) are simplified because ψ and θ are both zero, yielding:

$$X = 0 ; Y = H \tan \phi$$

and

$$R(Y) = (H^2 + Y^2)^{1/2} \quad (5.4)$$

There are two common scanning modes. In one the detectors scan in unison: ϕ has the same value for all detectors at any instant. In the other mode the detectors are evenly spaced around the cycle. If the angular rotation ω does not match the aircraft forward velocity, the overlap (if ω too large) or the gap (if ω too small) is evenly distributed between adjacent detectors if they are staggered, and is lumped if the detectors scan in unison. The staggered method is chosen as more nearly representative of today's IR. Therefore, the j^{th} detector "sees" at the angle ϕ_j , given by:

$$\phi_j = \omega t + 2\pi j / N_D$$

where N_D is the number, ω the angular frequency, and t the time between scans of the detector. Since the staggered scan mode is used, it is unnecessary to assign different angles of α (see Figure 5-3) to the different



detectors; α is zero for all of them. If V is the aircraft forward velocity, the beam centers for successive detector-scans are separated in the X-direction by the distance in the ground plane,

$$\Delta X = VT/N_D = 2\pi V/\omega N_D \quad (5.5)$$

where $T = 2\pi/\omega$ is the period of rotation of the mirrors.

The beam width in the ground plane, for a point target at P , is

$$\delta R(Y) = \delta(H^2 + Y^2)^{1/2}$$

where δ is the beam width in radians. For point targets at distance Y off the flight path the difference U , where

$$U = \delta R(Y) - \Delta X \quad (5.6)$$

is the amount of overlap between successive detector scans if U is positive; U is the gap between successive detector scans if it is negative. In the event that a gap occurs, the probability that a point target with coordinate Y is in the gap between scans is

$$(\Delta X - \delta R(Y)) / \Delta X \quad (5.7)$$

and the probability that the target is scanned and not missed, P_N , is

$$P_N = \text{Min} \{ 1, \delta R(Y) / \Delta X \} \quad (5.8)$$

P_N is next adjusted to account for targets not being "point targets":

$$P_N = \text{Min} \left\{ 1, \left(R(Y) + \frac{L}{2} \right) / \Delta X \right\} \quad (5.9)$$



where L is the length of the target in the X direction and Y is the Y -coordinate for the center of the target.

This probability is used multiplicatively in the equations for total detectability. Specifically, for processing level 1, the total detectability, PD , of a given target becomes:

$$PD = PDT (P_1) (P_2) (K_1) (P_N) \quad (5.10)$$

where:

- PDT = the conditional detectability for level 1
- P_1 = the terrain non-shadowing probability
- P_2 = the equipment up probability
- K_1 = the decision (0 = no, 1 = yes) of whether the IR sensor operates in level 1.

Similarly, the total detectability for levels 2,3, and 4 of processing becomes

$$PD = PCD (P_1) (P_2) (K_1) (P_N) \quad (5.11)$$

where:

- PCD = the conditional detectability for levels 2, 3, and 4
- K_1 = the decision (0 = no, 1 = yes) of whether the IR sensor operates in the level (2,3, or 4) being considered and all other terms are as defined above.

5.2.4 FLIR -- Forward Looking Infrared

There are two modes in which FLIR is operated: a not-slewed mode, and a slewed mode. For the not-slewed mode, the sensor is always directed forward and downward. In the slewed mode, the sensor is pointed toward a known target, typically off the flight line. These two modes



must be modeled separately. Although the computation of the probabilities of detection for each mode are somewhat modified, the method of combining the modes is unchanged from that reported in Paragraph 3.2.8.1 of AIRS, Vol. I.

5.2.4.1 FLIR, Not-slewed. For FLIR not-slewed, ψ is 0; equations (5.1a), (5.1b) and (5.1c) become:

$$\begin{aligned} X &= H \tan \theta \\ Y &= H \tan \phi / \cos \theta \\ Z &= H \end{aligned}$$

and equation (5.3) becomes

$$R(Y) = (Y^2 + H^2(1 + \tan^2 \theta))^{\frac{1}{2}} \quad (5.12)$$

The general reasoning that led to equation (5.7) may be applied here also but instead of the beam width, the ground-projected beam width must be used:

$$R(Y) / \sin \theta \quad (5.13)$$

And in place of $L/2$, half of the ground-projected length must be used

$L/2$ for flat targets

$(L/2) / \sin \theta$ for spherical targets,

so that the probability, P_N , that the target does not fall in a scan gap is:

$$P_N = \begin{cases} \text{Min } \{1, (\delta R(Y) + L \sin \theta/2) / \Delta X \sin \theta\} & \text{Flat Targets} \\ \text{Min } \{1, (\delta R(Y) + L/2) / \Delta X \sin \theta\} & \text{Spherical Targets} \end{cases} \quad (5.14)$$



Although equations are given for both flat and spherical targets, it was decided to model all targets as spherical. Equations (5.10) and (5.11) are then used to compute the probability the FLIR detected the target in the not-slewed mode.

5.2.4.2 FLIR Slewed. For slewed FLIR, equations (5.1) and (5.3) are used as written. The point P still traces a straight line, but the slope of the line is no longer zero. It is given by

$$\frac{dX}{dY} = -\tan \psi$$

Therefore, the distance between beam centers is not ΔX as given by equation (5.5), but is actually:

$$\Delta X |\cos \psi|$$

and this is the distance that must be used in place of ΔX in equation (5.13).

Then

$$P_N = \text{Min} \left\{ 1, \frac{(\delta R(Y) + L \sin(\frac{\theta}{2}))}{(|\cos \psi|) \Delta X \sin \theta} \right\} \quad (5.15)$$

$$\text{Min} \left\{ 1, \frac{(\delta R(Y) + (\frac{L}{2}))}{(|\cos \psi|) \Delta X \sin \theta} \right\} \quad (5.16)$$

for flat and for spherical targets, respectively.

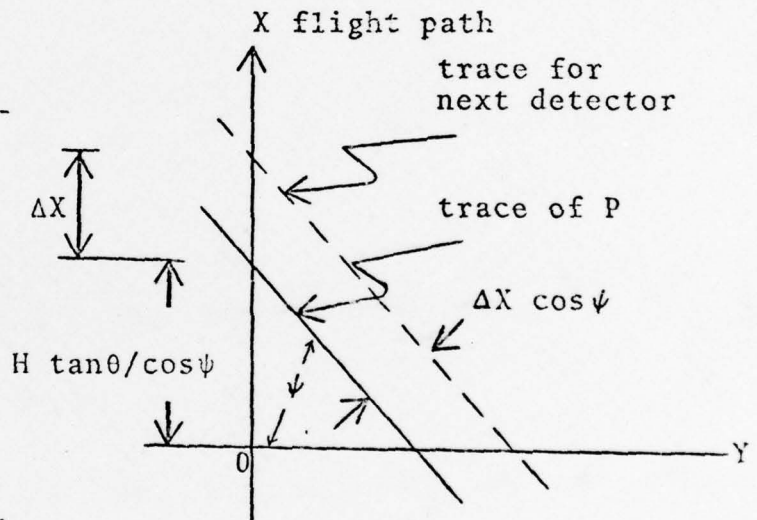


Figure 5-4
Ground Plane View



As in the case of FLIR not-slewed, a spherical target is assumed. Equations (5.10) and (5.11) can now be used to give the probability of detection for FLIR in (1) level 1, and (2) levels 2,3, and 4, respectively.

5.3 SLR

The SLR model has been extended to allow either synthetic or real aperture radars to be modeled. Heretofore, only synthetic aperture radar was modeled, and cross-range resolution was held to be the same in all four processing levels. Now, however, if a synthetic aperture radar is being modeled, consideration is given to the fact that the cross-range resolution attainable in level 1 is different from that attainable in the other processing levels.

5.3.1 Synthetic Aperture

If the user specifies synthetic aperture, he must also stipulate (1) the cross-range resolution attainable in level 1, and (2) the cross-range resolution attainable in levels 2, 3, and 4. The attainable resolution in level 1 is, of course, less than that of the other levels; this is due primarily to lack of time to adequately process the signal returns.

Equation (3.36) of AIRS, Vol. I, which gives the ground resolution cell size, A_r may be rewritten as:

$$A_r = j_1 \left(\sqrt{\rho^2 + h(2R+h)} - \rho \right) \quad \text{Level 1.}$$

$$A_r = j_2 \left(\sqrt{\rho^2 + h(2R+h)} - \rho \right) \quad \text{Level 2,3 or 4.}$$



where

j_1 = the cross-range resolution attainable in level 1

j_2 = the cross-range resolution attainable in levels 2, 3 or 4.

ρ = ground range to target

h = range resolution

R = slant range to target

5.3.2 Real Aperture

If real aperture (sometimes called brute force) radar is being modeled, the resolution attainable in all four processing levels is a direct function of both the beam width and slant range to the target. In particular, the cross range resolution for real aperture is given by βR ; where β is the half-power beam width and R is the slant range to the target. The half-power beam width is selected because it is consistent with what is usually meant by the term "beam width". Thus, rewriting equation (3.36) of AIRS, Vol. I for the real aperture case:

$$A_T = \beta R \left(\sqrt{\rho^2 + h(2R+h)} - \rho \right)$$

The symbols are defined in Paragraphs 5.3.1 and 5.3.2.

5.3.3 Detectability, Identifiability, and Localizability

A check was added in the SLR model to make certain that the target fell within the maximum and minimum slant ranges recorded on film. If the target did not fall within these limits, detectability and identifiability for levels 2, 3, and 4 were set to zero, as these levels require the targets' appearance on film. Also, if real aperture is used Δ_1 (eqn. 3.74 of AIRS Vol. I) is set to zero. With these exceptions, all equations given in AIRS, Vol. I for computing detectability, identifiability, and the CEP remain unchanged.



5.4 MOVING TARGET DETECTION BY SIDE LOOKING RADAR

The detection of moving targets by side looking radar (MTISLR model) has been refined by the more precise calculation of previously approximated equipment and environmental variables. The calculations permit the model to take into account the effects of radar instabilities, aircraft speed, precipitation particle velocity, and wind clutter. These refinements are available at the cost of the user having to provide about twice as many input parameters as were needed for the simpler model.

5.4.1 Outline of Revised Computations

With the aid of two assumptions (one dealing with the elimination of the effect of aircraft motion from the Doppler frequency shifts and the other dealing with the nature of the MTI filter), which are developed below, the output of the radar processing can be computed for the return from any resolution unit. For any particular resolution cell, containing a target, the output power is called S . If the target is replaced by background and the output power computed, the result is called C . Also the response of the filter to the radar noise can be computed, if the input noise characteristics are known: call the output noise N . Then the ratio $S/(C+N)$, can be used as the argument for the cubic polynomial given in the AIRS report, Vol. I., as equation (3.103), p.3-50, which gives the probability of detection P_D .

5.4.1.1 Doppler Shift of the Echo. For any target, or for any area-element of precipitation if any, equations (5.17), (5.18), and (5.19) provide the means for computing the Doppler shift of the echo.



Let (X_A, Y_A, Z_A) be the position of the aircraft and $V_A = dX_A/dt$ its velocity, assumed in the X-direction. Let (X, Y, Z) be the coordinates and (V_X, V_Y, V_Z) the velocity-vector components of an object from which a radar echo is received. Then the radar range is

$$R = [(X-X_A)^2 + (Y-Y_A)^2 + (Z-Z_A)^2]^{1/2} \quad (5.17)$$

and the rate of change with time is:

$$\frac{dR}{dt} = \dot{R} = \left(\frac{1}{R}\right) [(X-X_A)(V_X-V_A) + (Y-Y_A)V_Y + (Z-Z_A)V_Z] \quad (5.18)$$

The Doppler frequency shift in the received echo is:

$$f_D = -2\left(\frac{\dot{R}}{c}\right) f_R \quad (5.19)$$

Where c is the speed of light and f_R is the radar transmitted frequency.

Since the power in the echo is expressible for each such element via the computation of radar reflectivities, the power spectrum of the echo can be computed for any given resolution cell by summing over all the reflecting elements in the cell.

After the spectrum of the echo has been computed, the next step is to compute the output of the radar filter in response to an input with that spectrum. In order to compute the filter output two assumptions are needed.

5.4.1.2 Elimination of the Effect of Aircraft Motion from the Doppler Shifts. The first assumption deals with how the effect of aircraft motion is eliminated from the Doppler shifts. Equation (5.18) may be expressed as

$$\dot{R} = (\text{radial component of } V) - V_A \cos(\theta_{A,R}) \quad (5.20)$$



where (V_A, R) denotes the angle between the aircraft velocity vector and the range vector to the target. The radial component of V , the target velocity, is what is wanted; the other term, which represents the effect of the aircraft motion, is an error term to be eliminated to the extent possible. The extent to which the elimination of the error term is possible is the subject of the first assumption. The way in which the error-term reduction is performed may be considered to be by control of the receiver local-oscillator frequency. To eliminate the error-term completely would be possible if only a single point were illuminated at any instant, giving a unique value (over the resolution cell) for the correction term $V_A \cos (V_A, R)$. Even in that case, the local-oscillator frequency would have to be modulated rapidly. It is assumed that this rapid modulation is not feasible. The angle (V_A, R) varies with the range sweep, but its variation with the azimuth beam angle is much larger and much slower. It is assumed that the correction will be synchronized with the scan of the antenna but not with the range sweeps. At each beam position, therefore, the correction will be exact for one target position, taken to be on the ground at the middle of the azimuth beam angle halfway between minimum and maximum range. The resulting error in Doppler shift is then determined for any other position of the echoing object.

5.4.1.3 Nature of the MTI Filter. The second assumption deals with the nature of the MTI filter. It is assumed that the filter is of the form described in Modern Radar* as

* Berkowitz, R. S. Modern Radar: Analysis, Evaluation, and System Design. John Wiley & Son, New York, (1965). pp. 495, 496.



composed of single-delay filters in cascade. The filter output depends on the filter transfer function as well as on the spectrum of the input. The second assumption is dictated by a desire to keep the program options manageable and yet to permit some choice; in this case, the number of delay lines. The transfer function is then the function of a single parameter N , the number of delay lines.

5.4.2 Detailed Computations

This paragraph contains the equations for computing (1) the spectrum of the received echo; (2) signal power (S), clutter power (C), and noise power (N) input to the sensor; and (3) S , C , and N output by the sensor.

5.4.2.1 Frequency Spectrum. The resolution cell extends in the X -direction over

$$X_A - RB/2 \leq X_T \leq X_A + RB/2 \quad (5.21)$$

where the subscripts T and A refer to the target and aircraft, respectively, R is the slant range to the target, and B is the beam width angle in the radians.

Doppler frequency runs

$$-f_m \leq f \leq f_m \quad (5.22)$$

where

$$f_m = B f_R V_A / c \quad (5.23)$$

V_A is aircraft velocity

c is the speed of light

f_R is the radar transmitted frequency



For each target there must be computed the target Doppler frequency for entering the filter. The radial velocity component is:

$$V_{TR} = (1/R) \left[(X_T - X_A) (V_{TX} - V_A) + (Y_T - Y_A) V_{TY} \right] \quad (5.24)$$

(assuming $V_{TZ} = 0$) where $X_T - X_A$ is the instantaneous distance component along line of flight, $Y_T - Y_A$ the cross-flightline distance component, R the slant range, V_{TX} and V_{TY} the target velocity components, and V_A is aircraft ground velocity. Then for the Doppler frequency shift entering the filter, associated with target return,

$$f_T = -2 (f_R / c) V_{TR} \quad (5.25)$$

If there is precipitation, the resolution cell volume will also produce an echo from the precipitation, with a continuous power-density versus frequency characteristic. Three frequencies are calculated because the total clutter power is partitioned into three parts, each associated with a vertical beam angle segment ϕ_j ; then

$$\phi_3 = \arcsin \left[(H_A - H_T) / R \right] \quad (5.26)$$

where ϕ_{\min} is the depression angle for the top of the radar beam, and

$$\phi_j = \phi_{\min} + \left(\frac{j}{3}\right) (\phi_3 - \phi_{\min}), \quad j = 0, 1, 2 \quad (5.27)$$

For $j = 0, 1, 2, 3$ set:

$$X_j - X_A = \frac{(X_T - X_A) R \cos \phi_j}{\left[(X_T - X_A)^2 + (Y_T - Y_A)^2 \right]^{1/2}} \quad (5.28)$$



and

$$Y_j - Y_A = \frac{(Y_T - Y_A) R \cos \phi_j}{[(X_T - X_A)^2 + (Y_T - Y_A)^2]^{1/2}} \quad (5.29)$$

and

$$Z_j = R \sin \phi_j \quad (5.30)$$

Let V_{PX} , V_{PY} , V_{PZ} be the velocity components of the precipitation V_{PZ} positive downward. Where V_{PX} and V_{PY} are the wind-velocity components and V_{PZ} is one input constant for rain and another for snow. Let:

$$V_{P,j} = \left(\frac{1}{R}\right) \left[(X_j - X_A) V_{PX} + (Y_j - Y_A) V_{PY} + Z_j V_{PZ} \right] \quad (5.31)$$

and

$$V_{PE,j} = V_A (X_j - X_A) (1/R - 1/RC) \quad (5.32)$$

where

$$1/RC = 0.5 (1/R_{\max} + 1/R_{\min}) \quad (5.33)$$

Finally, the three frequencies associated with the partitioned clutter power are:

$$f_{PC,j} = -(f_r/c) (V_{P,j} + V_{PE,j} + V_{P,j-1} + V_{PE,j-1}), \quad j=1,2,3 \quad (5.34)$$

5.4.2.2 Power In. All power return can be characterized by the general equation:

$$PR = UV \quad (5.35)$$

where V is characteristic of the source of the return and U is common, regardless of the source, and is given by:

$$U = \frac{P_T P_{CR} \eta^2 \lambda^2 \beta \epsilon}{4\pi B^2 (\cot \omega_1 - \cot \omega_0)^2 (H_A - H_T)^4} \quad (5.36)$$

where

P_T = peak pulse power

P_{CR} = pulse compression ratio



η = antenna efficiency
 λ = radar wave length
 ϵ = precipitation attenuation
 B = horizontal beam width
 ω_1 = maximum depression angle = 90°
 ω_0 = minimum depression angle
 H_A = aircraft height above mean ground level
 H_T = target height above mean ground level
 β = the effective enhancement due to sweep-to-sweep processing. β is found by letting N be the effective number of sweeps processed. (If uniform weighting is employed N is actual. If shaded weighting is employed (e.g., linear) N is about half of actual, if parabolic weighting, N is two-thirds of actual. However, for input we take the effective N directly.) For incoherent processing including normal MTI

$$\beta = \sqrt{N}$$

For coherent processing

$$\beta = N$$

For pseudo-coherent processing (i.e., video-coherent or phase-insensitive processing) the \sqrt{N} case should be used.

