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*Final Report*

# CARRIER TASK FORCE ANTI-AIR WARFARE IN THE 1970 ERA (U)

*By:* L. J. LOW O. F. FORSYTH D. J. KAPLAN
L. I. KRAUSE J. H. KULLBACK R. C. LOGAN

*Prepared for:*

OFFICE OF NAVAL RESEARCH
NAVAL ANALYSIS GROUP – CODE 493
WASHINGTON 25, D.C.

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Subj: Navy Advanced Anti-Air Warfare System Study; forwarding of final report

Encl: (1) Carrier Task Force Anti-Air Warfare in The 1970 Era (U) SRI-4-2017, September 1964, SECRET NOFORN

1. Enclosure (1) is a report on a systems analysis study in future Carrier Task Force anti-air warfare conducted for the Office of Naval Research by the Naval Warfare Research Center at Stanford Research Institute under contract Nonr-2332(00)

2. The major objectives of the study were: (a) to determine, in an ECM environment, joint SAM and AAM effectiveness in future Strike Carrier Task Force anti-air warfare, and (b) to generate and to examine advanced airborne platform concepts for AAW with particular emphasis on the demands of electronic warfare.

3. Simulation and analysis of the operation of a 1970-era strike carrier task force under air attack in an electronic warfare environment is an extraordinarily complex undertaking. Any mathematical formulation which realistically addresses itself to this warfare area from the "total systems" approach must dynamically account for early warning and detection and for such doctrinal considerations as intercept assignment, threat evaluation and weapon assignment, and deployment and coordination requirements of surface and air-launched weapon platforms. Mathematically this can only be treated adequately by a Monte Carlo type computer simulation. Such a computer simulation program was developed. A feature of this computer "game" worth noting is the effective treatment of radar resolution and detection in a noise jamming environment.

4. The study itself generated questions which gave rise to ancillary explorations. Such subjects as CAP logistics, ship disposition, threat characteristics and jamming features had to be developed in sufficient detail to permit their use in the model. From these explorations insights were derived that have proven useful to many activities. Most of these subjects are documented and all are referenced in the report.

5. Worthy of note is the concept of fix-denial, an outgrowth of earlier work on TYPHON and F6D-EAGLE. This concept represents an approach to active ECM which may serve in meeting the requirements set forth

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# ABSTRACT

This report presents the results of a study program conducted by the Naval Warfare Research Center of Stanford Research Institute in the area of future carrier task force anti-air warfare. The research work described in the report was sponsored over the four year period (1959-63) by the Advanced Warfare Systems Division, Naval Analysis Group, Office of Naval Research (Code 493). The results of computer simulation studies conducted for Op 723 of the Office of the Chief of Naval Operations (1962-63) and for the G Organization of the Bureau of Naval Weapons (1963) are included in the report. The report presents a brief history of the research effort, the development of the limited war operating environment for future carrier task forces, a description of the analytical techniques employed by the study group and the results of analytical investigations pertaining to the effectiveness of the shipborne and airborne elements of a task force AAW complex. In addition, the report examines the desirability and feasibility of the employment of airborne platforms in an Electronic Warfare role, complementing the Ship Integrated Electronic Warfare System (SINEWS) currently under development. Conclusions derived from these study efforts, pertaining to AAW operations and AAW system technology, are presented.

# ACKNOWLEDGMENT

While the authors cannot acknowledge the efforts of all the organizations and individuals who have aided in the preparation of this report, special thanks must be extended to the following:

Among Naval Fleet and Shore activities, the Office of Naval Research (Code 493); The Office of the Chief of Naval Operations (Op 723, Op07T, Op92); The Bureau of Naval Weapons (Codes R-5, RM-2, RM-3); The Bureau of Ships (Code 671); The Naval Research Laboratory (Radar Division); The David Taylor Model Basin; The Naval Missile Center, Pt. Mugu, California; The Naval Electronics Laboratory, San Diego, California; The Fleet Anti-Air Warfare Training Center, San Diego, California; The Naval Postgraduate School, Monterey, California; COMCRUDESPAC, San Diego, California; The Naval Air Facility, Philadelphia, Pennsylvania; Naval Air Development Center, Johnsville, Pennsylvania; The Naval Ordnance Test Station, China Lake, California; Fighter Squadron 121, NAS Miramar, California; and Air Development Squadron Four, Pt. Mugu, California.

Many industrial and contractor research organizations provided data for this study. Among these should be mentioned the Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland; General Dynamics, Pomona, California; Bendix Systems Division, Ann Arbor, Michigan; Bendix Research Laboratories, Detroit, Michigan; Bendix Mishawaka Division, Mishawaka, Indiana; McDonnell Aircraft Corporation, St. Louis, Missouri; Hiller Aircraft Company, Palo Alto, California; Douglas Aircraft Corporation, El Segundo, California; Litton Industries, Canoga Park, California; Hughes Aircraft Corporation, Culver City, California; Ling-Temco-Vought (Chance-Vought), Grand Prairie, Texas; Raytheon Manufacturing Company, Bedford Massachusetts; Westinghouse Air Arm Division, Baltimore, Maryland; and Collins Radio Company, Information Sciences Center, Newport Beach, California.

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## 1. INTRODUCTION

### 1.1 Background

The present study is an outgrowth of a series of studies, which had their earliest origins in OpNav letter Serial 0233P03C of 31 October 1957 to the Chief of Naval Research. By this letter, CNO requested that the then-current missile programs of the Navy be examined as to their scheduled operational availability, their program costs, and their effectiveness against the enemy threats compatible with the periods of system operational availability. The systems selected for study were:

(1) SPARROW III
(2) SIDEWINDER
(3) Advanced Air-to-Air Missile (SPARROW X, EAGLE)*
(4) CORVUS*
(5) BULLPUP
(6) REGULUS II*
(7) TERRIER
(8) TALOS
(9) TARTAR
(10) SUBROC

The air-to-air missile systems in the above listing were singled out by CNO to receive priority attention by the study group.

The difficulties inherent in the "program" analyses of ten missile systems soon became apparent. Following the preparation by the Naval Warfare Research Center at the Stanford Research Institute (NWRC) of a preliminary Program Description report for each of the ten systems under study, CNO requested in August 1958 a shift in major study emphasis from the air-to-air systems to a complete program analysis of the TERRIER, TALOS and TARTAR (3T).

---

* Indicates missile system programs that have subsequently been cancelled.

The four volumes of 3T studies that followed were completed in July 1959. In brief, the studies attempted to assemble all of the technological, economic and scheduling factors relating to the 3T systems into a single set of documents in addition to presenting an analysis of 3T system effectiveness. The four volumes consisted of three program analysis reports (one each for the TERRIER, TALOS and TARTAR systems) and a summary report, which presented conclusions and recommendations pertaining to the Navy surface-to-air missile program as a whole.[1-4*]

Primary emphasis in these studies was determination of comparative effectiveness values for the various 3T systems. The effectiveness models employed made it possible to treat many variations in the attack and defense over selected periods in calendar time. Furthermore, these models permitted the systematic study of the sensitivity of 3T effectiveness to the variation of a number of important system parameters. Cost/effectiveness factors were derived in the Summary Report[4] for a series of 3T guided-missile/ship-missile system combinations. TYPHON, or the Advanced Weapon System (AWS) as it was called at that time, was not included in this study effort, since the system had not yet been adequately defined.

There were, however, certain limitations in the effectiveness analyses performed for the 3T studies in the light of problems that were rapidly developing in naval antiair warfare at the time. These were as follows:

(1) The models were restricted to either single-ship defense or homogeneous-task-force defenses (i.e., all-TERRIER, all-TALOS, or all-TARTAR), concentrically deployed around the attack carriers. These factors limited model utility in a general sense in that task force SAM defenses are composed of a variety of weapon systems. Furthermore, the deployment of guided missile ships should not necessarily be restricted to concentric rings around a defended point.

(2) The models employed in the 3T studies were mathematically deterministic containing no random or chance events and, as such, were concerned with system intercepts rather than the simulation of system kills. This, in turn, affected the

* References are listed at the end of the report.

realism of the fire coordination doctrine that was incorporated into the model, restricting model use to the analysis of highly stylized forms of attack. The attacks considered in the 3T study were mainly constant-altitude "point" raids, under the assumption that the point raid represented the most difficult unidirectional attack situation for the defenses to counter. Runs were also made involving single fire units against enemy "Indian file" or line-in-column formations with varying uniform spacings along the raid axis. While this type of analysis was considered to be adequate for purposes of the 3T studies, it lacked the flexibility and realism required to analyze the more general problem of task force antiair warfare (AAW). Even during the course of the 3T study, situations arose where the need for a Monte Carlo simulation model manifested itself. Such was the case whenever multiple-defense fire units were considered against enemy Indian-file attacks, a type of problem that the existing 3T study model could not handle.

(3) The enemy was restricted to the use of gravity bombs in weapon delivery. Some single-fire unit defenses were analyzed against enemy air-to-surface and surface-to-surface cruise missile attacks, wherein the enemy weapons were launched from points outside of defensive missile range. These ASM's and SSM's were assumed to carry nuclear warheads. In all cases of enemy bomb delivery, the computer games terminated when the first unengageable enemy weapon carrier reached his bomb release line. In the case of the ASM and SSM attacks, the games were terminated when the first unengageable enemy weapon reached a specified warhead overpressure contour related to the target under attack. No attempt was made to evaluate the effectiveness of enemy attacks against naval surface units under the varying attack conditions considered in the study.

(4) The model was exclusively concerned with the effectiveness of SAM systems and did not include the Airborne Early-Warning (AEW) or the air-to-air defense missile systems that are normally a part of a carrier task force AAW complex. From an engagement sequence point of view, the airborne elements of the defense are usually the first ones to become involved in an antiair operation. This was recognized in the 3T studies; however, the effects of early airborne system antiair action on SAM effectiveness were crudely taken into account by a parametric analysis, which considered variable "first detection" ranges on enemy attack formations and variable arrival rates of enemy attack aircraft against the SAM fire units. The first variation reflects the contribution of early warning to the SAM system capabilities; the second, a possible effect of early fighter/AAM engagements of a raid beyond the SAM zone, which would tend to "spread"

the enemy's attack formations by the time they came under SAM engagement. A more complete investigation of the possible interactions between SAM's and AAM's was, of course, not possible with the relatively simple models developed for the 3T studies.

(5) Effects of an enemy's employment of electronic countermeasures against TERRIER, TALOS, and TARTAR were treated only qualitatively in the 3T studies. The extent of performance degradations to be expected with each system when used in an environment in which the enemy makes use of chaff, noise jammers, or deception jammers could not be analyzed with the effectiveness models that had been developed. The need for further intensive research into methods that would permit the quantitative evaluation of the effects of ECM on AAW effectiveness was fully recognized at the time.

(6) The 3T models, as mentioned earlier, would not accommodate more advanced SAM system concepts, such as TYPHON, without considerable modification.

Following informal discussions with representatives of ONR, CNO (Op03, Op07), and BuWeps at the time of publication of the 3T reports, it became evident that the Navy had to face a number of significant problems relating to over-all carrier task force antiair warfare effectiveness that were far more sweeping in scope than the question of 3T system air defense capabilities. The TYPHON concept was now emerging as the definite "next-generation" shipborne air defense weapon system and the EAGLE (XAAM-N-10) showed promise of providing fighter aircraft with a much improved air-to-air weapon over the SPARROW III and the SIDEWINDER. Of concern to the naval weapons planners at the time was the question of how these new systems should be integrated into the task force AAW complex; indeed, were these new systems being proposed competitive or complementary in capabilities?

Following completion of the 3T studies, the next formal assignment to ONR/NWRC was made by CNO letter Serial 0190P91 of 13 April 1959 to the Chief of Naval Research. The observation was made in this letter that the program analysis type of study assignment was perhaps too broad to permit timely research findings in view of the fact that cost/effectiveness analyses must be performed in the "complex environment of naval warfare." It requested that NWRC undertake a parametric study of air-to-air missile systems, which would show the effects of varying the major functional components of the air-to-air systems on the task force AAW complex as a whole. The period 1970-75 was identified as the reference time frame for the study.

Recognizing some of the inherent limitations in the effectiveness work that had been performed to date and attempting to anticipate the Navy's needs for some thorough analytical efforts in the anti-air warfare area, the Office of Naval Research (Code 493) requested NWRC to embark on a program of developing techniques that would make it possible to evaluate the AAW effectiveness of an entire carrier task force of the future. This effort is described in more detail under Part 1.3, <u>Method of Approach</u>.

In December 1959, the NWRC task assignment of 13 April 1959 was modified to permit an early examination and comparison of the effectiveness of the proposed EAGLE and TYPHON system concepts in a realistic operational environment and to perform a study to derive a near-optimal weapons mix for task force AAW in the 1970 era. This incomplete study was terminated when the EAGLE program was cancelled in early 1961. A considerable amount of information was generated on the relative merits of current and planned surface-to-air and air-to-air systems; however, all of the results obtained pertained to a non-ECM attack environment. It was at this point in time that work started in earnest on the study effort that is the subject of this report. The final study objectives that evolved from continuing liaison with ONR (Code 493), BuWeps (RA, RM, R-5), and CNO (Op07), are described below.

## 1.2 Study Objectives

Briefly stated, the objectives of the current study are as follows:

(1) To develop a methodology that will permit the realistic evaluation of the effectiveness of an entire carrier task force antiair warfare complex in an electronic countermeasures environment.

(2) To determine the contributions to task force antiair warfare that may be expected from air-to-air and surface-to-air systems in the predicted naval warfare environment of the 1970-75 period. In so doing, this effort examines:

(a) The significance of airborne early warning to future task force AAW effectiveness;

(b) The contributions of surface-to-air and air-to-air missile systems to over-all task force AAW effectiveness;

(c) The degree of interaction between surface-to-air and air-to-air missile systems in defense of a carrier task force at sea;

(d) The effectiveness of proposed surface-to-air missile system concepts in order to establish a set of desirable characteristics for a 3T follow-on system; and

(e) Ways of increasing over-all task force AAW effectiveness in the 1970-75 time period through the introduction of advanced airborne system concepts compatible with the technological state of the art.

### 1.3 Method of Approach

At the outset of this study, three major problems presented themselves to the study group. The first had to do with the task of developing a flexible technique that would permit the analysis of advanced shipborne and airborne multichannel system concepts such as the TYPHON and EAGLE. The second had to do with the realistic treatment of firing doctrine compatible with the future tactical command and control system such as the NTDS/ATDS. The third was concerned with the problem of analytically assessing the effects of the enemy use of electronic countermeasures against defense missile systems and task force communication links. As a consequence, a two-pronged methodological approach was initiated. One approach was concerned with an examination of techniques for handling the analysis of advanced systems along with their employment doctrines without any consideration of degradations imposed on system performance by enemy electronic countermeasures. The other approach called for a parallel study of the fundamental effects of electronic countermeasures on the performance of missile systems, surveillance radars, and communications links.

Early in the "model development" phase of the study, it became clear that any realistic treatment of doctrine [NTDS Threat Evaluation and Weapon Assignment (TEWA), for example] called for analysis by Monte Carlo simulation since, with most practical firing doctrines, the next course of action is dependent on the outcome of the preceding engagement. There were several other reasons why simulation appeared to represent the most attractive analytical technique for study purposes; these are enumerated below.

(1) Simulation afforded an evaluation of AAW kills when realistic firing doctrines and missile-kill probabilities were incorporated into the analysis. The number of attacking targets destroyed by an AAW system is a performance measure of greater significance from an operational viewpoint than the number of intercepts the system can achieve.

(2) In a similar manner, the effectiveness of enemy attacks in disabling task force ships and their AAW weapon systems is a matter of importance to the eventual outcome of an air battle. Here again, the Monte Carlo technique permits an assessment of damage to fleet units during the course of the battle by those enemy weapons that succeed in penetrating the defenses.

(3) Simulation permits a fundamental treatment of radar performance in both ECM and non-ECM environments. The radar burn-through detection probability distributions as functions of target range can be generated directly for any raid/jammer geometry during the play of a game.

A high speed digital computer simulation, employing the CDC 1604, was selected as the most practical means for coupling sufficient detail and the desired degree of doctrinal and tactical flexibility with output of relatively high precision. Computer simulation programs were initiated for both clear and ECM environments.

The anticipated complexities of the radar detection and weapon assignment routines suggested the "time-incremented" game over the "event-store" game, although the computer model in its final form incorporates features of both game types. Furthermore, a one-sided game rather than a two-sided game was preferred for the problem at hand, since the computer models were being developed primarily for the purpose of analyzing weapon systems effectiveness rather than for the study of attack tactics and doctrine.

The development of the non-ECM or "clear" environment model was initiated and the start of a parallel effort to develop the ECM model occurred shortly thereafter. A corollary objective of the "two-model" approach was to achieve the rapid development of the clear model in order to satisfy partially the immediate CNO requirements for TYPHON and EAGLE information, described earlier. In attempting to respond quickly to this objective, certain desirable features could not be designed into the clear model. One such feature is that of radar resolution. In the clear model, enemy targets were always completely resolved at the time of initial detection and hence, at time of weapon assignment, perfect weapon target pairings were allowed. This procedure conformed with current practice in air defense modeling. The ECM model, however, treats resolution as a derived radar performance characteristic and actually simulates the resolution capabilities of each radar in a task force. As a result, weapon assignment doctrines can be evaluated more realistically, in that assignments are made to resolved "tracks" rather than to individual targets. The amount of tactical flexibility in the selection of enemy attack modes afforded by the ECM model is likewise vastly superior to that afforded by the clear model.

The clear model (which was debugged and running successfully by April 1961) was completely superseded by the ECM model in the spring of 1962 after it was determined that both models gave the same results for nonjamming enemy attacks. This latter model is described in Part 4.2.3.

A continuing interest in the status of weapon-assignment doctrines associated with NTDS and ATDS has been maintained throughout the course of the study because of the strong desire to incorporate doctrinal realism into the analysis effort. It was discovered that, while the NTDS TEWA was relatively well defined for SAM systems operating against "clear" targets, the problem of developing SAM doctrines for a jamming environment had remained largely unresolved. Furthermore, it appears that an ATDS doctrine for advanced air-to-air AAW systems is yet to be defined for any environment.

With respect to the surface-to-air systems, a successful effort was made to develop an ECM weapon-assignment doctrine that retained, in spirit, the essential features of the NTDS clear-environment TEWA. The task of doing as much for the air-to-air systems, however, turned out to be considerably more complex. As a consequence, a feature has been included in the computer model that allows fighter assignment doctrine to be treated (within limits) as a matter of input, rather than as a fixed procedure as in the case of the SAM's. This feature permits a suboptimization of air-to-air missile employment so that the maximum kill contributions to be expected from the airborne weapon systems can be explored.

In order to meet the objectives of the study, various future surface-to-air systems were analyzed in both single-ship and task-force operations. Some of this work was performed expressly for the present study, whereas some of it was accomplished under separate study assignments made by CNO and BuWeps. The strong dependence of the air-to-air systems on the Airborne Early Warning System (E-2A with AN/APS-96 radar) for initial vectoring information was, of course, recognized at the outset of the study. A subsequent analysis of AN/APS-96 detection capabilities under varying conditions of enemy jamming revealed inherent weaknesses in the performance of this radar when operating in an ECM environment. The problem of improving airborne AAW system performance in realistic attack situations narrowed down to one of first improving AEW radar performance. The value or utility of such improvements to the AEW radar can be measured directly by the resulting increased ability of the air-to-air missiles to destroy enemy attackers. Possible changes in assignment doctrine that may be desirable in the light of improved AEW radar performance must also be taken into account.

While in the process of investigating the active AAW effectiveness of fighters armed with air-to-air missiles, a promising alternative role for airborne systems in active and passive electronic warfare came to light. The feasibility and effectiveness of this new concept is also examined in considerable detail in this study.

### 1.4 Study Reporting Procedures

A reporting process was instituted for this study, which provided for a series of presentations, both formal and informal, to CNO, BuWeps, and ONR as study results of significance became available. These results were further documented in a series of Technical Memoranda (TM) and Research Memoranda (RM). Generally speaking, the Technical Memoranda represented collections of tactical and technical input information, obtained from Navy sources and assembled in a convenient manner for purposes of further analysis. The Research Memoranda actually present the results of analyses performed by NWRC in connection with the study.

In addition, a series of papers concerned with certain aspects of analytical model development were presented to MORS (Military Operations Research Symposia) and ORSA (Operations Research Society of America) during the course of the study. Study findings were also the subject of a paper presented to the Joint IAS/Navy meeting of August, 1961.

This report summarizes all of the pertinent information contained in the supporting publications associated with this study and presents for the first time new work described in Part 5.3 and Section 6. At the same time, it also provides for some updating of the earlier information wherever necessary. It will be noted that the back-up RM's and TM's are frequently referred to in this document for the benefit of the reader desiring to explore a particular aspect of the AAW analysis in more detail.

### 1.5 Current Study Limitations

There are certain limitations in both the scope and analysis of the current study that deserve emphasis. These are:

(1) The study is restricted to the problem of carrier task force AAW at sea in limited, conventional warfare. The related problem in an amphibious operation, for example, would involve a land sea interface, with attendant obstacles to system performance--such as the terrain masking of radars and ground clutter. In addition, there would be pronounced changes in enemy offensive tactics. Factors such as these could significantly affect the outcome of an effectiveness analysis were the warfare environment to be changed.

(2) The computer simulation model is presently capable of treating steady enemy noise jamming only. The effects of other forms of electronic countermeasures on the AAW system complex--such as blink jamming, chaff, repeater jamming, gate stealing, etc.--cannot be analyzed with the model as it now stands, although steps are underway to expand model capabilities in this respect. Steady-spot or barrage-noise jamming was selected for the initial effort to simulate ECM in a fundamental manner because it appears to be a very likely form of jamming to be employed by Communist forces in future anti-task force operations.

(3) The present analysis includes the employment by the task force of various active and passive counter-countermeasures. It does not, however, incorporate the effects of friendly electromagnetic interference on task force electronic systems, nor does it treat the use of active electronic countermeasures by the task force against enemy radars and weapon systems.

(4) An analysis of advanced fighter/AAM systems in an ECM environment has not been completed at the time of report preparation. Thus, the conclusions relating to advanced air-to-air system effectiveness are qualitatively derived from earlier clear-environment studies, a series of hand analysis efforts, and ECM computer simulation runs with current and near-future air-to-air systems.

## 2. SUMMARY AND CONCLUSIONS

### 2.1 Study Summary

#### 2.1.1 Introduction

The present study examines the anti-air warfare* capability of carrier task forces at sea in limited, conventional warfare. Neither the attackers nor defenders resort to the employment of nuclear weapons or warheads. The time period being considered is 1970-75.

The study integrates and places in perspective the results of a series of more or less independent analyses carried out over a number of years for various activities in the Naval Establishment. The purpose of the present report is to present a résumé of the entire analysis effort and from the more detailed study findings, derive a set of broader conclusions relating to the problem of future task force AAW.

The objectives of the study, as presented in Part 1.2, are repeated here for convenience:

(1) To develop a methodology that will permit the realistic evaluation of the effectiveness of an entire carrier task force AAW complex in an electronic countermeasures environment.

(2) To determine the contributions to task force AAW that may be expected from air-to-air and surface-to-air systems in the predicted naval warfare environment of the 1970-75 period. In so doing this effort examines:

   (a) The significance of airborne early warning to future task force AAW effectiveness;

   (b) The contributions of surface-to-air and air-to-air missile systems to over-all task force AAW effectiveness.

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* The term anti-air warfare is used in a restricted sense in that the study effort does not treat the strike effectiveness of a carrier force in neutralizing enemy air bases (a fundamental element of the anti-air warfare concept). See OpNav Notice 3320 of 12 March 1960.

(c) The degree of interaction between surface-to-air and air-to-air missile systems in defense of a carrier task force at sea.

(d) The effectiveness of proposed surface-to-air system concepts in order to establish a set of desirable characteristics for a 3T follow-on system.

(e) Ways of increasing over-all task force AAW effectiveness in the 1970-75 time period through the introduction of advanced airborne system concepts compatible with the technological state of the art.

The discussion that follows describes the degree to which study objectives have been met and summarizes the research findings in each of the objective areas.

2.1.2 Objective (1)

It was established that this task, as outlined, could only be satisfactorily accomplished by the development of a computer simulation model. The program for such a model has been written and is described in Part 4.2.3. It permits the simulation of all of the AAW elements in a task force including the Airborne Early Warning (AEW) aircraft and their radar systems; carrier-based fighter aircraft, their Airborne Intercept (AI) radars and air-to-air missile systems; and the surface units of the task force (carriers, replenishment ships, missile ships) operating either on picket stations or in the main body, with their air search, hemispheric scan, and fire control radars (as appropriate). The various shipborne surface-to-air missile systems are simulated as well as the tactical command and control systems (NTDS/ATDS) and their data/communication links. The computer program has been written to allow for a large degree of flexibility in the composition and deployment of friendly forces as well as in the composition of the attack, the attack formations and attack tactics. Enemy use of broadband barrage jamming against any or all of the fleet radars (shipborne or airborne) can be simulated as can the effects of enemy jamming on fleet communications and data links.

The computer program provides for variations in the enemy selection of surface targets in his attacks against the task force as well as for flexible attack emphasis on ships of the force. No provision exists at the present time, however, for enemy destruction of airborne units. As ships are sunk or disabled during the enemy attack, their radars and missile units (if they are so equipped) are removed from the game. This feature of the model, aside from providing air-battle realism, allows for the use of an "ultimate" measure of effectiveness in evaluating the relative performance of various task force weapons mixes, i.e., the identification of those units surviving the air battle.

The program is divided into distinct subroutines. These subroutines are, in effect, building blocks or modules, which can be independently modified as necessary so that desired changes in game structure involve only a minimum of reprogramming effort. The performance of individual defense elements or any grouping of such elements can be analyzed as removed from the environment of an entire task force. This is sometimes desirable when one wishes to test the sensitivity of defense element performance to variations in system design or threat parameters. Examples of the use of the computer program in this manner are presented in later sections of this report (Parts 5.2.1 and 5.3).

As more experience has been gained in exercising the model, it has become increasingly apparent that the technique of simulation provides a powerful tool for obtaining answers to certain types of AAW problems, particularly those involving electronic countermeasures. It would be most desirable to relate the results thus obtained with those of fleet exercises and operations. To date, however, the opportunity for direct comparisons between analysis and operations has been extremely limited.

It is a well-recognized fact that the results of an analysis are certainly no better than the inputs representing equipment performance parameters, operations execution times, and probability factors of one sort or another that are introduced into the analytical model. When one is dealing with future systems, these input parameters are, in turn, the results of engineering analyses or, at worst, predictions based on extrapolations of existing information. Unfortunately, they are often in time proven to be overly optimistic or pessimistic, thereby having a biasing effect on the results of broader analyses (such as operational gaming) in which they may be used. The problems of input aside, for the moment, there still remains the problem of establishing the validity (in a real world sense) of the model itself. Until realistic inputs are provided and model validity established, computer simulation cannot be relied upon to give absolute answers to operational problems. Their value rather lies in their ability to provide relative effectiveness answers as many facets of the offense and defense are varied.

2.1.3 Objective (2)

To satisfy this set of objectives, NWRC had recourse to a number of studies performed over the period 1961-64. The following three tasks were assigned to NWRC by the Office of Naval Research (Code 493):

(1) 1970-Era Task Force Antiair Warfare Effectiveness Against Low-Altitude Conventional Weapon Attacks (Non-ECM)

(2) AEW Detection Capabilities in an Electronic Warfare Environment

(3) The Role of Airborne Platforms in Future Task Force AAW.

In support of these tasks, four further study efforts were undertaken by the NWRC for ONR. These were:

(1) Air Attack Threat to a Task Force at Sea (1970-75)

(2) Enemy Anti-Fleet Reconnaissance Capabilities (1970-75)

(3) Attack Carrier Task Force Composition, Deployment, and Operations in the 1970 Era

(4) Availability and Deployment of Carrier Task Group CAP and AEW Aircraft in Antiair Warfare.

In addition, the following ad hoc tasks were requested by CNO (Op07):

(1) Multiplex Operation of TERRIER and TALOS

(2) Determination of Effectiveness for Three Variations of TYPHON DLG

(3) Determination of SEA MAULER Effectiveness in an Attack Carrier Task Force Environment.

All of the above studies are presented in NWRC Research Memoranda, which are listed in the Reference section of this report. The information derived from the above study efforts has been updated and is summarized in Secs. 3 through 6. In some instances, additional analysis has been performed in an attempt to fill some of the gaps that were found to exist in the analytical coverage of the total AAW problem.

The approach wherein separate studies are integrated into a single cohesive study effort gives rise to certain difficulties. This is particularly true when the period of investigation extends over a number of years. On the one hand, certain systems that were analyzed have been victims of cutbacks in the defense budget. On the other hand, there are bound to be inconsistencies in the defense/attack situations analyzed as specific study assignments varied or as the simulation model was modified to incorporate improvements in analysis technique. In short, the procedure being followed in the present study is generally less satisfactory than conducting, for example, one large study of comparable scope in a shorter time span wherein one could ensure a much greater consistency of study design and purpose.

Despite the inconsistencies in study design and analytical treatment mentioned above, a valid set of broad AAW conclusions can be derived from the various individual study efforts. Such a set of conclusions is presented in Sec. 2.2. They are also discussed to some extent below in connection with Objectives (2a) through (2e).

2.1.3.1 Objective (2a)

The airborne early warning concept has been subjected to repeated examinations during the course of this study. Its main value lies in the fact that it permits the placement of sensors away from and above the ships of the task force main body. The benefits thus accruing to the task force are two-fold. The horizontal displacement affords earlier detections of an approaching enemy so that carrier-based fighter aircraft can be vectored in sufficient time toward the raid whether the fighter aircraft are pre-positioned on Combat Air Patrol (CAP) stations or whether they are to be launched from the carrier decks. The vertical displacement provides for earlier detections of low-flying enemy aircraft, overcoming the serious radar horizon limitations associated with surface-based search radars. While picket ships can exploit the principle of horizontal displacement from the main force, their inability to detect low fliers at long enough ranges requires that large numbers of these ships be placed around the force to ensure unbroken coverage of the low-altitude attack corridors. The same problem can be solved with a much smaller number of AEW aircraft (two to four, for example). Relating this discussion more directly to task force AAW operations, the AEW concept provides for earlier vectoring of interceptors and the timely alert of impending attack to the surface missile units. If the enemy chooses to deliver the attack from low altitude, SAM system effectiveness would be seriously degraded without the warning provided by AEW radars.

The present E-2A/APS-96 AEW system has been carefully analyzed in this study. In a non-ECM environment, it lived up to all expectations in performing the functions described above. In a noise jamming environment however, the performance of the AN/APS-96 radars is degraded, affecting in turn the subsequent effectiveness of the entire task force AAW complex. On the one hand, it was determined that the AN/APS-96 was relatively invulnerable to stand-off noise jamming. On the other hand, the radar in its present form was found to be exceedingly vulnerable to self-screening (or main-lobe) jamming. In the presence of such jamming, bearing information can be obtained on the jammers by strobing with the AN/APS-96 radar and, with two AEW stations, passive ranging can be performed in accordance with the SYNTRAC concept (described in Appendix C). This concept was initially developed to provide surface-to-air missile systems with approximate open-fire range information on jamming enemy aircraft and its utility in vectoring fighter aircraft against a jamming raid was only subsequently explored. In brief, it has been determined that SYNTRAC proves to be of greater value to surface-to-air systems than to air-to-air systems for the following reasons:

(1) SAM's generally have greater ranges than AAM's and can tolerate larger errors in target position determination.

(2) SAM fire units are each supplied with a much larger number of missiles than can be carried by fighter aircraft, so that a greater number of aborted shots can be tolerated in the former case if SYNTRAC target range errors happen to be large.

(3) Surface ships are generally faced with a closing range-to-target situation as long as they are the objective of enemy attack activity, whereas the corresponding situation for fighters is more ambiguous.

The SYNTRAC concept has not been thoroughly explored in this study. It has been ascertained, for example, that an enemy can confuse SYNTRAC, as it is presently defined, by creating large range errors through the employment of rather extreme formations of jamming aircraft. It appears certain that elements of a widely separated jamming attack can be resolved in angle by SYNTRAC but such resolution, in turn, introduces a "ghosting" problem. Further study is deemed necessary and desirable to determine if a measure of "deghosting" cannot be effected through the observation of time-histories of strobe intersections coupled with the examination of these intersections with other fleet radars. In this manner, a large number of false targets could be eliminated and the remainder could conceivably be assigned to AAW weapon systems for engagement.

If the AEW aircraft are to perform a passive tracking mission effectively for the task force, they must be equipped with passive receivers to detect jamming on all fleet search and tracking radar frequency bands. In the present study, this capability has been assumed for the AEW.

2.1.3.2 Objective (2b)

A wide spectrum of surface-to-air missile system concepts was examined in the present study. These concepts ranged from the quick-reacting, high-rate-of-fire, short-range systems of the SEA MAULER variety up to the extremely complex, multichannel systems employing fixed-array radars and advanced ECCM techniques such as the 200 nm long-range TYPHON. The air-to-air missile systems, for reasons to be stated in Part 2.1.3.5, were never subjected to as complete an analysis. One advanced long-range air-to-air system was examined in a non-ECM task force environment (Part 5.4.2) using the Clear Environment Simulation Model described in Part 4.2.2. The performance of such a system under conditions of enemy jamming, however, has not been evaluated at the time of this writing. It was initially believed that some information relative to advanced air-to-air system effectiveness in an ECM environment could be extrapolated from such an analysis performed with the F-4B SPARROW III (Part 5.4.3). A careful evaluation of these results revealed that such an extrapolation could not be justified. For one thing, the extreme sensitivity of AAM system performance to employment doctrine was noted. The question of doctrine, on the other hand, is tightly interwoven with such considerations as the level and mode of enemy jamming, air-to-air missile launch range and type of guidance, warhead lethality, and the characteristics of the fighter AI radar. Examination of the entire assignment-through-intercept process for the F-4B under conditions of jamming revealed that numerous trade-offs might be involved in the case of an advanced AAM system under similar circumstances, so that the final effectiveness outcome for such a system was not at all clear.

The series of analyses presented in Sec. 5 do, however, shed significant light on the broad problem of task force AAW. With respect to surface-to-air systems, they point up the vast improvements in fire-power and kill effectiveness afforded by those system concepts employing fixed array guidance and tracking radars such as the AN/SPG-59. Indications are that two carrier task forces of the future* can withstand multi-level, multi-directional jamming attacks of from ninety to one hundred aircraft employing stand-off weapons with release ranges of 100 to 200 nm, suffering in the process ship losses of about 15 to 30 percent (Part 5.2.2.1). Similar task forces, on the other hand, equipped with advanced versions of TERRIER, TALOS, and TARTAR, are totally unable to survive such an attack. It is recognized that the size of the attack being postulated represents an upper bound in the force levels that an enemy could muster under the warfare conditions being considered in this study.

* Such forces, as analyzed, are accompanied by eleven missile ships, of which three are fitted with advanced SAM's.

The impressive performance of the advanced SAM systems, as exemplified by the TYPHON concept, can be traced to the simultaneous engagement capability and the ECCM characteristics of the guidance radar. With such radars, a very high rate of fire can be maintained, which not only enhances system effectiveness against targets at medium and high altitudes, but also overcomes to a significant degree, through the reduction of guidance channel availability restraints, the firepower limitations imposed by radar horizon against low-flying attackers. The relative invulnerability to noise jamming manifested by TYPHON stems from the high level of radiated power generated by the AN/SPG-59 radar coupled with pulse-to-pulse frequency diversity. In the course of analysis, it was determined that enemy employment of even jamming power densities of the order of 200 w/Mc did not seriously degrade the performance of the system. A more modest version of the TYPHON concept employing a rotating phased array (ROPAR) radar was examined in the study (Part 5.2.1.2). It, too, shows promise of firepower levels that are significantly greater than those associated with the 3T family of systems. Its performance in a jamming environment, however, was not analyzed.

The desirability of introducing a short-range, quick-reacting system such as SEA MAULER into the task force complement of defense weapons, was examined from an effectiveness standpoint. It was assumed that such a weapon system would be compact enough to permit its installation in place of existing 3"/50, 5"/38 and 5"/40 gun mounts aboard the ships of the task force. Its major function was considered to be that of "last-ditch" self-defense wherein it is only used in defending the ship on which it is installed against imminent hostile enemy action. This weapon concept was examined aboard a variety of single ships (Parts 5.2.1.2 and 5.2.1.3) where it was used as either a primary or a secondary missile battery. Furthermore, both coordinated and autonomous modes of operation were considered. In the former instance, battery tie-in with CIC and the ship's search radars was effected; in the later instance, the SEA MAULER battery was forced to acquire its own targets with an organic local acquisition radar. The system concept was further tested by introducing it into the 3T task force mentioned previously that had been overwhelmed by a rather large enemy attack (Part 5.2.2.2). Considerable improvement in defense effectiveness was noted in this case. It has been determined, however, that the degree of effectiveness improvement that can be attained with such a system depends very strongly on the performance of the primary supporting SAM systems (i.e., TERRIER, TALOS, TARTAR). The results obtained, for example, were extremely sensitive to home-on-jam (HOJ) capabilities assumed for the 3T systems, for this factor directly affected the amount of enemy jamming that would still be present at the time targets had closed sufficiently with the task force to be engaged by the short-range SEA MAULER. In short, its effectiveness when supported by longer-range SAM's is impressive. However, ships equipped solely with SEA MAULER and operating independently are not self-sufficient in their defensive capability against several likely forms of attack.

In general, it was found for all SAM systems tested in a task force environment that the number of rounds fired that failed to intercept (termed "aborts") was surprisingly high (approximately 40 to 50 percent). The reasons for the occurrence of these aborts are listed in Part 4.1.2. It does not appear that this phenomenon can readily be avoided, since most of the aborts can be attributed to the lack of perfect information by the defense. The implications with respect to SAM replenishment of missile ships may indeed be serious, especially if the enemy has a fairly rapid reattack capability. The observations made in the present study relative to task force AAW are, of course, based on only a single attack.

The possibility of improving the firepower of TERRIER and TALOS by multiplexing with a hypothetical track-while-scan search radar has been examined in the study. This guidance scheme involves the use of a low-data-rate, multichannel search radar for missile mid-course guidance, with the missile-tracking radar being employed for terminal guidance only. It was found that this mode of operation effected a 175 percent increase in TALOS firepower over two-channel simplex operation* when engaging wave

* The normal mode of system operation in which two guidance radars are employed with each launcher. These radars are used throughout the entire flight phase of the missile to control intercepts.

attacks at 35,000 ft in a non-ECM environment. The shorter-range TERRIER experienced a 67 percent firepower increase under the same conditions. Against low-altitude attacks, multiplexing increased the firepower of both systems by a comparatively modest but sorely needed 20 to 25 percent. While the multiplex concept does provide for significant firepower increases in a clear environment (favoring systems with longer ranges), its capabilities under conditions of jamming would depend strongly on the ECM vulnerability of the search radar. Presumably, however, the system could be designed to revert to the two-channel simplex mode of operation whenever search radar performance is seriously degraded by ECM.

It is firmly believed that further analysis is required in order to determine more precisely the capabilities and limitations of air-to-air systems under conditions of enemy jamming. Nevertheless, several significant factors concerning AAM systems were observed during the course of this study. In the first place, they were found to complement the SAM's most effectively in countering non-ECM attacks delivered at low altitudes (Part 5.4.2). In fact, AAM system effectiveness was determined to fall off with increasing attack altitude, whereas SAM effectiveness, because of radar horizon limitations, was generally found to increase significantly with the height of attack. Thus, on a percentage basis, the air-to-air contribution to over-all task force AAW showed up very strongly in low-level attack situations in a non-ECM environment.

Secondly, based on results obtained in a non-ECM environment, the contribution to be made by an advanced long-range AAM system with the capability to engage up to six targets simultaneously appears to be vastly superior to that that can be expected from the present generation F-4B SPARROW III system (Part 5.4.2). It is believed that this advantage would more than likely be retained in a countermeasures environment, although no analysis effort to support such a conclusion has been performed for this study.

A third factor relates to the extreme sensitivity of the effectiveness of present-day short-range AAM systems to the doctrines governing the employment of fighter aircraft against jamming attacks (Part 5.4.3).

It is strongly believed that further doctrinal studies will result in a much better understanding of the interactions between airborne system employment doctrine and system performance. For example, the brief doctrinal analysis presented in Part 5.4.3 revealed that a relatively unsophisticated passive ranging technique employed by the task force using two AEW aircraft was inadequate to provide fighters with target ranges of sufficient accuracy to permit the firing of AAM's in a home-on-jam mode. Consequently, the only successful engagements made by fighters were made in a mode wherein burn-through was achieved on their AI radars. These facts were substantiated by introducing appropriate doctrinal changes into the game governing the conditions under which fighters could launch AAM's against jamming targets. In this instance it is perhaps fortuitous that the jamming power density on AI radar frequency attributed to the enemy was extremely low (2 w/Mc) so that AI radar burn-through was indeed possible. It is estimated that higher levels of jamming on X band on the order of 20 w/Mc, for example, would have ruled out the possibility of any fighter engagements at all. Nevertheless, this study has pointed up the need for improving the fleet's passive ranging capabilities on elements of a jamming raid so that range errors are not in excess of about 20 percent of the AAM maximum range, if an air-to-air system capability is to be maintained in the face of higher jamming power levels. Such an improvement in passive ranging capability would, in turn, most likely effect a change in optimal employment doctrine.

Finally, it appears that some of the advanced SAM system concepts analyzed in this study are so effective as to be relatively self-sufficient regardless of the attack situation, provided an enemy is restricted to the delivery of nonnuclear weapons. If systems with the predicted capabilities of TYPHON were to be developed, for example, there would be little need for the additional support to be derived from fighters armed with air-to-air missiles. On the other hand, the enormous complexity of TYPHON and the high cost of developing such a system has already resulted in a sharp curtailment of the program. It is more than likely that a more modest, less costly system that can perhaps be fitted to smaller ships will be forthcoming in its stead. System effectiveness, too, may be compromised to a certain extent when compared with TYPHON. Under these circumstances, an advanced AAM system could perhaps be employed to advantage. If the AAM delivery aircraft furthermore had the capability of performing attack and ground support missions, then the carrier deck space that they require would not be lost to the task force for its primary mission, namely strike.

2.1.3.3 Objective (2c)

In the course of the earlier program analysis of the TERRIER, TARTAR and TALOS missile systems, it was established that the AAW effectiveness of these surface-to-air missile systems was quite sensitive to the arrival rate of enemy attack aircraft. In effect, the kinematic limitation on systems firepower was relaxed as the intertarget time spacing, $\tau$, was increased. It was anticipated at the outset of the present study effort that the friendly airborne missile systems of the task force could enhance the effectiveness of the surface-to-air missile systems by selectively thinning out the raid formation, thereby inducing an effective intertarget spacing in the residual raid. However, for the raid formations and attack tactics generated in the course of the several study efforts discussed above, it was found that such was not the case. Realistic attack tactics on the part of an intelligent enemy generally involve the concept of simultaneous arrival of the weapon-carrying aircraft so as to achieve maximum saturation of the AAW system over as short an interval of time as possible. Under such conditions, the contribution of the air-to-air missile systems can only be to lessen the number of attack aircraft that the surface-to-air missile systems must counter. No true interaction was found to exist against such enemy tactics in the clear environment. The surface units are particularly vulnerable to low-altitude enemy attack tactics and the interceptor aircraft can provide an invaluable supplement to the task force AAW capability against such raids. Such assistance is not, however, correctly termed a systems interaction.

Another form of possible systems interaction is that concerned with sector control and zones of exclusion. By doctrine, the interceptor aircraft may be prohibited from engaging targets that have penetrated a surface-to-air guided missile (SAGM) zone or conversely, the surface-to-air systems may be prohibited from making missile assignments to targets located in the vicinity of the known position of friendly airborne units. Generally, a buffer zone, or no-man's land, would be provided between the engagement zones to allow for a margin of error in position determination and to allow for completion of tail chase engagements originated in the air-to-air missile zone. In the present analysis, the interceptor aircraft were generally excluded from the SAGM zone, which was described in three dimensions, i.e., the radius of the exclusion zone is a function of interceptor altitude, reflecting the radar horizon limitations of the surface units.

The exclusion zone principle will work well in practice, being amenable to control by virtue of its simplicity. On the other hand, the free intermingling of AAW forces during the course of an air battle requires the implementation of two basic factors:

(1) A positive method of identification--friend-or-foe (IFF)--that is not vulnerable to jamming or deception; and

(2) A method of precise target identification and surface-to-air missile intercept control in closely spaced, multiple-target situations.

A detailed exploration of this type of systems interaction was not performed in the course of the present study.

In the ECM environment, however, a strong interaction of another sort was found to exist between the surfaceborne and airborne missile systems. When enemy jamming aircraft are employed in coordination with the weapon-delivery vehicles, severe radar burn-through and missile guidance problems are encountered by the defensive forces. The shipborne missile systems, particularly those of the present generation, are notably vulnerable and helpless to counter the effects of jamming aircraft that stand-off from the task force beyond maximum surface-to-air missile system ranges. Interceptor aircraft can be used to seek out and destroy such enemy jamming aircraft with the aid of a passive position fixing scheme such as SYNTRAC. Thus, the target kills achieved by the airborne missile systems may have a profound effect on the over-all task force defense effectiveness by providing the shipborne radar and missile systems a "cleaner" environment in which to operate.

There is yet another form of possible interaction between airborne and shipborne AAW systems that presents itself when the fix-denial concept described in Sec. 6 is considered. This concept relates to the noise or deception jamming of enemy target spotter radars by friendly airborne jammers remotely located from task force center. In confounding the enemy with respect to his target location ability, it is believed that enemy weapon release can be delayed, presenting the SAM systems with a greater opportunity to engage weapon-carrying aircraft rather than the stand-off weapons themselves. It is proposed in Sec. 6 that all task force ships maintain a condition of strict electronic silence while friendly airborne ECM platforms are engaged in deception jamming. The employment of such tactics will interact with SAM system performance in that a quick-reacting, high rate-of-fire system of moderate range will probably prove to be most effective, once the enemy is successful in overcoming friendly jamming efforts.

2.1.3.4 Objective (2d)

The systems analysis work performed in Sec. 5 of this study points to certain conclusions relative to an effective follow-on surface-to-air system to the 3T family of ship-launched weapons. The most critical factors involved in the effectiveness of SAM systems appear to be:

(1) Maximum system intercept range,
(2) System rate of fire, and
(3) Guidance subsystem ECCM characteristics.

Each of these are briefly discussed in Part 5.5.1.

Long-range SAM systems seem to be incapable of intercepting enemy aircraft delivering stand-off weapons against fleet units, prior to weapon launch.* More often than not, the long-range SAM system will be forced to engage enemy weapons rather than aircraft. The firepower vs. attack altitude characteristics of these systems in either an ECM or non-ECM environment are such as to cause an intelligent enemy to favor low-level attacks against fleet units if his losses are to be minimized. A SAM system of moderate maximum range (such as 40 nm) can be developed to deliver high firepower against low-altitude attackers. These missiles are smaller and lighter than their long-range counterparts and thus can be handled and launched more rapidly. Since launcher reload cycle time is a critical parameter in the low-altitude attack situation, the 40-nm system will generally outperform one of the longer maximum range (i.e., 100 or 200 nm) when operating against such attacks.

