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Selection of Mathematical Models of Target Acquisition by Electro-Optical Systems

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FOREWORD

This technical report was prepared by the Science and Technology Division, General Research Corporation, under Naval Weapons Center Contract N00123-75-C-0320 and documents work conducted from May 1976 to December 1976.

The Naval Air Systems Command is sponsoring a program on the image quality of cockpit displays, with application to A-6E TRAM, A-7E FLIR, and other airborne target acquisition systems. The work has included in-house laboratory research, simulation studies, and flight tests, under the direction of CDR P. Chatelier (AIR-340F). The study reported here was supported by NAVAIRSYSCOM AirTask A03P-3400/008B/7F55-525-000.

This report has been reviewed for technical accuracy by Dr. H. H. Bailey, The Rand Corporation, and Ronald A. Erickson, Naval Weapons Center.

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(U) *Selection of Mathematical Models of Target Acquisition By Electro-Optical Systems*, by A. D. Stathacopoulos and H. F. Gilmore, General Research Corporation. China Lake, Calif., Naval Weapons Center, January 1977, 52 pp. (NWC TP 5928, publication UNCLASSIFIED.)

(U) A general method is presented for selecting appropriate Electro-Optical (E-O) mathematical models for application to specific air-to-ground target acquisition problems. The method is illustrated by several examples. The report also abstracts and summarizes the key model descriptors which are germane to the selection process. This summary is based on a description of fourteen mathematical models of air-to-ground target acquisition by observers using FLIR and TV sensors presented in a previous NWC report by the same authors (NWC TP 5840).

CONTENTS

NOMENCLATURE

D*	specific detectivity of an infrared detector
E-O	electro-optical
EOS	Electro Optical Systems (division of Xerox Corporation)
FLIR	forward-looking infrared
GAMMA	Ground and Air Multisensor Model A (GRC)
GRC	General Research Corporation
IR	infrared
LTV	LTV Electrosystems, Inc.
LLTV	low-light-level television
MARSAM	Multiple Airborne Reconnaissance Sensor Assessment Model (Honeywell)
MDT	minimum detectable temperature difference
MRT	minimum resolvable temperature difference
MTF	modulation transfer function
NADC	Naval Air Development Center
NAFI	Naval Avionics Facility
NET	noise equivalent temperature
NVL	Night Vision Laboratory
NWC	Naval Weapons Center
RMS	root-mean-square
RPV	remotely piloted vehicle
SCREEN	SRI Countersurveillance Reconnaissance Effectiveness Evaluation (SRI)
SNR	signal-to-noise ratio
SRI	Stanford Research Institute
TAWG	Target Acquisition Working Group
TV	television

INTRODUCTION

A variety of electro-optical (E-O) imaging systems have been designed for airborne target acquisition. These systems operate in the visible and in the infrared portions of the electromagnetic spectrum. Typical sensors include daylight and low-light-level television and forward-looking infrared (FLIR) devices. The widespread development of these target acquisition devices has been accompanied by the development of many mathematical models which are used as tools in system design and performance predictions.

In 1975 General Research Corporation (GRC), working for the Target Acquisition Working Group (TAWG), performed a study whose objectives were to

1. Locate and document existing mathematical models of air-to-ground target acquisition by observers using electro-optical devices (primarily daylight TV, low-light-level TV, and FLIR).
2. Develop methods for describing and comparing the several models including type, regimes of applicability, and assumptions.
3. Perform a general comparison of these models.

Fourteen models were located and examined in the course of the study. These models were developed between 1966 and 1975 and are shown in Table 1. They were described in the study final report, Naval Weapons Center Technical Report TP-5840.[1] TP-5840 provides detailed descriptions of the portions of the models which represent the display-observer interface, the E-O sensor, the target-background scene, and the atmosphere.

The objectives of the current follow-on study are to:

1. Devise a general method of selecting an appropriate model or submodel for use in any particular application.
2. Illustrate the method with specific examples.

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[1] Naval Weapons Center. *Review of Mathematical Models of Air-to-Ground Target Acquisition Using TV and FLIR Sensors*, by A.D. Stathacopoulos, H.F. Gilmore, and G. Rohringer, General Research Corporation. NWC, January 1976. (NWC TP-5840, publication UNCLASSIFIED.)

TABLE 1. Models Reviewed.

Model	Sensors	Year Documented
GRC GAMMA	Multi-Sensor	1967-1968
MARSAM II	Multi-Sensor	1968
LTV	LLTV; IR Scanner	1971
Autonetics	LLTV; FLIR	1973
SRI SCREEN	Multi-Sensor	1968-1971
Westinghouse	TV	1972-1974
Rand	TV	1970-1974
Hughes	FLIR	1973
NADC	FLIR	1972
Xerox/EOS	FLIR	1975
Systems Consultants	FLIR	1974
NVL (Thermal Model)	FLIR	1975
NWC	FLIR	1975
NAFI	FLIR	1970

The general principles for selecting appropriate models for particular applications are discussed in the following section. Next we present a summary of the findings of the mathematical model review extracted from TP-5840. It is followed by a section which identifies all the model characteristics which enter the selection process and summarizes them in a matrix which is used as the basis for model screening and selection. Finally several examples are presented which use the model characteristics matrix to select the model or models which are most appropriate for each particular problem.

APPLICATIONS OF MODELS

The previous review by GRC covered the fourteen models listed in the preceding section. These range from large-scale multi-sensor models such as the Air Force MARSAM II (developed by Honeywell) and the GRC GAMMA model to special-purpose TV-only models (Rand, Westinghouse) and several special-purpose FLIR models. The different models also vary considerably in (1) the degree of sophistication used to model the observer, (2) the performance measures calculated (probabilities of detection or recognition, minimum resolvable temperatures, etc.), (3) the number of parameters describing the displayed scene and the associated assumptions, (4) the detail with which the sensor system parameters are included, (5) the simplifications made in representing the ground scene (target, background), (6) the atmospheric effects taken into account, and (7) the external factors included in the model (sensor platform dynamics, platform-target geometry, platform vibration, etc.). These differences are described in detail in the previous report.[1]

Choosing one or more of these models to solve any particular air-to-ground target acquisition problem presents a challenge for any military applications analyst or engineer. Furthermore, when specific models are used in the solution of particular problems, decision-makers in the various services and laboratories can have a difficult time in judging whether the results are adequate and reliable or not.

The GRC review of these models made a significant step in alleviating these difficulties by abstracting the voluminous documentation available, describing the various models in common terms, and outlining the key differences and similarities. In this follow-on report we have attempted to utilize the model descriptions of TP-5840 as a basis to devise a procedure for selecting particular applicable models and to illustrate the procedure through several examples of practical utility.

In this section we will review the types of problems for which the models can be useful and discuss the rationale for determining what is required to be calculated by the models. Then we will outline in general the procedure for selecting the most useful models that are applicable to each specific problem.

The variety of technical problems that can be solved by the use of E-O sensor models ranges from broad studies of sensor utility to detailed component trade-offs. The following examples indicate the breadth and scope of the various problems.

- E-O Sensor Utility Studies

  - Feasibility of using E-O sensors in real-time recce/strike with manned aircraft or RPVs
  - Utility of FLIR and TV sensors in European weather
  - Effectiveness of E-O sensor technology in permitting continuous (day-night) air operations with the same level of performance (e.g., percent of time in day and night operations that particular sensors will be useful)

- Requirement Studies

  - Number of sensors and mixes of sensors needed for particular military operations (theater-wide close air support, night interdiction, helicopter direct fire support, etc.)
  - Field-of-view requirements for airborne sensors used in recce/strike operations
  - Navigational and cueing requirements for E-O real-time target acquisition sensors
  - Stand-off surveillance system detection requirements for hand-off to E-O target acquisition sensors
  - Aircraft exposure time to enemy defenses during target acquisition and weapon delivery
  - Target hand-off, lock-on, field-of-view, detection range, etc., requirements for homing munitions used in connection with E-O target acquisition sensors
  - Task load requirements of air crews using E-O sensors

- Target Acquisition Effectiveness Studies

  - FLIR and TV performance from high-speed platforms (ranges of target acquisition, timing constraints, field-of-view implications)
  - FLIR and TV performance from low-speed or stationary standoff platforms (helicopters in flight or pop-up mode)
  - Ship detection using FLIR on airborne platforms
  - Alternative FLIR sensor comparisons: variable sensitivity, resolution, field-of-view, spectral response, etc.
  - Target acquisition effectiveness for release of different weapons in single or multiple passes
  - Weather limitations on performance of FLIR and TV

- Sensor Component Trade-Off Studies

  - Effects of cockpit design on E-O sensor performance (display size, observer-display distance, number of crew members, crew task loading, etc.)
  - Choice of display size for multisensor use
  - Sensor performance trade-offs with increasing resolution and field-of-view

- Minimum bandwidth needed for RPV video data link
- Spectral response effects of sensor, target, and atmosphere

We will examine some of these problems below to indicate the procedure for deciding what calculations are desirable from an E-O sensor model, and which model or models are best to use.

Let us first examine the following problem:

"Feasibility of using E-O sensors in real-time recce/strike with manned aircraft or RPVs."

Figure 1 diagrams a possible sequence for target acquisition and engagement. Penetration is accomplished at low altitude to reduce vulnerability of the airborne platform to ground defenses. As the target complex is approached, the aircraft climbs to an altitude which will allow the target to be viewed without its being masked by the terrain and which will allow weapon delivery. After the climb, the sensor is slewed to the target area and activated and the operator begins to search the display to locate the target. When a particular spot has been selected as the target, the weapon release phase begins; this may involve a dive before weapon release.