To compute V for each case, the factors A_R and A_T are needed. A_R is the ground illuminated area for a background cell and A_T corresponds to a target cell.

$$A_R = BR \left[(\rho^2 + h(2R+h))^{1/2} - \rho \right] \quad (5.37)$$

where

B = horizontal beam width
 R = slant range to target
 ρ = ground range to target
 h = radar range resolution



$$A_T \equiv \sigma_T / r_T \quad (5.38)$$

where

σ_T = the target cross section

r_T = target reflectivity

The various power contributions may now be computed. Power corresponding to receipt of target return in a target cell is:

$$P_{TT} = U r_T \text{ Min } \{ A_R, A_T \} \text{ watts} \quad (5.39)$$

Power corresponding to receipt of background return in the target cell is:

$$P_{TB} = U r_B (A_R - \text{Min } \{ A_R, A_T \}) \text{ watts} \quad (5.40)$$

where r_B is the reflectivity of the background. The background resolution cells will produce in the area of a target:

$$P_B = U r_B A_R \text{ watts} \quad (5.41)$$

5.4.2.3 Power Out. The power coming out of the filter for each component of power returned to the resolution cells may be computed, so that the power spectrum $C(f)$ for the clutter from the background is as shown:

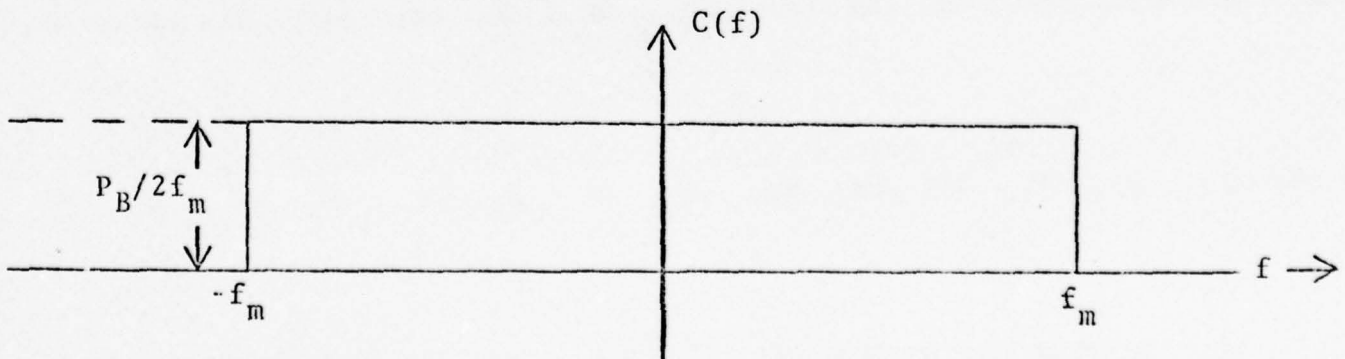


Figure 5-5
Power Spectrum - Clutter From Background



The clutter power coming out of the MTI filter is

$$Q_B = \int_{-\infty}^{\infty} C(f)G(f)df = (P_B / 2f_m) \int_{-f_m}^{f_m} G(f)df \quad (5.42)$$

Where the power transfer function $G(f)$ is given by

$$G(f) = (4 \sin^2 \pi f \tau)^N \quad (5.43)$$

where N is the number of delay lines and τ is the pulse repetition period.

$$\int_{-f_m}^{f_m} G(f)df = 4^N \int_{-f_m}^{f_m} \sin^{2N} (\pi \tau f) df = \frac{4^N}{\pi \tau} \int_{-\pi \tau f_m}^{\pi \tau f_m} \sin^{2N} f df$$

and, for $\pi \tau f_m \ll 1$ as is always the case, $\sin f \approx f$ and

$$\int_{-f_m}^{f_m} G(f)df = \frac{4^N}{\pi \tau} \cdot \frac{2(\pi \tau f_m)^{2N+1}}{2N+1} \quad (5.44)$$

then

$$Q_B = \frac{(2\pi \tau f_m)^{2N}}{2N+1} P_B \text{ watts} \quad (5.45)$$

The filter output signal power is for a resolution cell containing the target at X_T, Y_T :

$$Q_T = P_{TT} G(f_T) + \frac{(2\pi \tau f_m)^N}{2N+1} P_{TB} \text{ watts} \quad (5.46)$$

Signal power resulting from precipitation clutter is:

$$Q_P = P_{PC1} G(f_{PC1}) + P_{PC2} G(f_{PC2}) + P_{PC3} G(f_{PC3}) \quad (5.47)$$



In equation (3.46) of the cited AIRS reports, C_G is to be identified with P_B above in equation (5.26) for present purposes. Then

$$P_{PCj} = K_2 [(\cot \phi_{j-1}) (2 + \csc^2 \phi_{j-1}) - (\cot \phi_j) (2 + \csc^2 \phi_j)] , \quad j = 1, 2, 3 \quad (5.48)$$

where

$$K_2 = P_B \sigma_R H^4 / 3 \sigma_G R^3 \quad (5.49)$$

using the symbols of (3.46). This partitions the total clutter power into three parts

$$P_{PC} = P_{PC1} + P_{PC2} + P_{PC3} \quad (5.50)$$

each associated with a vertical beam angle segment.

To compute noise power out (Q_N), a noise power input is required in watts referred to the same point as the powers P of equations (5.39), (5.40), and (5.48). This power is called P_N , in watts, spread evenly over the system bandwidth:

$$P_N = (4 \text{ E-15}) (\text{BW}) (\text{NF}) \text{ watts} \quad (5.51)$$

where

BW = bandwidth in MHz

NF = noise figure, absolute units.

Then

$$Q_N = P_N (\text{average value of } G(f)) = \frac{(2N)!}{(N!)^2} P_N \quad (5.52)$$



5.4.2.4 Ratio of Powers. Combining from above for signal power

$$S = Q_T + Q_N + Q_P \quad (5.53)$$

for clutter-plus-noise power

$$(C+N) = Q_B + Q_N + Q_P \quad (5.54)$$

Finally:

$$S/(C + N) = (Q_T+Q_N+Q_P) / (Q_B+Q_N+Q_P) \quad (5.55)$$

is the argument of the cubic polynomial of (3.103) of the cited AIRS report.

5.5 MOVING TARGET DETECTION BY FORWARD-LOOKING RADAR

5.5.1 Introduction

The detection of moving targets by forward-looking radar model (MTIFLR) has been refined by the more precise calculation of previously approximated equipment and environmental variables. The calculations permit the model to take into account the effects of aircraft speed and precipitation particle velocity. To achieve these refinements the user must provide about twice as many input parameters as were needed for the simpler model.

Paragraph 5.5.2 contains the equations for the detailed computations. Paragraph 5.5.3 discusses the programming changes to the existing AIRS SCENARIO and EXECUTIVE computer programs. The additional input parameters required by the changes to the model are given in Paragraph 5.5.4.

5.5.1.1 Outline of Revised Computations. The revised general computations for MTIFLR are identical to the changes for MTISLR discussed in Paragraph 5.4.1. Because of differences in the geometry of MTIFLR and MTISLR, there are



several differences in the detailed computations. The equations for the detailed computations for MTIFLR are presented in Paragraph 5.5.2. Many paragraphs are the same for the two sensors, but the authors judge the redundancy to be preferable to extensive cross references.

5.5.2 Detailed Computations

This paragraph contains the equations for computing the spectrum of the received echo (Paragraph 5.5.2.1); signal power (S), clutter (C), and noise power (N) input to the filter (Paragraph 5.5.2.3).

5.5.2.1 Frequency Spectrum. For each target the target Doppler frequency for entering the filter must be computed. The radial velocity* component is:

$$V_{TR} = \left(\frac{1}{R}\right) [(X_T - X_A) (V_{TX} - V_A) + (Y_T - Y_A) V_{TY}] \quad (5.56)$$

To V_{TR} must be added V_{TRE} , the error in correcting for aircraft motion.

$$V_{TRE} = V_A (X_T - X_A) (1/R - 1/R_C) \quad (5.57)$$

where

$$1/R_C = 1/R_{max} + 1/R_{min} \quad (5.58)$$

Then for the Doppler frequency shift entering the filter, associated with target return,

$$f_T = -2(f_r/c) (V_{TR} + V_{TRE}) \quad (5.59)$$

* Assuming $V_{TR} = 0$, $X_T - X_A$ is the instantaneous distance component along line of flight, $Y_T - Y_A$ the cross-flightline distance component, R the slant range, V_{TX} and V_{TY} the target velocity components, and V_A is aircraft ground velocity. R_{max} and R_{min} are radar range limits.



where

c = the speed of light
 f_R = the radar transmitted frequency

The frequency associated with background return in the resolution cell is f_B :

$$f_B = -2(f_T/c) V_{TRE} \quad (5.60)$$

If there is precipitation, the resolution cell volume will also produce an echo from the precipitation, with a continuous power-density versus frequency characteristic. Three frequencies are calculated because the total clutter power is partitioned into three parts, each associated with a vertical beam angle segment ϕ_j . Then:

$$\phi_3 = \arcsin[(H_A - H_T) / R] \quad (5.61)$$

and

$$\phi_j = \phi_{\min} + (j/3) (\phi_3 - \phi_{\min}), \quad j = 0, 1, 2 \quad (5.62)$$

where ϕ_{\min} is the depression angle for the top of the radar beam.

Set, for $j = 0, 1, 2, 3$

$$X_j - X_A = (X_T - X_A) R \cos \phi_j [(X_T - X_A)^2 + (Y_T - Y_A)^2]^{-1/2} \quad (5.63)$$

and

$$Y_j - Y_A = (Y_T - Y_A) R \cos \phi_j [(X_T - X_A)^2 + (Y_T - Y_A)^2]^{-1/2} \quad (5.64)$$

and

$$Z_j = R \sin \phi_j \quad (5.65)$$



Let V_{PX} , V_{PY} , V_{PZ} be the velocity components of the precipitation (V_{PZ} positive downward). Where V_{PX} and V_{PY} are the wind-velocity components and V_{PZ} is one input constant for rain and another for snow. Then, let:

$$V_{P,j} = \left(\frac{1}{R}\right) [(X_j - X_A) V_{PX} + (Y_j - Y_A) V_{PY} + Z_j V_{PZ}] \quad (5.66)$$

and

$$V_{PE,j} = V_A (X_j - X_A) (1/R - 1/R_C) \quad (5.67)$$

The three frequencies associated with the partitioned clutter power are:

$$f_{PC,j} = -(f_r/c) (V_{P,j} + V_{PE,j} + V_{P,j-1} + V_{PE,j-1}) \quad j=1,2,3 \quad (5.68)$$

5.5.2.2 Power In. All power return to the filter can be characterized by the general equation:

$$PR = UV \quad (5.69)$$

where V is characteristic of the source of the return and U is common, regardless of the source, and is given by:

$$U = \frac{P_T P_{CR} \eta^2 \lambda^2 \beta \epsilon}{4\pi B^2 (\cot \omega_1 - \cot \omega_0)^2 (H_A - H_T)^4} \quad (5.70)$$

where

- P_T = peak pulse power
- P_{CR} = pulse compression ratio
- η = antenna efficiency
- λ = radar wave length
- ϵ = precipitation attenuation
- B = horizontal beam width
- ω_1 = maximum depression angle = 90°
- ω_0 = minimum depression angle
- H_T = target height above mean ground level



H_A = aircraft height above mean ground level
 β = the effective enhancement due to sweep-to-sweep processing. β is found by letting N be the effective number of sweeps processed. (If uniform weighting is employed, N is actual. If shaded weighting is employed (e.g., linear), N is about half of actual. If parabolic weighting, N is two-thirds of actual. However, for input we take the effective N directly.) For incoherent processing, including normal MTI,

$$\beta = \sqrt{N}$$

For coherent processing

$$\beta = N$$

For pseudo-coherent processing (i.e., video-coherent or phase-insensitive processing) the \sqrt{N} case should be used.

In order to compute V for each case the factors A_R and A_T are needed. A_R is the ground illuminated area for a background cell and A_T corresponds to a target cell.

$$A_R = BR [(\rho^2 + h(2R+h))^{1/2} - \rho] \quad (5.71)$$

where

B = horizontal beam width
 R = slant range to target
 ρ = ground range to target
 h = radar range resolution

$$A_T \equiv \sigma_T / r_T \quad (5.72)$$

where

σ_T = the target cross section
 r_T = target reflectivity

Finally, the various power contributions may now be computed. Power corresponding to receipt of target return in a target cell is:



$$P_{TT} = U r_T \text{ Min } \{ A_R, A_T \} \text{ watts} \quad (5.73)$$

Power corresponding to receipt of background return in the target cell is:

$$P_{TB} = U r_B (A_R - \text{Min } \{ A_R, A_T \}) \text{ watts} \quad (5.74)$$

where r_B is the reflectivity of the background. The background resolution cells will produce in the area of a target:

$$P_B = U r_B A_R \text{ watts} \quad (5.75)$$

5.5.2.3 Power Out. The power coming out of the filter for each component of power returned to the resolution cells may be computed. The filter output signal power is for a resolution cell containing the target at X_T, Y_T :

$$Q_T = P_{TT} G(f_T) + P_{TB} G(f_B) \quad (5.76)$$

where the power transfer function $G(f)$ is given by

$$G(f) = (4 \sin^2 \pi f \tau)^N \quad (5.77)$$

where N is the number of delay lines and τ is the pulse repetition period.

The filter output corresponding to background return is:

$$Q_B = P_B G(f_B) \text{ watts} \quad (5.78)$$

Signal power resulting from precipitation clutter is:

$$Q_P = P_{PC1} G(f_{PC1}) + P_{PC2} G(f_{PC2}) + P_{PC3} G(f_{PC3}) \quad (5.79)$$

In equation (3.46) of the AIRS reports, C_G is to be identified with P_B above in equation (5.75), for present purposes.



Then

$$P_{PCj} = K_2 [(\cot \phi_{j-1}) (2 + \csc^2 \phi_{j-1}) - (\cot \phi_j) (2 + \csc^2 \phi_j)] , \quad j=1,2,3 \quad (5.80)$$

where

$$K_2 = P_B \sigma_R H^4 / 3 \sigma_G R^3 \quad (5.81)$$

using the symbols of (3.46). This partitions the total clutter power into three parts

$$P_{PC} = P_{PC1} + P_{PC2} + P_{PC3} \quad (5.82)$$

each associated with a vertical beam angle segment.

To compute the noise power out (Q_N), a noise power input in watts referred to the same point as the powers P of (5.73), (5.74), and (5.75) is needed. This power is called P_N , in watts, spread evenly over the system bandwidth

$$P_N = (4 \text{ E-15}) (\text{BW}) (\text{NF}) \text{ watts} \quad (5.83)$$

where

BW = bandwidth in MH_z

NF = noise figure, absolute units

then

$$Q_N = P_N (\text{average value of } G(f)) = \frac{(2N)!}{(N!)^2} P_N \quad (5.84)$$

5.5.2.4 Ratio of Powers. Combining from above for signal power

$$S = Q_T + Q_N + Q_P \quad (5.85)$$

for clutter-plus-noise power

$$(C + N) = Q_B + Q_N + Q_P \quad (5.86)$$



Finally:

$$S/(C + N) = (Q_T + Q_N + Q_P) / (Q_B + Q_N + Q_P) \quad (5.87)$$

is the argument of the cubic polynomial of (3.103) of the cited AIRS report.

5.6 ECM

5.6.1 Introduction

The ECM model has been extended to include the possibility that a signal cannot be detected due to the density of the EM environment.

Though not implemented, one alternative approach to how this could be modeled was presented in the AIRS Report Vol. I, Paragraph 3.2.5.1). This alternative was rather simplistic, and Analytics has chosen to develop a better overload model.

Ideally, an ECM model would have sufficient available data to be able, when a given target entered the field of view of the sensor, to actually examine the signals being received from all other emitting radar at that time and determine if overload occurred. To implement this alternative would be difficult within the context of the present AIRS model -- enough data simply could not be passed from the SCENARIO program to the EXECUTIVE program (virtually all information regarding each look at each target would have to be made available to EXECUTIVE after first sorting by time).

The alternative chosen is to analyze the signal being received from the target radar in the face of an average EM environment.



5.6.2 Determination of Average EM Environment
Characteristics

The statistics of the average EM environment are computed from data on each of the radars in the scenario being studied. In particular, the following statistics represent an average EM environment:

- D_M The mean radar density per NM²
- G_M The mean radar transmitter gain in db
- R_M The mean PRF of the radar
- H The ECM horizon in NM
- X The expected number of interfering radars at any time
- $\bar{\alpha}$ The expected value of the fractional main beam time (averaged over all radars in the scenario)
- P_{TR} Percent of time the average radar is emitting

The mean radar transmitter gain, the mean PRF of the radars, and the mean percent of time emitting are found as weighted averages:

$$G_M = \frac{\sum_i n_i g_i}{\sum_i n_i} \quad (5.88a)$$

$$P_{TR} = \frac{\sum_i n_i w_i}{\sum_i n_i} \quad (5.88b)$$

$$R_M = \frac{\sum_i n_i r_i}{\sum_i n_i} \quad (5.88c)$$



Where:

- i is an index over all radar types
- n_i is the number of radars of type i in the scenario
- w_i is the percent of time a radar of type i emits
- g_i is the transmitter gain for radar type i
- r_i is the PRF of a radar of type i

in order to find the mean radar density, we must first find the area, denoted by A , in NM^2 covered by the relevant scenario. It will be recalled (see page 2-30 of AIRS, Vol. I) that the user provides the simulation with the maximum and minimum longitude and latitude;

let:

Lo_{MAX} = Maximum longitude in degrees

Lo_{MIN} = Minimum longitude in degrees

La_{MAX} = Maximum latitude in degrees

La_{MIN} = Minimum latitude in degrees

The area determined by these points is given by the following two equations:

$$A = \left[\frac{Lo_{MAX} - Lo_{MIN}}{360} \right] \int_{La_{MIN}}^{La_{MAX}} 2\pi r^2 \cos \theta \, d\theta \quad (5.89)$$



$$A = \frac{(L_{O_{MAX}} - L_{O_{MIN}}) 2\pi r^2}{360} \left[\sin (L_{a_{MAX}}) - \sin (L_{a_{MIN}}) \right] \quad (5.90)$$

and r is taken as $[21600/2\pi]$ nautical miles.