It is important that the system being proposed include surveillance and tracking/guidance radars with ECCM characteristics that will permit virtually undegraded system performance in the presence of enemy ECM, even though the attainment of this objective dictates the use of a radar that would be considered over-designed for the system in a non-ECM environment. One way of minimizing system ECM degradation in a noise jamming environment would be by firing on "burn-through" only, if radar burn-through ranges against likely levels of enemy jamming are such to afford intercepts at maximum missile range. In general, such invulnerability to countermeasures can more readily be achieved with a system that includes a missile of more modest maximum range than the 100 or 200 nm ranges associated with some of the proposed systems of the past.

It is also imperative that the guidance radar subsystem provide for a multiplicity of missile-guidance channels so that several missile target engagements can be carried out simultaneously. In this manner the firepower at low altitude (and, for that matter, at all altitudes) can be maintained at a high level, despite the fact that the system range is relatively short. A guidance technique that relies upon a series of

* See Parts 5.2.2, 5.5.1.

electronically scanned beams generated by the tracking radar for mid-course guidance of the missile and the short-term utilization of an illuminator for terminal guidance, appears to provide the highest fire-power capability short of the highly complex guidance system associated with TYPHON.

Such a SAM system would exhibit relatively constant firepower with altitude of attack, or, perhaps, a slight increase in firepower with increasing altitude. It would presumably retain these characteristics even under high levels of expected ECM. This SAM system should be complemented by an advanced airborne missile system whose major roles would be raid reconnaissance and the long-range engagement of weapon-carrying aircraft, stand-off jammers, and "spoofers." If the air-to-air systems are to be excluded from the surface-to-air guided missile zone, a SAM system of more moderate range will, in addition, provide greater freedom of action for the fighters through a reduction in the size of this zone of exclusion.

A cost analysis and additional effectiveness studies are required to provide further validation of the above rationale. Nevertheless, it is believed that the combination of systems being proposed represents an effective division of defense responsibility and the most efficient utilization of defense resources.

2.1.3.5 Objective (2e)

The very recent completion of the air-to-air missile portion of the simulation model has made it impossible to explore the effectiveness of advanced airborne missile system concepts in an ECM environment. For reasons discussed in Part 2.1.3.2, it was deemed inadvisable to attempt an extrapolation of results obtained with a present day 3T task force (TERRIER, TALOS and TARTAR) and F-4B/SPARROW III into conclusions that might pertain with airborne systems such as F-111B/PHOENIX.

Bypassing the kill effectiveness of future air-to-air systems, an investigation was made of an alternative anti-fix role for fighter aircraft (Sec. 6). If, despite advances made in reconnaissance techniques, it is assumed that an enemy must still locate fleet units with a target-spotter radar prior to weapon launch, then the possibility of jamming these radars becomes an exceedingly interesting one. The present study examines the use by the defending forces of noise jamming and pulse repeaters against a postulated Soviet target spotter radar of the 1970 era. It is concluded that such a jammer could be incorporated into a 1000-lb package occupying a volume of 40 cu ft. Estimated airborne jammer weight and size are of such magnitude as to allow a fighter such as the F-111B an additional payload of four PHOENIX air-to-air missiles so that the aircraft could possess a dual AAW mission capability if it were so desired. An even more attractive platform for an airborne jammer appears to be the light helicopter (gross weight of approximately 4000 pounds). Such a vehicle can fly at speeds that match the task force speed of advance; yet it has the capability of high enough speeds to allow it to be properly stationed for its jamming mission once the force receives early warning of impending hostile action. The cost of the helicopter is relatively low and it can be carried aboard all screening ships of the task force (destroyers or larger). In this manner the further sacrifice of valuable CVA deck space for a special-purpose aircraft can be avoided. It is believed that the helicopter-borne jammer concept described in Part 6.5 would minimize interference with the primary AAW or strike missions of the fighter aircraft carried aboard the CVA.

The airborne jammer would be automatically tuned over a range of 1000 Mc in X band to produce an output of 8 to 10 kw of broadband noise within a 20 Mc bandwidth. Thus, a noise power spectral density of 500 w/Mc would be produced; this power would be radiated from an antenna with 10 db gain. Such jamming power densities, when coupled with a suitable positioning of the jamming aircraft, could be used to screen the ships of the task force against enemy attempts at target localization, particularly when the attackers are at relatively long ranges from the fleet. At shorter ranges, the airborne jammer could be used in a pulse repeater mode, thus generating false ship targets so as to confuse the enemy and delay the process of target localization.

Airborne platforms offer several advantages over the use of ships for this purpose. A ship, for example, by using pulse repeater jammers, can only generate false targets that appear at greater ranges than the ship itself and that are further restricted to a line of bearing that coincided with the line of sight from the ship to the enemy radar. Jamming aircraft, on the other hand, can take stations ahead of or flanking the task force and in this manner generate false target positions that are removed from actual ship positions.

The expected utility of airborne jamming is examined in detail in Part 6.4. Since the simulation model developed for this study does not, in its present form, allow for the employment of ECM by the task force, no attempt has been made to measure the effectiveness of the concept described above.

## 2.2 Conclusions and Recommendations

Study conclusions and recommendations are presented in this section. They are grouped for convenience under three major headings: Technological, Operational and Methodological. In brief, the conclusions listed under the technological heading relate to system effectiveness and performance; those under the operational heading are concerned with operating doctrines and the employment and deployment of AAW elements, whereas those under the methodological heading pertain exclusively to analytical methods and techniques.

### 2.2.1 Technological Conclusions

- Present-day surface-to-air system concepts as represented by the 3T systems are inadequate, despite firepower and ECCM improvements that can be made, to provide a task force of the 1970-1975 era with effective AAW capability. Furthermore, short-range air-to-air systems--such as F-4B/SPARROW III--are incapable of filling the AAW gap. The achievement of an interim improvement in AAW effectiveness could be accomplished by the addition of a short-range, quick-reacting SAM system of the SEA MAULER variety to the present task force weapon complement.

In order to establish adequate levels of effectiveness for the future, however, a most promising course of action appears to consist of the development of a medium-range advanced SAM system to be complemented by an advanced air-to-air system. It is concluded that the advanced surface-to-air system should have the following characteristics:

(1) A maximum range capability of about 40 nm.

(2) High firepower against small targets (ASM's) at low altitudes. This can be achieved by designing into the system the capability for controlling several intercepts simultaneously and by providing for rapid launcher reload.

(3) Surveillance and tracking/guidance radar ECCM characteristics that will permit virtually undegraded system performance in the presence of likely enemy stand-off or self-screening jamming. The attainment of this objective is extremely important, even though it dictates the use of a radar that would be considered over-designed for the system in a non-ECM environment.

In the 1970-75 era, the system will in most instances be forced to engage enemy stand-off weapons rather than delivery aircraft. The long-range engagement of weapon delivery aircraft, stand-off jammers and "spoofers" might best be accomplished with an advanced air-to-air system. (Parts 5.2.1.1, 5.2.1.2, 5.2.2.1, 5.2.2.2, 5.2.2.3, 5.2.2.4, 5.4.2, 5.5.1)

• Advanced surface-to-air missile system concepts, as examplified by TYPHON, are vastly superior to their present day counterparts (TERRIER, TALOS, TARTAR). Such advanced systems operating in a task force environment against upper-bound enemy attacks compatible with limited warfare would assume most of the AAW burden. (Parts 5.2.1.1, 5.2.1.2, 5.2.2.1, 5.2.2.2, 5.4.2)

• The importance of an effective home-on-jam capability against multiple jamming targets, particularly for the air-to-air and the longer-range surface-to-air missile system cannot be overstressed. Analytical and experimental investigations of this problem area are urgently needed to establish the degree of present day home-on-jam effectiveness as well as to provide guidelines for future technical improvements. (Parts 2.1.2, 5.2.2.3, 5.2.2.4, 5.5.1.3, 5.5.4)

• Surface-to-air and air-to-air systems with an HOJ capability must be provided some estimate of range to their prospective target. To satisfactorily utilize a system with HOJ capability, this estimated range should not deviate from the true range by an error in excess of about 20 percent of the maximum range of the missile under consideration. On this basis, a short-range air-to-air missile system--such as SPARROW III--to be satisfactorily utilized in an ECM environment, requires a fairly accurate estimate of target range. There is no known technique for providing this information to the required accuracy at the present time. On the other hand, range estimates for such systems as PHOENIX are not as critical. And, in fact, such triangulation schemes as SYNTRAC seem to provide data of a sufficiently accurate nature. (Parts 5.4.4, 5.5.1.3, Appendix C)

- The airborne early warning aircraft, by virtue of their altitude and displacement forward of task force center, provide an ideal source of jamming strobe information for a passive triangulation position fixing scheme. The AN/APS-96 radar sets aboard these aircraft should be designed to be capable of obtaining clean strobe data to the degree required by the SYNTRAC triangulation concept discussed in Part 4.2.3 and Appendix C. Further, since it is quite likely that an enemy would employ complex, multidirectional, phased attack tactics with nonhomogeneous jamming configurations, a pressing need also exists for direction-finding equipment operating on other radar frequency bands to be installed aboard the AEW aircraft. In particular, the surface-to-air and air-to-air missile guidance radar frequency bands (C band and X band) should be monitored by the AEW for jamming strobe information. Additional triangulation solutions based on this data would yield jamming target position information, which could be correlated directly with the jamming strobes visible to the missile guidance radars. (Parts 5.5.3, Appendix C)

- The performance of the AN/APS-96 radar fitted aboard the E-2A Airborne Early Warning (AEW) aircraft is adequate to provide timely detection of non-jamming raid planes being screened by standoff jammers. This is due in large part to the sidelobe structure of the AN/APS-96 radar antenna pattern, which makes it very difficult for an enemy to introduce sufficient noise jamming energy into the radar receiver to outshout the target signal return. The selection of target acquisition criterion can greatly improve or degrade the detection capabilities of the AN/APS-96 radar when the enemy employment of ECM is restricted to stand-off jamming only.

Against self-screening jammers, the performance of the E-2A, stationed on a 200-nm radius circle from task force center, is totally inadequate against even relatively low jamming power densities of 5 w/Mc and less. (Part 5.3)

- The addition of SEA MAULER units to the missile complement of a present-day task force resulted in a remarkable increase in the task force AAW capability. The vast increase in total firepower is due in part to the fact that a high-rate-of-fire weapon system has been added to the force in large numbers and in part to the fact that the increased survivability of the guided missile ships in the task force main body provides an extended opportunity to engage the enemy. Such a "second-order" effect of a self-defense weapon system is perhaps of as much significance as the number of kills that may be directly attributed to that system. (Parts 5.2.1.3, 5.2.1.4, 5.2.1.5, 5.2.2.3, 5.2.2.4, 5.5.2)

- Due to the relative weakness of the SEA MAULER acquisition radar, it would be most desirable to make target detection and threat evaluation information from other ships' radars available to the SEA MAULER firing units. Ideally, data from the height-finding radars as well as from primary air search radars should be made available for this purpose. (Parts 5.2.1.3, 5.2.1.4, 5.2.1.5, 5.2.2.3, 5.2.2.4, 5.5.2)

- Nearly all of the SEA MAULER launcher reload requirements in the situations considered in this study could have been met by a single reload cycle. Thus, with a full nine-missile magazine supplemented with a ready service, rapid reload supply of nine additional missiles per launcher, the task force could achieve essentially the same SEA MAULER firepower as with the unlimited, rapid reload capability assumed. (Parts 5.2.2.3, 5.2.2.4)

● It has been found that, in most situations, there is no clear advantage for an interceptor with a maximum speed of much above Mach 1. On the other hand, there is a very definite advantage to be found in increasing the maximum range of the air-to-air missile employed by the interceptor. (Parts 5.4.2, 5.5.4)

● Airborne friendly-ECM complements ship-borne ECM by

(1) Creating noise-jamming strobes at spurious bearings to frustrate enemy triangulation efforts

(2) Projecting deception images ahead of the ships and at false bearings. (Parts 6.4, 6.7)

● Fixed-wing aircraft, including the TFX and certain helicopters, appear feasible for use as airborne ECM platforms. The helicopters afford operability from small ships and low cost as well as a low speed and hover capability. The TFX can perform the airborne anti-fix ECM mission as another part of its multipurpose capability although many of its capabilities, such as its high speed, would not be justified in an aircraft procured for the ECM role alone. (Parts 6.5, 6.7)

● A 1000-lb demountable-pod defensive ECM package is found feasible for use as a basic airborne-ECM module suitable for employment with fixed-wing or helicopter aircraft, singly or in multiples, where weight and space constraints permit. Such a device would occupy 40 cubic feet of space and combine capability for pulse-repeater deception, with peak power on the order of 25 kw, or 10 kw broad-band noise jamming. (Parts 6.6, 6.7)

● Noise jamming and pulse-repeater deception forms of ECM are both more effective against targets at longer ranges, whether ship-borne or airborne platforms are used. At closer ranges, noise jamming is burned through and peak power requirements for deception become excessive. The chief utility of anti-fix ECM is the denial of precise antiship weapon launch from long ranges. (Part 6.4)

2.2.2 Operational Conclusions

• Employment of the modular grouping concept (a module consists of one major ship and three escorting screen/support ships) affords appreciable degrees of freedom in the constitution and arrangement of carrier forces. The three escorts, when suitably positioned, can be made to provide uninterrupted surface and air coverage and an all-around submarine surveillance zone free of wake-masked areas. Through use of suitable active and passive deception and countermeasure techniques and devices, the modules all can be made to look and sound alike to enemy surveillance and monitoring systems. (Part 3.5)

• A system of low-altitude satellites appears capable of providing task force location to air attackers with a coordinate error of about 15 to 50 nm at the time the attackers arrive within anti-ship-weapon range from the force. (Part 3.3)

• It is estimated that a two-carrier striking force of the 1970-75 era will consist of approximately thirteen to sixteen major ships (attack carriers, combatant support ships and replenishment ships). A task force of this size is compatible with the Navy's shipbuilding program, and its world-wide commitments, the requirement for sustained operations and the elemental requirements for anti-submarine warfare, surface and air defense. (Part 3.5)

• An attractive concept relating to the use of AEW aircraft is the establishment of an additional station position over task force center, primarily to provide warning and rough tracking information for SAM batteries. Furthermore, vectoring information could be provided for interceptor aircraft against low-flying attackers that have penetrated outer defenses, but have not yet crossed the radar horizon of the main-body SAM batteries. An additional useful purpose of this AEW station would be to serve as a back-up for the AEW aircraft on remote stations that may be saturated or subjected to roll-back tactics, or that may develop electronic or other malfunctions limiting their effectiveness. Strobe information from such a station could be used to advantage in techniques of passive ranging by triangulation and further in deghosting the triangulation solutions from other AEW aircraft. (Part 3.5)

- It is considered desirable to place guided missile picket ships, when utilized, in the vicinity of AEW stations. The two can then complement each other in their air and surface surveillance. Furthermore, the picket ship can provide considerable protection to the AEW aircraft and it, in turn, can provide low-flyer warning to the picket ship, so that the latter can effectively defend itself. Interceptors and airborne CAP can then be freed of the task of defending pickets and AEW aircraft and be utilized to best effect in defense of the task force main body. (Part 3.1)

- It is generally more favorable to place missile ships equipped with high-performance SAM systems in the task force main body rather than on picket stations. (Parts 5.2.2.1, 5.2.2.2)

- Advanced airborne early warning aircraft should be procured in sufficient numbers to provide each attack carrier strike force with full early warning coverage during periods of imminent hostile enemy attack. A capability should exist for maintaining four or five AEW stations on a 100-200 nm station radius over a continuous period of 72 hours. A complement of approximately 20 E-2A aircraft within each carrier strike force would be required for such a capability. (Parts 3.5, 5.4.2, 5.5.3)

- It has been found that when the task force contains an advanced SAM system, the SAM system will provide an effective AAW capability (Part 5.2.2.1). This implies that an intelligent enemy, rather than concentrate his primary force upon an air attack which is likely to be unsuccessful, will attempt to meet his objective by other means. Such means could consist of submarine attacks on the task force and/or direct attack on the forces' strike aircraft. It is therefore imperative that a task force that can successfully meet attacks from the air have comparable capability against enemy submarines and against the expected direct enemy attack upon the forces' strike aircraft.

● Threat Evaluation and Weapon Assignment (TEWA) doctrine of the Naval Tactical Data System affords an effective means of accomplishing weapon/target pairings in a non-ECM environment. The flexibility of this doctrine in distributing assignments among available task force shipborne weapons in an efficient manner has been verified in the course of the computer analysis. However, a corresponding well-defined assignment doctrine for use in an ECM environment did not exist at the time the simulation model was formulated. Therefore, the development of such a doctrine was required in order to meet study objectives. A doctrine was developed that used synthetic target velocity and position information, derived from a passive triangulation scheme. It further provided for weapon assignments to both fully detected and jamming strobe targets without giving a prior preference to either type of assignment. It is believed that implementation of this ECM doctrine with the NTDS would effectively extend the applicability of the TEWA concept. (Parts 5.2.2.1, 5.2.2.3, Appendix B)

● It has been found in all task force situations examined that the total number of shots fired by the SAM systems exceeds by a significant amount the number of intercepts achieved. It does not appear as if this phenomenon can readily be avoided, since most of the shots that fail to intercept can be attributed to the lack of perfect information by the task force. The implications of this additional expenditure with respect to SAM replenishment of missile ships may indeed be serious, especially if the enemy has a fairly rapid reattack capability. (Parts 4.1.2, 5.2.2.1, 5.2.2.2)

● The airborne radars and communications links are task force elements highly susceptible to degradation by enemy ECM techniques. The employment and deployment doctrines for the airborne elements should be based as much as possible on autonomous operation, since these elements can be isolated from surface units by feasible enemy ECM tactics and therefore cannot depend on the availability of information from these sources. (Parts 5.4.4, 5.5.4)

• It should be pointed out that doctrine as to employment and deployment of the interceptor will have extremely important consequences as to the interceptor's ability to fulfill its mission. Furthermore, it should be noted that one doctrine cannot be effectively used by many distinct types of interceptors. Doctrine must be a function of the interceptor's inherent strengths and weaknesses. (Parts 5.4.4, 5.5.4)

• In a non-ECM environment, the air-to-air systems offer their greatest contribution to task force AAW against low-altitude attacks. Under these circumstances, deck-launch operation was found to be superior to CAP operation. (Parts 5.4.2, 5.4.3, 5.5.4)

• With the advent of improved and more effective surface-to-air and air-to-air guided missile systems and the Naval and Air Tactical Data System concepts, the coordinated firepower of mutually supporting anti-air warfare task force formation may force the enemy to use prohibitively high force levels to successfully thwart a carrier strike. The integrated task force formation offers advantages in mutually supporting firepower, communications, antisubmarine warfare protection, and some advantages in station keeping. Passive or deceptive measures can also be taken to make it difficult for the enemy to identify the position of the aircraft carriers within the task force main body. (Part 3.5)

• Use of friendly ECM against enemy target localization radar denies individual weapon ship pairings and forces the enemy to resort to area fire on targets of opportunity or else delays enemy weapon release, thereby increasing exposure to defense firepower. (Parts 6.4, 6.4.1, 6.4.2, 6.7)

• Effective use of fix-denial ECM requires strict EMCON by fleet radars, increases reliance upon fighters for long-range interception, and favors development of fast-reacting high-fire-rate SAM systems. (Part 6.6.8)

2.2.3 <u>Methodological Conclusions</u>

• A computer program simulating air-to-air and surface-to-air missiles system, together with their associated sensor and control systems operating in an ECM environment, has been completed and is operational. This model represents a significant step forward in the art of Monte Carlo simulation techniques for weapon system effectiveness analysis. However, further improvements can yet be accomplished--such as detailed consideration of complex forms of jamming (blinking noise jammers, deception jammers, track-lock breakers, etc.), investigation of sea and land clutter problems, and development of a full two-sided game with which to analyze armed reconnaissance efforts, fix denial and passive AAW formations. In any such extension to the modeling technique, it is imperative that the present capabilities of the simulation program be retained in full.

- Development of advanced simulation techniques should progress on a continuing basis in order to avoid lengthy and perhaps intolerable time delays in responding to specific problem assignments.

# 3. THE OPERATIONAL ENVIRONMENT

## 3.1 General

The purpose of this section is to develop the operational backdrop for the analytical effort connected with this study. We present here the rationale that supports the derivation of both the offensive and defensive forces. No attempt is made to associate the strike operations being considered with any particular area of the world.

Variations in enemy force levels and the sophistication of their weapons and techniques, as well as variations in task force composition and deployment, are treated in the study to provide a spectrum of air defense effectiveness values over a range of tactical situations.

## 3.2 The Role of the Attack Carrier Striking Force in the 1970-75 Era

Current naval long-range planning is predicated on the premise that carrier striking forces will remain one of the essential sources of naval power during the 1970-75 period. The two major missions envisaged for such forces are:

(1) To provide a flexible means of naval participation in wars and other military actions having limited objectives.

(2) To provide such means of participating in an all-out war effort as are compatible, operationally and economically, with optimization for limited action.

Carriers are expected to provide the Navy's primary and most effective capability for limited attack action against both sea and land targets. One of their greatest assets is expected to be their ability to satisfy attack requirements in geographic areas where prestocked, politically unencumbered air bases are not available or are inadequate for the occasion.

The significance of the contribution of carrier striking forces to all-out war deterrence will undoubtedly diminish as the U.S. arsenal of primary retaliatory weapons--such as POLARIS, MINUTEMAN, etc.--grows. Carrier striking forces will, however, retain the capability to participate in all-out war. In particular, such striking forces show promise of having a useful role to play in those phases of an all-out war that follow the initial nuclear exchange.

It is with the primary carrier striking force mission, that of coping with limited wars, that this study is concerned. Limited war is defined as military conflict whose outcome is considered by the major nations participating as not imminently involving their survival as a nation. Such wars will be restricted in geographical area and will usually be limited by the following:

(1) Political and military objectives
(2) Manpower and resources committed
(3) Weapons employed
(4) Types of targets attacked.

Within this context, open war against the existing governments of Communist China or the Soviet Union cannot be considered to be limited wars. For one thing, the objectives in such a war would not be limited, regardless of the degree to which the other requirements are satisfied under the definition of limited war. Furthermore, while it is recognized that certain types of discriminating nuclear weapons could be used offensively or defensively in limited war, it is believed that any expansion of a limited conflict involving U.S. and Communist bloc forces as to means used or as to objectives would adversely affect the stability of all-out war deterrence. In general, any disruption of deterrent stability in the direction of greater uncertainty runs counter to U.S. national interests and perhaps Soviet national interests as well. It is not at all clear, however, that the Communist Chinese are in accord with this philosophy. Despite the recent ideological split between the U.S.S.R. and Communist China, the Soviet Union must in all probability serve as the major arsenal for the Communist bloc for some time to come. For these reasons, it appears that conventional weapon exchanges are the most likely to be encountered in limited war and the present study concerns itself only with such exchanges.

A pattern for limited war has evolved over the last decade in which rebel forces in countries with characteristically weak or unstable governments are trained and armed by the Communists. This type of activity might be considered as the first phase of a two-phase Communist support effort. In some instances in the past, the United States has actually intervened at this point in order to hold the existing line between the Free World and the Communist bloc; in other instances it has not. If and when the United States or Free World forces intervene, a "just war of national liberation," as it is called by Mr. Khrushchev, is in progress. Communist aid to the rebels of the country in question increases, constituting the second phase of Communist support. "Volunteers" make their appearance, bringing with them more advanced equipment.

It should be pointed out that an identifiable form of the first support phase may never appear, as in the case of Cuba. In this instance, the Communists merely exploited a popular front movement, which subsequently revealed its pro-Communist sentiments after the existing government was overthrown. It was, in fact, the introduction of a second-phase-type of Soviet support effort, with all of its serious implications, that resulted in strong U.S. intervention.

While the most advanced or the most destructive weapons in the Communist Chinese or Soviet arsenal would probably not be employed in full force in the type of warfare being considered in this study, it still behooves the analyst to examine the problem of Carrier Force Anti-Air Warfare over a rather broad spectrum of possible enemy attack situations. The present study attempts to do this within the constraint of conventional weapon employment by both the offense and defense.

Under warfare conditions of the type being described, the carrier striking force would provide a mobile air base for air strikes against enemy territory in areas of the world where land air bases are either not available or else insufficient to support the forces required. Naval aircraft operating from the aircraft carriers would have the capability for precise, discriminating attacks with weapons of appropriate type and effectiveness against a variety of enemy targets located anywhere between about 50 and 1000 miles from the striking force. Furthermore, the striking force will be capable of sustained high-sortie-rate operations. Organic to it will be a reconnaissance capability as well as a capability for self defense against air, surface and subsurface attacks. The composition of such a force in 1970-75, its deployment, and its operating doctrines are described in greater detail in Part 3.5.

It appears likely that in a limited action, the outcome of which is of importance to the Communist bloc, reconnaissance information as to location of the carrier striking force obtained through Soviet or Communist bloc efforts would be made available to the Communist forces opposing the United States. Reconnaissance means that could be employed by the Communists in the 1970-75 era are discussed in Part 3.3.

It is not at all clear how the ideological differences that have sprung up between the Soviet Union and Communist China in recent months may affect the pattern of potential limited war in the Far East. Should the gulf between the U.S.S.R. and her most powerful partner in the Communist bloc widen to the point where all further Soviet military aid to Communist China is cut off, it is highly unlikely that the Chinese Communists will be capable of developing a significant weapon stockpile without Soviet support in the intervening ten-to-twelve-year period. Yet it is extremely difficult to picture Communist China playing anything but an aggressive role in Far Eastern affairs. From a conservative standpoint, it is perhaps advantageous to assume (in the absence of definite information to the contrary) that truly serious rifts in the Communist bloc will <u>not</u> occur, despite the encouraging evidence of internal difficulties within the bloc that may appear from time to time.

### 3.3 Enemy Anti-Fleet Reconnaissance Capabilities (1970-75)

Continuing advances in reconnaissance and surveillance equipment and techniques, especially the use of space platforms, indicate strongly that the fleet cannot remain hidden from Soviet view. Once the enemy has the capability to observe the passage of ships over a period of time he can distinguish military from commercial ships. Ship movements can be discerned through the collective means of covert intelligence, shore-based direction finders and radar, submarines, SOSUS-type surveillance nets, reconnaissance trawlers and merchant ships, search aircraft, satellites, satelloids and reconnaissance rockets.[5]

Soviet astronautic accomplishments noted in the open literature have demonstrated several pertinent facts about Soviet reconnaissance capability. Several satellites with payload capacity exceeding 10,000 lb have been launched. This is adequate for refined optical reconnaissance. Good capabilities have been demonstrated in vehicle guidance, orientation, stabilization, tracking, communication, on-board power, and environment control and recovery. The Cosmos network was established with timing, orbital inclination and distribution that appear more than coincidentally associated with U.S. nuclear tests.

A situation can be visualized in which the following elements are present. Eight satellites in a 500-mile polar orbit would pass any region on earth at 6-hour intervals. Soviet trawlers could serve as mobile data readout stations for these satellites to minimize the delay between satellite observation of the force and the time when these observation data are made available to attackers. A task force moving as fast as 30 knots (0.5 nm per minute) travels 180 nm during the 6-hour satellite-surveillance interval. The trawlers thus could use fleet position information periodically obtainable from the satellite to remain within communications distances of the satellite whenever it observes the force. Satellite surveillance position determination accuracy is on the order of 0.5 nm at the time of making the observation.[6] Velocity determination from a satellite is regarded as difficult if not impossible.

Now consider an aircraft attack upon the fleet, mounted from a land base 1000 nm distant. Average cruise velocity of the attackers might be about 8 nm per minute. The minimum cruise time to the fleet is then 125 minutes, or about two hours. The attackers carry ASM weapons with a 100 nm range capability, employing command or inertial midcourse guidance and active terminal homing in the last 25 miles or so of flight. The aircraft are fitted with target localization radar to locate individual ships in the task force for weapon assignment and possibly to provide midcourse guidance. The aircraft also are capable of direct data readout from the surveillance satellites.

The satellites' long data interval precludes their use in weapon fire control. Synchronous satellites that can accomplish continuous surveillance operate at about 20,000 nm, too high for adequate resolution. The data interval for low-altitude satellites can be reduced by increasing the number of satellites. A 90-minute interval would require 32 satellites, whereas 8 satellites yield a 6-hour interval. Satellites may be able to identify ship types within a task force by correlating data on size and emission signatures obtained cumulatively on successive passes of the satellite. Such information would disclose only the composition of a force; weapon assignment at time of ASM launch would require target localization capability aboard the delivery aircraft.

A crucial factor in any surveillance system employed to mount an attack upon the fleet is the time delay between observation and the availability of information to the attackers. Fundamental limitations are imposed by the trade-offs between quantity of information required to achieve necessary area coverage and resolution, and the necessary bandwidth and transmission time. The present state of knowledge permits only gross estimates of this delay; these range from a few minutes to more than an hour. However, considerable effort is being directed to the relevant technology (e.g., bandwidth compression techniques), and present limitations are regarded as poor indicators of 1970 capability. Growth of payload capacity and the evolution of superior data transmission and on-board processing capability can remove many present limitations. Weather and moonless nights remain as the major limits upon optical reconnaissance by satellite. A 1970 system capable of perhaps 5 minutes delay in updating the position of a force that has been under surveillance on previous passes is not inconceivable. During this delay, the fleet could travel 2.5 nm at most. In the situation posed for analysis, the fleet could travel at most 180 nm in the six hours between satellite observations. The sequence of events described below is suggested as one possiblity for use of such a surveillance system.

A satellite observes the fleet position within 0.5 nm, at some time that we shall call datum. Five minutes later, data from this observation is available. Meanwhile the fleet can have moved 2.5 nm. A set of position coordinates is known at the center of an uncertainty circle of 3.0 nm radius, which grows at the rate of 0.5 nm per minute. Six hours later, the circle will have grown to 183 nm and a new observation will be made, shrinking the uncertainty circle to 3.0 nm. Seventy-five minutes before this new observation, a group of attack aircraft departs its land base, heading toward the force position observed at datum, 1000 nm distant. Seventy-five minutes after departure, when the attackers are 380 nm from their original objective, a new observation will be made. Force position can again be known by the raiders within 3.0 nm, and the raid course changed to head for the new position. (The rationale for 75 minutes is that the new observation will become available when the raid is still 200 nm from the nearest possible approach to the fleet. This criterion is employed by the attackers to avoid blundering onto the fleet and thereby disrupting preplanned attack procedure.) The attackers employ passive listening gear to forewarn them of fleet surveillance.

When the new observation data is received, the raid might be as close as 200 nm to the force. The raid closes to within 100 nm of the new position within 12.5 minutes, by which time the uncertainty circle has grown from 3.0 to about 10 nm. At the other boundary, the raid might be as far as 560 nm from the force at update time. Closure to within 100 nm would require 57.5 minutes; meanwhile the uncertainty circle has grown from 3.0 to about 32 nm. These calculations of uncertainty bounds of 10 nm and 32 nm, support the range of task force location errors of from 15 to 50 nm presented in Ref. 5. Both sets of uncertainties are deemed to be well within the localization capability of enemy target spotter radar.

Closely related to the long-term orbiting satellite reconnaissance platform is the satelloid, a short-lived satellite making perhaps 1 to 3 passes, placed into orbit when advantageous to the enemy for mounting his attack. The capability to place into orbit and recover unmanned and manned devices of this type has been extensively demonstrated by both the U.S. and the U.S.S.R. Similarly, a rocket probe, perhaps fired from a trawler or from land bases, is another alternative short-term elevated reconnaissance platform. The long-term satellites can provide continuing coverage of the whole earth's surface at periodic intervals. Satelloids can cover extensive regions during their short lifetimes; probes can cover regions of several hundred miles extent for very short time periods, essentially on a one-shot basis.

The sensing capabilities of all three platform types are comparable; the major distinctions lie in platform deployment flexibility and cost. The important point for present purposes is that high-altitude (above 100 miles) platforms, sensors and data-transmission systems appear to be operationally feasible for surface fleet surveillance in the 1970 era, and that these can surmount the range limitations arising from the fact that the curvature of the earth is greater than that of the propagation paths of electromagnetic energy at frequencies that are useful for information-sensing systems.

Sensors deployed at high altitudes do not constitute the whole of the expected enemy surveillance capability, as intimated by the suggested deployment of trawlers operating in conjunction with these devices. Rather, collective surveillance is anticipated, employing a widely diverse array of information sources. Undercover agents may learn of the presence of a force at sea and its heading. In a geographically limited war situation, the objective of such a force may be highly predictable. Information from these sources reduces the effectiveness of surprise and deception measures and localizes the force sufficiently to permit further force localization by means of short-term satelloids launched into orbits appropriate to the regions specified by the intelligence information.

Information is available to the enemy (under some conditions) from short-based airborne radar and passive listening networks that can intercept radio-frequency emissions from the fleet to obtain direction and rough range (by triangulation). The KRUG-2 high-frequency direction finder is reported to operate in the 2-63 Mc band, to be capable of 2-degree (standard deviation) bearing accuracy on signals that permit one minute of observation and 3 degrees on signals of very short duration, and to have an operating range of 8200 nm. Coverage extends into the North Atlantic and blankets the Mediterranean.

Subsurface reconnaissance systems are another source of information. The current Soviet inventory of 450-500 submarines, including 200 capable of long-range operations, can establish a patrol barrier across likely attack routes defined by the circumstances of limited war. The Soviet Union might very plausibly "volunteer" some of these submarines for use as intelligence scouts by any puppet state that is at war with the U.S. It is predicted that by 1965 a sub in deep water will be able to detect passively a single CVA, making 25 knots, at ranges out to 400 nm with a bearing accuracy of 1.5 degrees. Information from covert intelligence agents can narrow the submarine's search area so that it becomes reasonably probable that one or more submarines might detect a carrier force and report its position, course and speed, thus permitting other enemy reconnaissance units to narrow their subsequent search.

In addition to submarines, fixed passive acoustic networks located in strategic areas can get bearing data upon (but cannot at present classify) unusual signatures or noises. A SOSUS-type station may be able to obtain a rough bearing out to 600 nm. The present state of information extraction in these systems is limited to determining that "there is a noise out there that wasn't there before." The accumulation and analysis of signature characteristics and the development of associative techniques may in the future bring into being some ability to classify targets.

Reconnaissance trawlers and merchant ships represent another means of fleet surveillance. One plausible cooperative employment of trawlers has been suggested in the preceding analysis of high-altitude platforms. Communist-bloc shipping is widely dispersed and much of it is outfitted with radar. The political and tactical rules of limited war may very well preclude actions that would render these intelligence-gathering ships inoperative.

Soviet reconnaissance aircraft in the Baltic, Black Sea and Pacific Fleets have the capability of covering ocean approaches out to ranges of 1500-2000 nm on a once-per-day basis with radar and twice-per-day with passive listening. Visual identification of all individual major ships encountered is feasible only in low-traffic areas. In heavily-travelled areas, individual visual identification of all ships requires a considerably larger complement of aircraft. Tracking, by airborne radar or visual means, imposes even more severe resource requirements. However, it is estimated that in the 1965-1970 period, by exploiting techniques of multiple-channel radar, the Soviets will be capable of maintaining air reconnaissance contact in crowded waters. The ability to identify ships will be enhanced by accumulation of data on U.S. fleet electromagnetic emission signatures and tactical operation patterns.

Numerous means are thus available to the Soviets for fleet surveillance. It is estimated that in the 1970 limited warfare environment, using a synthesis of several surveillance means at the Soviets' disposal, a U.S. carrier strike force could be located to within about 15 nm and identified as such. The number of ships in the force (and in some cases even the ship types) can probably be determined by visual inspection or signature analysis or both.

Information from these sources is less likely to be adequate for weapon launch and guidance, and the attackers will need to possess capability for target localization. It is conceivable that an air-to-surface missile might be designed that could be inertially guided from the launching aircraft to the vicinity of the carrier force on the basis of only the surveillance information provided to the attackers from outside sources such as those described in the preceding pages. Such a missile would need to possess terminal homing capability, and thereby it would acquire its targets autonomously. Because of the imprecise information available to the launch vehicle, missiles could not be assigned to individual ships before launching; hence area fire would result, with no fire coordination between the missiles. Current intelligence estimates deem it more likely that airborne target spotter radars will be used by the attack aircraft to localize the ships for weapon launch. One estimate foresees in 1970 a 1 kw radar with 1.5-degree beamwidth and a clear environment range capability against a ship well in excess of 250 nm. At best, large ships may be distinguishable from small ones but finer distinctions are unlikely. If the attackers seek to attack particular ships within the force, they will need to rely upon identification by visual means, which requires close range contact, or by the observation and analysis of unique signatures such as electromagnetic radiation. The latter is difficult to implement. It is therefore concluded that classification uncertainties will make it necessary to assign weapons to a larger number of ships in the force to ensure the engagement of prime targets.

3.4 Air Attack Threat to a Task Force at Sea (1970-75)

Three basic classes of enemy attack have been treated: a stylized ASM attack of variable size for analysis of single-ship effectiveness, a complex, fixed-size task force attack involving coordinated delivery of both ASM's and sub-launched SSM's, and a homogeneous task force attack of variable size comprising aircraft delivering ASM's, torpedoes, or gravity bombs. The last-named attack class was employed in the parametric analysis of task force survival probability as a function of raid size, performed early in the study, using the clear environment model.* Specific examples of this type of attack are discussed in Sec. VI of this report, under Clear Environment Results. Explicit data on aircraft, weapons, and tactics used in analysis of a low-altitude raid of this type are given in Ref. 7.

The single-ship ASM attack and the coordinated task force attack are described in this section. Both of these attack types entail the use of noise jamming by the enemy. The jamming power spectral densities and total power levels used in the analysis represent estimates of technically feasible capability in the 1970 era. Intelligence extrapolations of present Soviet Bloc ECM capabilities and intent indicate lower power levels. However, to design a defensive missile system capable of operating only in the face of jamming power levels lower than those that are technically feasible is to eventually invite the enemy to use higher feasible levels. Therefore, the missile system effectiveness studies have employed the higher levels of jamming power considered technically feasible.

* The analysis and the model are discussed in Sec. 4 of this report.

3.4.1 Single-Ship ASM Attack

The single-ship ASM attack is basically a methodological device conceived by CNO (Op 723) to measure the relative effectiveness and firepower of single ships of different types over an attack altitude spectrum extending from 200 to 60,000 ft. The attackers are ASM's launched by aircraft from a point just within the radar horizon of the ship being attacked. The launching aircraft are themselves never subjected to SAM firepower. The attacking aircraft are in a wave formation about 1000 ft apart, and all ASM trajectories converge in the horizontal plane on the ship being attacked. The number of attacking ASM's and the ASM cruise-leg altitudes are treated as variables. All ASM's have a terminal phase dive angle of 45 degrees. Variation of ASM speed with altitude is given in Fig. 3.1. The ASM radar cross-section area for a nose-on aspect was taken to be 0.5 square meters on L-band.

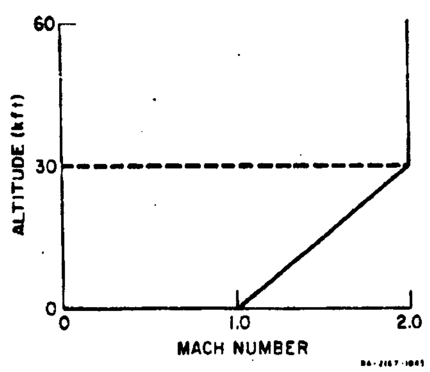


FIG. 3.1 VARIATION OF ASM SPEED WITH ALTITUDE

For the single-ship ECM runs, the ASM-launching aircraft described above are accompanied by two stand-off jammers. Stand-off ranges used for analysis were 30, 100, and 200 nm. Two levels of X-band jamming power density were examined, 20 and 100 w/Mc. In addition to the X-band jamming, the following densities were used on L, P, and S bands:

| | |
|---|---|
| L band | 15 w/Mc |
| P band | 30 w/Mc |
| S band | 60 w/Mc |

These stand-off jammers take station over the radar horizon at an altitude that places them at or near the maximum gain position in the search radar antenna pattern. Their relative bearing from the firing ship coincides with that of the missile-launching aircraft and the attacking ASM's, so that their jamming during most of the attack is being introduced into the main beam of the tracking radars as well. Like the missile-launching aircraft, the stand-off jammers are out of range of SAM firepower.

Since the enemy ASM's are assumed to be not jamming, they cannot be engaged by the defense in a home-on-jam (HOJ) mode. Thus, the single-ship ECM runs constitute a test of the burn-through capabilities of the various defense weapon system radars.

### 3.4.2 Coordinated-Task-Force Attack

The coordinated-task-force attack represents an effort to analyze task force AAW effectiveness against a raid that is believed to typify enemy capability in the 1970 era. Information on inventory and performance characteristics of attack vehicles and weapons was provided by the Scientific and Technical Information Center (STIC) of the Office of Naval Intelligence as reported in Ref. 8. Raid composition and tactics were formulated by Op 723, in collaboration with analysts from NWRC.

These efforts resulted in complex phased attacks involving the coordinated delivery of both ASM's and sub-launched SSM's in a noise-jamming ECM environment created by self-screening and stand-off aircraft that are a part of the raid. The attack is fixed in size with respect to numbers of aircraft, submarines, and weapons, and with respect to attack formations and tactics. The attack combatant units and attack phasing are summarized in Table 3.1. This attack is described chronologically below. All times are expressed in minutes.

t=0 (Fig. 3.2). At the start of the attack, two BEAR strike coordination aircraft proceed toward the task force at an altitude of 50,000 ft at 435 knots along lines of bearing ±35 degrees. They come in on either side of the formation axis and take positions just inside the task force main body radar horizon at reference time t=0. This places them roughly 255 nm from force center. One aircraft carries the strike commander, the other his alternate. Their functions are:

(1) To locate task force elements and assign targets to the attackers that will follow.

(2) To make command decisions to supplement or supplant preplanning in the light of the actual situation encountered.

Table 3.1
ATTACK COMBATANT UNITS

| Attack Phase | Delivery Vehicle | Number in Raid | Attack Payload per Vehicle |
|---|---|---|---|
| 1 | BEAR | 2 | Strike Commander and Alternate Target Localization Systems (Active and Passive) Radar and Communications Jammers |
| 2 | Submarines | 10 | Two SSM Missiles |
| 3A | BLINDER II Missile Carriers | 8 | One AS-4II |
| 3B | BLINDER II ECM Carriers | 2 | Radar and Communications Jammers |
| 4A | BLINDER I Missile Carriers | 30 | One AS-4I |
| 4B | BLINDER I ECM Carriers | 6 | Radar and Communications Jammers |
| 5 | BADGER Missile Carriers | 60 | One AS-2 |

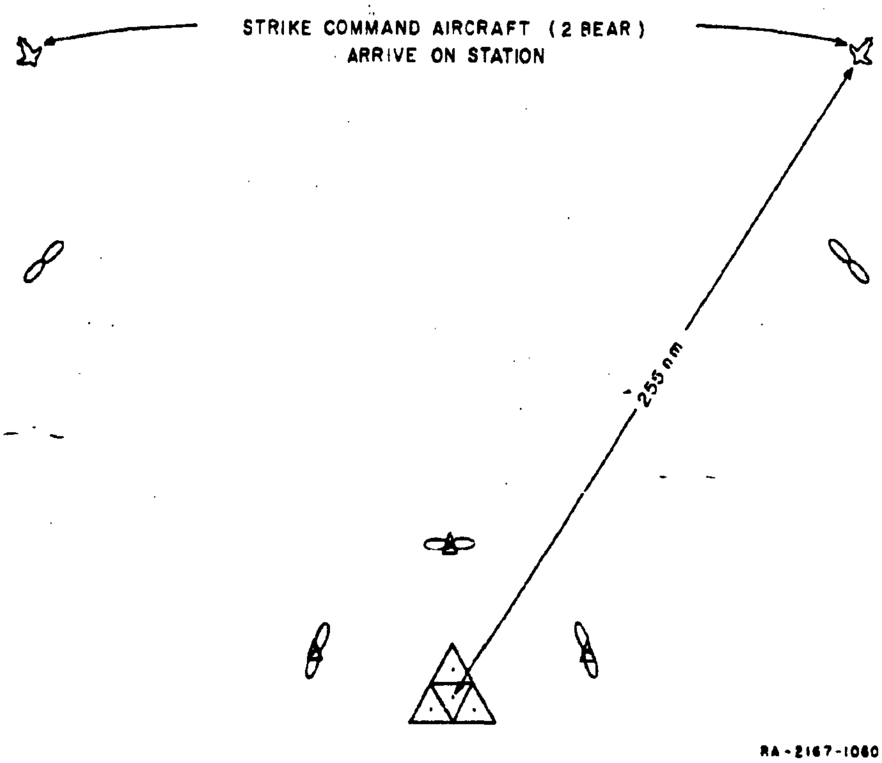


FIG. 3.2 RAID SEQUENCE, t = 0

These BEAR aircraft have a payload capacity of 25,000 lb and are equipped with long-range search radars, passive listening devices (electromagnetic radiation analyzers), computers, communications, and AAM countermeasures for self-defense against fleet fighter aircraft. These countermeasures take the form of noise jammers that operate on AEW, AI, ship search, and fire-control radar frequencies.

t=5 (Fig. 3.3). In the attack scenario, there are ten missile-launching submarines, which are broken down into two groups of five each. These two groups of submarines are located on lines of bearing ±45 degrees at a range of 300 nm from fleet center. Within each group, submarines are spaced 5 nm apart from each other, line-abreast. These submarines each carry two SSM's, which are fired in single missile salvos. Missile characteristics are shown in Table 3.2. The SSM's are fired in a pattern to cover the task force main body area and home in on targets of opportunity within this area. At t=5, the ten submarines launch one ASM each, which impact in the task force main body area at approximately t=28.

