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15 May 1977

Prepared by

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This report describes the dynamic nature of many of the information requirements of operational decision aids designed for Naval task force commanders. The methods for storing and maintaining track and readiness information are described. The dependence of performance, effectiveness and reliability parameters of military systems on environmental and tactical situation variables are examined. This information can be maintained in the data base as nominal values, tables or computer programs. Nominal values are adequate when the
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20. ABSTRACT

variations are small enough to ignore, tables are used when a small number of values is sufficient to express the variability and computer programs are required when there are many factors or wide variability. Models were examined and sensitivity analyses performed to determine the best way to provide this information to an operational command and control data base.

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1.0 INTRODUCTION

The purpose of this report is to present a complete description of the work undertaken by CTEC, Inc. on the Operational Decision Aids (ODA) Program for the Office of Naval Research (ONR). The purpose of the ODA Program is to examine whether and how recent advances in computer science, decision theory and computer simulation can be utilized to assist tactical decision making at the Task Force Commander (TFC) level.

The efforts of participants in the ODA program have focused on three areas:

- Information Processing
- Decision Structuring
- Outcome Calculators

Information processing concerns the application of hardware and software technology, data bases and data management systems. Decision structuring aids attempt to guide the decision maker's thinking process along the lines of normative decision theory as described in [4]. Outcome calculators provide a decision maker with tools to perform tradeoff analyses of his options by providing computer simulations of the outcome of engagements.

In the area of information processing, there are two complementary efforts in the ODA program: The effort at University of Pennsylvania to develop a Decision Aiding Information System (DAISY) ([5], [6]) and the WAND data base management system [7]; and the effort of CTEC, Inc. to develop an information base for the ODA program. These efforts are fundamental to the ODA effort because they provide the technical foundation of the decision structuring aids and the outcome calculators. This follows from the general principle that decisions made by those in command can only be as effective as the information on which those decisions are based.

An ODA test facility is being prepared at University of Pennsylvania in which all of the decision aids are being integrated ([8], [9]). This test facility is designed to simulate the task force decision environment. The decision aids will be tested in a series of experiments to be conducted at the ODA test facility. These tests will be concerned with two questions:

- How well does the decision maker interact with the decision aid.
- Does the use of the decision aid actually improve the decision maker's performance.

The basic purpose of CTEC's effort to develop an information base for the ODA program is to insure that all of the information required by the decision aids is available in the test facility at the University of Pennsylvania. A significant part of the integration of the decision aids consists of creating a single unified information base which they all utilize. Without this common information base, it would be impossible to conduct experiments in which all of the decision aids are simultaneously available. As a result, neither comparisons of the relative merits of the various decisions aiding approaches nor the synergistic effects of having all of these aids available could be examined. No decision aid should have its own unique block of information.



2.0 OVERVIEW OF ODA INFORMATION BASE

There are four categories of information being provided by the ODA information base:

- Fixed Data
- Track Information
- Naval Status of Forces (NSOF) Information
- Situation/Environment Dependent Information

These categories differ in how the data are stored by the system, the method and the frequency with which the data are updated, and the relative importance of the data in the planning and execution phases of task force operations.

(1) Fixed data consist of technical characteristics of own and enemy force platforms, sensors and weapons, and information about the operations area. These data are compiled and stored in the data base and are fixed in the sense that they remain unchanged by the decision maker and by the computerized decision aids. The fixed data in the ODA data base is derived from either sources of technical information about military systems or from the ONRODA scenarios ([1], [2]). A comprehensive data base is described in [3]. Actual data corresponding to the known information requirements of the ODA participants has been compiled and input into the ODA testbed. Table 2-1 indicates the number of records of technical data, i.e., platform, sensor and weapon characteristic data, that are currently in the data base at the University of Pennsylvania. In addition, there is a series of records that describe the geography, economics, terrain and climate of the ONRODA operations area and Naval Order of Battle records describing facilities that are potential targets in the scenarios. The ODA information base contains only the information required to conduct experiments using the ODA decision aids. The decision aids are, however, continuing to be developed. Therefore, information requirements over and above those described in [3] have risen during the past year. These additional requirements are for additional data elements to be added to the existing records. Appendix A provides a complete description of the ODA fixed information base by giving a list of the records and the data elements in each record type.

TABLE 2-1. NUMBER OF RECORDS OF EACH RECORD TYPE IN THE ODA TECHNICAL INFORMATION BASE

RECORD TYPE	NUMBER
SURFACE	51
SUBSURFACE	4
AIR	36
RADAR	36
SONAR	7
ESM	5
MISSILE	28
GUN	23
BOMB	10
TORPEDO	5

(2) Track information consists, at a minimum, of position, course, speed and identifying characteristics of all platforms (friendly, hostile and unknown) operating in the task force area of interest. In addition, these files may contain whatever information is required to perform track correlation or threat assessment. During the course of task force operations these data change very rapidly both in response to actions taken by the task force commander and actions taken by the enemy. Unlike fixed data where the information is input to the data base once and remains the same for all ODA experiments, the information in the track files will differ from one experiment to another. Therefore, it is the structure of these files rather than their specific content that must support the decision aids. A sample track file has been input to the ODA test facility. This track file can be used to perform software testing for the decision aids that will require a track file. Appendix B contains a complete description of this track file.

(3) Naval Status of Forces (NSOF) information consists of a complete description of own force readiness including a complete inventory of consumables, expendables, spare parts, etc. As with track data, this information changes as task force operations proceed, although the change in NSOF data is slower than with track data. NSOF data are similar to track data in that the actual information in the files will vary from one experiment to another. Therefore, it is the structure of these files rather than their specific content that must support the decision aids. A set of NSOF files was defined in [3]. Actual information will be input to these files when required to support experimental tests.

ION ATION RCRAFT.	EPENDENT BLE, D ODA	RANGE PTIMAL	OR ODA	PRIMARY UES RANGE.		MALLY 1-3 900

(4) Situation/Environment dependent information consists of platform and equipment performance, effectiveness and reliability. This information varies with the environmental and tactical situation with equipment status. It is stored in the form of tables or computer programs.

The reason for providing the information at this level of detail is that nominal values, such as provided in a fixed technical data base, cannot account for many complex factors that impact on the performance of military systems. It is not useful to provide a TFC with the nominal detection range of a sensor, the nominal kill probability of a weapon or a nominal sortie rate for an aircraft type. A TFC needs to know how far his sensor can see the targets of interest to him under prevailing conditions, the effectiveness of his weapons under his actual tactical situation, and the expected availability of his aircraft given his scheduled operations.

There are three types of situation/environment dependent data that are important to the support of the ODA decision aids:

- Variable Data. Platform/sensor/weapon performance as a function of the environment and the tactical situation.
- Force Effectiveness Data. Provides own force versus enemy force comparison of capabilities.
- Readiness Projection. Projections of the impact of planned operations on force readiness.

In each of these areas, computerized algorithms and simulations exist. In many cases, however, these computer programs are either too difficult to use from a man/machine interface standpoint or they require too much computer processing time to be useful in a tactical environment. The problem addressed in this report is how to provide quick and accessible answers that are accurate and sophisticated enough to be tactically useful. The situation/environment dependent information that has been provided to the ODA testbed in each of the three areas is described in the next three sections of this report.

3.0 VARIABLE DATA

3.1 General

The technical data in the ODA data base consist of physical and performance characteristics of platforms, sensors and weapons. The physical characteristics and some of the performance characteristics are built into the design of the system and are therefore fixed data. Examples of this are the displacement of a ship and the vertical beam width of a radar. Some performance characteristics, however, vary with environmental and tactical deployment parameters. These are called variable data. Examples of variable data include maximum ship speed and radar detection range. The problem addressed in this section is how to provide variable data in a useful and easily accessible fashion.

Variable data can be provided using nominal values, tables or computer programs. A nominal value is a single number that represents an average over the range of all of the factors that cause variation in the data. Nominal values are appropriate when the variation is sufficiently small that it can be disregarded. A table is appropriate when a few values are sufficient to express all of the variability. A computer program is needed if there are too many factors or the variations are too large to capture all of the information in a reasonably sized table.

In this section, all of the data elements in the technical data base are examined to determine which are fixed and which are variable. Those that are variable are further examined to determine which parameters impact the data and what is the sensitivity of the data to these parameters. An analysis is performed to decide if the information is best provided via a nominal value, a table or a computer program. In choosing how to provide the information, the requirement is to provide information that is accurate enough to be useful to a tactical decision maker. At the same time the tool that provides the information must be sufficiently quick and easy to use to be suitable for implementation in a tactical environment.

Sections 3.2, 3.3 and 3.4 contain this analysis of variable data for platforms, sensors and weapons respectively. For each record type there is a table that summarizes the analysis of the information in that record type. The table indicates for each data element whether it is fixed or variable. If it is variable, then the parameters that impact its value are indicated. The types of models (i.e., nominal value, table or computer algorithms) that are available and the types of models that were implemented for ODA are indicated for all variable data. In addition to the tables, these sections contain discussions of how the analysis was carried out.

3.2 Platforms

3.2.1 Surface Ships

Among the data elements for surface ships (cf. Table 3-1), only the range, fuel type, speed and fuel consumption are not fixed design characteristics. These four data elements are not independent. For non-nuclear ships, the range can be calculated using the formula:

$$\text{Range (nm)} = \frac{\text{Fuel capacity (lb) X speed (kn)}}{\text{Fuel consumption (lb/hr)}}$$

Nuclear ships have, for tactical analyses, an unlimited range.

Most non-nuclear ships operate on Navy Standard Fuel Oil (NSFO) and Navy Diesel (ND) fuels, the variation in fuel consumption as a function of fuel type is simply a known multiplicative factor [10]. All figures in the ODA data base assume ND is the fuel type.

Table 3-2 consists of a table of formulas of fuel consumption as a function of speed for various classes of ships. These formulas include a "known average" factor to account for weather, wind and hull fouling. The formulas were obtained using sanitized tables of fuel consumption vs. speed [10] and then fitting the data with a least squares curve. Using this table, for example, the fuel consumption of a DD806 proceeding at 20 knots is $y = \exp((.115)(20) + 4.84) = 1261$ gal/hr.

Although these formulas are suitable for developing operational decision aids they should not be used indiscriminately. Hull fouling can be quite severe and may increase fuel consumption by 25% [11]. Hull fouling has a smaller effect on ship speed. Generally, maximum ship speed may drop about two knots below design when the hull is severely fouled. The amount of hull fouling is dependent upon geographic location and deployment.

The variation of maximum ship speed with sea state is an extremely complicated subject. For example, in addition to the factors mentioned in Table 3-1, ship speed is often limited by the effect of ship motions, such as roll, on personnel and equipment. NAVSEASYSCOM is currently funding the Sea Keeping Program ([12], [13]) under which an analytical model for predicting ship maneuverability is being developed. Qualitative curves depicting gross speed reduction factors as a function of wave height and ship vs. wave direction are given in Figure 3-1 (reproduced from [14]). These type curves are normally obtained by reviewing ship logs.

Figure 3-2 is a set of histograms showing speed reduction factors vs. sea state for broad classes of major combatants. These histograms are based on operator modification to speed vs. sea state values computed from Figure 3-3. Each histogram contains two bars, one for following (B1) and one for head waves (B2). Speed vs. sea state values in the ODA data base are computed by degrading ship speed according to the appropriate speed reduction factors in Figure 3-2.

FILE NAME SURFACE PLATFORMS

TABLE 3-1

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
SHIP NAME	X									
FLAG	X									
TASK FORCE ID	X									FIXED FOR ODA APPLICATION.
SHIP CLASS	X									
TYPE HULL NBR	X									
CALL SIGN	X									
MAXIMUM SPEED	X									DESIGN PARAMETER.
ECONOMICAL SPEED	X									DESIGN PARAMETER.
RANGE		X			X		X			CALCULATE VALUE. SEE TEXT.
			• FUEL CONSUMPTION • SPEED • FUEL CAPACITY							
PROPULSION TYPE	X									
FUEL TYPE	X									NUCLEAR/NON-NUCLEAR [ND, NSFO].
USEABLE FUEL CAP	X									DESIGN PARAMETER.

TABLE 3-1 (cont'd)

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
SPEED VS. SEA CONDITION		X	• SEA STATE • HEADING • HULL FOULING • ENGINE POWER AND EFFICIENCY		X			X		HIGHLY DEPENDENT UPON SEA STATE PARAMETERS. LIMITED MODELS BEING DEVELOPED BY NAVSEA. TABLE BASED ON PRELIMINARY STUDIES AND OPERATOR EXPERIENCE (SEE TEXT).
FUEL CONSUMPTION		X	• SPEED • SEA STATE • HULL FOULING • ENGINE EFFICIENCY	X	X		X			

TABLE 3-2. TABLE OF FORMULAS FOR SHIP FUEL CONSUMPTION AS A FUNCTION OF SPEED

SHIP CLASS	ND FUEL CONSUMPTION (gal/hr)	
	At Speeds Under 29kn	At Speeds Over 29kn
CV63/CV59	exp (.090X + 6.91)*	exp (13.9X + 5.58)
CG-4/ -10	exp (.113X + 5.62)	exp (.179X + 3.71)
CG-16/CG-21	exp (.107X + 5.32)	exp (.132X + 4.78)
DD-963/964	exp (.122X + 4.85)	exp (.127X + 4.73)
DDG-21/DD710 DD826/806/864	exp (.115X + 4.84)	exp (.131X + 4.46)
FF	exp (.106X + 4.80)	N/A
LCC-19	exp (.065X + 6.08)**	N/A
LKA-113	exp (.090X + 5.40)**	N/A
LPD-1/LPD-4/LSD-36	exp (.090X + 5.56)**	N/A
LPA-248	exp (.072X + 5.31)**	N/A
LPH-2	exp (.062X + 5.73)**	N/A
LST-1179	exp (.105X + 4.49)**	N/A