One of the crucial issues of this target acquisition problem is the time and range at which the target is finally detected and recognized

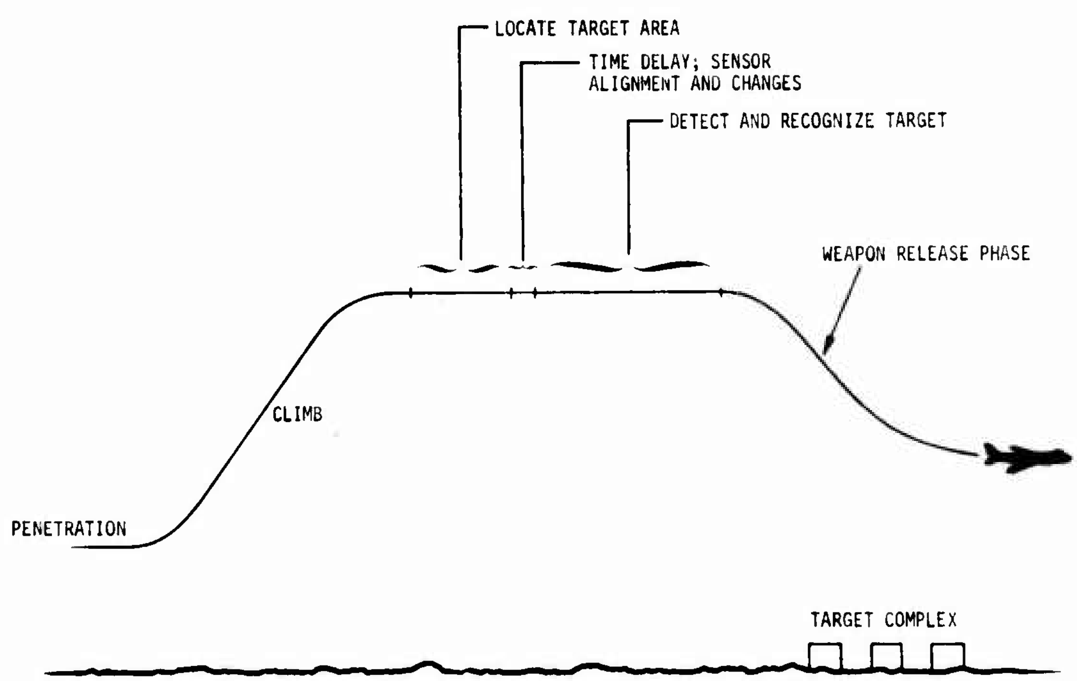

FIGURE 1. Target Acquisition and Engagement Sequence.

and how these match the weapon release requirements. A second crucial issue is the earliest time (longest range) at which the target can be detected, because this determines the range at which the aircraft should climb. The longer this range is, the more time the operator will have to search the display, the larger the ground area he can cover, and the more time he has for sensor alignment, slewing, etc. On the other hand, the longer the aircraft is at the higher altitude the longer it is exposed to ground defenses. A third key issue is the altitude to which the aircraft needs to climb.

It is obvious that none of the existing models is ready-made for the complete solution of this problem; rather several of the models can provide the key ranges and times that can be achieved with each sensor. The problem must be solved by an analyst who decides what calculations he needs from the E-O models and then chooses the appropriate model.

In this case the analyst needs three types of basic data: (1) weapon-release ground range curves; (2) target detection and recognition profiles as a function of range from the target, altitude, and weather conditions; and (3) timing data. Of these, the E-O target acquisition models can provide the target detection and recognition profiles, and the times required to search the target area on the display to detect and recognize the target. The remaining data must come from other sources.

With regard to the E-O models that can be used, the following comments apply. Since search timing data is required, one should not use a model based on static performance data only. If only one type of sensor (TV or FLIR) is being evaluated, some of the single-sensor models would be applicable; otherwise a multi-sensor model should be used. If weather is a key factor, the model should have the appropriate atmospheric scattering and absorption modules. Since both range and altitude information are needed, the model must treat the aircraft-target geometry properly.

From the above example it can be seen that, once the type of information needed is defined, then the choice of the model follows from the factors that are germane to the problem and must be treated in the model to be useful.

A second example problem is the following:

"Effects of cockpit design on E-O sensor performance."

With high-speed aircraft there are several constraints that affect the size of display that can be used, the location of the display in the cockpit, the distance of the observer from the display, and the illumination in the cockpit area. Inappropriate choice of any of these items can degrade the performance of E-O sensors.

E-O sensor models can be used to investigate parametrically the effects on sensor performance of the various key parameters. The models to be used, however, must have a good representation of the display/observer interface for operator performance and must treat the observer/display geometry. One then needs to calculate sensor performance (probabilities of detection and recognition) for typical target engagement geometries and flight profiles, as they are affected by variation in the key parameters listed above.

The same procedure can be demonstrated by analyzing others of the sample problems listed previously. It turns out, however, that the procedure is similar in all cases and rather straightforward.

1. The target acquisition analyst defines the operational or technical problem that needs to be solved.
2. The key variables of the problem are specified, and the necessary data to determine these are identified.
3. Of these necessary data, those which can be provided by E-O sensor models are defined in terms of the quantities that should be calculated and the key-parameter regimes of interest.
4. Examination of these quantities and of the operational and technical emphasis of the particular problem leads to the key features that the model should have.
5. The models are then examined (as is done in the following two chapters) to determine which are applicable.
6. The most appropriate model of those applicable is selected on the basis of its technical comprehensiveness, its correctness, and its availability to the user.

The first three steps must be provided by the individual problem-solver. In the following sections of this report we will provide the basic material and the procedure for steps four and five, followed by some examples. The report from our previous study (TP-5840) can then be used to proceed with step 6.

It is important that the reader keep the following points in mind.

1. The material provided in TP-5840 consists of summary descriptions of the technical aspects of the models. For details, the user may have to go to the original documentation.
2. TP-5840 is based primarily on the extensive documentation that was reviewed. It therefore represents the models as they were described, and not necessarily as they are now. For example, MARSAM II and GRC GAMMA have been undergoing changes during the past year which are not reflected in the documentation.
3. As time passes and new measurements are made, the modelers change their formulations.
4. Display search, which is an area identified as deficient in TP-5840, has been the subject of some recent work. As this

new work leads to insights in this very important area, we should see changes in the dynamic aspects of observer models.

5. During the past year, great attention has been paid to obtaining useful atmospheric data from Europe and to improving atmospheric models such as LOWTRAN.

In view of the above comments it is suggested that, for the final selection of a model, prospective users should contact the custodians of the models and obtain the latest details.

GENERAL CHARACTERISTICS OF MODELS

TP-5840 provides comparative descriptions of fourteen models of air-to-ground target acquisition using TV and IR sensors. The models are described in terms of their separate parts which model the display-observer interface, the E-O sensor, the target-background scene, and the atmosphere. The following key observations will make the comments and the selection method presented in subsequent sections clearer.

DISPLAY-OBSERVER REPRESENTATIONS

One of the key findings of the state-of-the-art review was the great variability among the models in representing the display-observer interface. Models differ greatly in the display parameters emphasized and ignored, as well as in the formulations used to treat the factors included. The choice of display-observer formulations appears to have been influenced by the state of knowledge about human performance at the time each model was built, and by the familiarity of the particular modelers with that knowledge. In addition, the formulations are affected by the intended purpose of the particular model and the measures of performance chosen for it.

All the models represent the displayed scene to which the observer responds by combinations of some of the following descriptors:

1. Target coordinates on the display
2. Target angular subtense at the observer's eye
3. Target-background contrast
4. Displayed target and background luminance
5. Resolution of the electro-optical system
6. Target dimensions on the display
7. Displayed two-dimensional noise
8. Photon noise arising at the display
9. Video noise in the electronics
10. Background structure such as objects or clutter
11. Display dimensions
12. Eye integration period (typically 0.1-0.2 sec)
13. Eye fixation period (typically about 0.3 sec)
14. Search time available to the observer

Of these, the target-related and time factors are either input parameters or are determined through straightforward geometrical calculations. The target and background signal levels are determined by the spectral reflectance and emittance of the target and the background, and are affected by the atmosphere (absorption and scattering) and the transfer function of the electro-optical system, including its dynamic range. The resolution of the system is usually expressed in number of TV lines, number of cycles, or cycles per millimeter. Finally, various noise factors are included which can limit the performance of the observer in his image interpretation tasks.

Over the past 20 years, workers in the field have investigated the effects of these descriptors on the performance of the observer. These investigations and the resulting formulations include both theoretical derivations, based on numerous assumptions, and experiments. In experiments a specific test image is usually selected, so that only a limited set of descriptors are varied to affect observer performance. These investigations have resulted in several fundamental concepts which have been used as building blocks by the modelers in various ways on the basis of some more or less expressly stated logic.

Some models select a single derived descriptor, such as the signal-to-noise ratio (SNR) defined in a certain way, as the key image descriptor and then, using experimental results, express the probability of target detection as a function of this descriptor. Implicitly these models may have de-emphasized other factors such as contrast or resolution. In other cases, resolution may be chosen as the key descriptor, with the contrast assumed to be high and the noise either assumed to be low or used for deriving a noise-degraded effective resolution. Only a few models provide display search formulations. Those that do so provide radically different treatments, which in most cases lack experimental validity.

The various models resulting in this way obviously apply primarily to the real-life situations encompassed by the assumptions made and the parameter variations chosen. There is a danger here for the users of the models if they are unaware of the assumptions on which particular model formulations are based and therefore proceed to draw too-broad conclusions about a system and its performance.

SENSOR REPRESENTATIONS

Representations of the electro-optical system involve mostly relatively well defined concepts of physics and engineering. The mathematical tools are those used for analyzing linear systems, where Fourier transforms play an important role. Practically all models follow this basic approach. There are, nevertheless, significant differences in emphasis and in the detail and accuracy with which the computer subroutines describe the various components. Even greater differences exist in the way the subroutines are tied together, which determines whether the model can be used to simulate different combinations of components.