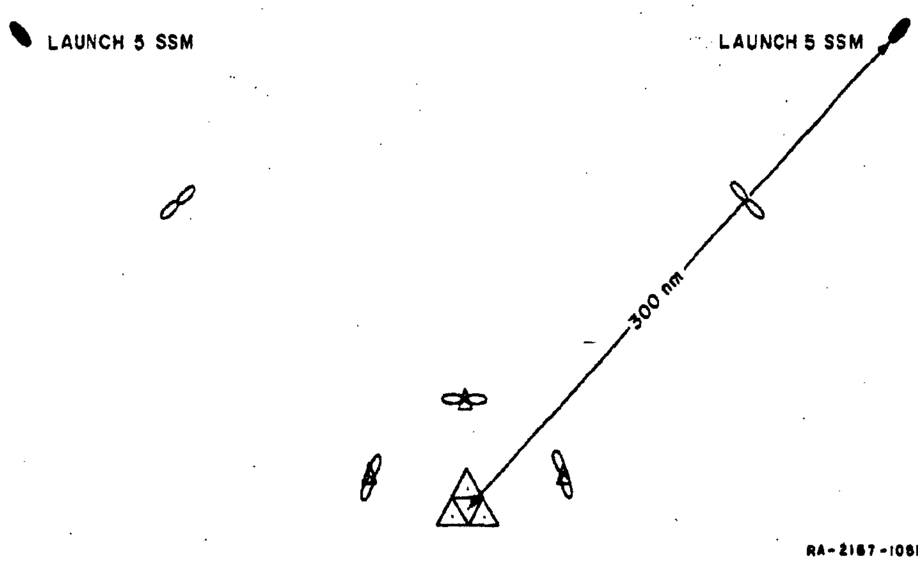


FIG. 3.3 RAID SEQUENCE, t = 5 MINUTES

Table 3.2

PERFORMANCE CHARACTERISTICS OF SUBMARINE-LAUNCHED MISSILES

| | |
|---|---|
| Designation | SS-N-3 |
| Number of Missiles per Sub | 2 |
| Maximum Range | 300 nm |
| Speed | 790 kts |
| Cruise Altitude | 1000 feet |
| Propulsion | Turbojet |
| Guidance | Inertial Midcourse, Terminal Homing |
| Radar Cross Section (Nose-On, L-Band) | $4M^2$ |
| Warhead (H.E.) | |
| Weight | 2,000 lbs |
| CEP | 150 feet |

t=10 (Fig. 3.4). Two waves of four improved BLINDER's (BLINDER II) each, which have been approaching the task force at an altitude of 200 ft and a speed of 600 knots, reach their weapon release points at a range

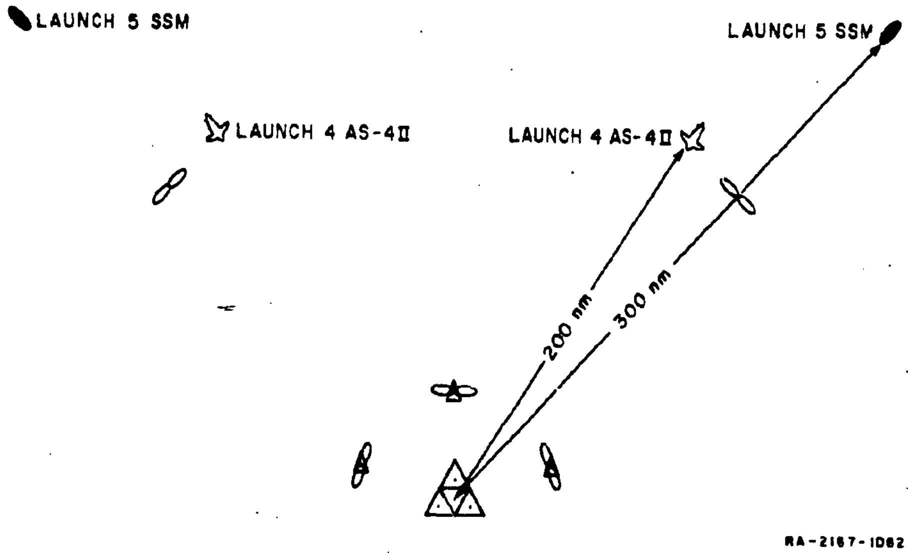


FIG. 3.4 RAID SEQUENCE, t = 10 MINUTES

of 200 nm from fleet center. Their approach to the task force was made along lines of bearing ±35 degrees from the formation axis and by time t=10, they have climbed to 50,000 ft and accelerated to a speed of 1040 knots. Prior to weapon release, the attack groups have spent three minutes inside of the task force main body radar horizon, reconnoitering ship positions. Each of the two four-plane groups of BLINDER II weapon carriers is screened by an additional BLINDER II jamming aircraft that barrage noise jams on ship search, SAM fire control, AEW and AI radar, and NTDS communication link frequencies. These aircraft close on the task force at an altitude of 35,000 ft and a speed of 1040 knots. They are phased to meet BLINDER II weapon carriers at approximately the time they cross the main body radar horizon. The BLINDER II aircraft have a total payload capacity of 15,000 lb. The weapon delivery aircraft carry and launch one ASM each, with the characteristics shown in Table 3.3. The ASM's are fired at individual ship targets in the task force main body and impact at approximately t 15. After ASM release, the BLINDER II weapon delivery aircraft execute 180-degree turns and return home, again dropping to an altitude of 200 ft. The BLINDER II jamming aircraft in each of the two attack groups continue on toward task force center at an altitude of 35,000 ft and a speed of 1040 knots, taking stations at positions 30 nm from fleet center.

Table 3.3

PERFORMANCE CHARACTERISTICS OF AIRBORNE MISSILE DELIVERY SYSTEMS

| | BLINDER II | BLINDER I | BADGER |
|---|---|---|---|
| Missile Release Altitude--Feet | 50,000 | 9,700 | 4,600 |
| Aircraft Speed--Knots | | | |
| At Missile Release Altitude | 1,040 | 700 | 425 |
| At 200 Feet Altitude | 600 | 600 | 425 |
| Number of Missiles Carried | 1 | 1 | 1 |
| Missile Designation | AS-4II | AS-4I | AS-2 |
| Guidance | Inertial Midcourse, Terminal Homing | | |
| Release Range--nm | 200 | 110 | 80 |
| Cruise Altitude--Feet | 60,000 | 200 | 200 |
| Speed--Knots | 2,290 | 925 | 725 |
| Radar Cross Section (Nose-On, L-Band)--$M^2$ | 2 | 2 | 2 |
| Warhead (H.E.) | | | |
| Weight--lbs | 3,000 | 3,000 | 3,000 |
| CEP--Feet | 150 | 150 | 150 |

Also at t=10, the submarines all fire their second SSM. These impact in task force main body area at approximately t≈33.

t=15 (Fig. 3.5). At t=15, two more waves of 15 unimproved BLINDER's (BLINDER I) each reach their release points at roughly 110 nm from fleet center and an altitude of about 9,700 ft. They have approached the task force at low altitude (200 ft, 600 knots) along lines of bearing ±35 degrees. By weapon-release time the aircraft have accelerated to a speed of 700 knots. The enemy has employed the same "reconnaissance" tactic described above for the first wave of attacking aircraft. In this case, however, the time required above radar horizon for reconnaissance purposes is two minutes instead of three. Each of the 30 attacking BLINDER I aircraft carries one ASM apiece with characteristics shown in Table 3.3. It can be seen from this table that, after launch, each ASM descends to an altitude of 200 ft where its run-in is made on the task force. BLINDER I jamming aircraft again accompany the weapon carriers. There are three such aircraft with each of the two attacking groups, however, instead of one. The tactics employed by these jamming aircraft are

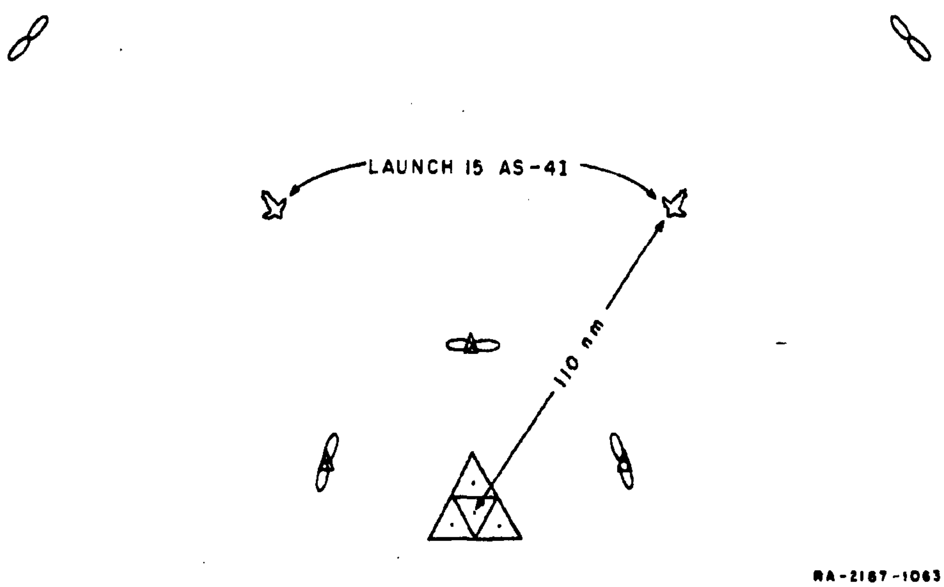


FIG. 3.5 RAID SEQUENCE, t = 15 MINUTES

identical to those described for the jammers associated with the first attacking wave, except that they proceed on in toward fleet center at an altitude of 9700 ft and a speed of 700 knots.

Impact time for the second wave of ASM's is approximately t=22.

t=20 (Fig. 3.6). At this point in time, two waves of 15 BADGER's each reach weapon-release points at a range of 80 nm from fleet center at an altitude of about 4600 ft. Their speed at this point is 425 knots and they have been over the task force main body radar horizon for two minutes prior to weapon launch. The two groups of aircraft have again approached the task force on lines of bearing ±35 degrees at an altitude of 200 ft and a speed of 425 knots. Each BADGER carries one ASM with the characteristics shown in Table 3.3. These two waves are not accompanied by jamming aircraft. Their ASM's impact on target at about t=27.

t=25 (Fig. 3.6). At t=25, two more waves, identical in every respect to the ones described above for t=20, release their weapons against the task force main body. The weapons impact at approximately t=32.

A summary of enemy weapon release and impact times appears in Table 3.4; a summary of enemy attack profiles is illustrated in Fig. 3.7.

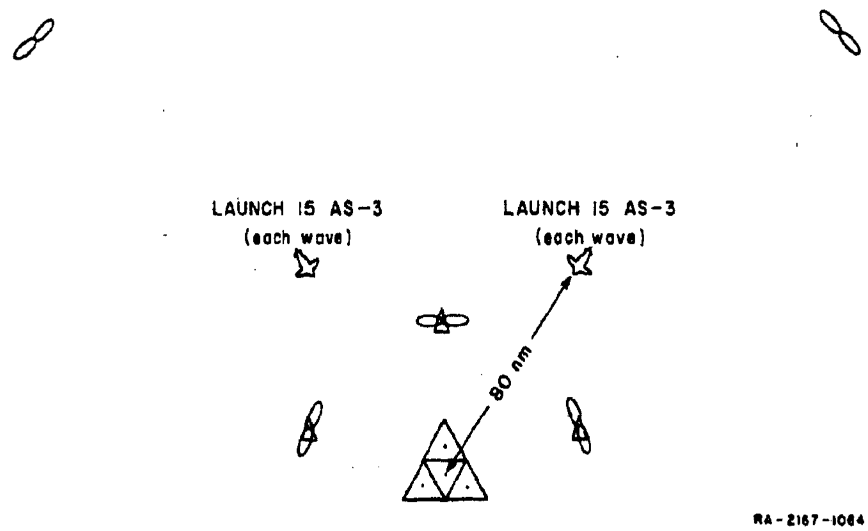


FIG. 3.6 RAID SEQUENCE, t = 20 AND 25 MINUTES

Table 3.4

ECM THREAT

| Radar Band | Search/Track | $P_j$ (watts/Mc) | Frequency Range (Mc) |
|---|---|---|---|
| P | Search | 30.0 | 200-225 |
| L | Search | 15.0 | 400-450<br>1250-1350 |
| S | Search | 60.0 | 2900-3100 |
| C | Track | 200.0 | 5200-5900 |
| X | Track | 20.0 | 8700-9400 |

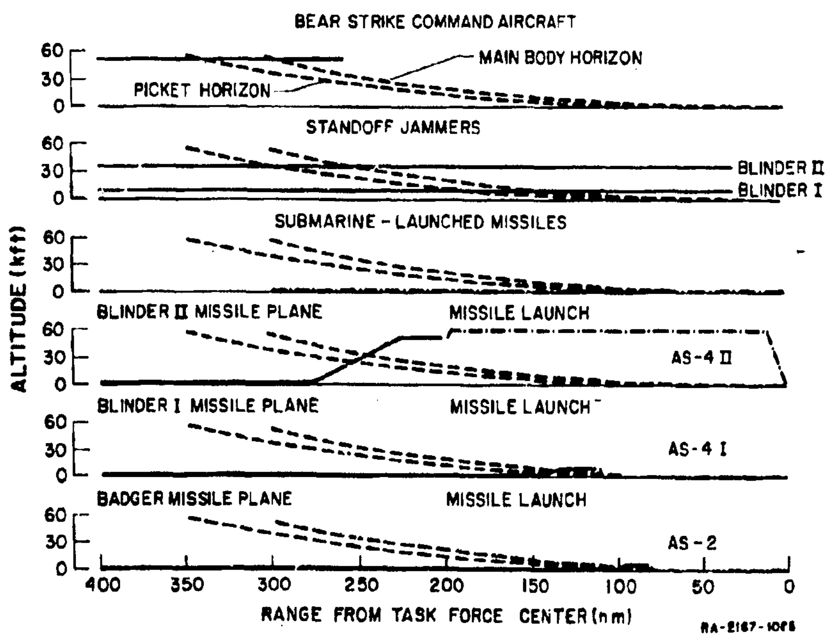


FIG. 3.7 RAID PROFILE

Figure 3.8 presents a perspective illustration of all phases of the enemy attack.

Enemy HE warhead effects on ships of the task force were computed on the basis of "Severe Topside Damage"* to the ship under attack. For analysis purposes, such damage corresponded to the disablement of all missile batteries aboard a missile ship and to the disablement of most aircraft parked on the flight deck of a CVA. A unity probability of severe topside damage was assumed for all ships, given a direct hit by an enemy weapon. The single-shot hit probabilities (SSHP) for a weapon with a CEP of 150 ft, and hence the probabilities of severe topside damage, were computed to be 0.43 for a CVA (Ranger), 0.27 for a CLG (Boston) and 0.26 for an AOE. A damage probability of 0.30 has been used in the simulation model (Part 4.2.3) for all ship types.

The probability of a near miss inflicting partial damage to the ship was assumed to be 0.5. The program allows for the accumulation of partial damage such that the damage inflicted by four near misses corresponds to the total disablement of AAW capability.

Barrage jamming power levels assumed for the enemy stand-off (BEAR) and self-screening jammers (BLINDER I's and II's) on the various task force search and tracking radar frequency bands are shown in Table 3.5 and Table 3.6.

The C-band jamming power levels are obtained through the use of a forward-looking high-gain directional antenna. The antenna systems on all other bands are omnidirectional.

Communications jamming is allowed to degrade intership communication links progressively as the jamming aircraft approach the task force.

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* Severe Topside Damage is defined by NWIP 50-1 (A), "Battle Control," as follows: "That degree of damage to topside structure, armament, equipment and appurtenances which destroys or seriously impairs the offensive aspects of military efficiency. Retirement from action at or near full power is possible. Restoration requires availability at a repair facility."

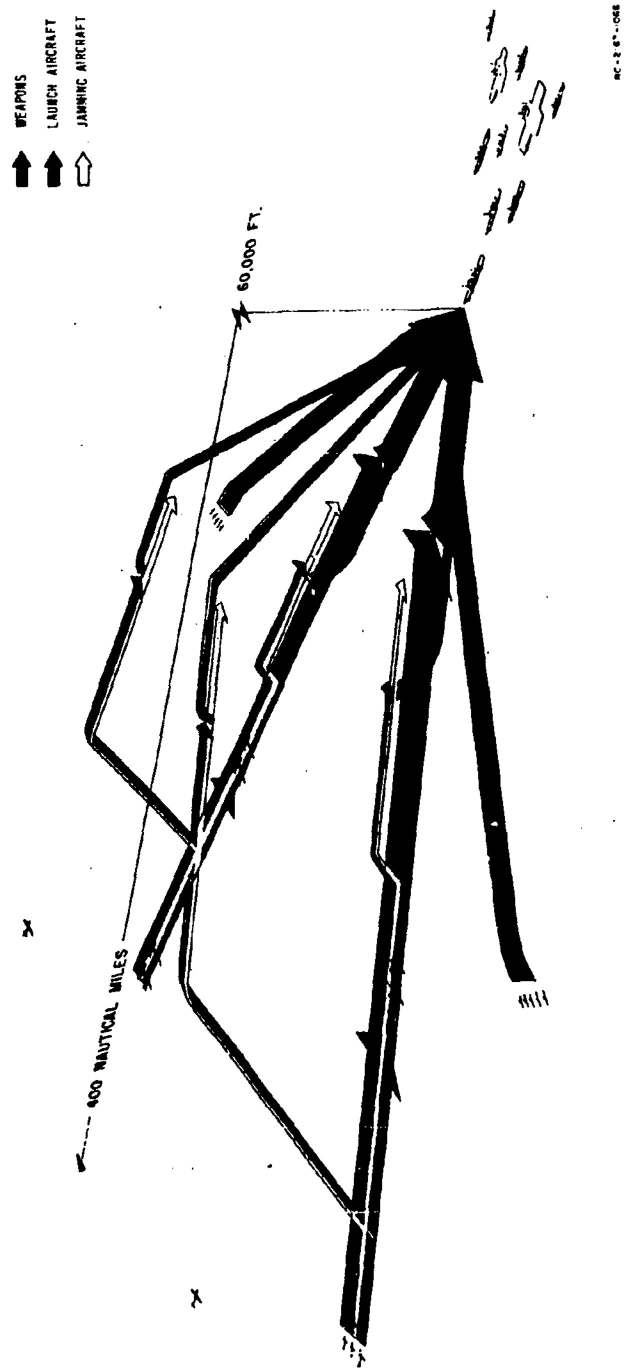


FIG. 3.8 PERSPECTIVE VIEW OF ATTACK

Table 3.5

WEAPON RELEASE AND IMPACT TIMES

| Weapon | Time After BEARS Reach Station (minutes) | |
|---|---|---|
| | Release | Impact |
| SSM | | |
| Salvo 1 | 5 | 27.8 |
| Salvo 2 | 10 | 32.8 |
| BLINDER II: AS-4II | 10 | 15.3 |
| BLINDER I: AS-4I | 15 | 22.4 |
| BADGER: AS-3 | | |
| Wave 1 | 20 | 26.6 |
| Wave 2 | 25 | 31.6 |

Table 3.6

PERFORMANCE CHARACTERISTICS
OF STAND-OFF JAMMERS

| | BEAR | BLINDER II | BLINDER I |
|---|---|---|---|
| Cruise Altitude--Feet | 50,000 | 50,000 | 9,700 |
| Speed--Knots | | | |
| At Cruise Altitude | 435 | 1,040 | 700 |
| At 200 Feet | 435 | 600 | 600 |
| Jamming Power--Watts/Mc | | | |
| P-band | 30 | 30 | 30 |
| L | 15 | 15 | 15 |
| S | 60 | 60 | 60 |
| C | 200 | 200 | 200 |
| X | 20 | 20 | 20 |

The Strike Command BEAR aircraft described earlier are stationed outside the range of SAM's, but are subject to attack by F-4B interceptors stationed on Combat Air Patrol (CAP). Modifications in the attack plan were formulated to represent conditions that might result if the interceptors should destroy these enemy aircraft. In the event that both BEAR aircraft were destroyed prior to t=5, the following changes in the enemy's attack plan were introduced:

(1) The approaching BLINDER II aircraft, after realization of BEAR destruction (presumed to take one minute after destruction of the second BEAR), would go into autonomous operation and immediately initiate their climb to high altitude (50,000 ft). The total time required for the BLINDER II's to be over the task force main body radar horizon before weapon release was increased from three to six minutes. Presumably this additional time-over-horizon would permit the initial wave of BLINDER II's to radio ship position information to the SSG's (submarines) and succeeding waves of missile-launching aircraft.

(2) The launching of the first salvo of SSM missiles from the SSG's would be delayed until after the BLINDER II's had been in level flight on their terminal dash over the fleet radar horizon for a period of at least five minutes. The second submarine SSM salvo, as before, would follow the first by five minutes, and the phasing of all succeeding waves of attackers would remain the same as described above.

### 3.5 Carrier Striking Force Composition, Deployment and Doctrine (1970-75)

Prediction of its needs for attack carriers in the 1970 era has led the Navy tentatively to plan on an allocation of nine carriers to the Pacific Fleet and six to the Atlantic Fleet. Of these, six are to be maintained in a ready status in the Pacific and four are to be similarly maintained in the Atlantic. It is expected that five basic attack carrier striking forces will be constituted around these ready carriers, utilizing two carriers as the nucleus of each force and providing them with suitable types and numbers of support, screen, and picket units. These basic forces are to be amenable to division, so that one-carrier operations can be conducted as needed. Frequent division into one-carrier forces appears to be inevitable in the Pacific Fleet.

The goal in assignment of escort ships to the carriers is to provide as favorable a basis as possible, in the face of innumerable operational considerations, for fulfilling the roles discussed earlier in this chapter. Future basic-force concepts suggest use of one guided missile cruiser, three guided missile frigates or destroyers, and an unspecified number of augmenting destroyer-type screen ships per attack carrier. Each carrier is to have embarked about six AEW aircraft and twenty-four fighter aircraft.

The various types of ships, aircraft, weapons, and supporting systems that might be expected to appear in an attack carrier task force of the 1970 era are indicated in Table 3.7. As will be noted, specific ship types may serve more than one function, and they may do so on either an alternative or a simultaneous basis.

While submarines will, no doubt, work with the carrier forces, particularly as pickets, it does not appear likely, for practical reasons, that they will attempt to operate as an integral part of the forces. On the other hand, it could be expected that CVS's would be called on to provide direct support to attack carrier forces from time to time; it appears reasonable to expect that when so assigned, they and some of their accompanying units might well be integrated into the task force disposition. It also appears reasonable to believe that 1970-era CVS's, when so assigned, might function as all-around support carriers, providing AEW, AAW, and ASW support, rather than ASW support alone. AOE's are to be capable of accompanying an attack carrier striking force and resupplying it as required, making the force self-supporting for an extended period of time.

Although actual ship-building plans afford insight as to the general types and approximate quantities of ships that might be available in the 1970 era, they are not particularly necessary (nor even particularly desirable) during analytical explorations of alternative long-range courses of action. So long as the composition of each force analyzed is such that the Navy could actually deploy such a force on a given mission, the bounds of credibility will not have been exceeded. It is, of course, more desirable to work with the kinds of forces that represent

Table 3.7

ATTACK CARRIER TASK FORCE ELEMENTS

| Function | Ships |
|---|---|
| Attack: | CVA |
| Support: | CG, CLG, DLG, DDG, CVS |
| Screen: | DLG, DDG, DD |
| Picket: | DLG, DDG |
| Logistic: | AOE |
| Augmenting: | DLG, DDG, DD |
| | **Aircraft** |
| Attack: | A-4, A-6, VAX |
| Fighter: | F-4, F-111 |
| Warning: | E-2 |
| Anti-submarine: | SH-3, S-2 |
| | **Weapon Systems** |
| SAM: | TARTAR, TERRIER, TALOS, Advanced Surface-to-Air Missile System Point Defense Weapons |
| AAM: | SPARROW III, SIDEWINDER, PHOENIX |
| ASW: | ASROC, DASH, Torpedoes |
| | **Supporting Systems** |
| Air detection: | Advanced dish-type and phased-array radars |
| Submarine detection: | AN/SQS-26, AN/SQS-23 with VDS, advanced airborne systems |
| Data processing and relay: | NTDS, ATDS |
| Communications: | HICAPCOM, Automatic Data Links |

what the Navy might be expected to deploy on a day-in day-out, year-around basis. This latter view is followed here in the derivation of sample forces.

In the 1970 era, a major portion of the Navy's responsibilities can be satisfactorily met only through sustained forward deployment of part of its ready carrier forces, with maintenance of the balance of the ready forces in a backup status, available for prompt use in augmentation and replacement roles during periods of sustained conflict. Simultaneously, nonready units will be undergoing overhaul, modernization, and retraining. In order that an equitable system of unit rotation between forward deployment, backup deployment, and nonready status can be effected on a continuing basis during noncritical periods, it will be necessary to divide the total force into three more or less equal groups and to cycle these groups successively through each duty category on a regular schedule.

The over-all defense requirements of an attack carrier force can be described directly: its carriers must be shielded so as both to preserve their ability to conduct air operations and to protect their embarked attack aircraft from damage prior to launch. Premature loss or impairment of either the operating ability or the embarked aircraft could effectively negate the offensive power of the force. Unfortunately, any defensive arrangement devised can eventually be broached in one manner or another by a determined attacker. So, realistically, the most that should be expected is a posture that yields, against the most severe opposition foreseen, an acceptable probability that the offensive capabilities of the force can be kept intact sufficiently long to be brought to bear.

To be of practical value, concepts for a defense posture must allow for the fact that both the size and the composition of carrier forces are variables and are dependent upon and responsive to numerous assorted and changeable operational considerations. Types of capabilities to be sought in the establishment of such a posture can be grouped into six broad categories, all of which must be provided if a suitably well-rounded posture is to be realized. Summarily stated, these are:

(1) Simultaneous defense capabilities against air, surface, and submarine attack, with the quality and quantity of each type of capability commensurate with the anticipated threat.

(2) A means of dispersing major units that both provides reasonable passive protection against nuclear attack and limits the likelihood that any one attacker will be able to hold a satisfactory fire-control solution on more than one major unit at a time during the terminal phase of his attack.

(3) A task force structure that provides for engagement of an attack in such manner as will afford an opportunity to employ all appropriate components of the task force complex to best advantage against it, and that provides for an increasing density of available firepower as major units of the force are approached.

(4) A system for the control of air, surface, and undersea defenses that maximizes the capacity of the task force complex for simultaneous engagement of targets and minimizes its reaction time against any individual target.

(5) Various means of practicing deception, which inject significant amounts of misinformation and confusion into hostile surveillance and attack-control systems, and which tend to decoy attackers away from major units.

(6) Means of readily varying levels of defensive strength and staying power of the force as a whole, in accordance with its current assignment and operating environment.

During the 1970 era, the phasing into widespread operational use of advanced anti-submarine warfare systems, advanced surface-to-air and air-to-air guided missile systems, and the Naval and Air Tactical Data Systems could well raise the effectiveness of task force firepower to a level where a suitably constituted task force complex would force an opponent into expenditure of an unreasonably large portion of his attack force in order to ensure destruction, or even suitable reduction, of the strike capability of an attack carrier force. The effective ranges of such a force's weapons and support systems are expected to be sufficient to permit it to disperse its units rather widely, while simultaneously maintaining an integrated and uninterrupted air, surface, and undersea defense network--a presently unattainable combination. The means should be available, then, for providing the first two capabilities.

A unit stationing and employment arrangement favored by Navy planners, which would establish the third type of capability, provides for:

- Early warning by carrier-based AEW aircraft on outer (150-200 nm) stations, and surveillance and tracking by picket ships on stations of unspecified radius
- Outer defense, under AEW-CIC control by long-endurance CAP aircraft
- Intermediate defense by medium and heavy support ships
- Inner defense by heavy, medium and light support ships and carriers
- Augmentation of task force defenses, as necessary, by high-performance fighters (presumably through deck-launch techniques).

The NTDS and ATDS would tie this disposition together and afford the means whereby the force could attain suitable simultaneous engagement capacities and minimum reaction times--Requirement (4). The fifth capability, deception and decoy of attackers, can be provided through force employment of jamming, suppression of distinctive radiation patterns, use of reflectors, repeaters and deceptive formations, and misleading use of electromagnetic, sonic, infrared, and visual emissions.

Capability (6) can be provided through employment of a "modular" concept in the assignment and arrangement of ships of the main body. Under this concept, described in the paragraphs following, a force would be built up by combining modules of various types, according to the dictates of the tactical situation to be faced and the duration of the effort. As will be seen, the concept goes farther than merely providing the sixth capability. It offers a method of efficiently utilizing 1970-era weapon and support systems in obtaining Capabilities (1) and (2). It is compatible with the type of unit stationing arrangement favored by the Navy in meeting Capability (3). It allows maintenance of the line-of-sight links needed by NTDS and ATDS in meeting Capability (4). And it provides a way of making different groups of naval units look alike and of constructing usable deceptive formations for confusion and decoy purposes--Capability (5).

The concept is compatible with Navy carrier task force operating concepts for the 1970 era and meets the many diverse needs of attack carriers for support and defense. Although originally developed for use simply as an analytical tool, it shows promise of becoming useful operationally as a staff planning aid. A detailed discussion of the concept and a number of related considerations is presented in NWRC Research Memorandum 13.[9]

Employment of a modular grouping concept affords appreciable degrees of freedom in the constitution and arrangement of carrier forces. Individual modules can be added, changed, or removed with minimum disturbance of the basic capabilities of any other module in the force. Each module consists of one major ship and three escorting screen/support ships. The three escorts, suitably positioned, provide uninterrupted surface and air defense coverage and an all-around submarine surveillance zone free of wake-masked areas. Through use of suitable active and passive deception and countermeasure techniques and devices, the modules all can be made to look and sound alike to enemy surveillance and monitoring systems.

It is convenient to allocate among four distinct kinds of modules the various major ship types that might be expected to become involved in attack carrier force operations at one time or another.

These are:

(1) Air strike module, in which the major ship is a CVA.

(2) Anti-submarine/anti-air warfare module, in which the major ship is a CVS.

(3) Anti-surface/anti-air warfare module, in which the major ship is a CG/CLG.

(4) Logistic support module, in which the major ship is an AOE.

To enhance significantly the flexibility and usability of this modular concept of organization, it is desirable to provide a small pool of unassigned frigates and destroyers, for use as either augmenting units or augmenting modules. Extra escorts would be sent to this pool in cases where modules are integrated and there is an excess of escorts, or drawn from it in cases where extra escorts are required for rounding out a particular disposition, for use as supplemental pickets, or for some other special purpose (e.g., deception, scouting, SAR, etc.).

Following general concepts of major ship procurement and distribution being considered by the Navy for the 1970 era, it might be expected that units would be distributed between the two permanent fleets about as follows:

| Type of Module | Pacific | Atlantic |
|---|---|---|
| CVA | 9 | 6 |
| CVS | 3 | 6 |
| CG/CLG | 6 | 3 |
| AOE | 3 | 3 |

Taking the case of the Pacific Fleet as an example and following the one-in-three rotational policy described earlier, it would be expected that the Seventh Fleet normally should contain, on a continuing basis, 3 CVA's, 1 CVS, 2 CG/CLG's and 1 AOE. This actually represents about as high a continuing availability as can be hoped for, and is suggested as an upper quantitative limit for regularly available task forces.

In the modular concept, escorting ships are assigned to each major unit on the basis of probable need for antiair, antisurface, and antisubmarine support. An end objective is to make each module, for all practical purposes, a self-contained force. Each module is then in a position to transit and to operate independently as necessary without having to borrow basic support from other forces. This objective, tempered by knowledge of current ship availability and likely future construction and conversion programs, suggests selection and assignment of escorts as follows:

| CVA | CVS | CG/CLG | AOE |
|---|---|---|---|
| 1-CVA | 1-CVS | 1-CG/CLG | 1-AOE |
| 2-DLG's | 1-DLG | 3-DD's | 2-DLG's |
| 1-DDG | 2-DD's | | 1-DDG |

Individual modules may be expanded or contracted at will to afford a wide array of combinations of density and depth of surveillance and active defense coverage, as well as numerous levels of passive defense.

The extent to which one of these 1970-era modules could be expanded generally would be limited by considerations of AAW coverage against low-altitude attacks, rather than by considerations of either sonar coverage or integrity of communication links. Uninterrupted surface-to-air missile coverage against low flyers dictates a spacing between escorts of not more than about 15 miles. Undoubtedly, there will be cases where sonar conditions will require employment of lesser spacings; but for the purposes of this study, 15 miles represents a good working figure. Operational availability of today's developmental systems is the key to tactical usefulness of this modular concept. Without these systems there can be no simultaneous wide dispersal of units and interlocking of coverages.

Each warfare module operating alone could be expected to operate in the conventional fashion for air defense, that is, with an air defense area surrounding it and containing the normal surveillance and destruction subareas. Where more than one module is present, there would be the usual adjustment of the defense area and the operating doctrine to fit the needs and capabilities of the particular combination. It is to be expected that during an engagement, each missile ship would maneuver so as to unmask its missile battery, while approximately maintaining its assigned station. Pickets could be expected to participate directly in force air defense operations whenever NTDS/ATDS links permitted.

Suitable groupings of modules can result in the formation of a large, continuous protected area, which can be utilized in almost any manner desired. There is no particular reason to require that major units maintain any fixed position; in fact, deception efforts would be enhanced if they did not hold fixed positions. Carriers would be free to make long launch/recovery runs inside this protected area, passing from one module to another as necessary during the conduct of air operations. Other major ships would be free to move as necessary to keep out of the way of the carriers. It is a relatively simple matter to create, in the process of combining modules, some additional, false modules, which will not only provide more maneuvering room for major ships, but also will tend to compound an enemy's identification problem.

Placement of pickets is dependent,in large measure, on the amount of early warning required for the AAW complex to produce an adequate response. As a first approximation they can be placed at a distance from force center equal to the nominal range of the longest range surface-to-air missile in the force. This arrangement produces a good balance between early warning range and AAW system range capabilities for 1970-era systems, as well as fitting in well with various operational considerations. In an ECM environment, wherein range information is being denied, a placement consideration that arises is that surveillance units capable of obtaining and passing strobe data should, insofar as possible, be so located that the strobe data they obtain is usable in obtaining approximate range of targets through application of triangulation techniques.

An attractive concept relating to AEW aircraft is the establishment of an additional station over force center, primarily to provide warning and rough tracking information for SAM batteries and vectoring information for interceptors against low flyers that have penetrated outer defenses, but have not yet crossed the radar horizon of the main body SAM batteries. A second quite useful purpose would be to serve as a back-up for AEW aircraft on remote stations that may be saturated or subjected to roll-back tactics, or that may develop electronic or other malfunctions that limit their effectiveness.

When picket ships are utilized, it is suggested that they be placed under AEW stations. The two can then complement each other in their air and surface surveillance. Also, the picket ship can provide considerable protection to the AEW plane and it, in turn, can provide low-flyer warning to the picket ship, so that the latter can effectively defend itself. Interceptors and airborne CAP can then be freed of the task of defending the pickets and be utilized to best effect in defense of the main body.

An example of what might be considered as representative of a typical arrangement of units of an air strike module employing a 15-mile escort spacing is shown in Fig. 3.9(a). If an augmenting frigate were added for some particular reason, then the module might resemble Fig. 3.9(b). An example of an integrated two-carrier force is shown in Fig. 3.10. There

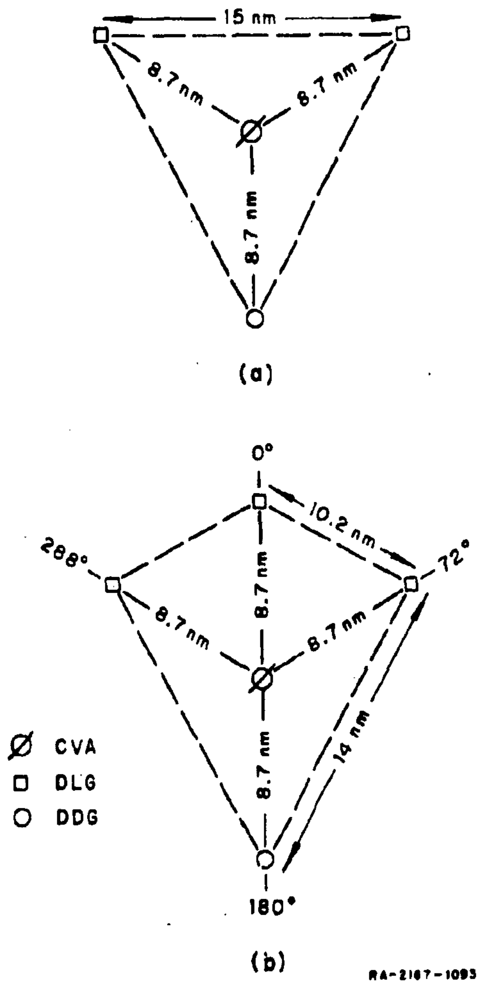


FIG. 3.9 AIR STRIKE MODULE DISPOSITIONS

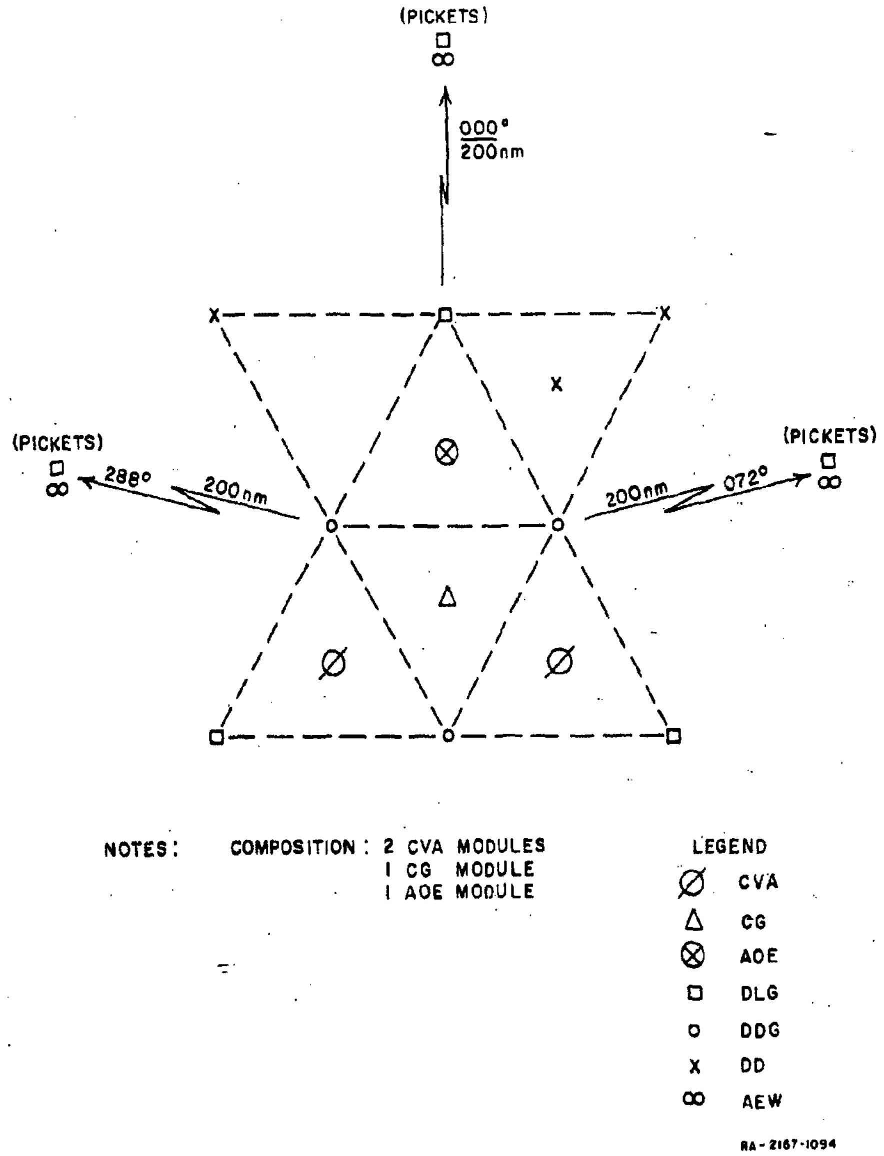


FIG. 3.10 TWO-CARRIER TASK FORCE DISPOSITION

are of course, numerous other dispositions attainable with these same units; and under various sets of circumstances, some will be more appropriate than others. For instance, it would be desirable to consider interchanging the stations of the CG and the AOE (if a comparatively weak DLG is to be stationed in the van) so that the AOE (a large and helpless target) would not be unduly exposed. An example of a one-carrier disposition with false modules is shown in Fig. 3.11; the gist of the foregoing comments applies to it too.

If the dashed lines of the figures are replaced by concentric circles, it can be seen that these examples are, in reality, simply expanded concentric dispositions, altered in a straightforward manner so as to embody the principles of the modular concept. These dispositions, then, represent no radical breaks with present proven concepts--they merely suggest another step in the unending process of innovating to improve the effectiveness and scope of application of those concepts. As a consequence, mathematical models based on the modular scheme might be expected to possess a high degree of operational credibility--an essential feature if findings derived therefore are to be significant from the viewpoint of a force commander.

The Navy visualizes the role of surface-to-air missiles in the 1970 era as being one of defeating large-scale attacks by high-flying aircraft and surface-launched missiles, and a gradually increasing responsibility for destruction of low-flying aircraft and missiles. The role of the fighter in a CAP capacity is seen as one of destruction of reconnaissance and attack aircraft beyond the SAGM zone, under the control of AEW aircraft and/or picket ships. Deck-launching of fighters is visualized as being useful for the extension and augmentation of low-altitude SAM defenses. Fighters of the F-111 type are considered suitable for either CAP or deck-launch utilization. However, there seems to be some question about whether unrestricted utilization of the F-4 type on airborne CAP stations is advisable.

For purposes of analysis, it is acceptable to presume that AEW aircraft launch would start as a carrier force approached its objective area, with initial coverage being provided only in the general direction(s)

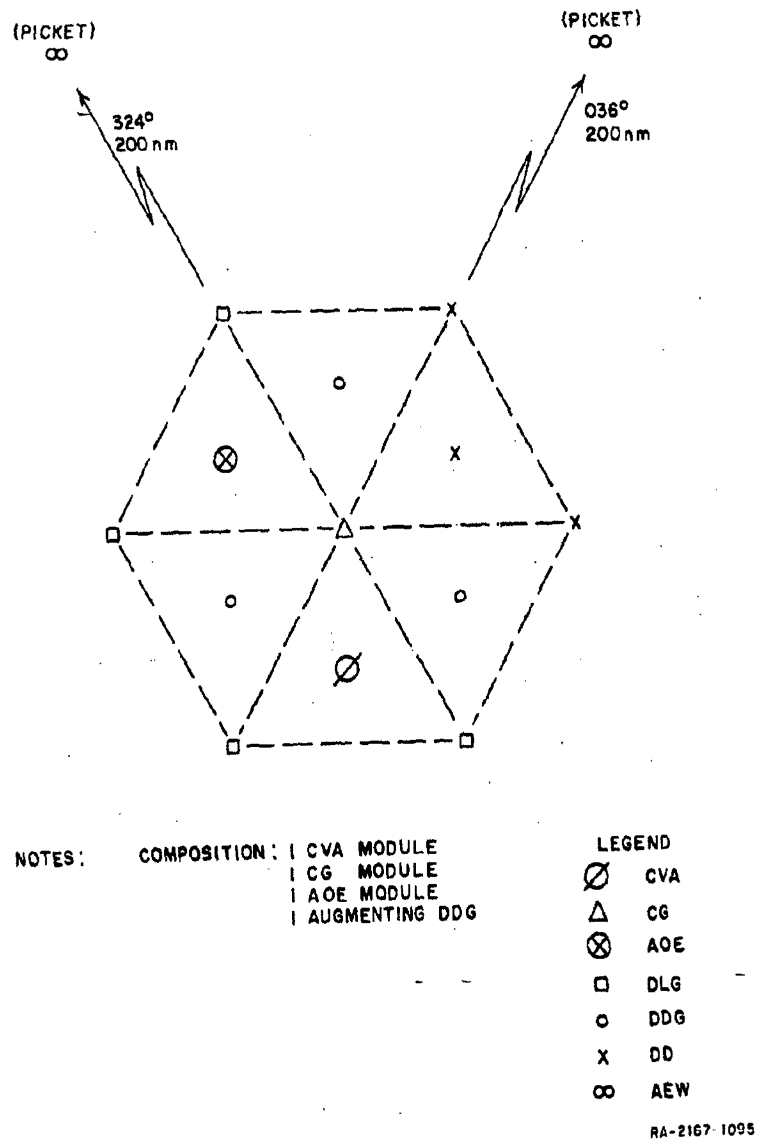


FIG. 3.11 ONE-CARRIER TASK FORCE DISPOSITION

of the attacker's air bases. As the objective area was neared, this coverage would be expanded in azimuth until a condition of near or actual all-around coverage was reached. In cases where the force is covering an amphibious assault or providing close air support to land forces, this condition might be expected to exist for about 72 hours or more. At the end of the period, withdrawal would commence, and the AEW coverage would be withdrawn in appropriate increments as the force proceeded out of range of shore-based attackers. This same general process could be expected to apply to any airborne CAP that might be employed.

Control of airborne CAP and interceptors can be expected to remain vested directly in main body units, so long as such an arrangement remains effective in producing the desired results. As CAP or interceptors pass out of effective control range, or as it becomes apparent that an intercept will take place outside of the surveillance envelope of the main body air controller, control would be passed to the best-situated picket ship, or if there were none, to the appropriate picket aircraft. Fighters operating within the SAM envelope of a picket ship might be expected to be placed under the control of that ship in order that coordination of fire could be effected. Picket ships could be expected to pass control to an appropriate picket aircraft as fighters approached the boundaries of the ship's surveillance envelope.

If one can assume the validity of the findings of Part 3.3 relative to the precision of future enemy capabilities to locate a task force at sea, it can be shown that an Electromagnetic Radiation Control doctrine that allows the AEW aircraft to radiate on station while the rest of the fleet observes electronic silence is one that generally affords the task force the greatest defense advantage under the conditions prescribed in this study. If the enemy has knowledge of task force location within 15 to 50 nm--(as postulated in Part 3.3), he need not utilize his target-spotter radar in the early phases of an armed reconnaissance sweep. He could perhaps delay turning on this radar until his estimated distance from the task force is about 250 nm without seriously compromising his ability ultimately to detect the force and locate his targets. This radar activation would be followed by the initiation of jamming by the enemy. Under these circumstances, were the AEW aircraft not radiating but engaged in passive listening only, they would generally fail to detect the enemy in sufficient time to vector defense fighter aircraft effectively.

On the other hand, consider the case in which the AEW aircraft are permitted to radiate on station while the task force ships remain silent. Since the AEW aircraft are remotely located from the task force main body, enemy triangulation on their radiation would not necessarily reveal ship locations. Assuming, again, that the enemy desires to take as much advantage as is possible of his a priori knowledge of our task force location, one could postulate that he would initially refrain from activating his target-location radars but would most likely man his passive ECM equipment shortly after take-off from his home base. Under such circumstances, he would in all probability detect our AEW radiations long before the AEW could actively ascertain the enemy's presence with its AN/APS-96 radars. Assuming the enemy wished to self-screen noise-jam our AEW radars to deny the availability of early target range information to the task force AAW system, it clearly behooves him to delay the activation of such jamming to the point where he would normally come within active detection range of the E-2A (AEW) aircraft and its AN/APS-96 radar. Due to some uncertainty in the enemy's knowledge of task force location as well as precise stationing information on our AEW aircraft, he must allow for a margin of error and will more than likely initiate his noise-jamming activities early enough to preclude clear detections by the AEW. This jamming would afford the AEW at least early passive bearing information on enemy targets, which could be used with a triangulation scheme such as SYNTRAC (described in Appendix C) to vector task force fighter/interceptors.

Once either active or passive detections have been made by the AEW, it is postulated in the present study that, after a suitable threat evaluation time, all shipborne radars in the task force would be activated upon designation of the contacts as "hostile."