* X - speed (knots)
** For speeds under 20 knots

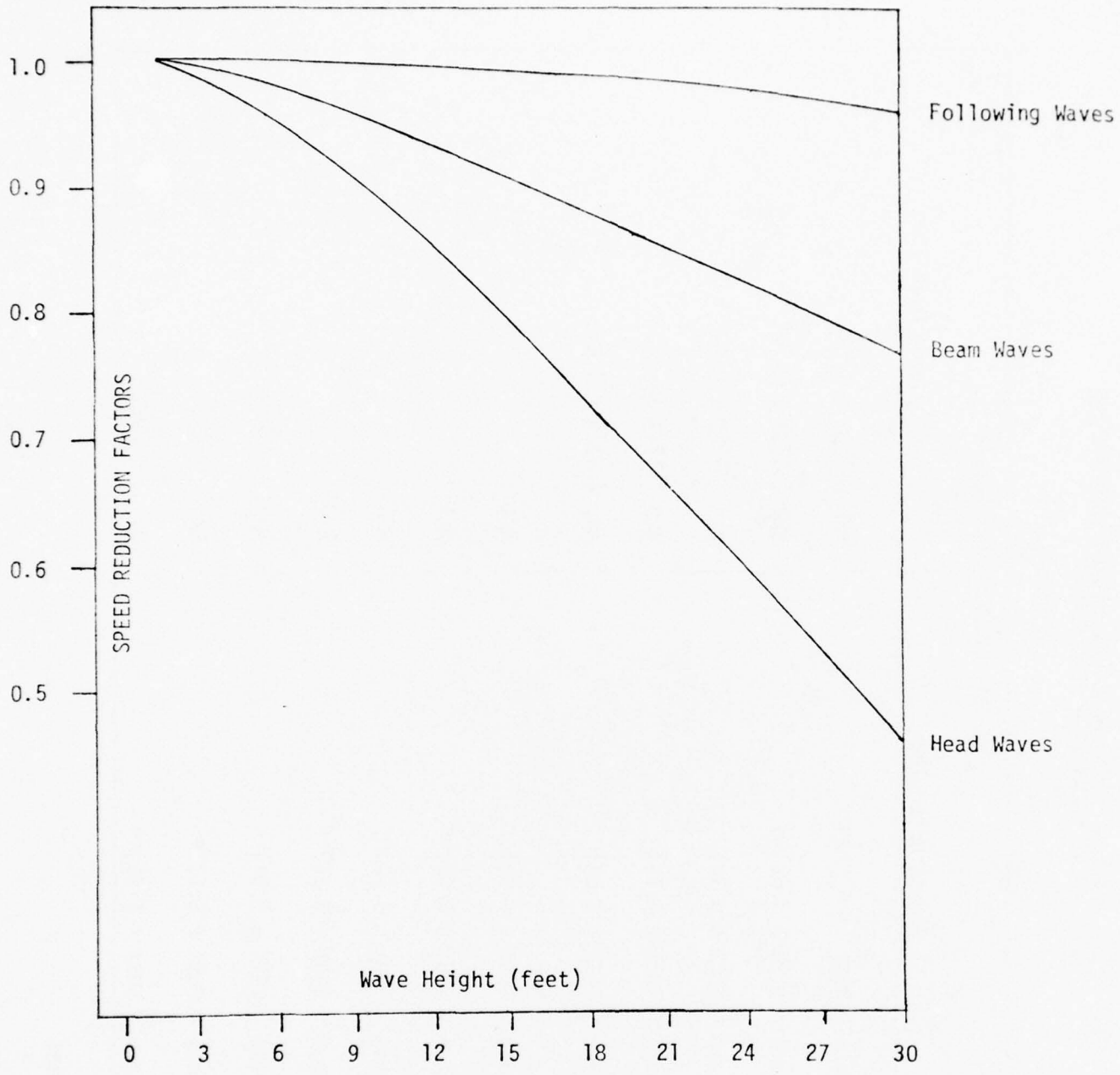


FIGURE 3-1. SPEED REDUCTION FACTORS COMBINED HULL TYPES

CG CLASS

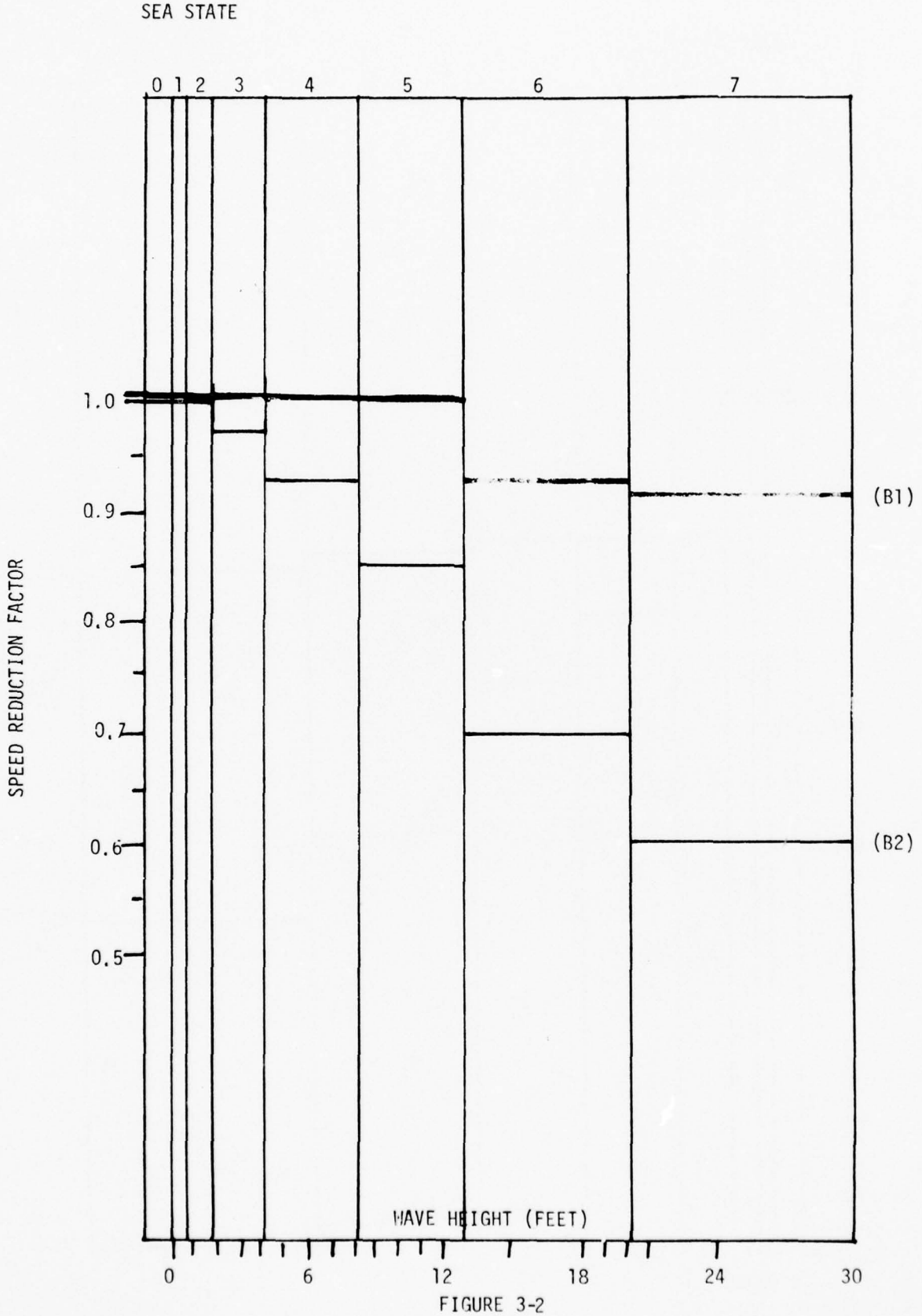


FIGURE 3-2

CV CLASS

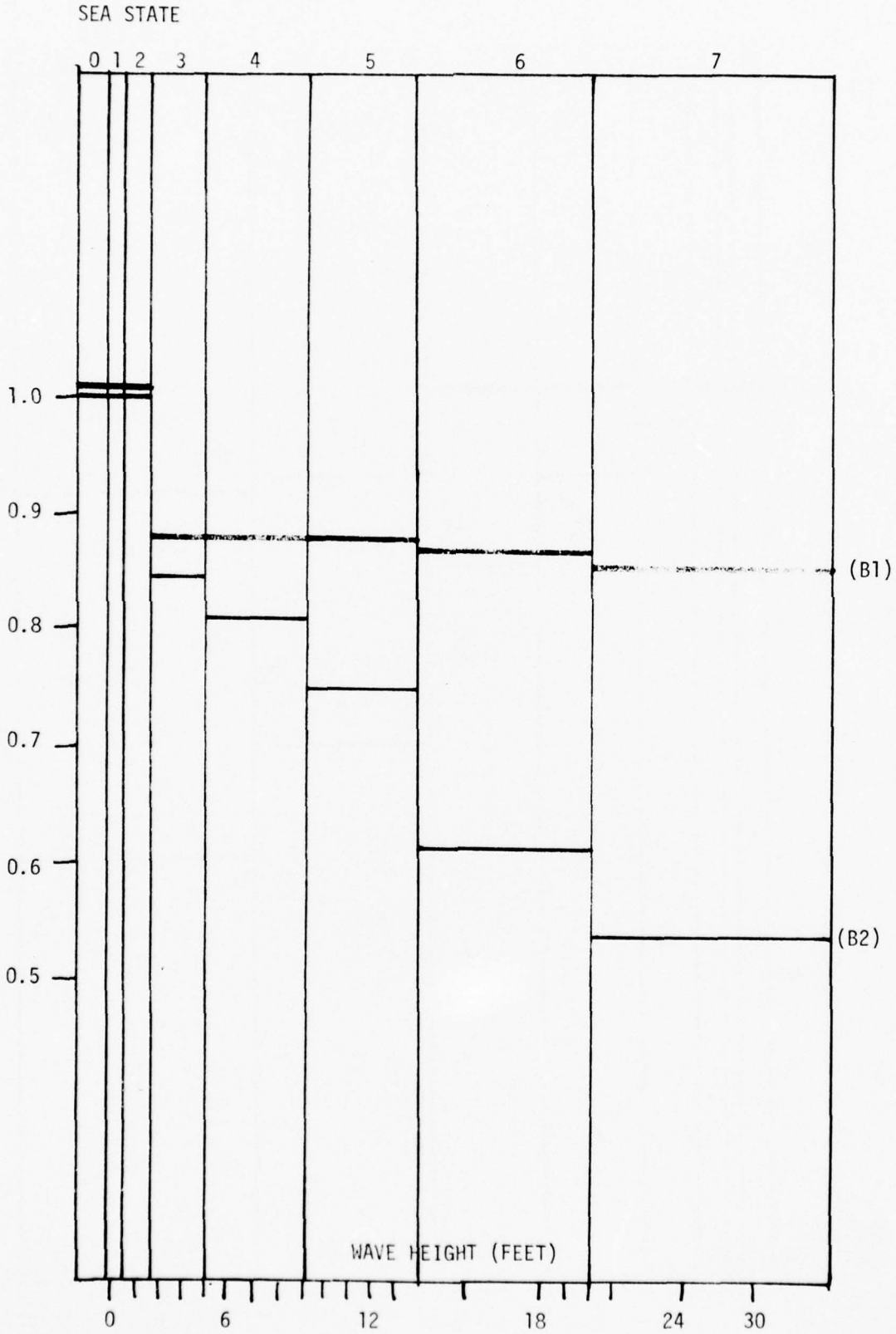


FIGURE 3-2 (cont'd)

DD/DDG CLASS



FIGURE 3-2 (cont'd)

3.2.2 Submarines

Of the data elements listed in Table 3-3, only the maximum submerged speed and normal operating depth are considered variables. The remaining elements either identify the platform or are considered a fixed value based upon submarine design constraints.

The operating depth of a submarine is a decision variable that is dependent upon the sound velocity profile of the surrounding ocean environment and the operational mission. For example, if a submarine is operating in a search mode, it would attempt to operate on the same side of the mixed layer depth (cf. Section 3.3.3 for a discussion of this concept) as the target. Conversely, if in an evade, mode, the submarine would attempt to operate on the opposite side of the mixed layer depth. Thus, environmental factors strongly influence the choice of submarine operating depth.

In addition, operating depth is influenced by the need to minimize the effects of a phenomenon called cavitation. Cavitation is the formulation of a partial vacuum in a flowing liquid as a result of the separation of its parts. Cavitation is caused by the motion of the submarine in the water and directly affects its sound emitting properties.

Normally, the operating depth of a submarine will increase as speed increases in order to decrease the effects of cavitation. Optimum operational depths relative to submarine speed and environmental factors are usually computed through the employment of appropriate tables and graphs.

Maximum submerged speed is a performance value which is dependent upon the submarine hull design and power plant. As in surface platforms, the degree of hull fouling does not significantly affect actual speed.

Nominal values have been compiled for speed and operating depth. These values are representative of widely published capabilities and are sufficient to support the tactical decision making process.

3.2.3 Aircraft

The variable data elements (cf. Table 3-4) for aircraft are fuel capacity, cruise speed, maximum speed, maximum altitude, combat altitude, combat radius and cruise radius. Fuel consumption and mission time are also variable elements for which information on selected aircraft has been furnished. In the following paragraphs, each of these elements is discussed.

FILE NAME SUBMARINES

TABLE 3-3

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
NAME	X									IDENTIFICATION INFORMATON UNIQUE TO EACH PLATFORM.
TYPE/HULL NBR	X									
CLASS	X									
FLAG	X									
CALL SIGN	X									
PROPULSION	X									
FUEL TYPE FUEL CAPACITY	X X									FUEL TYPE AND CAPACITY UNIQUE TO EACH PLATFORM. FUEL TYPE CONSIDERED EITHER NUCLEAR OR NON-NUCLEAR. FUEL CAPACITY NOT APPLICABLE TO NUCLEAR BOATS AND RANGE CONSIDERED UNLIMITED.
MAXIMUM SUBMERGED SPEED		X	• POWER • HULL FORM • HULL FOULING		X				X	
NORMAL OPERATING DEPTH		X	• MISSION (SEARCH/ EVADE • SOUND VELOCITY PROFILE OF OCEAN		X				X	HIGHLY DEPENDENT UPON MISSION AND OCEAN CHARACTERISTICS.

TABLE 3-3 (cont'd)

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
MAX. OPERATING DEPTH	X									HULL DESIGN CONSTRAINT.

FILE NAME AIRCRAFT

TABLE 3-4

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
DESIGNATOR	X									DESIGNATOR THROUGH PROPULSION TYPE ARE STATIC, IDENTIFICATION ELEMENTS UNIQUE TO EACH AIRCRAFT.
FLAG	X									
PRIMARY ROLE	X									
PROPULSION TYPE	X									
MAXIMUM SPEED		X	• ALTITUDE • LOADING • THRUST COMPONENT		X	X		X	X	VALUES HIGHLY A/C DESIGN DEPENDENT. MATHEMATICAL MODELS AVAILABLE. NOMINAL VALUES USED DUE TO ODA SECURITY CONSTRAINTS.
CRUISE SPEED		X	SAME AS ABOVE		X	X			X	THRUST SETTING FOR OPTIMAL RANGE AND FUEL CONSUMPTION AT OPTIMAL ALTITUDE.
MAXIMUM ALTITUDE		X	• LOADING • THRUST COMPONENT		X	X			X	NOMINAL VALUES REQUIRED FOR ODA CONSTRAINTS.
COMBAT ALTITUDE		X	• MISSION PROFILE • LOADING		X	X			X	NOMINAL VALUE BASED UPON PRIMARY MISSION PROFILE. ALT. VALUES USUALLY VARY WITHIN A ± RANGE.
FUEL TYPE	X									
FUEL CAPACITY		X	EXTERNAL FUEL CAPABLE		X			X		AIRCRAFT DEPENDENT. NORMALLY 1-3 EXTERNAL TANKS FROM 250-600 GAL/TANK.

TABLE 3-4 (cont'd)

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
REFUEL CAPABILITY	X									AIRCRAFT DESIGN DEPENDENT.
COMBAT RADIUS		X	• MISSION PROFILE • TIME ON STATION		X			X		MISSION DEPENDENT
CRUISE RADIUS		X	• MISSION PROFILE			x			x	AIRCRAFT DESIGN DEPENDENT.

An aircraft's internal fuel capacity is considered a fixed value; however, the total fuel that an aircraft carries is mission/load dependent. Aircraft can generally carry from 1-3 external fuel tanks with a capacity varying between 250 and 600 gallons. The external fuel configuration directly impacts mission time but exerts a minimal effect on the performance parameters since external tanks are expendable in a combat situation. Table values for fuel capacity and mission time as a function of mission profile have been provided.

The speed of an aircraft is a complicated relationship involving thrust setting, load and altitude. Figure 3-3 shows speed vs. altitude for settings of thrust and loading. This figure is an operational graph for a particular aircraft. The Loading Condition Column number refers to standard mission loadings for the aircraft.

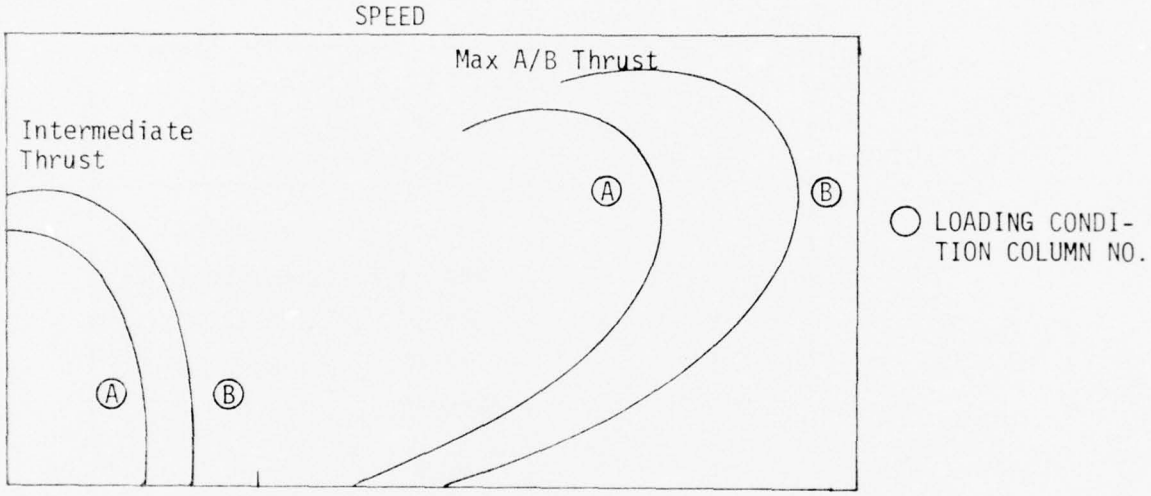


Figure 3-3

This figure shows only qualitative information because the scale and other identifying features are classified. By inspecting similar figures and tables of mission profiles, it was concluded that the use of a nominal value for combat altitude and cruise speed (intermediate thrust) is suitable. Even though combat ceiling is load dependent, its variation with load is usually no more than 10,000 ft. Cruise speed usually varies within a small range (± .05 MACH) and is considered as an optimal thrust setting to optimize range and fuel consumption. For subsonic aircraft, a nominal value for maximum speed is also suitable.

A problem does arise for the maximum speed of supersonic aircraft because of the load dependence and security classification. Thus it was determined that maximum speed can be expressed on a nominal value at altitudes of 40 kft and higher and that the maximum speed varies linearly between 1.1 and the nominal value for aircraft altitudes of sea level to 40 kft. Table 3-5 provides a table of formulas for maximum speed as a function of altitude for each supersonic aircraft. The assumption concerning load introduces an error no greater than the selection of "nominal values".

Supersonic Aircraft	Maximum Speed (Mach)*
F-18/A18	min {2.5, 1.1+0.035A}
F-5	min {1.5, 1.1+0.010A}
F-4	min {2.0, 1.1+0.0225A}
F-14	min {2.0, 1.1+0.0225A}
mig-25	min {2.8, 1.1+0.0425A}

*A = altitude (kft)

TABLE 3-5

The combat radius depends on mission profile, load and time on station. Figure 3-4 is a typical operational graph illustrating the dependence on these parameters. The mission profile accounts for speed and altitude.

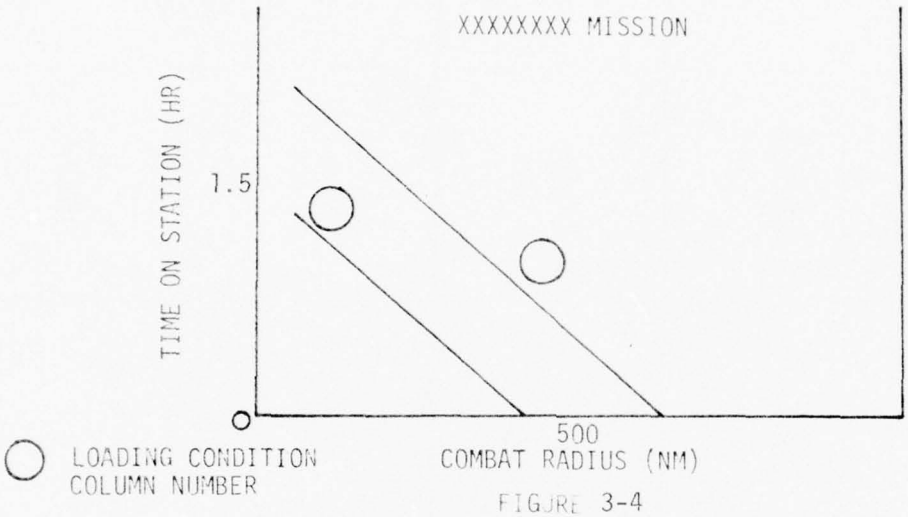


FIGURE 3-4

Tables of performance values for combat radius, mission time, fuel capacity and fuel consumption as a function of mission have been provided for F-14, F-5, KA-6, A-6, A-4, E-2, EA-6, S-3 and F-18 aircraft. Nominal values are used for all other aircraft. For example, the F-14 values are given in Table 3-6.

3.3 Sensors

3.3.1 Radar

Among the data elements for radar (cf. Table 3-7), only detection range is a variable data element. Maximum detection range is computed by considering detection range vs. a $1M^2$ target, target size, line of sight distance, PRF, beam width and weather. Because of the number of parameters affecting maximum detection range and the sensitivity of the range to these factors, a computer program was implemented to compute it.

Detection range vs. $1m^2$ target represents free space detection range in clear weather and is maintained as a nominal value in the ODA data base. The parameters that impact it include peak transmitter power, pulse duration, minimum received power required to detect a signal, effective area of the antenna, antenna gain, operating temperature and transmitted

TABLE 3-6

MISSION	SIMULATED LOAD	COMBAT RADIUS (NM)	MISSION TIME (hrs)	FUEL CAPACITY (lb)	FUEL CONSUMED (lb/hr)
Hi-Hi-Hi	clean	750	3.6	15000	4000
Fighter Escort	(4) sparrows	450	2.1	15000	6500
Fleet air defense	(6) Phoenix (2) 250 gal tanks	150	2.1	18500	8000
deck launched intercept	(4) sparrows (2) 250 gal tanks	150	0.7	18500	25000

A = altitude in kilofeet

FILE NAME RADAR

TABLE 3-7

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
DESIGNATOR	X									
HORIZONTAL BEAMS WIDTH	X									
FREQUENCY BAND	X									
TRANSMISSION FREQUENCY	X									
PRF	X									
DETECTION RANGE VS. $1m^2$ TARGET		X	POWER, GAIN, EFFICIENCY, TEMPERATURE, EFFECTIVE AREA, ETC.	X		X			X	VARIATION IS SMALL; MSXIMUM VALUE IS MEASURED/COMPUTED BY RADAR ENGINEERS AND TABULATED.
MAXIMUM DETECTION RANGE		X	TARGET SIZE, LINE OF SIGHT, PRF, BEAM SHAPE LOSS, WEATHER	X	X		X			

frequency. Even when the standard radar equation ([15], [16]) is used, a large number of parameters are involved. Since modern radars use filters to improve performance, this calculation can be quite complicated.

Factors, in addition to those mentioned above, that impact maximum detection range include Electronic Counter Measures (ECM), sea clutter, cloud coverage, operator efficiency and ducting. ECM is not considered as a factor in any of the ODA decision aids, nor is it discussed in the scenarios. Sea clutter and cloud coverage are second order effects that need only be considered when high precision calculations are required. There are currently no models that deal with radar performance as a function of operator efficiency. This problem is, however, being considered in depth by another ODA participant (cf. [17]). Ducting is an anomalous phenomenon. There are currently no operational programs for predicting the existence of or propagation within a duct. However, a program to do this is being developed at NELC [18] and should be available in FY-78.

The maximum detection range is computed by adjusting the detection range vs. a $1m^2$ target for the target size and then computing the effects of atmospheric attenuation, effects of earth's curvature and refraction, power loss due to the shape of the beam and the limitations imposed by pulse repetition frequency (PRF). If R_0 is the detection range vs. a $1m^2$ target and σ is the target size in square meters, then the adjustment of R_0 for σ is given by

$$R = R_0 \sqrt[4]{\sigma}$$

The detection range, adjusted for target size, is next adjusted to account for the attenuation due to inclement weather. Some of this attenuation is due to gaseous absorption and the remainder is due to backscatter. It is the attenuation because of inclement weather that causes the greatest inaccuracies in the detection range. This attenuation depends upon rainfall rate, optical visibility, temperature, humidity, and the distance through the inclement weather that the radio wave must travel. These parameters are especially difficult to measure. Therefore, nominal values are used depending on weather type: i.e., fog, light rain, or heavy rain. These values are given in Table 3-8 Formulas for calculating the attenuation due to weather were developed by Van Vleck in 1947. These formulas are given together with a basic discussion of the factors influencing radar detection range by Blake in [19]. The Radar Detection Range program (Appendix C) uses these formulas.

The effect of snowfall has been excluded from this analysis. Equations describing this effect are given in [16]. It is not expected that this effect would be large, even for the heaviest snows.