Thus, the density of interfering radars per NM^2 is just:

$$D_M = P_{TR} \left(\sum_i n_i \right) / A \quad (5.91)$$

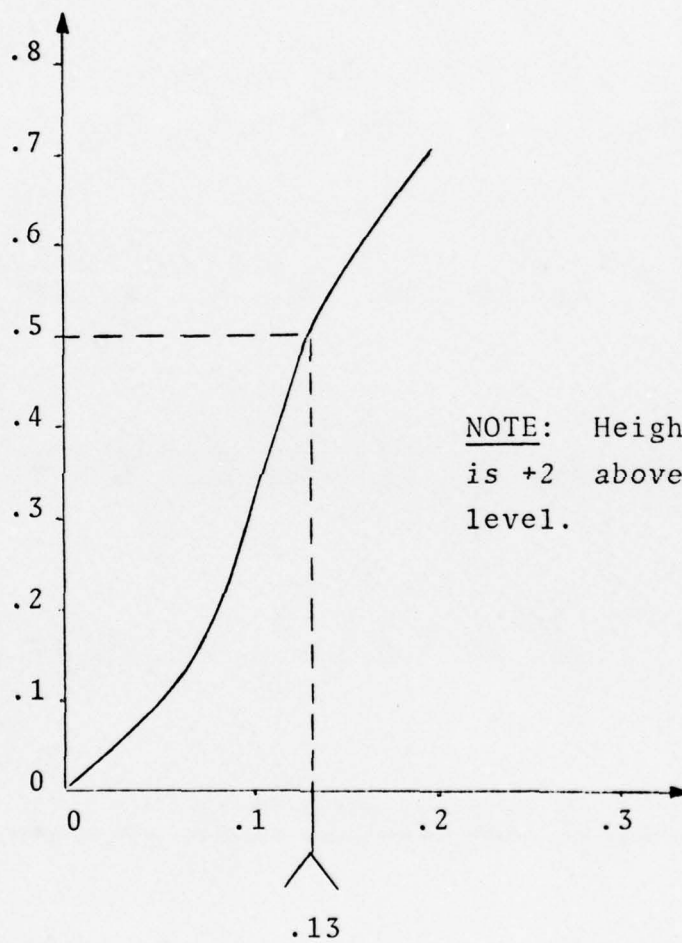
where:

- n_i is the number of radars of type i
in the scenario
- i is the index over all radar types

The ECM horizon is defined as that distance at which the probability that a radar (at elevation $+2\sigma$ above mean ground level -- a typical height for radars) is obscured by terrain is just 0.5. Paragraph 2.4 of AIRS, Vol. I. describes the terrain algorithm built into the SCENARIO model. As discussed in the referenced paragraph, the algorithm was run off line and the resulting curves incorporated directly into SCENARIO. The algorithm was fully normalized so that the resulting probability of non-blocking (as a function of depression angle from the target) was not a function of the aircraft height, wavelength of terrain, or standard deviation of the height of the terrain about its mean. Using the model, the following graph was developed:



Probability target not masked by terrain



NOTE: Height of target is +2 above mean ground level.

Depression Angle in Radians

Figure 5-6
ECM Horizon



Thus, for a target at height $+2\sigma$ above mean ground level (AMGL), the probability that the target is blocked is 0.5 at a depression angle of 0.13 radians. Therefore, H is found by:

$$H = \frac{(h_a - 2\sigma)}{6080 \tan(.13)} = \frac{7.69}{6080} (h_a - 2\sigma) \quad (5.92)$$

where

- h_a = height of aircraft above mean ground level in feet
- σ = standard deviation of terrain height about its mean

and H has the units of NM.

The expected number of interfering radars in view at any one time is given by:

$$X = \pi H^2 D_M$$

For the average radar, the expected value of fractional main beam time is:

$$\bar{\alpha} = \frac{1}{\left[\pi 10 \left(\frac{G_M}{10} \right)^{1/2} \right]} \quad (5.93)$$

All these parameters of the average EM environment are computed in the SCENARIO program. Of them, $\bar{\alpha}$, R_M , D_M , and X are transferred to the EXECUTIVE program via SCENARIO output tape.



5.6.3 Overload Analysis

5.6.3.1 Assumptions and Definitions of Terms. The following terms will be used in the overload analysis:

- Sweep -- the interpulse period of a radar
Radar Scan -- intermain lobe period of a radar
ECM Scan -- one cycle of the ECM sweep receiver
ECM Look -- the time period during which a
 radar is within a given ECM beam.
ECM Dwell Time -- the time during which an ECM
 receiver dwells on a frequency.

The following assumptions are made:

- (1) The radar scan period is much longer than the ECM scan period.
- (2) The ECM look period is much longer than the ECM scan period.
- (3) The primary interference effect is due to overloading of the ECM processor, which, upon overload takes the first pulses presented to it per unit time provided they are not so different in amplitude as given by the front to back ratio of each.
- (4) Non-marginal action - at a given instant the radar signal is either above or below the interference level; probabilistic sweep chopouts may be ignored.

Let the following parameters be given for the ECM (via user input to EXECUTIVE):

- R_p = maximum ECM signal processing rate in pulses per second
 N_R = the number of ECM receive channels
 B_1 = the ECM instantaneous receive bandwidth, in MHz
 B_2 = the ECM total system bandwidth, in MHz

Finally, a given radar (radar j) has the following parameters:

- T_j = transmitter gain in db
 F_j = PRF
 $P_{RAD,j}$ = fraction of time emitting



5.6.3.2 Computation of Overload Probabilities. R_p is the maximum ECM signal processing rate. Then, if

$$(R_M) (X) < R_p$$

no interference will exist in either the main or side lobes. If this condition does not exist, interference may occur.

Let R_d be the estimated fractional dwell time of the ECM; R_d is given by:

$$R_d = (B_1) (N_R) / B_2 \quad (5.94)$$

Then $R_{\alpha,j}$, the number of competing pulses per second in the main lobe for target j is:

$$R_{\alpha,j} = [F_j + (\bar{\alpha}) (R_M) (X)] R_d \quad (5.95)$$

and the non-interference probability for the main lobe, $P_{nint\alpha,j}$ is:

$$P_{nint\alpha,j} = \begin{cases} 1.0 & \text{if } R_M X < R_p \\ \text{MIN} \left[\frac{R_p}{R_{\alpha}}, 1 \right] & \text{if } R_M X \geq R_p \end{cases} \quad (5.96)$$

Similarly, $R_{\beta,j}$, the number of competing pulses per second in the side lobe for target j is given by:

$$R_{\beta,j} = [F_j + (1-\bar{\alpha})R_M X] R_d \quad (5.97)$$

and the side lobe non-interference probability, $P_{nint\beta,j}$ by:

$$P_{nint\beta,j} = \begin{cases} 1.0 & \text{if } R_M X < R_p \\ \text{MIN} \left[\frac{R_p}{R_{\beta}}, 1 \right] & \text{if } R_M X \geq R_p \end{cases} \quad (5.98)$$



5.6.4 Computation of Target Detectability

Additional information must be computed at this point, namely, the fractional main beam time for target j . Let this be denoted as α_j ; then

$$\alpha_j = \frac{1}{\left[\pi \frac{T_j}{10} \right]^{1/2}} \quad (5.99)$$

Now, for each look of the ECM, the detectability of target j , denoted by PD_j , is found by:

$$PD_j = P_{NS,j} P_{RAD,j} \left[\alpha_j PDC_{\alpha,j} P_{nint\alpha,j} + (1-\alpha_j) PDC_{\beta,j} P_{nint\beta,j} \right] \quad (5.100)$$

where

$P_{RAD,j}$ = Pr (target j is emitting), i.e., percent of time target j is emitting.

$PDC_{\alpha,j}$ = the "raw" detectability [i.e., assuming (1) the target was emitting, (2) the target was not obscured by terrain, and (3) the target was not lost due to overloading] in the main lobe for target j .

$PDC_{\beta,j}$ = the "raw" detectability of the side lobe for target j .

$P_{NS,j}$ = the probability that target j is not obscured on the present look by terrain.

$PDC_{\alpha,j}$ and $PDC_{\beta,j}$ are computed as shown in AIRS, Vol. I. Paragraph 3.2.6.1 as P_1 and P_2 , respectively. Let $PD_j^{(k)}$

($k = 1, 2, \dots$) be the detectability of target j on look k . This set is found via equation (5.100) computed once for each look. Then the overall target detectability for target j , denoted by \overline{PD}_j , is:

$$\overline{PD}_j = \left[1 - \prod_k (1 - PD_j^{(k)}) \right] P_{up} \quad (5.101)$$

where P_{up} is the probability that the ECM equipment is operational.



5.6.5 Identifiability and Localizability

The methods discussed in AIRS, Vol. I for computing the identifiability and localizability of a given target are not changed.

5.7 PHOTO

5.7.1 Introduction

A number of improvements were made in the PHOTO model as described in Paragraph 3.2.7 of AIRS, Vol. I. Specifically, the methods for computing contrast, for both day and night photography, have been improved. Paragraph 5.7.2 of this report gives the new method for computing contrast for daylight photography, while Paragraph 5.7.3 presents contrast computation for night photography.

5.7.2 Contrast-Day Photography

The method given in Paragraph 3.2.7.1.1 of AIRS, Vol. I, for computing the logarithmic contrast has been modified. Let:

- r_t = target reflectivity
- r_b = background reflectivity
- λ_h = scattering coefficient for haze -- NM^{-1}
- λ_r = scattering coefficient for rain -- NM^{-1}
- λ_a = scattering coefficient for clear air -- NM^{-1}
- R_h = slant range to the target through haze -- NM
- R_r = slant range to the target through rain -- NM
- R_a = slant range to the target through clear air -- NM
- B_o = brightness of the sky



Consider a target of reflectivity r_t , illuminated by a sky of uniform brightness B_o . The target is considered small (that is, it is assumed to subtend less than 5° of arc) so that second order scattering may be ignored. Assuming operation on the linear portion of the film gamma scale, the perceived brightness of the target, denoted by B_t , is given by:

$$B_t = B_o \left[(1 - e^{-(\lambda_a R_a + \lambda_h R_h + \lambda_r R_r)}) + r_t e^{-(\lambda_a R_a + \lambda_h R_h + \lambda_r R_r)} \right] \quad (5.102)$$

In this equation, the first term on the right of the equality represents scattering; the second term represents attenuation. Absorption is ignored. Similarly, the perceived brightness of the background, denoted by B_b , is:

$$B_b = B_o \left[(1 - e^{-(\lambda_a R_a + \lambda_h R_h + \lambda_r R_r)}) + r_b e^{-(\lambda_a R_a + \lambda_h R_h + \lambda_r R_r)} \right] \quad (5.103)$$

In the above equations for the brightness of the target and background, λ_a can be taken as zero since optical scattering through clear air is negligible.

Therefore, the logarithmic contrast, C is given by:

$$C \equiv \gamma \left| \log_{10} \frac{B_t}{B_b} \right| \\ = \gamma \left| \log_{10} \frac{1 - (1 - r_t) e^{-(\lambda_h R_h + \lambda_r R_r)}}{1 - (1 - r_b) e^{-(\lambda_h R_h + \lambda_r R_r)}} \right| \quad (5.104)$$

where γ is the film gamma.

One further detail remains; λ_h and λ_r must be developed. Both are functions of the prevailing visibility (haze or rain as appropriate).



The following relationship is used*:

$$\lambda_i = 4.5/V_i \quad i = \begin{cases} h & \text{for haze} \\ r & \text{for rain} \end{cases} \quad (5.105)$$

where λ_i is the scattering coefficient and V_i is the prevailing visibility in statute miles (λ_i has the units of NM^{-1}).

Note that, in the above development, shadow contrast has been ignored and that scattering is assumed isotropic. The former assumption is good on a hazy day or under clouds; it may be taken to represent a worst case. Optical haze scattering is actually anisotropic, with the angular dependence highly sensitive to the distribution in size of haze particles. Theoretically, the appropriate model is that of Mie scattering; however, since the particle size distribution is not known, and since experimental data yield variations of not more than 0.2 C-units, these can be ignored.

5.7.3 Contrast-Local Illumination**

Consider the case of local illumination only where the ambient plays no role. The chief culprit of contrast reduction is back-scattered light.

Terms to be used in this discussion are shown in Figure 5-7; the light source is assumed offset some distance d from the line of sight at an angle θ from that line of sight. The angle θ can be taken as constant over the field of view of the camera***. For simplicity, d is assumed

* Wolfe, William L. (ed.) Handbook of Military Infrared Technology, Office of Naval Research, Dept. of the Navy, Washington, D.C., 1965, p. 203.

** This model is appropriate for either (1) night photography, or (2) monochromatic photography with a laser source.

***In the implementation, θ is taken to be 90° .



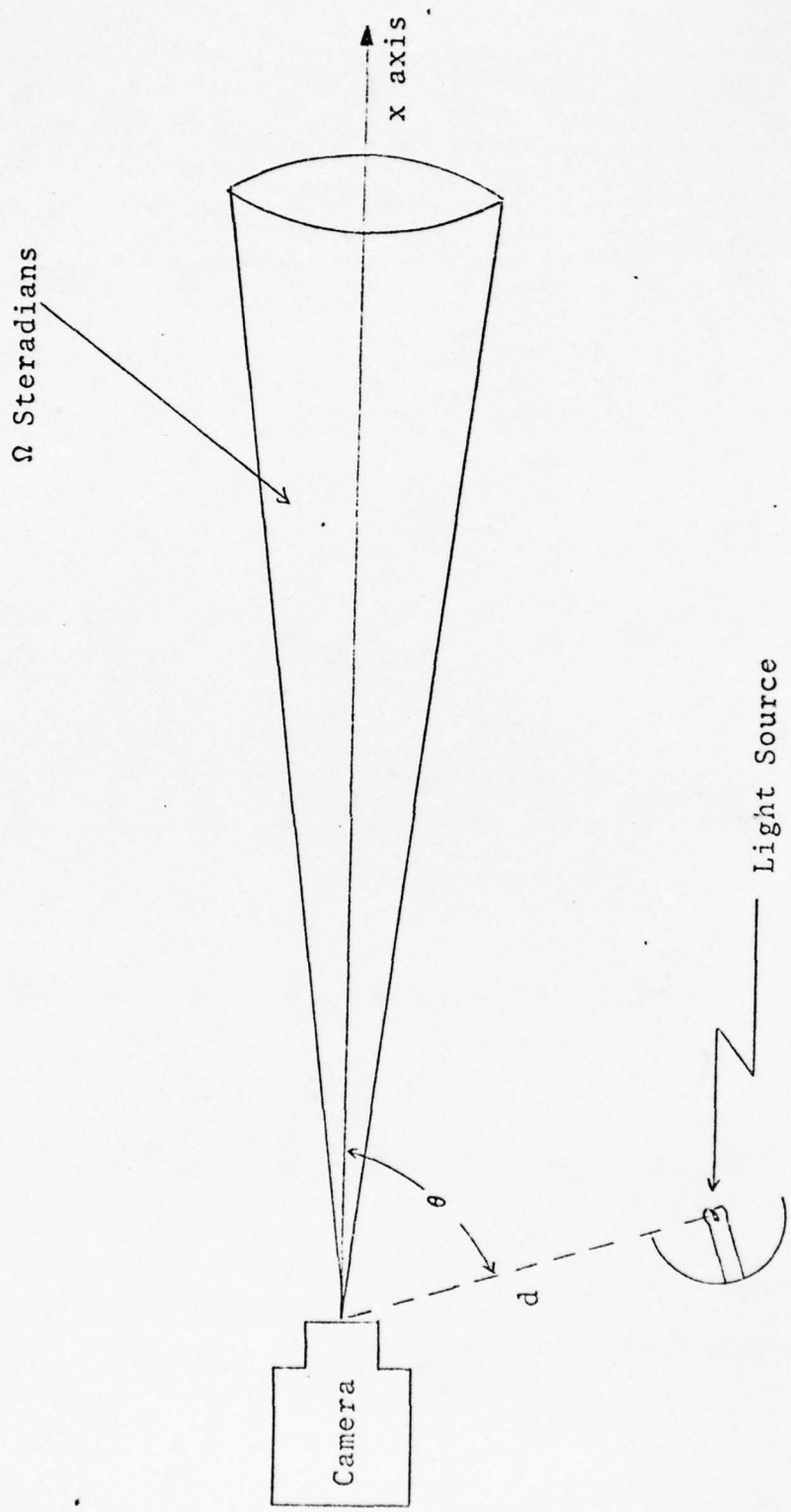


Figure 5-7
 Illustration of Terms for Photo



constant with time; such would not be the case if the light source were a flare. This assumption is tantamount to assuming the strobe lighting is used for night photography; this assumption is most likely correct with modern reconnaissance aircraft where room (e.g., to carry flares) is at a premium.

As illustrated in Figure 5-5, the "field-of-view" of one resolution element is Ω steradians (a typical value of Ω is 10^{-11}). It is further assumed that there is a minimum backscattering range of R_0 ; this minimum range would be provided by either: (1) baffling, or (2) an electronic shuttering system.