If the enemy were to employ remote stand-off jamming against the AEW to screen "clear" groups of penetrating weapon carrier aircraft, the appearance of jamming strobes on the AEW AN/APS-96 radar scopes would signify a hostile action calling for the activation of all fleet radars.

With the present AN/APS-93 radar and its ECCM capabilities, it is probable that detections of the weapon-delivery aircraft would be denied by the presence of strong stand-off jamming. The jammers themselves, however, could be passively located by the AEW, with the result that fighters might be assigned to intercept them. With all shipborne radars activated, burn-through on the enemy weapon-delivery aircraft and/or weapons could conceivably be accomplished in sufficient time by pickets and formation main-body ships for at least the SAM's to engage this part of the attack. With an improved AN/APS-96, it is likely that clear detections on the weapon-delivery aircraft could be made in time to assign fighters to these targets, thereby increasing the over-all AAW capabilities of the task force.

Some of the factors that relate to the balance between passive and active anti-air warfare should be considered. The dispersed randometric and the "haystack" concepts for deploying combatant ships were developed primarily for defense against a possible nuclear attack during the next few years. During this time, defense capability will probably lag behind offense capability and "enemy" reconnaissance is not expected to be as advanced as it perhaps will be by 1970. Because of the geometry of such formations, missile ships would operate autonomously as "missile traps" and their fire would not be coordinated in a mutually supporting fashion. Fighters would likewise be operated as "CAP traps" to attack enemy targets penetrating their areas of responsibility. However, with the advent of vastly improved surface-to-air systems and the Naval Tactical Data System, the coordinated firepower of a mutually supporting anti-air warfare formation that we refer to as an "integrated" formation, may force the enemy to use prohibitively high force levels to thwart a carrier strike. The integrated formations offer advantages in mutually supporting firepower, communications, anti-submarine warfare protection, and some advantages in station keeping. The approach in this study has been to consider first what active anti-air warfare effectiveness "integrated" combat formations will provide, and then to consider what further measures should be taken to increase the probability of carrier survival. With either the integrated or the widely dispersed formations, passive or deceptive measures can be taken to make it difficult for the enemy to single out the carrier. Such measures might include the use of ship-simulating decoys or fitting smaller ships in the force--such as destroyers--with corner reflectors that produce a carrier's radar echo. Spurious carrier communications might also be simulated and made to radiate from such false carrier targets. Initial pin-pointing of the force by the enemy might be avoided by allowing AEW aircraft to radiate on a large station radius while the main body of the force maintains electronic silence. Once the battle was joined, the force could use active ECM to countermeasure the enemy bombing navigation radars. It is worth noting that the design of a suitable decoy to confuse a clever enemy may represent quite a problem. Also, the question of the friendly use of ECM has to be studied carefully in view of the critical mutual interference problems that it poses.

# 4. DISCUSSION OF ANALYTICAL METHODOLOGY

## 4.1 Effectiveness Measures

### 4.1.1 Single-Ship Analysis

A series of single-ship runs were made to measure the relative effectiveness and firepower of each ship type against a spectrum of attack altitudes. The method employed to make such a comparison of capabilities was that of determining the ship's tolerable raid size for each attack situation. Thus, the size of the attacking raid was varied until an arbitrarily defined level of saturation was reached.

Two types of curves are of importance in developing these results. Figure 4.1 illustrates the effect on the firepower of the ship as the raid size is varied (all other parameters of the raid remaining fixed.) Firepower is defined as the total number of missile salvos launched by the ship against some specified enemy attack.

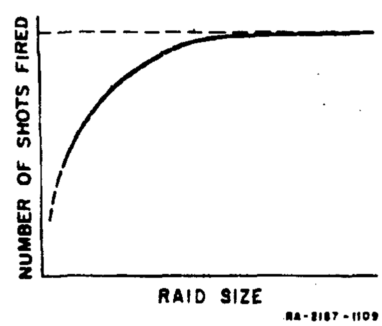


FIG. 4.1 TYPICAL FIREPOWER CHARACTERISTIC

A factor that has an important bearing on the effectiveness of enemy attack tactics is that of simultaneity of arrival at the limits of the defense envelope. In attacking any defense system composed of weapons whose operation is in some way constrained by time, it is a known fact that the mathematical concept of a point raid (in which all attacking vehicles are concentrated at a point) represents the most severe attack condition. It goes without saying that the "point" formation in a strict sense is physically impossible to attain. Even if it were possible, the enemy would still want to space his attack vehicles so as to limit the destructive effects of a defense warhead to only one vehicle. Since it is generally necessary for the attackers to be spaced in some manner--thus deviating from the point formation--the enemy can retain a large measure of the advantage accruing to him through the use of the point formation by spacing his vehicles laterally and by observing some upper limit on the over-all lateral dimension of the formation. In this single-ship analysis, the employment by the enemy of such an attack formation, commonly referred to as a wave attack, is postulated. Against such an attack formation, the defense has available only a limited amount of time in which to react; this time is independent of the number of attackers. This has the effect of placing a theoretical upper limit on the number of shots the defense can fire during the course of the battle. Such a limit is represented by the dotted line in Fig. 4.1.

At small raid sizes, the defense is able to kill all of the attack vehicles with fewer shots than the maximum number possible. This generally corresponds to the last kill being achieved some distance from the defending ship. As the raid size is increased, the number of shots required increases, with the last kill occurring closer and closer to the defending ships. The defense system has begun to saturate when maximum firepower is achieved (i.e., required) and the kills are achieved at the minimum intercept range of the AAW missile system. Beyond this point, the weapon system is considered to be saturated.

This leads to the second important type of curve, which relates firepower to survivability of the ship as raid size is increased. If the kill probability of the defensive missile is applied to each of the missile intercepts, the total number of kills achieved can be measured. Then, for a given situation, the number of enemy vehicles that succeed in penetrating the AAW network can be determined from the relationship:

Penetrators = Raid Size - Kills

Thus, with knowledge of the single-shot kill probability of the AAW missile system, a curve such as the one shown in Fig. 4.2 can be obtained. Here the number of penetrators is plotted as a function of raid size. The portion, of the curve labeled (1) applies when the raid size is so small that the AAW system can, with a high probability, expect to kill all of

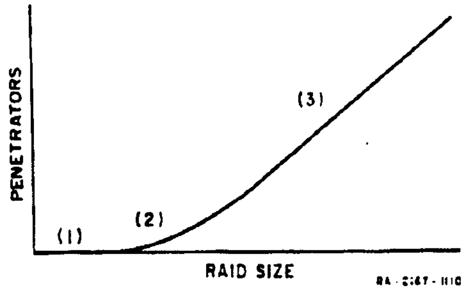


FIG. 4.2 TYPICAL SATURATION CHARACTERISTIC

the targets. At the knee of the curve, or part (2), the defense is beginning to saturate and some penetrations may now be expected. The linear portion of the curve, part (3), occurs at saturation and for every added attack vehicle, there results one additional penetrator.

The measure of effectiveness chosen for the purpose of comparing individual ship performance has been the saturation raid size corresponding to four enemy penetrators. With this number of ASM penetrations, it is estimated that the enemy will disable the ship under attack with a probability of 0.94. The ship firepower at this level of saturation has also been measured. Figure 4.3 illustrates the method of determining the raid size required for four penetrators and the corresponding AAW firepower achieved.

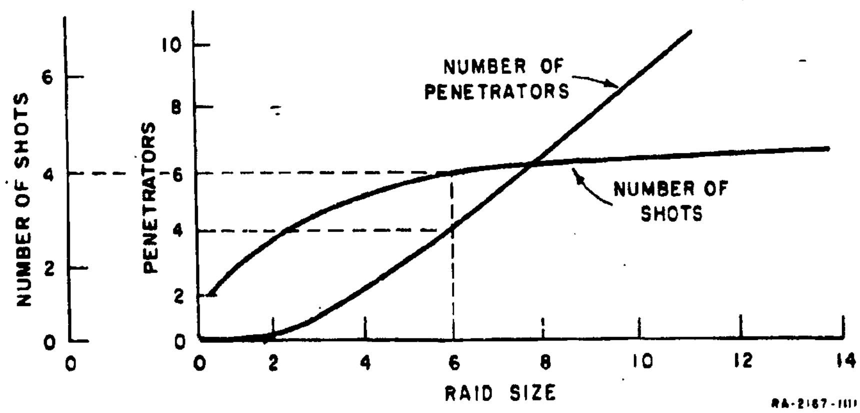


FIG. 4.3 DETERMINATION OF TOLERABLE RAID SIZE

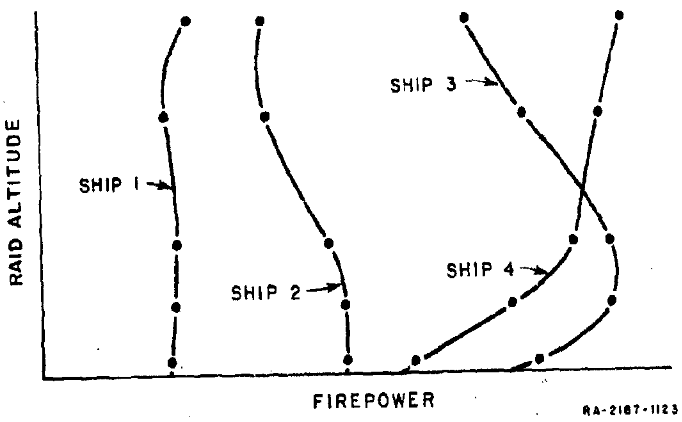


FIG. 4.4 TYPICAL AAW SYSTEMS FIREPOWER CURVES

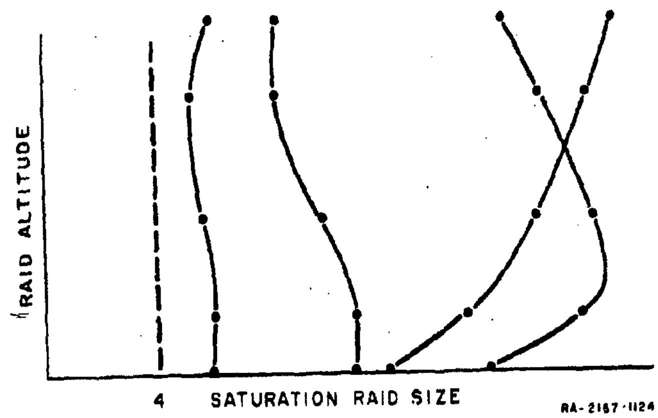


FIG. 4.5 TYPICAL AAW SYSTEMS EFFECTIVENESS CURVES

A series of such saturation points may be obtained for different attack situations, in particular, for varying attack altitudes (ASM cruise altitudes). By then plotting the data thus obtained, as in Figs. 4.4 and 4.5, direct comparisons may be made between various ships or among alternate AAW configurations of a given ship type.

Variability is inherent in the nature of a Monte Carlo computer simulation model; the amount and significance of this variability is dependent on the situation considered. Multiple replications were made of these single-ship runs in order better to measure the average, or expected, outcome of a particular game. It was found that for a given raid size, near saturation, the number of shots fired by the AAW system remained nearly constant. The number of kills, and therefore the number of penetrators, varied considerably more, due to the stochastic element involved in evaluating missile intercepts. For this reason, an "expected value" method of analysis was developed in order to reduce the number of machine replications required for consistent and valid results.

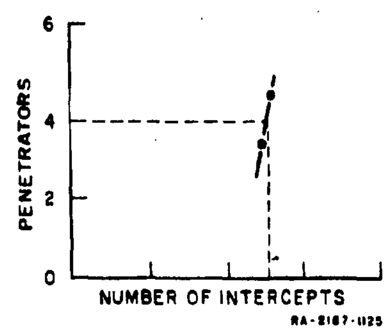


FIG. 4.6 DETERMINATION OF EXPECTED FIREPOWER AT SATURATION

In the "expected value" method of analysis, the number of intercepts that the defense can achieve against raid sizes near the four penetrator saturation level is determined. Two or three points, as in Fig. 4.6 are first established based on 8-10 replications per point.

A linear interpolation between observed points is generally valid to determine the firepower at the desired level of saturation. The observed points are as close to four penetrators, both above and below, as the selected raid sizes will allow. The known AAW missile kill probability may then be applied to this number of intercepts to yield the expected number of kills:

$$\text{Expected Kills} = (P_K)\ (\text{Expected Intercepts})$$

Since the firepower was determined at the desired level of four penetrators, the expected saturation raid size for four enemy penetrations can be determined directly:

$$\text{Saturation Raid Size} = (\text{Expected Kills}) + (4)$$

This is the measure of effectiveness presented in the single-ship analysis.

#### 4.1.2 Task Force Analysis

Another portion of the study placed the ships in a realistic operational environment so that their performance and interaction with other ships, interceptors, and early warning aircraft could be further analyzed. The various ships of interest were assembled into task forces (Carrier Striking Forces) as described in Sec. 3 of this report. Briefly, these forces generally consisted of two carrier task forces composed of a main body of ten ships with three additional air defense ships on picket stations forward of the main body. Airborne early warning aircraft of the E-2A type fitted with AN/APS-96 radars were employed to provide the AAW units with sufficient early warning of an approaching nonjamming attack and to provide a source of strobe information suitable for making rough range estimates to jamming aircraft in the ECM environment.

Attack vehicles and weapons for most of the task force runs were defined in accordance with Part 3.4. Enemy raids and attack tactics were generated by Op723 for several of the ECM environment task force runs. These were complex, phased attacks involving the coordinated delivery of both ASM's and sub-launched SSM's in combination with self-screening and standoff jamming aircraft. A detailed description of one such raid is contained in Part 3.4 above.

It is important to stress the fact that, quite independent of any measurement criteria chosen for task force effectiveness, primary interest should focus on relative comparisons of results that are obtained with, for example, a fixed AAW system against varying threats, or varying AAW system mixes against a fixed threat. Too much reliance should not be placed on absolute effectiveness values, because the assumptions one is forced to make for study purposes will not necessarily pertain in a real-life situation. Furthermore, a certain degree of uncertainty is associated with the technical parameters that go with the future systems under study, despite the best efforts made to accurately pinpoint such parameters. A large measure of this uncertainty will be eliminated only after the systems in question have reached operational status.

When it comes to the question of evaluating the performance of the man in a complex man machine system, one runs into a difficult problem. The advancements or degradations imposed on the system by the presence of humans in the system must, for the moment, remain a matter of conjecture, for there exists at the present time hardly any data that can be analytically applied to the problem. It is fortunate, from the analytical standpoint, that many of the operations associated with 1970 Task Force anti-air warfare will be automatic, once the battle is joined.

The approach in this study has been to derive an effectiveness measure that includes the effects of enemy weapons against the Task Force, as well as the effects of Task Force firepower against the attackers. One such measure that was applied to the multiple-ship analysis involves three considerations:

(1) The number of enemy weapons penetrating over each ship in the task force.

(2) The status of each ship at the end of the attack, i.e., undamaged, partially damaged, disabled.

(3) The number of shots fired (together with the number of kills and misses achieved against each target type) by each weapon type aboard each ship.

From this basic data, comparisons between various ships and weapon types within a task force environment may be made. It must be kept in mind, however, that certain target kills are considerably more significant than others. For example, the killing of a jamming aircraft by a long-range missile system may enable other missile systems to achieve considerably more firepower because of the resulting "cleaner" environment.

The self-defense capability of each ship may, to some extent, be measured by the number of enemy penetrations suffered and by the ship's status at the end of the game. However, it is pertinent that the attack will be weighted toward the more important and easily identified ships (such as aircraft carriers and TYPHON missile ships).

More significant comparisons have been made between task force runs in which the composition of the defensive force has been varied. Against a given enemy threat, the end effect of alternate weapon system development and procurement programs may be measured. For example, a task force containing several TYPHON frigates, along with other ships of the 3T variety, may be analyzed with any combination of medium-, intermediate-, or long-range TYPHON missiles available for ship missile suits. Many other parameters, including delay times, radar characteristics, inter-ship coordination, firing doctrine, and missile kill probabilities may be varied. Thus, it would appear worthwhile to develop a proposed weapon system that yields significantly more target kills and fewer enemy penetrations than obtained in a task force configured with a competing weapon system (provided that the enemy threat utilized is realistic in size and associated attack tactics).

It has been found in all of the task-force runs that the total number of shots fired by the SAM systems exceeds by a significant amount the sum of SAM kills plus SAM misses. For the sake of convenience, the term <u>aborts</u> has been applied to the difference between shots and intercepts. These aborts can be ascribed to the following causes:

(1) The target assigned to a particular missile is destroyed by a second missile while the first missile is in flight. If this missile cannot be redirected against another target because of maneuverability or guidance constraints, it is "splashed." These aborts are a direct result of the NTDS TEWA procedure, which allows multiple assignments to be made to a given target.

(2) A missile is fired in the HOJ mode when the passive ranging solution (SYNTRAC) indicates that a jamming target is within missile open-fire range. If, as a result of differences in predicted target position derived from SYNTRAC and actual locations of individual jamming targets, it develops that targets are really out of range, the assigned missile is flown out to maximum or self-destruct range and "splashed."

(3) A missile is fired in HOJ mode against a target pre-emptively destroyed by another missile [as in case (1)]. If the missile is unable to find other jamming targets within appropriate constraints, it is "splashed" at maximum range.

(4) When a target course change occurs and TYPHON missiles are reassigned in flight, a forced violation of guidance channel constraints will sometimes result and missiles thus affected will be "splashed."

(5) Missiles assigned to weapons that impact or to targets that change course so as to exit from the missile performance envelope while the missile is in flight are "splashed", provided that the assignment cannot be transferred to another target.

(6) Missiles are "splashed" if they are being actively guided in flight at the time the guiding ship is disabled by enemy weapons.

Since the computer model includes radar resolution capability as a factor, multiple missile assignments are often made against unresolved raids, which are treated in the simulated NTDS TEWA procedure as unresolved "tracks." The effect of this is to reduce the efficiency of weapon/target pairing to a realistic level, with the result that approximately 45 to 50 percent of all missiles fired during each of the task force air battles analyzed were found to be in the abort category.

In some of the task-force analysis done early in the course of the study, the threat-level information was not available, and it was necessary that raid size be treated parametrically and that the AAW mixes analyzed should be forced to saturation. As pointed out in Sec. 3 of this report, the mission of the task force is to launch a strike against the enemy's target system. Without going into a detailed study of strike effectiveness, it can be stated that the task force capability to launch such a strike (or, in other words, to carry out its basic mission) depends very strongly on whether or not the carriers can survive, among other things, enemy air attacks. Thus, for this portion of the study, an effectiveness measure was used that incorporates the probability of survival of at least one CVA in the two-carrier strike force.

If the probability of survival of at least one carrier in the force is considered as a function of enemy raid size, for some specific task force AAW composition, saturation would by definition occur at raid sizes where the survival probability begins to fall off rapidly. By comparing Probability of Survival vs. Raid Size curves for various task force AAW mixes, it can readily be ascertained which AAW system mixes or which deployments within a mix are the most effective under the attack conditions postulated. This effectiveness measure, however, is applicable only to simple, homogeneous enemy attacks, since the raid size of a realistic attack employing self-screening and stand-off jamming aircraft together with a mixture of offensive weapons and weapon carriers is not so easily varied.

## 4.2 Computer Simulation Models

### 4.2.1 Background

When this study was begun, three methods seemed worthy of consideration for making quantitative evaluations of various missile systems. These were:

(1) Hand analysis using a series of charts and maps, i.e., "playing" an air battle and subjectively analyzing the branch points of the battle as they develop;

(2) Non-Monte Carlo analysis of the firepower of the several systems, a method similar to the model used in the earlier study of surface-to-air missile systems by NWRC; or

(3) Monte Carlo simulation of the progress of an entire battle, with several replications available to analyze the inherent variability in such a situation.

In the end, the Monte Carlo simulation technique was chosen. In the Monte Carlo technique, those events which are stochastic in nature have associated with them a probability of successful occurrence, either by input (SAM and AAM single shot kill probabilities; ASM, bomb, and torpedo kill and damage probabilities) or by computation (radar single scan detection probabilities). The evaluation of such an event is made at the time of its occurrence by comparing its probability with the value of a random number selected from a uniform distribution. It is then possible to measure the variability in the outcome of a given situation by replaying, or replicating, a game with a different series of random numbers.

It was decided to attack the problem of programming the Monte Carlo simulation in two separate stages. The first stage was the programming of the AAW problem, with no consideration given to the enemy employment of ECM and with the assumption of perfect target resolution by the fleet radars. With the experience gained through this preliminary stage, a more sophisticated and complex simulation model--including the previously omitted ECM and the target-resolution problem--was constructed. For simplicity, these are referred to hereafter as the "clear model" and the "ECM model", respectively.

Care was taken to provide as much overlap as possible between the two models, and to ensure that, as nearly as possible, the results produced by the ECM model would converge on those of the clear model as the enemy use of ECM diminished. This proved to be the case, and the ECM model has now completely superseded the clear model for all computer runs.

An important consideration in the early stages of the model development was whether the simulation should be one- or two-sided. In a two-sided simulation, either the attacking or defending forces may alter their tactics during the course of the battle. In a one-sided simulation, however, only one side is permitted this freedom of action. It is apparent that in a given raid, there would be little need for the enemy to change tactics during the course of the battle, except as necessary to detect and identify surface units and to decide which units to attack. If the task force were widely dispersed and using ship-simulating decoys, the enemy raid might find it difficult to identify which surface units should be attacked and, consequently, might change course several times as the battle developed. It was felt, however, that during the time period of the study, the task force will probably rely on an active AAW disposition*--the guided missile ships will be in a fairly close formation (except for picket ships) and reliance will be placed on the firepower of the close formation, rather than on the deception provided by a dispersed formation. For these reasons, it was assumed that the enemy units would have little difficulty in locating and identifying the task force. Under these conditions, it is the enemy's best tactic to close with the task force directly and not to regroup, alter course, change target selection, or incur any other delays while within defense surveillance and perhaps within missile or interceptor engagement range. Accordingly, the simulation models were designed to be one-sided with the enemy attack tactics predetermined at the start of the play of a game (but, of course, variable from game to game).

The models have been programmed for the 1604 computer. Because of the large amounts of data involved and the requirement to optimize computer memory usage and, hopefully, minimize the running time, the models were programmed in the machine language of the 1604 rather than in a compiler language. The CDC 1604 is especially well suited to this problem by virtue of its large memory capacity (32,768 48-bit words) and its fast computing speed. Most of the model development work and production runs were completed using the computer at the U.S. Naval Postgraduate School in Monterey, California. Some additional computer work was done at the Control Data Corporation facility in Palo Alto, California, and at the University of California at La Jolla computation center.

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* See also Sec. 3 of this report, The Operational Environment.

4.2.2 Clear Environment Model

Because many of the conventions and organizational techniques used were common to both models, the development of the clear model will not be treated in detail in this report. Interested readers are referred to "Simulation of Task Force Anti-Air Warfare--Non-ECM Environment."[13]

The principal part of the clear model is the Executive Routine, which controls the positions of enemy units and the attrition afflicted on the offensive and defensive units. The Executive Routine also controls the pairing of targets and weapons by simulating the NTDS TEWA procedure. There are several subroutines that describe to the Executive Routine the action of the various surface-to-air and air-to-air missile units. These subroutines are connected to the Executive Routine through the normal program entries and through a number of lists indicating weapon status and intercept times.

The model is capable of handling a wide variety of weapon subroutines, enabling the study of a variety of hypothetical weapon systems merely by the writing of appropriate subroutines to simulate the system characteristics. Those systems that were described in the clear model included TERRIER, TARTAR, TALOS, TYPHON, F-4B/SPARROW III, and the now defunct LRMF EAGLE.

4.2.3 ECM Environment Model

The ECM model is divided into several major parts. The game input compiler and raid generator selects the appropriate AAW mix of ships and weapons, and produces as many independent segments of the attacking raid as desired for a play of the game. The Mainstream Routine controls the positions of enemy units and the attrition afflicted on the offensive and defensive units as the game progresses. The Radar Detection Routine computes the probability of detection of each target, or group of unresolved targets, for each of the task-force search radars once each scan period and for any tracking radar, against a specified target when required. The threat evaluation and weapon assignment routines control the pairing of targets and weapons by simulating the NTDS TEWA procedure. A Synthetic

Tracking Routine (SYNTRAC) is used to obtain rough jammer position and velocity information, based upon triangulation of jamming strobes received by selected AEW aircraft. A Communications Degradation Routine allows intership radio communication links to be severed progressively as the portion of the raid carrying communications-jamming equipment approaches the task force. Each of these major routines discussed in greater detail in the following paragraphs.

In a time-step game, the control method used is to advance the game time by an increment, $\Delta t$, and ask if any "events" have occurred during the current time interval that affect the simulation. With this control method, either the offense or the defense must be given the advantage of having its actions processed first, thereby introducing a bias into the outcome of the game. Such a bias is minimized in this model by making the basic game time step as small as the accuracy to which any of the input parameters are described, i.e., one second. Running time is conserved by entering certain of the simulation subroutines less frequently when it is felt that the situation described within the routine does not significantly change during this longer period. This feature is indicated in Fig. 4.7 by the boxes labeled "entry control"; each entry rate is independent of the others and all are a part of the input data to the game compiler.

The number of AAW units in the task force, their disposition, and their armament is determined by input and is, therefore, completely arbitrary, within wide limits. AAW mixes of interest are prepared in advance and stored on numbered files of an ECM game tape. For any play of the game, the compiler selects the desired mix of ships and weapons from those available on the game tape. Other information packed into the game compiler includes the initial value of the random number, an AAW mix code, the number of replications desired of the game, the run date and run number, the simulation routine entry rates, and miscellaneous other coded input data.

The raid generator has been designed to allow the user to construct a wide variety of enemy threats with ease. Any airborne vehicle

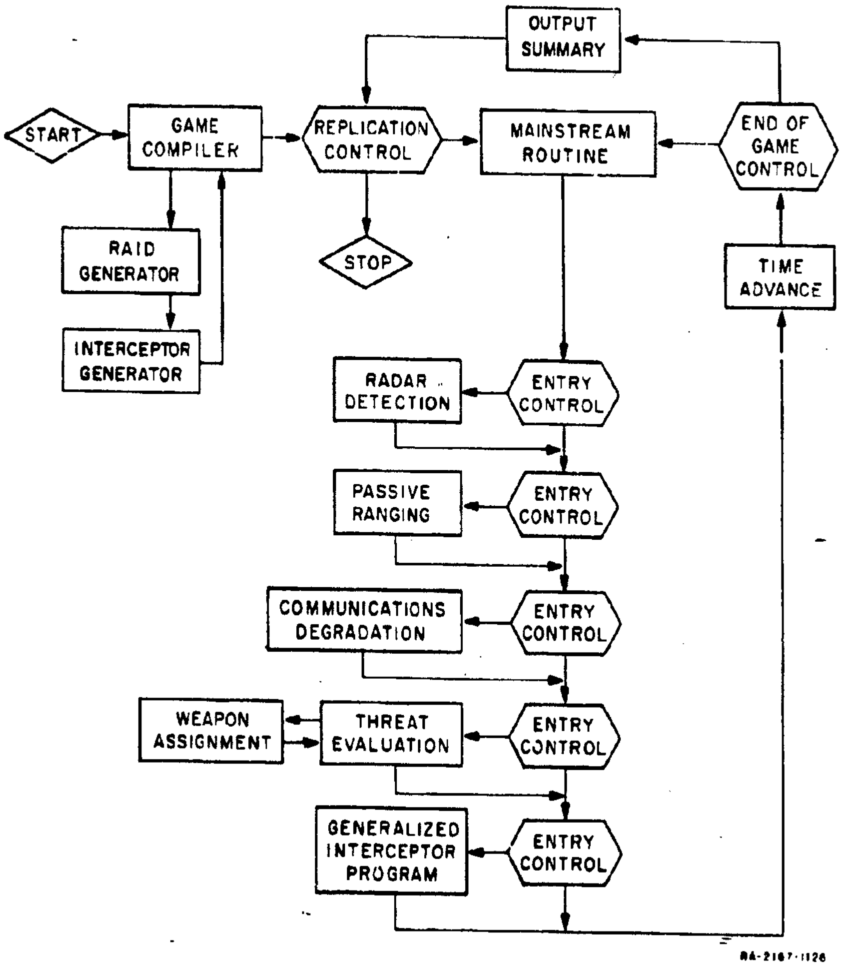


FIG. 4.7 BLOCK DIAGRAM OF ECM ENVIRONMENT SIMULATION MODEL

in the simulation (except a bomb) is a "target", i.e., a vehicle against which AAW action may be taken. The flight path of each target consists of up to four straight-line segments or legs; the speed along each of the legs is assumed to be constant, except for instantaneous accelerations at course-change points. The X, Y, and Z coordinates of each terminal point, the time of arrival at the terminal points, and the speed on the path segment leaving each terminal point are stored for each target. A target may enter the simulation at any time but ceases to exist when either it reaches its fifth terminal point or is killed by AAW action. A raid may be composed of any number of segments, which are independent as to attack vehicle type and quantity, direction of attack, mission profile, interplane spacings, jamming power levels, time phasing, and ships under attack.

Over-all control of the simulation program is provided by the Mainstream Routine. This routine keeps a record of the status and positions of enemy and friendly units, controls the entry into the other simulation subroutines, and provides for the printed output from the model. A series of 50 event types are listed on an output tape as they occur during the play of a game. Upon completion of a replication, an output summary is printed, which shows the number of targets of each type (e.g., bombers, ASM's, decoys, etc.) killed and missed by each weapon type aboard each ship, as well as the total number of shots fired by each ship weapon-type combination. A tabulation is also made of the status of each AAW unit (undamaged, partially damaged, or disabled) and of the number of enemy penetrators over each unit.

The impact of an enemy weapon on a task force unit is evaluated in two stages in this model. First, it is determined if a direct hit ship kill has been achieved by the enemy penetration, where "ship kill" implies total disablement from AAW activity for the remainder of the engagement--not necessarily ship sinking. If the weapon impact does not result in a direct hit kill, a second evaluation is made to determine if partial damage has been inflicted on the ship. There is generally a higher probability associated with this event than with the direct hit kill event. Each ship has associated with it by input, an intolerable level of accumulated near miss damage which is considered to be equivalent to a ship kill as defined above. When an offensive weapon impact results in the damage accumulation exceeding this threshold, the ship is removed from the play of the game, just as is done in the case of a direct hit kill. The relative vulnerabilities of different ship types (carriers, cruisers, destroyers, etc.) to various enemy weapon types is reflected to the kill and damage probabilities associated with those weapons.

The Radar Detection Routine computes the signal-to-noise ratio of a target (or group of unresolved targets) as a function of current raid geometry, target cross-section area (which is a function of target aspect angle), and the three-dimensional antenna gain pattern of the radar being considered. The probability of detection of the target is then computed from the signal-to-noise ratio in a manner following Marcum and Swerling's approach. A Monte Carlo evaluation of the detection is then made and a reference listing of the detection status of each target with respect to each ship is maintained. Target-detection information is exchanged among defensive units having functioning intership communication links. Each of the AAW units may be equipped with any combination of the sixteen surveillance radar types described in the model. Each such radar set is independent of all others as to scan rate and phasing. The radar equations used in the analysis are presented in Appendix A.

The threat evaluation and weapon assignment doctrine has been tailored to simulate as nearly as possible the doctrine planned for the NTDS. The NTDS threat evaluation of a hostile target is based on two main considations:

(1) The target's time-to-close on the task force defended area; and

(2) The probability that the target will survive the current missile assignments made to it.

Although the NTDS TEWA procedure for assigning surface-to-air missile systems to targets in a clear environment was well defined, it was necessary to develop a comparable procedure for making assignments to jamming targets in an ECM environment. Each resolved jamming strobe visible to a given ship is treated as a separate target. The time-to-close on the defended zone of these jamming strobe targets is determined from the location and velocity of the SYNTRAC point and separate threat lists are kept on these targets. It is assumed that strobe correlation among ships is sufficiently difficult in a heavy ECM environment that no intership coordination of strobe target engagements is allowed, as it is for fully-detected targets, communications permitting. The ECM-threat-evaluation doctrine has been developed so as not to give a priori preference for engagement to either fully-detected targets or jamming-strobe targets, since knowledge by the enemy of any such bias could be exploited. Targets are divided into high-, medium-, and low-threat queues with respect to each ship and are ordered within each threat queue by time-to-close on the defended area. From this priority listing, targets are chosen for possible AAW missile assignments.

The Weapon Assignment Routine performs the following functions for surface-to-air missile systems:

(1) It determines if a given ship has a weapon (launcher/guidance channel combination) available for possible assignment;

(2) It attempts to assign an available weapon to a designated target in command guidance or passive homing mode, as appropriate;

(3) It determines whether a previously assigned weapon can still intercept a target whose course has changed, and either computes a new intercept time for the weapon or releases the weapon and readjusts any assignments affected by the release; and

(4) It can release assigned weapons from a target that has vanished (target pre-emption) and can readjust other assignments affected by the release.

Missile systems that have been simulated by this portion of the model include TERRIER, TARTAR, TALOS, TYPHON, and SEA MAULER. A more detailed description of the TEWA Routine is presented in Appendix B.

The Synthetic Tracking Routine (SYNTRAC) provides a method for deriving passive range information on jamming targets. Strobe information from selected AEW aircraft is combined by a central control ship, which also maintains a time history of the triangulation solution, thus obtaining passive range rate information. This data is used in vectoring interceptor aircraft and in determining open-fire range to jamming targets for the surface-to-air missile systems. Use of the AEW aircraft for this function is desirable by virtue of their loiter altitude, which offers an extended radar horizon, and by their displacement from the task force main body position, which provides both extended strobe-detection capability and a wide base for the triangulation solution. A more detailed discussion of SYNTRAC appears in Appendix C.

With attempts at extending the air-to-air missile system simulations to the ECM environment, many difficulties became evident. Unfortunately, no effective Air Tactical Data System assignment appears to have been developed for an ECM environment and most of the work on fighter deployment/employment has been designed for non-ECM situations. Since electronic warfare introduces more than performance degradations in hardware, the doctrine applicable in the clear case cannot readily be extended to include ECM; in an ECM environment, even the employment concepts of various systems may change. The entire task-force operation may have to be altered and new doctrines and equipment may be required before the airborne systems can operate effectively in an ECM environment. The situation, in summary, is:

(1) There was no previously defined effective employment doctrine for use of interceptor aircraft in an ECM environment.

(2) It was unclear just what such a doctrine would be or, indeed, if any such doctrine existed.

(3) Any such doctrine and its consequences would be dependent upon the raid's progress from moment to moment, taking into account such diverse considerations as the raid geometry, jamming power levels, interception geometry, aircraft-control-station locations, etc.

For these reasons, it was decided that, instead of using a fixed doctrine, it was more appropriate to have available in the simulation the ability to vary interceptor tactics with ease.

If the interceptor simulation were to have much significance, it would be necessary to model in some detail the interceptor's radars and the interceptor's and missiles' dynamic properties. These requirements determined the properties of the generalized interceptor program (GIP).

The variable assignment doctrine allowed to the interceptor is implemented by dividing this doctrine into two distinct phases. The initial vectoring of each interceptor is semipreprogrammed; that is, the general direction in which the aircraft is to be vectored and the events that may trigger the commitment of the interceptor are parts of the input to the game. Two course legs, each of which consists of a constant-speed climb and a constant-altitude cruise section, are defined for each interceptor aircraft as a part of the game input.

The time at which the interceptor is activated, i.e., begins to fly along the prescribed course vectors, may be either "absolute" or "relative". An absolute activation time implies that at the predescribed game time, the interceptor is activated, regardless of what events have or have not occurred in the play of the game up to that time. In this manner, an aircraft assigned a routine scouting mission, for example, may be introduced into the play of the game. A relative activation time is actually a delay time, which must elapse after the occurrence of a prescribed event before the interceptor becomes activated. Events whose occurrence may cause such an activation include the first detection (two-dimensional) of an approaching hostile target, or the establishment of a synthetic speed solution based on the passive ranging data derived from strobe information on jamming targets. An interceptor may be activated upon the occurrence of one or upon the occurrence of the other, or upon the occurrence of either of the above events.

The interceptor vector direction <u>may</u> be altered at the time of activation if it is desired to send the aircraft directly toward, or on a collision course with, the detected target or the jamming strobe solution point. Control over such deviations is, again, a part of the input to the game.

The interceptor may be allowed to deviate from the predescribed course, depending on what it is able to detect with its AI radar and on certain doctrinal constraints imposed upon the aircraft. For example, each interceptor may be assigned any one of the following doctrinal constraints:

(1) No deviation from the predescribed flight path is allowed.

(2) Deviation allowed for engagement of target(s) detected on the aircraft AI radar.

(3) Deviation allowed for engagement of jamming strobe targets visible on the AI radar (assumed range to such jamming targets may be derived from the distance to the SYNTRAC solution point).

(4) Deviation allowed for either (2) or (3) above.

These doctrinal constraints can be specified independently for each of the four sections of the predescribed course vector. Once an interceptor has satisfied one of the above doctrinal constraints, as allowed, the aircraft reverts to the second, or autonomous, phase of the engagement.

In the autonomous phase of the engagement, additional constraints may be described in the model to provide exclusive preference, strong preference, or indifference as to the type of target (clear or jamming) that is selected for the final attack conversion. There are also available similar, but independent, launch criteria, which determine what types of targets the interceptor's missiles are to be launched against.

The GIP portion of the simulation model allows for the simulation of diverse aircraft and airborne missile systems. This will enable analysis of the effectiveness of these systems in an ECM environment and allow for the development of suitable associated employment doctrine.

### 4.3 Analytical Models

During the course of this study, it became advantageous to use analytical models in addition to the anti-air warfare simulation models discussed earlier. Two such analytical models worthy of note are described here.

The first of these is the combat air patrol (CAP) availability model, which was used in conjunction with the main simulation program to provide input information as to the numbers of CAP and airborne early warning (AEW) aircraft that could reasonably be expected to maintain a continuous station alert over a specified time period. A two-carrier task force, as described in Part 3.5 of this report, was analyzed; however, the model has sufficient flexibility to handle changes in the number of carriers in the force, maintenance docks on each carrier, failure probabilities and repair times, launch and recovery rates, station radii, and so on.

The second analytical model employed a graphical intercept, or hand analysis technique. By representing the targets' flight paths and the AAW missile time-of-flight characteristics on a range-time plot, and with consideration of such other time and range constraints as radar detections, maximum and minimum intercept ranges, threat-evaluation time, tracking radar acquisition and kill assessment times, launcher recycling times, and guidance channel constraints, the firepower (number of intercepts achieved) of a missile battery against a given raid may be measured. Applications of this technique included investigation of alternate guidance channel capacity configurations for the 3T weapon systems and also to provide a datum for the debugging of the anti-air warfare simulation model, particularly the routines dealing with the intricate TYPHON weapon system. A similar method was employed for deterministic, kinematic analysis of the intercept capability of CAP and deck launch fighters.

### 4.3.1 CAP Availability Model

The purpose of the CAP availability or logistics model was to determine the number of CAP and AEW stations that could be maintained on a continuous airborne alert over the carrier task group for a specified period of time. For the present study, a 72-hour continuous alert time period was selected. Furthermore, the percentage of CVA deck space allocated to defensive aircraft was taken to be a constant 36.65 percent based on NAEF projections.[14] A requirement was established that at least enough E-2A aircraft be maintained on station during the entire 72-hour period to provide a 0.9 probability of detecting the enemy (in a clear environment)

200 nm from a 360 degree AEW circle. After the number of E-2A aircraft required on each of the two CVA's was determined, the residual portion of the 36.65 percent of the deck space allocated to anti-air warfare was assigned to interceptor aircraft.

The principal considerations that determine the number of aircraft that can be maintained on station for a given period of time are:

(1) Loading on carriers
(2) Number of maintenance spots
(3) Deployment radius and time on station
(4) Failure rate
(5) Deck-dud rate
(6) Average time in maintenance
(7) Parts availability
(8) Average turnaround time

The initial consideration is the number of aircraft loaded on board a carrier; the remaining considerations will determine the percentage of this complement that can be kept in an airborne status.

It was determined that no aircraft availability data were obtainable for the specific task group analysis being conducted. Extensive data exist on the availability of various types of aircraft under particular combat and peacetime conditions, but none of these data address themselves specifically to the determination of a reasonable availability of aircraft under the 72-hour time period studied. Several government contractors had completed mathematical analyses of the expected availability of interceptor aircraft under particular conditions; but none of these studies considered the decline in availability of aircraft over a continuous CAP cycle of long duration. It was felt that as the duration of the CAP cycle increased, the length of the maintenance queues that could be expected to develop on the hangar deck would also increase, and a logistics-computed analysis was determined to be the only realistic method by which the length of the maintenance queues could reasonably be estimated.

Historic availability data indicate that the increased complexity of advanced aircraft models has brought about a reduced expected availability of aircraft.

The most important consideration to be assessed in the logistics analysis was not the average availability of aircraft, but an actual projection of the expected availability from the first hour of the CAP cycle through the last hour. The average availability data tends to be misleading in that the important consideration is not the average number of aircraft that could be maintained on station, but rather the minimum number that might be expected at any point in the 72-hour period. It was originally hoped that it might be possible to estimate realistically the degradation in availability over the entire length of the CAP/AEW cycle, and an effort was made to obtain estimates of this availability from cognizant Navy personnel. As was expected, the availability estimates made by Navy personnel on aircraft that are not yet deployed in the fleet covered a wide range. This wide variation made it impossible to assess realistically the ratio of CAP stations to the total aircraft complement, and it was felt to be essential that a computer analysis be devised that would make it possible to predict with a higher degree of accuracy the availability that could be expected over the 72-hour time period. The length of the maintenance queues and the bottlenecks that would develop in performing maintenance under these hectic operating conditions could not be accurately estimated in the absence of a detailed mathematical analysis.

The vast majority of the historical maintenance data on naval aircraft is concerned with the number of maintenance manhours that are required per aircraft flight hour. The critical consideration in the logistics model was not, however, the number of maintenance hours per hour of flight, but rather the number of clock hours of maintenance that would be required before a given aircraft could be relaunched for CAP or AEW duty. It was found to be impossible to transpose the maintenance manhours data into usable maintenance clock hours data without an elaborate study of the manpower skill levels that could be expected on board the carrier, the working schedules of these personnel, and the adaptability of their skills to highly varied maintenance operations. Therefore, only that historical maintenance data concerned with clock hours of repair time was utilized to derive mean repair times for the various aircraft studied. This and other input information for the logistics model was obtained both from official documents and by personal contact with cognizant contractors and military officers, including a field visit to the USS RANGER.

By representing the passing of units through the duty cycles and maintenance areas as a stochastic process, the model exhibits the probability that any number of aircraft will be airborne at any given time. The time history of the progress of the various aircraft through the duty and maintenance cycles has been described as a stochastic process, which is reducible to a bivariate Markov process.

Several assumptions were made regarding the nature of the stochastic elements in the process:

(1) As the launch of each aircraft is attempted, the aircraft fails (is a "deck dud") with a given probability.

(2) When an aircraft returns to the carrier at the end of its duty cycle, it will require nonroutine maintenance with a given probability, independent of the amount of time that has elapsed since last maintenance. If no maintenance is required, the aircraft is immediately available for takeoff. (Turnaround times are dominated by the length of the duty cycles).

(3) If a returning aircraft requires nonroutine maintenance, it proceeds to the hangar deck where there are a given number of maintenance spots available for each type of aircraft. If all of the maintenance spots are occupied, the aircraft enters a queue, which feeds each spot as it becomes unoccupied. Once work commences on an aircraft, the repair time is exponentially distributed with a given mean.

(4) No major aircraft failures occur while the aircraft is deployed on CAP or AEW station.

(5) Independence is assumed throughout.

The exponential service portion of Assumption (3) is justified by OEG Report 585,[15] describing the times of nonroutine maintenance required during the Korean War. Although the aircraft in this study are considerably more complex than those of the Korean period, it seems reasonable that the same type of distribution would pertain with perhaps an increase in the mean repair time.

The above assumptions are combined to derive the model that is completely described in "Availability and Deployment of Carrier Task Group CAP and AEW Aircraft in Anti-Air Warfare".[16]

The model requires generation of a Markov matrix of large dimension, many of whose elements are obtainable only as solutions to systems of differential equations; this led to the use of the CDC 1604 digital computer. The model was programmed in parametric form so that the inputs can be varied readily for examination of the sensitivity to the various inputs.

4.3.2 Graphical Intercept Model

With this method, the performance of several configurations of a weapon system may be measured in terms of the number of intercepts that can be achieved, given the specified conditions of target speed and altitude, and the determinants of system capability such as ranges, tie-up, delay, and cycle times and number of rails and channels available.

Graphical computation methods have been used to compute the performance measure from the appropriate set of conditions and system capability parameters. This method of computation is well suited to the cumulative interactions of the multiple factors that govern firepower. It affords ready determination not only of the total number of intercepts, but also of the factors that constrain each intercept and the magnitude required of any factor to avoid limiting firepower. The inherent flexibility of the method affords ready examination of different system configurations as well as different parameter values, although the time required to examine any single case is not inconsiderable.

The graphical intercept method is most useful for investigation of the interactions between deterministic kinematic weapon system constraints.

These may include launcher recycle time, missile time of flight, target velocity, guidance channel capacity (tie-up times and data rates), acquisition and evaluation times, initial detection range, and elevation angle limits of launchers and guidance radars.

The first application of the graphical intercept method in this study was to provide a datum for the purpose of debugging the large-scale digital computer simulation program, particularly the portion dealing with the intricate TYPHON guidance channel data rate constraints. An investigation of several alternative guidance channel capacity configurations for the 3T weapon systems was also done with this technique. The results of this investigation are reported in "Multiplex Operations of TERRIER and TALOS".[17]

A similar method was employed for deterministic kinematic analysis of the intercept capability of CAP and deck-launched interceptor aircraft. An initial determination of the number of intercepts that could be achieved by the F-4B/SPARROW III and the F-6D/EAGLE interceptor systems in both CAP and DL operating modes was made with fighter fuel consumption constraints included in the analysis.

# 5. DISCUSSION OF EFFECTIVENESS RESULTS

## 5.1 General

The results and findings of a series of effectiveness analyses of surface-to-air and air-to-air guided missile systems are presented in this section. Also included are the broader implications of the analyses that have been performed, which are summarized in Part 5.5. It is recognized that certain systems treated in this chapter have been cancelled or curtailed since the analysis work was performed; however, the results and conclusions presented may be directly applicable to future systems of similar configuration.

The surface-to-air systems analyzed cover a rather wide spectrum of system concepts ranging from the very-short-range, quick-reacting SEA MAULER, through the advanced versions of TERRIER, TALOS, TARTAR, on into various configurations of the multichannel, high rate-of-fire TYPHON. The bulk of the SAM effort being presented was performed at the request of ONR (Code 493) and Op-723, CNO and the results of special studies undertaken in response to these requests are summarized in Part 5.2. On the other hand, the results presented for airborne systems in Parts 5.3 and 5.4 evolved from study efforts sponsored by ONR (Code 493) and BuWeps (G). Although the information presented in this chapter was for the most part generated in response to various requests for studies each defined by specific sets of objectives, the information has now been integrated to provide a broader picture of how certain system concepts will contribute to AAW in limited war.