TABLE 3-8. NOMINAL VALUES USED TO COMPUTE ATTENUATION DUE TO INCLEMENT WEATHER

Weather	Fog	Light Rain	Heavy Rain
Temperature (^{o}C)	25	22	22
Relative Humidity	99	100	100
Precipitation Rate (mm/hr)	0	4	16
Visibility (ft)	100	1000	500

Having accounted for atmospheric attenuation, it is next necessary to account for the earth's curvature and refraction. Refraction of radio waves has the effect of extending the radar line of sight beyond the visual line of sight. The formulas for radar line of sight is:

$$R_{LOS} = \sqrt{2kR_E H_R} + \sqrt{2KR_E H_T}$$

where R_E is the radius of the earth, H_R is the height of the radar and H_T is the height of the target; k is the index of refractivity (if $k = 1$, R_{LOS} is the optical line of sight). The value of k depends on meteorological conditions. This value varies between 1.2 and 1.9; however, the nominal value of 4/3 is valid when H_R and H_T are small compared to R_E and precise height finders are not required [2]. When more accurate measurements are required, a model developed by Bean and Taylor [20] can be used. The value of R_{LOS} is an upper bound on the radar detection range.

If the angle required for maximum range is such that the target would lie outside the elevation half-beam width, then it is necessary to account for power loss due to the shape of the beam.

A nominal value for this loss is $4\sqrt{2}$, i.e., the range must be reduced by the factor of $1/4\sqrt{2}$ because the range is proportioned to the fourth root of the peak power. For more precise calculations, other approximate formulas are given in [16].

The final limitation imposed on the radar range is related to the PRF. Before a second pulse can be transmitted by the radar, time must elapse to allow for return of echos from the first pulse; otherwise, the return signal is ambiguous. Thus, for a given PRF, the maximum unambiguous detection range is:

$$R_{MAX} = c / 2\ PRF$$

where c is the speed of light (approximately 3×10^8 m/sec), and the PRF is given in cycles per sec. This limit has little effect unless the PRF exceeds 500.

The computer program to compute maximum detection range has been input to the ODA test facility. This program is discussed in Appendix C.

3.3.2 ESM

Among the data elements for ESM (Table 3-9), the sensitivity, DF accuracy and detection range are classified as variable data elements. Because of problems with the classification of this data and because of the nature of the requirements of the ODA program, the ESM file contains records for typical but non-existent equipment. In some equipment, DF accuracy and sensitivity vary with frequency but are always constant

FILE NAME ESM

TABLE 3-9

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
DESIGNATOR	X									
DESCRIPTION	X									
FREQUENCY BANDS	X									
SENSITIVITY		X	FREQUENCY		X	X			X	
DF ACCURACY		X	FREQUENCY						X	
DETECTION RANGE		X	• LINE OF SIGHT • WEATHER • SENSIVITY • EFFECTIVE RADIATED POWER • TRANSMITTED FREQUENCY	X	X		X			

within each frequency band. In the ODA ESM file, each equipment has a single sensitivity and DF accuracy that are the same for all frequencies. The detection range of an ESM depends on ESM sensitivity (SENS) target output power (ERP), line of sight distance and weather. Because of the number of parameters affecting detection range and its sensitivity to these parameters, a computer program was written to compute it.

The detection range of an ESM against a target is computed by first checking if there is a frequency match, that is, the ESM can detect the frequency that the target emits. If there is a frequency match, then the free space detection range R is computed as follows [21]:

$$R = 0.869 \times 10^{[ERP-SENS-36.6-20LOG\ F]/20}$$

where F is the frequency in MHz.

Under most circumstances, this range far exceeds line of sight (LOS). In these cases, the detection range is taken as LOS. However, when LOS is greater than the free space detection range, then it is necessary to account for atmospheric attenuation due to weather. A discussion of the attenuation of radio waves due to weather is given in Section 3.3.1.

3.3.3 Sonar

Among the data elements for Sonar (Table 3-10), only detection range is indicated as a variable data element. Detection range depends on ocean characteristics, target characteristics and sensor characteristics. The relevant ocean characteristics are propagation loss and ambient noise. Propagation loss in turn depends on the velocity profile of the area (a function of temperature, salinity and pressure), acoustic frequency, and bottom bounce. The target characteristics are target source level and target depth. The sensor characteristics are mode, sensor depth and directivity index.

In passive sonar detection, the sensor listens for the acoustic signal generated by the target as it moves through the water. The intensity of this signal is the target source level and is measured in decibels (db). This information is known for various target types. As this signal travels through the water, it loses intensity due to absorption and scattering. This loss of intensity is called propagation loss and is measured in db. In order for detection to occur, the intensity of the signal when it reaches the sensor must be above the ambient noise level by an amount required by the sensor for detection. This amount is the recognition differential and depends on the directivity index of the sonar which is a design feature. If the source level minus the propagation loss minus ambient noise equals the recognition differential, then there is an 0.5 probability of detection. If this quantity is higher or lower than the recognition differential, then the probability of detection is higher or lower.

FILE NAME SONAR

TABLE 3-10

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
CONTROL NUMBER	X									
DESIGNATOR	X									
DESCRIPTION	X									
MODES	X									
FREQUENCY BANDS	X									
RANGE SCALES	X									
DETECTION RANGE		X	TEMP vs DEPTH PROPAGATION LOSS SOUND VELOCITY vs DEPTH SALINITY BOTTOM BOUNCE AMBIENT NOISE MODE FREQUENCY SENSOR DEPTH TARGET DEPTH RECOGNITION DIFFERENTIAL DIRECTIVITY INDEX TARGET SOURCE LEVEL	X	X	X	X			

Sources of ambient noise include surface environment (sea state), marine life and shipping. Values of ambient noise are in ODA Observed Ocean Characteristics files. These represent nominal values which would be based on historical data.

Propagation loss does not increase monotonically with range. The reason for this is that the movement of acoustic waves through the ocean is governed by Snell's law [22]. Snell's law implies that acoustic waves bend toward the depth where sound velocity is minimum. Sound velocity increases with temperature, salinity of the water and depth (pressure). The ODA data base gives a salinity of 35 parts per thousand for the ocean area around ONRODA and the propagation loss profiles in the data base are consistent with this figure.

Figure 3-5 is a graph of the sound velocity profile in the ODA data base representing the ONRODA Island ocean area. It shows sound velocity in meters per second as a function of depth in meters. The curve can be subdivided into four parts each with a different shape. These parts correspond to layers of the water temperature profile:

1. Surface Layer: This is the area from 0 to 200 meters depth. In this layer, the velocity profile is susceptible to daily and local changes of heating, cooling and wind action. The surface layer may contain a mixed layer of isothermal water formed by the action of wind. Sound tends to be trapped in the mixed layer.

2. Seasonal Themocline: This is the area from 200 to 600 meters depth. In this layer the temperature changes are seasonal. It is characterized by a negative velocity gradient (velocity decreasing with depth).

3. Main Thermocline: This area from 600 to 1400 meters depth is affected only slightly by seasonal changes. This layer is characterized by a negative velocity gradient with decreasing temperature outweighing increasing depth.

4. Deep Isothermal layer: Extends to the bottom and has a constant temperature of approximately 39°F. With temperature constant, velocity increases with depth.

The depths of these layers vary with season, weather and ocean area.

The velocity minimum occurs between the main thermocline and the deep isothermal layer. Sound traveling at great depths tends to be bent or focused toward this minimum. Figure 3-6 illustrates the path of acoustic waves through the ocean, based on the velocity profile in Figure 3-5 The sound source (upper left) is at 550 feet and the only wave paths shown are those emanating in a direction of $\pm$ 10° from the horizontal. The bending effect results in a stronger surface signal being present at 70 KYDS than at 50 KYDS.

A propagation loss curve corresponding to the velocity profile in Figure 3-5 a frequency of 150 Hz, a source at 550 feet, and a sensor

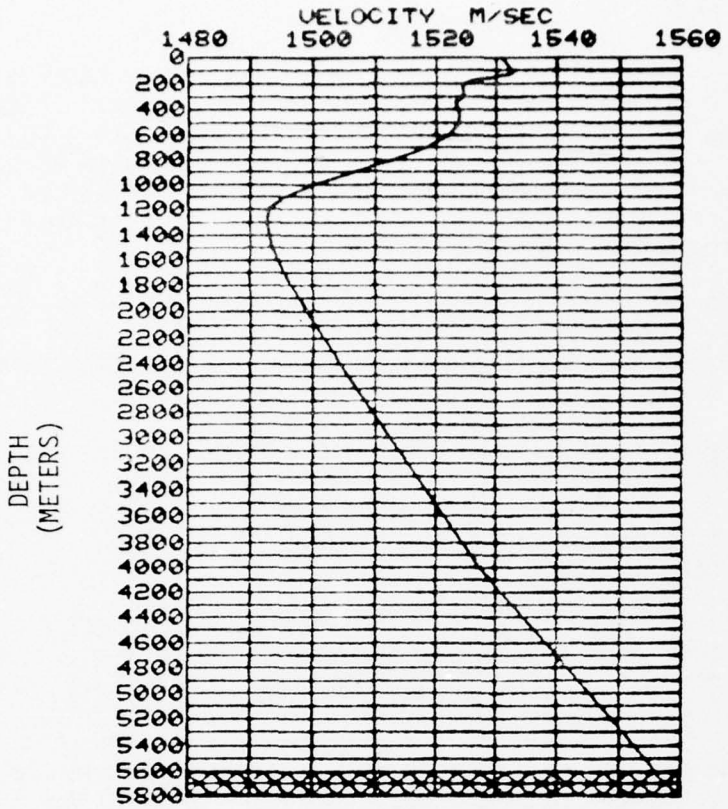


FIGURE 3-5. SOUND VELOCITY PROFILE

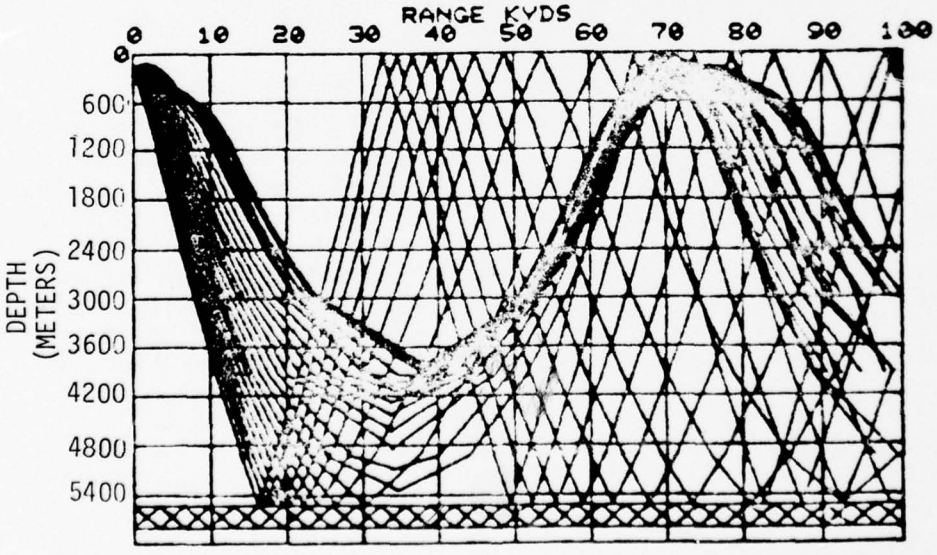


FIGURE 3-6. ACOUSTIC RAY TRACE

at 300 feet is shown in Figure 3-7. Note that the propagation loss between 68 KYDS and 75 KYDS is less than the loss between 10 KYDS and 67 KYDS. The area between 68 KYDS and 75 KYDS is called a convergence zone. When a convergence zone exists, the detection area of a sonar is not described by a single range but by a range plus one or more annuli as in Figure 3-8. In Figure 3-8 the detection area is the 10 KYDS circle and the annulus between 68-75 KYDS.

To obtain detection area, first compute Figure of Merit (FOM):

FOM = Source Level - Ambient Noise - Recognition Differential + Directivity Index

Detection will occur, with probability of 0.5, when propagation loss equals FOM. The ranges shown in Figure 3-8 represent POM = 83 db. If FOM = 90 the detection ranges become 0-60 KYDS and 66-80 KYDS. This can be seen by examining Figure 3-7 and illustrates the sensitivity of detection range to these variables.

The Integrated Carrier Acoustic Prediction System (ICAPS) program, which is on board several carriers, outputs propagation loss profiles for input sensor and target depths, frequency and environmental data. This is an extremely large program which is therefore, not suitable for use by the ODA program. An alternate approach, widely used by the Navy, is to use outputs of the Acoustic Sensor Range Prediction (ASRAP) System. ASRAP is generated by the Fleet Numeric Weather Center (FLTNUMWEACEN) and is broadcast to the fleet on demand. Propagation loss profiles, such as those reported by ASRAP, are in the ODA data base for 3 combinations of sensor and target depth. A computer program was written to use these profiles to output sonar coverage.

3.4 Weapons

3.4.1 Missiles

The characteristics which are considered as variable among the data elements for missiles [cf. Table 3-11] are the maximum and minimum effective altitudes, the nominal effective range, the speed (and hence the time to the target), the lethal radius, and the probability of kill.

There are basic design factors which impact the maximum altitude obtainable for any type of aerodynamic flight vehicle. The two most significant factors are the lift-to-drag ration and the thrust available. In the case of aerodynamic missiles, the maximum effective altitude can be strongly influenced by the specifics of any given guidance system and the limits imposed by its use. Also, in the case of aircraft launched missiles, the altitude at launch can be a strong factor especially in those cases where the thrust is provided by a rocket motor which does not have enough total flight endurance to reach the high flight profile

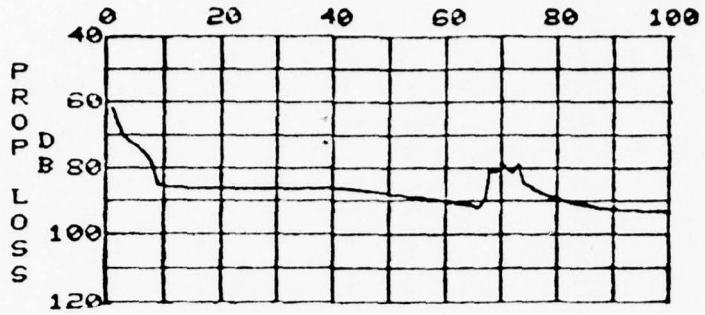


FIGURE 3-7. PROPAGATION LOSS PROFILE

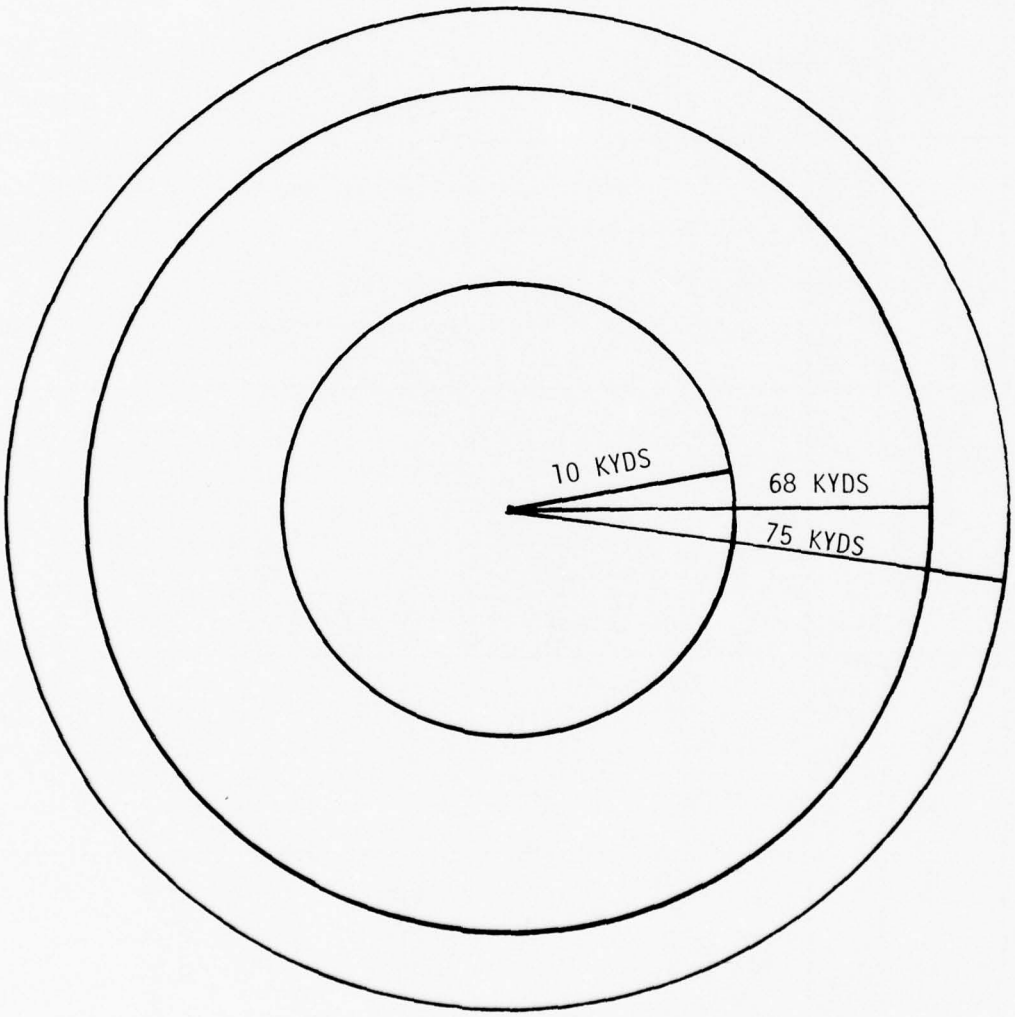


FIGURE 3-8. SONAR COVERAGE

FILE NAME MISSILE

TABLE 3-11

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
CONTROL NUMBER	X									IDENTIFICATION INFORMATION
DESIGNATOR	X									
DESCRIPTION	X									
MAX.EFF.ALTITUDE		X							X	
			LAUNCH ANGLE			X				FUEL SAVING IF THRUST ENDURANCE LIMITED
			LAUNCH ALTITUDE			X				DESIGN ALTERNATIVES BECOME NOMINAL
			THRUST			X				
			LIFT/DRAG			X				CHARACTERISTICS WHEN DEVELOPED
			GUIDANCE			X				
MIN.EFF.ALTITUDE		X	GUIDANCE			X			X	NOM. CAPABILITY OF GUIDANCE TO FUNCTION
			FUZE			X				SUBJECT TO CLUTTER AT LOW ALT.
SPEED		X	THRUST			X			X	
			LIFT/DRAG			X				
			LAUNCH CONDITIONS			X				
NOMINAL EFFECTIVE HORIZONTAL RANGE		X	THRUST ENDURANCE			X			X	
			THRUST MAGNITUDE			X				
			LIFT/DRAG			X				
			LAUNCH CONDITIONS			X				
			GUIDANCE			X				

FILE NAME MISSILE (CON'T.)

TABLE 3-11 (cont'd)

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
TIME TO TARGET		X							X	
			SPEED			X				
			MAX. RANGE			X				
			FLIGHT PROFILE		X					
PROBABILITY OF KILL (LETHAL RADIUS)		X							X	LETHAL RADIUS IS SUBJECT OF PK
			TARGET HARDNESS			X				
			COUNTERMEASURES			X				
			PROPER SYS.OPER.			X				
			MISSILE RELIABIL.			X				
			INTERCEPT EFF.			X				
			PERSONNEL PERFOR.			X				
			WEATHER		X					
			SEA STATE			X				

it would have reached if launched from a surface platform. The altitude that some such vehicles can attain may also be a function of the angle at which it is launched.

The minimum effective altitude is generally not limited by aerodynamic performance, but rather by the performance of accessory devices such as the guidance or the fusing system. In at least one case, the minimum effective altitude of a missile is determined by the fact that the fuse is subject to clutter at low altitudes. Radar target discrimination is generally much more difficult over land than over sea targets but a strong sea return to radar guidance or fusing is an important design consideration for naval missile systems.