The complexity of the sensor modeling depends on the amount of information that can be utilized by the display-observer model. Consequently, it is never considered necessary to simulate accurately the display of a general scene. Rather, the performance of sensors is modeled with several simplifications. The most important of these are as follows.

The computations regarding the spectral distribution of radiation emitted or reflected by the target, the spectral transmission of the atmosphere, and the response of the sensor are usually treated in simplified formulations. In the case of models of TV this simplification consists of the use of photometric quantities.

The performance of TV camera tubes is usually specified by providing the following relationships either in the form of curves or by tabulation: TV lines resolved per raster height as a function of cathode illuminance, with contrast modulation as a parameter; output current versus photo-cathode illuminance; and signal-to-noise ratio as a function of photo-cathode illuminance.

In IR systems, the characteristics of different components are specified, such as detector specific detectivity, amplifier bandwidths, and collector area; or the overall performance is described by giving its noise equivalent temperature difference (NET), instantaneous field of view, system modulation transfer function, etc.

The determination of the signal-to-noise ratio (SNR) is usually straightforward. For TV camera tubes it is obtained from the computed value of cathode illuminance and from the manufacturer's specification of SNR as a function of that illuminance. For FLIRs it is the usual practice to compare the collected target-background power difference with the detector noise-equivalent power. Resolution for TV is obtained from curves relating the number of lines resolved per picture height to photosurface illuminance and contrast modulation. For FLIRs, a common simplification is to use the angle subtended by a detector to specify resolution; the modulation transfer function is sometimes evaluated to obtain a measure of the number of lines resolved per picture height. Contrast is obtained directly from the displayed target and background illuminance, or calculated from the actual target-background reflected or emitted radiation modified by the atmosphere and the stages of the system.

TARGET-BACKGROUND REPRESENTATIONS

In all sensor models the descriptions of targets and backgrounds include only the most basic parameters. Targets are usually represented by rectangular blocks, or are approximated as either aperiodic patterns such as squares or circles or periodic patterns such as bar targets.

For TV models, it is usual to specify target reflectance and illuminance. For infrared systems, emissivity and temperature difference with respect to the background are specified. It is always assumed that the targets are viewed against a uniform background. The radiative properties of the background, are specified in the same terms as those of the target. Models which consider the effects of background structure upon the detection process do this in the display-observer model. They inject the effects of a number of distracting features by computing a reduction in detection probability, rather than by tracing all signals through the electro-optical sensors.

All the more subtle characteristics of optical signature, such as perspective, the distribution of shadows over the target surface and over the adjoining background, the appearance of highlights, and the dependence of these quantities upon the viewing angle are not modeled. The exact conditions of lighting, as, for example, the presence of back-lighting or of flat illumination, are also not taken into consideration. Most models do not consider any shadows at all. Those which do treat them as separate targets and compute a corresponding probability of detection.

There are two reasons for choosing such an oversimplified description. One is that a detailed determination of the luminance from any target requires a very large computing effort. (Such computations, however, are feasible.) The other reason is that even if the results of such a computation were available, present understanding of the detection and recognition process is too limited for an effective utilization.

ATMOSPHERIC EFFECTS REPRESENTATIONS

The physical mechanisms responsible for causing loss and redirection of radiative energy within the atmosphere are molecular absorption, scattering by aerosols and molecules, absorption by aerosols, and turbulence.

Molecular absorption is of primary importance in the IR portion of the spectrum and of secondary importance in the visible. The most important contributors to absorption are water vapor and carbon dioxide. All the electro-optical sensor models use certain approximations to estimate the absorption suffered by radiation in traversing a given amount of water vapor. (Only some models consider absorption by carbon dioxide.) These approximations give average values of transmissivity over a given wavelength region; thus the models are limited to illumination and emission over relatively broad spectral regions. There are significant differences in the sophistication with which different models compute approximate values of absorption. Most models are based on methods published by Altshuler, Larmore, and Kruse; only two models used the relatively modern treatments contained in the LOWTRAN II code of the Air Force Cambridge Research Laboratory.

Aerosol scattering is usually the limiting mechanism for the propagation of visible radiation, except in extremely clear atmospheres. For infrared radiation, aerosol scattering is of importance in thick haze, fog, or smoke. Not all the models include the effects of aerosol scattering; those that do so use simple formulations applicable only to haze. The formulations are based on work by Langer and by Rensch which involves the calculation of an extinction coefficient from the visibility range, which is provided as an input.

None of the models treats aerosol absorption or the effects of atmospheric turbulence. These are secondary effects but can be important under specific atmospheric conditions.

SUMMARY COMPARISON OF MODELS

As discussed earlier, the selection of a model depends on a matching of features which vary greatly from model to model with the characteristics of a problem. TP-5840 describes the features of the models in sufficient detail to provide a useful guide for such a selection. However, the matching process can be simplified by further summarizing these features in the form of a chart, as is done in Table 2. This chart permits a preliminary selection of models useful in a particular application and guides the user to the correct sections of TP-5840 or to the original literature describing the models. In addition, duplicates of the chart can be used as worksheets to further systematize the selection procedure; this process is discussed and illustrated with examples later.

In Table 2 the different models appear as column headings. Model characteristics that we believe to be most pertinent in matching a model to a particular application appear as row headings. Note that this selection of characteristics is somewhat arbitrary; other characteristics such as computer programming language or availability may in some cases be determining factors. The ones listed in Table 2 appear to us to determine how well the model represents reality under particular conditions.

The table entries are explained in the following series of notes keyed to the numbers appearing in the table. For more complete information TP-5840, the original literature, or the modelers themselves should be consulted.

MODEL CHARACTERISTICS

1. Some of the models represent more than one sensor; some are restricted to either TV or FLIR sensors. When comparing the utility of two sensors of different types there is some advantage in using a multisensor model because the outputs corresponding to different sensor types can be easily compared. If different models are used to represent TV and FLIR sensors, some care is required to ensure that the outputs can be related.

2. All the models allow sensor characteristics to be input. Some models provide additional flexibility; this is desirable when a sensor is to be optimized for a particular application. Flexibility may be of at least two types. Some models allow the elements composing a system

TABLE 2. Matrix of E-O
(Numbers refer to

	GRC GAMMA 17	MARSAM II 21	LTV 28	AUTONETICS 32	SRI SCREEN 39	WESTINGHOUSE 41
Sensor Type 1	18 FLIR TV LLTV	22 FLIR TV	LLTV	33 FLIR TV LLTV	LLTV	TV LLTV
Sensor Description Flexibility (Modular, Component Variations) 2	19 Modular	23 Component Variations	29 Component Variations	34 Component Variations		42
Observer-Display Relations (Geometry, Luminance) 3	Target Subtense, Display Subtense	Target Subtense, Display Subtense	Target Subtense, Display Subtense	Target Subtense, Display Subtense, Luminance		
Display Search Mode 4	Random, Glance Area Fixed	Random, Glance Area Fixed	Random, Glance Area Fixed	35 Random, Part of Display, Glance Area Variable		
Time Available for Target Acquisition 5	Yes	Yes	Yes	Yes		
Platform-Ground Scene Geometry, Terrain Masking 6	Geometry	Geometry	Geometry	36 Geometry, Masking	40 Masking	
Platform-Ground Scene Dynamics (Flight Profile) 7	Yes	Yes	Yes	Yes	Yes	
Displayed Scene Dynamics 8		24 Scene Motion, Target Motion	30 Target Motion, Probability Accumulation	37 Probability Accumulation		
Target Description (Shape) 9	Block	25 Mean Area, Target Clusters	One Dimension	Block	Two Dimensions	Rectangle or Bar Pattern
Target-Background-Sensor Wavelength Dependent Characteristics 10	Spectral	Non-Spectral	Non-Spectral	Non-Spectral	Non-Spectral	
Contrast, Noise, Resolution Effects on Observer Performance 11	Contrast, Noise, Resolution	Contrast, Noise, Resolution	Contrast, Noise, Resolution	Contrast, Noise, Resolution	Contrast, Noise, Resolution	Noise, Resolution
Background Structure 12	20 Confusing Objects	26 Confusing Objects	31 Confusing Objects	38 Confusing Objects		43 Clutter
Atmospheric Scattering (Spectral or Non-Spectral) 13	Non-Spectral	Non-Spectral	Non-Spectral	Spectral	Non-Spectral	Non-Spectral
Atmospheric Absorption (Spectral or Non-Spectral) 14	Non-Spectral	Spectral in IR	Non-Spectral	Non-Spectral	Non-Spectral	
Vibration 15		27 Resolution Degradation				
Output Type: 16						
Static Probabilities	Yes	Yes	Yes	Yes	Yes	Yes
Time Dependent Probabilities	Yes	Yes	Yes	Yes		
Probability Accumulation			Yes	Yes		
Sensor Performance Detail	Yes	Yes	Yes			

TABLE 2. Matrix of E-O Model Characteristics.
(Numbers refer to notes in text.)