For the analysis of airborne systems, a train of logic was initially established, which might briefly be outlined in the following way:

(1) Fighters armed with air-to-air missiles for task force AAW will rely on AEW and ATDS for initial vectoring.

(2) An early analysis of AN/APS-96 capabilities by NWRC revealed inherent weaknesses in the performance of this radar in a realistic noise jamming environment.

(3) Since the AEW function represents an early element in the chain of events leading the successful intercept of an air-to-air missile with an enemy target, there appeared to be little point in attempting improvements to other elements of the air-to-air system unless AEW deficiencies could be rectified.

(4) Therefore, the major effort of the airborne system portion of the study would be directed toward the establishment of ways in which the ECCM capabilities of the AN/APS-96 radar might be improved.

(5) The value or utility of such radar improvements, however, would be measured in terms of the increased effectiveness of the task force AAW weapons (particularly the air-to-air missile systems) against jamming attacks. If, for example, the relative effectiveness of fighter/air-to-air systems is low even under conditions allowing for the most spectacular improvements in AN/APS-96 ECCM capabilities and, at the same time, surface-to-air system performance is not appreciably enhanced, one might question the advisability of proceeding with such an AN/APS-96 improvement program.

(6) Any attempt to measure air-to-air missile system effectiveness required the development of an analytical model that would provide a reasonable duplication of the intercept processes under conditions of enemy jamming.

The development of a generalized interceptor program (GIP) was undertaken in order to meet the requirements of Step (6) in the above logic sequence. Since this program was only recently completed, it has not been possible to carry out Step (5) directly with respect to advanced air-to-air systems of the 1970-75 era such as F-111/PHOENIX. Rather, an attempt has been made to deduce the ultimate utility of advanced interceptor systems in a future attack/defense environment by an extrapolation of the results of various analyses, which, though limited in one way or another with respect to their direct applicability to Step (5), are nevertheless considered to be pertinent. These results are fully discussed in Part 5.4.

The research effort outlined in Step (4) is presented in Part 5.3. Refined value measurements of the proposed improvements to the AN/APS-96 cannot be presented at this time, for the reasons just discussed. It is anticipated that the Department of the Navy will continue to address its attention to this study area.

5.2 Future SAM Systems Effectiveness

The effectiveness studies of future surface-to-air systems were carried out from two basic analytical viewpoints. On the one hand, single guided-missile ships of various types with varying weapon suits were considered to be defending themselves against stylized, enemy air-to-surface missile attacks. These attacks are of the form described in Part 4.1.1 and, as stated earlier, are launched against the defending ship in both clear and jamming environments. The second viewpoint involves pitting an entire two-carrier task force against more realistic enemy attacks, which, following the best estimates of future enemy tactics, include jamming, are multilevel and multidirectional and call for some phased arrival of enemy weapon carriers to weapon-release points. The single-ship analyses are indicative of the contributions that these ships would make to anti-air warfare as part of a task force were it not for the factor of deployment geometry, which will place some ships in more advantageous positions than others vis-à-vis the raiders. In addition, some operational significance can be tied to the single-ship results in that they represent the ability of an isolated multipurpose ship to defend itself against air attack while engaged in some other basic mission such as, for example, ASW.

It will be noted that a large variety of ships and surface-to-air systems have been considered in this study. These ship/SAM system combinations are described in Appendix D.

5.2.1 Single-Ship Analysis

The following ship types have been investigated in single-ship operations with the weapon suits indicated:

(1) DLG-TYPHON (3400-element radar)†

(a) With three MR TYPHON launchers, DLG (0-3)
(b) With one LR, 2MR TYPHON launchers, DLG (1-2)
(c) With one IR,§2MR TYPHON launchers, DLG (1-2)*

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† All DLG-TYPHON launchers are center-line launchers

§ The IR, or Intermediate Range, TYPHON Missile is a 100-nm boosted Super TARTAR.

(2) DLG-16 Class

(a) With two TERRIER HT-3 launchers (one fore and one aft)

(b) With two TERRIER HT-3 launchers (one fore and one aft) and two SEA MAULER launchers (one port and one starboard)

(3) CG-10 Class

(a) With two TALOS 6c1 launchers (one fore, one aft) and two Improved TARTAR launchers (one port, one starboard)

(b) With two TALOS 6c1 launchers (one fore, one aft); two Improved TARTAR launchers (one port, one starboard) and two SEA MAULER launchers (one port and one starboard)

(4) DDG-2 Class

(a) With one Improved TARTAR launcher (aft)

(b) With one Improved TARTAR launcher (aft) and two SEA MAULER launchers (one fore, one aft)

(c) With one SEA MAULER launcher (aft)

(d) With two SEA MAULER launchers (one fore, one aft)

(e) With one Advanced TARTAR (ROPAR) launcher (aft)

(f) With two 5"/54 gun mounts (one port, one starboard), and GFCS MK68

(5) CLG-3 Modified with one TALOS 6c1 launcher aft and six guidance channels (See Appendix D--Table D.4).

Superstructure interference with port- and starboard-mounted main missile batteries was avoided in the simulation studies by assuming that the firing ship (e.g., CVA-59 and AOE-1) turned directly toward or away from the target so as to unmask port and starboard launchers simultaneously. Ships with a centerline-mounted main battery and one or more port- and starboard-mounted secondary batteries (e.g., CG-10 and one configuration of DLG-16) were assumed to turn so as to unmask all centerline launchers and either the port or the starboard secondary battery launchers.

The purpose of the single-ship runs was to measure the relative effectiveness and firepower of each ship over an attack altitude spectrum of 200 to 60,000 ft. In all cases, the attackers are ASM's launched by aircraft from a point just within the radar horizon of the ship being attacked. The launching aircraft are themselves never subjected to SAM firepower. The attacking aircraft are in a wave formation about 1000 ft apart and all ASM trajectories converge in the horizontal plane on the ship being attacked. The number of attacking ASM's and the ASM cruise-leg altitudes are treated as variables. All ASM's have a terminal phase dive angle of 45 degrees. Variation of ASM speed with altitude is given in Fig. 5.1. The ASM radar cross-section area for a nose-on aspect was taken to be 0.5 $m^2$ on L band.

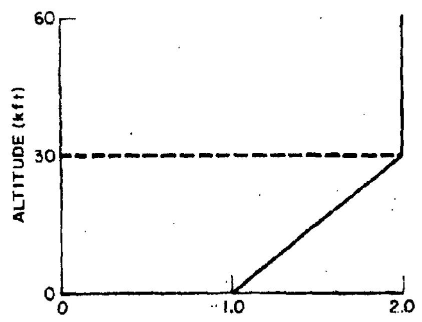



FIG. 5.1 VARIATION OF ASM SPEED WITH ALTITUDE

For the single-ship ECM runs, the ASM-launching aircraft described above are accompanied by two stand-off jammers. Both the stand-off range and the jamming powers carried on the various frequency bands are varied in the analysis. These stand-off jammers take station over the radar horizon at an altitude that places them at or near the maximum gain position in the search radar antenna pattern. This relative bearing from the firing ship coincides with that of the missile-launching aircraft and the attacking ASM's so that their jamming during most of the attack is being introduced into the main beams of the tracking radars as well. Like the missile launching aircraft, the stand-off jammers are out of range of SAM firepower.

Since the enemy ASM's are not assumed to be jamming, they cannot be engaged by the defense in a home-on-jam (HOJ) mode. Thus, the single-ship ECM runs constitute a test of the burn-through capabilities of the various defense weapon system radars.

With reference to the defense, the firing doctrine is defined by NTDS TEWA except that for the single-ship runs only, the TEWA Medium/Low Threat Threshold was lowered to zero, which removes the missile conservation feature from TEWA and allows each ship analyzed to achieve maximum firepower against the attack. All missiles are fired in a single missile salvos except where otherwise noted.

For SEA MAULER, two doctrinal procedures are examined. One implies close NTDS coordination of SEA MAULER with the other fleet SAM systems; the other permits autonomous operation of SEA MAULER at the battery level.

The measure of effectiveness chosen for the purpose of comparing individual ship performance has been the saturation raid size corresponding to four enemy ASM penetrations of the defense (See Part 4.1.1). Ship firepower has also been measured against saturation raids of the type.

5.2.1.1 TYPHON/3T

5.2.1.1.1 Results and Discussion

First to be discussed will be the results of computer runs that compare three DLG (TYPHON) configurations [DLG(0-3), DLG(1-2), DLG(1-2)*] with four 3T ships (DDG-2, DLG-16, CG-10, CLG-3 Modified) over the attack altitude spectrum 0-60,000 ft. Figures 5.2 and 5.3 pertain respectively to saturation raid sizes and firepower† at saturation raid size for the ships in question in a nonjamming environment.

The shape of the curves shown in these figures results from the interaction between three constraining factors that pertain to SAM system performance when employed against ASM's. These are:

(1) Range of initial engagement as governed by maximum missile range or the radar horizon

(2) Time available for engagement as governed by ASM speed which is a function of its cruise altitude

(3) The rate of fire characteristics of the weapon system.

Variations in the first two parameters as a function of altitude are shown in Fig. 5.1 and 5.4. The effectiveness trade-offs as these two parameters vary in the prescribed manner with altitude, are, of course, automatically accounted for in the computer program. It can

† Defined in Part 4.1.1.

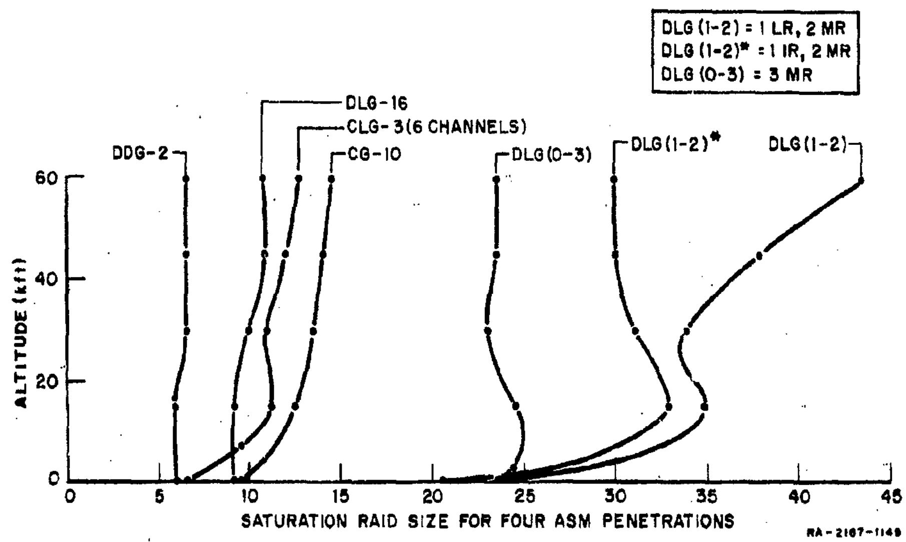



FIG. 5.2 EFFECTIVENESS OF DLG (TYPHON) AND 3T SHIPS AGAINST ASM ATTACKS

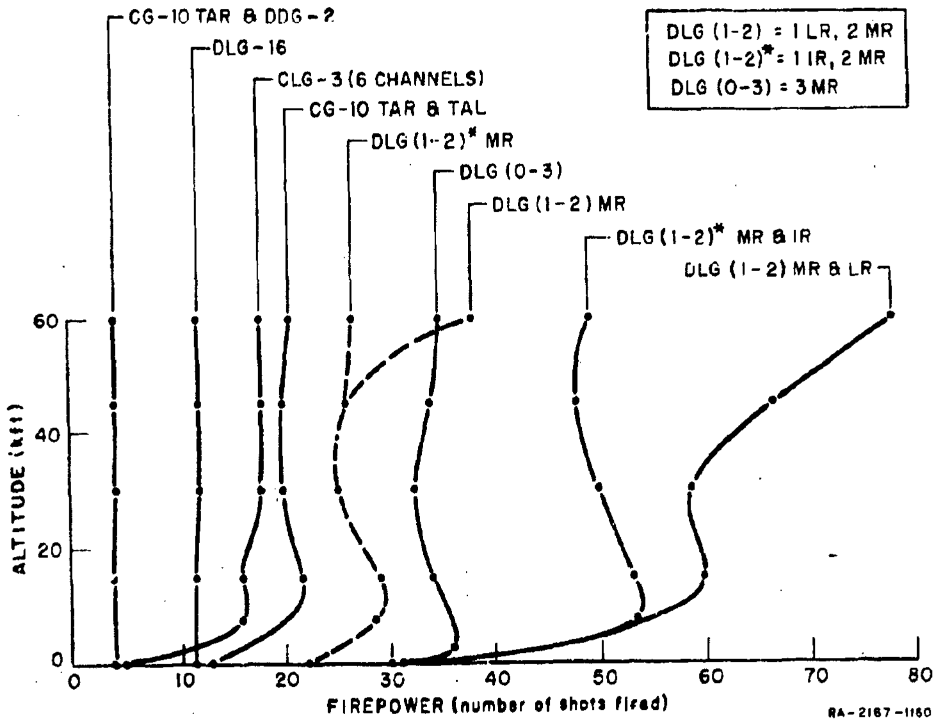



FIG. 5.3 FIREPOWER OF DLG (TYPHON) AND 3T SHIPS AGAINST ASM ATTACKS

be seen that for the longer-range systems, the range-to-radar horizon increase with altitude has the dominant effect on both saturation raid size (Fig. 5.2) and firepower (Fig. 5.3). This increase is particularly noticeable in the case of the DLG(1-2) for attack altitudes above 30,000 ft, due to the fact that range to the radar horizon is sufficiently great to permit LR TYPHON intercepts to occur at the 200nm maximum range of the missile.

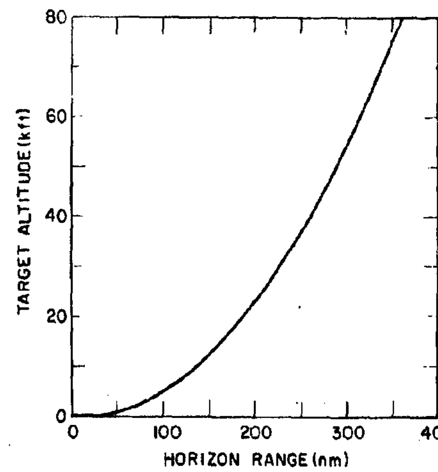



FIG. 5.4 RADAR HORIZON RANGE VARIATION WITH TARGET ALTITUDE

It is interesting to note and compare the firepower contributions made by MR TYPHON systems aboard the DLG(1-2), (1-2)* and (0-3) in Fig. 5.3. For all altitudes up to about 45,000 ft, the two MR TYPHON launchers aboard the DLG(1-2) and (1-2)* are closely matched in firepower. Above 45,000 ft, there is a pronounced increase in MR TYPHON firepower for the DLG(1-2). In fact, at an altitude of 60,000 ft, two MR launchers aboard the DLG(1-2) appear to out-perform three MR launchers aboard the DLG(0-3). This phenomenon can be explained by reference to Figs. 5.5, 5.6, and 5.7.

Figure 5.5 [for DLG(1-2)] shows that an entire magazine load of LR missiles have been fired by the time the attackers are 40 nm from the firing ship. All TYPHON guidance channels are then free to handle MR TYPHON missiles exclusively. Figure 5.6 is an expanded plot of MR TYPHON intercepts, which start at approximately 40 nm from the firing ship. In this figure it can be seen that intercepts occur in a uniform fashion as two launchers feed MR TYPHON missiles into the available guidance channels. Fig. 5.7 illustrates the intercept pattern for the DLG (0-3). With three MR launchers feeding the available guidance channels, the system becomes channel-limited, with the result that intercept

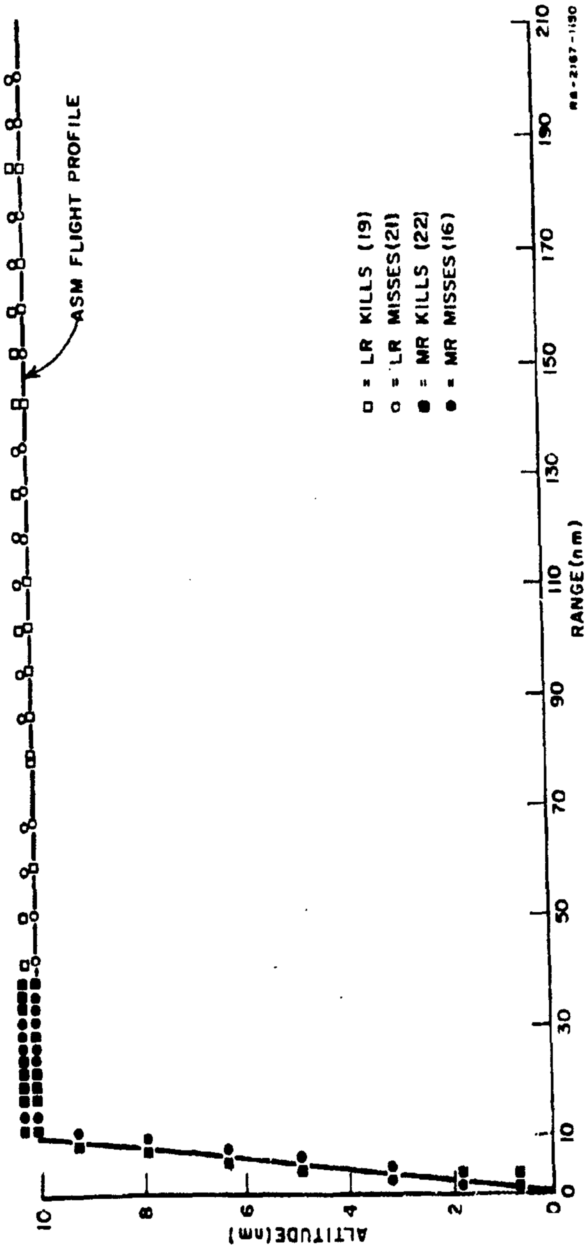



FIG. 5.5 INTERCEPT PLOT FOR DLG (1–2) (60,000 ft ASM attack)

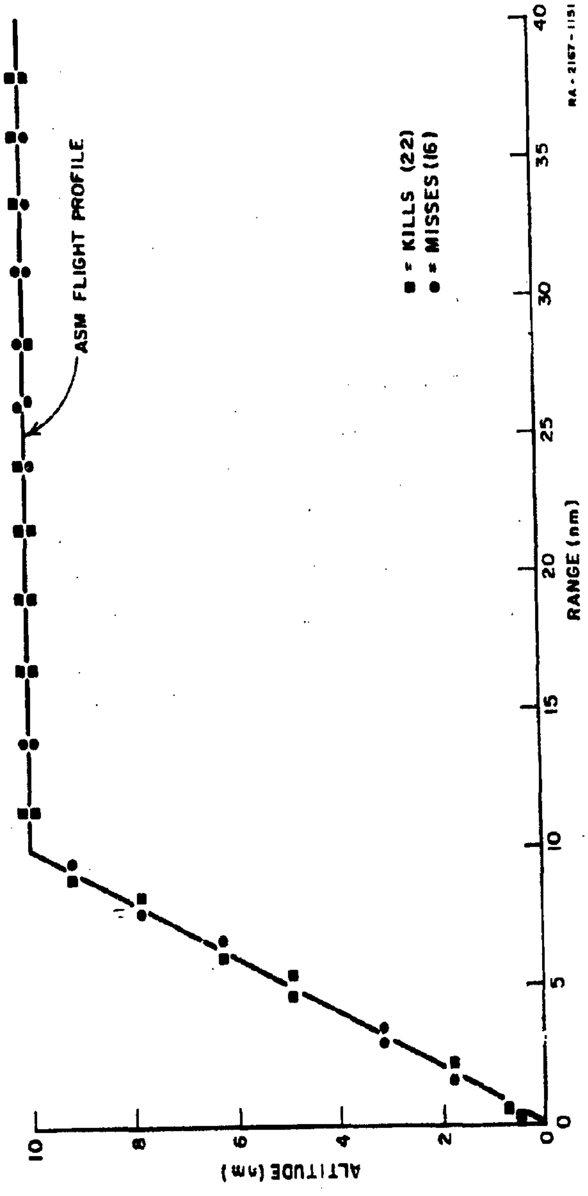



FIG. 5.6 EXPANDED INTERCEPT PLOT (MR) FOR DLG (1-2) (60,000 ft ASM attack)

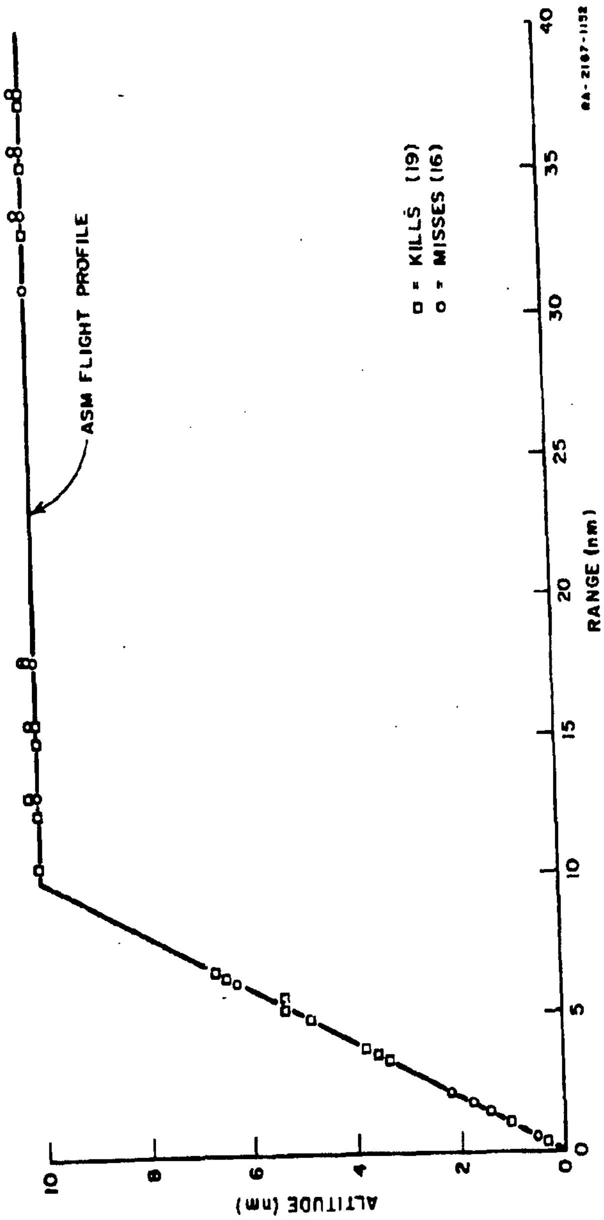



FIG. 5.7 INTERCEPT PLOT FOR DLG (0–3) (60,000 ft ASM attack)

patterns occur in groups of ten each, rather widely separated in range. The net result is that the two DLG(1-2) MR TYPHON launchers fire a total of three more shots than do the three DLG(0-3) launchers. Such an apparent disadvantage to the DLG(0-3) can, of course, be overcome by a change in doctrine that would spread the launching of missiles more uniformly over time.

With respect to the DLG(1-2)*, it was found that IR TYPHON firings overlap MR firings, even at the higher altitudes, with the result that MR must share available guidance channels with IR missiles. This sharing has the effect of suppressing MR firepower on the DLG(1-2)* as compared with the DLG(1-2).

Figures 5.8 and 5.9, which again are respectively concerned with saturation raid sizes and firepower, illustrate how particular levels of stand-off jamming degrade the performance of the DLG(0-3), the DLG(1-2), the DLG(1-2)* and the CG-10. For these runs, the two stand-off jamming aircraft are assumed to be generating jamming power densities on P, L, S and C bands of 30, 15, 60 and 200 w/Mc respectively. Both Figs. 5.8 and 5.9 reveal that, under the above jamming conditions, the burn-through range of the 3400-element AN/SPG-59 radar is such so that it remains quite compatible with IR TYPHON missile range performance and, of course, MR TYPHON performance. This is borne out by the minor degradations in saturation raid size and firepower shown in Figs. 5.8 and 5.9 for the DLG(0-3) and the DLG(1-2)* under conditions of jamming. The LR TYPHON/MR TYPHON aboard the DLG(1-2), on the other hand, is degraded down to about the same effectiveness as the DLG(1-2)* in the ECM environment specified. For comparison purposes, it is interesting to note the effect of the same stand-off jamming power densities on the CG-10, which was analytically demonstrated to be the most effective 3T ship. Its firepower in the specified ECM environment is reduced, on the average, to about 17 percent of its "clear environment" value with corresponding reductions in saturation raid size.

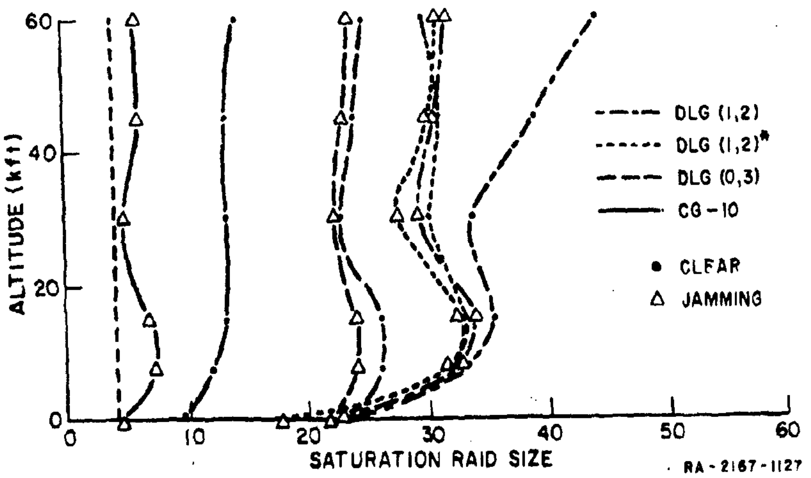



FIG. 5.8 EFFECTIVENESS OF DLG (TYPHON) AND 3T SHIPS AGAINST ASM ATTACKS — ECM ENVIRONMENT

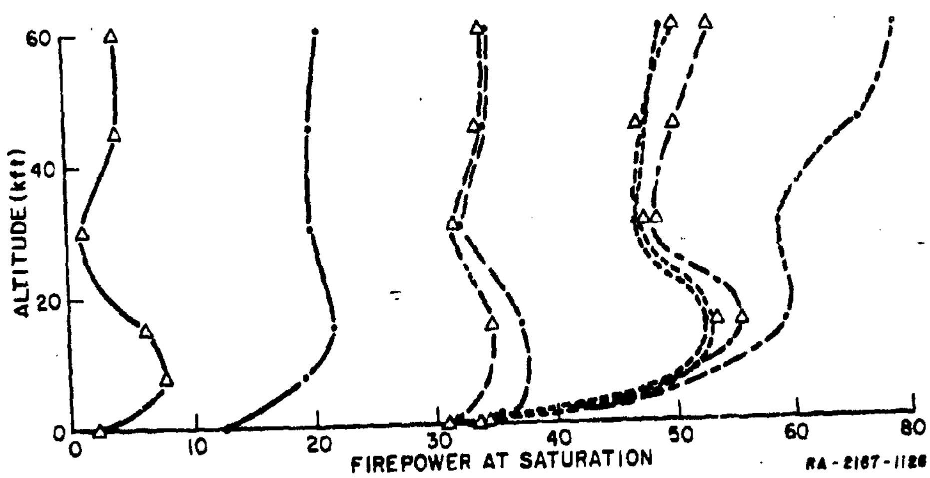



FIG. 5.9 FIREPOWER OF DLG (TYPHON) AND 3T SHIPS AGAINST ASM ATTACKS — ECM ENVIRONMENT

5.2.1.1.2 Summary of Findings

1. The single-ship runs generally point up the clear superiority of the three TYPHON configurations over their 3T counterparts.

2. Of the TYPHON ships analyzed, the DLG(1-2) is the most effective, except against very-low-altitude attacks, where the DLG(0-3) enjoys a slight advantage in firepower and effectiveness, due to the low launcher reload cycle time (10 sec) on all three MR missile launchers.

3. The performance of the DLG(1-2)* lies between the DLG(0-3) and the DLG(1-2) at altitudes greater than 30,000 ft. Below 30,000 ft it tends to lean more toward the DLG(1-2) with respect to effectiveness and firepower.

4. Under the conditions of jamming specified, the DLG(1-2) appears to lose much of the effectiveness advantage it enjoys over the other two TYPHON frigates at the higher altitudes. With ECM, its saturation raid size and firepower characteristics are approximately the same as those for the DLG(1-2)*.

5. For the jamming specified in the analysis, the burn-through capability of the 3400-element AN/SPG-59 radar allows both the IR and MR TYPHON systems to operate with very little ECM degradation in firepower or effectiveness.

6. A comparison of the four 3T ships analyzed in a non-ECM environment (DDG-2, DLG-16, CLG-3, CG-10) reveals the CG-10† to be the most effective ship class.

7. The CLG-3 modified with six TALOS guidance channels is considerably inferior to the CG-10 against low-altitude attacks, although it tends to approach the CG-10 more closely in effectiveness and firepower at the higher altitudes. The dominance of the CG-10 at low altitude is due to two basic factors:

† In the CG-10 analysis, as stated previously, one of the TARTAR batteries was suppressed (did not fire) under the assumption that the ship maneuvered in such a way as to unmask its main TALOS battery against the attack and either its port <u>or</u> starboard secondary TARTAR battery.

(a) The contribution of the "fast-reacting" TARTAR; and

(b) The "launcher limited" condition, which exists aboard the CLG-3 (TALOS) at lower altitudes (the availability of more guidance channels than can be effectively handled by the one TALOS launcher), which is overcome by the presence of two TALOS launchers aboard the CG-10.

8. The CG-10 was selected as a representative 3T ship for the single-ship ECM analysis because of its high relative effectiveness within the group of four 3T ships studied in a non-ECM environment. In the ECM environment specified, the CG-10 lost about 17 percent of its clear environment firepower. It is presumed that the CLG-3, DLG-16 and DDG-2 would suffer similar, if not greater, effectiveness degradations against ASM attacks with stand-off jamming, although these ships were not specifically investigated in the single-ship ECM analysis.

5.2.1.2 SEA MAULER/3T

5.2.1.2.1 Results and Discussion for Coordinated Fire Operation

The results of a comparison of SEA MAULER effectiveness with that of several contemporary SAM and gun system concepts will next be discussed. The SEA MAULER results presented in this report will, of course, pertain to the defense of single ships and carrier task forces in deep sea operations, far removed from the vicinity of any land mass. The analysis of SEA MAULER is considered to be of-value in the current summary examination of SAM systems in that it is representative of a class of short-range, quick-reacting systems that intuitively might play an important role as secondary battery "last ditch" defense weapons. It is in this light that it has been examined.

The results of the single-ship runs without enemy jamming are illustrated in Figs. 5.10 and 5.11. Figure 5.10 compares the saturation raid sizes for the DDG-2 class ship, fitted with various weapon systems as indicated, with that of the CG-10 and DLG (0-3) TYPHON ship over the attack altitude spectrum 0-30,000 ft. These results are based

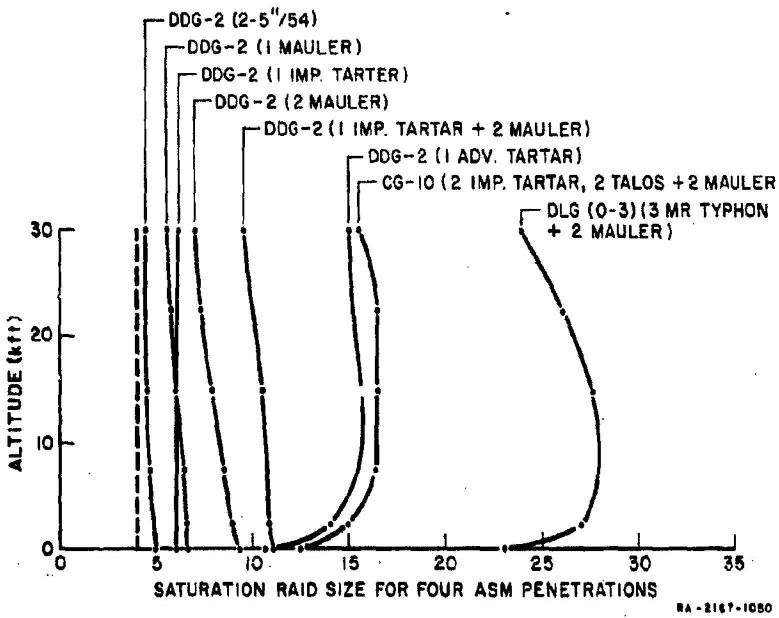



FIG. 5.10 DLG(0-3), CG-10, AND DDG-2 CLASS SHIP EFFECTIVENESS AGAINST ASM ATTACKS WITH SEA MAULER

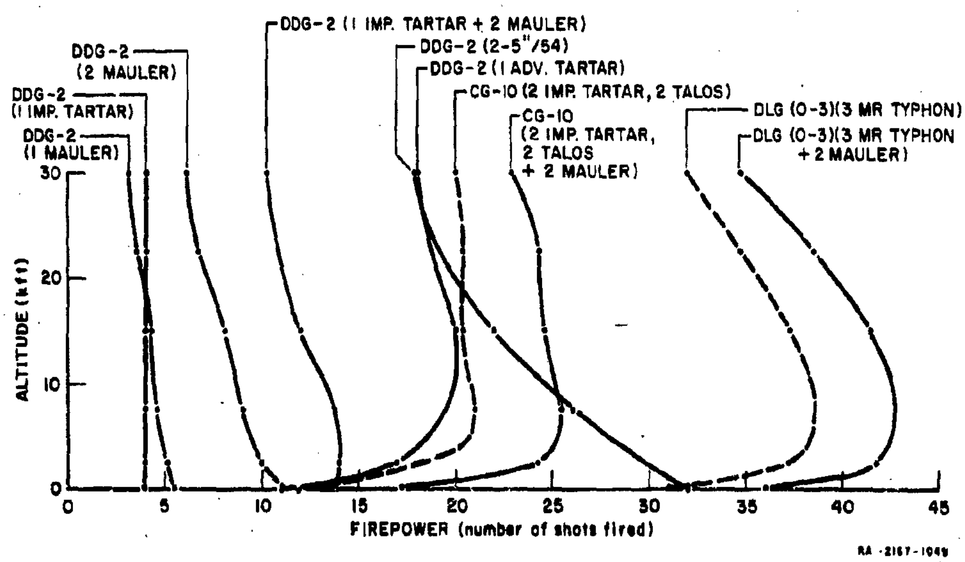



FIG. 5.11 DLG(0-3), CG-10, AND DDG-2 CLASS SHIP FIREPOWER AGAINST ASM ATTACKS WITH SEA MAULER

on complete coordination between SEA MAULER and other missile systems on those ships fitted with SAM systems in addition to SEA MAULER. An altitude cutoff of 30,000 ft was selected in Figs. 5.10 and 5.11, since it represents the upper engagement limit for both SEA MAULER and the 5"/54 gun. Fig. 5.11 compares the firepowers for the various single weapons and weapons mixes that result at the saturation raid sizes shown in Fig. 5.10.

From Figs. 5.10 and 5.11, it can be seen that, for the specific types of attacks being considered, one SEA MAULER pod installed aboard the DDG-2 is about as effective as the single Improved TARTAR fire unit currently planned for installation on this class of ship. The SEA MAULER's effectiveness closely matches that of TARTAR, being slightly superior to TARTAR up to attack altitudes of about 15,000 ft and slightly inferior at higher altitudes (to 30,000 ft). Both SEA MAULER and TARTAR are more effective than the armament consisting of two 5"/54 single mounts, despite the higher firepower of the latter as shown in Fig. 5.11. It should be pointed out that gun effectiveness for this study was derived analytically rather than by computer simulation. This analysis of 5"/54 effectiveness and firepower is presented in Ref. 18.

Referring to Figs. 5.10 and 5.11 and proceeding from left to right, it can be seen that the two SEA MAULER pods on the DDG appear to offer a definite advantage over the installation of a single TARTAR for the attacks considered. This advantage diminishes, however, as the attack altitude increases.

The single-launcher Advanced TARTAR, described in Part D.1.6 of Appendix D, shows an impressive effectiveness margin over the SEA MAULER/TARTAR installations on the DDG-2 except at low altitude, where the Advanced TARTAR becomes launcher limited. Better Advanced TARTAR system balance could undoubtedly be achieved by the additional installation of at least one launcher aboard the ship.

The dotted curves associated with CG-10 and DLG(0-3) firepower reflect the number of shots being fired by the non-SEA MAULER systems aboard these two ships at saturation raid sizes that obtain with the addition of SEA MAULER, as shown in Fig. 5.10. As stated earlier, one of the TARTAR batteries on the CG-10 was suppressed to account for superstructure masking; and the same assumption pertains to the port/starboard SEA MAULER pods added to both the CG-10 and DLG (0-3). Under these circumstances, it is interesting to note that the DDG firepower with a single Advanced TARTAR launcher comes quite close to matching the firepower of the TALOS and TARTAR aboard the CG-10.

The DLG (0-3) more or less stands alone at the far right of both Figs. 5.10 and 5.11, attesting to its superior firepower and effectiveness over the other ship classes and armaments considered in the study.

It was stated earlier that the limiting engagement altitudes for both SEA MAULER and the 5"/54 gun was about 30,000 ft and that, as a consequence, Figs. 5.10 and 5.11 compare the various systems analyzed up to the 30,000-ft attack level. If the firing ship is the objective of the enemy attack, however (as in the case of the stylized attacks being considered for the single-ship analyses), these more limited systems may be able to engage the enemy weapons while they are in their terminal dive. Figure 5.12 illustrates the firepower and effectiveness (saturation raid size) of two SEA MAULER pods on the DDG under these conditions and compares them with the corresponding performance of a single Improved TARTAR, an improved TARTAR and two SEA MAULER's, and, finally, a single-launcher Advanced TARTAR. The altitude range of comparison is for ASM attacks from 200 to 60,000 ft.

It is interesting, though perhaps somewhat academic, to note in Fig. 5.12 the slight increase in both SEA MAULER firepower and effectiveness at altitudes above 30,000 ft. This is due to the fact that, for attacks at and above 30,000 ft, missile/target assignments cannot be made while the ASM's are on their cruise leg because of defense missile altitude limitations on intercepts. Assignments must await the entry of ASM's into their terminal dive. With a constant 45-degree dive angle, irrespective of the ASM cruise leg altitude, the dive legs become progressively longer as ASM cruise altitudes increase. For a 30,000-ft cruise altitude, terminal dive entry occurs at such a slant range as not

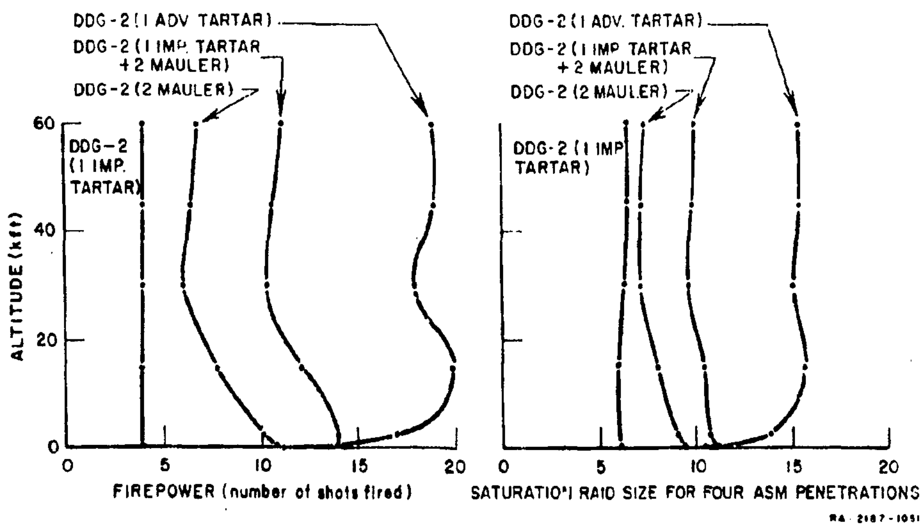



FIG. 5.12 COMPARISON OF MAULER, IMPROVED TARTAR, AND ADVANCED TARTAR (DDG-2) AGAINST ASM ATTACKS (0 – 60,000 ft)

to afford a maximum slant range intercept with MAULER. As the slant range to ASM terminal dive entry increases with increasing attack altitude, this situation is progressively alleviated until one finds that, for 60,000 ft cruise altitudes, the dive legs are now long enough to permit MAULER to intercept at maximum slant range. The firepower that the system can achieve is, of course, dependent on whether or not it is capable of maximum range intercepts. This explains the increasing trend in the SEA MAULER firepower and effectiveness curves in Fig. 5.12 above altitudes of 30,000 ft.

Generally speaking, the answer to the question of what $P_k$ values to use for the various defense missile warheads is shrouded in uncertainty. For purposes of this study, an attempt was made to rule out warhead kill probability as a determining factor in the comparison of weapon systems, since the relative differences between warhead effectiveness against a rather advanced, sophisticated target spectrum is so poorly defined. Those relative differences, however, are important when comparing two systems that are closely matched in potential firepower, such as Improved TARTAR and SEA MAULER. The kill probability values used for the single-ship runs (including intercept component and in-flight reliability) are those presented in Part D.1 of Appendix D. Realization of higher (or lower) kill probabilities for any or all of the systems analyzed in this study would result in a horizontal translation of the associated firepower and effectiveness curves.

The results of ECM attacks against single ships fitted with the SEA MAULER system are considered next. The ship under attack is of the DDG-2 class fitted with two SEA MAULER weapon pods, an AN/SPS-37 (small) search radar (P band) and an AN/SPS-39 search and height finder radar (S band). The mode of attack, which involves the enemy's use of stand-off jammers to screen ASM's launched against the DDG, is more fully described earlier in this section.

The firepower of the two-MAULER DDG under varying conditions of enemy jammer stand-off range (30, 100, and 200 nm) is illustrated in Fig. 5.13. The following power densities were generated by each of the two stand-off jammer aircraft:

| | |
|---|---|
| L band | 15 w/Mc |
| P band | 30 w/Mc |
| S band | 60 w/Mc |
| X band | 20 and 100 w/Mc . |

For the ECM runs whose results are shown in Fig. 5.13, the normal system sequence of operation was observed in which a search radar must first acquire a target and a three-dimensional radar must make height determination before a track-illuminating radar can be assigned. Despite the high jamming power densities being generated by the enemy stand-off jammers on the search and height-finder radar frequencies, these radars invariably managed to burn-through on the incoming attack before the L-band MAULER acquisition radar. The results of this run series revealed that, for a given jammer stand-off range, the search radars were always jammed down to ranges that were less than tracking radar burn-through ranges at time of assignment. Thus these runs constitute only a test of the search radars, and indifference to X-band jamming power densities of either 20 or 100 w/Mc is reflected in the figure.

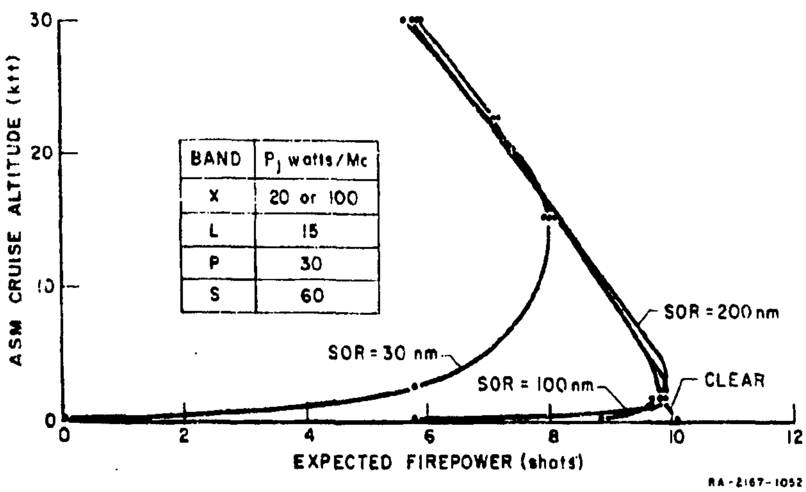



FIG. 5.13 DDG-2 CLASS SHIP FIREPOWER: CONSTANT POWER LEVELS
(Two aircraft standing off at ranges indicated)

It can be seen that for ASM attack altitudes of 15,000 ft and above, the system firepower demonstrated insensitivity to jammer stand-off range, achieving full clear-environment firepower levels.

The system firepower at the 200-ft attack altitude was reduced by about 12 percent and 40 percent from the clear-environment performance for 200 and 100-nm stand-off ranges, respectively. At 30-nm stand-off range, the system achieved no firepower at the 200-ft attack altitude due to the inability of the search radars to detect the ASM's in time to assign any defensive missiles. There is better than a 40 percent degradation in firepower at 2,500-ft attack altitude for 30-nm stand-off range, again due to the reduced burn-through capabilities of the surveillance radars.

In order to measure the sensitivity of system firepower to tracking radar jamming, the worst case, or 30-nm stand-off range situation, was further examined with and without jamming on surveillance radar frequencies and at two X-band power levels (20 and 100 w/Mc). As seen in Fig. 5.14, the performance at 15,000 ft and above remained at or near the clear environment level for all conditions. With surveillance band radar jamming, the system demonstrated an indifference to X-band

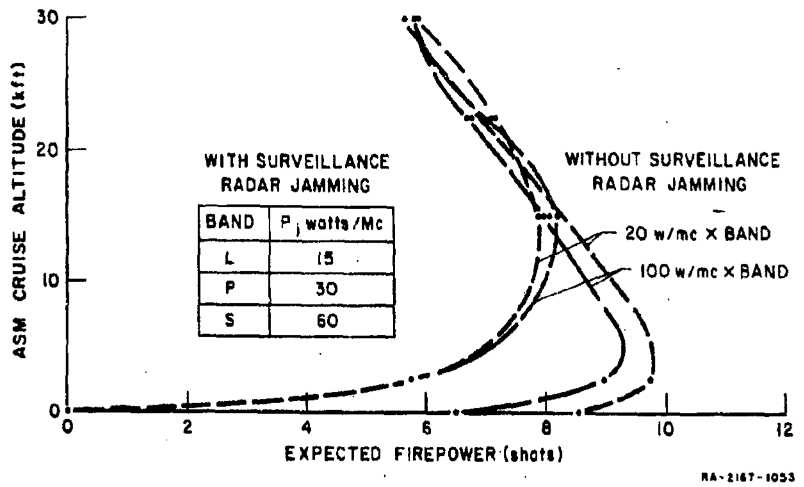
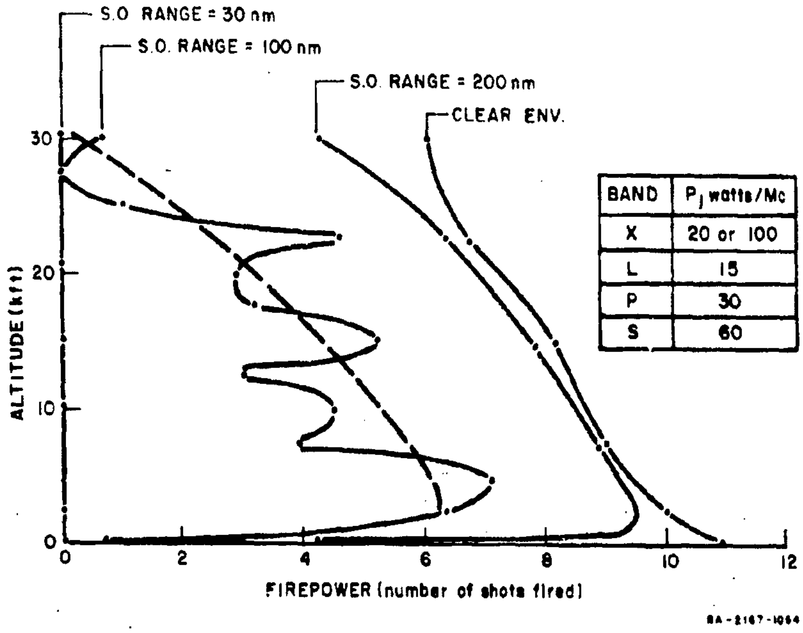



FIG. 5.14 DDG-2 CLASS SHIP FIREPOWER: CONSTANT STAND-OFF RANGE
(Two aircraft standing off at 30 nm from ship)

power density and a severe fall-off of performance at low altitudes, as before. However, with X-band jamming only, the low-altitude firepower increased to the extent that at the 30-nm stand-off range, the 100 w/Mc and 20 w/Mc performance corresponded roughly to that obtained at stand-off ranges of 100 nm and 200 nm, respectively, with all bands jammed (see Fig. 5.13).