Let the light source intensity in the target direction be L lumens/steradian. Then the illumination at the target element within Ω (letting $d \ll R$), denoted by I_T , is given by:

$$I_T = \frac{L}{R^2} \Omega R^2 e^{-\lambda R} = L \Omega e^{-\lambda R} \quad (5.106)$$

where

R = the slant range to the target = $R_a + R_h + R_r$

λ = scattering coefficient

λ is taken as the weighted average of λ_a, λ_h , and λ_r :

$$\lambda = \frac{R_a \lambda_a + R_h \lambda_h + R_r \lambda_r}{R} \quad (5.107)$$

The illumination received at the camera from the target, denoted by J_T , is:

$$J_T = I_T e^{-\lambda R} \left(\frac{1}{R^2}\right) r_t \alpha \left(\frac{1}{2\pi}\right) \quad (5.108)$$

where α is the camera aperture area. Rewriting:

$$J_T = \frac{L \Omega}{R^2} e^{-2\lambda R} r_t \alpha \left(\frac{1}{2\pi}\right) \quad (5.109)$$



Similarly, the illumination received at the camera from the background, denoted by J_B , is:

$$J_B = \frac{L\Omega}{R^2} e^{-2\lambda R} r_b \alpha \left(\frac{1}{2\pi}\right) \quad (5.110)$$

Backscattering must now be introduced. Take an elemental unit of path (a thin cylinder) at an arbitrary distance x and with a cross section Ωx^2 and length dx . Its total illumination, I_p , is:

$$I_p = L\Omega e^{-\lambda Z} \cos \phi \frac{x^2}{Z^2} \quad (5.111)$$

where

$$Z = \sqrt{(x - d \cos \theta)^2 + (d \sin \theta)^2}$$

ϕ = the source-element-camera angle and is:

$$\phi = \arctan \left[\frac{\sin \theta}{\frac{x}{d} - \cos \theta} \right]$$

This path length scatters a fraction λdx into a sphere; hence, the backscatter received by the camera, J_s , is found from:

$$dJ_s = \frac{L\Omega}{Z^2} e^{-\lambda(Z+x)} \lambda \cos \phi \frac{\alpha}{4\pi} dx$$

$$J_s = \frac{L\Omega\alpha\lambda}{4\pi} \int_{R_0}^R \frac{e^{-\lambda(Z+x)} \cos \phi}{Z^2} dx \quad (5.112)$$

This integral cannot be solved explicitly, so a Laguerre integration technique is used.



First, define a function $G(X)$ as:

$$G(X) \equiv e^{-(Z-x)\lambda} \cos \phi/Z^2$$

Then

$$J_s = \frac{L\Omega\alpha\lambda}{4\pi} \left[\int_{R_0}^{\infty} G(x)e^{-2\lambda x} dx - \int_R^{\infty} G(x)e^{-2\lambda x} dx \right] \quad (5.113)$$

Let μ be defined as the term in square brackets above; further, let:

$$F(k) \equiv \int_k^{\infty} G(x)e^{-2\lambda x} dx \quad (5.114)$$

This function, $F(k)$, is evaluated by the method described on page 923 of the NBS Handbook of Mathematical Functions*; namely, the Laguerre numerical integration:

$$\int_0^{\infty} e^{-x} f(x) dx \approx \sum_{i=1}^n w_i f(x_i) \quad (5.115)$$

where (w_i, x_i) are tabulated as a function of n .

Using this approximation, and transforming the variables:

$$F(k) = \int_k^{\infty} e^{-x2\lambda} G(x) dx \approx e^{-2\lambda k} \sum_{i=1}^n \left[\frac{w_i}{2\lambda} \right] G \left[\left(\frac{x_i}{2\lambda} \right) + k \right] \quad (5.116)$$

In the implementation, n is chosen as 5.

Table 5-1 gives (w_i, x_i) for $i=1,2,\dots,5$.

* Abramowitz and Stegun (ed.), U. S. Department of Commerce, Handbook of Mathematical Functions, U. S. Government Printing Office, Washington, D.C., June 1964, page 923.



SECTION VI

OUTPUT OF FACTORS AFFECTING SENSOR PERFORMANCE

6.1 INTRODUCTION

This section discusses a program, designated as INTER, which has been developed to enable the AIRS user to study intermediate sensor performance factors in an organized fashion.

6.2 THE INTER PROGRAM

Until this program was developed, the user could only analyze sensors by their macro-performance; that is, he could examine the detectability, identifiability and localizability of each target-sensor pass combination (by



use of the EXECUTIVE hard copy output--see paragraph 3.6.3 of AIRS, Volume 1) or he could examine how a sensor performed vis-a-vis groups of targets (by using the EVAL outputs--see paragraph 4.6 of this report). However, the user was unable to determine why the detectabilities, identifiabilities, and localizabilities were as they were. Thus, for example, if the IR sensor continually gave low detectabilities, the user would be unable to determine if it were due to poor target contrast, bad weather, etc.

For each sensor, a list of intermediate factors which would be most useful to the user in answering questions of why sensors performed as they did was prepared--these lists are given in Table 6.1. It would have been possible to output these intermediate factors during the running of the EXECUTIVE program each time a particular target-sensor-pass combination was considered. This method of providing the data to the user would have been both clumsy and overwhelming; rather, it was decided that all intermediate factors would be stored on the EXECUTIVE Target/Sensor Output Tape (see paragraph 7.3.2.1 of this report). This tape would then serve as input to the INTER program which would organize the data and output it in a succinct manner.

The next question was how to portray the data in a manner that would be most useful to the user. After consideration of a number of alternatives, it was decided that for each sensor the factors of interest would be averaged over all valid* target-sensor-pass combinations and output as a

* Thus, if on a particular pass a target never fell within the field of view of a particular sensor, this would not degrade the average performance factors.



function of range interval in tabular form. The range intervals used for each sensor are given in Table 6.1. This method of presentation reduced the data to a manageable amount while still providing the user with sufficient information to enable him to examine why a sensor performed as it did.

Hence, for each of the 14 sensors (the dummy sensor is not considered), a table is printed out by the INTER program. Figure 6-1 is a sample output* for the FLIR sensor; all other sensors are analogous. Across the horizontal axis are the relevant range intervals for the sensor to which the table pertains; on the vertical axis is a mnemonic list of the factors appearing in Table 6-1 for that sensor. At the top of the table is a summary of the number of target-pass sightings within each range interval by target type. (The total number of target-pass sightings within a given range interval is the denominator of the averaging equation for that range interval.)

Interpretations of the mnemonics used for each sensor are provided in Table 6-2. Mnemonic names were used for security reasons.

6.3 HOW TO USE THE INTER PROGRAM

The only necessary input to the INTER program is the Target/Sensor Output Tape provided by the EXECUTIVE program. This tape is to be mounted on logical unit number 2. No other user controls are needed.

The output of the program is as discussed above--one data table for each of the 14 sensors.

* All outputs in this sample table are zero; this is for security reasons.



FIGURE 6-1

SAMPLE INTER OUTPUT

| NO. OF | RANGE INTERVAL (IN NM) | | | | | | | | |
|-------------|------------------------|-----|-----|-----|-----|-----|-----|---|---|
| | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-7 | 7-9 | | |
| CHIC1P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC2P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC3P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC4P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC5P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC6P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC7P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC8P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC9P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC10P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC11P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC12P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC13P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC14P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC15P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC16P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC17P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC18P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC19P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC20P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC21P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC22P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC23P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC24P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC25P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC26P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC27P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC28P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC29P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC30P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC31P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC32P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC33P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC34P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC35P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC36P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC37P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC38P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC39P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC40P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC41P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC42P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC43P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC44P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC45P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC46P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC47P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC48P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC49P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC50P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC51P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC52P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC53P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC54P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC55P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC56P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC57P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC58P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC59P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC60P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC61P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC62P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC63P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC64P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC65P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC66P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC67P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC68P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC69P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC70P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC71P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC72P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC73P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC74P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC75P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC76P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC77P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC78P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC79P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC80P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC81P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC82P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC83P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC84P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC85P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC86P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC87P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC88P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC89P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC90P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC91P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC92P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC93P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC94P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC95P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC96P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC97P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC98P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC99P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CHIC100P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SUM OF ROWS | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

(NOTE: Only ranges to 9 NM are shown; remaining intervals are as given in Table 6-1.)



Table 6.1 - continued

Factor to be Analyzed

- . Contrast
- . Effective output resolution for processing level 1
- . Effective output resolution for processing levels 2,3,& 4
- . Effective system resolution for processing level 1
- . Effective system resolution for processing levels 2,3,& 4
- . Conditional detectability--for each of the four processing levels
- . Total detectability--for each of the four processing levels
- . Total identifiability--for each of the four processing levels

MTISLR Sensor Range Intervals (NM)

- . 0-2 . 6-8 . 15-20 . 30-40
- . 2-4 . 8-10 . 20-25 . > 40
- . 4-6 . 10-15 . 25-30

Factors to be Analyzed

- . Power output at the sensor due to both target and background return
- . Precipitation clutter power
- . Noise power introduced by the sensor delay lines
- . Ratio: $(\text{Target} + \text{Noise} + \text{Precipitation}) / (\text{Background} + \text{Noise} + \text{Precipitation})$
- . Radial target speed (in knots)
- . Conditional Detectability--for each of the four processing levels
- . Total Detectability--for each of the four processing levels
- . Total Identifiability--for each of the four processing levels



Table 6.1 - continued

| NTIFLR | Range Intervals (NM) | | |
|--------|----------------------|---|-------|
| . | 0-2 | . | 15-20 |
| . | 2-4 | . | 20-25 |
| . | 4-6 | . | 25-30 |
| . | 6-8 | . | 30-40 |
| . | 8-10 | . | > 40 |
| . | 10-15 | . | |

Factors to be Analyzed

- . Radial target speed in knots
- . Power output at the sensor due to both target and background return
- . Precipitation clutter power
- . Noise power introduced by the sensor delay lines
- . Ratio: (Target+Noise+Precipitation)/(Background+Noise+Precipitation)
- . Expected number of unobstructed looks at the target this sighting
- . Conditional Detectability for each of the four processing levels
- . Total Detectability for each of the four processing levels
- . Total Identifiability for each of the four processing levels

| PHOTO Sensors | Range Intervals (NM) | | |
|---------------|----------------------|---|--------|
| . | 0-1 | . | 10-15 |
| . | 1-2 | . | 15-20 |
| . | 2-4 | . | 20-30 |
| . | 4-6 | . | 30-40 |
| . | 6-8 | . | 40-100 |
| . | 8-10 | . | > 100 |

- Factors to be Analyzed
- . Contrast*
 - . Resolution--Processing levels 1 and 2*

* Averaged over all valid looks (i.e., frames) at the target



Table 6.1 - continued

- . Resolution--Processing levels 2 and 3*
- . Number of frames on which the target appears
- . Conditional Detectability--Processing levels 1 and 2*
- . Conditional Detectability--Processing levels 3 and 4*
- . Total Detectability--for each of the four levels of processing
- . Total Identifiability--for each of the four levels of processing

| FLIR Sensor | Range Intervals (NM) | | |
|-------------|----------------------|-----|-------|
| | 0-1 | 3-4 | 7-9 |
| | 1-2 | 4-5 | 9-11 |
| | 2-3 | 5-7 | 11-13 |
| | | | 13-15 |
| | | | 15-20 |
| | | | > 20 |

Factors to be Analyzed

- . Contrast in Band 1 assuming cloud cover
- . Contrast in Band 1 assuming no cloud cover
- . Contrast in Band 2 assuming cloud cover
- . Contrast in Band 2 assuming no cloud cover
- . Conditional Detectability--Band 1
- . Conditional Detectability--Band 2
- . Total Detectability--for each of the four levels of processing
- . Total Identifiability--for each of the four levels of processing
- . Slant range to target at last valid look

* Averaged over all valid looks (i.e. frames)



Table 6.1 - continued

| ECM Sensor | Range Intervals (NM) | | | |
|------------|----------------------|-------|--------|---------|
| . | 0-5 | 15-20 | 30-40 | 100-200 |
| . | 5-10 | 20-25 | 40-50 | > 200 |
| . | 10-15 | 25-30 | 50-100 | |

Factors to be Analyzed

- . Signal to noise ratio for both main and side lobe radiation
- . Conditional Detectability in the main and side lobes averaged over all looks (assumes no terrain blocking, equipment failure, or interference from other radars)
- . The probability of no interference averaged over all looks for both the main and side lobes
- . The overall sensor Conditional Detectability for each of the four processing levels
- . The overall sensor Total Detectability for each of the four processing levels
- . The overall sensor Total Identifiability for each of the four processing levels



TABLE 6-2
MNEMONIC LIST

| SENSOR | MNEMONIC | DEFINITION |
|----------|--------------------------------|---|
| IR | CB1CIR | Contrast in Band 1 when clouds are present |
| | CB1NIR | Contrast in Band 2 when clouds are absent |
| | CB2CIR | Contrast in Band 2 when clouds are present |
| | CB2NIR | Contrast in Band 2 when clouds are absent |
| | CDET1 | Conditional Detectability--Band 1 |
| | CDET2 | Conditional Detectability--Band 2 |
| | CDIR-1 | Conditional Detectability--level 1 |
| | CDIR-2 | Conditional Detectability--level 2 |
| | CDIR-3 | Conditional Detectability--level 3 |
| | CDIR-4 | Conditional Detectability--level 4 |
| | TDIR-1 | Total Detectability--level 1 |
| | TDIR-2 | Total Detectability--level 2 |
| | TDIR-3 | Total Detectability--level 3 |
| | TDIR-4 | Total Detectability--level 4 |
| | TIIR-1 | Total Identifiability--level 1 |
| | TIIR-2 | Total Identifiability--level 2 |
| TIIR-3 | Total Identifiability--level 3 | |
| TIIR-4 | Total Identifiability--level 4 | |
| SLR | SLRCON1 | Contrast--level 1 |
| | SLRCON24 | Contrast--levels 2, 3, and 4 |
| | EORLEV1 | Effective Output Resolution--level 1 |
| | EORLEV2-4 | Effective Output Resolution--levels 2, 3, and 4 |
| | ESRLEV1 | Effective System Resolution--level 1 |
| | ESRLEV2-4 | Effective System Resolution--levels 2, 3, and 4 |
| | CDSLRL-1 | Conditional Detectability--level 1 |
| | CDSLRL-2 | Conditional Detectability--level 2 |
| | CDSLRL-3 | Conditional Detectability--level 3 |
| | CDSLRL-4 | Conditional Detectability--level 4 |
| | TDSLRL-1 | Total Detectability--level 1 |
| | TDSLRL-2 | Total Detectability--level 2 |
| | TDSLRL-3 | Total Detectability--level 3 |
| | TDSLRL-4 | Total Detectability--level 4 |
| | TISLRL-1 | Total Identifiability--level 1 |
| | TISLRL-2 | Total Identifiability--level 2 |
| TISLRL-3 | Total Identifiability--level 3 | |
| TISLRL-4 | Total Identifiability--level 4 | |



TABLE 6-2

MNEMONIC LIST (CONT.)

| SENSOR | MNEMONIC | DEFINITION |
|----------|--------------------------------|---|
| MTISLR | PDSPSL | Radial Speed of Target in knots |
| | POSFTSL | Power output (in watts) at the sensor due to signal return from the target |
| | POSFBSL | Power output (in watts) at the sensor due to signal return from background |
| | PCPWSL | Precipitation clutter power (in watts) |
| | NPFDLSL | Noise power (in watts) introduced by the sensor delay lines |
| | PRASL | Ratio of target signal plus noise plus precipitation clutter power to background signal plus noise plus precipitation clutter power |
| | TNPRSL | Terrain nonshadowing probability |
| | CDMRSL-1 | Conditional Detectability--level 1 |
| | CDMRSL-2 | Conditional Detectability--level 2 |
| | CDMRSL-3 | Conditional Detectability--level 3 |
| | CDMRSL-4 | Conditional Detectability--level 4 |
| | TDMRSL-1 | Total Detectability--level 1 |
| | TDMRSL-2 | Total Detectability--level 2 |
| | TDMRSL-3 | Total Detectability--level 3 |
| | TDMRSL-4 | Total Detectability--level 4 |
| | TIMRSL-1 | Total Identifiability--level 1 |
| | TIMRSL-2 | Total Identifiability--level 2 |
| TIMRSL-3 | Total Identifiability--level 3 | |
| TIMRSL-4 | Total Identifiability--level 4 | |
| MTIFLR | RDSPFL | Radial Speed of target in knots |
| | POSFTFL | Power output (in watts) at the sensor due to signal return from target |
| | POSFBFL | Power output (in watts) at the sensor due to signal return from background |
| | PCPWFL | Precipitation clutter power (in watts) |
| | NPFDLFL | Noise power (in watts) introduced by the sensor delay lines |
| | PRAFL | Ratio of target signal plus noise plus precipitation clutter power to background signal plus noise plus precipitation clutter power |
| | EXNONL | Expected number of unobstructed looks on this pass |
| | CDMRFL-1 | Conditional Detectability--level 1 |
| | CDMRFL-2 | Conditional Detectability--level 2 |
| | CDMRFL-3 | Conditional Detectability--level 3 |
| | CDMRFL-4 | Conditional Detectability--level 4 |



TABLE 6-2

MNEMONIC LIST (CONT.)

| SENSOR | MNEMONIC | DEFINITION |
|--------|--|--|
| | TDMRFL-1 | Total Detectability--level 1 |
| | TDMRFL-2 | Total Detectability--level 2 |
| | TDMRFL-3 | Total Detectability--level 3 |
| | TDMRFL-4 | Total Detectability--level 4 |
| | TIMRFL-1 | Total Identifiability--level 1 |
| | TIMRFL-2 | Total Identifiability--level 2 |
| | TIMRFL-3 | Total Identifiability--level 3 |
| | TIMRFL-4 | Total Identifiability--level 4 |
| PHOTO | CFOTO | Contrast |
| | RFOTO-12 | Resolution--levels 1 and 2 |
| | RFOTO-34 | Resolution--levels 3 and 4 |
| | FFOTO | Number of frames on which target appears |
| | ACDET-12 | Conditional Detectability, averaged over all looks--levels 1 and 2 |
| | ACDET-34 | Conditional Detectability, averaged over all looks--levels 3 and 4 |
| | ATDET-12 | Total Detectability, averaged over all looks--levels 1 and 2 |
| | ATDET-34 | Total Detectability, averaged over all looks--levels 3 and 4 |
| | ATIDEN-12 | Total Identifiability, averaged over all looks--levels 1 and 2 |
| | ATIDEN-34 | Total Identifiability, averaged over all looks--levels 3 and 4 |
| | CDFOTO-1 | Overall Conditional Detectability--level 1 |
| | CDFOTO-2 | Overall Conditional Detectability--level 2 |
| | CDFOTO-3 | Overall Conditional Detectability--level 3 |
| | CDFOTO-4 | Overall Conditional Detectability--level 4 |
| | TDFOTO-1 | Overall Total Detectability--level 1 |
| | TDFOTO-2 | Overall Total Detectability--level 2 |
| | TDFOTO-3 | Overall Total Detectability--level 3 |
| | TDFOTO-4 | Overall Total Detectability--level 4 |
| | TIFOTO-1 | Overall Total Identifiability--level 1 |
| | TIFOTO-2 | Overall Total Identifiability--level 2 |
| | TIFOTO-3 | Overall Total Identifiability--level 3 |
| | TIFOTO-4 | Overall Total Identifiability--level 4 |
| FLIR | (Identical with IR with one addition.) | |
| | SLANT RAN | Slant range (in NM) to target at last valid look |



TABLE 6-2
MNEMONIC LIST (CONT.)

| SENSOR | MNEMONIC | DEFINITION |
|--------|----------|--|
| ECM | SNML | Signal to noise ratio, main lobe radiation |
| | SNSL | Signal to noise ratio, side lobe radiation |
| | CDML | Conditional Detectability in main lobe averaged over all looks* |
| | CDSL | Conditional Detectability in side lobe averaged over all looks* |
| | NIPRML | Probability of no interference in main lobe, averaged over all looks |
| | NIPRSL | Probability of no interference in side lobe, averaged over all looks |
| | CDECM-1 | Conditional Detectability--level 1 |
| | CDECM-2 | Conditional Detectability--level 2 |
| | CDECM-3 | Conditional Detectability--level 3 |
| | CDECM-4 | Conditional Detectability--level 4 |
| | TDECM-1 | Total Detectability--level 1 |
| | TDECM-2 | Total Detectability--level 2 |
| | TDECM-3 | Total Detectability--level 3 |
| | TDECM-4 | Total Detectability--level 4 |
| | TIECM-1 | Total Identifiability--level 1 |
| | TIECM-2 | Total Identifiability--level 2 |
| | TIECM-3 | Total Identifiability--level 3 |
| | TIECM-4 | Total Identifiability--level 4 |

* Conditional here means assuming no terrain blocking, equipment failure, or interference from other radars.