EN 39	WESTINGHOUSE 41	RAND 44	HUGHES 48	NADC 50	XEROX/EOS 53	SYSTEMS CONSULTANTS 57	NVL 62	NWC 69	NAFI 74
	TV LLTV	TV	FLIR	FLIR	FLIR	FLIR	FLIR	FLIR	FLIR
	42				Modular, Component 54 Variations	58	63		
		Target Subtense, Display Subtense			55 Target Subtense, Luminance	Target Subtense, Display Subtense	64 Target Subtense, Luminance		
		Random, 45 Glance Area Variable				Two Modes, 59 Glance Area Variable			
		Yes				Yes			
40		Geometry		Geometry		Geometry		Geometry	Geometry
		Yes				Yes			
		Probability 46 Accumulation				Probability 60 Accumulation			
ons	Rectangle or Bar Pattern	Block	Square Bar Pattern	Block 51 or Structure		Three Dimensions	Rectangle	Generic 70 Building or Ship	Block
ectral			Greybodies, Sensor Flat	Blackbodies, Sensor Flat		Greybodies, Sensor Flat	Greybodies, Sensor Spectral Response	Greybodies, Sensor Flat	Sensor Spectral Response
st, tion	Noise, Resolution	Contrast, Resolution	Noise, Resolution (MRT)	Noise, Resolution (MRT)	Noise, Resolution (MRT)	Noise, Resolution	Noise, Resolution (MRT)	Noise, Resolution (MRT)	Noise, Resolution
	Clutter 43	Scene 47 Complexity					Detection 65 Criterion		
ectral	Non-Spectral	Non-Spectral					LOWTRAN 66	LOWTRAN 71	Non-Spectral
ectral				Non-Spectral		Non-Spectral	LOWTRAN 67	LOWTRAN 72	Anding Model 7
						Three MTF 61 Forms	Exponential 68 MTF		
	Yes	Yes Yes Yes	49	52	56	Yes Yes Yes	Yes Yes	73	

to be varied; for example, additional amplifiers and storage devices can be included. Other models allow detailed specification of certain components; for example the type of television tubes may be chosen and the appropriate representations applied. We have referred to these properties as "modular" and "component variations", respectively.

3. The performance of the human observer viewing a display is affected by the angular size of the target, the angular size of the display, and the display luminance, among other things. Target angular subtense is important because of the limited resolution of the eye, display subtense affects the search process, and the resolution of the eye tends to vary with display luminance.

4. It is generally considered that the observer searches a display in a series of glances, each lasting about one-third of a second, and each glance encompassing an area of the display around the fixation point. In models which attempt to represent this process, the glances may be distributed at random or in some pattern, and the area encompassed by each glance may be fixed or variable. These factors are shown in the table.

5. The display search process takes a certain length of time; this is represented in some of the models.

6. The location of the sensor platform determines the range to the target, and also the angle at which the target is seen and the probability of the target being masked by terrain features. These factors are included in some of the models.

7. Some of the models permit the sensor platform to be moved along a designated flight path to represent an operational scenario.

8. When the sensor is moving and the sensor depression and offset angles are fixed, the displayed scene changes continuously. This is sometimes represented. Also, if a target is moving with respect to the background it affects the detection of the target. This factor too may be modeled.

9. Target shapes are seldom represented explicitly. Usually the target is replaced by a rectangular prism (or block), or a bar-pattern or rectangle having about the same area, as shown in the table.

10. The reflectivities or emissivities of the real target and background vary with wavelength, as does the sensitivity of the sensor. In some models these factors are treated spectrally; in others they are averaged or lumped. In the infrared region, keeping emissivities of the target and background constant is equivalent to considering them grey bodies as indicated in the table.

11. The principal characteristics of the target on the display which affect its detection or recognition seem to be its size (see note 3) and its contrast, the amount of noise on the display, and the resolution of the display. TV models tend to treat all of these; FLIR models tend to ignore contrast, under the assumption that high-contrast targets are of principal importance. Noise and resolution can be taken into account together in the concept of Minimum Resolvable Temperature (MRT), which is often used to describe FLIR performance.

12. Background structure affects performance, but is very difficult to take into account. In various models this is done by a "confusing object" concept in which performance is degraded if a number of hypothetical confusing objects appear on the display, or by introducing terms representing clutter or scene complexity. Some background structure is inherent in detection criteria based on resolution, as used in some models, since with no background structure, no resolution is required for detection.

13. Atmospheric scattering is of major importance in limiting atmospheric transmittance in the visual region; it is less important in the infrared. It can be treated spectrally or lumped values appropriate to the spectral region can be used. One of the best current representations of scattering is that embodied in the LOWTRAN* computer code.

14. Atmospheric absorption is of major importance in the infrared spectral region and less important in the visual. It can be treated spectrally or non-spectrally. One of the best current representations is that in the LOWTRAN computer code.

15. Angular vibration of the line of sight causes the image to move on the display. This can be assumed to produce a resolution degradation, if the vibration frequencies are high enough.

16. The outputs of the models vary widely. Most of the models calculate different probabilities of target detection, recognition, and identification as a function of the input descriptors used to represent the target/background and atmosphere characteristics, the sensor-to-target geometry, and the sensor characteristics. The types of probabilities calculated depend on the model's display/observer formulation. Most models assume that either the background is essentially unstructured or the operator is not time-constrained; such models calculate static probabilities of detection, recognition, and identification. Other models assume that display search is constrained by time but the displayed scene does not change during this time; such models calculate time-dependent probabilities of detection, recognition, and

*LOWTRAN is the generic name for a family of codes still under development. LOWTRAN IIIB is the current version.

identification. Finally, some models account for the dynamic changes of the displayed scene; such models calculate performance by accumulating probabilities of target detection, etc., for each glimpse.

Some models also provide output covering the detailed performance of the sensor and its modules. For example, the sensor's modulation transfer function (MTF) or signal-to-noise ratio may be computed. This type of detailed output is useful when alternative sensors and components are considered in a particular application.

Finally, some models provide more specialized outputs, which are useful for the particular application these models were developed for (see notes 49, 52, 56, 73, and 76).

GRC GAMMA

17. GRC GAMMA is a computer model coded in FORTRAN IV, which features modular representation of sensors, flexible data input, and a detailed representation of the display-observer interface.

18. FLIR, TV, and LLTV sensors are assembled out of a limited set of modules, and their performance is evaluated in similar ways.

19. The model is flexible in that a variety of systems can be constructed, but little variation in the more subtle characteristics of individual modules is possible.

20. An attempt is made to represent background structure by specifying a "confusing object" density. This quantity has not been related to real scenes, and its use has not been validated.

MARSAM II

21. MARSAM II is a large computer program coded in FORTRAN IV for representing airborne imaging sensors. It contains separate FLIR and TV modules, and includes a detailed representation of the display-observer interface.

22. FLIR and TV are represented by different blocks in the program; however, these provide similar inputs to the display-observer formulation.

23. The TV module permits specifying the type of camera tube (vidicon, orthicon) but otherwise there is no unusual flexibility.

24. System resolution is degraded to account for linear and angular scene motion. Target motion also degrades system performance.

25. For TV, the mean of the front and side projected areas is used as the target area. For FLIR, two target dimensions are used. Linear targets and clusters of targets may be accounted for in evaluating system performance.

26. See Note 20.

27. The program allows system resolution to be degraded by sensor platform vibration.

LTV MODEL

28. The LTV model is designed to represent and evaluate LLTV systems in the detection of night-time vehicular traffic.

29. The program simulates the response and resolution of various types of camera tube such as vidicons, secondary-electron-conduction vidicons, and image orthicons.

30. Probabilities of detection and recognition are calculated every second and accumulated, thus accounting for some of the effects of scene changes. Target motion can be represented; it degrades the performance of the system.

31. See Note 20.

AUTONETICS MODEL

32. The Autonetics model is a computer program, coded in FORTRAN IV, for simulating airborne active and passive TV and LLTV systems and FLIR sensors. It includes the effects of terrain masking, and clouds, fog, rain, and haze. It includes a detailed representation of the display-observer interface.

33. TV and FLIR sensors are represented by different modules, but both provide the same inputs necessary for the display-observer model.

34. Various relations are available for representing different TV tubes.

35. The search of the display is random, but an input allows the search to be restricted to only a part of the display. The effective glance area is variable and depends on characteristics of the displayed target.

36. Terrain masking can be represented by giving a percent cover, or by giving the probability of a clear line of sight.

37. The probabilities of detection and recognition are calculated for each glance and accumulated from glance to glance, thus taking into account the effect of scene changes.

38. See Note 20.

SRI SCREEN

39. The SRI computer model is coded in FORTRAN and represents airborne and ground-based sensors. It has an elaborate capability for simulating flight patterns and scenarios. Targets may move and appear in complexes. Shadows and terrain masking are considered.

40. Terrain masking is represented by a probability that the line of sight is clear.

WESTINGHOUSE MODEL

41. The Westinghouse model, coded in FORTRAN, represents TV and LLTV systems by calculating a display signal-to-noise ratio which includes the effects of the system noise and modulation transfer function (MTF).

42. A single calculation format is available representing a high-sensitivity camera tube. Most system parameters are included.

43. The effects of clutter are included by requiring a higher display signal-to-noise ratio for target detection in cluttered backgrounds.

RAND MODEL

44. The Rand model, coded in FORTRAN, represents an observer using an airborne TV sensor to acquire a target. Major emphasis is placed on the dynamic aspects of the problem. Two display-observer models are available.

45. The display search is random, but the glance area depends on scene complexity.

46. Considerable emphasis is placed on accumulating the probabilities of detection and recognition accurately. The accumulation is based on the idea that these probabilities represent the fraction of the population that can detect or recognize the target under given conditions.

47. Scene complexity is represented (in one of the two display-observer formulations) by a factor which reduces detection probability as scene complexity increases.

HUGHES MODEL

48. The Hughes model, programmed in FORTRAN IV, is a design tool for FLIR sensors and does not simulate reconnaissance missions. It uses the "minimum resolvable temperature" (MRT) concept to represent sensor performance.

49. The outputs are the theoretical NET and MRT of a sensor as a function of the sensor characteristics.

NADC MODEL

50. The NADC model, programmed in BASIC, represents airborne FLIR sensors used in attacking ships. It makes use of the MRT concept. The representation of the two-dimensional shape of ship targets is unusually detailed.

51. Ship targets have been carefully examined to determine the number of pixels (picture elements) which must be reproduced to permit classification and identification. In the model this number is related to spatial frequency, which is the independent variable in the MRT relation.

52. The output is the ship-to-background temperature difference that can be detected at particular ranges, using a FLIR sensor.

XEROX/EOS MODEL

53. The Xerox/EOS model computes the performance of infrared systems, which are specified in detail, through the use of the MRT concept. A computer program exists, but is unpublished.