Thus, an enemy could achieve nearly the same degradation of the SEA MAULER system firepower by employing X-band-only jamming at 100 w/Mc and 30 nm stand-off range or by employing all-band jamming (with power levels as previously indicated) at a stand-off range of 100 nm. This factor assumes particular importance if operation of the SEA MAULER system in conjunction with other, longer-range systems, such as TALOS, is considered.

In an earlier run series, the AN/SPS-39 radar had been omitted from the ship radar configuration, requiring all targets detections to be made by the AN/SPS-37 and/or MAULER acquisition radars. A peculiar phenomenon was observed, as seen in the curves of Fig. 5.15. At the far right of the figure is the non-ECM or clear-environment firepower of the two SEA MAULER pods previously described. When two stand-off




| BAND | $P_j$ watts/Mc |
|---|---|
| X | 20 or 100 |
| L | 15 |
| P | 30 |
| S | 60 |

FIG. 5.15 DDG-2 CLASS SHIP FIREPOWER: NO 3D RADAR (Two aircraft standing off at indicated ranges jamming with power densities shown in table)

jammers, jamming all of the radar bands of interest, are introduced into the attack, it will be noted that, at 200-nm stand-off range, very little degradation in system performance results, except at very low altitude and at the highest altitude considered (30,000 ft). In these two instances, the enemy jamming energy is penetrating the lobing structure of the AN/SPS-37 antenna pattern, delaying burn-through detections of the ASM's, with an attendant fall-off in firepower. As in the previous cases with surveillance radar jamming, the same curve obtained whether the enemy produced jamming power densities of 20 or 100 w/Mc on X band.

At a stand-off range of 100 nm, the penetrations of the search radar antenna pattern lobing structure by enemy jamming, and a corresponding fluctuation in returned signal energy, becomes even more apparent producing the erratic firepower pattern with altitude shown in Fig. 5.15. It will be noted that attack altitude was varied in 2,500-ft increments in order better to define the curve shape; however, it is not clear that the fine-grain variations of firepower due to this phenomenon have been fully explored. The dotted curve shown superimposed over the solid oscillating curve has no significange other than to provide a "mean" measure of firepower for comparison with the other conditions considered.

At a jammer stand-off range of 30 nm, the search and acquisition radars were unable to obtain target detections in sufficient time to achieve any firepower at all altitudes of attack considered.

Slight variations in defining the search radar antenna pattern would, of course, produce corresponding variations in detection patterns and, in turn, in the shape of the firepower curves, particularly in the fine-grain shape of the 100-nm stand-off range curve. Since the antenna pattern lobing structure is due to sea reflection (cancellation and reinforcement), which varies with sea state, it is apparent that the actual points obtained in the analysis of the SEA MAULER system under these conditions (at the stand-off range of 100 nm, for example) are not nearly so important as is the realization that the phenomenon illustrated in the figure actually exists.

The desirability of making data from the AN/SPS-39 radar available to the SEA MAULER batteries is apparent from comparison of the results presented in Figs. 5.13, 5.14, and 5.15.

5.2.1.2.2 <u>Results and Discussion for Autonomous Operation</u>

In this portion of the analysis, the SEA MAULER System aboard the DDG-2 class ship was restricted to operating entirely on information available from the MAULER acquisition and tracking radars. The sequence of operations then became

(1) Initial detection of a target by the acquisition radar,

(2) An initial threat evaluation delay, followed by

(3) Designation of detected targets to the track-illuminating radars for missile assignments.

An alternative method of measuring system performance in an autonomous mode would be to allow any radar aboard the ship to establish the first detection event, triggering the initial threat evaluation delay.

Thereafter, the acquisition radar must detect each of the targets independently, prior to weapon designation. This method (not analyzed) would result in increased system firepower if the acquisition radar were the limiting link in the sequence and if reduction or elimination of the threat evaluation delay were possible by earlier first detection by some other radar.

The reduction in system firepower in a non-ECM environment that could be expected in shifting from coordinated to autonomous operation of the MAULER fire units is illustrated in Fig. 5.16. The amount of degradation in firepower varies from 33 percent at the highest attack altitude considered (30,000 ft) to about 10 percent at the lower altitudes.

This may be accounted for by the range performance of the MAULER acquisition radar, which is barely adequate at the lower altitudes (when the threat evaluation delay is included) to somewhat inadequate at the higher altitudes due to the concentration of radar energy at low elevation angles by the beam pattern of the MAULER acquisition radar.

As discussed earlier, performance approaching that obtained under nonautonomous operation might be expected if the threat

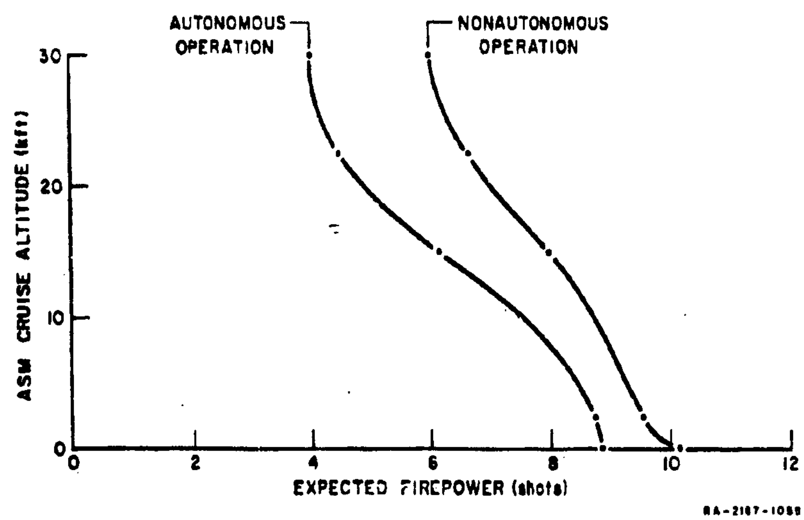
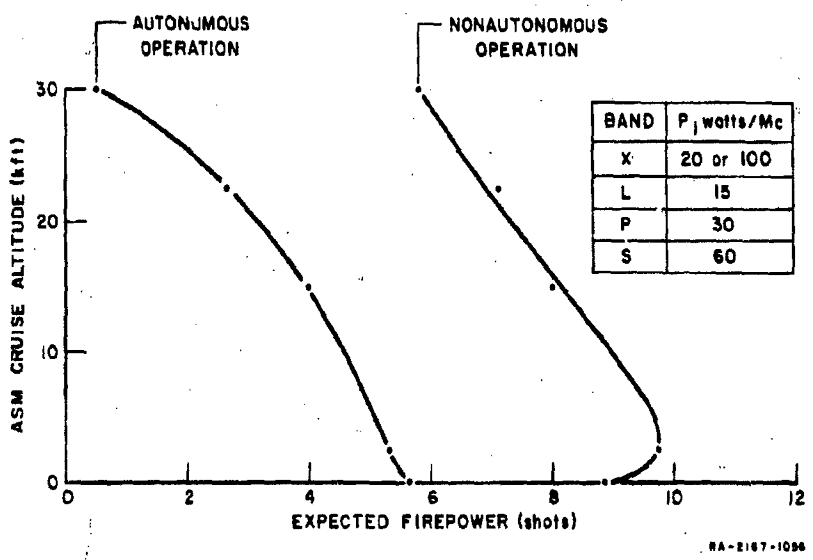



FIG. 5.16 DDG-2 CLASS SHIP FIREPOWER: CLEAR ENVIRONMENT

evaluation delay were to be allowed to be initiated by other surveillance radars aboard the ship. This is reflected in the performance of the "autonomous task force" situation of Part 5.2.2.2.

With enemy jamming of both the surveillance radar and tracking radar frequency bands, the SEA MAULER system suffers severe degradation in firepower capability when operating in an "autonomous" mode, even for jammer stand-off range of 200 nm. Figure 5.17 indicates that, under these conditions, degradations varied from about 45 percent at low altitudes to over 90 percent at 30,000 ft, where the firepower has been reduced nearly to zero.




| BAND | $P_j$ watts/Mc |
|---|---|
| X | 20 or 100 |
| L | 15 |
| P | 30 |
| S | 60 |

FIG. 5.17 DDG-2 CLASS SHIP FIREPOWER: ALL BANDS JAMMED (Two aircraft standing off 200 nm from ship jamming with power densities shown in table)

In the instance of X-band jamming only, the MAULER system firepower was reduced by about 25 percent at the higher attack altitudes, diminishing to no degradation at the 200-ft attack altitude (Fig. 5.18). It is of interest to compare the autonomous operation curves of Figs. 5.16 and 5.18. Since these curves are nearly identical, it can readily be seen that the X-band-only jamming has virtually no effect on the system

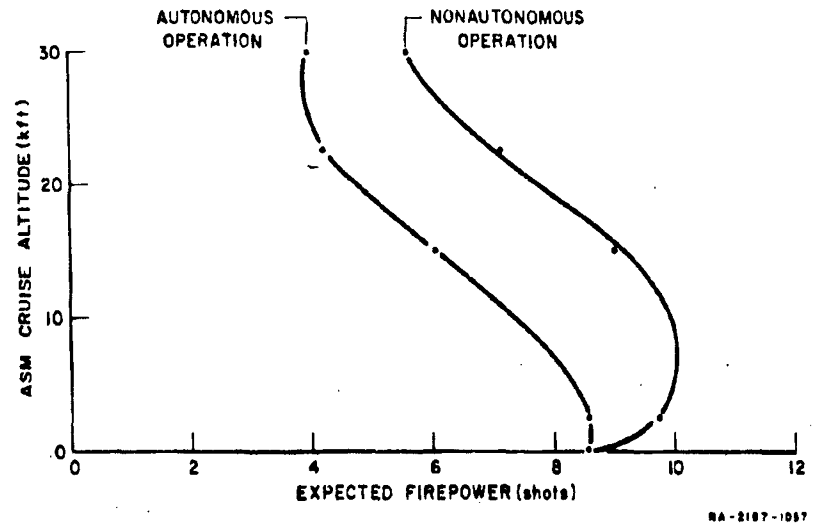



FIG. 5.18 DDG-2 CLASS SHIP FIREPOWER: X-BAND-ONLY JAMMING (Two aircraft standing off at 30 nm from ship jamming X band only at 20 w/Mc)

performance under these conditions, the degradation in firepower being entirely attributable to the change from coordinated to autonomous operation.

These cases all point up the relative weakness of the MAULER acquisition radar and the desirability of making available at least initial threat evaluation data from other ships' radars, if not complete target detection information.

5.2.1.2.3 Summary of Findings

The following findings are based on the conditions, modes of operation, and target threats postulated in Part 5.2.1. Unless otherwise specified, all findings pertain to the coordinated mode of operation of SEA MAULER wherein target position information is made available to the SEA MAULER units from other ships' surveillance radars.

1. Two SEA MAULER pods on the DDG offer a definite effectiveness advantage over the installation of a single TARTAR for the attacks considered, particularly at low altitudes.

2. The single launcher Advanced TARTAR (ROPAR) shows an impressive effectiveness margin over the one TARTAR/two SEA MAULER installation on the DDG-2 except at low altitude, where the Advanced TARTAR becomes launcher limited.

3. The firepower of the DDG with a single Advanced TARTAR launcher comes quite close to matching the performance of the CG-10.

4. In the single-ship ECM environment analysis, the firepower of the SEA MAULER system was found to be independent of surveillance and tracking radar band jamming levels for ASM cruise altitudes above 15,000 ft, except for severe degradations in performance under autonomous operation. Below this altitude, there is marked sensitivity to the presence or absence of surveillance radar jamming. At these lower altitudes, the jamming aircraft are more nearly in the maximum gain position of the acquisition radars and are more effective in denying initial detection of incoming ASM's. When the surveillance radars are jammed, there exists an indifference to the X-band jamming power level over all altitudes considered.

5. Single-ship autonomous operation of the SEA MAULER system in the clear environment results in 8 to 33 percent reduction in firepower, with the highest reduction occurring at the higher ASM cruise altitudes considered. The MAULER acquisition radar does not have sufficient detection range capability to act as the initial detection radar, allow for initial threat evaluation, and still achieve maximum range missile intercept. The relative increase in the degradation of autonomous operation firepower as cruise altitude increases is a result of the beam pattern shape of the acquisition radar, which concentrates most of its radiated energy at low elevation angles.

6. Against jammers standing off at 200 nm from the firing ship, SEA MAULER suffered from 33 to 83 percent reduction in firepower in going from coordinated to autonomous operation. As before, the largest degradation in firepower occurred at the higher altitudes as a result of the acquisition radar antenna beam pattern.

7. It is not altogether clear that SEA MAULER would be a completely effective primary battery weapon system in the case of single-ship operations. The single-ship ECM runs of this study, for example, point up the necessity of keeping enemy jammers at "arms length" from the SEA MAULER ship (with, perhaps, longer-range SAM's) if any appreciable degree of SEA MAULER firepower is to be realized. An additional problem is created by the fact that enemy weapon-carrying aircraft can, in some cases, completely evade SEA MAULER battery fire in the delivery of free-fall weapons. Such evasion likewise pertains in the air delivery of long-range homing torpedoes. Overflights of a SEA MAULER ship can be accomplished with relative ease by high-performance aircraft engaged in reconnaissance activities.

8. Considerations of this sort lead to the conclusion that a defense consisting solely of SEA MAULER units may be effective against only certain types of attack. Yet, were it to be used on small ships that are presently fitted with only gun systems, it appears that defense effectiveness against a considerable portion of the attack threat spectrum would be significantly improved.

#### 5.2.1.3 Multiplex Operation of TERRIER and TALOS

##### 5.2.1.3.1 Concept and Approach

In searching for ways to achieve higher firing rates and over-all effectiveness of SAM systems, the NAVY has considered the use of multiplex operation of the TERRIER and TALOS. The data presented in this section provides information on a potential level of performance that might be attainable through modifications of current weapons systems. These data were developed in an analytical study reported in Ref. 17.

The multiplex concept exploits two technical facts:

(1) Data rate requirements are lower during the midcourse phase of missile flight than during the terminal phase (which includes kill assessment); and

(2) The duration of the terminal phase is short relative to the midcourse phase, for all but very short-range intercepts.

The two-channel simplex guidance system currently used with the TERRIER and TALOS missile systems ties up a missile fire control radar channel during the entire flight and kill assessment period of each missile. This information channel must be capable of the relatively high data rate required for the terminal phase. Since only two fire control channels are provided for each launcher, firepower in many situations is constrained by guidance channel availability. The number of simplex fire control channels per launcher could be increased to relieve this constraint. But this increase in channels would be a rather costly way to increase guidance capacity, since each channel would need to be capable of the relatively high terminal data rate, and that rate is in most cases required during only a small fraction of the total flight.

The multiplex concept potentially affords a more efficient use of system information capacity to relieve guidance constraints. The essence of the concept is to provide the low-data-rate midcourse information separately to a large number of missiles and high-date-rate information to a smaller number of missiles in the terminal phase. In this way, a larger total number of missiles can be guided with a given system information capacity. One way to implement this concept is to introduce another radar (called the "midcourse radar") that would provide low-data-rate midcourse guidance information, while using the original fire-control radars to guide the missiles in their terminal homing phase only. A system embodying this concept would employ a midcourse radar with track-while-scan capability so that it could supply data on a time-sharing basis to a relatively large number of low-data-rate midcourse channels. By switching the high-data-rate fire-control radar to a missile only during the terminal phase of its flight, several missiles can be in flight for each radar. The total number of missiles in flight at any one time can be no greater than the combined number of midcourse and terminal data channels. Similarly, the number of missiles in midcourse or in terminal phase of flight can be no greater than the respective number of channels of that type.

The study was conducted to determine the potential performance improvement in the TERRIER and TALOS missile systems by using the multiplex concept to increase guidance capacity. The study scope did not include investigation of the technical feasibility or cost to attain a workable multiplex capability. It is a study of the utility of several levels of increased guidance capacity. The measure of utility was system firepower, for a missile battery (comprising launcher, guidance radar and magazine), expressed as the number of intercepts. The analysis of firepower observed the constraints imposed by missile flight times and maximum ranges, radar range as governed by horizon and by power considerations, launcher recycle time and number of rails, delay time for data smoothing and weapon designation, number of midcourse and terminal guidance channels and the appropriate channel tie-up times throughout the course of an engagement (including pre-launch target acquisition, in-flight midcourse and terminal guidance and post-intercept assessment). The essence of the analysis was

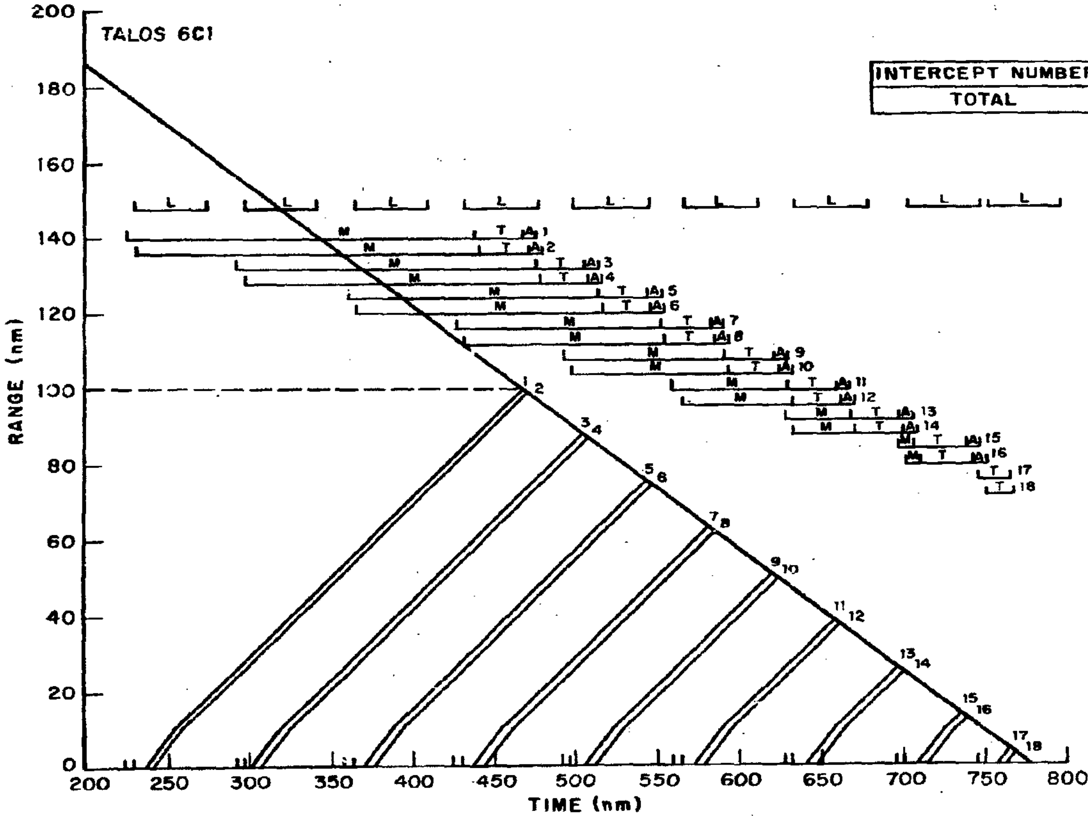
(1) The exploration of firepower constraint boundaries for each of several missile system configurations, and

(2) The measurement of slack in selected constraints.

Graphical computation methods were developed to compute the performance measure from the appropriate set of conditions and system capability parameters. Forty cases were examined; each case represents a different combination of target, weapon system type and configuration, and system capability parameters. The computation sheet for a representative case is shown in Fig. 5.19. These methods of computation are well suited to the cumulative interactions of the multiple factors that govern firepower.

The missiles considered in this study were the TALOS 6C1, the advanced TERRIER HT-3, and in some cases the TERRIER BT-3. Missile maximum range in nautical miles was taken as follows:

| | |
|---|---|
| TERRIER HT-3 | 40 nm |
| TERRIER BT-3 | 20 nm |
| TALOS 6C1 | 100 nm. |




LAUNCH CONSTRAINTS

| | MMR | MCA | TCA | LR |
|---|---|---|---|---|
| INTERCEPT NUMBERS | 1,2 | — | 3-16 | 17, 18 |
| TOTAL | 2 | 0 | 14 | 2 |

PLMCC: 8

INTERCEPT SUMMARY

| DIAGRAM POINT | NO. OF MISSILES | RANGE nm |
|---|---|---|
| 1 | 1 | 100 |
| 2 | 1 | 99 |
| 3 | 1 | 88 |
| 4 | 1 | 87 |
| 5 | 1 | 76 |
| 6 | 1 | 75 |
| 7 | 1 | 63 |
| 8 | 1 | 62 |
| 9 | 1 | 51 |
| 10 | 1 | 50 |
| 11 | 1 | 39 |
| 12 | 1 | 38 |
| 13 | 1 | 26 |
| 14 | 1 | 25 |
| 15 | 1 | 14 |
| 16 | 1 | 13 |
| 17 | 1 | 4 |
| 18 | 1 | 3 |
| TOTAL | 18 | |

FIG. 5.19 REPRESENTATIVE GRAPHICAL INTERCEPT COMPUTATION SHEET



SECRET

Coordinated operation of the TERRIER BT-3 in simplex along with the HT-3 in multiplex was studied in selected cases. A single missile battery was considered, consisting of dual-rail launcher and appropriate missile control equipment. A 100-ft radar antenna height was assumed for both the midcourse and the missile fire control radars, resulting in a radar horizon of 29.7 nm on a target at 200 ft altitude. Twelve seconds were allowed for data smoothing and weapon designation after the target crosses the horizon, before acquisition and tracking begin.

In multiplex operation, the fire-control channel is needed only for the terminal phase of the intercept, since assessment, after initial and midcourse guidance, has been provided by the midcourse radar. In simplex operation, fire-control radar target acquisition must occur before missile launch, and target illumination by the fire control radar is required throughout the flight.

Fire-control radar target-acquisition time in all cases studied was 5 sec and target-illumination time was specified at 10 and 15 sec, respectively, for TALOS and TERRIER. To examine the effect of longer illumination times, 25 secs was also studied for both missile systems. Assessment times of 8 sec and 0 sec was studied in all cases.

Multiplex operation against both the medium- and the low-altitude targets was considered under the assumption that any desired number of midcourse channels were available. Also, limited numbers of midcourse channels were studied in operation against the medium-altitude targets.

Further details on system parameters are presented in Ref. 17.

Firepower was measured to determine the following effects:

(1) Capability of the two-channel simplex guidance configuration (conventional system design) of each missile system against each target, for use as a reference to assess the multiplex configurations.

(2) Maximum capability of the multiplex guidance configuration of each missile system against each target. The analysis determined the minimum number of midcourse channels that do not constrain firepower.

(3) Capability of the multiplex guidance configuration of each missile system, employing fewer than the maximum useful number of midcourse channels. The TERRIER system studied in this part of the analysis is the coordinated HT-3 and BT-3 configuration. Results for this configuration are compared in Table 5.2 with the two-channel simplex and the maximum-channel multiplex configurations described above.

(4) The effect of extended director tie-up time upon multiplex operation for either missile system against either target, with as many multiplex channels as needed to avoid constraint.

(5) The effect of a reduced launcher cycle time for the TALOS system against the medium-altitude target. A hypothetical 10-sec reduction in launcher cycle time is examined.

All situations are studied for both 8-sec and 0-sec assessment times.

5.2.1.3.2 <u>Results and Summary of Findings</u>

The results for each case are stated in terms of the number of intercepts achieved and, where appropriate, in terms of the numbers of midcourse channels required to avoid intercept limitation by the lack of channel availability. The numbers of intercepts are presented in total and also in terms of the factor constraining each intercept. These factors are radar horizon, missile maximum range, midcourse and terminal guidance channel availability, and launcher recycle. Intercepts simultaneously constrained by guidance channel availability and launcher recycle are listed under launcher constraint, because any further reduction in guidance constraint would, by itself, yield no benefit.

The results for each of the effects studied are presented in Tables 5.1 through 5.4. Table 5.1 presents a comparison of the two-channel simplex configurations with the maximum-channel multiplex configurations. Table 5.2 presents the effect of limited number of midcourse channels for the medium-altitude target. Table 5.3 presents the effect of extended fire control radar tie-up time. Table 5.4 shows that against the medium-altitude target, a 10-sec reduction in TALOS launcher recycle time (to 35 sec from 45) does not affect total number of intercepts with 8-sec assessment times. Results for all 40 cases examined are summarized in Table 5.5.

The following points emerge from the foregoing analysis:

1. The maximum number of midcourse channels that need to be provided is ten for TALOS and four for TERRIER. A larger number could be utilized only if other constraints were relieved.
2. Multiplex operation affords significant fire-power increase against medium-altitude targets, 175 percent for TALOS and 67 percent for TERRIER. Low-altitude firepower is increased 20-25 percent.
3. Multiplex operation relieves the fire control channel constraint upon firepower to the point where launcher recycle governs. The relief margin is small, and further significant firepower improvements require reduction in both launcher recycle time and fire control radar tie-up time.
4. Coordinated operation of the two-channel simplex BT-3 with HT-3 multiplex accomplishes effectively the same firepower as operation of the HT-3 multiplex exclusively.

5.2.2 Task-Force Analysis

In this subsection, each of the ship classes analyzed in Part 5.2.1 is placed in a more realistic operational environment so that its performance can be further analyzed in such an environment. To achieve this end, the various ships of interest were assembled into task forces (Carrier Striking Forces). With respect to the study of the TYPHON frigate variants, two basic task force types were considered. One type placed the TYPHON DLG's on picket stations (Formation I); the other placed them in the formation main body (Formation II).

There were three variants of Task Force Formation I considered [corresponding to the three DLG (TYPHON) variations described in Part 5.2.1] and four variants of Task Force Formation II. Three of the four Formation II cases studied covered variations in TYPHON DLG configurations

Table 5.1

COMPARISON OF TWO-CHANNEL SIMPLEX OPERATION
AND MAXIMUM-CHANNEL MULTIPLEX CONFIGURATION

| Situation | Results: Number of Intercepts — Total | Distribution by Launch Constraints: Radar Horizon | Missile Maximum Range | Guidance Availability: Midcourse | Guidance Availability: Terminal | Launcher Recycle | Midcourse Channels at Peak Load | Case |
|---|---|---|---|---|---|---|---|---|
| Assessment Time: 8 sec | | | | | | | | |
| TERRIER | | | | | | | | |
| Medium Altitude | | | | | | | | |
| Simplex | 6 | 0 | 2 | 0 | 4 | 0 | -- | 4 |
| Multiplex | 10 | 0 | 2 | 0 | 0 | 8 | 4 | 5 |
| Low Altitude | | | | | | | | |
| Simplex | 10 | 2 | 0 | 0 | 4 | 4 | -- | 1 |
| Multiplex | 12 | 2 | 0 | 0 | 0 | 10 | 2 | 2 |
| TALOS | | | | | | | | |
| Medium Altitude | | | | | | | | |
| Simplex | 8 | 0 | 2 | 0 | 6 | 0 | -- | 24 |
| Multiplex | 22 | 0 | 2 | 0 | 0 | 20 | 10 | 26 |
| Low Altitude | | | | | | | | |
| Simplex | 8 | 2 | 0 | 0 | 4 | 2 | -- | 21 |
| Multiplex | 10 | 2 | 0 | 0 | 0 | 8 | 2 | 22 |
| Assessment Time: 0 sec | | | | | | | | |
| TERRIER | | | | | | | | |
| Medium Altitude | | | | | | | | |
| Simplex | 8 | 0 | 2 | 0 | 4 | 2 | -- | 14 |
| Multiplex | 10 | 0 | 2 | 0 | 0 | 8 | 4 | 15 |
| Low Altitude | | | | | | | | |
| Simplex | 10 | 2 | 0 | 0 | 4 | 4 | -- | 11 |
| Multiplex | 12 | 2 | 0 | 0 | 0 | 10 | 2 | 12 |
| TALOS | | | | | | | | |
| Medium Altitude | | | | | | | | |
| Simplex | 10 | 0 | 2 | 0 | 6 | 2 | -- | 34 |
| Multiplex | 22 | 0 | 2 | 0 | 0 | 20 | 10 | 36 |
| Low Altitude | | | | | | | | |
| Simplex | 8 | 2 | 0 | 0 | 2 | 4 | -- | 31 |
| Multiplex | 10 | 2 | 0 | 0 | 0 | 3 | 2 | 32 |

Unlimited Multiplex Channels
Multiplex: Terminal Guidance tie-up Time: TERRIER, 15 seconds; TALOS, 20 seconds
Launcher Recycle Time: TERRIER, 35 seconds; TALOS, 45 seconds

Table 5.2

EFFECT OF LIMITED NUMBER OF MULTIPLEX MIDCOURSE CHANNELS

| Situation | Number of Midcourse Channels | Results: Number of Intercepts: Total | Distribution by Launch Constraints: Radar Horizon | Missile Maximum Range | Guidance Availability: Midcourse | Guidance Availability: Terminal | Launcher Recycle | Case |
|---|---|---|---|---|---|---|---|---|
| Assessment Time: 8 sec | | | | | | | | |
| TERRIER | | | | | | | | |
| HT-3 Only | 4 or more | 10 | 0 | 2 | 0 | 0 | 8 | 5 |
| HT-3 and BT-3 Coordinated | 4 or more | 10 | 0 | 2 | 0 | 1 | 7 | 6 |
| | 3 | 8 | 0 | 2 | 1 | 1 | 4 | 7 |
| | 2 | 8 | 0 | 2 | 3 | 1 | 2 | 8 |
| | 1 | 7 | 0 | 2 | 1 | 2 | 2 | 9 |
| HT-3 Only | Simplex | 6 | 0 | 2 | 0 | 4 | 0 | 4 |
| TALOS | 10 or more | 22 | 0 | 2 | 0 | 0 | 20 | 26 |
| | 8 | 22 | 0 | 2 | 2 | 0 | 18 | 27 |
| | 4 | 16 | 0 | 2 | 4 | 0 | 10 | 28 |
| | 2 | 12 | 0 | 2 | 6 | 0 | 4 | 29 |
| | Simplex | 8 | 0 | 2 | 0 | 6 | 0 | 24 |
| Assessment Time: 0 sec | | | | | | | | |
| TERRIER | | | | | | | | |
| HT-3 Only | 4 or more | 10 | 0 | 2 | 0 | 0 | 8 | 15 |
| HT-3 and BT-3 Coordinated | 4 or more | 10 | 0 | 2 | 0 | 1 | 7 | 16 |
| | 3 | 8 | 0 | 2 | 1 | 1 | 4 | 17 |
| | 2 | 8 | 0 | 2 | 3 | 1 | 2 | 18 |
| | 1 | 8 | 0 | 2 | 1 | 2 | 3 | 19 |
| HT-3 Only | Simplex | 8 | 0 | 2 | 0 | 4 | 2 | 14 |
| TALOS | 10 or more | 22 | 0 | 2 | 0 | 0 | 20 | 36 |
| | 8 | 22 | 0 | 2 | 2 | 0 | 18 | 37 |
| | 4 | 16 | 0 | 2 | 4 | 0 | 10 | 38 |
| | 2 | 12 | 0 | 2 | 6 | 0 | 4 | 39 |
| | Simplex | 10 | 0 | 2 | 0 | 6 | 2 | 34 |

Medium Altitude

Multiplex: Terminal Guidance Tieup Time: TERRIER, 15 seconds; TALOS, 20 seconds

Launcher Recycle Time: TERRIER, 35 seconds; TALOS, 45 seconds

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Table 5.3

MULTIPLEX OPERATION WITH EXTENDED ILLUMINATION TIME

| Situation | Director Illumination Time, Seconds | Results | | | | | | | Case |
|---|---|---|---|---|---|---|---|---|---|
| | | Number of Intercepts | | | | | | Midcourse Channels at Peak Load | |
| | | Total | Distribution of Launch Constraints | | | | | | |
| | | | Radar Horizon | Missile Maximum Range | Guidance Availability | | Launcher Recycle | | |
| | | | | | Midcourse | Terminal | | | |
| Assessment Time: 8 sec | | | | | | | | | |
| TERRIER | | | | | | | | | |
| Medium Altitude | 25 | 8 | 0 | 2 | 0 | 6 | 0 | 2 | 10 |
| | 10 | 10 | 0 | 2 | 0 | 0 | 8 | 4 | 5 |
| | Simplex | 6 | 0 | 2 | 0 | 4 | 0 | -- | 4 |
| Low Altitude | 25 | 8 | 2 | 0 | 0 | 4 | 2 | 2 | 3 |
| | 10 | 12 | 2 | 0 | 0 | 0 | 10 | 2 | 2 |
| | Simplex | 10 | 2 | 0 | 0 | 4 | 4 | -- | 1 |
| TALOS | | | | | | | | | |
| Medium Altitude | 25 | 18 | 0 | 2 | 0 | 14 | 2 | 8 | 30 |
| | 15 | 22 | 0 | 2 | 0 | 0 | 20 | 10 | 26 |
| | Simplex | 8 | 0 | 2 | 0 | 6 | 0 | -- | 24 |
| Low Altitude | 25 | 8 | 2 | 0 | 0 | 0 | 6 | 2 | 23 |
| | 15 | 10 | 2 | 0 | 0 | 0 | 8 | 2 | 22 |
| | Simplex | 8 | 2 | 0 | 0 | 4 | 2 | -- | 21 |
| Assessment Time: 0 sec | | | | | | | | | |
| TERRIER | | | | | | | | | |
| Medium Altitude | 25 | 10 | 0 | 2 | 0 | 6 | 2 | 4 | 20 |
| | 10 | 10 | 0 | 2 | 0 | 0 | 8 | 4 | 15 |
| | Simplex | 8 | 0 | 2 | 0 | 4 | 2 | -- | 14 |
| Low Altitude | 25 | 10 | 2 | 0 | 0 | 0 | 8 | 2 | 13 |
| | 10 | 12 | 2 | 0 | 0 | 0 | 10 | 2 | 12 |
| | Simplex | 10 | 2 | 0 | 0 | 4 | 4 | -- | 11 |
| TALOS | | | | | | | | | |
| Medium Altitude | 25 | 22 | 0 | 2 | 0 | 18 | 2 | 10 | 40 |
| | 15 | 22 | 0 | 2 | 0 | 0 | 20 | 10 | 36 |
| | Simplex | 10 | 0 | 2 | 0 | 6 | 2 | -- | 34 |
| Low Altitude | 25 | 6 | 2 | 0 | 0 | 0 | 6 | 2 | 33 |
| | 15 | 10 | 2 | 0 | 0 | 0 | 8 | 2 | 32 |
| | Simplex | 8 | 2 | 0 | 0 | 2 | 4 | -- | 31 |

Unlimited Multiplex Channels

Launcher Recycle Time: TERRIER, 35 seconds; TALOS, 45 seconds



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Table 5.4

EFFECT OF REDUCED LAUNCHER RECYCLE TIME
(Medium-Altitude Target)

| Assessment Time, (Seconds) | Launcher Recycle Time, (Seconds) | Results | | | | | | | Case |
|---|---|---|---|---|---|---|---|---|---|
| | | Number of Intercepts | | | | | | | |
| | | Distribution of Launch Constraints | | | | | | Midcourse Channels at Peak Load | |
| | | Total | Radar Horizon | Missile Maximum Range | Guidance Availability | | Launcher Recycle | | |
| | | | | | Midcourse | Terminal | | | |
| 8 | 35 | 22 | 0 | 2 | 0 | 20 | 0 | 10 | 25 |
| | 45 | 22 | 0 | 2 | 0 | 0 | 20 | 10 | 26 |
| 0 | 35 | 28 | 0 | 2 | 0 | 0 | 26 | 12 | 35 |
| | 45 | 22 | 0 | 2 | 0 | 0 | 20 | 10 | 36 |

Unlimited Multiplex Channels

Terminal Guidance Fire Control Radar Tie-up Time: 20 seconds

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Table 5.5

SUMMARY OF ALL CASES

| Remarks | Case No. | Conditions | | | | Terminal Guidance Tieup (in seconds) | | | Numb… Distributio… | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Missile | Target | Mode | Midcourse Channels Available | Acquis. | Illum. | Kill Assess | Radar Horizon | Missile Maximum Range |
| | 1 | TERRIER | Low | Sim | -- | 5 | Flt | 8 | 2 | 0 |
| | 2 | | | Multi | As need | | 10 | | 2 | 0 |
| | 3 | | | | | | 25 | | 2 | 0 |
| | 4 | | Med | Sim | -- | | Flt | | 0 | 2 |
| | 5 | | | Multi | As need | | 10 | | 0 | 2 |
| | 6 | | | Combi | 4 and up | | | | 0 | 2 |
| | 7 | | | | 3 | | | | 0 | 2 |
| | 8 | | | | 2 | | | | 0 | 2 |
| One HT-3 Rail in Simplex | 9 | | | | 1 | | | | 0 | 2 |
| | 10 | | | Multi | As need | | 25 | | 0 | 2 |
| | 11 | | Low | Sim | -- | | Flt | 0 | 2 | 0 |
| | 12 | | | Multi | As need | | 10 | | 2 | 0 |
| | 13 | | | | | | 25 | | 2 | 0 |
| | 14 | | Med | Sim | -- | | Flt | | 0 | 2 |
| | 15 | | | Multi | As need | | 10 | | 0 | 2 |
| | 16 | | | Combi | 4 and up | | | | 0 | 2 |
| | 17 | | | | 3 | | | | 0 | 2 |
| | 18 | | | | 2 | | | | 0 | 2 |
| One HT-3 Rail in Simplex | 19 | | | | 1 | | | 1 | 0 | 2 |
| | 20 | | | Multi | As need | | 25 | 0 | 0 | 2 |
| | 21 | TALOS | Low | Sim | -- | 5 | Flt | 8 | 2 | 0 |
| | 22 | | | Multi | As need | | 15 | | 2 | 0 |
| | 23 | | | | | | 25 | | 2 | 0 |
| | 24 | | Med | Sim | -- | | Flt | | 0 | 2 |
| Lch. Cycle 35 Sec | 25 | | | Multi | As need | | 15 | | 0 | 2 |
| Normal Lch. Cycle | 26 | | | | As need | | 15 | | 0 | 2 |
| | 27 | | | | 8 | | | | 0 | 2 |
| | 28 | | | | 4 | | | | 0 | 2 |
| | 29 | | | | 2 | | | | 0 | 2 |
| | 30 | | | | As need | | 25 | | 0 | 2 |
| | 31 | | Low | Sim | 0 | | Flt | 0 | 2 | 0 |
| | 32 | | | Multi | As need | | 15 | | 2 | 0 |
| | 33 | | | | | | 25 | | 2 | 0 |
| | 34 | | Med | Sim | 0 | | Flt | | 0 | 2 |
| Lch. Cycle 35 Sec | 35 | | | Multi | As need | | 15 | | 0 | 2 |
| Normal Lch. Cycle | 36 | | | | | | 15 | | 0 | 2 |
| | 37 | | | | 8 | | | | 0 | 2 |
| | 38 | | | | 4 | | | | 0 | 2 |
| | 39 | | | | 2 | | | | 0 | 2 |
| | 40 | | | | As need | | 25 | | 0 | 2 |

Table 5.5

SUMMARY OF ALL CASES

| Conditions | | | | | Results | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Terminal Guidance Tieup (in seconds) | | | Number of Intercepts | | | | | | | Case No. |
| | | | | | Distribution by Launching Constraint | | | | | | Midcourse Channels at Peak Load | |
| de | Midcourse Channels Available | | | | | | Channel Availability | | | | | |
| | | Acquis. | Illum. | Kill Assess | Radar Horizon | Missile Maximum Range | Midcourse | Terminal | Launcher Recycle | Total | | |
| .m | -- | 5 | Flt | 8 | 2 | 0 | 0 | 4 | 4 | 10 | -- | 1 |
| ılti | As need | | 10 | | 2 | 0 | 0 | 0 | 10 | 12 | 2 | 2 |
| | | | 25 | | 2 | 0 | 0 | 4 | 2 | 8 | 2 | 3 |
| .m | -- | | Flt | | 0 | 2 | 0 | 4 | 0 | 6 | -- | 4 |
| ılti | As need | | 10 | | 0 | 2 | 0 | 0 | 8 | 10 | 4 | 5 |
| ɔmbi | 4 and up | | | | 0 | 2 | 0 | 1 | 7 | 10 | -- | 6 |
| | 3 | | | | 0 | 2 | 1 | 1 | 4 | 8 | -- | 7 |
| | 2 | | | | 0 | 2 | 3 | 1 | 2 | 8 | -- | 8 |
| | 1 | | | | 0 | 2 | 1 | 2 | 2 | 7 | -- | 9 |
| ılti | As need | | 25 | | 0 | 2 | 0 | 6 | 0 | 8 | 2 | 10 |
| im | -- | | Flt | 0 | 2 | 0 | 0 | 4 | 4 | 10 | -- | 11 |
| ılti | As need | | 10 | | 2 | 0 | 0 | 0 | 10 | 12 | 2 | 12 |
| | | | 25 | | 2 | 0 | 0 | 0 | 8 | 10 | 2 | 13 |
| im | -- | | Flt | | 0 | 2 | 0 | 4 | 2 | 8 | -- | 14 |
| ulti | As need | | 10 | | 0 | 2 | 0 | 0 | 8 | 10 | 4 | 15 |
| ombi | 4 and up | | | | 0 | 2 | 0 | 1 | 7 | 10 | -- | 16 |
| | 3 | | | | 0 | 2 | 1 | 1 | 4 | 8 | -- | 17 |
| | 2 | | | | 0 | 2 | 3 | 1 | 2 | 8 | -- | 18 |
| | 1 | | | 1 | 0 | 2 | 1 | 2 | 3 | 8 | -- | 19 |
| ulti | As need | | 25 | 0 | 0 | 2 | 0 | 6 | 2 | 10 | 4 | 20 |
| im | -- | 5 | Flt | 8 | 2 | 0 | 0 | 4 | 2 | 8 | -- | 21 |
| Multi | As need | | 15 | | 2 | 0 | 0 | 0 | 8 | 10 | 2 | 22 |
| | | | 25 | | 2 | 0 | 0 | 0 | 6 | 8 | 2 | 23 |
| Sim | -- | | Flt | | 0 | 2 | 0 | 6 | 0 | 8 | -- | 24 |
| Multi | As need | | 15 | | 0 | 2 | 0 | 20 | 0 | 22 | 10 | 25 |
| | As need | | 15 | | 0 | 2 | 0 | 0 | 20 | 22 | 10 | 26 |
| | 8 | | | | 0 | 2 | 2 | 0 | 18 | 22 | -- | 27 |
| | 4 | | | | 0 | 2 | 4 | 0 | 10 | 16 | -- | 28 |
| | 2 | | | | 0 | 2 | 6 | 0 | 4 | 12 | -- | 29 |
| | As need | | 25 | | 0 | 2 | 0 | 14 | 2 | 18 | 8 | 30 |
| Sim | 0 | | Flt | 0 | 2 | 0 | 0 | 2 | 4 | 8 | -- | 31 |
| Multi | As need | | 15 | | 2 | 0 | 0 | 0 | 8 | 10 | 2 | 32 |
| | | | 25 | | 2 | 0 | 0 | 0 | 6 | 8 | 2 | 33 |
| Sim | 0 | | Flt | | 0 | 2 | 0 | 6 | 2 | 10 | -- | 34 |
| Multi | As need | | 15 | | 0 | 2 | 0 | 0 | 26 | 28 | 12 | 35 |
| | | | 15 | | 0 | 2 | 0 | 0 | 20 | 22 | 10 | 36 |
| | 8 | | | | 0 | 2 | 2 | 0 | 18 | 22 | -- | 37 |
| | 4 | | | | 0 | 2 | 4 | 0 | 10 | 16 | -- | 38 |
| | 2 | | | | 0 | 2 | 6 | 0 | 4 | 12 | -- | 39 |
| | As need | | 25 | | 0 | 2 | 0 | 18 | 2 | 22 | 10 | 40 |

(0-3), (1-2)* and (1-2). The fourth case replaced all TYPHON ships with DLG-16's (TERRIER). This fourth variation reflects the situation where development work on TYPHON is terminated so that the task force is entirely composed of 3T ships. It is this variation that is also used in the SEA MAULER analysis, as described later in this subsection. The Defense Force Composition by ship types for the TYPHON task force analysis is summarized in Table 5.6 whereas Formations I and II are shown in Figs. 5.20 and 5.21 respectively.