It is important to note that, although the parameters discussed above are those which have a major impact upon altitude performance of missiles, those variables are considered as tradeoffs in the design and engineering of a missile system. Once that missile system is engineered, those parameters become characteristics of the missile and as such are no longer unconstrained variables; however, they still may exhibit some fluctuation within the design values. During a missile flight there are limited changes in some characteristics, such as increased lift due to fuel consumption weight loss, but these are also factored into the nominal values of the missile parameters.

Aerodynamically, the effective range of any flight vehicle is also a function of its lift-to-drag ratio and the endurance of its thrust. The thrust is that force which propels the vehicle and at any given constant altitude determines the speed of travel (under equilibrium conditions an increase in thrust alone causes an increase in altitude). An increase in speed, of course, increases the distance which can be traveled in any given time. The magnitude and duration of thrust therefore determines the aerodynamic range capability of a missile. An aircraft launched missile has the fuel saving advantage derived from its initial speed being that of the launch platform. The effective maximum range for a missile system is also determined by the capability of the guidance system to perform at longer ranges. Hence long range missiles require mid-course and terminal guidance systems. Command guidance requires data exchange between the missile and the launch platform for target location relative to the missile, a function which is only accomplishable up to the limits of the effective horizon from the launch platform. This is true unless the missile itself can perform the function of a data relay. The characteristics of the terminal guidance, if present, affect the maximum effective range less than they do the probability of kill to be discussed later. Both the maximum effective range and the speed of a given missile system are characteristics resulting from design criteria, just as were the altitude characteristics, and therefore can be treated in this work by reference to nominal values.

The time-to-target parameter for surface-to-surface missiles is also characterized by the design flight profile (to a given range) and the speed can also be satisfied by the use of a nominal value. The data on any particular missile of this type that has the capability to fly a number of profiles could be handled by the use of a table presenting time-to-target as a function of several flight or mission profiles. In those cases, however, the missile time-of-flight for any given mission used in the particular scenario being exercised could be considered as a nominal value. Tactical air or anti-air missiles (AAM, ASM, SAM), however, fly much more direct trajectories and therefore exhibit a time-of-flight parameter which can be calculated by the simple distance-speed relationship. The engagement distance called for in the scenario and the nominal speed provided in the data base are used in a simple division calculation to provide the time-to-target value for the missile engagement.

As discussed previously the probability of kill for a missile system is a function of, among many others, the accuracy and the precision of the guidance system. The radius of lethality is a subset of the kill probability in that it, along with the delivery of the weapon to the vicinity of the target (intercept effectiveness), contributes to the probability of target destruction. Beyond that, however, the probability of such destruction is also a function of the hardness of the target, its ability to withstand physical damage. In addition to intercept effectiveness and target hardness the probability of kill can also be a function of countermeasures, missile reliability, proper system operation, personnel performance, weather and sea state. The intended class of targets, the expected encounter geometry and other employment requirements are considered in the design and development of a missile system. For that specific scenario, the determination of a nominal kill probability can be useful for the planning tradeoffs required of a tactical action officer in determining the likelihood of missile success. In that context the kill probability effectively becomes a nominal descriptor of the expected performance of a particular missile system against its intended targets. Although the factors discussed above do impact upon the probability, a refinement of this parameter appears not to be justified and, additionally, the data appears not to be able to produce sets of tables or graphs presenting the probability of kill for a missile or family of missiles.

If necessary, individual charts depicting the missile range envelope and time to intercept as a function of platform/target speed and altitude could be developed to fit specific scenarios. However, it has been determined that for the level of sophistication and/or complexity required in the ONRODA scenario, the sensitivity of the missile parameter values to normal system variables is sufficiently low to warrant the use of nominal values for the characterization of missile performance.

3.4.2 Guns

Among the data elements for guns (Table 3-13) maximum effective horizontal and vertical range are variable. These data elements are not independent. The maximum effective horizontal range varies as a

FILE NAME GUNS

TABLE 3-13

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
Designator	X									
Description	X									
Maximum Horizon. Eff. Range		X	Maximum Vertical Eff. Range	X	X	X	X			
Maximum Vertical Eff. Range		X	Maximum Horizon. Eff. Range	X	X	X	X			
Accuracy		X	Tactics			X			X	Spotter aircraft, etc. can improve accuracy
Fire Rate	X									

function of the maximum effective vertical range. It is assumed herein that gun projectiles follow a ballistic or parabolic trajectory.

Formulas for the ranges are given in Table 3-13. These formulas are derived from either sanitized or unclassified operational curves. Figure 3-9 (reproduced from [23] is an example of these available curves.

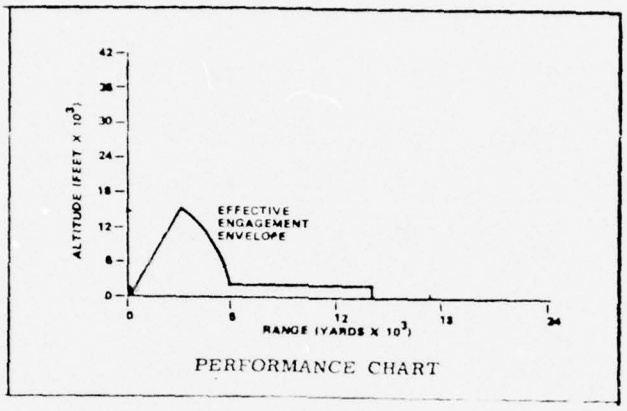


FIGURE 3-9. 5"/38 CALIBER PROJECTILE MK 66 MOD 0

Referring to Table 3-14, these formulas are used in two ways. The operator can specify a target range (the value of z) and calculate a maximum effective vertical range (the value of y). Alternatively, the operator can specify an altitude (the value of y) and calculate the maximum effective horizontal range (the value of z).

These formulas are based on the fact that air targets should be engaged by a projectile while it is still rising whereas, ground targets can utilize the entire ballistic trajectory (thereby doubling the range). A number of parameters that influence range have been ignored because of their second order effect. These parameters include the verticle jump, ship roll, variations in muzzle velocity, rotation of the earth and air temperature.

The accuracy of a gun depends on a large number of parameters including those mentioned above, plus ballistic drift, crosswinds and hygroscopicity. Some ship guns have controls that compensate for ship motions. The primary item affecting gun accuracy, however, is tactics. Battery aim will usually be in error because of errors in target position (relative the own ship), in own ship course and speed, in ballistic data and in gun alignment. Generally there is a means of spotting the results of an initial blast and adjusting the gun or battery aim for the subsequent rounds. Thus, a nominal value for gun accuracy (mean dispersal) is used.

TABLE 3-14. GUN HORIZONTAL VS. VERTICAL RANGE FORMULAS

GUN (U.S)	Maximum effective vertical range vs. maximum effective horizontal range.	
	air targets	surface targets
3"/50	$y=16.0 \times 10^3 - (0.52 \times 10^{-3}) z^2$	z = 12000
5"/38	$y=25.2 \times 10^3 - (.575 \times 10^{-3}) z^2$	z = 14000
5"/38 R.A.	$y=29.1 \times 10^3 - (.323 \times 10^{-3}) z^2$	z = 22000
5"/54	$y=27.7 \times 10^3 - (.292 \times 10^{-3}) z^2$	z = 22000
5"/54 R.A.	$y=43.3 \times 10^3 - (.273 \times 10^{-3}) z^2$	z = 27000
20 mm	$y=5.28 \times 10^3 - (1.40 \times 10^{-3}) z^2$	N/A
30 mm	$y=10.5 \times 10^3 - (1.10 \times 10^{-3}) z^2$	N/A
40 mm	$y=12.1 \times 10^3 - (3.76 \times 10^{-3}) z^2$	N/A
20 mm CIWS	y=3000 ft. z=900 yd.	

note: z = maximum effective horizontal range (yd)

y = maximum effective vertical range (ft)

R.A. = rocket assisted

CIWS = close in weapons system

	RED	US
equivalence:	76 mm/85 mm	3"/50
	130 mm	5"/38
	21 mm/23 mm	20 mm
	30 mm	30 mm
	37 mm	40 mm

3.4.3 Bombs

The only characteristic which might be considered as variable among the data elements for bombs (Table 3-15), is the lethal radius. The destructive effect of any explosive device is a function of the explosive force (amount and type of explosive), the environment or medium in which the explosion occurs, the distance from the target, and the capability of the target to withstand the explosive force (target hardness).

The types of explosives which are available in the Navy inventory for use in general purpose bombs are Minal II, Tritonal 80-20 and H-6. Minal II becomes very sensitive under high temperature and humidity conditions and is consequently restricted from use on carrier based aircraft. The difference in the explosive force produced by the types is small compared to the variability exhibited in the amount of explosive available in the different sizes of bombs (e.g., 500 vs. 1000 pounds). The explosive capability is therefore treated as a nominal characteristic of each specific type of bomb.

The mission and the environment in which a bomb explosion occurs affects the choice of bomb type. Underwater bombs can be set to explode at different depths but the environmental effect upon the lethal radius is normally constant. In the case of air exploded bombs, the lethal radius is affected by the geometrical relationship between the bomb and the target at the time of explosion. A bomb which explodes on impact with the surface has a smaller lethal radius than the same bomb exploded above the surface because of the absorption of the shock by the earth. For practical cases the effects of the environment upon bomb performance are embodied in the variability due to fuse type.

The distance at which a particular bomb can destroy a target is a function of the explosive force delivered at the target and the capability of that target to withstand that force, i.e., the target hardness. The targets can generally be treated by categories such as tanks/armored vehicles, concrete buildings, frame buildings, etc. Hence, the target hardness effects upon the lethal radius of any given bomb can be expressed as a function of target type or mission.

As discussed previously, the lethal radius of a bomb is affected by the elevation above the earth at which it explodes. There are numerous fuses available for use on a variety of bombs. These fuses are basically divided into those which detonate upon impact and those which use proximity detonation. The proximity sensing elements, M20/M20A1, employ active RF radiation and return reflection to detonate the bomb to which they are affixed. The sensing elements can be set for HI or LO corresponding to burst heights of 100-160 feet and 20-60 feet, respectively. The MD. 43 detecting device has a nominal burst height of 16 feet. The selection of a particular fuse is therefore dictated by the mission to be performed.

FILE NAME BOMBS

TABLE 3-15

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
CONTROL NB.	X									
DESIGNATOR	X									
DESCRIPTION	X									
LETHAL RADIUS		X							X	
			EXPLOSIVE TYPE			X				
			AMOUNT OF EXPLOSIVES			X				
			ENVIRONMENT			X				
			TARGET HARDNESS			X				
			FUZE TYPE			X				
			GUIDANCE (PROB. OF KILL)			X				

Prior to a mission, bombs are assembled from the available combinations of bomb and fuse types which provide the most effective device against the targets planned for that mission. Therefore, the lethal radius of a bomb can be considered to be a nominal value assigned as a function of the bomb type (bomb plus fuse) and the mission to be flown.

The levels of damage inflicted on targets and probability of attaining a level of damage as a function of delivery accuracy is discussed in Section 4.4.

3.4.4 Torpedoes

Among the data elements for torpedoes (Table 3-16), maximum range and endurance times are variable. Fuse type may vary according to mission requirements but is considered as a fixed data element in the ODA data base.

Both maximum range and endurance time are functions of depth and speed. The MK 44, MK 46 and 406 mm torpedoes are short range torpedoes. They are assigned nominal maximum range and endurance times since these torpedoes are used in shallow to medium depths and the sensitivity of usage and time in these depths is small.

The MK 48 and 533 mm torpedoes operate at greater ranges and depths. For these torpedoes, tables have been constructed to show range as a function of speed and depth. Two speed settings (designated HIGH and LOW) are used and range values are given for six depths. Table 3-17 illustrates this table for the MK 48 torpedo.

SPEED (KN) / DEPTH (FT)	LOW	HIGH
100	30	25
500	30	25
1000	28	23
1500	25	21
2000	20	18
2500	15	15

TABLE 3-17

MK 48 ENDURANCE RANGE (KYD)

FILE NAME TORPEDO

TABLE 3-16

DATA ELEMENTS			PARAMETERS	TYPES OF AVAILABLE MODELS			IMPLEMENTATION			REMARKS
NAME	FIXED	VAR		ALG	TBLS/ GRHS	NOM VAL	ALG	TABLE	NOM VAL	
DESIGNATOR	X									
FUZE TYPE	X									MAY VARY ACCORDING TO MISSION APPLICATION BUT CONSIDERED FIXED FOR ODA APPLICATIONS
MAXIMUM RANGE		X								
			• OPERATING DEPTH		X	X		X	X	TABLE PROVIDED FOR MK 48 AND 533 MM NOMINAL VALUE FOR MK 44, MK 46 AND 406 MM TORPEDO
CRUSH DEPTH	X									CONSIDERED AS A FIXED DESIGN CHARACTERISTIC OF TORPEDO. ARBITRARY VALUES ASSIGNED
ENDURANCE TIME		X								
			• OPERATING DEPTH		X				X	
			• SPEED							

4.0 FORCE EFFECTIVENESS INFORMATION

4.1 General

Force Effectiveness information refers to assessments and comparisons of own force and enemy force capabilities. This information is required by ODA participants who are developing outcome calculator decision aids. Outcome calculators are computer simulations of Navy task force operations which aid a decision maker by providing predictions of the costs and benefits of tactical options. Force Effectiveness information provides combat effectiveness comparisons of single opposing units and assessments of the damage inflicted by single units against single targets. This information is required as input to the Outcome Calculators.

There are four types of Force Effectiveness information that CTEC has analyzed in order to provide inputs for ODA Outcome Calculator decision aids:

1. Fighter Escorts versus Interceptors

   This includes Blue fighters escorting an air strike against ONRODA airport and CAP and DLI defending the task force against attack.

2. Attack Aircraft versus SAM Defense

   This includes Blue defense supression aircraft against land based SAM sites and SAM missiles on task force escort ships defending the task force against attack.

3. Damage inflicted by Blue attack aircraft on hangars, runways and parked aircraft.

4. Damage inflicted by missiles and bombs on a ship.

Each of these four areas is discussed in Section 4.2 to 4.5. The factors that impact on force effectiveness and the methods of quantifying these factors are indicated. The types of information that are available are illustrated with tables or graphs in each section. Appendix E presents mathematical formulas that were used in this analysis.

Information is available in each of these four areas. Since the Outcome Calculator decision aids are continuing to be developed, the development and analysis of Force Effectiveness information is continuing.

4.2 Figure Escorts Versus Interceptors

An air strike force will generally include both attack aircraft and fighter escorts. Attack aircraft are responsible for the destruction of targets on the ground and the escorts are responsible with protecting the attack aircraft from enemy fighters. The strike force may also include aircraft that do not directly engage in combat (e.g., a US Navy strike force usually includes an E-2C for coordination, and one or more EA-6B's for ECM support).

This section discusses the methodology for computing the effectiveness of interceptors engaging the strike force and the effectiveness of the escorts in engaging the interceptors. This methodology is based on material in references [24] to [26]. The mathematical analysis involved in these computations is discussed in Appendix E. The methodology is relevant to a Blue carrier based strike against a land target and an enemy air strike against the carrier task force. The problem is to determine how many attack aircraft, interceptors and escorts survive the engagement.

The factors that impact the outcome of an escort/interceptor engagement include: (1) technical parameters such as missile range, (2) decision parameters such as engagement tactics and weapon loads, and (3) parameters requiring assessment by the decision maker such as relative skill of the pilots.

In order to be useful inputs to a decision aid, the methodology allows the decision maker to vary both the decision parameters and his assessments.

The technical parameters that must be considered include:

- Missile range - The maximum distance between the firing platform and target at which the missile can be employed
- P_K - Probability of Kill - The probability that a single missile will shoot down its target given that the target is within the missile range. This value represents an average over-all figure which considers attack configuration, ECM environment, altitude constraints, fuse types and pilot skills
- Capabilities of the fire control system
- Aircraft speed
- Reliability parameters of the missile/fire control systems

The decision variables include:

- Number of own force aircraft to be committed. In the case of a Blue strike force, both number of escorts and number of attack aircraft must be considered. In the case of task force defense, the distinction must be made between airborne Combat Air Patrol (CAP) and Deck Launched Interceptors (DLI) which are launched only after an attack is sighted.

- Weapons loading of aircraft.

Parameters requiring assessments of the decision maker include:

- The forces that the enemy will employ.

- The relative skill of the combatants. In the context of escort/interceptor engagements, this parameter must be considered in the analysis of close-in fighting when both sides are within range of other's missiles. This variable is quantified by specifying for each volley of missiles, who fires first and/or the relative numbers of missiles that each side fires.

In the ONRODA Warfare Scenario [1], the Blue forces use the F-14 for strike escort, CAP and DLI missions. The F-14 can carry Phoenix, Sparrow, and Sidewinder missiles and has the AWG-9 fire control system. The Phoenix missile has a range of 80NM and, using the AWG-9 fire control system, the F-14 can simultaneously fire up to six Phoenix missiles at separate targets. The Sparrow missile has a maximum effective range of 30 NM and can be multiple fired but only against one target at a time. The Sidewinder has a range of 4NM and must be fired one at a time. The enemy fighters consist of MIG-19 and MIG-21 fighters based at ONRODA Island. These aircraft are equipped with Alkali and Atoll missiles, respecitvely, with each aircraft having two missiles. Both missiles have ranges of 4 NM and must be fired one at a time.

Figures 4-1 and 4-2 illustrate in graphical form the type of results that can be obtained with an Escort/Interceptor outcome computation. These graphs illustrate the case of a Blue air strike against ONRODA Island and consider the damage inflicted on the strike force by the interceptors. The two graphs cover the cases of 36 and 48 enemy interceptors deployed against friendly attack and escort aircraft. The graphs show the number of surviving enemy interceptors and friendly escorts and attack aircraft as a function of the number of escorts sent on the strike. These graphs are examples of the type of information that is available and involve the following assumptions, all of which can be varied by the user of the information:

- The interceptors are assumed to be MIG-21's. The calculations were based on the assumption that all interceptors were airborne at the start of the actual engagement.

- The interceptors distribute their fire among both the attack aircraft and the interceptors.

- Uniform coordination of fire is assumed for both sides (see Appendix E for a discussion of this assumption).

- Escort aircraft are F-14's with a loading of 4 Phoenix and 4 Sidewinder missiles.

- Missile reliability is 90%.