SECTION VII
INPUTS AND OUTPUTS OF THE SCENARIO AND
EXECUTIVE PROGRAMS

7.1 INTRODUCTION

The purpose of this section is to provide the reader with the complete input requirements of the SCENARIO and EXECUTIVE programs of the AIRS Model. In addition, this section will provide descriptions of the outputs of these programs. Paragraph 7.2 will discuss the input and output of the SCENARIO program; specifically, the input will be discussed in paragraph 7.2.1 and the output in paragraph 7.2.2. Similarly, within paragraph 7.3 the inputs and outputs of the EXECUTIVE program will be discussed in 7.3.1 and 7.3.2 respectively.

7.2 SCENARIO INPUTS AND OUTPUTS

The only required input to the SCENARIO program is a user-developed and supplied card input deck. The output consists of two tapes. These will be discussed in the following paragraphs.



7.2.1 Inputs

The best way to illustrate the form of the new input deck required by SCENARIO is by Table 7.1. This table serves a dual purpose: 1) it defines all necessary input parameters, and 2) it provides instruction for the preparation of the input deck itself. This table supercedes and replaces pages 2-30 through 2-36 inclusive of AIRS, Volume I.

7.2.2 Outputs

SCENARIO outputs are on two, or optionally three magnetic tapes.

Output Tape 1 contains a descriptive record of target sightings by each of the 15 sensors that are switched on for a given run, and serves as input to the EXECUTIVE Model.

The second tape, Output Tape 2, contains a frame-by-frame descriptive record of what each of the (up to 8) cameras on board the aircraft surveyed. After sorting, this tape serves as input to the PI-Q Model (See AIRS Vol. I, Section V)

The optional tape^{*}, Output Tape 3, lists target number, target type, and the time at which the aircraft flew past the target for each target sighting. This tape is sorted by time and then listed to provide a time-line record of the mission.

7.2.2.1 Output Tape 1. The form of Output Tape 1 has not been changed from that reported in paragraph 2.7.2 of AIRS, Volume I. Table 2-1 and Table 2-2 of AIRS, Volume I are valid; however, Table 7-2 of this report replaces Tables 2-3a and 2-3b of the cited AIRS report.

* This tape is procuded if Sense Switch 2 on the CDC Computer Console is turned on.



7.2.2.2 Output Tape 2. The second output tape of the SCENARIO program has not been modified in any manner. Hence paragraph 2.7.3 of AIRS Volume I remains completely valid and will not be restated here.

7.2.2.3 Output Tape 3. As in the case of Output Tape 2, this tape remains unchanged. The reader is referred to paragraph 2.7.4 of AIRS, Volume I, for a complete discussion of Output Tape 3.

7.3 EXECUTIVE INPUTS AND OUTPUTS

7.3.1 Inputs

The inputs to the EXECUTIVE program are of two types: 1) tape and 2) card. The tape input to EXECUTIVE is Output Tape #1 of the SCENARIO program, as discussed in paragraph 7.2.2.1 above.

Table 7.3 gives the form of the EXECUTIVE input deck by card number, variable name, variable definition and format. It is sufficiently complete to serve as a guide to the AIRS user in developing an EXECUTIVE input deck. There are 35 cards in the input deck, each card(s) pertains to a specific sensor as follows:



CARDS

SENSOR

| | |
|-------------------------|-----------------------------------|
| 1,2,3, and 4 | IR |
| 5,6,7,8, and 9 | SLR |
| 10,11, and 12 | MTISLR |
| 13,14, and 15 | MTIFLR |
| 16,17,18, and 19 | ECM |
| 20 through 30 inclusive | PHOTO |
| 31,32,33, and 34 | FLIR |
| 35 | Control card for hard copy output |

7.3.2 Outputs

The Executive program prepares two output tapes: Output Tape 1 describes, on a pass-target basis, the detectability, and localizability statistics for each of the sensors. This tape serves as input to the Evaluation Model discussed in AIRS, Section V. The second tape (Output Tape 2) contains information computed within the Executive program which is used by the PI-Q model discussed in Section V.

In addition, if the user so desires, a hard copy of the information recorded on Output Tape 1 is prepared.

7.3.2.1 Output Tape 1. This tape, also called the Target/Sensor Output Tape, is written in binary form and is organized on a pass basis. Within each pass, each target is considered in order (up to a maximum of 200 targets) and a group of 20 records for each pass-target combination generated.

The 20 records for each combination can be logically divided into three groups:



- . Group 1 consists of the first 15 records. Record 1 contains general header information, true target data (e.g., actual time of beam passage), and various system parameters (e.g., navigational or speed errors). This information is in reality the statistics provided by the Dummy Sensor. The remaining records contain, for each of the four levels of processing, statistics on the 14 other sensors - ordered by sensor number. These statistics include detectability, identifiability, and localizability, terrain shadowing probability for the sensor and target being considered, etc.

- . Group 2 contains, in logical records 16 through 19, the combined data from all sensors on each level of processing for the given target. This data describes, for the overall system of sensors, how effectively the target was detected, identified, and localized.

- . Group 3 consisting of record 20, contains the geodetic probability and localizability for the target.

Table 7-5 defines these records in greater detail. Figure 7-1 shows the logical grouping of records on the tape.

After the last pass, target, and sensor have been analyzed, and end-of-file record, which does not contain data, is placed at the end of the tape.



7.3.2.2 Output Tape 2. The reader is referred to paragraphs 3.6.2 of AIRS, Volume I for a complete discussion of this tape.

7.3.2.3 Hard Copy Output. As reported in paragraph 3.6.3 of AIRS, Volume I, as an option (if computer console sense switch #1 is on) a printout of Output Tape 1 can be produced. The output is easily interpreted since all variables are labeled. This output does not print, however, words 35 through 56 of Group 1 (Table 7-4) as data contained in these words will be processed and output by the INTER program, as discussed in Section VI of this report.



| Pass 1 Target 1 | Header Information, target and system parameters | (Record 1) |
|-----------------------------|--|-------------|
| Sensor 2 | How well did sensor 2 do vis-a-vis target 1, pass 1 | (Record 2) |
| . | . | . |
| Sensor 15 | How well did sensor 15 do vis-a-vis target 1 on pass 1 | (Record 15) |
| System Performance, Level 1 | How well did the system as a whole do against target 1 pass 1 | (Record 16) |
| . | . | . |
| System Performance, Level 4 | How well did the system as a whole do against target 1 pass 1 | (Record 19) |
| Geodetic Information | What was the geodetic localizability and probability of the target | (Record 20) |
| Pass 1 Target 2 | . | . |
| Pass 2 Target 1 | . | . |

Figure 7-1. FORM OF OUTPUT TAPE 1



TABLE 7.1

SCENARIO INPUT DECK

Data cards for the Scenario Model are to be prepared in the order and form described below:

| Order | Description | Variable | Card Columns | Format Specification | Description |
|-------|--|-------------|--------------|----------------------|---|
| 1 | TITLE | I ALPHA (I) | 1-80 | 20 (A4) | Alphabetic title for run |
| 2 | Sensor On/Off | II(1) | 1-5 | 15 | Code for each of the 15 possible sensors, designating if sensor is on for this run (set to "1" for on, "0" for off) |
| | | II(2) | 6-10 | 15 | |
| | | . | . | . | |
| | | . | . | . | |
| | | II(14) | 66-70 | 15 | |
| | | II(15) | 71-75 | 15 | |
| 3 | Boundary restriction (all location inputs must lie within these limits)* | LATMIN | 1-5 | 15 | Min. degrees latitude for run (+ for North, - for South) |
| | | LATMAX | 6-10 | 15 | Max. degrees latitude for run |
| | | LONMIN | 11-15 | 15 | Min. degrees longitude for run (+ for East, - for West) |
| | | LONMAX | 16-20 | 15 | Max. degrees longitude for run |
| 4 | Index Limits | NT | 1-5 | 15 | No. of target types (max of 30) |
| | | N | 6-10 | 15 | No. of targets (max of 200) |
| | | NBKG | 11-15 | 15 | No. of backgrounds (max of 15) |

* These boundaries should closely define the area covered by the scenario being studied.

Table 7.1 - continued

| Order | Description | Variable | Card Columns | Format Specification | Description |
|---|--|--|--|---|--|
| 5 | Target - One of these cards must appear for each target. | ITP(I) X(I) Y(I) Z(I) IPRE(I) ITK(I) IBKG(I) IWEATH(I) V(I) THT(I) PRAD(I) | 1-5 6-15 16-25 26-35 36-40 41-45 46-50 51-55 56-65 66-75 76-80 | I5 F10.0 F10.0 F10.0 I5 I5 I5 I5 F10.0 F10.0 F5.0 | The index for type of target (1 through 30) Latitude (+ for North, - for South)* Longitude (+ for East, - for West)* Altitude code -- specified as a multiple of the rms value (see card 9) Preplanned code (0=yes, 1=no) Code for air-to air keying (0=yes, 1=no) The index for type of background (1 through 15) Rain-on-target code (1 for yes, 2 for no) Ground speed of target (knots) Heading, in degrees clockwise from North Target ECM -- the fraction of the time that target I radiates |
| (Card #5 is repeated for I = 1, 2, ..., N, where N is the number of targets; see card #4) | | | | | |
| 6 | Target Type ECM One of these cards must appear for each type of target. | PT(I) GT(I) FREQ(I) CKA(I) PRF(I) THETA 1 (I) TSCPS(I) | 6-15 16-25 26-35 36-45 46-55 56-65- 66-75 | F10.0 F10.0 F10.0 F10.0 F10.0 F10.0 F10.0 | Peak transmitter power (db above 1 watt) Transmitter antenna gain (db) Frequency (MHz) Transmitter antenna front-to-back ratio (db) Pulses per second Pulse width in microseconds Target scan period (seconds) |
| (Card #6 is repeated for I = 1, 2, ..., NT)** | | | | | |

* Latitude and longitude are to be punched as XXX.YZZZ, where XXX are the degrees, YY the minutes, and ZZ the seconds. This convention applies throughout.

** Note: If target type I is not a radar, card may be left blank.

*** Z(I) must be specified as an integer between -3 and +3.



Table 7.1 - continued

| Order | Description | Variable | Card Columns | Format Specification | Description |
|--|--|---|---|--|---|
| 7 | Background One of these must appear for each type of background. | BKG(K, 1) BKG(K, 2) BKG(K, 3) BKG(K, 4) BKG(K, 5) BKG(K, 6) BKG(K, 7) | 1-10 11-20 21-30 31-40 41-50 51-60 61-70 | F10.0 F10.0 F10.0 F10.0 F10.0 F10.0 F10.0 | Photo-reflectivity MTISLR-backscatter coefficient SLR-backscatter coefficient MTIFLR-backscatter coefficient IR-emissivity for band 1 IR-emissivity for band 2 IR-temperature (in °K) |
| (Card #7 is repeated for K = 1, 2, ..., NBKG) | | | | | |
| 8a | Target/Sensor Matrix | TS(K, 1)* TS(K, 2) TS(K, 3) TS(K, 4) TS(K, 5) TS(K, 6) TS(K, 7) TS(K, 8) | 1-10 11-20 21-30 31-40 41-50 51-60 61-70 71-80 | F10.0 F10.0 F10.0 F10.0 F10.0 F10.0 F10.0 F10.0 | Photo-reflectivity Photo-resolution (ft.) for 90% prob. of det. MTIFLR-cross section (in m ²) SLR;MTISLR-cross section (in m ²) SLR-reflectivity SLR-resolution (m.) for 50% prob. of det. IR-area (in m ²) IR-temperature (in °K) |
| 8b | | TS(K, 9) | 1-10 | F10.0 | IR-resolution (m.) for 90% prob. of detection |
| | | TS(K, 10) TS(K, 11) | 11-20 21-30 | F10.0 F10.0 | IR-emissivity for band 1 IR-emissivity for band 2 |
| (The pair of cards 8a and 8b are repeated for K = 1, 2, ..., NT) | | | | | |
| 9 | Terrain | OMEGA SIGMA PHI | 1-10 11-20 21-30 | F10.0 F10.0 F10.0 | Wavelength of terrain (ft.) rms of terrain (ft.) Coherence angle (radians) |

* The index K denotes the Kth target type.



Table 7.1 - continued

| Card | | Variable | Card Columns | Format Specification | Description |
|-------|-------------|--|---|--|--|
| Order | Description | | | | |
| 10 | ECM | NBEAM RMAX THETA 2 | 1-5 6-15 16-25 | I5 F10.0 F10.0 | No. of beams Max. range (NM) Total blind angle (degrees) beneath aircraft (A/C) |
| 11 | SLR | THET 12 THET 13 RMIN 1 RMAX 1 | 1-10 11-20 21-30 31-40 | F10.0 F10.0 F10.0 F10.0 | Min. angle from nadir (deg.) for det. Max. angle from nadir (deg.) for det. Min. slant range (NM) for detection Max. slant range (NM) for detection |
| 12 | MTISLR | THET 22 THET 23 RMIN 1 RMAX 2 | 1-10 11-20 21-30 31-40 | F10.0 F10.0 F10.0 F10.0 | Min. angle from nadir (deg.) for det. Max. angle from nadir (deg.) for det. Min. slant range (NM) Max. slant range (NM) |
| 13 | MTIFLR | PHIA PHIB RMINF RMAXF OMEGF FLFRQ | 1-10 11-20 21-30 31-40 41-50 51-60 | F10.0 F10.0 F10.0 F10.0 F10.0 F10.0 | Max. depression angle (deg.) Min. depression angle (deg.) Min. slant range (NM) Max. slant range (NM) Half angle (deg. of azimuth sweep) Scan interval, in tenths of a second |
| 14 | IR | THET 32 RMAXIR | 1-10 11-20 | F10.0 F10.0 | Max. angle from nadir (deg.) for det. Max. slant range (NM) |



Table 7.1 - continued

| Order | Description | Variable | Card Columns | Format Specification | Description |
|---|--------------|--|---|---|--|
| 15 | Photo Type | IKIND(1) IKIND(2) IKIND(3) IKIND(4) IKIND(5) IKIND(6) IKIND(7) IKIND(8) | 1-5 6-10 11-15 16-20 21-25 26-30 31-35 36-40 | I5 I5 I5 I5 I5 I5 I5 I5 | Camera 1 Code describing the type of each camera sensor: Camera 2 set "0" for pan; set "1" for side oblique frame Camera 3 or vertical frame; set Camera 4 "2" for forward oblique frame. Camera 5 Camera 6 Camera 7 Camera 8 |
| (For each of the eight cameras which are on, either card #16a or card #16b is punched. Card #16a is to be used for a pan camera, and #16b for the other types.) | | | | | |
| 16a | Pan Camera | FLENG(I) ANGS(I) HFLM(I) OPR(I) THTC(I) PREVR(I) EIG | 1-10 11-20 21-30 31-40 41-50 51-60 61-70 | F10.0 F10.0 F10.0 F10.0 F10.0 F10.0 F10.0 | Focal length (inches) Half-angle (deg.) subtended by film Height of film (inches) Overlap percentage Angle (deg.) between A/C vertical and focal axis. Darkness code (1 for day, 2 for night) Half-angle of slewing capability, (degrees) if camera is not slewable, set to zero |
| 16b | Frame Camera | FLENG(I) SW(I) SL(I) OPR(I) | 1-10 11-20 21-30 31-40 | F10.0 F10.0 F10.0 F10.0 | Focal length (inches) Frame width (inches)* Frame length (inches)* Overlap percentage |

* Length is measured along the wing axis; width along the aircraft axis.