Table 5.6

DEFENSE FORCE COMPOSITION (TYPHON)

| Number in Task Force | Ship Type | Missile Batteries |
|---|---|---|
| 3 | DLG, 3400 Element TYPHON Radar | One LR, Two MR; Or One IR, Two MR; Or Three MR |
| | or | |
| 3 | DLG-16 | Two Advanced TERRIER |
| | plus | |
| 1 | CG-10 | Two TALOS 6C1, Two Improved TARTAR |
| 1 | CLG-3 | One TALOS 6C1 with 6 Guidance Channels |
| 2 | DLG-16 | Two Advanced TERRIER |
| 3 | DDG-2 | One Improved TARTAR |
| 1 | CVA-63 | Two Advanced TERRIER |
| 1 | CVA-62 | None |
| 1 | AOE | None |

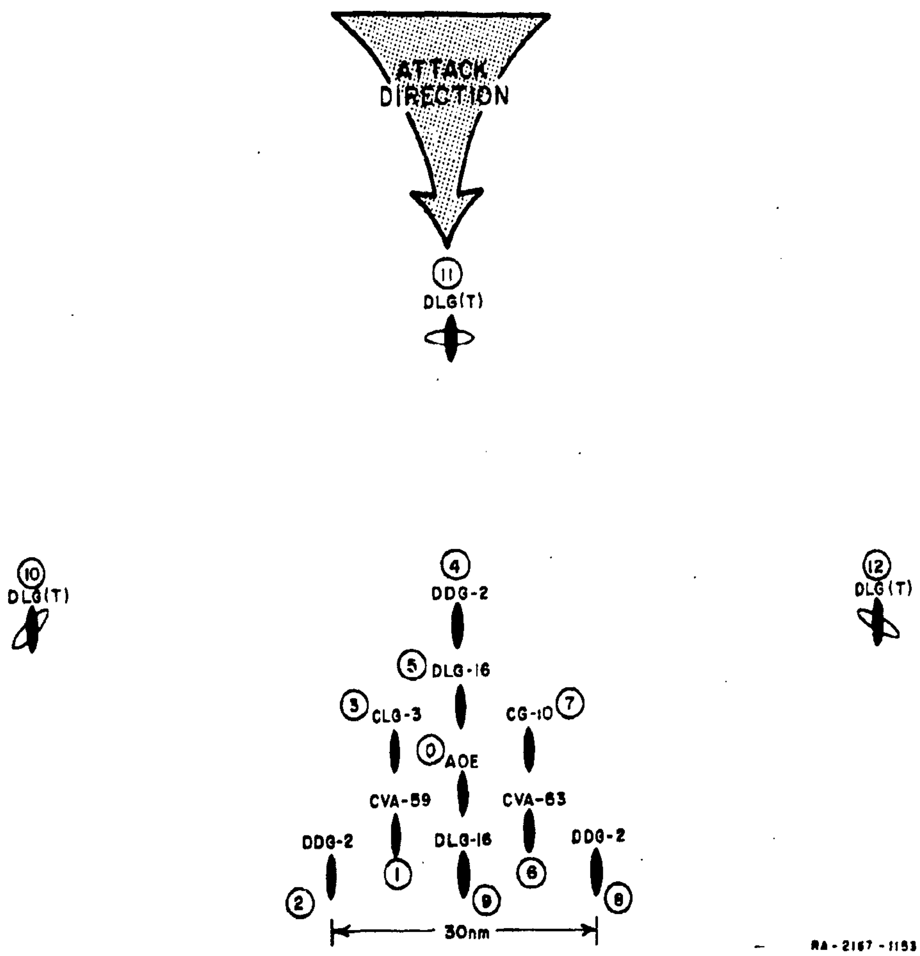


FIG. 5.20 TASK FORCE FORMATION I

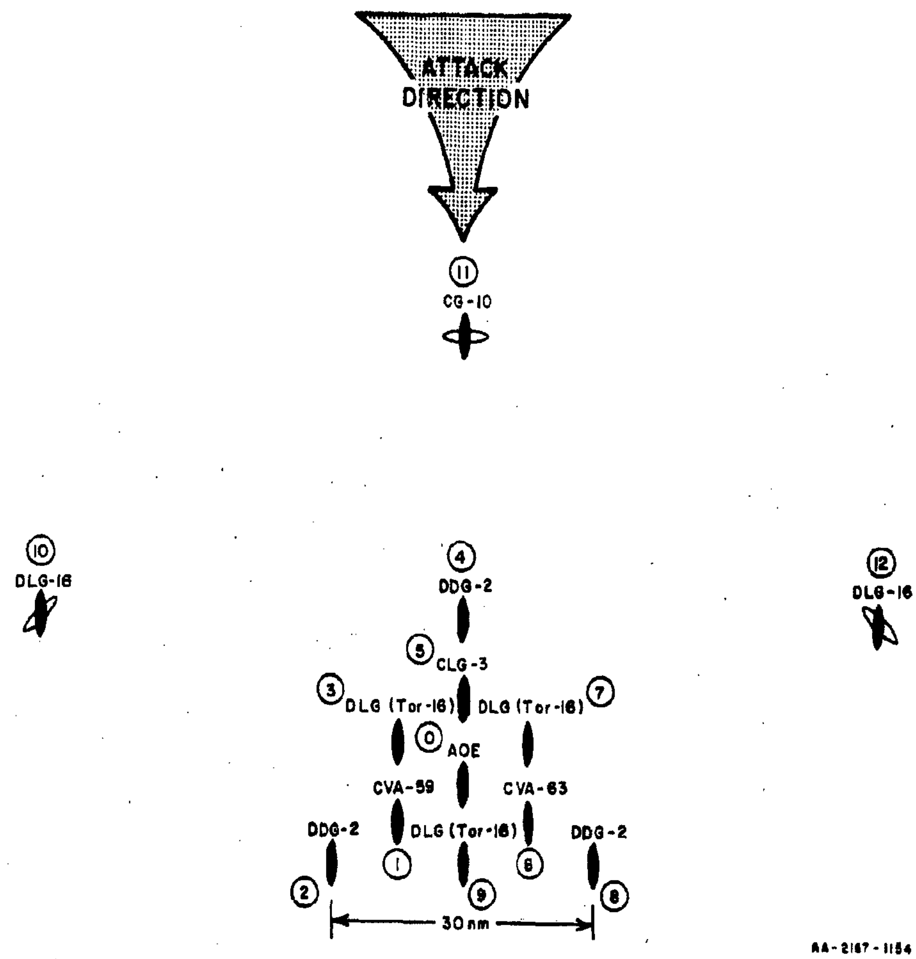


FIG. 5.21 TASK FORCE FORMATION II

The basic task force disposition is shown in Fig. 5.22. In addition to the ship types called out in Figs. 5.20 and 5.21, there are four E-2A aircraft with APS-96 radars stationed on an AEW station radius of 200 nm from fleet center. They are spaced equidistantly around the station circle 45 degrees off the formation axis as shown in Fig. 5.22. In addition, there are three CAP stations, one directly over each picket ship. The CAP station over the center picket ship is composed of four aircraft; those over the wing picket ships are composed of two aircraft each. All F-4B aircraft are armed with four SPARROW III 6b AAM's, and

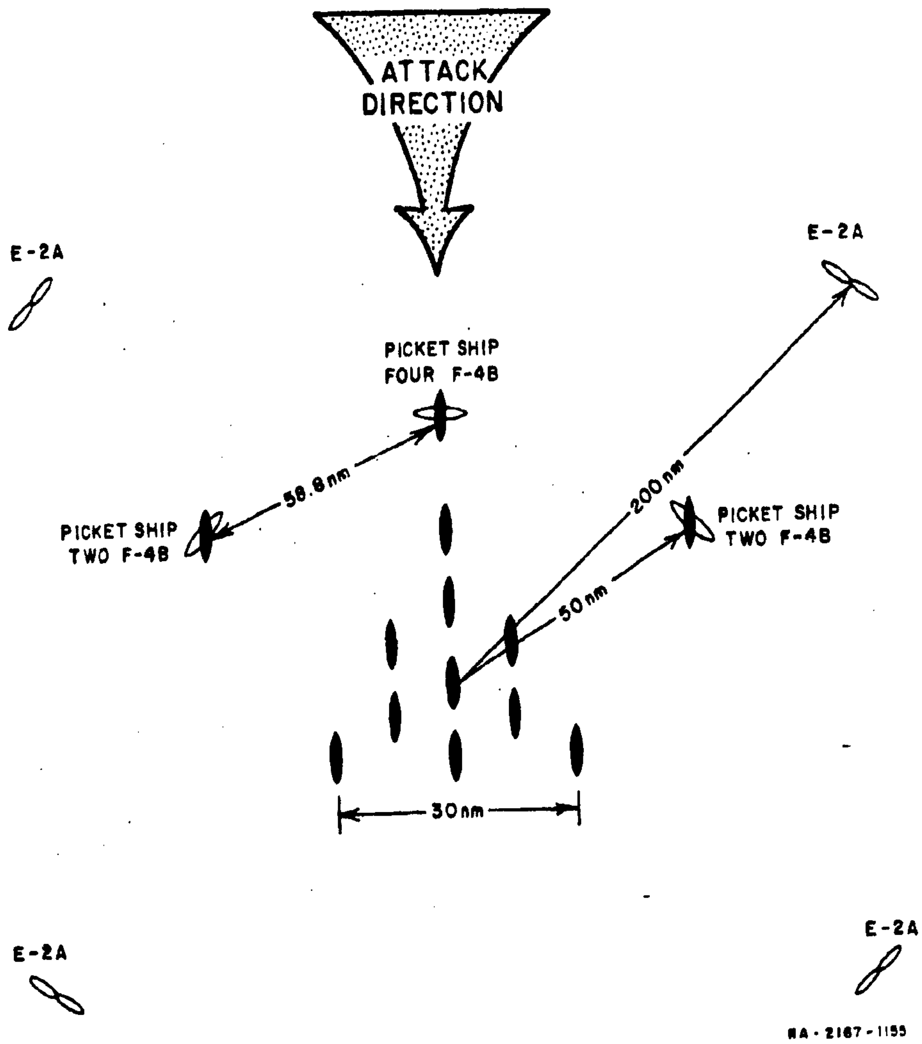


FIG. 5.22 TASK FORCE DISPOSITION — FORMATIONS I AND II

a "look down" capability has been incorporated into their AN/APQ-72 radars. More detailed information pertaining to CAP and AEW aircraft availability and deployment may be found in Part 5.4 as well as in NWRC Research Memo 9,[16] whereas task force composition and deployment has been derived from information presented in Part 3.5.

The measure of effectiveness that was applied to the task force analysis (involving six TYPHON/3T task force configurations, one basic 3T task force configuration and one SEA MAULER/3T configuration, subjected to the attack described in (Part 3.4.2) was to tally the number of penetrating enemy weapons over the task force main body and the number of ships disabled by the attack. In the course of each attack, all ships in the main body (not pickets) were fired upon by the enemy. Very large targets--such as the CVA's--as well as ship targets with distinctive radar signatures--such as the TYPHONS DLG's--(when in the main body force) recieved attack emphasis.

Because of the high X-band jamming power levels specified in the attack of Part 3.4.2, the only feasible doctrine for F-4B CAP aircraft assignment was to vector them against the Strike Command BEAR aircraft. An analysis of the ability of the F-4B Combat Air Patrol to destroy the BEAR Strike Command Aircraft was performed in the following manner:

The BEAR jamming aircraft are passively detected by the AEW radars at about 425 nm from force center. Ninety seconds later, threat evaluation is presumably accomplished and the F-4B fighters can begin vectored flight. The F-4B CAP objective is to destroy the incoming BEAR's no later than five minutes after the time the BEAR's reach their stations at 255nm from force center. The BEAR's reach their stations about 22 minutes after the F-4B's begin vectored flight.

The BEAR stations are 217 nm from the nearest F-4B CAP stations. The minimum fuel available to the F-4B fighters for combat at the end of a CAP loiter cycle is 4235 lb. The F-4B's can reach the points at which the BEAR's will be stationed by the time the BEAR's arrive, even under this minimum fuel condition, by nonafterburning cruise at about 515 knots at

35,000 ft for the first 160 nm. Maximum power is used over the remaining distance and for the launch maneuver.

Four F-4B's are assigned to each of the two BEAR stations, each carrying four SPARROW III missiles. Because the BEAR's jam the F-4B AI radar, target-bearing data can only be derived autonomously and all missiles are fired in the home-on-jam (HOJ) mode. The F-4B's must rely upon communications with the AEW to obtain target-range data. Because of the target-range rate uncertainty, the four fighters are assumed to avoid firing simultaneously. Rather, they would space their fire as they approach the BEAR's. First one F-4B would open fire, expending his four missiles, then the next F-4B, and so on. It is assumed that the second and third F-4B will fire their missiles within the launch envelope, but the first and fourth will be outside the maximum and minimum launch range boundaries, respectively, and will therefore fail to intercept the BEAR's.

For the second and third F-4B engaging each BEAR, the following factors are applied:

| | |
|---|---|
| Probability of successful fighter conversion maneuver for firing | 0.80 |
| Operability of missile control system (passive mode) | 0.80 |
| Probability of successful missile launch and guidance, each missile | 0.89 |
| Probability of successful fuzing, each missile | 0.83 |
| Warhead kill probability, each missile | 0.61 |

Appropriately combined, these yield a probability of 0.59 that each F-4B will destroy the BEAR it attacks, and of 0.83 that the BEAR's will be destroyed by the two F-4B aircraft attacking it. The probability that both BEAR's are destroyed by the F-4B's is then 0.69.*

* Since the time that these results were obtained for TYPHON and SEA MAULER, a computer program has been developed that would simulate F-4B action against the BEAR's discussed above, making available another analytical method of assessing air-to-air missile system effectiveness.

Having determined that both BEAR Strike Command aircraft were destroyed by the F-4B CAP with a certain probability prior to t=5, a possible procedure would have been to run the air battle several times performing a Monte Carlo on the probability of destruction of both BEAR's with the attendant use of the enemy's alternative attack strategy (see Part 3.4.2) in the event of a successful Monte Carlo evaluation. Since the computer running time required for the task-force runs varied between four and twelve hours per run, such a method of analysis, requiring several replications of one task force/attack situation, was ruled out as being impractical. It was decided instead to test the sensitivity of task force effectiveness to both the original and alternative enemy attack plans described in Part 3.4.2. Should the effectiveness prove to be insensitive to the enemy's use of either plan, the bulk of the runs would be made assuming the BEAR's always remained alive and active in the game or that they were always killed by the F-4B CAP. The insensitivity of task force effectiveness to the enemy's use of either plan was demonstrated, as is shown below, and all seven task force configurations were run against the attack which follows as a result of the BEAR's having been killed by the F-4B.

5.2.2.1 TYPHON/3T and Basic 3T

5.2.2.1.1 Results and Discussion

An example of a typical outcome of an air battle as to ranges and altitudes of intercepts, target types engaged and firepower contribution by weapon category (i.e., TYPHON or 3T) is presented in the overlays of Fig. 5.23 and 5.24 and in Fig. 5.25. The case chosen for illustration purposes is that of the phased attack (Part 3.4.2) against a DLG(1-2)* Task Force with BEAR's active, in which the TYPHON ships are located in the main body of the task force (Formation II). Figure 5.23 presents overlaid geoplots for three different air battle time intervals (0 to 25 min, 20 to 25 min, 25 to 30.5 min). These intervals were chosen to illustrate the progress of a typical air battle, since no intercepts occur much before t=15 minutes [at least for the DLG(1-2)* task force] and the

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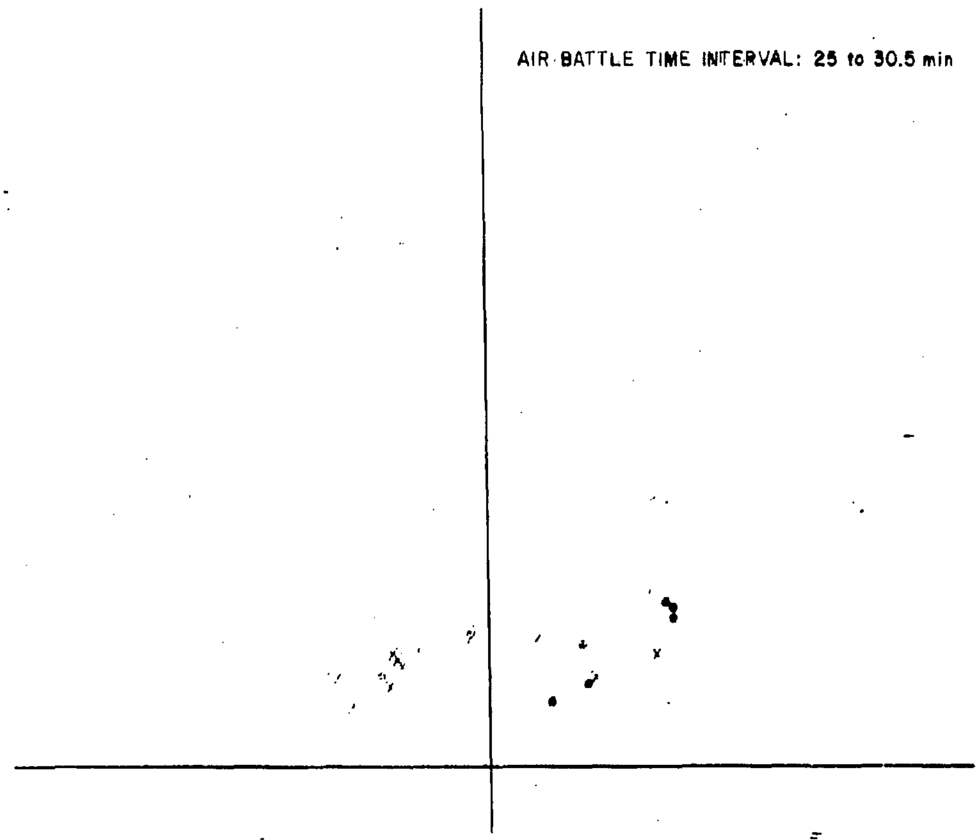


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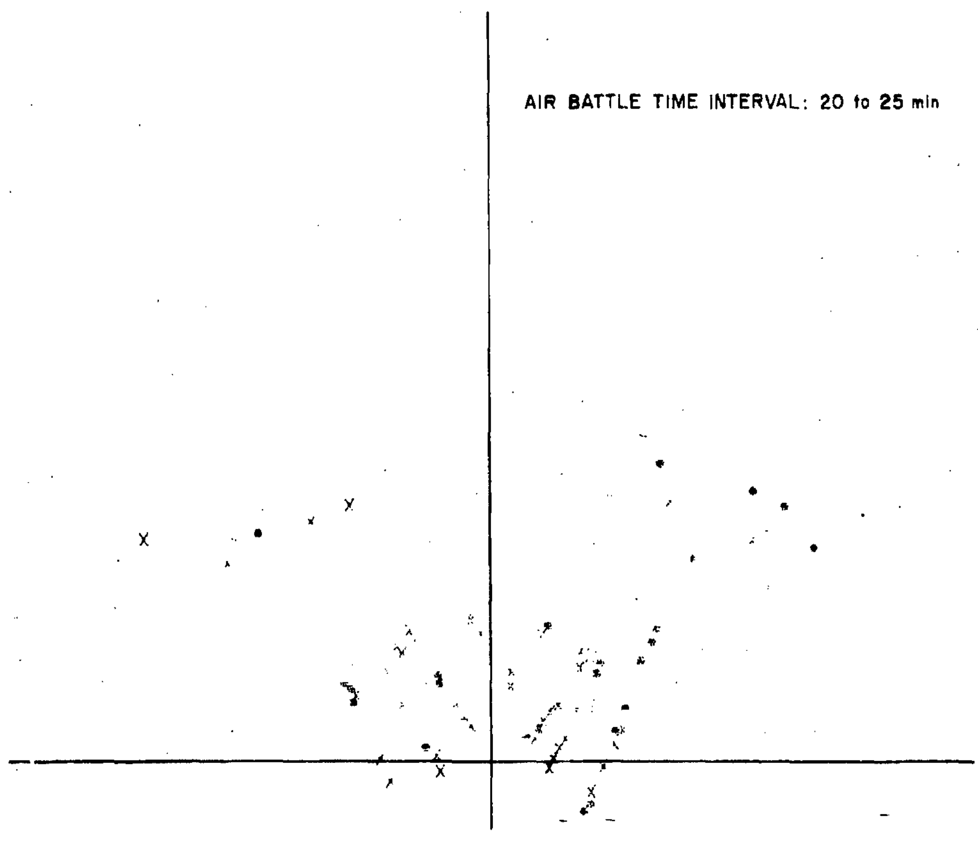
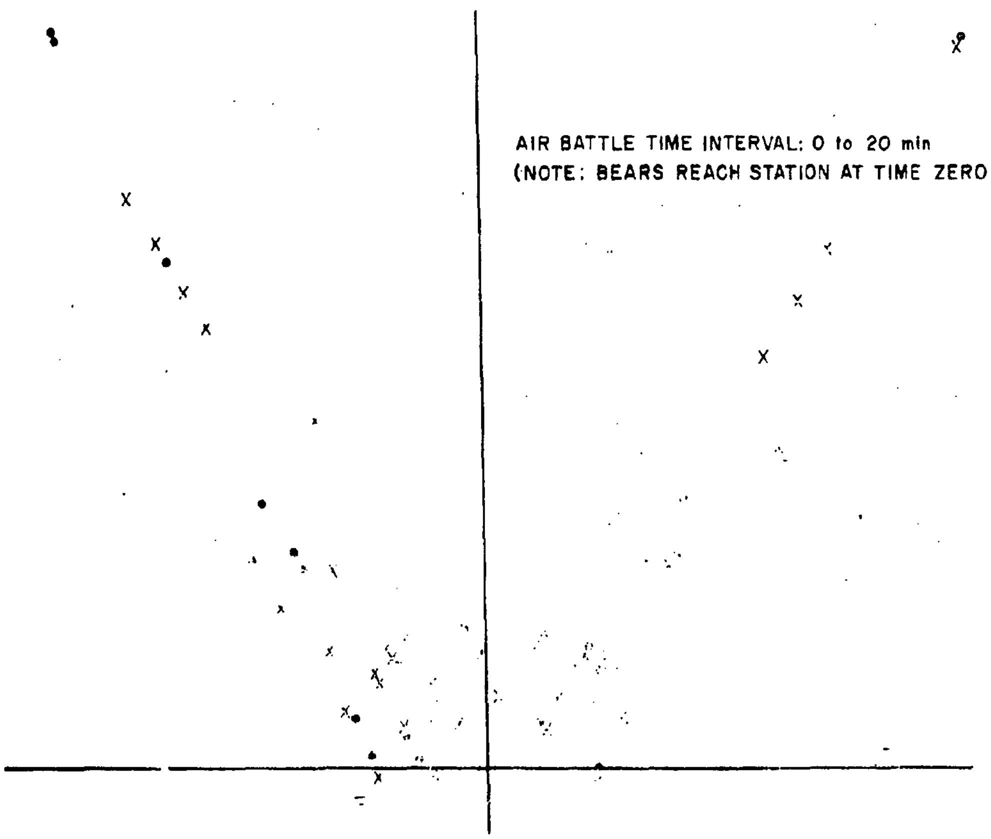

AIR BATTLE TIME INTERVAL: 20 to 25 min


AIR BATTLE TIME INTERVAL: 0 to 20 min
(NOTE: BEARS REACH STATION AT TIME ZERO)

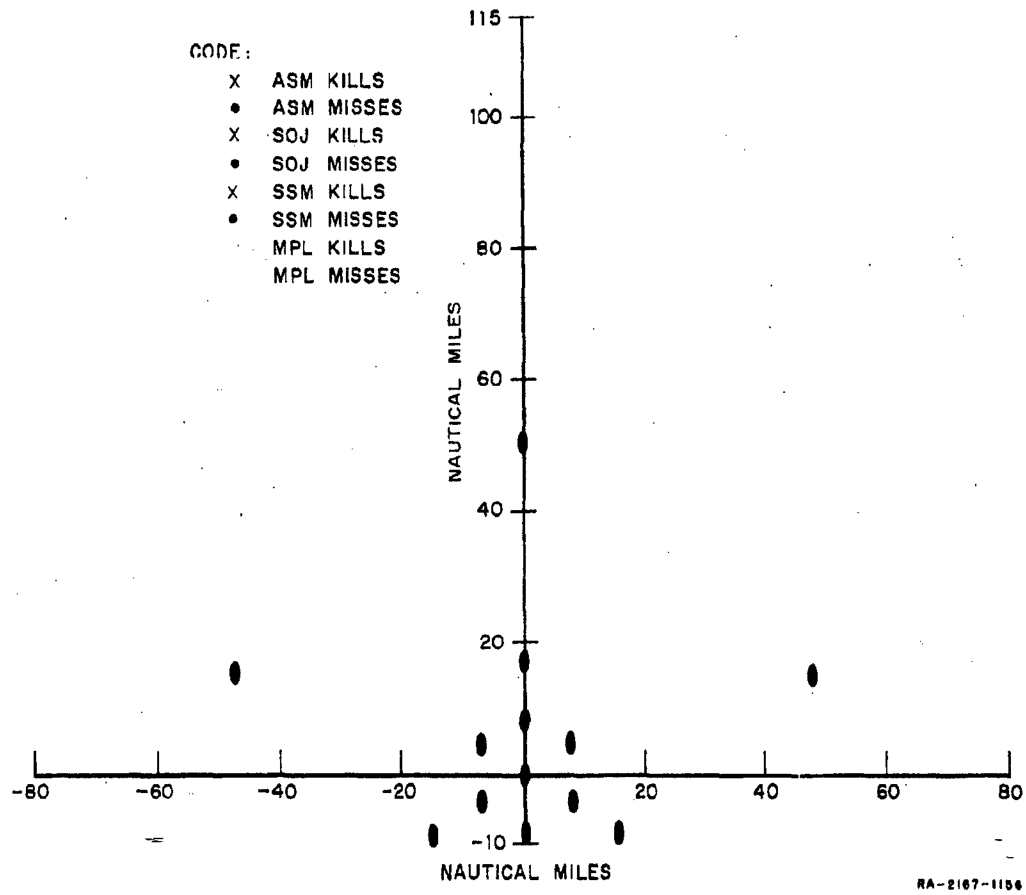



FIG. 5.23 RANGE-AZIMUTH PLOT OF TASK FORCE FIREPOWER

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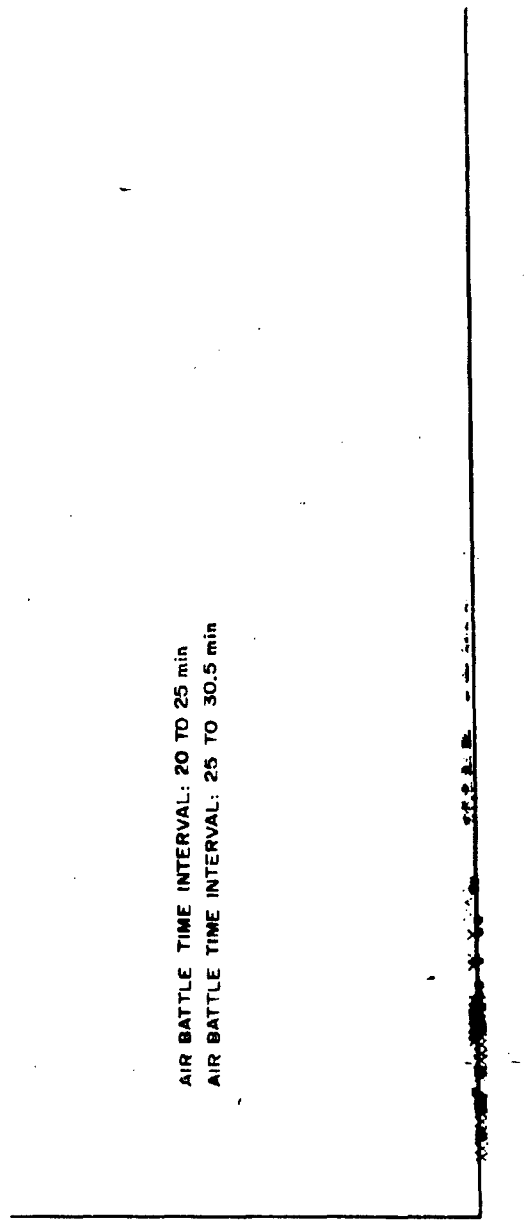


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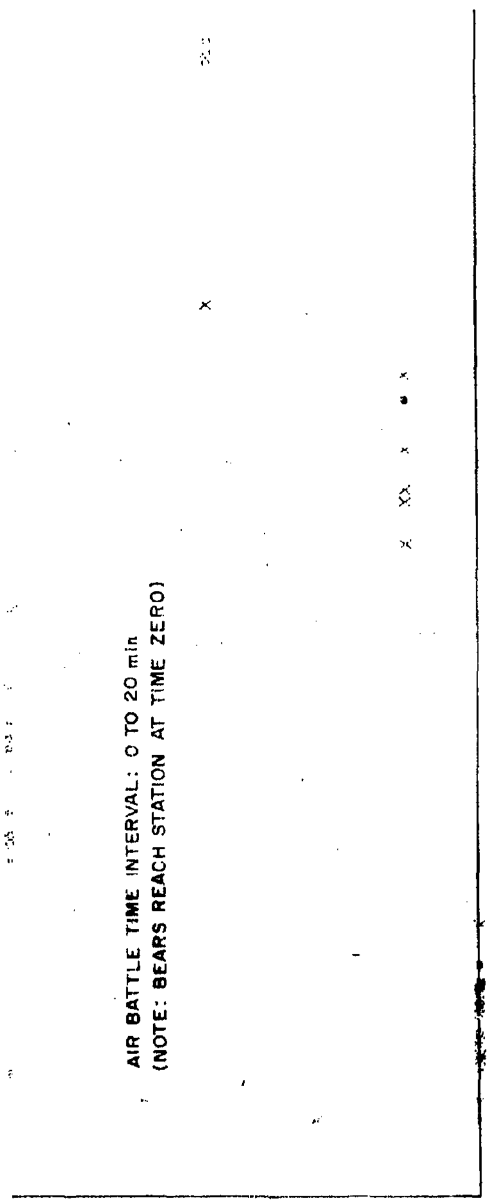

AIR BATTLE TIME INTERVAL: 0 TO 20 min
(NOTE: BEARS REACH STATION AT TIME ZERO)

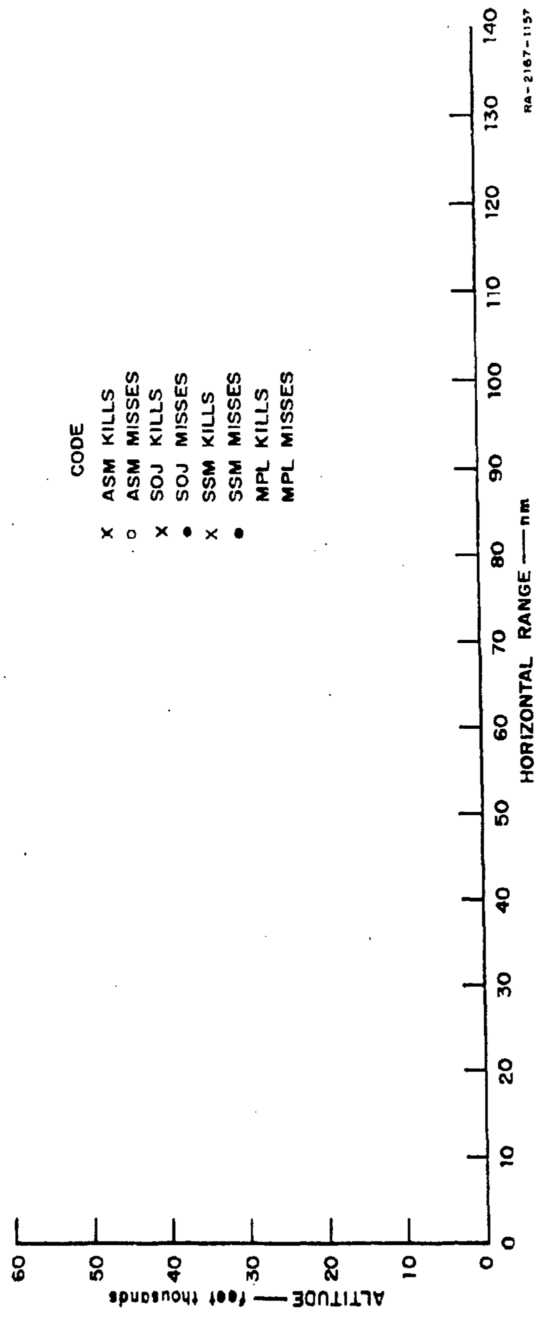



FIG. 5.24 RANGE–ALTITUDE PLOT OF TASK FORCE FIREPOWER

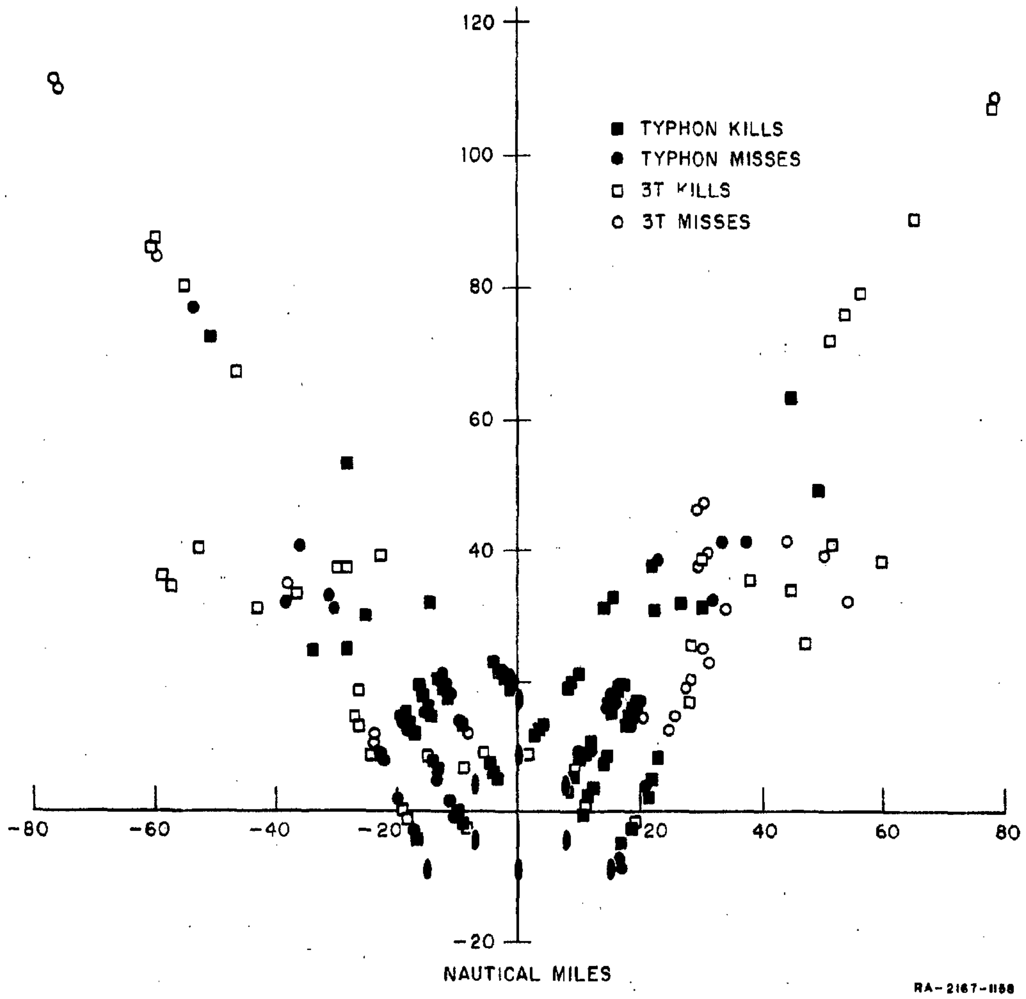



FIG. 5.25 TASK FORCE FIREPOWER: TYPHON-3T BREAKDOWN

last enemy weapon has impacted by t=30.5 min. The intercepts shown in Fig. 5.23 (and Fig. 5.24) are color-coded to reflect the different enemy target types being engaged (ASM's, SSM's, missile-launching aircraft, and self-screening/stand-off jammers). The overlays of Fig. 5.24 are corresponding time-interval plots for intercept altitude vs. intercept horizontal range. Figure 5.25 is another geoplot of the intercepts by either TYPHON or 3T ships. For the air battle illustrated in Figs. 5.23, 5.24 and 5.25, an over-all comparison of task force TYPHON and 3T performance is as shown below in Table 5.7.

Table 5.7

TASK FORCE TYPHON AND 3T PERFORMANCE

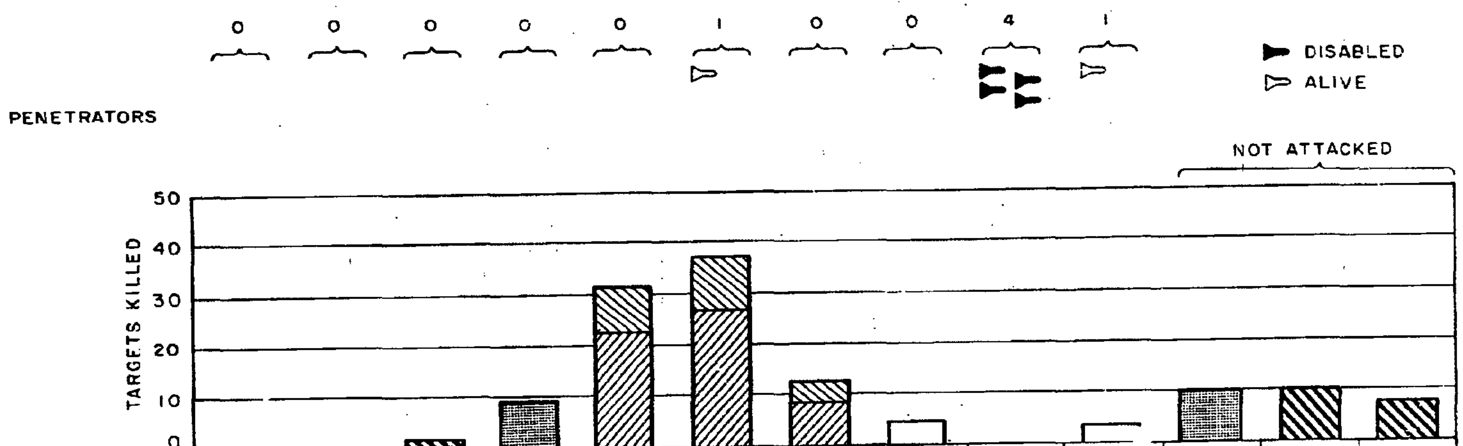
| | Total | Percent Typhon | Percent 3T |
|---|---|---|---|
| Shots fired | 406 | 67.5 | 32.5 |
| Kills | 123 | 66.0 | 34.0 |
| Misses | 81 | 70.0 | 30.0 |

The performance in Table 5.7 was achieved with a total of nine TYPHON launchers, compared with a total of fourteen 3T launchers in the task force.

Multiple-ship results are treated and presented as two major blocks of information. One block is concerned with the relative performance of ship types within a task force. The other involves a comparison of the various task forces studied.

The results of the intership comparison within the various task forces are shown in Figs. 5.26 through 5.32. Figure 5.33 is a summary comparison of the effectiveness of task forces as entities.

Figures 5.26 and 5.27, which compare the performance of two task forces [DLG(1-2)* and DLG 16, respectively] under conditions of BEAR's active and BEAR's dead, demonstrate the relative insensitivity of task force air defense effectiveness to the enemy's original and alternative attack plans. It will be noted that in choosing a DLG(1-2)* task




| WEAPON (S) | (NONE) | (NONE) | TERRIER | TALOS | 1-IR AND 2-...R TYPHON | 1-IR AND 2-MR TYPHON | 1-IR AND 2-MR TYPHON | TARTAR | TARTAR | TARTAR | TARTAR AND TALOS | TERRIER | TERRIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG (1-2)* | DLG (1-2)* | DLG (1-2)* | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| TARTAR | 5 | 6 | 13 |
| TERRIER | 18 | 32 | 62 |
| TALOS | 19 | 28 | 57 |
| MR TYPHON | 60 | 97 | 170 |
| IR TYPHON | 21 | 41 | 104 |
| TOTALS | 123 | 204 | 406 |

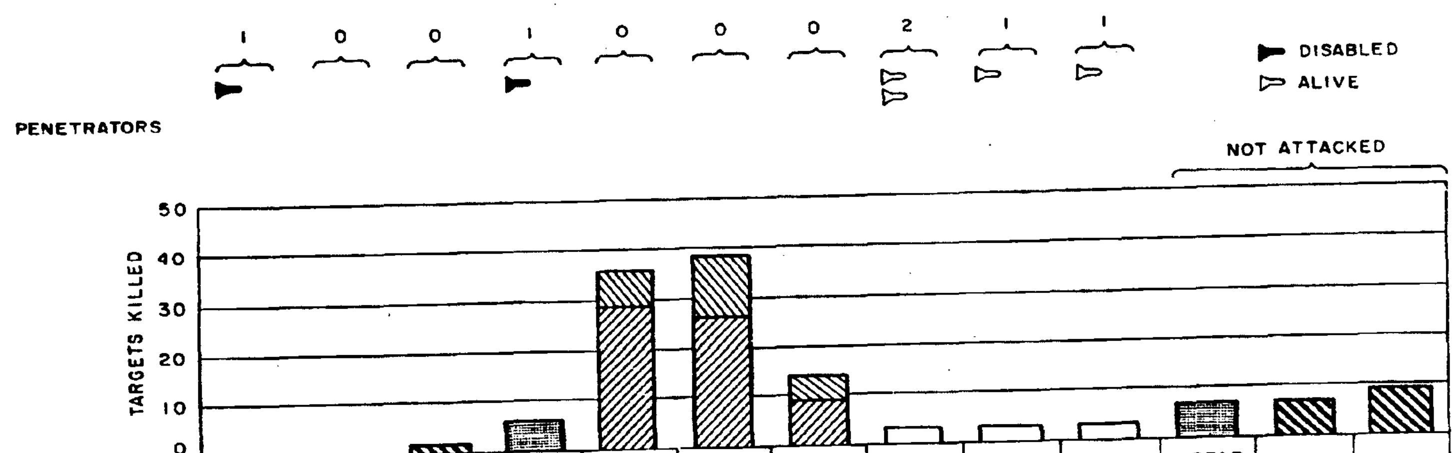
TOTAL PENETRATORS = 6

TOTAL SHIPS SURVIVING = 12

IR TYPHON MR TYPHON TALOS TERRIER TARTAR

RB-2167-1129

FIG. 5.26 TASK FORCE AAW EFFECTIVENESS: DLG(1-2)* MAIN BODY
(a) BEAR's alive




| WEAPON (S) | (NONE) | (NONE) | TERRIER | TALOS | 1-IR AND 2-MR TYPHON | 1-IR AND 2-MR TYPHON | 1-IR AND 2-MR TYPHON | TARTAR | TARTAR | TARTAR | TARTAR AND TALOS | TERRIER | TERRIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG (1-2)* | DLG (1-2)* | DLG (1-2)* | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| TARTAR | 6 | 8 | 24 |
| TERRIER | 16 | 44 | 69 |
| TALOS | 11 | 26 | 51 |
| MR TYPHON | 65 | 110 | 181 |
| IR TYPHON | 22 | 46 | 103 |
| TOTALS | 120 | 234 | 428 |

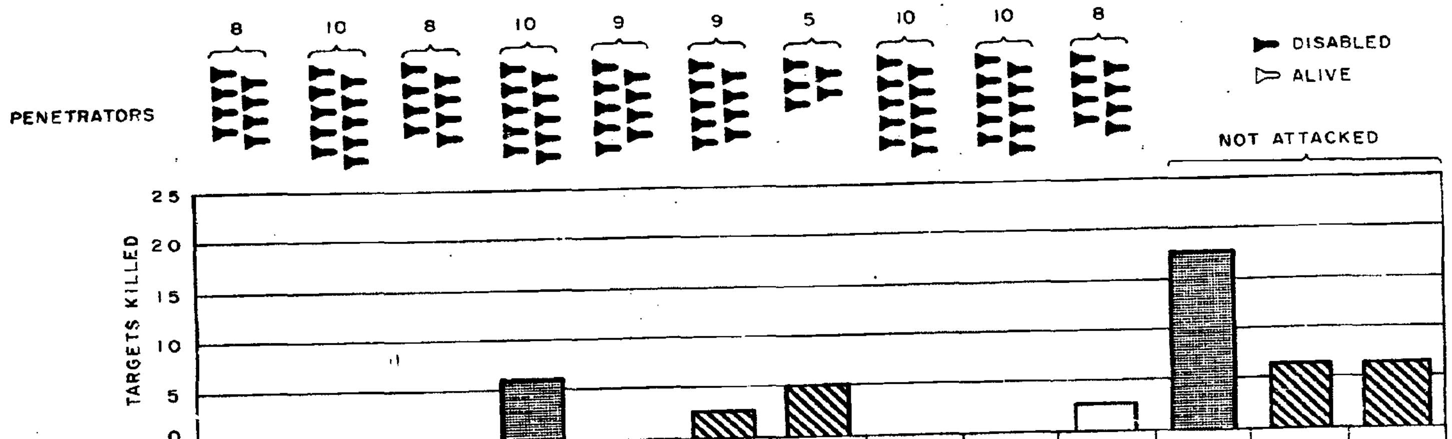
TOTAL PENETRATORS = 6

TOTAL SHIPS SURVIVING = 11

IR TYPHON　MR TYPHON　TALOS　TERRIER　TARTAR

RB-2167-1130

FIG. 5.26 TASK FORCE AAW EFFECTIVENESS: DLG(1-2)* MAIN BODY
(b) BEAR's dead




| WEAPON (S) | (NONE) | (NONE) | TERRIER | TALOS | TERRIER | TERRIER | TERRIER | TARTAR | TARTAR | TARTAR | TARTAR AND TALOS | TERRIER | TERRIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG-16 | DLG-16 | DLG-16 | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| TARTAR | 2 | 2 | 12 |
| TERRIER | 19 | 36 | 86 |
| TALOS | 24 | 34 | 48 |
| TOTALS | 45 | 72 | 146 |

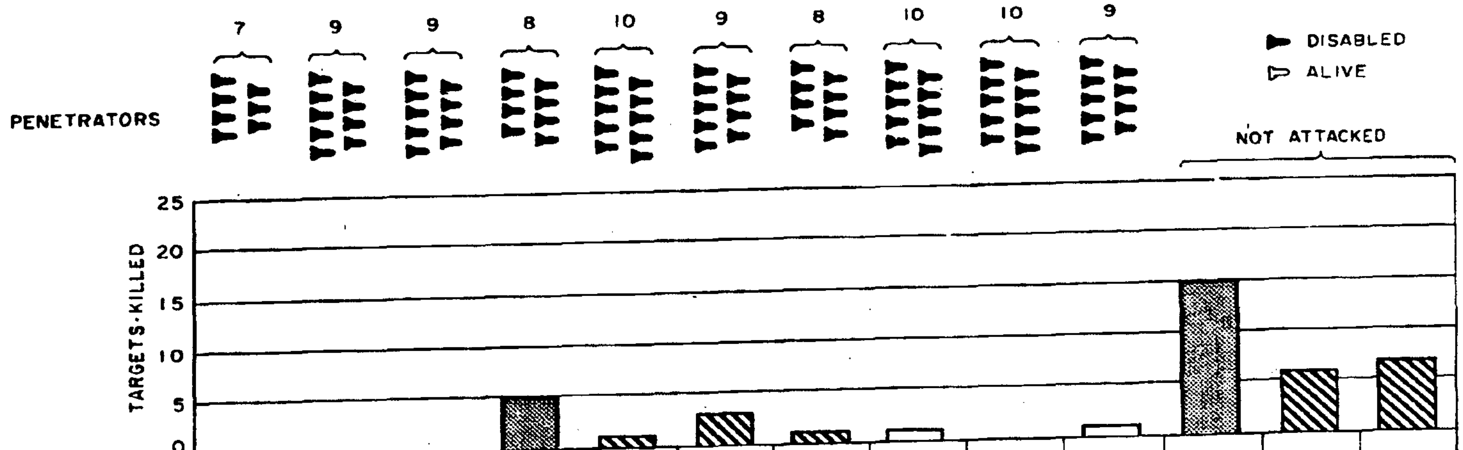
TOTAL PENETRATORS = 87

TOTAL SHIPS SURVIVING = 3

TALOS TERRIER TARTAR

RB-2 67-1161

FIG. 5.27 TASK FORCE AAW EFFECTIVENESS: DLG-16 MAIN BODY
(a) BEAR's alive




| WEAPON(S) | (NONE) | (NONE) | TERRIER | TALOS | TERRIER | TERRIER | TERRIER | TARTAR | TARTAR | TARTAR | TARTAR AND TALOS | TERRIER | TERRIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG-16 | DLG-16 | DLG-16 | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| TARTAR | 2 | 2 | 5 |
| TERRIER | 18 | 38 | 81 |
| TALOS | 20 | 37 | 60 |
| TOTALS | 40 | 77 | 146 |

TOTAL PENETRATORS = 89

TOTAL SHIPS SURVIVING = 3

TALOS TERRIER TARTAR

RB-2167-1067

FIG. 5.27 TASK FORCE AAW EFFECTIVENESS: DLG-16 MAIN BODY
(b) BEAR's dead



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force and a DLG-16 task force as yardsticks for comparison purposes, an attempt was being made to verify this insensitivity for both a "strong" and a "weak" task force. The significance of this sensitivity test ties in with the question of variability, which was also checked by means of an additional replication on a representative attack/defense situation and was found to be surprisingly small. A summary of the results from the two runs made to check variability is presented in the tabulation below.