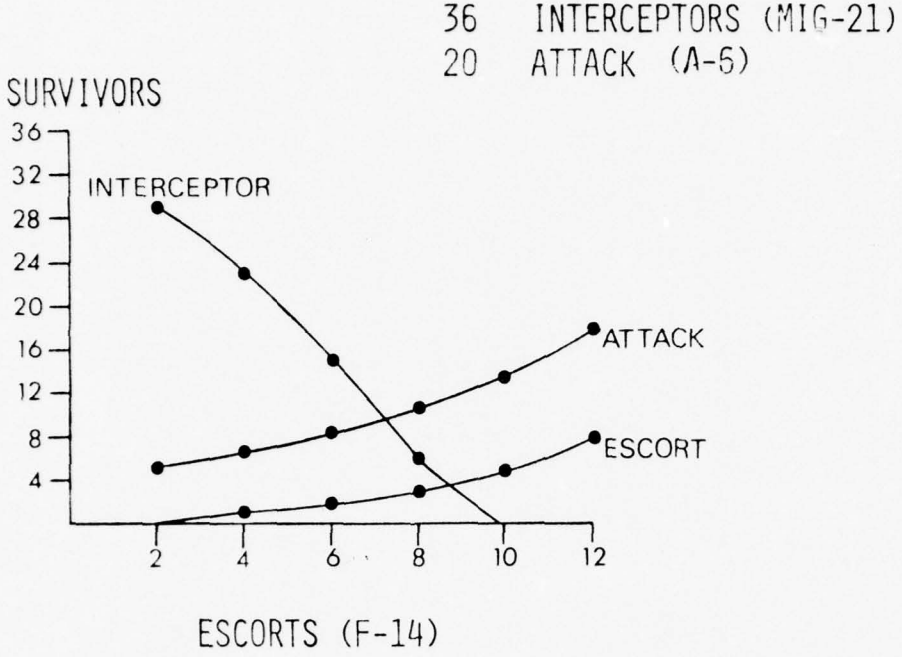
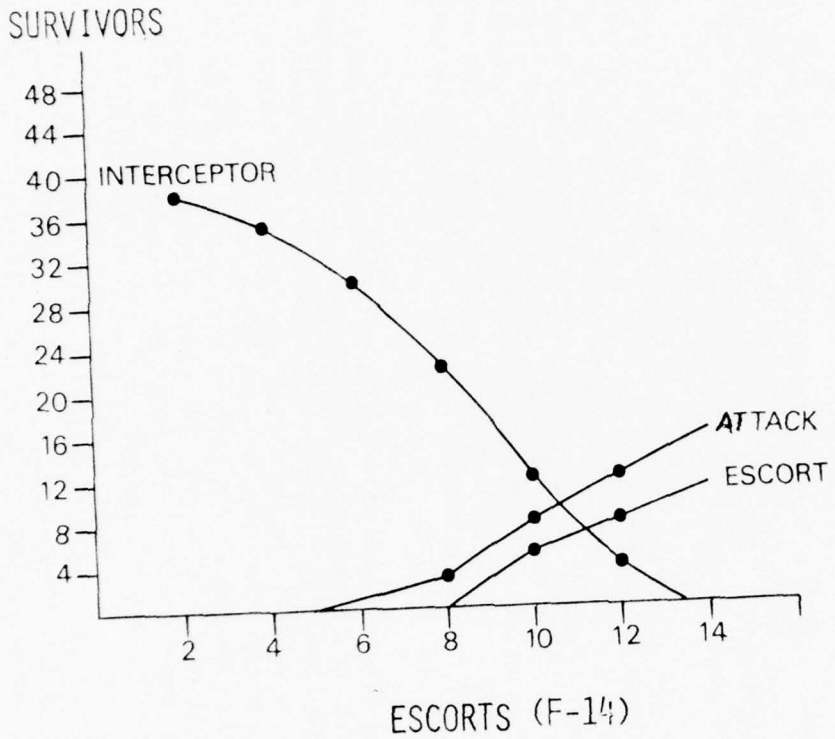


FIGURE 4-1. ESCORT/INTERCEPTOR OUTCOME

48 INTERCEPTORS (MIG-21)
20 ATTACK (A-6)



Since the Phoenix missile has a longer range than the other missiles, the first calculation is the number of interceptors killed by the Phoenix missiles. The outcome of a close-in engagement is based on each side successively releasing a volley of one missile from half the surviving aircraft until all missiles are expended.

Given all of these assumptions, it is a straightforward application of probability theory to compute the expected number of survivors of each type of combatant. The mathematical formulas used are presented in Appendix E.

4.3 Attack Aircraft vs. SAM Defense

This section discusses the effectiveness of attack aircraft in neutralizing Surface to Air Missile (SAM) defense systems. This discussion applies to both the cases of neutralizing a land-based SAM site and countering the air defenses of a ship.

An air attack is first detected by the defenders with a target acquisition or air search radar. As the aircraft approach the range of the SAM missiles, they are picked up and closely followed by a fire control radar which focuses a narrow beam on an aircraft and provides a fire control solution to the missile itself. In some SAM systems, the fire control radar also illuminates the target for the terminal guidance of the missile. If the acquisition radar or the fire control radars are neutralized by the attacking forces, then the defense systems are incapacitated.

The attack force will try to neutralize the defense radars by Electronic Countermeasures (ECM) or by physically destroying them with Anti-Radiation Missiles (ARM). ECM tactics include dropping chaff, noise jamming or using deceptive tactics. Chaff consists of bundles of small metal bits which present false radar targets. Noise jamming consists of aiming at the radar a strong signal which, ideally, has the effect of "whiting out" the radar-screen. Deceptive tactics include transmitting signals to the radar which cause it to mislocate its targets. These tactics require the ECM system to precisely monitor radar signal features such as frequency, PRF and scan rate. The radar systems attempt to neutralize ECM with Electronic Counter Counter Measures (ECCM). ECCM tactics include randomly changing or encoding the radar signal to make jamming and deception difficult. The defense forces will also use jamming to try to neutralize the missile guidance signals between the attack aircraft and launched Air to Surface Missiles (ASM). ECM and ECCM tactics are discussed in references [27], [28], and [29].

In addition to using ECM, the attack forces may try to neutralize SAM defenses with ARM's. These missiles home on the radar itself and require no guidance by the aircraft after they acquire their targets. The defense can counter these missiles by turning off their radars when ARM's are released. However, while the radars are turned off, the SAM missiles cannot be used and the aircraft can follow up with other guided

ASM's or bombs to destroy the SAM defense. ARMS can also be used in a Home-on-Jam (HOJ) mode to neutralize the defense jamming capability. On each side, the successful use of these tactics requires very precise timing and coordination on the part of cooperating elements.

As with escort vs. interceptor engagements, the attack aircraft vs. SAM defense engagement assessments require consideration of technical parameters, decision parameters and parameters requiring assessment by the decision maker. These technical and decision parameters are the same in both cases. The factors that impact most heavily, however, are the relative effectiveness of both sides in using ECM tactics and in coordinating fire. Since these factors are intangible, the decision maker can only make a subjective assessment of what losses will occur on both sides.

References [30] and [31] contain information on the effectiveness of Blue attack forces against various targets including SAM sites. These data are based on tests that were conducted at the Naval Weapons Test Center at China Lake. It includes number of passes per kill for various attack aircraft and weapon loadings. It does not, however, account for the tactics discussed above.

Table 4-1 contains the technical information on own and enemy ground to air and air to ground weapon systems. For each weapon type the table indicates the associated platform types, range, guidance and probability of kill. These figures are unclassified nominal values.

4.4 Airfield Damage

The basic factors that impact the amount of destruction levied by an air strike against an airfield is the number and type of attack aircraft that survive the defenses of the facility and the weapon loading of these aircraft. The information discussed in this section concerns the damage inflicted by the weapons that are successfully delivered to the target area.

In assessing the damage done to an airfield by an air strike, three targets were considered:

- Aircraft on the ground
- Hangars
- Runways

In order to provide meaningful quantitative estimates of this damage, it is necessary to have precise definitions of what constitutes a "kill" or destruction of the targets. The following definitions, which were taken from [32], are used:

TABLE 4-1
CHARACTERISTICS OF ASM AND SAM MISSILES

WEAPON TYPES	ASSOCIATED PLATFORMS	RANGE (NM)		GUIDANCE		P_k
		MIN	MAX	INITIAL	TERMINAL	
AGM 12 ASM BULLPUP A&B	A4, A6, A7	-	6	Command	Command	0.5
AGM 45 A ASM SHRIKE	A6, F-4	-	15		Passive radar homing	0.8
AGM 62A ASM WALLEYE	A-4, A-7	-	30		Television	100 ft CEP
AGM 78 C&D ASM WALLEYE	A-4, A-7	-	20		Television with data link	40 ft CEP
AGM 78 C&D ASM STANDARD ARM	A6	-	100		Passive radar homing	10 ft CEP
RIM 2 SAM TERRIER	CGN, CV, DLG, DLGN	4.0	12		Semi-active radar homing	0.4
RIM 8 SAM TALOS	CGN, CG, CLG	5.5	65		Semi-active radar homing	0.8
RIM 24 SAM TARTAR	CG, DDG	1.5	20		Semi-active radar homing	0.4
RIM 66A SAM/SSM STANDARD MR	PF, DLGN,	2.5	15		Semi-active radar homing	0.5
RIM 67 SAM/SSM STANDARD ER	DLGN, SES DF, DG	2.9	30		Semi-active radar homing	0.5
RIM 7H SAM SEA-SPARROW	CVA, CVAN,	1	12		Semi-active CW radar homing	0.6
AS-1 (KENNEL)	BADGER B	35	60		Semi-active homing	0.5
AS-2 (KIPPER)	BADGER C	30	100	Pre-programmed auto-pilot	Active radar	0.9

TABLE 4-1
CHARACTERISTICS OF ASM AND SAM MISSILES (continued)

WEAPON TYPES	ASSOCIATED PLATFORMS	RANGE (NM)		GUIDANCE		P_k
		MIN	MAX	INITIAL	TERMINAL	
AS-3 (Kangaroo)	BEAR B&C	50	350	Pre-programmed auto-pilot	Command	0.6
AS-4 (Kitchen)	BLINDER B BACKFIRE B	70	250	Pre-programmed auto-pilot	Possibly active J-Band radar	0.6
AS-5 (KELT)	BADGER G	15	100	Possibly track command	Active radar	0.9
AS-6 (KINGFISH)	BADGER G	20	150	Possibly pre-programmed auto-pilot or simple inertia with command override.	Possibly active J-Band radar	0.7
SA-N-1 (GOA)	KOTLIN KOTUN KASHIN KRESTA-I KYNDA KANIN	3	10	Command	Command	0.6
SA-N-2 (GUIDELINE)	SVERDLOV	4	30	Command	Command	0.4
SA-N-3 (GOBLET)	MOSKVA	3	20	Command	Command; Possible IR *homing*	0.5
SA-N-4	KRIVAK NANUCHKA KRISHA SVERDLOX KARA	1.5	30	Command	Command	0.7
SA-2 (GUIDELINE)	TRACTOR/ SEMI-TRLR	-	30	Command	Command	0.4

TABLE 4-1
CHARACTERISTICS OF ASM AND SAM MISSILES (continued)

WEAPON TYPES	ASSOCIATED PLATFORMS	RANGE (NM)		GUIDANCE		P_k
		MIN	MAX	INITIAL	TERMINAL	
SA-3 (GOA)	Tractor Truck	-	20	Command	Command	0.4
SA-4 (GANEF)	Tracked Vehicle	-	30	Command	Command	0.4
SA-5 (GAMMON)	Tracked Vehicle	-	100	Command	Radar homing	0.5
SA-6 (GAINFUL)	Tracked Vehicle	-	12	Command	Semi-active radar	0.5
SA-7 (GRAIL)	Shoulder Launched	-	3	-	Passive infra-red	0.6
SA-9 (GASKIN)	Ground Mobile Launcher	150 ft	20,000 ft.	Command	Active radar homing	0.7

1. Aircraft on the ground - There are two definitions of kill for an aircraft on the ground:

   - PTO Kill - sufficient damage to prevent takeoff
   - K Kill - catastrophic destruction, i.e., aircraft useful only for scrap and cannibalization

2. There are two types of hangars considered: Hangars with wooden structure and hangars with steel structure. For both types, the definition of kill is the same:

   Destruction of 50% of the roof's supporting structure or 50% of the floor area including shops.

3. There are two types of runways considered:

   - Permanent runways - concrete runways designed to handle most civilian and military aircraft.
   - Forward runways - usually dirt, designed for smaller military aircraft to provide close support of forces.

   In this case the definitions of kill are different:

   - Permanent - cratered to leave less than a 50 foot strip in width
   - Forward - cratered to leave less than a 25 foot strip in width

The damage inflicted to a target by a weapon fired from an aircraft depends on the accuracy of the weapon and its destructive firepower. The accuracy of a weapon is measured by its CEP which is defined as the distance from the target inside which the weapon has a 50% probability of striking. One simple way to quantify destructive firepower is by pounds of explosive. This, however, is not a suitable measure because weapons are designed for specific purposes and this design must be taken into account. For example, anti-personnel weapons will do very poorly against a steel hangar compared to a weapon designed for that target type. Therefore, information on the destructiveness of weapons must be compiled separately for each weapon system.

In determining weapon accuracy, the two cases of guided weapons and free falling bombs must be distinguished. For guided weapons, there is a CEP value that does not vary greatly with range. For free falling bombs it is necessary to consider:

- Slant range
- Degree of slant approach
- Mil accuracy - This is defined as CEP per 1000 foot slant range and is a function of aircraft type. weapon type, aircraft speed and weather
- Number of bombs dropped on each pass. This is expressed as a STK number.

Table 4-2 is an illustration of the type of information that is available. The table gives the PTO and K kill probabilities as a function of CEP against parked aircraft for the MK-81, 82, 83, 84 bombs. For the MK-81 the figures assume STK=6. This means that on each pass, 6 bombs are dropped. For the other three bombs, STK=1.

4.5 Damage to Ships

In order to determine a probability that a ship will be destroyed, it is necessary to define the level of damage that constitutes destruction. There are three levels of damage considered here:

- The ship's combat systems are disabled
- The ship is dead in the water, i.e., unable to maneuver
- The ship is sunk

For the case of an aircraft carrier, its combat systems are considered to be disabled if there is sufficient damage that it is unable to conduct air operations for a period of 24 hours or longer.

The sources for the information that has been compiled are [33] and [34]. Figure 4-3 illustrates the type of information that is available. The figure shows the probability that an aircraft carrier will sustain either of two levels of damage as a function of the number of hits that it takes of a 1000 pound anti-ship missile or bomb. These results are based on a computer simulation [33] in which the architecture of the carrier was defined in detail and the effect of the weapon coming at various angles was determined. Both azimuth and elevation angles were varied by 3° but all angles involved in an elevation of 5° or greater from the water line. The overall probability is the average overall angles. The carrier architecture included specification of the thickness of metal, and the location of all fuel and ammunition stores.

TABLE 4-2. KILL PROBABILITY VS. CEP AGAINST PARKED AIRCRAFT

PROBABILITY OF PTO KILL

CEP (FT)	MK81 (STK=6)	MK82 (STK=1)	MK83 (STK=1)	MK84 (STK=1)
10	.95	.825	.85	.9
20	.9	.8	.8	.85
30	.85	.75	.75	.8
40	.8	.7	.7	.775
50	.75	.65	.75	.75

PROBABILITY OF K-KILL

CEP	MK81 (STK=6)	MK82 (STK=1)	MK83 (STK=1)	MK84 (STK=1)
10	.8	.825	.85	.85
20	.75	.8	.8	.8
30	.7	.75	.75	.75
40	.6	.65	.7	.7
50	.5	.55	.6	.65

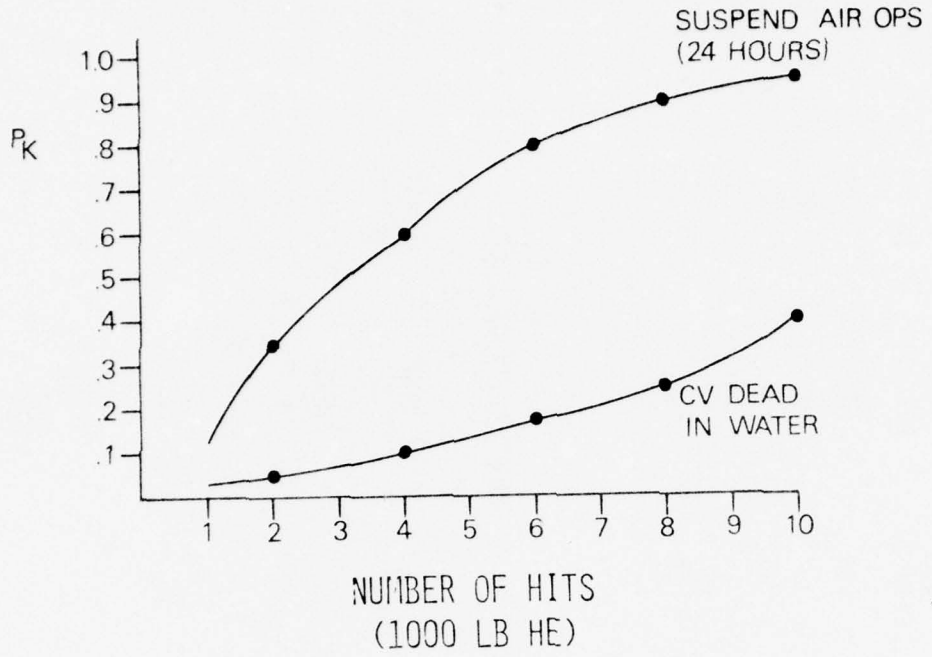


FIGURE 4-3. CARRIER DAMAGE FROM MISSILE HITS

5.0 READINESS PROJECTION

Naval operations, by their nature, involve sending forces into areas that are remote from established supply facilities. As a result, the readiness and inventory situation of own force assets are a significant limiting factor on these operations. This factor must be considered in Naval tactical decision making.

The NSOF files in the ODA data base [3] provide for a complete description of the current status of own forces. Although these files contain expected consumption rates for general categories of supplies, these files do not always provide a sufficient capability to assess the effects of tactical decisions on readiness and inventory. In order to provide for consideration of the feasibility [35] of planned operations, it is necessary to be able to make these assessments. These assessments require an ability to project the future readiness of own forces given the planned tactical decision.

An examination of the scenarios and decision aids developed in the ODA program have indicated two areas where such a projection is a useful input to the decision process. These projections are:

1. Projection of ship fuel consumption.
2. Projection of aircraft sortie capability.

A projection of ship fuel consumption is required by the Options Selection Matrix decision aid when used with the Tattletale Scenario [36] and [37]. The decision in this scenario calls for dispatching a ship (the Tattletale) away from the task force to closely follow a Kresta which is perceived as a potential threat to the task force. The Tattletale must operate on its own for a sufficiently long time so that it is necessary to consider if its fuel capacity and consumption rate will permit the ship to accomplish its mission. In this case the fuel consumption rate given in the ODA ship inventory file will provide the needed input to the Options Selected Matrix decision aid that is used to select the Tattletale.

There are several decision points in the ONRODA scenarios where a projection of aircraft sortie rate is required in order to determine the feasibility of relevant tactical options. For example, the option of placing an air blockade around ONRODA Island is discussed in [38]. This air blockade would involve placing 6 F-14's on station between ONRODA and Gray for 24 hours a day for a period of up to two months. The question of the feasibility of this option is equivalent to asking if the aircraft complement of a two carrier task force can maintain its sortie rate. Another example occurs in the Amphibious Scenario [2]. A two carrier task force is tasked with escorting an amphibious force from Midocean Island to Gray. The TFC must decide on the levels of air patrols that will be maintained in order to protect his forces while in transit. Not only must protection of the task force be provided for but there is also a requirement to provide close air support after the amphibious forces have landed.

The requirement to consider the limitations posed by aircraft sortie capability on task force operation goes beyond direct input to specific decisions. Any simulation of carrier task force operations, including some of the simulations being considered in the ODA program, must account for these limitations.

One way to handle these limitations is to use a nominal sortie rate for aircraft. A sortie rate is the expected number of flights per day over a thirty day period. For example, if an aircraft type has a sortie rate of 1.5 then it can be expected to be able to fly approximately 45 sorties in any thirty day period. The difficulty with using nominal sortie rate is that it does not account for the variations inherent in aircraft operations over a long period of time. For a short time period the air wing might be capable of a sortie rate that is higher than the nominal rate and over a longer time period the sortie rate may drop below the nominal value even if averaged over the whole period. The information that a decision maker needs is how many aircraft he can expect to have available at some specified future time given his operational plans.

Whereas Outcome Calculators predict losses due to combat operations, sortie capability predicts losses due to maintenance. The reasons that maintenance poses a serious problem are that modern Naval combat aircraft are extremely complex machines and that an aircraft carrier is a basically hostile environment for aircraft. Typically these aircraft contain several thousand electronic components, all of which must be operational in order for the aircraft to be at full capability. When aircraft operate from a carrier, they are catapulted at launch and then have to land at full throttle and are then stopped quickly by arresting gear. Even when there are no air operations, the aircraft sit on the carrier flight deck where they are continuously jostled due to ship movement, and they are subject to the corrosive effects of salt air and water.