54. The model provides an extremely detailed engineering description of FLIR performance. Subcomponents include optics, detector, amplifier, multiplexer, pulse width modulator, light-emitting diode, etc.

55. The MTF of the eye is included; it is a function of display luminance.

56. See Note 49.

SYSTEMS CONSULTANTS MODEL

57. The Systems Consultants model, coded in FORTRAN IV, represents airborne FLIR sensors. The electro-optical system is not modeled in detail, but the display-observer interface and the display search process are.

58. Noise-equivalent temperature differences or MTFs may be input or calculated from simple sensor representations.

59. Two search modes are provided; one is a more-or-less random search, the other involves fixations on prominent display features. The effective glance area varies with target and sensor characteristics.

60. Detection and recognition probabilities are carefully accumulated from glance to glance, accounting for scene changes.

61. Three different MTF forms are available for characterizing the effects of vibration on the displayed image.

NVL MODEL

62. The NVL model, coded in FORTRAN IV, predicts the static detection and recognition performance of FLIR sensors. It uses the characteristics of the sensor to compute the MRT; this is then used to calculate probabilities of detection and recognition.

63. This model uses the MRT (and MDT) concept but the sensor descriptor inputs involve moderate detail.

64. The MTF of the eye is included; this is a function of display luminance.

65. The model requires that the target be displayed with some resolution for detection. As mentioned in Note 12, this implies detection in a certain amount of background structure.

66. LOWTRAN is probably the best available representation of atmospheric effects.

67. See Note 66.

68. Vibration can be represented by an additional factor in the overall system MTF; this has an exponential form.

NWC MODEL

69. The NWC model, programmed in BASIC, estimates FLIR detection ranges against ships and buildings. It uses the MRT concept, has a detailed representation of the shape and thermal signatures of generic ship and building targets, and uses LOWTRAN for atmospheric calculations.

70. Ships and buildings are represented by partitioning them into various surfaces having different temperature characteristics. Hot spots may also be modeled.

71. See Note 66.

72. See Note 66.

73. The outputs are the target/background contrast irradiance, the irradiance needed for detection, and the MRT and MDT of the system as a function of sensor-to-target range. This output can be used to plot altitude-versus-range contours for detection of ships and buildings.

NAFI MODEL

74. The NAFI model, programmed in FORTRAN IV, computes the range-altitude envelope of FLIR sensors in air-to-ground applications. The performance is based on the calculated signal-to-noise ratio of the sensor.

75. The data of Anding is combined with Townsend's scaling methods to obtain transmission along slant paths. This representation of atmospheric absorption is probably quite good.

76. This model calculates the Noise Equivalent Temperature Difference (NETD), The Noise Equivalent Fractional Emittance (NEFE), and the signal-to-noise ratio (S/N) at 5000-foot increments in ground range and altitude. This data can be used to plot curves of constant NETD, NEFE, and S/N as functions of altitude and horizontal range.

SIMPLIFICATION OF TABLE 2

Table 2 can be reduced to the more manageable form shown in Table 3. Here the row headings have been abbreviated and dots have been entered to indicate models which provide the corresponding characteristics. Some judgement was exercised in making up Table 3; whether or not dots should be entered was sometimes a problem. Table 3 provides only a very attenuated picture of what any of the models actually are, but because of its simplicity, it is very useful in the initial phases of model selection.

To use Table 3 in selecting a model suitable for a particular application, it is necessary first to select the characteristics (given in the left-hand column) which the model must have. Then inspection of the entries in the table will lead to a rapid weeding-out of inapplicable models; the remainder can be examined more carefully as described in the second section. This weeding-out process will be illustrated in the next section.

TABLE 3. Summary of E-O Model Characteristics.

		GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
Sensor Types	TV	●	●		●		●	●							
	LLTV	●		●	●	●									
	FLIR	●	●		●				●	●	●	●	●	●	●
	Flexible Sensor Description	●	●	●							●				
	Display Geometry, Luminance	●	●	●	●			●			●	●	●		
	Display Search Mode	●	●	●	●			●				●			
	Search Time	●	●	●	●			●				●			
	Platform-Ground Geometry	●	●	●	●			●		●		●		●	●
	Platform-Ground Dynamics	●	●	●	●	●		●				●			
	Displayed Scene Dynamics		●	●	●			●				●			
	Target Type, Shape	●	●	●	●	●	●	●	●	●		●	●	●	●
	Spectral Characteristics	●											●		●
	Contrast, Noise, Resolution	●	●	●	●	●		●							
	Background Structure	●	●	●	●		●	●							
	Atmospheric Scattering	●	●	●	●	●	●	●					●	●	●
	Atmospheric Absorption	●	●	●	●	●				●		●	●	●	●
	Vibration		●									●	●		
Outputs	Static Probability	●	●	●	●	●	●	●				●	●		
	Time-Dependent Probability	●	●	●	●			●				●			
	Probability Accumulation			●	●			●				●			
	Sensor Performance Details	●	●	●									●		
	Other								●	●	●			●	●

Notes:

1. NWC target type, shape restricted to ships and buildings.
2. Westinghouse background structure implicit in observer-display laboratory measurements; calculation method does not allow quantification.
3. NVL resolution criteria contain implicitly the effects of light background structure.

EXAMPLES

In this section we will present several examples of how one can use the chart shown in Table 3 to select the most applicable model or models. We find it convenient to start with a blank copy of Table 3 and mark in the left margin the features that are judged to be desirable for the particular application. In the examples, we mark two groups of features: desirable (○) and highly desirable (●). We then mark the spaces in the table corresponding to the models that have these features. This process is not a simple copying of Table 3; one may also have to use Table 2 and its notes, the more detailed descriptions in TP-5840, and perhaps other documentation, to decide which models have the desired features in the form that is needed.

When the table has been thus marked, as the examples will show, the possible choices of a model become evident. Settling on one may require examination of the current versions of the candidates; alternatively, it may be enough to choose the most readily available candidate.

In this section we present the following example problems:

1. Real-time target acquisition for weapon delivery from high-speed platforms using alternative E-O sensors in variable weather.
2. FLIR performance from helicopters operating in a pop-up mode.
3. TV performance from helicopters operating in a pop-up mode.
4. FLIR performance from stationary platforms (static limits).
5. TV performance from stationary platforms (static limits).
6. Choice of display size for cockpit applications (FLIR).
7. Choice of display size for cockpit applications (TV).

EXAMPLE 1: REAL-TIME TARGET ACQUISITION FOR WEAPON DELIVERY

The first example of model selection is the one analyzed in the second section of this report. It was pointed out in the discussion of this problem that the key data needed from E-O sensor models for the solution of the problem were:

1. The latest time (closest range) at which the target can be finally detected and recognized, so that the range can be compared with the weapon release range characteristics.

2. The earliest time or longest range at which there is a reasonable probability that the target can be detected; this determines the range at which the aircraft must climb to the target acquisition altitude.
3. The altitude to which the aircraft needs to climb for target acquisition.

To begin the selection process, let us turn to the summary of model characteristics presented in the previous section, and identify those that are highly desirable and those that are desirable.

Since in this problem we are evaluating alternative E-O sensors, the model must treat all three types of sensors (FLIR, TV, and LLTV). It is **highly desirable** that the model treat the dynamic aspects of search and the time required for search. It must deal with the target shape and aspect, and must handle target-background contrast explicitly since TV and LLTV performance (especially in unfavorable weather) is a strong function of contrast. Finally, since weather is a key issue in this problem, the model must treat the scattering and absorption properties of the atmosphere at the wavelengths of interest. These are the "highly desirable" characteristics for models to be applicable to this problem.

It is also desirable that the model:

- Treat the platform-ground geometry accurately
- Treat the platform-ground dynamics
- Have some flexibility in modeling the sensors, especially if more than one sensor of a given type is to be considered
- Account for the spectral response of the sensor and the spectral characteristics of the target and the background, especially in the visible portion of the spectrum for the TV and LLTV evaluation

Combining the "highly desirable" and "desirable" model characteristics identified here with the data presented in Table 2 and summarized in Table 3, we can fill in the applicable models as shown in Table 4. In the left margin we have marked the "highly desirable" and "desirable" characteristics. In the "Sensor Types" box we have marked the sensor types to be evaluated. The dots in the remaining boxes identify the models that have the required characteristics.

The choices of models are rather evident from this chart. It can be seen that three multi-sensor models (GRC GAMMA, MARSAM II, and Autonetics) treat in some way most of the characteristics identified as desirable and highly desirable. If a particular user does not have access to one of these multi-sensor models, then a combination of single-sensor models (Systems Consultants for FLIR, Rand for TV, and LTV for LLTV) can be used; although, when different models are used for different types of sensors, the user must be careful to check the models to determine whether various

TABLE 4. Real-Time Target Acquisition for Weapon Delivery: FLIR, TV, LLTV: High Speed: Variable Weather.

		GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
	Sensor Types ● TV	●	●		●		●	●							
	Sensor Types ● LLTV	●		●	●	●									
	Sensor Types ● FLIR	●	●		●				●	●	●	●	●	●	●
O	Flexible Sensor Description	O	O	O							O				
	Display Geometry, Luminance														
●	Display Search Mode	●	●	●	●			●				●			
●	Search Time	●	●	●	●			●				●			
O	Platform-Ground Geometry	O	O	O	O			O		O		O		O	O
O	Platform-Ground Dynamics	O	O	O	O	O		O				O			
	Displayed Scene Dynamics														
●	Target Type, Shape	●	●	●	●	●	●	●	●	●		●	●		●
O	Spectral Characteristics	O											O		O
●	Contrast, Noise, Resolution	●	●	●	●	●		●							
	Background Structure														
●	Atmospheric Scattering	●	●	●	●	●	●	●					●	●	●
●	Atmospheric Absorption	●	●	●	●	●				●		●	●	●	●
	Vibration														
	Outputs: Static Probability														
●	Outputs: Time-Dependent Probability	●	●	●	●			●				●			
O	Outputs: Probability Accumulation			O	O			O				O			
O	Outputs: Sensor Performance Details	O	O	O									O		
	Outputs: Other														

Conclusions:

1. Multi-sensor models can be used: best candidates are GRC GAMMA, MARSAM II, and AUTONETICS.
2. Combination of single-sensor models can be used: best combination is LTV (LLTV), RAND (TV), SYSTEMS CONSULTANTS (FLIR).
3. If sensor description flexibility is important, best candidates are GRC GAMMA and MARSAM II.
4. Only GRC GAMMA represents spectral characteristics.