Table 7.1 - continued

| Order | Description | Variable | Card Columns | Format Specification | Description |
|---|--------------------------|-----------|--------------|----------------------|---|
| 16b (cont'd) | | THTC (I) | 41-50 | F10.0 | Angle (deg.) between aircraft vertical and focal axis. |
| | | PREVR (I) | 51-60 | F10.0 | Darkness code (1 for day, 2 for night) |
| | | ELG | 61-70 | F10.0 | Depression angle of the focal axis, in degrees, when the camera is raised to its highest slewing position. Leave blank if camera is not slewable. |
| | | EIG1 | 71-80 | F10.0 | Depression angle of the focal axis, in degrees, when the camera is lowered to its lowest slewing position. Leave blank if camera is not slewable. |
| (Note: The index (I) in cards #16a and 16b will vary from 1 to 8 - depending on the cameras which are on for this run.) | | | | | |
| 17 | Forward Looking Infrared | THEMA | 1-10 | F10.0 | The maximum depression angle of the field-of-view of FLIRE |
| | | THEMI | 11-20 | F10.0 | The minimum depression angle of the field-of-view of FLIRE |
| | | BETA15 | 21-30 | F10.0 | The (positive) half angle of the azimuth area that can be covered by FLIRE |
| | | RHO15 | 31-40 | F10.0 | The (positive) half angle of the horizontal spread of the FLIRS beam |
| | | PMI15 | 41-50 | F10.0 | The (positive) half angle of the vertical spread of the FLIRS beam |
| | | THA15 | 51-60 | F10.0 | The depression angle of the central ray of the FLIRS beam |
| | | DTO | 61-70 | F10.0 | The optimal display time for a single picture of terrain taken by FLIRE |



Table 7.1 - continued

| Order | Card | Description | Variable | Card Columns | Format Specification | Description |
|--|----------------|-------------|----------|--------------|----------------------|---|
| 18 | Weather | WINDTH | | 1-10 | F10.0 | Wind direction (degrees from North) - direction from |
| | | WINDSP | | 11-20 | F10.0 | Wind speed (knots) |
| | | IRAIN | | 21-30 | F10.0 | Rain code (1 for rain, 2 for snow, 0 for no precipitation) |
| | | TRAIN | | 31-40 | F10.0 | Inches of rain (or snow) |
| | | XO | | 41-50 | F10.0 | Prevailing visibility (statute miles) |
| | | XOC | | 51-60 | F10.0 | Prevailing visibility in clouds (statute miles) |
| | | XCP | | 61-70 | F10.0 | Prevailing visibility in rain (statute mi.) |
| | | XOH | | 71-80 | F10.0 | Prevailing visibility in haze (statute mi.) |
| 19 | Weather | PREVERE | | 1-10 | I10 | 1 for day, 2 for night |
| | | P3 | | 11-20 | F10.0 | Probability of no undercast clouds |
| | | CLOUDE | | 21-30 | F10.0 | Height (ft.) of cloud base |
| | | CLOUDT | | 31-40 | F10.0 | Height (ft.) of cloud top |
| | | Q | | 41-50 | F10.0 | Height (ft.) of haze level |
| | | PPR | | 51-60 | F10.0 | Percentage of rain area |
| 20 | Flight Indices | ITT | | 1-5 | I5 | Simulation clock time at mission inception (tenths of second) |
| | | NPASS | | 6-10 | I5 | No. of passes |
| | | IIND | | 11-15 | I5 | Index for evasion (0 for yes, 1 for no) |
| (the following card (#21) should appear in the data only if IIND on card #20 is equal to "0".) | | | | | | |
| 21 | Evasion | AMPLTD | | 1-10 | F10.0 | Amplitude of wave course (NM) |
| | | DSCROS | | 11-20 | F10.0 | Distance between zero crossings (NM) |
| | | ROLLMN | | 21-30 | F10.0 | Min. roll angle (deg.) |
| | | ROLLMX | | 31-40 | F10.0 | Max. roll angle (deg.) |

| Order | Description | Variable | Card Columns | Format Specification | Description |
|---|-------------|---|--|---|---|
| 22 | No. of Legs | NLEG(1) NLEG(2) . . . NLEG(NPASS) | 1-5 6-10 etc. . . . | I5 I5 etc. . . . | The number of legs for each pass Each pass must have at least 2 legs The last leg is always a turn, or flight to base, during which time all sensors are off. |
| 23 | Flight Plan | XX(I,J) YY(I,J) HH(I,J) TT(I,J) | 1-10 11-20 21-30 31-40 | F10.0 F10.0 F10.0 I10 | Latitude* at start of leg J of pass I Longitude* at start of leg J of pass I Altitude (ft.) for leg J of pass I Time (tenths of sec.) to fly leg J of pass I |
| (Card #22 is repeated for I = 1, J = 1, 2, ..., NLEG(1); then for I = 2, J = 1, 2, ..., NLEG(2); until I = NPASS.) | | | | | |
| 24 | Navigation | ANAVHD I MAVSP ANAVSP ANAVPS ANAVPR ITCP ANAVHT | 1-10 11-20 21-30 31-40 41-50 51-60 61-70 | F10.0 I10 F10.0 F10.0 F10.0 I10 F10.0 | Heading error (radians) Speed error code - "0" if ANAVSP is in knots; "1" if ANAVSP is a % of the true speed Speed error (based on code above) Initial position error (NM) Position error rate (NM/hr.) from checkpoint Time of checkpoint intervals (tenths of second) Altitude error (ft.) |

* Latitude and longitude are to be punched as XXX.YYZZ, where XXX are the degrees, YY the minutes, and ZZ the seconds of the position. Latitude is positive if North; longitude is positive if West.



Table 7.1 - continued

| Order | Description | Variable | Card Columns | Format Specification | Description |
|-------|-------------|--|----------------------------------|-----------------------------------|---|
| 25a | Reliability | AMTBF(1) AMTBF(2) AMTBF(3) . . | 1-10 11-20 21-30 . . | F10.0 F10.0 F10.0 . . | |
| | | AMTBF(7) AMTBF(8) | 61-70 71-80 | F10.0 F10.0 | |
| 25b | | AMTBF(9) AMTBF(10) . . | 1-10 11-21 . . | F10.0 F10.0 . . | The mean time (in hours) between failures for each of the 15 sensors. |
| | | AMTBF(14) AMTBF(15) | 51-60 61-70 | F10.0 F10.0 | |

Notice: All the preceding cards must appear in a deck for each run with two exceptions:
 (1) The #16 card will not be required for a camera which is off; i.e., the card is not required if the value punched for that sensor on card #2 is "0".
 (2) Card #21 will not be required unless it is an evasion run; i.e., unless the value of IIND on card #20 is set to "0".



TABLE 7.2

VARIABLE OUTPUT LISTS BY SENSOR TYPE

| <u>Dummy Sensor</u> | |
|---------------------|---|
| G(1) | - time at which the target lies broadside of the aircraft (in .1 sec.). |
| G(2) | - ground offset range in NM. The positive direction is to the right. |
| G(3) | - slant offset range in NM. This parameter is always positive. |
| G(4) | - frame count for camera 1, when target is broadside of the aircraft. |
| G(5) | - frame count for camera 2, when target is broadside of the aircraft. |
| G(6) | - frame count for camera 3, when target is broadside of the aircraft. |
| G(7) | - frame count for camera 4, when target is broadside of the aircraft. |
| G(8) | - frame count for camera 5, when target is broadside of the aircraft. |
| G(9) | - frame count for camera 6, when target is broadside of the aircraft. |
| G(10) | - frame count for camera 7, when target is broadside of the aircraft. |
| G(11) | - frame count for camera 8, when target is broadside of the aircraft. |
| G(12) to G(15) | - not used. |
| P(1) | - navigational error in heading (radians). |
| P(2) | - navigational error in speed (knots). |
| P(3) | - navigational CEP (NM). |
| P(4) - P(5) | - not used. |
| W(1) to W(5) | - not used. |
| T(1) | - the target type code. |
| T(2) | - a code designation for preplanned targets (set to "0" if preplanned, set to ";" if not). |
| T(3) | - a code denoting if the target is keyed to air-to-air communications (set to "0" if keyed, set to "1" if not). |
| T(4) to T(10) | - not used. |



Table 7.2 - continued

Infrared Sensor

- G(1) - ground range to target (when passing broadside) in NM.
- G(2) - slant range to target in NM.
- G(3) - target height above mean-ground-level (MGL) in feet.
- G(4) - variance of the terrain height about its mean in (feet)²
- G(5) - slant range of haze traversed in NM.
- G(6) - slant range through clouds in NM.
- G(7) -- depression angle to the target in radians.
- G(8) - not used.
- G(9) - aircraft ground speed in knots.
- G(10) to G(15) - not used.
- P(1) - probability of no terrain shadowing.
- P(2) - probability that the equipment is up.
- P(3) - variance in heading error in (radians)²; arising from navigational subsystem.
- P(4) - variance in altitude error in (feet)²; arising from navigational subsystem.
- P(5) - not used.
- W(1) - prevailing visibility through haze in statute miles.
- W(2) - prevailing visibility through clouds in statute miles.
- W(3) - probability of no undercast clouds.
- W(4) - W(5)
- W(5) - not used.



Table 7.2 - continued

Infrared Sensor (cont'd)

- T(1) - target area in (meter)²
- T(2) - target temperature in °K.
- T(3) - resolution in meters required for 90% probability of detection.
- T(4) - target emissivity for band 1.
- T(5) - target emissivity for band 2.
- T(6) - background emissivity for band 1.
- T(7) - background emissivity for band 2.
- T(8) - background temperature in °K.
- T(9) - T(10) - not used.

Side Looking Radar

- G(1) - ground range to target (when passing broadside) in NM.
- G(2) - slant range to target in NM.
- G(3) - aircraft height above MGL in feet.
- G(4) - target height above MGL in feet.
- G(5) - variance of the terrain height about its mean in (feet)²
- G(6) - radial ground projection component of target velocity in knots. (positive towards aircraft)
- G(7) - aircraft ground speed in knots.
- G(8) - haze height.
- G(9) to G(15) - not used.
- P(1) - probability of no terrain shadowing.
- P(2) - probability that the equipment is up.
- P(3) to P(5) - not used.



Table 7.2 - continued

Side Looking Radar (cont'd)

- W(1) - precipitation rate of rain or snow in inches per hour.
- W(2) - precipitation index ("0" for none, "1" for rain, "2" for snow).
- W(3) - a code denoting if precipitation is falling upon the target ("1" for yes, "2" for no).
- W(4) - not used.
- T(1) - radar cross section in (meter)².
- T(2) - radar reflectivity of the target.
- T(3) - the resolution in meters required for 50% probability of detection.
- T(4) - background reflectivity.
- T(5) to T(10) - not used.

Side Looking Radar (MTI)

- G(1) - ground range to target (when passing broadside) in NM.
- G(2) - slant range to target in NM.
- G(3) - aircraft height above MGL in feet.
- G(4) - target height above MGL in feet.
- G(5) - slant range of rain traversed in NM.
- G(6) - absolute value of target speed (in knots) projected along the slant range vector.
- G(7) - variance of the terrain height about its mean in (feet)².
- G(8) - aircraft ground speed in knots.
- G(9) - maximum radar range in NM.
- G(10) - minimum radar range in NM.



Table 7.2 - continued

Side Looking Radar (MTI) (cont'd)

- G(11) - wind direction (from which it blows) in radians from North.
- G(12) - wind speed in knots.
- G(13) to G(15) - not used.
- P(1) - probability of no terrain shadowing.
- P(2) - probability that the equipment is up.
- P(3) to P(5) - not used.
- W(1) - precipitation rate of rain or snow in inches per hour.
- W(2) - precipitation index ("0" for none, "1" for rain, "2" for snow).
- W(3) - a code denoting if precipitation is falling upon the target ("1" for yes, "2" for no).
- W(4) - W(5) - not used.
- T(1) - radar cross section of the target in (meter)².
- T(2) - backscatter coefficient.
- T(3) - radar reflectivity of the target.
- T(4) to T(10) - not used.

Forward Looking Radar (MTI)

- G(1) - target speed projected along the slant range vector in knots* positive towards aircraft.
- G(2) - aircraft height above MGL in feet.
- G(3) - target height above MGL in feet.
- G(4) - minimum ground range, in NM, at which target is detectable.
- G(5) - maximum ground range, in NM, at which target is detectable.
- G(6) - expected number of target sightings unmasked by terrain.

* when the ground range to the target is $(G(4) + G(5))/2$



Table 7.2 - continued

Forward Looking Radar (MTI) (cont'd)

- G(7) - variance of the number of unobstructed sightings.
- G(8) - variance of the terrain height about its mean in (feet)².
- G(9) - slant range of rain traversed in NM.*
- G(10) - half angle of azimuth sweep (always positive).
- G(11) - direction from which wind blows (radians from North).
- G(12) - wind speed in knots.
- G(13) - aircraft ground speed in NM/sec.
- G(14) - minimum radar range in NM.
- G(15) - maximum radar range in NM.
- P(1) - probability of terrain shadowing.
- P(2) - probability that the equipment is up.
- P(3) to P(5) - not used.
- W(1) - precipitation rate of rain or snow in inches per hour.
- W(2) - precipitation index ("0" for none, "1" for rain, "2" for snow).
- W(3) - a code denoting if precipitation falling upon the target ("1" for yes, "2" for no).
- W(4) - W(5) - not used.
- T(1) - radar cross section of the target in (meter)².
- T(2) - backscatter coefficient of the background.
- T(3) - radar reflectivity of the target.
- T(4) - component along course axis of the ground range to the target at last look in NM.

* when the ground range to the target is $(G(4) + G(5))/2$



Table 7.2 - continued

Forward Looking Radar (MTI) (cont'd)

- T(5) - component perpendicular to course axis of the ground range to the target at last look in NM.
- T(6) - not used.
- T(7) - angle in the azimuth plane between aircraft course and the line of sight to the target*.
- T(8) - target height above mean ground level in feet.
- T(9) - minimum depression angle in radians at which a target is in the beam.
- T(10) - maximum depression angle in radians at which a target is in the beam.

ECM Sensor

- G(1) - ground distance of target from flight line in NM.
- G(2) - aircraft speed in knots.
- G(3) - aircraft height above MGL in feet.
- G(4) - slant range to target in NM at this look.
- G(5) - time of the look in tenths of a second.
- G(6) - not used.
- G(7) - code: set to "1" if target passed directly underneath the aircraft (within θ_2 degrees of nadir, where θ_2 is an input value); set to "0" otherwise.
- G(8) - the value of θ_2 in radians (used to determine G(7)).
- G(9) - slant range of rain traversed in NM, this look.
- G(10) - target height in feet.
- G(11) - the fraction of the time that the target is radiating.

* when the ground range to the target is $(G(4) + G(5))/2$



Table 7.2 - continued

ECM Sensor (cont'd)

- G(12) - the density of enemy radars in the scenario (NM^{-2}).
- G(13) - the mean PRF of all radars in the scenario (pulses/sec.).
- G(14) - expected value of the fractional main beam time -- mean of all radars in the scenario.
- G(15) - not used.
- P(1) - probability of no terrain shadowing.
- P(2) - probability that the equipment is up.
- P(3) - expected number of interfering radars at any given time.
- P(4) - P(5) - not used.
- W(1) - precipitation rate of rain or snow in inches per hour.
- W(2) - precipitation index ("0" for none, "1" for rain, "2" for snow).
- W(3) to W(5) - not used.
- T(1) - peak transmitted power in db above 1 watt.
- T(2) - transmitter antenna gain - main lobe in db.
- T(3) - frequency in MHz .
- T(4) - transmitter antenna front to back ratio, in db.
- T(5) - pulses per second; pulse repetition rate.
- T(6) - pulse width (microseconds).
- T(7) - target scan period in seconds.
- T(8) to T(10) - not used.

Photo Sensors

- G(1) - aircraft height above MGL in feet
- G(2) - depression angle to the target in radians; this frame.
- G(3) - slant range to target in NM; this frame.
- G(4) - slant range of haze traversed in NM; this frame.



Table 7.2 - continued

Photo Sensors (cont'd)

- G(5) - slant range of rain traversed in NM; this frame.
- G(6) - the frame number of this photo.
- G(7) - G(8) - not used.
- G(9) - perpendicular distance from the target to the heading axis for frame camera (set to 1.0 if camera is a pan type) in ft. Positive if target is to the right of the heading axis.
- G(10) - average distance from the heading axis to the right-most edge of the rest field of view for frame cameras (set to 1.0 if pan camera) in ft.* Distance is positive if to the right of the heading axis.
- G(11) - average distance from the heading axis to the left-most edge of the rest field of view for frame cameras (set to 1.0 if pan camera) in ft.* Distance is positive if to the right of the heading axis.
- G(12) to G(15) - not used.
- P(1) - terrain non-shadowing probability.
- P(2) - probability that the equipment is up.
- P(3) to P(5) - not used.
- W(1) - prevailing weather visibility in statute miles.
- W(2) - visibility in rain in statute miles.
- W(3) - code: set to "1" for day; set "2" for night.
- W(4) - the probability of no undercast clouds.
- W(5) - visibility in haze in statute miles.
- T(1) - reflectivity of target.
- T(2) - resolution required in feet for 90% probability of detection.
- T(3) - reflectivity of the background.
- T(4) to T(10) - not used.

* Rest field of view is defined as that area covered by a camera when in an unslewed mode.



Table 7.2 - continued

Forward Looking Infrared Sensor

- G(1) - ground range to target in NM on this snapshot.
- G(2) - slant range to target in NM on this snapshot.
- G(3) - target height above mean ground level (MGL) in feet.
- G(4) - variance of the terrain height about its mean in (feet)².
- G(5) - slant range of haze traversed in NM on this snapshot.
- G(6) - slant range through clouds in NM on this snapshot.
- G(7) - depression angle to the target in radians on this snapshot.
- G(8) - azimuth angle to the target in radians from heading axis; this snapshot
- G(9) - an index which indicates whether the target is seen on this record:
set to "0" for yes, set to "1" for no.
- G(10) - aircraft ground speed in knots.
- G(11) to G(15) - not used.
- P(1) - probability of no terrain shadowing.
- P(2) - probability that the equipment is up.
- P(3) - navigational variance in heading in (radians)².
- P(4) - navigational variance in altitude in (feet)².
- P(5) - not used.
- W(1) - prevailing visibility through haze in statute miles.
- W(2) - prevailing visibility through clouds in statute miles.
- W(3) - probability of no undercast clouds.
- W(4) - W(5) - not used.