There are several computerized models available which can be used to predict the status of an air group given an air operations schedule. Models for which documentation is available include the Carrier Aircraft Support Effectiveness Evaluation (CASEE) Simulation Model [39], the Logistics Composite Model (L-COM) [40], and the Aircraft Station Keeping Model [41]. CASEE and L-COM are very detailed models which have processing time requirements that prohibit their being used in an operational environment and therefore also in the ODA testbed. The reason for the size of these models is that they are designed not only to predict the overall status of an air group but also to assess the effect of changes in maintenance and supply procedures. Therefore, these models keep track of every aircraft component down to the "black-box" level. The Aircraft Station Keeping Model is designed to provide inputs to the air strike simulation C-BASE II [42]. The Aircraft Station Keeping model does therefore have a level of aggregation and corresponding processing requirements which are suitable for ODA purposes. This model does not, however, allow for the flexibility of inputs and outputs needed for ODA. It only works for one type of

aircraft at a time and does not allow the schedule to vary over the time period in question. In addition, the computer program that implements this model is not compatible with the ODA test facility. Therefore CTEC has constructed and implemented the Carrier Air Group Maintenance Simulation (CAGMS). The underlying model in CAGMS is similar to the one in the Aircraft Station Keeping Model but CAGMS is designed to meet the more general ODA requirements.

CAGMS accepts, as inputs, the air group composition, a schedule of air operations and the initial status of air group. The output is the status of the air group at user specified time intervals. The status of the air group is defined as the number of each type aircraft that are at Full Operational Capability (FOC), Reduced Material Capability (RMC), or Not Operationally Ready (NOR).

5.1 Description of CAGMS

CAGMS models the activity of a carrier air wing when it is responsible for maintaining a specified level of air operations over a specified period of time. Air operations may be scheduled for some part of each day (normally 12 to 24 hours). An air operations schedule will usually call for launch and recovery events at adjacent time intervals where each event involves launch and recovery of several aircraft. The reason for this is the aircraft launch and recovery require a relative wind speed of 35 Kts across the deck; this usually requires the carrier to turn off the course for the launch and recovery time. Launch events normally precede recovery events. There is usually a fixed time interval between different launch and recovery events. This time interval is called the deck cycle time.

At all times, CAGMS keeps account of how many of each type aircraft are FOC, RMC, or NOR. FOC is defined as all systems on the aircraft are completely operational. RMC means that some systems on the aircraft are not operational or are operating in a degraded mode but that the aircraft can still perform some of its basic missions. NOR means that the aircraft cannot perform any of its basic missions.

Figure 5-1 describes the aircraft missions turnaround cycle. This is the process modeled by CAGMS. The ready pool consists of those aircraft that are fueled, armed, and ready to be launched. Prior to being launched, an aircraft is given a preflight checkout. If the preflight checkout reveals that the aircraft is NOR, then it is moved into maintenance and a replacement aircraft is brought from the ready pool if one is available. If the aircraft is found to be RMC, then it may or may not be launched depending on the requirements of the mission. If the aircraft is not launched, then it is moved into maintenance and a replacement aircraft is brought in from the ready pool if one is available. The aircraft that are launched go out on their missions, return and are recovered after a period of time approximately equal to

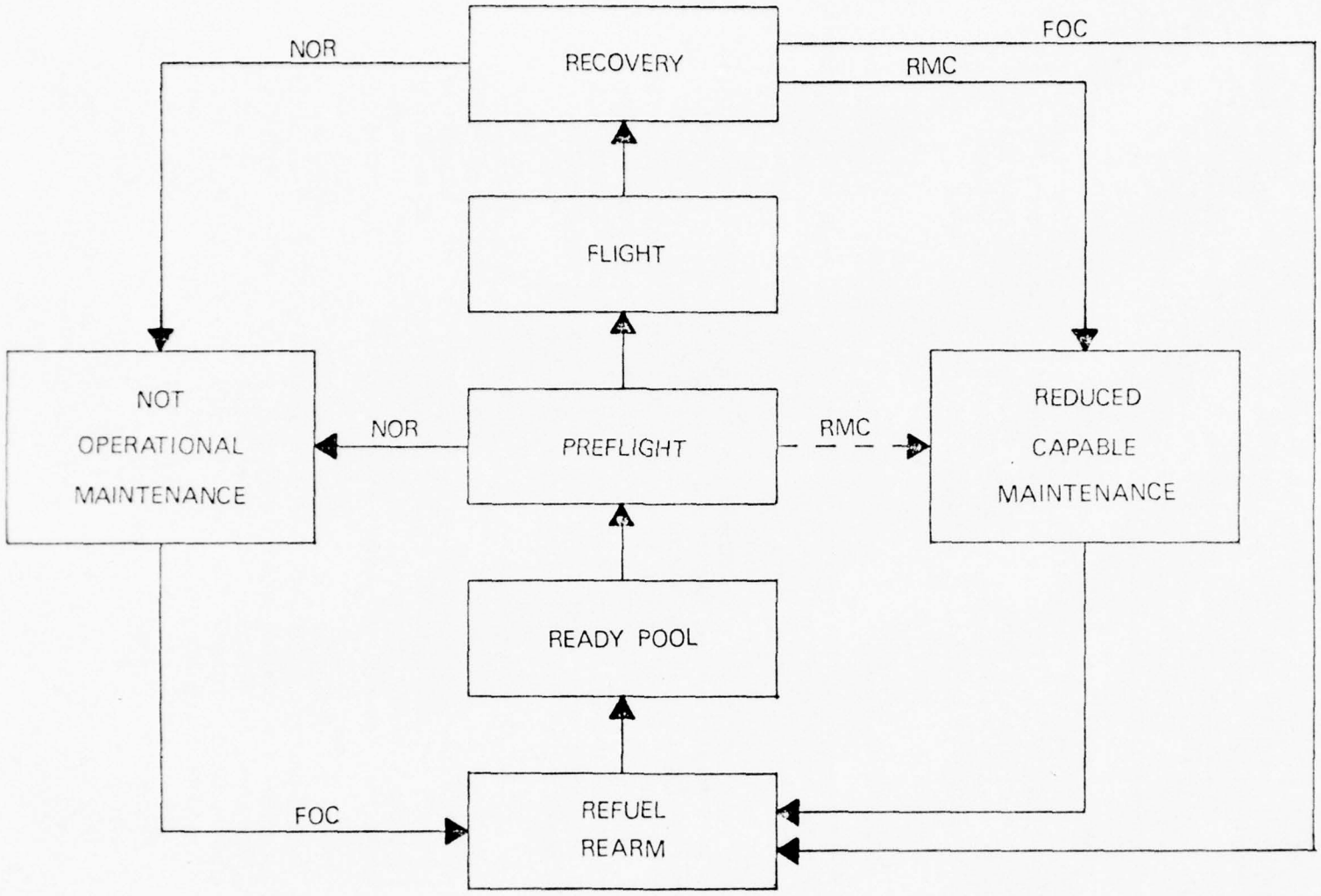


FIGURE 5-1. AIRCRAFT MISSION TURNAROUND CYCLE

the deck cycle time. When the aircraft is recovered, the pilot indicates that the aircraft is "up" or "down". If the aircraft is up, then it is ready to be moved into refuel/rearm turnaround. If the aircraft is down, then it requires maintenance. The period of time required to refuel and rearm an aircraft and to perform preflight checkout is called turnaround time and is accounted for in CAGMS.

CAGMS is a Monte Carlo simulation. The simulation traces the movement of each aircraft in the air group through the aircraft mission turnaround cycle. This process is modeled as a Markov Chain with non-stationary state transition probabilities [43]. There are two points, preflight checkout and recovery where an aircraft can be determined to require maintenance. Sometimes a flight is aborted after takeoff but in order to simplify the model, CAGMS treats this as a preflight failure. In addition, some problems are discovered during maintenance itself. There are three state changes that can occur during preflight or recovery. These are : FOC to RMC, FOC to NOR, RMC to NOR. The probabilities that these state changes will occur during preflight or recovery were calculated based on data contained in Maintenance Support Office Reports ([44], [45]). If an aircraft goes into maintenance then CAGMS assigns a repair time. Repair time curves were found by fitting curves to data in [45].

Sections 5.2, 5.3 and 5.4 discuss the input, processing and output of CAGMS. A detailed user's guide to the simulation including illustrations of inputs and outputs is presented in Appendix D.

5.2 Input

There are three factors that a user must input into CAGMS.

1. Initial status of air group
2. Flight operations schedule
3. Time interval for which he wants to see the output.

The initial status of the air wing refers to the number of each type of aircraft that are FOC, RMC, and NOR. As soon as the program is called, the system prompts the user for aircraft type (e.g., F-14, A-7, etc.) and the number of that type aircraft that are FOC, RMC, and NOR. The numbers that are entered define the readiness of the air wing with regard to that type of aircraft at the start of time period to be simulated. The system will prompt the user for this information for each type aircraft.

CAGMS provides two ways in which to input an air operations schedule:

1. The user can input a specific detailed schedule. This is called a Launch/Recovery input. In this input option, for each launch and recovery event, the user inputs:

- Event time
- An indication if the event is launch or recovery
- The number of each type of aircraft scheduled to be involved in the event
- A flag indicating, for each type aircraft, if a reduced capable aircraft can be sent on the mission.

2. The user can indicate how many of each type of aircraft he schedules to be airborne over various intervals of time. This is called a Daily Operations Input. This option allows the user to examine the long term feasibility of tactical options that are not formulated in as much detail as would be required to use the first input option. In the examples cited above regarding the air blockade and the protection of the amphibious task group in transit, the plan was expressed in terms of keeping certain numbers of various type aircraft airborne continuously over time periods of up to 60 days.

If the user chooses the Daily Operations Input option, then he must specify:

- The Date/Time intervals involved.
- The number of hours per day of flight operations to be conducted from the carrier.
- The number of each type of aircraft scheduled to be maintained airborne over each specified time interval.
- A flag indicating for each type aircraft, if a reduced capable aircraft can be sent on the mission.

CAGMS has a scheduling subroutine (described in Section 5.3.2) which translates the schedule as input by the user into a set of numbers useable by the simulation. Finally, the user must indicate the time intervals for which he wants to see outputs. For example, if he wants to see the air group status at the end of each day he asks for 24 hour outputs.

5.3 Processing

5.3.1 General

CAGMS is a discrete time Monte Carlo simulation. It partitions the period of time being simulated into 10 minute intervals. These intervals are called single event intervals. Each of these intervals is considered in chronological order and for each time interval, the simulation computes how many of each type aircraft are FOC, RMC or NOR. The computations are probabalistic and depend on the situation at the beginning of the time interval, the activity scheduled for that time interval and the reliability and maintainability parameters of the aircraft.

CAGMS consists of three submodules:

1. Scheduling submodule - accepts the schedule as input by the user and converts it into an input file for the simulation.

2. Aircraft Operations Cycle Simulation (AOCS) - this submodule performs all of the computations implied by the activity of the air group.

3. Output Processor - arranges the output for the user.

These submodules are discussed in Sections 5.3.2, 5.3.3 and 5.3.4.

5.3.2 Scheduling Submodule

The scheduling submodule accepts the air operations schedule as input by the user and transforms it into an input file for AOCS. The file contains a logical record for each single event interval. Each logical record contains the number of each type aircraft to be launched, an indication if RMC aircraft are acceptable for that mission and the number of each type aircraft to be recovered. The scheduling submodule also determines the total number of single event intervals in the total time period to be simulated. This number is used to determine when the simulation should stop.

If the user selects the launch/recovery input option, then the scheduling submodule converts the DTG of each event into a single event interval index and creates the logical record for each single event interval from the numbers specified by the user for each launch/recovery event.

If the user selects the daily operations input option, then the scheduling submodule must first create a launch/recovery schedule. This schedule is created using the following assumptions:

- A deck cycle time of 2 hours
- Launch and recovery events each take one single event interval
- The air operations for each day start with a launch event and end with a recovery event. All other launch and recovery events are scheduled at adjacent single event intervals with launch events preceding recovery events.
- The E-2 and S-3 aircraft are triple cycled (flight time equals 6 hours). Other aircraft are single cycled (flight time equals 2 hours).

After a launch/recovery schedule has been created from the daily operations input, then the scheduling submodule proceeds as above.

5.3.3 Aircraft Operations Cycle Simulation (AOCS)

AOCS is the heart of CAGMS. This module simulates the action of launching, recovering and performing maintenance on aircraft. The input to this module is the logical file built by the scheduling submodule. AOCS considers each single event interval in chronological order. It first performs any actions required for the interval and then performs appropriate maintenance and turnaround actions. Finally it collects the aircraft status after all simulated actions have been performed and passes it to the output submodule. The status of the aircraft indicates which of the following states it is in:

- FOC and On Station
- RMC and On Station
- FOC and in Turnaround
- FOC and Ready
- RMC and in Turnaround
- RMC and in Maintenance
- NOR and in Maintenance

At each single event interval the AOCS performs the following steps:

1. The remaining repair times for aircraft in a maintenance state and the remaining turnaround times for aircraft in turnaround are reduced. If one of these times becomes zero, then an appropriate change of status is made.

2. AOCS reads the logical file from the scheduling subroutine to determine if a launch or recovery event is scheduled for the event interval.

3. If a launch event is scheduled, then the number of aircraft scheduled to be launched is removed from the ready pool. If this number is greater than the number of aircraft in the ready pool, then all aircraft are removed from the ready pool. In removing aircraft from the ready pool, FOC aircraft are chosen first. RMC aircraft are only chosen if RMC aircraft are acceptable for the mission and there is an insufficient number of FOC aircraft available. For each aircraft removed from the ready pool, a preflight checkout is performed to determine if it can in fact be launched. If the flight is not aborted then the aircraft is moved into an on-station state. If the flight is aborted then the aircraft is moved into a maintenance state and is assigned a repair time.

4. If a recovery event is scheduled, then the aircraft scheduled to be recovered are removed from the on-station state. AOCS checks if each aircraft is down (NOR or RMC) on recovery. If the aircraft is down, then it is moved into the appropriate maintenance state and is assigned a repair time. If the aircraft is not down, then it is moved into turnaround.

5. The status of all aircraft is passed to the output submodule.

5.3.4 Output Submodule

The output submodule accepts from the AOCS the status of all aircraft at the end of each single event interval and creates files to be used to generate the output of the simulation. There is a separate file for each type aircraft. The file translates the index of each event interval into a DTG for output to the user.

After AOCS is completed, the output submodule creates the outputs for each aircraft type for the time intervals requested by the user.

5.4 Output

The output is displayed separately for each type aircraft and consists of a DTG and the number of aircraft FOC, RMC and NOR. The user can request this information for time intervals ranging from one single event interval to the entire simulated time period.

APPENDIX A

APPENDIX A

FIXED DATA

The purpose of this appendix is to indicate the records and data elements in the ODA data base. Reference [3] contains a description of a comprehensive data base. This description was based upon the ITFCC/IFCC data base and was, therefore, not specifically related to ODA requirements. A careful analysis of the ONRODA scenarios and extensive discussions with other ODA participants have revealed that some of the information described in [3] is not required in the ODA testbed; and, on the other hand, the ODA decision aids pose data requirements that were not anticipated.

Table A-1 contains the list of records and the information categories in the ODA data base. Table A-2 is a list of data elements in each record type. The platforms listed in Table A-1 are the platforms mentioned in the ONRODA scenarios and the sensors and weapons correspond to either sensors and weapons that are carried by these platforms or to sensors and weapons that would be used at the land-based facilities (such as ONRODA airport) in the scenarios.

The information indicated in Table A-1 and A-2 consists of the fixed data that have been input to the ODA test facility at the University of Pennsylvania. This information has been integrated with the WAND data base management system and are available to all users of the test facility.

It is important to reiterate, however, that in addition to the fixed data described in Tables A-1 and A-2, a track file has been input to the ODA testbed (described in Appendix B), NSOF files have been defined and a set of tables and computer programs have been implemented to provide situation/environment dependent data.

The files indicated in Tables A-1 and A-2 should not be regarded as a final ODA information base. For one thing, the ODA decision aids are continuing to be developed and this further development may point to the need for further information requirements. In addition, the experiments to be carried out at the test facility may reveal additional information requirements.

TABLE A-1. ODA DATA BASE LIST OF RECORDS

Record Type	Information
• OPERATIONS AREA	
- Summary	ONRODA, GREY AREAS
- Terrain	ONRODA, GREY AREAS
- Climate	ONRODA, GREY AREAS
- Weather	ONRODA AREA
- Ocean Characteristics	ONRODA AREA
• NAVAL ORDER OF BATTLE	ONRODA AIRPORT, GREY PORT

• PLATFORMS CHARACTERISTICS - SHIPS

BLUE	GREY	RED	ORANGE
KITTY HAWK	LOWRY	SEVASTOPOL	SVOBODNY
CHICAGO	OWENS	DEDRY	SERDITY
COCHRANE	USS PC CLASS	STORYNY	STEPENNY
SPRUANCE	NASTY CLASS	BESSEMY	SWOVY
AGARHOLM	WIDGEON	STATNY	OSA-1 CLASS
HOLT HE	VIERO	VRAZUMITELNY	KOMAR CLASS
BOWEN		PRIMORYE	P6 CLASS
FORRESTAL			T-43 CLASS
OKLAHOMA CITY			VYDRA CLASS
GRIDLEY			
FOSTER PF			
FISKE			
HIGBEE			
TRUETT			
KISKA			
PONCHATOULA			
BLUE RIDGE			
NIAGARA FALLS			
GARCIA			
ROARK			
DOWNES			
CONVERTED DE TYPE CLASS			
IWO JIMA CLASS			
PAUL REVERE CLASS			
CHARLESTON CLASS			
NEWPORT CLASS			
ANCHORAGE CLASS			
RALEIGH CLASS			
AUSTIN CLASS			
TARAWA			

TABLE A-1. ODA DATA BASE LIST OF RECORDS (continued)

- PLATFORMS CHARACTERISTICS - AIRCRAFT

BLUE		GREY	RED	ORANGE
F-14	C-2A	A-4	TU-95	MIG-19
A-7	UH-46	F-4	TU-16/8	MIG-21
A-6	UH-34	F-5	TU-16/6	SU-7B
S-3	CH-53D			IL-28
E-2C	UH-1			TU-16A
EA-6	CH-46			MIG-23
E-2	KA-6			MIG-25
P-3	SH-3			
AV-8A	C-1			
RF-14	RA-5C			
A-18	SH-2			
F-18				

- PLATFORMS CHARACTERISTICS - SUBMARINES

RED	ORANGE
ECHO II	WHISKEY-1
ECHO I	WHISKEY-2

- SENSOR CHARACTERISTICS - RADAR

BLUE		RED
SPS-5	FPS-100	BEE HIND
SPS-6	MPS-36	BIG NET
APQ-7	SPS-40	HEADLIGHT
SPS-10	SPS-43	HEAD NET C
SPS-29	SPS-48	POT HEAD
SPS-30	SPS-52	SLIM NET
SPS-37	SPS-55	SQUARE NET
SPS-39	APQ-92	STRUT CURVE
AWG-9	APS-116	S BAND
SPS-12	APS-120	FANSONG
SPS-46	APS-126	BARLOCK
APQ-126	APQ-148	
APS-115		

- SENSOR CHARACTERISTICS - SONAR

BLUE	
UQS-1	SQS-23
SQS-26	SQS-31
SQS-53	SQS-35 VDS

TABLE A-1. ODA DATA BASE LIST OF RECORDS (continued)

- SENSOR CHARACTERISTICS - ESM

BLUE	RED
BLUE SHIPBORNE RECEIVER	RED SHIPBORNE RECEIVER
BLUE AIRBORNE RECEIVER	RED AIRBORNE RECEIVER

- WEAPON CHARACTERISTICS - MISSILES

BLUE		RED	
AIM-7	AIM-9	AA-2	AS-1
AIM-54	AGM-12	AS-5	AS-6
AGM-45	RIM-2	SA-N-1	SA-N-4
RIM-7	RIM-8	SA-N-2	SA-N-3
RIM-24	MIM-72	SA-N-10	SA-N-2A
RGM-84	AGM-53	SA-N-14	AA-1
RIM-66A	RIM-67A	SS-NX-12	AS-2

- WEAPON CHARACTERISTICS - TORPEDOES

BLUE	RED
MK 44	406 MM TORPEDO
MK 46	533 MM TORPEDO
MK 48	

- WEAPON CHARACTERISTICS - BOMBS

BLUE	RED
MK-1	1100 KG BOMB
MK-5	250 KG BOMB
MK-20	500 KG BOMB
MK-84	750 KG BOMB
MK-82	

- WEAPON CHARACTERISTICS - GUNS

BLUE		RED
MK 2	MK 10	21 MM
MK 11	MK 12	25 MM
MK 16	MK 24	37 MM
MK 30	MK 32	57 MM
MK 33	MK 42	76 MM
MK 45	MK 61	85 MM
MK 67		130 MM
		GSH 23
		NR 30

TABLE A-2. DATA ELEMENTS IN THE ODA FIXED DATA BASE

OPERATIONS AREA

SUMMARY

- AREA ID
- AREA TYPE
- GRID COORDINATES
- COUNTRY NAME
- PORTS (ALLIED)
- AIRFIELDS (ALLIED)
- MAJOR BRIDGES
- MAJOR HIGHWAYS
- RAIL LINES
- CITY OR VILLAGE
  - NAME
  - LOCATION (LAT/LON)
  - POPULATION
  - ECONOMIC ACTIVITY
  - SIGNIFICANT RESOURCES
  - REMARKS
- RURAL POPULATION DENSITY
- MISCELLANEOUS FACILITIES (ALLIED)
  - TYPE
  - LOCATION (LAT/LON)
  - REMARKS
- POSSIBLE RESTRICTED AREAS
  - NAME
  - LOCATION (LAT/LON)
  - REMARKS
- POSSIBLE LANDING AREAS
  - TYPE
  - LOCATION (LAT/LON)
- POSSIBLE TARGETS
  - NAME
  - TYPE
  - PRIORITY
  - LOCATION (LAT/LON)
  - REMARKS
- REMARKS

TABLE A-2. DATA ELEMENTS IN THE ODA FIXED DATA BASE (cont'd.)