Note:

● Highly desirable model characteristics

O Desirable model characteristics

aspects of the problem are treated in compatible analytic formulations. For example, the difference in performance among different types of sensors might be dictated by the difference in the display-observer models used. It can also be seen from Table 4 that, if sensor flexibility is important, the GRC GAMMA and MARSAM II models would be most appropriate.

To complete the example, we present in Figure 2 the performance of a particular FLIR (on a 1500-ft-high platform) as it would be calculated by one by the multisensor models. Two measures of performance are given here: the probability of target detection, and the probability of target recognition. The target is a van carrying an air-defense tracking radar. The atmosphere has been varied by considering two conditions of humidity and a variable set of aerosol conditions characterized by a visibility range of one to 10 miles in the visible portion of the spectrum. This data shows the earliest ranges (times) at which the target can be detected ($R > 20,000$ ft for $P_d = 0.8$). It also gives the latest range at which the target can be detected and recognized ($R \simeq 10,000$ ft for $P_r = 0.8$). It also provides data for computing the available time for the operator to search for the target. For example, under the most adverse conditions, search can take place once a reasonable probability of detection exists, e.g., at 24,000 ft. Then if the aircraft is traveling at 865 ft/s (515 knots) there are about 16 seconds available for display search before the 10,000 ft range is reached.

EXAMPLE 2: FLIR PERFORMANCE FROM HELICOPTERS IN A POP-UP MODE

One form of target acquisition from helicopters in a high-threat environment is to hover behind a rise in the ground and at the appropriate time "pop up", search for targets, hand the target over to a strike element, and then descend. In this application the crucial trade-off is the area on the ground that can be searched for targets as a function of time, from a given fixed altitude and range. Consequently the model that would be suitable for this application must be able to treat the dynamic aspects of display search from a fixed range. Also, since we are evaluating a FLIR, the model must adequately treat absorption loss in the atmosphere in the 8-14 μm spectral region. It is useful if the model handles the target-platform geometry. Also, if alternative FLIR configurations are being evaluated, it is desirable that the model be flexible in its sensor description and include some treatment of spectral response.

Table 5 shows the highly desirable and desirable model characteristics for this problem. It can be seen that, although ten of the fourteen models analyze FLIR sensors, only four of these have the appropriate characteristics to generate the type of data needed for this problem. The three multisensor models (GRC GAMMA, MARSAM II, and Autonetics) are applicable; of the FLIR-specific models only the Systems Consultants model has the appropriate display-search formulations to be useful in this case.

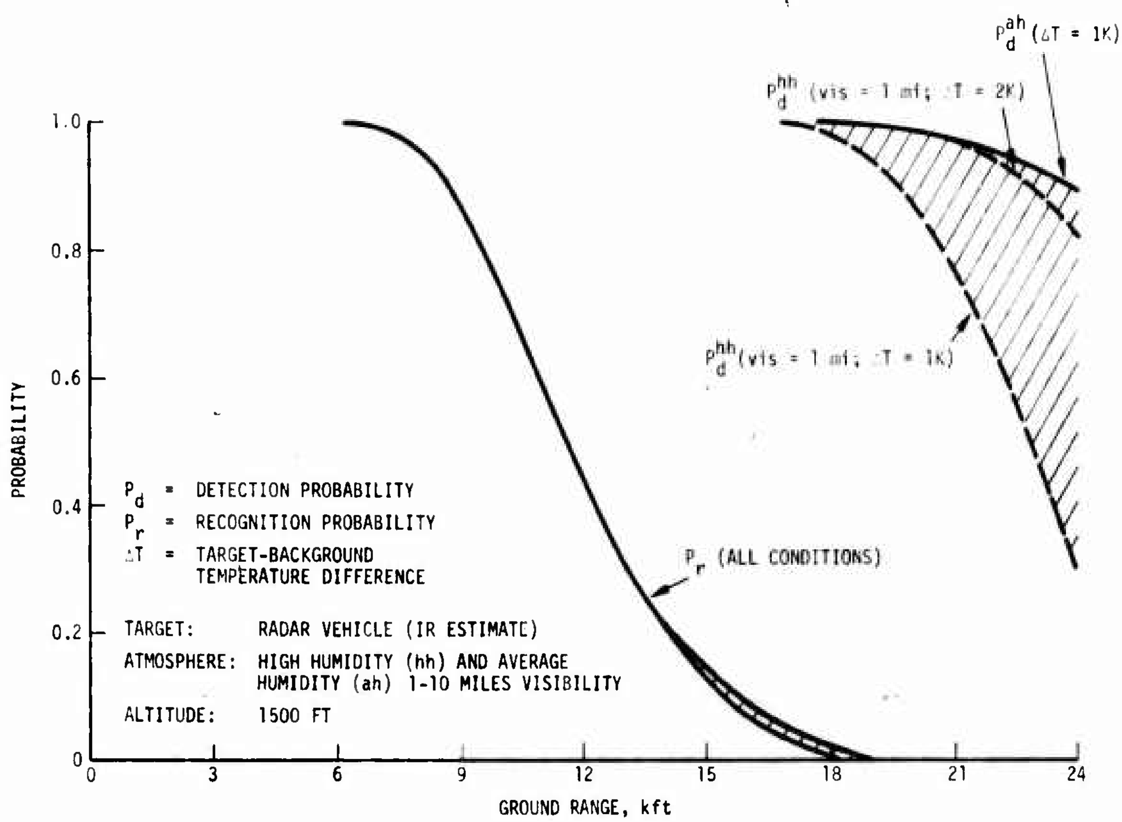

FIGURE 2. Medium Resolution FLIR: Probabilities of Detection and Recognition Versus Range.

If vibration is a problem with helicopter operations, only MARSAM II and the Systems Consultants model are applicable.

EXAMPLE 3: TV PERFORMANCE FROM HELICOPTERS IN A POP-UP MODE

In this example we have the same application as Example 2 except that the sensor being evaluated is TV. The desirable characteristics in this application are the same with the following two changes:

- Treatment of target contrast is essential for low-contrast targets degraded by atmospheric scattering
- The highly desirable atmospheric characteristic here is the treatment of aerosol scattering, and to a lesser extent atmospheric absorption

TABLE 5. Target Acquisition By Helicopter in Pop-Up Mode (FLIR).

		GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
	Sensor Types: TV LLTV ● FLIR	●	●		●				●	●	●	●	●	●	●
O	Flexible Sensor Description	O	O								O				
	Display Geometry, Luminance														
●	Display Search Mode	●	●		●							●			
●	Search Time	●	●		●							●			
O	Platform-Ground Geometry	O	O		O					O		O		O	O
	Platform-Ground Dynamics														
	Displayed Scene Dynamics														
●	Target Type, Shape	●	●		●				●	●		●	●		●
O	Spectral Characteristics	O											O		O
	Contrast, Noise, Resolution														
O	Background Structure	O	O		O										
O	Atmospheric Scattering	O	O		O								O	O	O
●	Atmospheric Absorption	●	●		●					●		●	●	●	●
O	Vibration		O									O	O		
	Outputs: Static Probability ● Time-Dependent Probability Probability Accumulation Sensor Performance Details Other	●	●		●							●			

Conclusions:

1. GRC GAMMA, MARSAM II, AUTONETICS and SYSTEMS CONSULTANTS models have suitable characteristics.
2. Of the above only MARSAM II and SYSTEMS CONSULTANTS treat vibration.
3. GRC GAMMA and MARSAM II provide flexible sensor representations.

Note:

● Highly desirable model characteristics

O Desirable model characteristics

Table 6 shows the table as filled in for this application. There are only five models that analyze TV sensors. All of these are suitable for this problem except the Westinghouse model, which is basically a static performance model and does not treat display search. If vibration is a consideration, only MARSAM II would be applicable.

TABLE 6. Target Acquisition By Helicopter in Pop-Up Mode (TV).

		GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
●	Sensor Types: TV	●	●		●		●	●							
	Sensor Types: LLTV														
	Sensor Types: FLIR														
O	Flexible Sensor Description	O	O												
	Display Geometry, Luminance														
●	Display Search Mode	●	●		●			●							
●	Search Time	●	●		●			●							
O	Platform-Ground Geometry	O	O		O			O							
	Platform-Ground Dynamics														
	Displayed Scene Dynamics														
●	Target Type, Shape	●	●		●		●	●							
O	Spectral Characteristics	O													
●	Contrast, Noise, Resolution	●	●		●			●							
O	Background Structure	O	O		O		O	O							
●	Atmospheric Scattering	●	●		●		●	●							
	Atmospheric Absorption														
O	Vibration		O												
	Outputs: Static Probability														
●	Outputs: Time-Dependent Probability	●	●		●			●							
	Outputs: Probability Accumulation														
	Outputs: Sensor Performance Details														
	Outputs: Other														

Conclusions:

1. GRC GAMMA, MARSAM II, AUTONETICS, and RAND models have suitable characteristics.
2. Only MARSAM II treats vibration.
3. GRC GAMMA and MARSAM II provide flexible sensor representations.