Table 7.2 - continued

Forward Looking Infrared Sensor (cont'd)

- T(1) - target area in (meter)².
- T(2) - target temperature in °K.
- T(3) - resolution in meters required for 90% probability of detection.
- T(4) - target emissivity for band 1.
- T(5) - target emissivity for band 2.
- T(6) - background emissivity for band 1.
- T(7) - background emissivity for band 2.
- T(8) - background temperature in °K.
- T(9) - T(10) - not used.



TABLE 7-3 INPUT TO EXECUTIVE MODEL

| CARD NUMBER | VARIABLE | DEFINITION | FORMAT |
|-------------|--|--|------------|
| 1 | RES(1) RES(2) ALAM22(1) ALAM22(2) ALAM21(1) ALAM21(2) DIEMP(1) DIEMP(2) | Angular resolution for Band 1 of the IR in radians Angular resolution for Band 2 of the IR in radians Highest wavelength of Band 1 of the IR in microns Highest wavelength of Band 2 of the IR in microns Lowest wavelength of Band 1 of the IR in microns Lowest wavelength of Band 2 of the IR in microns Thermal resolution of Band 1 of the IR in K ^o Thermal resolution of Band 2 of the IR in K ^o | 8F10.5 |
| 2 | SIGTHI(1) SIGTHI(2) GAMMA2 CØ2 | Variance in angle measurement of Band 1 of the IR in (radians) Variance in angle measurement of Band 2 of the IR in (radians) IR system film gamma Minimum detectable logarithmic contrast for the IR sensor | 4F10.5 |
| 3 | BNWDIR TROT NODTIR | Beam width of a single IR detector in radians Rotational period of the mirrors in sec. Number of IR detectors in sensor | 2F10.0, I5 |
| 4 | IFALS2 ILEVEL(J,L)* (L=1,...4) JIR | Probability of false alarm coefficient. This is -Log ₁₀ of the noise induced false alarm rate per unit detection time. It should be between 5 and 12.** This variable gives the levels of processing desired (1 if desired, 0 if not). For those levels of interest, a probability of target detection at that level is computed. If JIR=1, a diagnostic printout will be generated in the IR subroutine. If JIR#1, no printout is generated. | 6I5 |



TABLE 7-3 INPUT TO EXECUTIVE MODEL (Cont.)

| CARD NUMBER | VARIABLE | DEFINITION | FORMAT |
|-------------|---|---|--------|
| 5 | ISLRTY | Type Index; 1 if real apperture, 2 if synthetic | I5 |
| 6 | HLITS PHEMIS ALAMDS GAMMAS CØS ALIS ALIPS | Range resolution in NM Beam depression angle in radians Radar wavelength in centimeters System gamma, including film gamma. Minimum detectable logarithmic contrast Film resolution in lines/millimeter. Display resolution in line pairs. | 8E10.0 |
| 7 | DI RMAX RMIN RIP SIGTSS | Width of film in meters. Maximum slant range covered by film in meters. Minimum slant range covered by film in meters. Width of range displayed in the display in meters. 2 (θ) in radians2 (θ) is the perceived azimuth angle.) | 5F10.0 |
| 8 | AJ AJ24 BETSLR | Cross range resolution in NM, level 1, synthetic. May be left blank if real apperture is used. Cross range resolution in NM, levels 2,3, and 4, synthetic. May be left blank if real apperture is used. Half power beam width (in radians) if real processing is used. May be left blank if synthetic apperture SLR. | 3F10.0 |
| 9 | ILEVEL(J,L)* L=1,4 JSLR | ILEVEL(J,L) is 1 if PD appears in Level L; it equals 0 if otherwise. Levels 1 to 4. If JS LR=1, a diagnostic printout will be generated in the SLR subroutine. If JS LR=1, no printout will be generated. | 5I5 |



TABLE 7-3 INPUT TO EXECUTIVE MODEL (Cont.)

| CARD NUMBER | VARIABLE | DEFINITION | FORMAT |
|-------------|--|--|--------|
| 10 | DX DR PHE4 ALAMD4 SIGTS4 PDC4 | Forward resolution in meters Slant range resolution in meters Top of beam depression angle in radians Radar wavelength in centimeters σ^2 (θ); (θ is the perceived azimuth angle) in radians squared. Threshold detectability probability below which target is unidentifiable. | 6F10.0 |
| 11 | A101 A301 A302 A303 A304 A901 A902 B603 C101 C102 | Horizontal beamwidth of radar in degrees Peak pulse power in kilowatts Pulse compression ratio Antenna efficiency in percent (i.e. 0-100) Sweep integration factor Pulse repetition period in milliseconds No. of delay lines Verticle velocity of rain drop in knots Receiver subsystem noise figure in decibels Effective system bandwidth in megahertz | 10F8.0 |
| 12 | IFALS4 ILEVEL(J,L)* L=1,4 JMSLR | Probability of false alarm coefficient. This is $-\log_{10}$ of the noise induced false alarm rate per unit detection time.** The levels in which PD (output variable) appears; 1 if it appears, 0 if not. Levels are L=1, L=2, L=3, and L=4. If JMSLR=1, a diagnostic printout will be generated in the MTISLR subroutine. If JMSLR \neq 1, no printout is provided. | 6I5 |



TABLE 7-3 INPUT TO EXECUTIVE MODEL (Cont.)

| CARD NUMBER | VARIABLE | DEFINITION | FORMAT |
|-------------|--|--|--------|
| 13 | HLIT ALANDA PDC5 SIF SI6T | Edge of the (rectangular) resolution cell in NM Radar wavelength in centimeters Threshold detectability probability below which target cannot be identified. Sweep integration factor. Standard deviation of θ in radians; θ is the perceived azimuth angle. | 5F10.0 |
| 14 | AA02 AA03 AA04 AA05 AA07 AA08 AA09 AA11 AA12 AA13 | Number of delay lines Verticle velocity of rain drop in knots. Receiver subsystem noise figure in decibles. Radar bandwidth in megahertz. Antenna efficiency in percent (0 to 100). Pulse compression ratio Peak pulse power Range resolution in meters Cross range resolution in meters Pulse repetition period in milliseconds. | 10F8.0 |
| 15 | IFALSE ILEVEL(J,L)* JMFLR | -Log10 of the noise induced false alarm rate per unit detection time (must be between 5 and 12)** For Level L (L=1,2,3,4), the value is 1 if the level is to be considered and 0 otherwise. If JMFLR=1, a diagnostic printout will be generated within the MTIFLR subroutine. If JMFLR \neq 1, no printout will be generated. | 6I5 |



TABLE 7-3 INPUT TO EXECUTIVE MODEL (Cont.)

| CARD NUMBER | VARIABLE | DEFINITION | FORMAT |
|-------------|---|--|--------|
| 16 | A SIGTS SIGVS FREQL ANF BAND | Measurement of the angular measurement precision (sigma) relative to beam width (typically 1/6). Variance of the aircraft position (from the actual) as given by the aircraft avionics systems. Variance of (true) velocity as given by the avionics systems in knots squared. Threshold frequency in megahertz, above which it is possible to get an angular fix on the target. Receiver noise figure in db Receiver bandwidth in megahertz. | 6F10.0 |
| 17 | NRECM RPECM E1ECM B2ECM | Maximum signal processing rate in pulses per second The number of receive channels Instantaneous receiver bandwidth in MHz Total system bandwidth in MHz | |
| 18 | NBEAM ITABM ILEVEL(J,L)* JECM | Number of beams. The number of entries in the table (i.e., the number of type 5 cards). The levels of processing for which a probability of detection should be computed l=yes, 0=no. If JECM=1, a diagnostic printout will be generated in the ECM subroutines. If JECM#1, no printouts will be provided. | 7I5 |



TABLE 7-3 INPUT TO EXECUTIVE MODEL (Cont.)

| CARD NUMBER | VARIABLE | DEFINITION | FORMAT |
|--|---|--|--------|
| 19 (There are "ITABM" of these cards) | XTAB YTAB | The frequency associated with "YTAB" in megahertz. This is the receiver antenna gain plus line losses experienced at frequency "XTAB". Units are in db. | 2F10.0 |
| 20 | Q(1) Q(2) . . Q(8) | Q(I) is the fraction of keyed photos which are transmitted to the ground station by sensor number I + 6. | 8F10.0 |
| 21 | ALIP(1) ALIP(2) . . ALIP(8) | ALIP(I) is the display (or scanner) resolution for sensor I + 6. The units are display line pairs per millimeter | 8F10.0 |
| 22 | ALI(1) ALI(2) . . ALI(8) | ALI(I) is the film resolution, in optical lines per millimeter for sensor I + 6. | 8F10.0 |
| 23 | AL2(1) AL2(2) . . AL2(8) | AL2(I) is the effective lens resolution, in optical lines per millimeter for sensor I + 6. (Resolution taking into account vibration, noise, turbulent air flow, etc.) | 8F10.0 |



TABLE 7-3 INPUT TO EXECUTIVE MODEL (Cont.)

| CARD NUMBER | VARIABLE | DEFINITION | FORMAT |
|-------------|--|---|--------|
| 24 | F(1) F(2) . . F(8) | F(I) is the lens focal length (in inches) for sensor I + 6 | 8F10.0 |
| 25 | D(1) D(2) . . D(8) | D(I) is the logarithmic scale of film (or of the display if TV) of sensor I + 6 | 8F10.0 |
| 26 | CØ(1) CØ(2) . . CØ(8) | CØ(I) is the minimum detectable logarithmic contrast. It is equal to log ₁₀ (minimum target to background brightness ratio detectable) for sensor I + 6. | 8F10.0 |
| 27 | GAMMA(1) GAMMA(2) . . GAMMA(8) | GAMMA(I) is the film (or display if TV) gamma for sensor I + 6 | 8F10.0 |



TABLE 7-3 INPUT TO EXECUTIVE MODEL (Cont.)

| CARD NUMBER | VARIABLE | DEFINITION | FORMAT |
|-------------|---|---|---------------------|
| 28 | DIS(1) DIS(2) . . DIS(8) | DIS(I) is the distance between sensor I + 6 and the electronic flare in meters. | 8F10.0 |
| 29 | RO(1) RO(2) . . RO(5) | RO(I) is the minimum range at which back scatter occurs for sensor I + 6 in meters. | 8F10.0 |
| 30 | ILEVEL(J,1)* ILEVEL(J,2) ILEVEL(J,3) ILEVEL(J,4) ILEVEL(J,1) . . ILEVEL(J,4) ILEVEL(J,1) . . ILEVEL(J,4) JPHOTO | ILEVEL(J,L) is equal to 1 if detection is possible at Level L. If this is not the case, ILEVEL(J,L) = 0. The first four ILEVEL values are for camera #1, the next four for camera #2, ..the last four for camera #8. If JPHOTO=1, a diagnostic printout is generated within the photo sub-routine. If JPHOTO#1, there will be no printout. | 32(1X,11), 1X,11 |



TABLE 7-3 INPUT TO EXECUTIVE MODEL (Cont.)

| CARD NUMBER | VARIABLE | DEFINITION | FORMAT |
|-------------|---|---|-----------|
| 31 | <p>ANGRES(1) ANGRES(2) HLANDA(1) HLANDA(2) BLANDA(1) BLANDA(2) TEMRES(1) TEMRES(2)</p> | <p>Angular resolution for Band 1 of the FLIR in radians Angular resolution for Band 2 of the FLIR in radians Highest wavelength of Band 1 of the FLIR in microns Highest wavelength of Band 2 of the FLIR in microns Lowest wavelength of Band 1 of the FLIR in microns Lowest wavelength of Band 2 of the FLIR in microns Thermal resolution of Band 1 of the FLIR in degrees Kelvin Thermal resolution of Band 2 of the FLIR in degrees Kelvin</p> | 8F10.0 |
| 32 | <p>ANGVAR(1) ANGVAR(2) SYSGAM AMDLC</p> | <p>Variance in angle measurement of Band 1 of the FLIR in radians². Variance in angle measurement of Band 2 of the FLIR in radians². IR system film gamma. Minimum detectable logarithmic contrast for the FLIR sensor.</p> | 4F10.5 |
| 33 | <p>BEMWID PERIOD NUMDET</p> | <p>The beam width of an individual detector in radians. The period of rotation of the mirrors in seconds. The number of detectors in the sensor.</p> | 2F10.0,I5 |
| 34 | <p>IFAL15 ILEVEL(J,L)* L=1 to 4 JFLIR</p> | <p>Probability of false alarm coefficient. This is -Log₁₀ of the noise induced false alarm rate per unit detection time. It should be between 5 and 12.** This variable gives the levels of processing desired (1 if desired, 0 if not). For those levels of interest, a probability of target detection at that level is computed. If JFLIR=1, a diagnostic printout will be generated within the FLIR subroutines. If JFLIR ≠ 1, there will be no printout.</p> | 6I5 |



TABLE 7-3 INPUT TO EXECUTIVE MODEL (Cont.)

| CARD NUMBER | VARIABLE | DEFINITION | FORMAT |
|-------------|----------|--|--------|
| | JEXC1 | If JEXC1 = 1, a hard copy of EXEC is prepared. If JEXC1 ≠ 1, no hard copy. | |
| 55 | JEXC2 | If JEXC2 = 1, the phrase "official use only" will be printed on each sheet of the hard copy output. If JEXC2 ≠ 1, no official phrase is printed. | 215 |

* For the variable ILEVEL(J,L) the index J is a code number for the sensor number - these code numbers are given in Appendix I(Vol. III) of the AIRS report.

** The quantity is computed as $-\frac{1}{n} \log_{10} \frac{F}{B}$, where B is the system bandwidth which is equivalent to the product of display frequency and the number of distinguishable spots on the screen, n is the number of consecutive false alarm spots constituting a false alarm, F is the acceptable false alarm rate measured in false alarms per second.



TABLE 7-4 RECORDS ON OUTPUT TAPE 1

| GROUP 1 RECORD 1 WORD NUMBER | NAME | DEFINITION |
|------------------------------------|---------------------|---|
| 1-20 | IALPHA(J) J=1,20 | Header information, obtained from Scenario tape |
| 21 | ITARG | Target ID = YYXX where YY is the pass index and XXX is the target index |
| 22 | ITTYPE | Target type code |
| 23 | ITPP | Time of passage (tenths of seconds) |
| 24-25 | PK(I) | Probability of automatic keying |
| 26-27 | CEPKEY | CEP of automatic keying |
| 28-29 | XOFFG | Ground offset range (NM) |
| 30-31 | EN1 | Error in heading |
| 32-33 | EN2 | Error in speed |
| 34-35 | EN3 | CEP NAV (NM) |
| 36 | ITKEY | Code denoting if target is keyed to air-to-air communications (0=no, 1=yes) |
| Records 2 - 15 | | |
| 1 | I1 | Sensor Number |
| 2 | NSEN(I1) | Indicates whether the sensor saw target (1=yes, 0=no) |
| 3-4 | PRI(I1) | Probability target is not shadowed by terrain |
| 5-6 | PR2(I1) | Probability that equipment is up |
| 7-8 | PR3(I1) | Probability of no undercast cloud, fraction not observed |
| 9-10 | PDC(I1,1) | Conditional Detectability for Level 1 |
| 11-12 | PDC(I1,2) | Conditional Detectability for Level 2 |
| 13-14 | PDC(I1,3) | Conditional Detectability for Level 3 |
| 15-16 | PDC(I1,4) | Conditional Detectability for Level 4 |



TABLE 7-4 RECORDS ON OUTPUT TAPE 1 (Cont.)

| WORD NUMBER | NAME | DEFINITION |
|-------------|--------------|---|
| 17-18 | PD(11,1) | Total Detectability for Level 1 |
| 19-20 | PD(11,2) | Total Detectability for Level 2 |
| 21-22 | PD(11,3) | Total Detectability for Level 3 |
| 23-24 | PD(11,4) | Total Detectability for Level 4 |
| 25-26 | PI(11,1) | Conditional Identifiability for Level 1 |
| 27-28 | PI(11,2) | Conditional Identifiability for Level 2 |
| 29-30 | PI(11,3) | Conditional Identifiability for Level 3 |
| 31-32 | PI(11,4) | Conditional Identifiability for Level 4 |
| 33-34 | CEP(11) | CEP, conditional on detection |
| 35-36 | DATA (1,11) | |
| 37-38 | DATA (2,11) | |
| 39-40 | DATA (3,11) | |
| 41-42 | DATA (4,11) | |
| 43-44 | DATA (5,11) | |
| 45-46 | DATA (6,11) | |
| 47-48 | DATA (7,11) | |
| 49-50 | DATA (8,11) | |
| 51-52 | DATA (9,11) | |
| 53-54 | DATA (10,11) | |
| 55-56 | DATA (11,11) | |

These words contain the data array for sensor 11.
 This array differs for each sensor; the meaning of
 each entry in the array for each sensor type is given
 in Table 7-5.