OPERATIONS AREA

TERRAIN

- AREA ID
- AREA TYPE
- GRID COORDINATES
- COUNTRY NAME
- TOPOGRAPHY
- AVG HEIGHT ABOVE SEA LEVEL
- AVG AMPLITUDE OF TERRAIN
- SIGNIFICANT FEATURES
  - NAME/TYPE
  - LOCATION
  - DESCRIPTION
- TYPE VEGETATION
- SPECIAL FACTORS
- REMARKS

WEATHER

- AREA ID
- DTG
- TEMPERATURE
- HUMIDITY
- BAROMETRIC PRESSURE
- WIND DIRECTION
- WIND VELOCITY
- CLOUD COVER
- PRECIPITATION TYPE
- PRECIPITATION RATE
- REMARKS

CLIMATE

- AREA ID
- SEASON OF YEAR
- AVERAGE NUMBER OF PRECIPITATION DAYS
- AVERAGE WIND SPEED
- AVERAGE WIND DIRECTION
- AVERAGE CLOUD CEILING
- AVERAGE HUMIDITY
- REMARKS

OCEAN CHARACTERISTICS

- CONTROL NUMBER
- AREA ID
- DTG
- SEA STATE
- SWELL PATTERN HEIGHT
- SWELL PATTERN DIRECTION
- LAYER DEPTH
- BOTTOM DEPTH
- DEEP SOUND CHANNEL
- BOTTOM BOUNCE PROVINCE NUMBER
- MARINE LIFE NOISE ESTIMATE
- PROPAGATION LOSS VS. RANGE
- TEMPERATURE VS. DEPTH
- SALINITY
- AVERAGE TIDE
- REMARKS

TABLE A-2. DATA ELEMENTS IN THE ODA FIXED DATA BASE (cont'd.)

NAVAL ORDER OF BATTLE

PORTS/HARBORS

- CONTROL NUMBER
- NAME
- LOCATION
- TARGET - PRIORITY
- STATUS
- STATUS DATE
- RESTRICTIONS
- CONDITION
- NATIONALITY/COUNTRY
- CALL SIGN
- BERTHS
  - TYPE
  - NUMBER
- SHIPS SUPPORTED
  - TYPE
  - NUMBER
- REPAIR/CONSTRUCTION CAPABILITY
- SHIPS IN PORT
- DEFENSE CAPABILITY
- MAX BOTTOM DEPTH
- TYPE OF BERTH
- FACILITIES
  - TYPE
  - NUMBER
  - LOCATION
  - TYPE CONSTRUCTION
- REMARKS

AIRFIELDS

- CONTROL NUMBER
- NAME
- LOCATION
- ELEVATION
- TARGET - PRIORITY
- STATUS
- STATUS DATE
- RESTRICTIONS
- CONDITION
- NATIONALITY/COUNTRY
- CALL SIGN
- NUMBER OF RUNWAYS
- LENGTH OF LONGEST RUNWAY
- AIRCRAFT
  - GENERIC TYPE
  - NUMBER
- FACILITIES
  - TYPE OF FACILITY
  - FUEL STORAGE
  - A/C STORAGE
  - TYPE OF CONSTRUCTION
- DEFENSE CAPABILITY
- REMARKS

TABLE A-2. DATA ELEMENTS IN THE ODA FIXED DATA BASE (cont'd.)

PLATFORM CHARACTERISTICS

SHIP

- SHIP NAME
- FLAG
- TASK FORCE ID
- SHIP CLASS
- CALL SIGN
- TYPE/HULL NUMBER
- PRIMARY ROLE
- MAXIMUM SPEED
- MAXIMUM ENDURANCE SPEED
- ECONOMICAL SPEED
- RANGE AT ENDURANCE SPEED
- RANGE AT ECONOMICAL SPEED
- PROPULSION TYPE
- FUEL TYPE
- USABLE FUEL CAPACITY
- CRUISING SPEED VS. SEA CONDITION
- ASSOCIATED EQUIPMENT
  - CONTROL NUMBER
  - DESIGNATOR
  - DESCRIPTION
  - NUMBER ON BOARD
- REMARK
- LENGTH
- BEAM
- DRAFT
- DISPLACEMENT
- MAST HEIGHT

AIRCRAFT

- DESIGNATION
- FLAG
- PRIMARY ROLE
- AIRCRAFT DESCRIPTION
- PROPULSION TYPE
- MAXIMUM SPEED
- CRUISE SPEED
- MAXIMUM CEILING
- COMBAT CEILING
- FUEL TYPE
- FUEL CAPACITY
- REFUEL CAPACITY
- COMBAT RADIUS
- CRUISE RADIUS
- ASSOCIATED EQUIPMENT
  - CONTROL NUMBER
  - DESIGNATOR
  - DESCRIPTION
  - NUMBER ON BOARD
- REMARKS

SUBMARINE

- CONTROL NUMBER
- NAME
- FLAG
- CLASS
- TYPE/HULL NUMBER
- CALL SIGN
- PROPULSION TYPE
- MAXIMUM SUBMERGED SPEED
- NORMAL OPERATING DEPTH
- MAXIMUM OPERATING DEPTH
- FUEL TYPE
- FUEL CAPACITY
- ASSOCIATED EQUIPMENT (COMMUNICATION/SENSORS/WEAPONS)
- - CONTROL NUMBER
  - DESIGNATOR
  - DESCRIPTION
  - NUMBER ON BOARD
- REMARKS

TABLE A-2. DATA ELEMENTS IN THE ODA FIXED DATA BASE (cont'd.)

SENSOR CHARACTERISTICS

RADAR

- DESIGNATOR
- DESCRIPTION
- EFFECTIVE RADIATED POWER
- VERTICAL BEAM WIDTH
- HORIZONTAL BEAM WIDTH
- FREQUENCY BAND
- TRANSMISSION FREQUENCY
- DETECTION RANGE VS. 1 m^2 TARGET
- REMARKS

ESM

- DESIGNATOR
- DESCRIPTION
- FREQUENCY BANDS
- SENSITIVITY
- DF ACCURACY
- REMARKS

SONAR

- CONTROL NUMBER
- DESIGNATOR
- DESCRIPTION
- FREQUENCY BANDS
- MODES
- REMARKS

TABLE A-2. DATA ELEMENTS IN THE ODA FIXED DATA BASE (cont'd.)

WEAPON CHARACTERISTICS

MISSILE

- DESIGNATOR
- DESCRIPTION
- MAXIMUM EFFECTIVE ALTITUDE
- MINIMUM EFFECTIVE ALTITUDE
- SPEED
- NOMINAL EFFECTIVE HORIZONTAL RANGE
- TIME TO TARGET AT MAXIMUM RANGE
- LETHAL RADIUS
- PROBABILITY OF KILL
- REMARKS

TORPEDO

- DESIGNATOR
- DESCRIPTION
- MAXIMUM EFFECTIVE HORIZONTAL RANGE
- ACCURACY
- TIME TO TARGET
- REMARKS

GUNS

- DESIGNATOR
- DESCRIPTION
- MAXIMUM EFFECTIVE HORIZONTAL RANGE
- MAXIMUM EFFECTIVE VERTICAL RANGE
- ACCURACY
- FIRE RATE
- REMARKS

BOMBS

- DESIGNATOR
- DESCRIPTION
- LETHAL RADIUS
- TOTAL WEAPON WEIGHT
- REMARKS

APPENDIX B

APPENDIX B

TRACK FILES

The track files are that portion of the data base that contain current and historical information on the position and movement of all ships and aircraft that are operating in the task force area of interest. It is important to note that the term "all ships and aircraft" refers to friendly and neutral as well as hostile platforms. The reason for including neutral platforms is that, in many cases, tactical options must be revised or not taken because their execution would endanger the neutral platforms. The information in the track files is perhaps the most important input to tactical decisions during the execution phase of task force operations.

In the track file, each platform is associated with an individual record which is referred to as a "track" for that platform. A track consists of a chronological sequence of position reports or POSITS. A POSIT is a report indicating the location, course and speed of a platform at some specified time. The data elements in a POSIT in the ODA data base are the following:

- TRACK NUMBER
- FORCE TYPE
- FLAG
- NAME
- COURSE
- SPEED
- ALTITUDE
- LATITUDE
- LONGITUDE
- DATE/TIME GROUP (DTG)
- UNIT REPORTING
- ASSIGNED TRACKING UNIT

Table B-1 contains the definition of these terms and Tables B-2 and B-3 contain force type codes and reporting/tracking unit codes used in POSITs.

Figure B-1 is a sample POSIT for the Red Ship Sevastopol. It indicates that on February 15, 1979, at 12 noon, the ship was southeast of ONRODA Island (whose location is contained in the Operations Area Summary Record for ONRODA Island) heading northwest at a speed of 15 KTS.

When a new POSIT is received and input to the data base, old POSITs on that platform are not purged. Thus the track file consists not merely of the latest reported position of all platforms but also a complete track history. This history of platform movements may then be utilized as a threat assessment input or to reconstruct and evaluate task force operations.

The ODA data base includes a track file which is available to all users of the ODA test facility.

TABLE B-1. DEFINITIONS OF TRACK DATA ELEMENTS

Element	Definition
TRACK NUMBER	A unique numeric designator assigned to each track.
FORCE TYPE	Indicates if the track is surface/ subsurface/aircraft and if it is friendly/unfriendly/unknown. Use Table B-2.
FLAG	Indicates nationality of current user.
NAME	Indicates name of vessel of aircraft. May indicate class if name is unknown but class is known.
COURSE	The heading of the target given in degrees measured clockwise from true north.
SPEED	Speed of the target measured in knots.
ALTITUDE	The altitude or depth of the target in feet.
LATITUDE/LONGITUDE	Indicates the position of the target at the time the sighting was made.
DTG	Date Time Group indicating when the sighting was made. Format is YYMMDDHHMM.
UNIT REPORTING	The unit reporting the contact (use Table B-3).
ASSIGNED TRACKING UNIT	If a unit has been assigned to continuously track a target, the identity of the unit is indicated in thie field (use Table B-3). If there is no assigned tracking unit, then this field is left blank.

TABLE B-2. FORCE TYPES

00	Undefined or Dummy Track
01	Hostile Aircraft
02	Unknown Aircraft
03	Friendly Aircraft
04	Hostile Submarine
05	Unknown Submarine
06	Friendly Submarine
07	Hostile Surface Ship
08	Unknown Surface Ship
09	Friendly Surface Ship

TABLE B-3. REPORTING/TRACKING UNITS

A	KITTY HAWK	CV 63
B	CHICAGO	CG 11
C	COCHRANE	DDG 21
D	SPRUANCE	DD 963
E	AGERHOLM	DD 826
F	HAROLD E. HOLT	DE 1074
G	BOWEN	DE 1079
H	FORRESTAL	CV 59
I	OKLAHOMA CITY	CLG 5
J	GRIDLEY	DLG 21
K	PAUL F. FOSTER	DD 964
L	FISKE	DD 842
M	HIGBEE	DD 806
N	TRUETT	DE 1095
O	TOMCAT	F-14
P	CORSAIR II	A-7E
Q	INTRUDER	A-6E
R	VIKING	S-3A
S	HAWKEYE	E-2C
T	PROWLER	EA-6
U	SEAKING	SH-3
V	LAMPS	SH-2
W	ORION	P-3
X	Other	

POSIT

NAME	SEVASTOPOL
DTG	7902151200
TRACK NUMBER	4020
FORCE TYPE	07
FLAG	RD
LATITUDE	32-40N
LONGITUDE	033-32E
COURSE	325
SPEED	15
ALTITUDE	0
REPORTING UNIT	I
ASSIGNED UNIT	X

FIGURE B-1. SAMPLE ODA POSIT

One of the most important capabilities of modern command and control systems is the capability for a computer generated display of tracks of interest against a geographic background. In order to create such a display, the system would utilize a digitized world map to display a map of the area of interest and then the system would access the track file and place appropriate symbols on the display at points corresponding to the reported location of the platforms.

The display can include any user specified set of tracks. The display could also include not only the latest positions of the platforms but also previous positions back to some specified time.

The ODA test facility will have a capability for geographic display of tracks. Table B-4 contains the symbols that will be used to indicate the force type of the platform. These symbols are based on standard Naval Tactical Data System (NTDS) symbology. CTEC has supplied a digitized world map [46] to the University of Pennsylvania in order to support this display capability.

Figure B-2 shows an example of a track display against a map of the ONRODA area. The tracks are identified by placing the first four letters of the platform name at the symbol representing the last reported position. Figure B-2 shows the track for the Sevastopol whose last reported position is as shown in Figure B-1. In addition, the Blue aircraft carrier Kitty Hawk and cruiser Chicago are shown at their positions west of ONRODA Island.

TABLE B-4. SYMBOLOGY FOR TRACK FORCE TYPE

SYMBOL	CODE	FORCE TYPE
	00	Undefined Track
	01	Hostile Aircraft
	02	Unknown Aircraft
	03	Friendly Aircraft
	04	Hostile Submarine
	05	Unknown Submarine
	06	Friendly Submarine
	07	Hostile Surface Ship
	08	Unknown Surface Ship
	09	Friendly Surface Ship

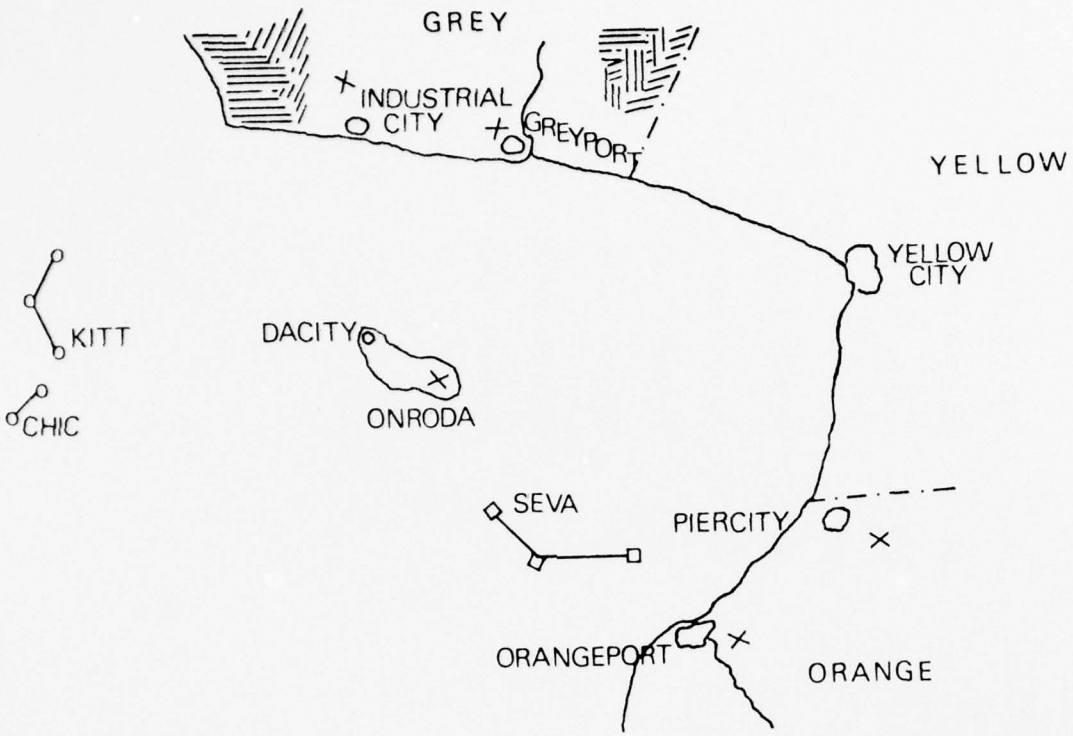


FIGURE B-2

GEOGRAPHIC DISPLAY OF TRACKS

AD-A041 223 CTEC INC FALLS CHURCH VA F/G 15/7
INFORMATION SUPPORT FOR OPERATIONAL DECISION AIDS.(U)
MAY 77 N00014-65-C-0965
UNCLASSIFIED CTEC-57283 NL

2 OF 2
ADA041223



END
DATE FILMED
8-77

APPENDIX C

APPENDIX C

RADAR DETECTION RANGE PROGRAM

The Radar Detection Range program computes the detection range in NM of a specified radar against a specified target. The program considers the target size, target and radar platform altitude and weather as well as the capability of the radar itself.

The user of the radar program must input:

- Radar ID
- Target Type
- Target Radar Cross-Section
- Target Altitude
- Radar Altitude
- Radar Frequency

The user must input Radar ID and Target Type. Default values are available for the remaining inputs. The default values used in a particular case depend on Radar and Target types. Radar and weather parameters used by the program are obtained from the data base with no user interaction. The program will successively prompt the user for each of the user specified inputs.

The program first prompts the user for the Radar ID as follows:

RADAR ID:

INDICATE ONE OF THE FOLLOWING: DESIGNATOR
PLATFORM NAME
TRACK NUMBER
TRACK NAME

The user can specify the Radar ID in any one of four ways. The designator refers to the A/N designator (e.g., SPS-43) or the NATO code name (e.g. HEAD NET C). This uniquely identifies a radar. If the user indicates a platform name, then after target type is input, the program queries the characteristic file for that platform to find what radars it carries and chooses the radar most appropriate for the target type. If the user inputs a track number, the program queries the track file (cf. Appendix B) to determine platform name and then proceeds as above. The track groups refer to all Blue, Red, Gray or Orange tracks. The user types B, R, G, O respectively. The program computes radar coverage for all tracks of that nationality.

After the user specifies Radar ID the program prompts him for target type as follows:

TARGET TYPE:

INDICATE:
1 SMALL AIRCRAFT
2 LARGE AIRCRAFT
3 SMALL SHIP
4 MEDIUM SHIP
5 LARGE SHIP

The user types a number from 1 to 5. The target type (aircraft or ship) is used to choose which radar on a specified platform is used and for the target altitude default value. It is also used to get a default value for target cross section. The default values for targets are 5, 15, 100, 1000, 2000 m^2 respectively.

The program then instructs the user that default values are available for the remaining inputs and asks for each of these inputs in turn indicating the unit of measure. Then the program outputs the detection range in NM.

Figure C-1 is a sample input/output menu for the program. Inputs are indicated by underscoring. The sample computes the detection range of an SPS-10 against a small aircraft (10m cross section) flying at 3000-feet altitude. The detection range is computed to be 29 NM.