Note:

● Highly desirable model characteristics

O Desirable model characteristics

EXAMPLE 4: FLIR STATIC RANGE PERFORMANCE LIMITS

There are situations in which the time required for detection and recognition is not a driving factor, such as in the evaluation of alternative FLIR designs. In such situations what is required is data on the maximum range at which the operator could detect and recognize a particular target if he knew the target's position on the display (or he had unlimited time to search the display). For this type of application the model does not need to account for the dynamic aspects of display search. The desirable characteristics are summarized in Table 7. In this case all the FLIR-specific models should be useful, with two exceptions: the Hughes and EOS models do not treat the atmosphere and the platform-ground geometry. It is obvious from this example that there are many candidates for static performance data.

EXAMPLE 5: TV STATIC RANGE PERFORMANCE LIMITS

This example is the same as the previous application except that the sensor has been changed to TV. In this case the important atmospheric characteristic is aerosol scattering; and the model must have reasonable treatment of contrast. The results are summarized in Table 8, where it can be seen that any of the TV models might be applied. The choice among them will depend on the detail and fidelity of sensor modeling that may be required. For example, if altitude-range plots are needed, the Westinghouse model, which has no platform-ground geometry module, cannot be used except by solving the geometry and the target aspect details by hand. Similarly if flexible sensor description is desired, MARSAM II and GRC GAMMA would be more suitable.

It should be pointed out here that, to compare FLIR and TV sensors on a static basis, the user can use one of the multi-sensor models, or a combination of the single-sensor models provided he is careful about compatibility of performance measures.

EXAMPLE 6: CHOICE OF FLIR DISPLAY SIZE FOR COCKPIT APPLICATION

This is the sample problem discussed in the second section of this report, where one of the issues is to choose the display size that is compatible with the cockpit, the sensor being used, and the application. For example, if the sensor is to be used in real-time recce-strike it is desirable that the model treat display search. The highly desirable model characteristics in this case are display geometry and luminance and target type and shape. Desirable characteristics are the display search and time characteristics, the ability to account for contrast changes due to cockpit illumination, and the aspects of atmospheric and vibration degradation.

TABLE 7. FLIR Static Performance Limits (Range).

		GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
	Sensor Types: TV														
	Sensor Types: LLTV														
	Sensor Types: ● FLIR	●	●		●				●	●	●	●	●	●	●
○	Flexible Sensor Description	○	○								○				
	Display Geometry, Luminance														
	Display Search Mode														
	Search Time														
○	Platform-Ground Geometry	○	○		○					○		○		○	○
	Platform-Ground Dynamics														
	Displayed Scene Dynamics														
●	Target Type, Shape	●	●		●				●	●		●	●		●
○	Spectral Characteristics	○											○		○
	Contrast, Noise, Resolution														
	Background Structure														
○	Atmospheric Scattering	○	○		○								○	○	○
●	Atmospheric Absorption	●	●		●					●		●	●	●	●
	Vibration														
	Outputs: ● Static Probability	●	●		●							●	●		
	Outputs: Time-Dependent Probability														
	Outputs: Probability Accumulation														
	Outputs: Sensor Performance Details														
	Outputs: ○ Other									○					○

Conclusions:

1. Seven models - GRC GAMMA, MARSAM II, AUTONETICS, NADC, SYSTEMS CONSULTANTS, NVL, and NAFI - have suitable characteristics.
2. Choice among them depends on detail and fidelity required, such as atmospheric scattering or spectral treatment of sensor and target.

Note:

● Highly desirable model characteristics

○ Desirable model characteristics

TABLE 8. TV Static Performance Limits (Range).

			GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
	Sensor Types	● TV	●	●		●		●	●							
		LLTV														
		FLIR														
○		Flexible Sensor Description	○	○												
		Display Geometry, Luminance														
		Display Search Mode														
		Search Time														
○		Platform-Ground Geometry	○	○		○			○							
		Platform-Ground Dynamics														
		Displayed Scene Dynamics														
●		Target Type, Shape	●	●		●		●	●							
○		Spectral Characteristics	○													
●		Contrast, Noise, Resolution	●	●		●			●							
		Background Structure														
●		Atmospheric Scattering	●	●		●		●	●							
		Atmospheric Absorption														
		Vibration														
	Outputs	● Static Probability	●	●		●		●	●							
		Time-Dependent Probability														
		Probability Accumulation														
		Sensor Performance Details														
		Other														

Conclusions:
1. All the models which represent TV can be used.
2. Choice among them depends on detail and fidelity required.

Note:
- ● Highly desirable model characteristics
- ○ Desirable model characteristics

The model characteristics are summarized in Table 9, which shows that five models are generally applicable: GRC GAMMA, MARSAM II, Autonetics, Systems Consultants, and NVL. Here a caution is required; from Table 2 it can be seen that of these only the Autonetics and Systems Consultants models represent display luminance. If dynamic conditions (real-time recce/strike problems) are used in the evaluation, then the NVL model is not applicable. On the other hand, if vibration is important, only MARSAM II and NVL may be appropriate.

EXAMPLE 7: CHOICE OF TV DISPLAY SIZE FOR COCKPIT APPLICATION

In this example the desirable model characteristics, summarized in Table 10, are similar to the previous example with the exception of contrast, which is more important with TV sensors. For TV sensors there are four models that can be used: GRC GAMMA, MARSAM II, Autonetics, and Rand, but only MARSAM II treats vibration.

TABLE 9. Choice of Display Size for Cockpit Application (FLIR).

		GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
	Sensor Types: TV, LLTV, ● FLIR	●	●		●				●	●	●	●	●	●	●
	Flexible Sensor Description														
●	Display Geometry, Luminance	●	●		●						●	●	●		
O	Display Search Mode	O	O		O							O			
O	Search Time	O	O		O							O			
	Platform-Ground Geometry														
	Platform-Ground Dynamics														
	Displayed Scene Dynamics														
●	Target Type, Shape	●	●		●				●	●		●	●		●
	Spectral Characteristics														
O	Contrast, Noise, Resolution	O	O		O										
	Background Structure														
O	Atmospheric Scattering	O	O		O								O	O	O
O	Atmospheric Absorption	O	O		O					O		O	O	O	O
O	Vibration		O										O	O	
Outputs	● Static Probability	●	●		●							●	●		
Outputs	O Time-Dependent Probability	O	O		O							O			
Outputs	Probability Accumulation														
Outputs	Sensor Performance Details														
Outputs	Other														

Conclusions:

1. For static conditions, five models-GRC GAMMA, MARSAM II, AUTONETICS, SYSTEMS CONSULTANTS, and NVL - have suitable characteristics.
2. For dynamic conditions, only the first four are suitable.
3. If vibration is important, only the MARSAM II and NVL models are suitable.

Note:

● Highly desirable model characteristics

O Desirable model characteristics

TABLE 10. Choice of Display Size for Cockpit Application (TV).

		GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
	Sensor Types ● TV LLTV FLIR	●	●		●		●	●							
	Flexible Sensor Description														
●	Display Geometry, Luminance	●	●		●			●							
O	Display Search Mode	O	O		O			O							
O	Search Time	O	O		O			O							
	Platform-Ground Geometry														
	Platform-Ground Dynamics														
	Displayed Scene Dynamics														
●	Target Type, Shape	●	●		●			●							
	Spectral Characteristics														
●	Contrast, Noise, Resolution	●	●		●			●							
	Background Structure														
●	Atmospheric Scattering	●	●		●			●							
O	Atmospheric Absorption	O	O		O										
O	Vibration		O												
Outputs	● Static Probability O Time-Dependent Probability Probability Accumulation Sensor Performance Details Other	● O	● O		● O			● O							

Conclusions:

1. GRC GAMMA, MARSAM II, AUTONETICS, and RAND models have suitable characteristics.
2. Only MARSAM II treats vibration.

Note:

● Highly desirable model characteristics

O Desirable characteristics

GENERAL COMMENTS ON MODEL UTILITY

An examination of the previous section indicates that certain models appear to stand out in having a large number of desirable qualities and in being applicable to a wide range of problems. Although this is determined to some extent by the problems selected for discussion, it is to a considerable extent due to the models themselves; some models appear to be more complete and flexible than others.

In considering the choice of a model for a specific application, however, the user should consider various factors besides the applicability of the model to the specific problem at hand. Among these are:

The availability of the model to prospective users. The equations representing the model may be quite simple, so that it is easy to write a computer program based on them. Some models are embodied in computer programs which can be run for outside users, or copies of which (with adequate comment cards) can be supplied to users. This usually requires that custodians of the programs have personnel sufficiently familiar with them to run them or provide assistance to users. Unless a particular model is available in one of these ways, it probably should not be considered for a particular application.

The degree to which the model represents the current state of the art. Some models incorporate the current state of the art in representing sensors and display observers. Older models may be less up to date. Still other models incorporate unique insights of the modelers. Conclusions obtained from a model are more convincing if it represents current thinking.

Acceptance of the model by the technical community. The general acceptance of the model depends, of course, on how well it represents the current state of the art. The latter is continually improving, especially in the area of representing the human observer. Several of the models are based on original work and have had great influence on other models and on the thinking of workers in the field.

Evidence of continuous evolution of the model. Closely connected with the availability of the model is the quality of its evolution. If a particular model is in active use it will probably be undergoing more or less continuous changes which adapt it for new applications and introduce new formulations and insights. Since this evolutionary process means that the model is active and is being improved, it is a key quality.

Spectrum of possible uses for the model. If the user has a variety of problems to solve, a flexible model which can help solve all of them may be preferable to two or more special-purpose models. Even if a model is to be used for a specific purpose, the choice of a flexible model, which may be valuable for future problems, can eliminate the need for having to acquire and become familiar with a second model at a later date.

Based on these five criteria, and on the previous section which helps to indicate those models having the widest range of applications, six models seem to stand out. These are:

GRC GAMMA
MARSAM
Westinghouse
Rand
Systems Consultants
NVL

These models seem to be the ones deserving initial consideration, even though they do not all have all the qualities discussed above. In the following paragraphs each is considered briefly.