TABLE 7-4 RECORDS ON OUTPUT TAPE 1 (Cont.)

| WORD NUMBER | NAME | DEFINITION |
|--------------------------|-------|-----------------------------|
| GROUP 2 | | |
| Records 16 through 19 | | |
| 1 | L | Level Number |
| 2-3 | PRC | Conditional Detectability |
| 4-5 | PR | Total Detectability |
| 6-7 | PRI | Conditional Identifiability |
| 8-9 | PRIT | Total Identifiability |
| 10-11 | CEPR | Relative Localizability |
| 12-15 | CEPT | Total Localizability |
| GROUP 3 | | |
| Record 20 | | |
| 1-2 | PG4 | Geodetic Probability |
| 3-4 | CEPG4 | Geodetic Localizability |

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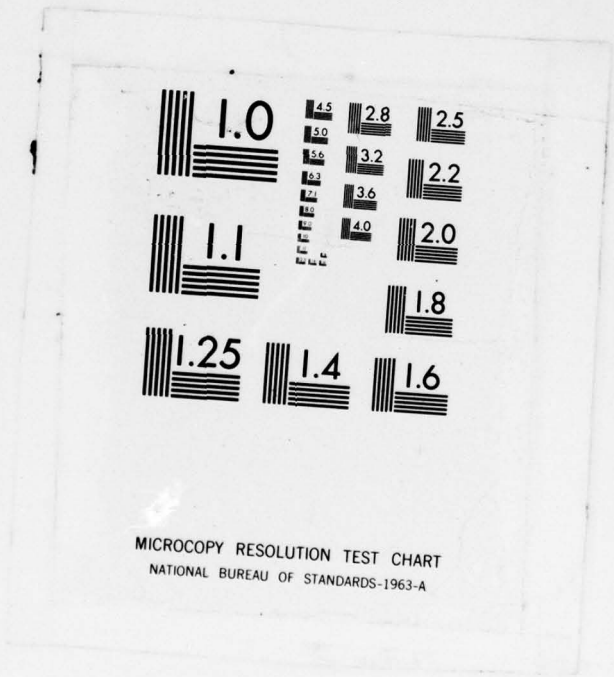
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TABLE 7-5 DATA ARRAY FOR EACH PASS-TARGET COMBINATION

| | Data (1,N) | Data (2,N) | Data (3N) | Data (4,N) |
|--|---|--|--|---|
| N represents sensor type. If N represents: | | | | |
| IR | Range to target, NM | Contrast in Band 1 when clouds are present | Contrast in Band 1 when clouds are not present | Contrast in Band 2 when clouds are not present |
| SLR | Range to target, NM | Contrast, Level 1 | Effective output resolution Level 1 | Effective output resolution Levels 2, 3, & 4 |
| MTISLR | Range to target, NM | Radial Speed, KTS | | Power output in watts at the sensor due to signal return from target |
| MTIFLR | Range to target, NM | Radial Speed, KTS | | Power output in watts at the sensor due to signal return from background |
| PHOTO | Range to target (Averaged over all looks), NM | Contrast-averaged over all looks | Resolution-averaged over all looks Level 1-2 | Number of frames on which target appears |
| ECM | Range to target when passing broadside, NM | S/N; main lobe radiation | S/N; side lobe radiation | Detectability in main lobe averaged over all looks (no terrain blocking, interference, or equipment down consideration) |



TABLE 7-5 DATA ARRAY FOR EACH PASS-TARGET COMBINATION (Cont.)

| N represents sensor type. If N represents: | Data (1,N) | Data (2,N) | Data (3,N) | Data (4,N) |
|--|--|--|--|--|
| FLIR | Range to target when passing broadside, NM | Contrast- Band 1 clouds. Averaged over all valid looks | Contrast- Band 1, no clouds. Averaged over all valid looks | Contrast- Band 2 clouds. Averaged over all valid looks |



TABLE 6-3 DATA ARRAY FOR EACH PASS-TARGET COMBINATION

| N represents sensor type. If N represents: | Data (5,N) | Data (6,N) | Data (7,N) | Data (8,N) |
|--|---|--|---|---|
| IR | Contrast in Band 2 when clouds are not present | Conditional detect-ability Band 1 | Conditional detect-ability Band 2 | |
| SLR | Effective system resolution Level 1 | Effective system resolution Levels 2,3, & 4 | Contrast, Levels 2,3, & 4 | |
| MTISLR | Precipitation clutter power in watts | Noise power in watts introduced by sensor delay lines | Ratio: target signal plus noise plus precipitation clutter power to background signal plus noise plus precipitation clutter power | Conditional detectability |
| MTIFLR | Precipitation clutter power in watts | Noise power in watts introduced by sensor delay | Ratio: target signal plus noise plus precipitation clutter power to background signal plus noise plus precipitation clutter power | Conditional detectability |
| PHOTO | The conditional detectability averaged over all looks; Levels 1-2 | The total detect-ability averaged over all looks; Levels 1-2 | The total identi-fiability averaged over all looks; Levels 1-2 | The conditional detectability averaged over looks; Levels 3-4 |



TABLE 6-3 DATA ARRAY FOR EACH PASS-TARGET COMBINATION (Cont.)

| N represents sensor type. If N represents: | Data (5,N) | Data (6,N) | Data (7,N) | Data (8,N) |
|--|---|---|---|---|
| ECM | Detectability in side lobe averaged over all looks (no terrain blocking, interference, or equipment down consideration) | Non-interference probability main lobe; averaged over all looks | Non-interference probability side lobe; averaged over all looks | |
| FLIR | Contrast-Band 2; no clouds averaged over all valid looks | Conditional detectability Band 1 averaged over all valid looks | Conditional detectability Band 2 averaged over all valid looks | Conditional detect-Slant range to target at last valid look, NM |



TABLE 6-3 DATA ARRAY FOR EACH PASS-TARGET COMBINATION (Cont.)

| N represents sensor type. If N represents: | Data (9,N) | Data (10,N) | Data (11,N) |
|--|---|---|---|
| IR | | | |
| SLR | | | |
| MTISLR | Terrain non-blocking probability | | |
| MTIFLR | The expected number of looks unobstructed by terrain | | |
| PHOTO | Average of (the total detectability averaged over all looks) Levels 3-4 | Average of (the total identifiability averaged over all looks) Levels 3-4 | Resolution averaged over all looks Levels 3-4 |
| ECM | | | |
| FLIR | | | |



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APPENDIX A.

PROOF OF ALGORITHM FOR DETERMINING
 PROBABILITY OF REALIZING k OUT OF N_h EVENTS

We first find the probability of exactly k targets identified as type T_h . Let N_h be the number of targets of type T_h in the complex. Let E_j = the event the j^{th} target of type T_h is identified where $j \leq N_h$.

Let $E_{k,j}$ = the event that exactly k events E_j occur (i.e., $E_{k,j}$ = the event that exactly k out of the first j targets of type T_h are identified). Thus we are seeking first $P(E_{k,N_h})$, the probability of exactly k targets of type T_h being identified all N_h targets of type T_h . We find $P(E_{k,j})$ for by iteration (induction) over j.

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In other words, we first find $P(E_{k,0})$ for $k = 0, N_h$. Then we calculate $P(E_{k,1})$ for $k = 0, N_h$ from $P(E_{k,0})$ for $k = 0, N_h$ using the general technique described below. Continuing in this manner, we finally calculate $P(E_{k,N_h})$ for $k = 0, N_h$ from $P(E_{k,N_h-1})$ for $k = 0, N_h$.

Clearly $E_{0,0}$ always happens, since exactly 0 targets of type T_h will be identified out of the first 0 targets of type T_h . Similarly, $E_{k,0}$, $k \neq 0$ never happens since exactly k targets out of the first 0 targets of type T_h cannot be identified if $k \neq 0$. Therefore,

$$P(E_{k,0}) = \begin{cases} 1 & \text{if } k = 0 \\ 0 & \text{if } k \neq 0 \end{cases} \quad (\text{A.1})$$

So we know $P(E_{k,0})$ for $k = 0, N_h$. Now suppose we know $P(E_{k,j})$ for $k = 0, N_h$. We want to calculate $P(E_{k,j+1})$ for $k = 0, N_h$. First we find $P(E_{k,j+1})$ for $k = 0$. $E_{0,j+1}$ happens only when $E_{0,j}$ happens and E_{j+1} does not happen. So $P(E_{0,j+1}) = P(E_{0,j})(1 - P(E_{j+1}))$. Next we calculate $P(E_{k,j+1})$ for $k > 0$. We distinguish between two mutually exclusive and exhaustive cases of $E_{k,j+1}$

- (1) E_{j+1} occurs and E_{k-1} occurs
- (2) E_{j+1} does not occur and $E_{k,j}$ occurs

The probability of case (1) is $P(E_{j+1}) P(E_{k-1,j})$, since E_{j+1} and $E_{k-1,j}$ are independent. Likewise, the probability of case (2) is $1 - P(E_{j+1}) P(E_{k,j})$. In addition, $P(E_{k,j+1})$ is the probability of case (1) plus probability of case (2).



Therefore, we conclude:

$$P(E_{k,j+1}) = P(E_{j+1}) P(E_{k-1,j}) + (1-P(E_{j+1})) P(E_{k,j}), \text{ for } k > 0 \quad (\text{A.2})$$

Thus we now have the general technique to find $P(E_{k,j+1})$ for $k = 0, N_h$ in terms of $P(E_{k,j})$ for $k = 0, N_h$. Now by N_h successive applications of this technique we find $P(E_{k,N_h})$ for $k = 0, N_h$. This is our desired result.



APPENDIX B

PROBABILITY THAT AT LEAST ONE OF SEVERAL DECISION FUNCTIONS IS SATISFIED

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This appendix describes in detail the algorithm used to determine the probability of observing the target complex. *First* the decision rule is outlined. Then the algorithm is *explained*. ~~explained.~~

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The decision rule has associated with it target types T_1, \dots, T_g and decision functions D_1, D_2, \dots, D_n . The rule is satisfied (i.e., the complex is observed) if at least one of the decision functions is satisfied. Each decision function consists of a set of g numbers, each corresponding to a target type. Each number specifies the minimum number, i , of targets of the corresponding type which must be identified for the decision function to be satisfied.

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() We are given the probability of identifying at least m ($m=0,1,2,\dots$) targets of each type T_1, T_2, \dots, T_g , and wish to determine the probability of observing the complex. Obviously, if we limit the decision rule to the first target type, T_1 , the probability of observing the complex would be trivial to compute. In that case, letting m be the least minimum (for the first type, T_1) of all the decision functions, we have immediately that the probability of identifying at least m is the probability of observing the complex. We could limit the decision rule not only to the first type T_1 , but still further to some subset of the set of decision functions. In this case the probability of observing the complex is obtained just as trivially. Since the case with the rule limited to T_1 is so simple it is natural to consider the case with two target types T_1 and T_2 .

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It is shown later in this appendix that the probability of observing the complex with the rule limited to T_1 and T_2 can be obtained if one knows the probability of observing the complex with the rule limited to a subset of the decision functions which in turn are limited to T_1 . In general, it is shown that, if we can calculate the probability of observing the complex with the decision rule limited to a subset of the decision functions which in turn are limited to types T_1, T_2, \dots, T_r , then we can calculate the probability of observing the complex with the decision rule limited to some subset of the decision functions which are in turn limited to types T_1, T_2, \dots, T_{r+1} . Continuing with this procedure we obtain the probability of observing the complex with the decision rule limited to some subset of the decision functions which are in turn limited to types T_1, T_2, \dots, T_g . If we let the subset of decision functions include all the decision functions, we have not limited the rule at all. Hence we would then have calculated the true probability of observing the complex.

To explain the above procedure we define some useful terms. Let $E_{k,i}$ = the event of satisfying decision function D_k 's minimum for target type T_i . Notice, $E_{k,i}$ is merely the event that at least m (the minimum for target type T_i in D_k) targets of type T_i are identified. Furthermore, for all $m=0,1,2\dots$ we know the probability of identifying at least m targets of type T_i . Hence we know $P(E_{k,i})$, the probability that $E_{k,i}$ occurs. Also $\bigcap_{j \leq i} E_{k,j}$ is the event that decision function D_k is satisfied for all target types T_1, T_2, \dots, T_i . In particular $\bigcap_{j \leq g} E_{k,j}$ is the event that decision function D_k is satisfied. Consequently $\bigcup_{k=1}^g \bigcap_{j \leq g} E_{k,j}$ is the event of satisfying at least one of the decision functions, i.e. the event of observing the complex. Similarly, $\bigcup_{k=1}^g \bigcap_{j \leq i} E_{k,j}$ is the event of satisfying the decision rule when it is limited to target types T_1, T_2, \dots, T_i .



Now, let $S \subset \{1, 2, \dots, n\}$ so S represents a subset (the set of all decision functions with index in S) of $\{D_1, D_2, \dots, D_n\}$ the set of decision functions. Then $\bigcup_{k \in S} \bigcap_{j \leq i} E_{k,j}$ is the event of satisfying the rule when it is limited to the subset of decision functions represented by S , which are in turn limited to types T_1, \dots, T_i . This event is referred to frequently, so we devise a new symbol: $F_{S,i} = \bigcup_{k \in S} \bigcap_{j \leq i} E_{k,j}$. By definition, $F_{\{1, 2, \dots, n\}, g}$ is the event of observing the complex. So we want to calculate $P(F_{\{1, \dots, n\}, g})$. This is done by iteration (induction) over the second index. That is, each step of the iteration increments the second index; thus, as mentioned earlier, incrementing the number of types to which we restrict the rule.

To perform the iteration we must first calculate $P(F_{S,i})$ where S is a non-empty subset of $\{1, \dots, n\}$. (\emptyset is the empty set so we write: $\emptyset \neq S \subset \{1, \dots, n\}$).

For each $k \in S$ we have a minimum number of targets required to be identified as type T_1 to satisfy D_k . We may order the decision functions in S by the minimum number of targets they require to be identified as type T_1 . Let D_{ORD1} be the decision function requiring the least number (that is the most easily satisfied) of type T_1 ; D_{ORD2} be the one requiring the second least number of type T_1 ; etc. We notice that if $F_{S,1}$ occurs D_{ORD1} is satisfied for type T_1 , because if any decision function with indice in S is satisfied for type T_1 , so is D_{ORD1} . Also, if D_{ORD1} is satisfied for type T_1 $F_{S,1}$ occurs by definition. Therefore, $P(F_{S,1}) = P(E_{ORD1,1})$ for all non-empty $S \subset \{1, 2, \dots, n\}$. However, as explained earlier we know $P(E_{ORD,1})$ and therefore we know $P(F_{S,1})$.

Now we describe the general technique used in the iteration procedure. Suppose we know $P(F_{S,r})$ for all non-empty



$S \subset \{1, 2, \dots, n\}$ and want to find $P(F_{S, r+1})$ where $\emptyset \neq S \subset \{1, 2, \dots, n\}$.
 We first reorder the decision functions for T_{r+1} as we did above for T_1 . Let the number of elements in S be 2. Then for calculation purposes we break $F_{S, r+1}$ into the following mutually exclusive and exhaustive cases:

1. $F \{ \text{ORD1} \}, r$ occurs and
 $E_{\text{ORD1}, r+1}$ occurs and
 $E_{\text{ORD2}, r+1}$ does not occur
2. $F \{ \text{ORD1}, \text{ORD2} \}, r$ occurs and
 $E_{\text{ORD2}, r+1}$ occurs and
 $E_{\text{ORD3}, r+1}$ does not occur
 \vdots
- q-1. $F \{ \text{ORD1}, \text{ORD2}, \dots, \text{ORD}(q-1) \}, r$ occurs and
 $E_{\text{ORD}(q-1), r+1}$ occurs and
 $E_{\text{ORD}q, r+1}$ does not occur
- q. $F \{ \text{ORD1}, \text{ORD2}, \dots, \text{ORD}q \}, r$ occurs and
 $E_{\text{ORD}q, r+1}$ occurs

1. The probability of case 1 =

$$P(F \{ \text{ORD1} \}, r) \left[P(E_{\text{ORD1}, r+1}) - P(E_{\text{ORD2}, r+1}) \right]$$



2. The probability of case 2 =

$$P(F \{ ORD1, ORD2 \}, r) \left[P(E_{ORD2, r+1}) - P(E_{ORD3, r+1}) \right]$$

$$\vdots$$

q-1. The probability of case q-1 =

$$P(F \{ ORD1, \dots, ORD(q-1) \}, r) \left[P(E_{ORD(q-1), r+1}) - P(E_{ORDq, r+1}) \right]$$

q. The probability of case q =

$$P(F \{ ORD1, ORD2, \dots, ORDq \}, r) P(E_{ORDq, r+1})$$

All of the values on the right of equations 1 through q are known so we know the probability of each case. Also $P(F_{S, r+1}) =$ probability of case 1 + ... + probability of case q, since the cases are mutually exclusive and exhaustive. Thus, we now have the general technique for finding $P(F_{S, r+1})$ where $\emptyset \neq S \subset \{1, \dots, n\}$ given $P(F_{S, r})$ for non-empty $S \subset \{1, \dots, n\}$. By $g - 1$ successive applications of this technique to $P(F_{S, 1})$ for non-empty $S \subset \{1, \dots, n\}$ we obtain $P(F_{S, g})$ for non-empty $S \subset \{1, \dots, n\}$. In particular, we obtain $P(F_{\{1, \dots, n\}, g})$, the probability of observing the complex.

To be certain of the validity of our result we must prove our assertion that the q cases are indeed mutually exclusive and exhaustive. To prove the q cases mutually exclusive, consider two different cases J and K. Without loss



of generality we may assume $J < K$. Case J requires that $E_{ORD(J+1),r+1}$ does not occur, which implies that $E_{ORDK,r+1}$ does not occur. (This is clear from the following argument. $E_{ORD(J+1),r+1}$ does not occur means that $D_{ORD(J+1)}$ is not satisfied for target type T_{r+1} , but $D_{ORD(J+1)}$ is satisfied for target type T_{r+1} , whenever D_{ORDK} is because $J+1 \leq K$. So D_{ORDK} must not be satisfied for target type T_{r+1} ; that is $E_{ORDK,r+1}$ does not occur.) However, case K requires $E_{ORDK,r+1}$ to occur. Therefore, case J and case K cannot both happen at once. Consequently, the q cases are mutually exclusive.

To show the q cases are exhaustive, suppose that $F_{S,r+1}$ has occurred. Then there is some K such that $ORDK \in S$ and D_{ORDK} is satisfied for T_1, \dots, T_{r+1} . Let D_{ORDJ} be the last decision function in $(D_{ORD1}, D_{ORD2}, \dots, D_{ORDq})$ that is satisfied for target type T_{r+1} . Then case J is satisfied as seen by the following inspection technique. $F_{\{ORD1, \dots, ORDJ\}, r}$ must occur since $K \leq J$ (because D_{ORDK} is satisfied) and D_{ORDK} is satisfied for T_1, \dots, T_{r+1} by assumption. Also $E_{ORDJ,r+1}$ occurs since D_{ORDJ} is satisfied for target type T_{r+1} . Similarly, $E_{ORD(J+1),r+1}$ does not occur since D_{ORDJ} was chosen as the last decision function to be satisfied by target type T_{r+1} . Thus, the q cases are also exhaustive.

Therefore, our method is indeed valid and by $q - 1$ successive applications we obtain the probability of observing the complex.

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