RADAR DETECTION RANGE

RADAR ID: SPS-10

INDICATE ONE OF THE FOLLOWING: DESIGNATOR

PLATFORM NAME

TRACK NUMBER

TRACK GROUP (B, R, G, O)

TARGET TYPE: 1

INDICATE:

1	SMALL AIRCRAFT
2	LARGE AIRCRAFT
3	SMALL SHIP
4	MEDIUM SHIP
5	LARGE SHIP

FIGURE C-1a

DEFAULT VALUES ARE AVAILABLE FOR REMAINING INPUTS

TO USE DEFAULT VALUE HIT RETURN AFTER INPUT IS PROMPTED

TARGET CROSS SECTION 10 MSQ

TARGET ALTITUDE 3000 FT

RADAR ALTITUDE 50 FT

FREQUENCY 5600 MHZ

DETECTION RANGE: 29 NM

FIGURE C-1b

APPENDIX D

APPENDIX D

CARRIER AIR GROUP MAINTENANCE SIMULATION (CAGMS)

CAGMS determines the future availability of aircraft in a carrier based air wing given the initial availability of the aircraft and a planned schedule of operations.

The user of CAGMS must input:

- Initial composition and status of air wing.
- The Operational Schedule.
- The type and frequency of Output.

After CAGMS is called, the system will successively prompt the user for all of the required input. When the system requests information, the user enters it on the screen; then when he is satisfied that it is what he wishes to enter, he should type a carriage return. Up to the point when he hits a carriage return, the information he has typed may be changed. For example, suppose he wishes to enter "F-14" and instead he types "F-13". He may correct this error by typing a "Control-A", which deletes the last character input and then enter a 4. If this were to occur, the output would appear as F-13/4. The "/" implies that character has been removed from the input string. If the user makes an error in the first letter of an entry, then he should hit a carriage return. The system will recognize the error and ask that the information be re-entered.

The system will initially prompt the user for the initial composition and status of the air wing. For each aircraft type to be considered, the user must input how many of what type aircraft are in the air wing and their readiness state at the beginning of the time period to be simulated. The system will first instruct the user as follows:

```
THIS IS THE INITIALIZATION SECTION, WHICH INCLUDES
A/C NAME
NUMBER WITH FULL OPERATIONAL CAPABILITY (FOC)
NUMBER WITH REDUCED MATERIAL CAPABILITY (RMC)
NUMBER NOT OPERATIONALLY READY (NOR)
ENTER THE NAME OF THE A/C OR "DONE" WHICH
TERMINATES A/C INITIALIZATION
```

The user enters the designator of one of the aircraft types to be considered in the simulation. The system then asks for the number of this aircraft type in each readiness state at the beginning of the simulated time.

First, the number of FOC type aircraft is requested:

ENTER THE NUMBER OF A/C FOC

Then, the number of RMC type aircraft is requested:

ENTER THE NUMBER OF A/C RMC

Then, the number of NOR type aircraft is requested:

ENTER THE NUMBER OF A/C NOR

After all this has been input, the system again asks for an aircraft type.

If the user wishes to consider additional aircraft types, he inputs the aircraft type and the process continues as above. This process is repeated until composition and status of each aircraft to be considered in the simulation is input. After the user has completed this input for the last aircraft type to be considered and the system requests the name of another aircraft type, the user types DONE.

Figure D-1 is a sample input of air wing composition and status. The user wishes to consider the F-14 and A-7 aircraft types. There are 23 F-14's and 15 A-7's. At the start of the simulation 13 F-14's and 10 A-7's are FOC. 5 F-14's are RMC and 5 F-15's and 5 A-7's are NOR.

The next input required of the user is the air operations schedule for the time period to be simulated. The user has a choice of two ways to input an air operations schedule: The Launch/Recovery option and the Daily Operations Option. If the user chooses the Launch/Recovery option, then for each launch or recovery event he must specify

- Time of the event.
- Whether the event is a launch or recovery event.
- The number of each type aircraft to be launched or recovered.
- If the event is a launch, an indication if RMC aircraft can be used on the mission.

If the user chooses a daily operations input schedule, then he indicates how many of each type aircraft that he wishes to keep airborne on station over various type intervals. In this case the user must specify

- The time intervals.
- The number of hours per day that air operations are to be conducted.
- The number of each type aircraft to be kept on station.
- An indication if RMC aircraft can be used for the mission.

(Inputs are indicated by underscoring)

THIS IS THE INITIALIZATION SECTION, WHICH INCLUDES
AIRCRAFT NAME
NUMBER OF AIRCRAFT WITH FULL OPERATIONAL CAPABILITY (FOC)
NUMBER OF AIRCRAFT WITH REDUCED MATERIAL CAPABILITY (RMC)
NUMBER OF AIRCRAFT NOT OPERATIONALLY READY (NOR)

ENTER THE NAME OF THE AIRCRAFT OR "DONE" WHICH TERMINATES AIRCRAFT INITIALIZATION F-14

ENTER THE NUMBER OF AIRCRAFT FOC 13

ENTER NUMBER OF AIRCRAFT RMC 5

ENTER THE NUMBER OF AIRCRAFT NOR 5

ENTER THE NAME OF THE AIRCRAFT OR "DONE" WHICH TERMINATES AIRCRAFT INITIALIZATION A-7

ENTER THE NUMBER OF AIRCRAFT FOC 10

ENTER NUMBER OF AIRCRAFT RMC 0

ENTER THE NUMBER OF AIRCRAFT NOR 5

ENTER THE NAME OF THE AIRCRAFT OR "DONE" WHICH TERMINATES AIRCRAFT INITIALIZATION DONE

FIGURE D-1. SAMPLE INPUT OF AIR WING COMPOSITION AND STATUS

The system will first ask the user which input option he wishes to use as follows:

ENTER LAUNCH OR DAILY TO SELECT THE INPUT FORMAT

If the user wants the Launch/Recovery option he enters
LAUNCH

If he wants the Daily Operations option he enters
DAILY

If the user has chosen the Launch/Recovery option, the system prompts for the time of the first event as follows:

ENTER THE DATE TIME GROUP OF THE EVENT OF "Ø" WHICH
ENDS THE SCHEDULING OF OPERATIONS

The Date Time Group (DTG) that the system accepts is 8 digits long. The first two digits are the number of the month (Ø1-12), the third and fourth digits are the day of the month (Ø1-31, as applicable), the last four digits are the time on the 24-hour clock. For example, 05041159 is 1159 hours on 4 May, 12311950 is 1950 hours on 31 December.

It is important to note that two different events may occur in the same 10 minute time interval so that 2 events may have the same DTG.

After the DTG has been entered, the system wishes to know whether the event is launch or recovery. It prompts with:

ENTER TYPE OF EVENT EITHER "L" OR "R"

The user enters L if the event is a launch, R if the event is a recovery.

If the user is inputting a Launch event, then he will next be prompted with:

ENTER THE NAME OF THE A/C TO BE LAUNCHED OR "DONE"
TO END THIS EVENT

The user enters the designator of one of the aircraft types to be launched. The user is then asked for the number of that type of aircraft to be launched:

ENTER THE NUMBER OF A/C TO BE LAUNCHED

The user enters the number of aircraft to be launched. He is then asked if RMC aircraft are acceptable for the mission

ENTER Ø = RMC ACCEPTABLE, 1 NOT ACCEPTABLE

The user enters 0 if RMC aircraft can be used on the mission and 1 if they cannot. The user is then asked for another type aircraft to be launched and the process is repeated. When the user has specified all the aircraft for this event he types DONE when he is asked for another aircraft type. The system will then ask for the time of the next

event. If he enters a time then the process proceeds as above. If, however, he has entered all his events he indicates that the schedule is complete by entering 0 when the system asks for the time of the next event.

Figure D-2 is an example of a Launch/Recovery input format showing two launch and two recovery events. The date is October 20. In this case, 2 F-14s and 1 E-2 are launched at 1200 and 2 F-14s and 3 A-6s are launched at 1330. 2 F-14s are recovered at 1340 and 1 E-2, 2 F-14s and 3 A-6s are recovered at 1510. The A-6s may be RMC but the others must be FOC.

If the User has choosen the Daily Operations option, the system prompts for the beginning of the time interval as follows:

ENTER BEGINNING DTG OR "0" TO END SCHEDULING

The user enters the beginning of the time interval. Then the system asks for the end of the first time interval as follows:

ENTER ENDING DTG

The format for the DTG is the same as for Launch/Recovery and they are validated to assure that the ending DTG is a later date than the beginning DTG.

The user is then asked for the number of hours that air operations are to be conducted each day:

ENTER THE NUMBER OF HOURS/DAY FOR THIS OPERATIONAL SCHEDULE

The user enters the number of hours per day that air operations are to be conducted. The user is then prompted for the number of each type aircraft to be maintained on station and whether RMC aircraft are acceptable as follows:

ENTER THE NAME OF THE A/C OR "DONE" WHICH ENDS THIS SCHEDULE

ENTER THE NUMBER OF A/C

ENTER Ø = RMC ACCEPTABLE, 1 NOT ACCEPTABLE

The user enters the appropriate values after each prompt. The system then prompts the user for this information for additional type aircraft until the user indicates that the schedule for the time interval is complete by entering DONE when asked for an aircraft name. The system then asks for a new time interval. The user can continue as above or indicate the schedule is complete by entering 0.

Figure D-3 is a Daily Operations Input Schedule. It indicates that from September 1 until September 7, there will be 12 hours a day of air operations between 0600 and 1800. During those 12 hours, 2 F-14's and 3 A-6's will be kept on station if possible. The A-6 may be RMC but the F-14's must be FOC.

ENTER LAUNCH OR DAILY TO SELECT THE INPUT FORMAT LAUNCH

ENTER THE DATE TIME GROUP OF THE EVENT OF "O" WHICH ENDS THE SCHEDULING OF OPERATIONS 10201200

ENTER TYPE OF EVENT EITHER "L" OR "R" L

ENTER THE NAME OF THE AIRCRAFT TO BE LAUNCHED OR "DONE" THIS EVENT F-14

ENTER THE NUMBER OF AIRCRAFT TO BE LAUNCHED 2

ENTER O = RMC ACCEPTABLE, 1 NOT ACCEPTABLE 1

ENTER THE NAME OF AIRCRAFT TO BE RECOVERED OR "DONE" TO END THIS EVENT E-2

ENTER THE NUMBER OF AIRCRAFT TO BE LAUNCHED 1

ENTER O = RMC ACCEPTABLE, 1 NOT ACCEPTABLE 1

ENTER THE NAME OF THE AIRCRAFT TO BE LAUNCHED OR "DONE" THIS EVENT DONE

ENTER THE DATE TIME GROUP OF THE EVENT OF "O" WHICH ENDS THE SCHEDULING OF OPERATIONS 10201330

ENTER TYPE OF EVENT EITHER "L" OR "R" L

ENTER THE NAME OF THE AIRCRAFT TO BE LAUNCEHD OR "DONE" THIS EVENT F-14

ENTER THE NUMBER OF THE AIRCRAFT TO BE LAUNCHED 2

ENTER O = RMC ACCEPTABLE, 1 NOT ACCEPTABLE 1

ENTER THE NAME OF THE AIRCRAFT TO BE LAUNCHED OR "DONE" THIS EVENT A-6

ENTER THE NUMBER OF AIRCRAFT TO BE LAUNCHED 3

ENTER O = RMC ACCEPTABLE, 1 NOT ACCEPTABLE 0

ENTER THE NAME OF THE AIRCRAFT TO BE LAUNCHED OR "DONE" THIS EVENT DONE

FIGURE D-2

ENTER THE DATE TIME GROUP OF THE EVENT OF "0" WHICH ENDS THE SCHEDULING OF OPERATIONS 10201340

ENTER TYPE OF EVENT EITHER "L" OR "R" R

ENTER THE NAME OF THE AIRCRAFT TO BE RECOVERED OR "DONE" TO END THIS EVENT F-14

ENTER THE NUMBER OF AIRCRAFT TO BE RECOVERED 2

ENTER THE NAME OF THE AIRCRAFT TO BE RECOVERED OR "DONE" TO END THIS EVENT DONE

ENTER THE DATE TIME GROUP OF THIS EVENT OF "0" WHICH ENDS THE SCHEDULING OF OPERATIONS 010201500

ENTER TYPE OF EVENT EITHER "L" OR "R" R

ENTER THE NAME OF THE AIRCRAFT TO BE RECOVERED OR "DONE" TO END THIS EVENT F-14

ENTER THE NUMBER THE NUMBER OF AIRCRAFT TO BE RECOVERED 2

ENTER THE NAME OF THE AIRCRAFT TO BE RECOVERED OR "DONE" TO END THIS EVENT E-2

ENTER THE NUMBER OF AIRCRAFT TO BE RECOVERED 1

ENTER THE NAME OF THE AIRCRAFT TO BE RECOVERED OR "DONE" TO END THIS EVENT A-6

ENTER THE NUMBER OF AIRCRAFT TO BE RECOVERED 3

ENTER THE NAME OF THE AIRCRAFT TO BE RECOVERED OR "DONE" TO END THIS EVENT DONE

ENTER THE DATE TIME GROUP OF THE EVENT OF "0" WHICH ENDS THE SCHEDULING OF OPERATIONS

FIGURE D-2 (cont.)

ENTER LAUNCH OR DAILY TO SELECT THE INPUT FORMAT DAILY

ENTER BEGINNING DTG OR "0" TO END SCHEDULING 09010600

ENTER ENDING DTG 09071800

ENTER THE NUMBER OF HOURS/DAY FOR THIS OPS SCHEDULE 12

ENTER THE AIRCRAFT NAME OR "DONE" WHICH ENDS THIS SCHEDULE F-14

ENTER THE NUMBER OF AIRCRAFT 2

ENTER 0 = RMC ACCEPTABLE, 1 NOT ACCEPTABLE 1

ENTER THE AIRCRAFT NAME OR "DONE" WHICH ENDS THIS SCHEDULE A-6

ENTER THE NUMBER OF AIRCRAFT 3

ENTER 0 = RMC ACCEPTABLE, 1 NOT ACCEPTABLE 0

ENTER THE AIRCRAFT NAME OR "DONE" WHICH ENDS THIS SCHEDULE DONE

ENTER BEGINNING DTG OR "0" TO END THIS SCHEDULE 0

FIGURE D-3

The system will then ask the user for the frequency with which he wants to see the outputs:

ENTER THE NUMBER OF HOURS BETWEEN THE OUTPUT OF
AIRCRAFT STATUS, IT MUST BE GREATER THAN 0 AND
LESS THAN 1000 HOURS

The user enters some number of hours. If for example he enters 24 then he will see output corresponding to the situation once each day starting 24 hours after the beginning of the simulated time period. The output is formatted separately for each aircraft. Since the output is stored in a file the user can ask for the output for each aircraft types as he wants to look at it. The system asks for which aircraft types the user wants to see

ENTER AIRCRAFT OR "DONE" WHICH ENDS THE STATUS REVIEW

The user successively enters the designation of each aircraft type for which he wants to see output.

Figure D-4 is a sample output. It shows a daily status review of the F-14 aircraft compliment for September 1 to September 7.

DTG	#FOC	#RMC	#NOR
10020600	18	3	4
10030600	16	4	5
10040600	15	2	7
10050600	10	6	8
10060600	9	6	9
10070600	8	6	10
10071800	9	3	12

FIGURE D-4. STATUS OF F-14 AIRCRAFT

APPENDIX E

APPENDIX E

MATHEMATICAL ANALYSIS OF ENGAGEMENT OUTCOMES

The purpose of this appendix is to present the mathematical formulas that are used to compute escort/interceptor and Attack Aircraft/SAM engagement outcomes. The particular problems dealt with here are:

(1) Given that m missiles are fired at n targets, what is the probability that k ($\leq$ n) targets

(2) What is the expected number of targets to survive given the situation in (1)?

(3) How to factor in the reliability of available missiles?

In order to compute survivor probabilities, it is necessary to make some assumptions about coordination of fire. Coordination of fire refers to the assignment of individual weapons to individual targets during a battle [26]. There are two types of coordination of fire that were analyzed:

- Uniform Coordination
  - Continuous Uniform Coordination - this assumes all targets are engaged the same number of times. In this case, each target is engaged by m/n missiles.
  - Discrete Uniform Coordination - This takes into account the fact that the number of missiles is not usually an integer multiple of the number of targets. In this case q=m - [m/n] n targets are engaged by [m/n] + 1 missiles and n - q targets are engaged by [m/n] missiles where [m/n] = greatest integer less than m/n.
- Random Coordination - In this case, the missiles engage the targets at random with each missile having an equal probability of engaging any target.

Uniform coordination is an optimistic assumption in the sense that it represents a better coordination than would normally be achieved. On the other hand, random coordination is a pessimistic assumption.

If continuous uniform coordination of fire is assumed, then the probability of P(n,k) of k survivors out of n targets is given by

(E-1) $$P(n,k) = \binom{n}{k} (1-P)^{k\ m/n}[1-(1-P)^{m/n}]^{n-k}$$

where P = Probability of kill of a single missile

The expected number of survivors is given by

(E-2) $$E = n(1-P)^{m/n}$$

If discrete uniform coordination of fire is assumed, and if $a = [m/n]$, then it is necessary to consider how many targets are engaged by a missiles, how many targets are engaged by a+1 missiles, and how the survivors can be distributed among these two groups. Let $q = m-an$, then $n-q$ targets are engaged by a missiles and a q targets are engaged by a+1 missiles. The probability $P(n,k)$ of k survivors out of n targets is given by

(E-3) $$P(n,k) = \sum_{i=0}^{q} \left[\binom{q}{i}(1-P)^{i(a+1)}[1-(1-P)^{a+1}]^{q-i}\right]$$

$$\left[\binom{n-q}{k-i}(1-P)^{(k-i)a}[1-(1-P)^{a}]^{((n+i)-(k+q))}\right]$$

The expected number of survivors is

(E-4) $$E = q(1-P)^{a+1} + (n-q)(1-P)^{q}$$

If random coordination of fire is assumed, then the computations are more complicated. It is necessary to compute the probability of every possible distribution of missiles among the targets and, for each of these distributions, the probability of k survivors out of n targets given that distribution. The total probability of k survivors out of n targets is the sum of each conditional probability times the probability of the distribution of missiles.

The various distributions of m missiles among n targets can be represented as n - tuples of the form $(m_1, \ldots m_n)$ where

$$\sum_{i=1}^{n} m_i = m$$

Let R denote the set of all these n - tuples. The probability of the distribution

$v = (m_1, \ldots, m_n) \in R$ is given by

(E-5) $$P(v) = \frac{n!m^{-n}}{m_1! \ldots m_n!}$$

Let J_k represent the set of all n - tuples with k entries equal to 0 and n-k entries equal to 1. J_k represents the set of all choices of k survivors among the n targets. If $v \varepsilon R$ and $w \varepsilon J_k$ define S(v,w) by

$$(E\text{-}6) \qquad S(v,w) = \prod_{i=1}^{n} S_i(v,w) \text{ where}$$

$$(E\text{-}7) \qquad S_i(v,w) = \begin{cases} (1-P_k)^{m_i} \text{ if } w_i = 0 \\ \sum_{a=1}^{m_i} \binom{m_i}{a} P^a (1-P)^{m_i - a} \text{ if } w_i = 1 \end{cases}$$

where $v = (m_1, \ldots, m_n)$

and $w = (w_1, \ldots, w_n)$

S (v,w) is the probability of the distribution of survivors represented by w given the distribution of missiles represented by v.

The probability

$$P(n,k) = \sum_{v \varepsilon R} P(v) \cdot \left[\sum_{w \varepsilon J_k} S(v,w) \right]$$

The expected distribution of missiles among targets in random coordination of fire is the distribution of fire assumed in continuous uniform coordination of fire. Therefore, the expected number of survivors for random coordination of fire is given by equation (E-2).

The equations presented so far assume that m missiles are successfully fired. If the input quantity is the number M of missiles available, then it is necessary to consider the reliability of missile system. The reliability is expressed by the probability Q that a missile will successfully fire given that it is available. If M missiles are available, then the expected number of successfully fired missiles is QM and the probability that m will fire successfully is

$$F(M,m) = \binom{M}{m} Q^m (1-Q)^{M-m}$$

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