GRC GAMMA

This model is currently being used and can be run for outside users. At the time it was written it embodied the current state of the art in representing observer performance; recent changes have been made so that it is kept up to date. Originally it influenced other modeling efforts (such as MARSAM, LTV, and the Autonetics model). It is a relatively general-purpose model, and is quite flexible in structure and use.

MARSAM

This model is also currently being used and can be run for outside users. It is presently being extensively revised to make it current with the state of the art in sensor and observer performance modeling. It appears to be widely used within the Air Force. This is a general-purpose model with many uses and a variety of output options.

WESTINGHOUSE

This model was developed after GAMMA and MARSAM, and Westinghouse personnel have assisted users in employing the model. It represents the current state of the art in dealing with resolution and the noise which appears on the display of a television system. Targets in simple and complex backgrounds are considered, but the display search process is not represented. The model is based on original work which has influenced other modeling efforts (including Rand, Systems Consultants, and NVL). It does not appear that further developments of this model are under way, and it is a rather special-purpose model in its current formulation.

RAND

This model is based on relatively simple equations and is adaptable to programming by users. It embodies the current state of the art in two ways: the Westinghouse formulation of the effects of noise on target detection and recognition is used, as well as an alternative observer formulation, developed at Rand, which makes use of the concept of scene complexity. Of especial interest is the display search formulation, which is more sophisticated than earlier treatments, and similar to that in the Systems Consultants model. It does not appear that further work is being done on this model; it is relatively special-purpose.

SYSTEMS CONSULTANTS

This model is a relatively recent development and is available to outside users. It uses the noise concepts of the Westinghouse model, and a very detailed, unique treatment of the display search process; the accumulation of detection probabilities in this model is similar to that in the Rand model. This model does not appear to be under further development; it is relatively special-purpose.

NVL

This model is also a relatively recent development; a listing of the program appears in a recent NVL report. It represents the current state of the art in dealing with noise and resolution in FLIR displays. The procedure is rather different from that of the Westinghouse model; a final decision between the two methods cannot be made at present. This model does not represent display search; current work is directed towards understanding the search process. The computer program output is quite comprehensive and provides considerable information about the sensor being modeled.

The remaining eight models have various shortcomings with respect to the five criteria discussed above; these aspects are considered briefly below.

LTV

This model has two qualities to be noted: it is quite special-purpose (dealing only with LLTV) and it does not appear to have been used since its original development and must be considered essentially unavailable.

AUTONETICS

This model has the same broad capabilities as GRC GAMMA and MARSAM. However, it is not being used or worked on, so in the sense of this report it seems to be unavailable.

SRI SCREEN

This model is special-purpose (representing only LLTV) and has not been used or worked on for a number of years; it is considered to be essentially unavailable.

HUGHES

This model is a relatively simple representation of the sensor, and calculates only the MRT and NET of the sensor. Thus it does not seem to represent the current state of the art in sensor and observer modeling. It does not appear that any additional development is being done.

NADC

This model does not represent the sensor in any detail; the MRT is calculated from an empirical fit to detector subtense and NET. Thus the current state of the art in sensor and observer representation is not a part of the model. Also, the model is special-purpose in that the principal targets are ship profiles. Although these are represented in considerable detail, the treatment probably cannot be extended directly to other targets.

XEROX/EOS

This model is only used within the company and is not considered available. It is a special-purpose model for the analysis and design of sensors and does not appear to be applicable directly to the solution of military operational problems.

NWC

This model uses the MDT/MRT modeling approach and assumes that when the target-background contrast is above a certain threshold the operator detects the target. It represents the current state of the art in a rather simplified way, and it is special-purpose, in that the targets considered are buildings and ships. Although these targets are treated in some detail, application of the methods to other targets might require development.

NAFI

This model, as it stands, is a special-purpose model designed primarily to compute range-altitude performance envelopes of IR air-to-ground sensors at constant signal-to-noise ratio. It does not appear to represent the current state of the art in sensor and observer modeling, and does not seem to be as flexible as other models, although it does contain provisions for comparing alternative proposed or existing sensors.

In summary, it seems that GRC GAMMA, MARSAM, and the models of Westinghouse, Rand, Systems Consultants, and NVL warrant first consideration when choosing a model for a specific application. Any of the other models could be valuable under particular circumstances, however, and a prospective model user should give some consideration to the possibility that one of them will solve his problem exactly, or has qualities (such as availability within a particular organization) which outweigh other possible disadvantages.

ADDITIONAL WORK SHEETS

For the convenience of report users we are providing here several blank copies of the Model Selection Form developed in this study.

WORK SHEET
Model Selection Form

	GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
Sensor Types: TV, LLTV, FLIR														
Flexible Sensor Description														
Display Geometry, Luminance														
Display Search Mode														
Search Time														
Platform-Ground Geometry														
Platform-Ground Dynamics														
Displayed Scene Dynamics														
Target Type, Shape														
Spectral Characteristics														
Contrast, Noise, Resolution														
Background Structure														
Atmospheric Scattering														
Atmospheric Absorption														
Vibration														
Outputs: Static Probability, Time-Dependent Probability, Probability Accumulation, Sensor Performance Details, Other														

WORK SHEET
Model Selection Form

		GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
Sensor Types	TV LLTV FLIR														
	Flexible Sensor Description														
	Display Geometry, Luminance														
	Display Search Mode														
	Search Time														
	Platform-Ground Geometry														
	Platform-Ground Dynamics														
	Displayed Scene Dynamics														
	Target Type, Shape														
	Spectral Characteristics														
	Contrast, Noise, Resolution														
	Background Structure														
	Atmospheric Scattering														
	Atmospheric Absorption														
	Vibration														
Outputs	Static Probability Time-Dependent Probability Probability Accumulation Sensor Performance Details Other														

WORK SHEET
Model Selection Form

	GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
Sensor Types: TV, LLTV, FLIR														
Flexible Sensor Description														
Display Geometry, Luminance														
Display Search Mode														
Search Time														
Platform-Ground Geometry														
Platform-Ground Dynamics														
Displayed Scene Dynamics														
Target Type, Shape														
Spectral Characteristics														
Contrast, Noise, Resolution														
Background Structure														
Atmospheric Scattering														
Atmospheric Absorption														
Vibration														
Outputs: Static Probability, Time-Dependent Probability, Probability Accumulation, Sensor Performance Details, Other														

WORK SHEET
Model Selection Form

		GRC GAMMA	MARSAM II	LTV	Autonetics	SRI SCREEN	Westinghouse	Rand	Hughes	NADC	Xerox EOS	Sys. Consult.	NVL	NWC	NAFI
Sensor Types	TV LLTV FLIR														
	Flexible Sensor Description														
	Display Geometry, Luminance														
	Display Search Mode														
	Search Time														
	Platform-Ground Geometry														
	Platform-Ground Dynamics														
	Displayed Scene Dynamics														
	Target Type, Shape														
	Spectral Characteristics														
	Contrast, Noise, Resolution														
	Background Structure														
	Atmospheric Scattering														
	Atmospheric Absorption														
	Vibration														
Outputs	Static Probability Time-Dependent Probability Probability Accumulation Sensor Performance Details Other														

4 Naval Postgraduate School, Monterey
  Code 55, TWORAS (1)
  Dr. James Arima (1)
  Dr. Gary Poock (1)
  Technical Library (1)
2 Naval Research Laboratory (Code 4109)
1 Naval Submarine Medical Center, Naval Submarine Base, New London
1 Naval Surface Weapons Center, White Oak (Technical Library)
2 Naval Training Equipment Center, Orlando
  Code 215 (1)
  Technical Library (1)
1 Office of Naval Research Branch Office, Pasadena
1 Operational Test and Evaluation Force
3 Pacific Missile Test Center, Point Mugu
  Code 1226 (2)
  Technical Library (1)
1 Headquarters, U. S. Army (DRCBSI)
1 Office Chief of Research and Development
1 Army Armament Command, Rock Island (AMSAR-SAA)
1 Army Combat Developments Command, Armour Agency, Fort Knox
1 Army Combat Developments Command, Aviation Agency, Fort Rucker
1 Army Combat Developments Command, Experimentation Command, Fort Ord (Technical Library)
1 Army Combat Developments Command, Field Artillery Agency, Fort Sill
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1 Army Missile Command, Redstone Arsenal
1 Army Training & Doctrine Command, Fort Monroe
1 Aeromedical Research Laboratory, Fort Rucker
1 Army Ballistics Research Laboratories, Aberdeen Proving Ground
1 Army Field Artillery School, Ft. Sill
2 Army Human Engineering Laboratory, Aberdeen Proving Ground
2 Army Materiel Systems Analysis Agency, Aberdeen Proving Ground
1 Army Mobility Equipment Research & Development Center, Fort Belvoir (Library)
1 Army Research Institute, Arlington
1 Fort Huachuca Headquarters, Fort Huachuca
2 Frankford Arsenal
4 Night Vision Laboratory, Fort Belvoir
  Systems Analysis Team (3)
  DRSEL/NV/VI (1)
2 Picatinny Arsenal
  SMUPA-AD-C (1)
  SMUPA-FRL-P (1)
1 Redstone Arsenal (DRXHE-MI)
1 White Sands Missile Range (TRASANA)
1 Air Force Logistics Command, Wright-Patterson Air Force Base
1 Air Force Systems Command, Andrews Air Force Base (SDW, Roger Hartmeyer)
1 Strategic Air Command, Offutt Air Force Base (XPFS)
1 Tactical Air Command, Langley Air Force Base
1 Oklahoma City Air Materiel Area, Tinker Air Force Base
6 Aeronautical Systems Division, Wright-Patterson Air Force Base
  Code AERR (1)
  Code RW (1)
  Code XR (1)
  Code XRO-MAF (3)
1 Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base (Code HEA)