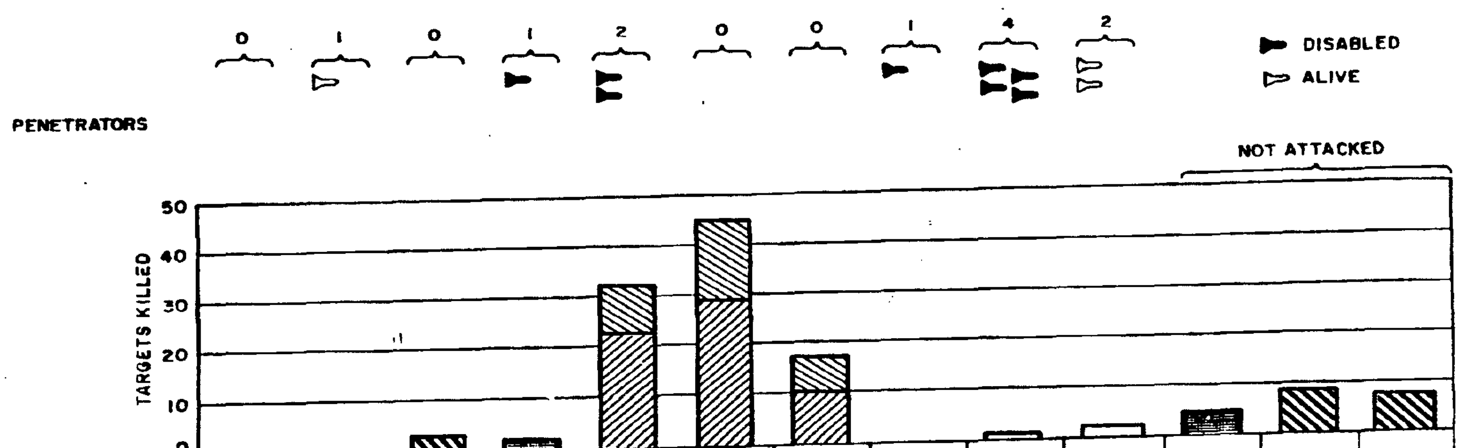
| Run | Total Kills | Total Misses | Total Shots | Total Penetrators | Ships "DEAD" |
|---|---|---|---|---|---|
| 1 | 126 | 97 | 365 | 23 | 3 |
| 2 | 113 | 110 | 364 | 26 | 4 |

While a sample size of two is perhaps unsupportable from a strict statistical standpoint, the required computer running rime for a replication (approximately 7-1/2 hr) prohibited an exhaustive study of variability.

It is worth noting that the runs upon which Figs. 5.26 through 5.32 are based revealed that total shots fired by the SAM systems exceeded by a significant amount the sum of SAM kills plus SAM misses (for example, see Table 5.7). For the sake of convenience, the term "aborts" has been applied to the difference between "total shots fired" and "kills plus misses." In the course of a game these aborts arise for the reasons discussed in Part 4.1.2.

Perhaps the result of greatest significance, granting the realism of the attack defined earlier in this section, is the need for the TYPHON concept in task force AAW. This fact clearly emerges when DLG(TYPHON) task forces are compared with task forces that are predominantly made up of DLG-16's.

When TYPHON frigates are placed in the task force main body, DLG(1-2) and DLG(1-2)* performances are closely matched, and are both superior to the DLG(0-3) from the standpoint of targets killed (see Figs. 5.26, 5.28 and 5.29). Even though the DLG(1-2) task force




| WEAPON(S) | (NONE) | (NONE) | TERRIER | TALOS | 1-LR AND 2-MR TYPHON | 1-LR AND 2-MR TYPHON | 1-LR AND 2-MR TYPHON | TARTAR | TARTAR | TARTAR | TARTAR AND TALOS | TERRIER | TERRIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG (1-2) | DLG (1-2) | DLG (1-2) | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| TARTAR | 3 | 7 | 15 |
| TERRIER | 19 | 32 | 64 |
| TALOS | 7 | 25 | 54 |
| MR TYPHON | 62 | 113 | 183 |
| LR TYPHON | 33 | 54 | 114 |
| | 124 | 231 | 430 |

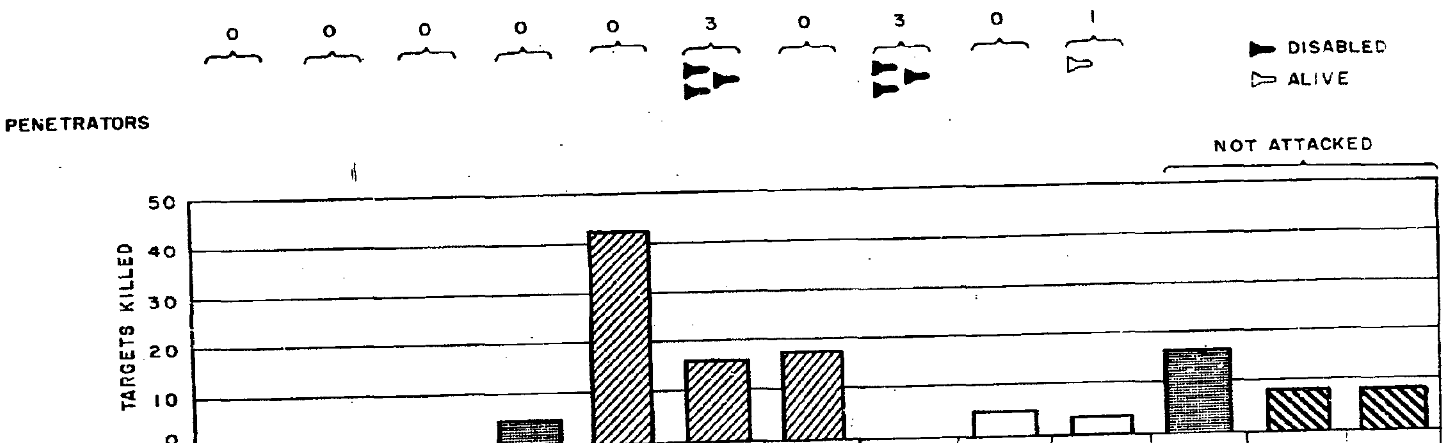
TOTAL PENETRATORS = 11

TOTAL SHIPS SURVIVING = 9

LR TYPHON   MR TYPHON   TALOS   TERRIER   TARTAR

RB-2187-1131

FIG. 5.28 TASK FORCE AAW EFFECTIVENESS: DLG(1-2) MAIN BODY




| WEAPON (S) | (NONE) | (NONE) | TERRIER | TALOS | 3-MR TYPHON | 3-MR TYPHON | 3-MR TYPHON | TARTAR | TARTAR | TARTAR | TARTAR AND TALOS | TERRIER | TERRIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG (0-3) | DLG (0-3) | DLG (0-3) | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| TARTAR | 7 | 10 | 18 |
| TERRIER | 16 | 33 | 70 |
| TALOS | 20 | 31 | 67 |
| MR TYPHON | 78 | 127 | 225 |
| TOTALS | 121 | 201 | 380 |

TOTAL PENETRATORS = 7

TOTAL SHIPS SURVIVING = 11

MR TYPHON    TALOS    TERRIER    TARTAR

RB-2167-1132

FIG. 5.29 TASK FORCE AAW EFFECTIVENESS: DLG(0–3) MAIN BODY achieves more kills than does the DLG(1-2)* task force (Figs. 5.26 and 5.28), there are a greater number of penetrators over the task force in the case of the DLG(1-2). This is due to the fact that a greater proportion of DLG(1-2) firepower, because of the longer range of LR TYPHON, was directed against nonlethal types of targets during the battle. These included self-screening jammers and missile-launching aircraft to which missile assignments had been made prior to ASM launch but that did not intercept until after ASM release. It should further be noted that the DLG(1-2) in ship position 3 was disabled some 14 min before the end of the enemy attack. Had it survived the attack, it is conceivable that a somewhat larger discrepancy between the DLG(1-2) and (1-2)* task force results would have been noted, favoring the former.

Figures 5.30, 5.31, and 5.33 demonstrate the superiority of the DLG(1-2) and DLG(1-2)* over the DLG(0-3) as picket ships. The effect of using the TYPHON DLG's as pickets, however, against the type of attack postulated, is to degrade over-all task force effectiveness, as demonstrated by the increase in numbers of penetrators when compared with the deployment of these ships in the formation main body (see Fig. 5.33.)

The comparison of task forces shown in Fig. 5.33 summarizes the information already presented. The figure readily shows the increasing insensitivity of task force effectiveness to the deployment of major firepower units (i.e., on picket stations or in the main body) as primary weapon range increases. Note, for example; how closely matched are the effectiveness values for the DLG(1-2) task forces for both Formulations I and II. The discrepancy between Formation I and II results becomes increasingly larger as one goes from DLG(1-2) (200-nm missile) to DLG(1-2)* (100-nm missile) to DLG(0-3) (40-nm missile) task forces.

5.2.2.1.2 <u>Summary of Findings</u>

1. When the TYPHON ships are deployed on picket stations (Formation I), the DLG(1-2) emerges from the analysis as the strongest TYPHON frigate. The effectiveness of the TYPHON frigates when so deployed is, in fact, directly proportional to the range of their AAW weapons.

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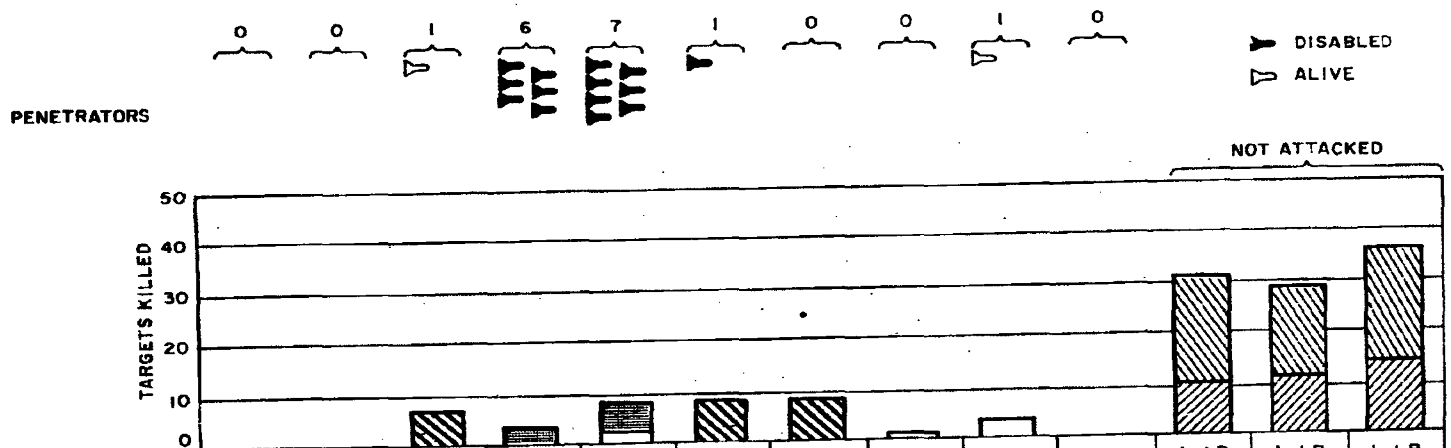


| WEAPON(S) | (NONE) | (NONE) | TERRIER | TALOS | TARTAR AND TALOS | TERRIER | TERRIER | TARTAR | TARTAR | TARTAR | 1-LR AND 2-MR TYPHON | 1-LR AND 2-MR TYPHON | 1-LR AND 2-MR TYPHON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 3 | 7 | 5 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | CG-10 | DLG-16 | DLG-16 | DDG-2 | DDG-2 | DDG-2 | DLG (1-2) | DLG (1-2) | DLG (1-2) |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| TARTER | 9 | 17 | 32 |
| TERRIER | 23 | 32 | 56 |
| TALOS | 9 | 11 | 33 |
| MR TYPHON | 37 | 52 | 159 |
| LR TYPHON | 60 | 93 | 120 |
| | 138 | 205 | 400 |

TOTAL PENETRATORS = 16

TOTAL SHIPS SURVIVING = 10

LR TYPHON MR TYPHON TALOS TERRIER TARTAR

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FIG. 5.30 TASK FORCE AAW EFFECTIVENESS: DLG(1-2) PICKET



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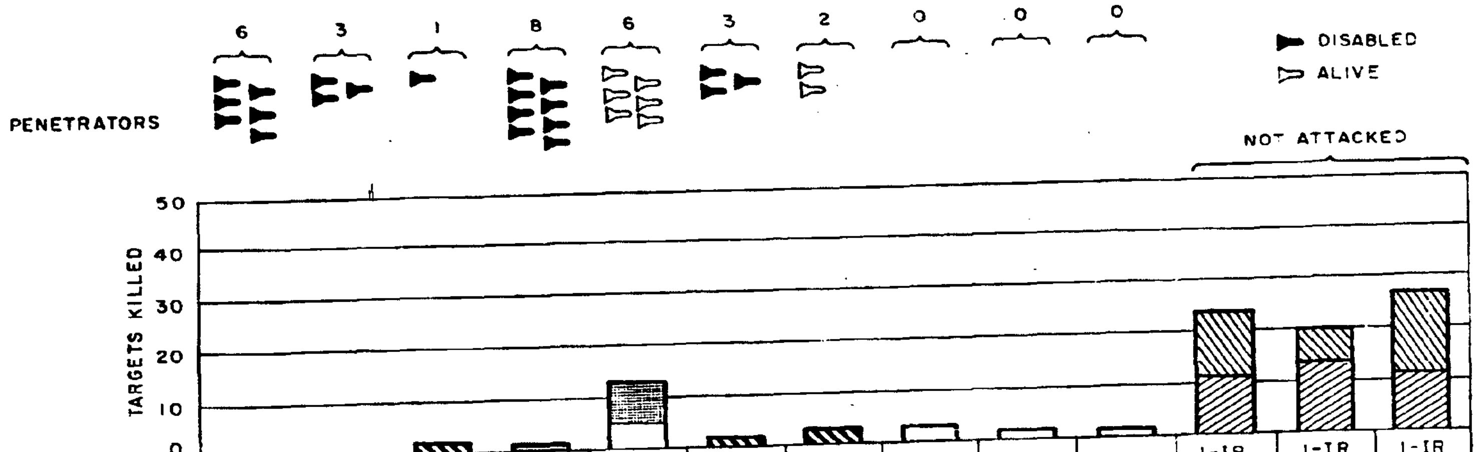



| WEAPON (S) | (NONE) | (NONE) | TERRIER | TALOS | TARTAR AND TALOS | TERRIER | TERRIER | TARTAR | TARTAR | TARTAR | 1-IR AND 2-MR TYPHON | 1-IR AND 2-MR TYPHON | 1-IR AND 2-MR TYPHON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 3 | 7 | 5 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | CG-10 | DLG-16 | DLG-16 | DDG-2 | DDG-2 | DDG-2 | DLG (1-2)* | DLG (1-2)* | DLG (1-2)* |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| TARTAR | 11 | 20 | 38 |
| TERRIER | 7 | 15 | 46 |
| TALOS | 9 | 16 | 38 |
| MR TYPHON | 36 | 58 | 156 |
| IR TYPHON | 35 | 63 | 118 |
| TOTALS | 98 | 172 | 396 |

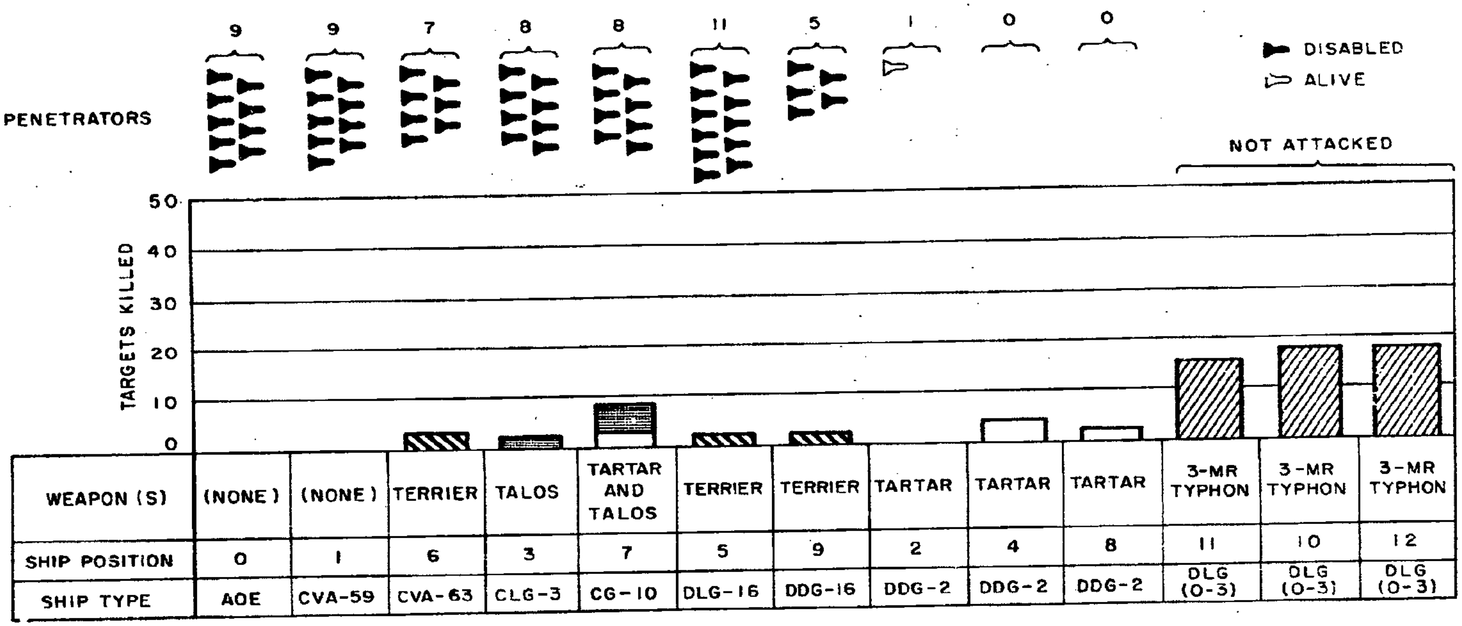
TOTAL PENETRATORS = 29

TOTAL SHIPS SURVIVING = 8

IR TYPHON   MR TYPHON   TALOS   TERRIER   TARTER

RB-2167-1134

FIG. 5.31 TASK FORCE AAW EFFECTIVENESS: DLG(1-2)* PICKET




| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| TARTAR | 6 | 12 | 26 |
| TERRIER | 4 | 4 | 21 |
| TALOS | 7 | 16 | 29 |
| MR TYPHON | 49 | 87 | 233 |
| TOTALS | 66 | 119 | 309 |

TOTAL PENETRATORS = 58

TOTAL SHIPS SURVIVING = 6

MR TYPHON   TALOS   TERRIER   TARTAR

RB-2167-1135

FIG. 5.32 TASK FORCE AAW EFFECTIVENESS: DLG(0-3) PICKET

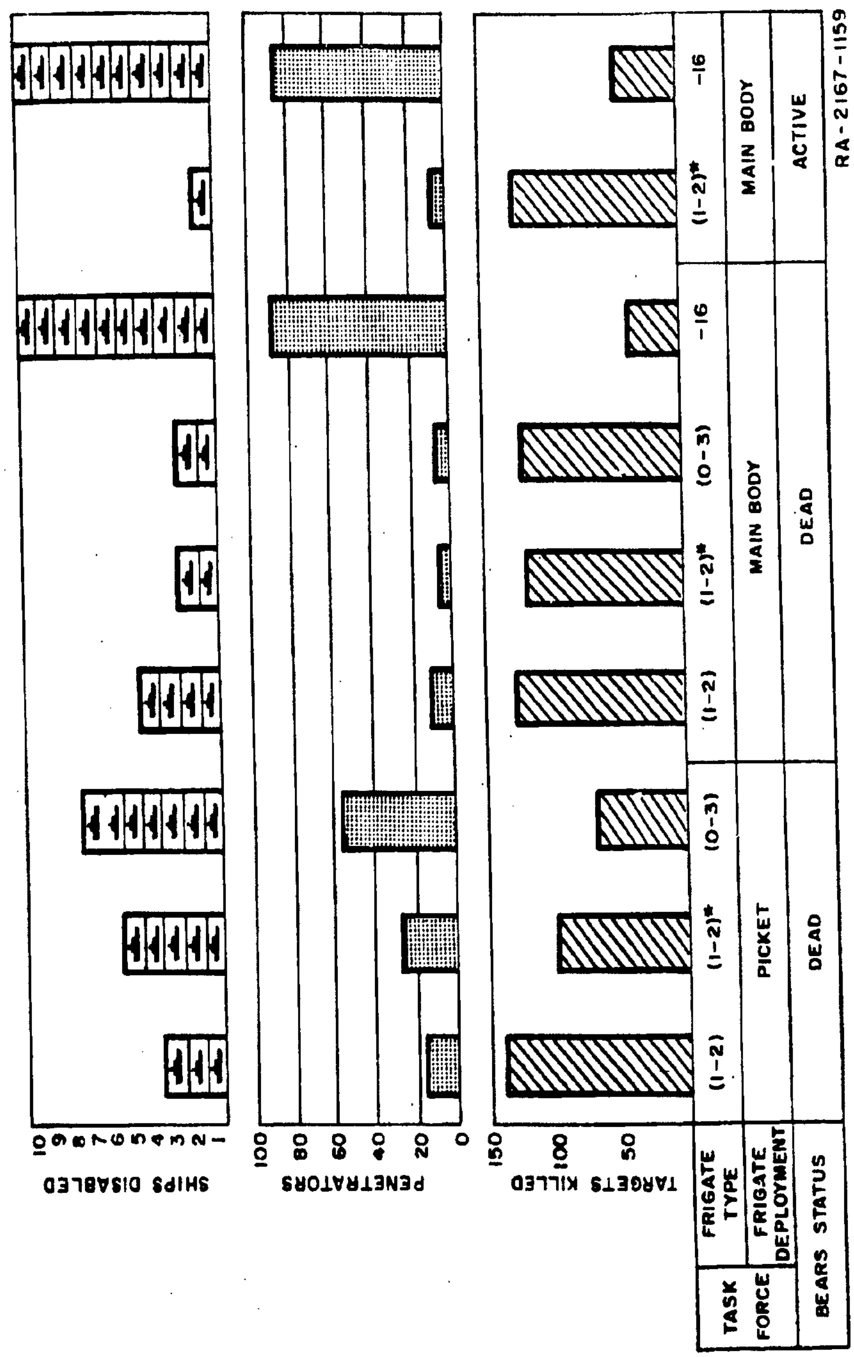



FIG. 5.33 TYPHON AND 3T TASK FORCES COMPARISON

2. With the TYPHON ships in the task force main body, and for the attack postulated (which is predominantly low level) all three TYPHON frigate variants are closely matched in effectiveness.

3. When operating exclusively with 3T missile systems the task is completely saturated and destroyed by the enemy attack that has been assumed for this study.

4. All three TYPHON frigates considered were generally more effective against the postulated attack when deployed in the task force main body than when assigned to picket stations.

5. The total number of shots fired by the SAM systems in all of the air battles analyzed exceeded by a significant amount the number of intercepts (kills plus misses) achieved. This can be attributed to the lack of perfect information by the task force, as discussed in Part 4.1.2.

#### 5.2.2.2 SEA MAULER

##### 5.2.2.2.1 Results and Discussion

The objective of this portion of the study was to assess, through computer simulation, the contribution of SEA MAULER (a naval adaptation of the Army MAULER system) to the over-all fleet AAW effectiveness in carrier task for ce operations. Various ship types, fitted with SEA MAULER as a primary battery or a secondary battery in lieu of 3"/50, 5"/38, or 5"/40 gun mounts have been analyzed in task-force dispositions against which the enemy launches a complex, phased, multidirection, and multilevel, jamming attack.

An analysis of the effectiveness of the following ship types in task-force operations has been made with the weapon suits indicated:

(1) DDG-2 Class (two SEA MAULER launchers, one fore, one aft)

(2) DLG-16 Class (two TERRIER HT-3 launchers, one fore and aft and two SEA MAULER launchers, one port and one starboard)

(3) CG-10 Class (two TALOS 6C1 launchers, one fore, one aft; two Improved TARTAR launchers, one port, one starboard; and two SEA MAULER launchers, one port and one starboard)

(4) CLG-3 Class, Modified, (one TALOS 6C1 launcher, aft, with six guidance channels and one SEA MAULER launcher, foreward)

(5) CVA-59 Class (four SEA MAULER launchers, two port and two starboard)

(6) CVA-63 Class (two TERRIER launchers, one port, one starboard; and two SEA MAULER launchers, one port and one starboard).

(7) AOE-1 Class (four SEA MAULER launchers, two port and two starboard).

The Defense Force Composition by ship types is summarized in Table 5.8 and the Task Force Formation is shown in Fig. 5.34. Table 5.9 describes the manner in which task force ship weapon suits have been altered to accommodate SEA MAULER.

Twenty-nine SEA MAULER weapon pods have been added to the task force to supplement the 3T systems normally fitted aboard the CG, CLG, CVA-63, and the DLG's. In the case of the DDG-2 class ship, TARTAR was removed and two SEA MAULER's were added whereas two SEA MAULER's were added to the two TERRIER's aboard the CVA-63 class, even though this ship normally carriers no gun systems. Following the main battery/secondary battery engagement rules described in Part 5.2.1.2 of this study, the fire of six SEA MAULER batteries in the task force is suppressed during the simulated air battle and only 23 of them remain active.

No overlapping field of fire coverage with SEA MAULER exists between the ships carrying this system. Rather than the "mutual support" type of defense of the task force as a whole afforded with TERRIER, TALOS and TARTAR, SEA MAULER is employed as a "last-ditch" AAW weapon, only to be used in defending the ship on which it is installed against imminent hostile enemy action. SEA MAULER can only engage in the case of attacks that are directed against "own-ship" or in the event of overflights of the ship by enemy vehicles within range of the system.

Table 5.8

DEFENSE FORCE COMPOSITION (SEA MAULER)

| Number in Task Force | Ship Type | Missile Batteries |
|---|---|---|
| 3 | DLG-16 | Two Advanced TERRIER |
| 1 | CG-10 | Two TALOS 6C1, Two Improved TARTAR |
| 1 | CLG-3 | One TALOS 6C1 with 6 Guidance Channels |
| 2 | DLG-16 | Two Advanced TERRIER |
| 3 | DDG-2 | One Improved TARTAR |
| 1 | CVA-63 | Two Advanced TERRIER |
| 1 | CVA-59 | None |
| 1 | AOE | None |

Table 5.9

SEA MAULER ARMAMENT FOR 3T TASK FORCE

| Ship Type and Class | No. in Task Force | Present Gun Battery | No. of SEA MAULER Pods Per Ship | Active SEA MAULERS During Attack Per Ship |
|---|---|---|---|---|
| DLG-16 | 1 | 2-3"/50 (p&s) | 2(p&s) | 1 |
| CG-10 | 1 | 2-5"/38 (p&s) | 2(p&s) | 1 |
| DDG-2 | 3 | 2-5"/54 (f&a) | 2(f&a)-- NO TARTAR | 2 |
| CLG-3 | 1 | 1-5"/38 (f) | 1(f) | 1 |
| CVA-59 | 1 | 8-5"/54 (4p&4s) | 4(2p&2s) | 4 |
| CVA-63 | 1 | None | 2(p&s) | 2 |
| AOE-1 | 1 | 4-3"/50 (2p&2s) | 4(2p&2s) | 4 |

Total SEA MAULERS installed in task force-------------29

Total SEA MAULERS active in task force during attack--23

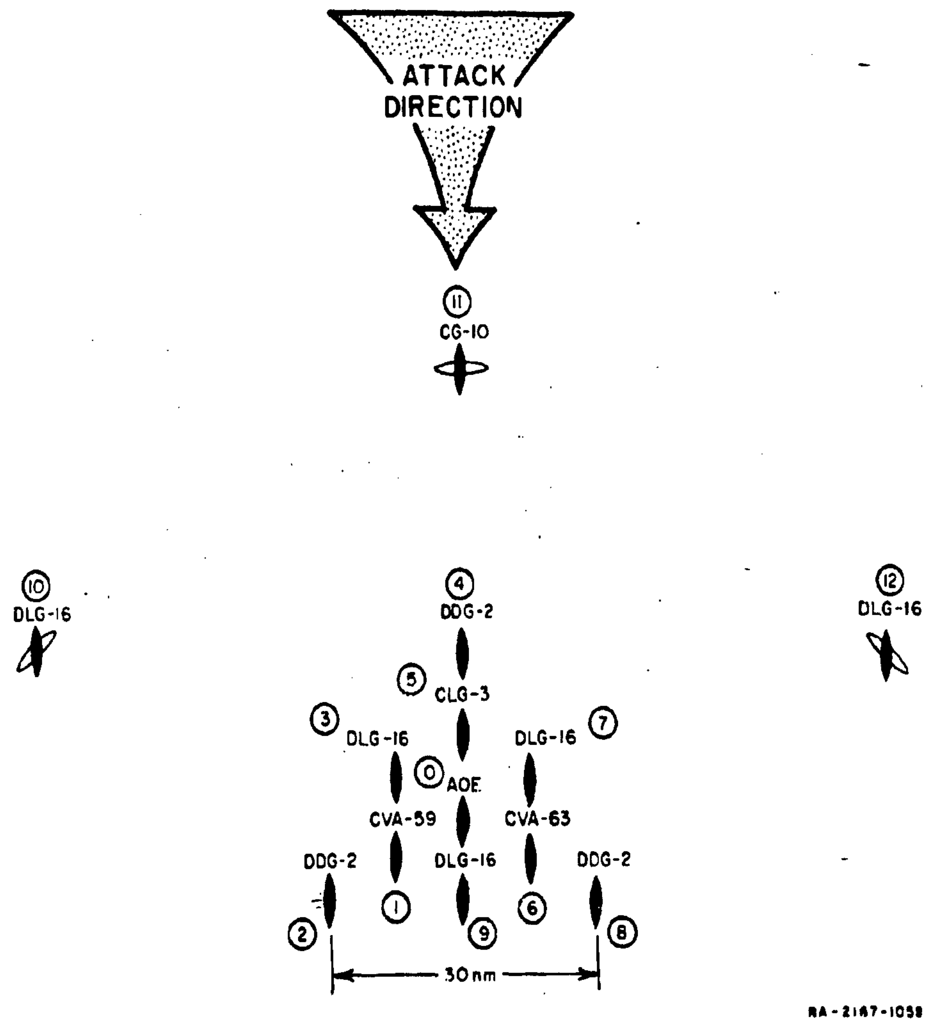



FIG. 5.34 SEA MAULER TASK FORCE FORMATION

For the SEA MAULER analysis, it was decided to pick the weakest task force from the earlier TYPHON study results (i.e., the 3T task force), substitute SEA MAULER pods for the gun systems on all ships so equipped, and determine if the use of such a weapon as a "last-ditch" self-defense measure would significantly improve the performance of the 3T force against the original heavy enemy attack. Five task force situations, based on the two basic force compositions, have been considered in the course of this study:

Case A - The original, or reference, run, based on the basic 3T task force and with relatively high single-shot kill probability values; undegraded home-on-jam kill probabilities.

Case B - Basic 3T task force with the addition of SEA MAULER batteries as previously described. Single-shot kill probability values as in Case A.

Case C - SEA MAULER augmented force composition as in Case B, except that single-shot kill probability values for all weapon systems were reduced to reflect latest BuWeps estimates; undegraded HOJ values.

Case D - Same situation and input values as Case C, except that home-on-jam kill probabilities were reduced for all weapon types (by a factor of one-half for all but TALOS, which was reduced to one-fourth of the undegraded value)

Case E - Autonomous operation of SEA MAULER fire units (i.e., no tie-in with ship's surveillance radar sets, NTDS, or weapon control stations); all other input values as in Case D.

In every case in which HOJ single-shot kill probability values were undegraded from the command guidance values, the task force succeeded in killing all of the enemy jamming aircraft prior to the time that any of the SEA MAULER batteries had available targets within range. In Cases D and E, however, at least one of the jamming aircraft survived the entire engagement, thus providing a test of the performance of SEA MAULER as a task-force AAW system in an ECM environment.

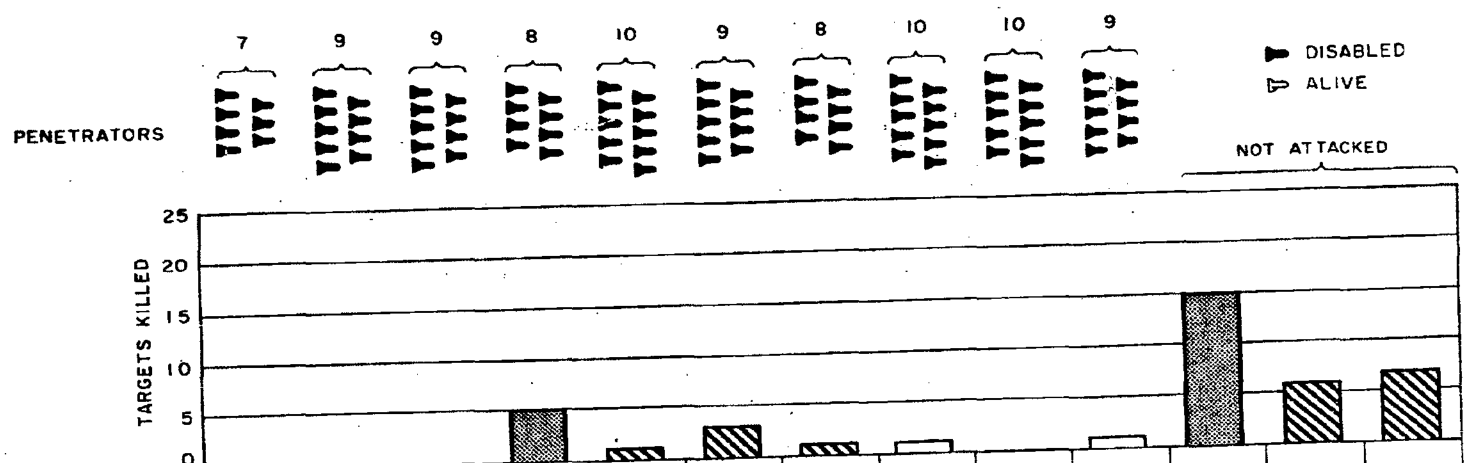
The results of Cases A through E are presented in Figs. 5.35 through 5.39 respectively. Each figure shows the kills achieved by each weapon type aboard each ship, the number of penetrators over each ship under attack and the status of each ship at the end of the game, i.e., Alive or Disabled. Also shown for each case is a cumulative total, by weapon type, of kills and intercepts (kills plus misses) achieved as well as total shots fired by each weapon type. The difference between shots fired and intercepts achieved represents the number of missile assignments that were aborted for any one of several possible causes. Chief among these causes are target pre-emptions (associated with multiple missile assignments to a single target), maximum range limitations (associated with passive homing mode assignments made on the basis of imperfect passive ranging information), and target course changes (since missile trial intercept solutions are obtained, of necessity, from extrapolation of a target's known position and velocity).

The results of the five task force situations are summarized in Table 5.10. The unaugmented 3T task force (Case A) faired poorest in every measure and clearly offers the least effective defense, in spite of the use of what were perhaps unrealistically high single-shot kill probability values in the input data.

Table 5.10

TASK FORCE RUN SUMMARY

| Case | Kills Achieved | Intercepts Achieved | Shots Fired | Penetrators | Ships Disabled |
|---|---|---|---|---|---|
| A | 40 | 77 | 146 | 89 | 10 |
| B | 109 | 205 | 291 | 20 | 5 |
| C | 97 | 257 | 332 | 29 | 3 |
| D | 45 | 166 | 216 | 77 | 9 |
| E | 63 | 176 | 217 | 61 | 6 |




| WEAPON(S) | (NONE) | (NONE) | TERRIER | TALOS | TERRIER | TERRIER | TERRIER | TARTAR | TARTAR | TARTAR | TARTAR AND TALOS | TERRIER | TERRIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG-16 | DLG-16 | DLG-16 | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| TARTAR | 2 | 2 | 5 |
| TERRIER | 18 | 38 | 81 |
| TALOS | 20 | 37 | 60 |
| TOTALS | 40 | 77 | 146 |

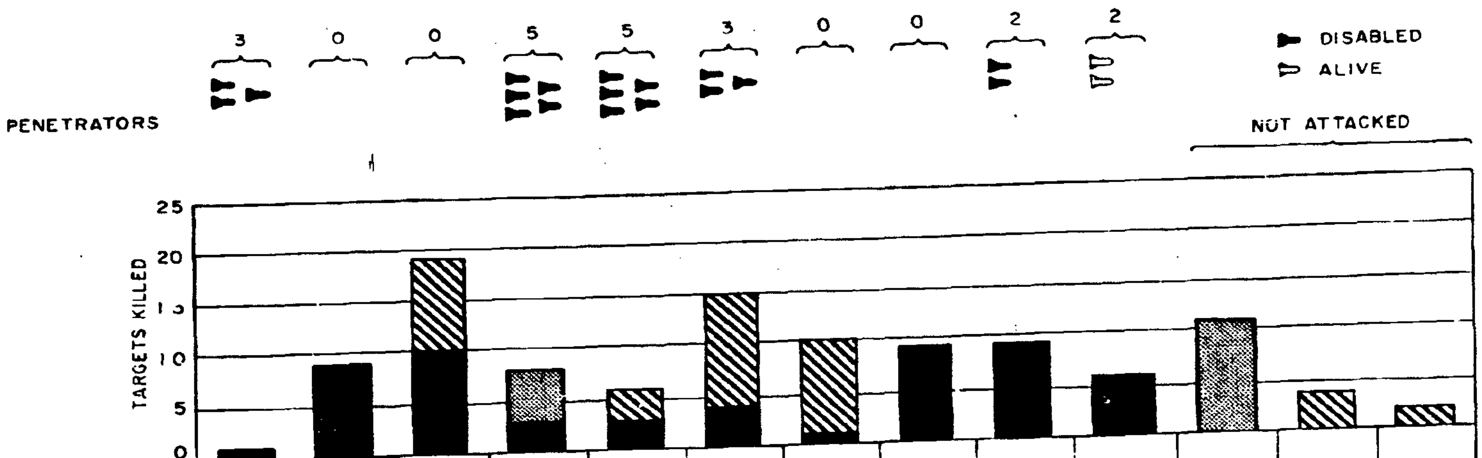
TOTAL PENETRATORS = 89

TOTAL SHIPS SURVIVING = 3

TALOS  TERRIER  TARTAR

RB-2 67-1067

FIG. 5.35 TASK FORCE AAW EFFECTIVENESS: SEA MAULER CASE A




| WEAPON(S) | MAULER | MAULER | TERRIER AND MAULER | TALOS AND MAULER | TERRIER AND MAULER | TERRIER AND MAULER | TERRIER AND MAULER | MAULER | MAULER | MAULER | TALOS | TERRIER | TERRIER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG-16 | DLG-16 | DLG-16 | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| MAULER | 55 | 113 | 140 |
| TERRIER | 38 | 70 | 111 |
| TALOS | 16 | 22 | 40 |
| TOTALS | 109 | 205 | 291 |

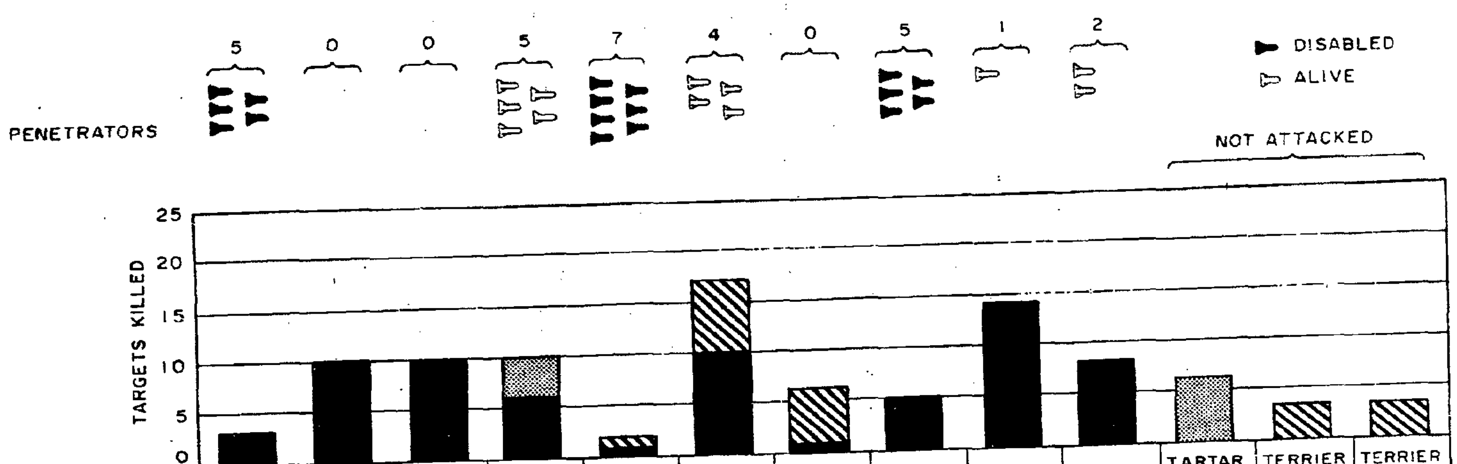
TOTAL PENETRATORS = 20

TOTAL SHIPS SURVIVING = 8

MAULER TALOS TERRIER TARTAR

RB-2167-1068

FIG. 5.36 TASK FORCE AAW EFFECTIVENESS: SEA MAULER CASE B




| WEAPON(S) | MAULER | MAULER | TERRIER AND MAULER | TALOS AND MAULER | TERRIER AND MAULER | TERRIER AND MAULER | TERRIER AND MAULER | MAULER | MAULER | MAULER | TARTAR TALOS & MAULER | TERRIER AND MAULER | TERRIER AND MAULER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG-16 | DLG-16 | DLG-16 | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| MAULER | 68 | 173 | 194 |
| TERRIER | 19 | 59 | 90 |
| TALOS | 10 | 25 | 48 |
| TOTALS | 97 | 257 | 332 |

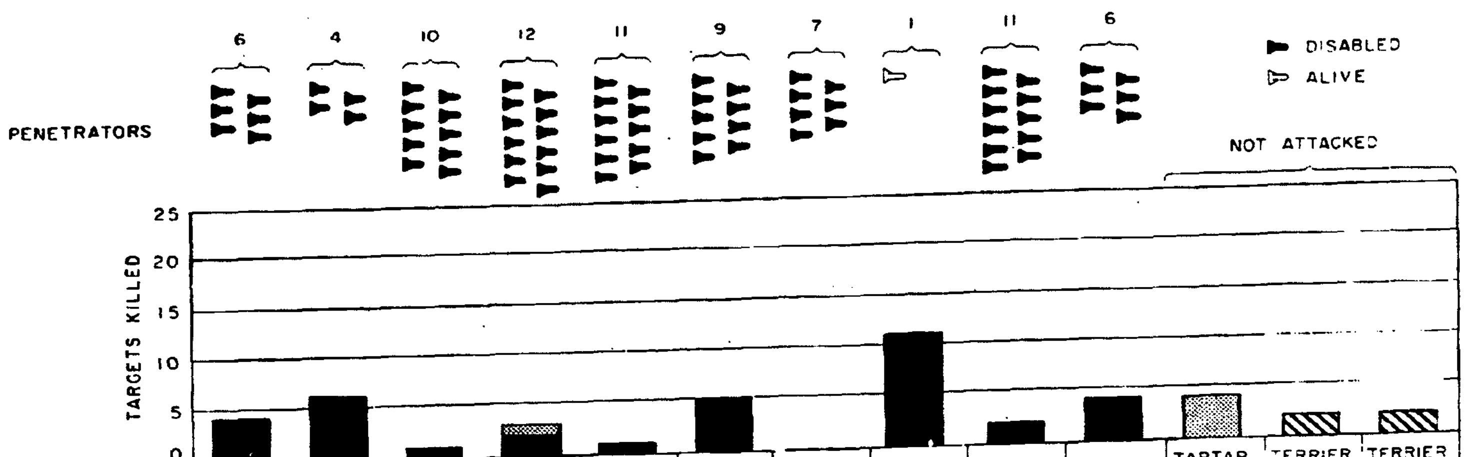
TOTAL PENETRATORS = 29

TOTAL SHIPS SURVIVING = 10

MAULER    TALOS    TERRIER    TARTAR

RB-2167-1069

FIG. 5.37 TASK FORCE AAW EFFECTIVENESS: SEA MAULER CASE C




| WEAPON(S) | MAULER | MAULER | TERRIER AND MAULER | TALOS AND MAULER | TERRIER AND MAULER | TERRIER AND MAULER | TERRIER AND MAULER | MAULER | MAULER | MAULER | TARTAR TALOS & MAULER | TERRIER AND MAULER | TERRIER AND MAULER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG-16 | DLG-16 | DLG-16 | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| MAULER | 36 | 110 | 127 |
| TARTAR | 0 | 0 | 2 |
| TERRIER | 4 | 12 | 22 |
| TALOS | 5 | 44 | 65 |
| TOTALS | 45 | 166 | 216 |

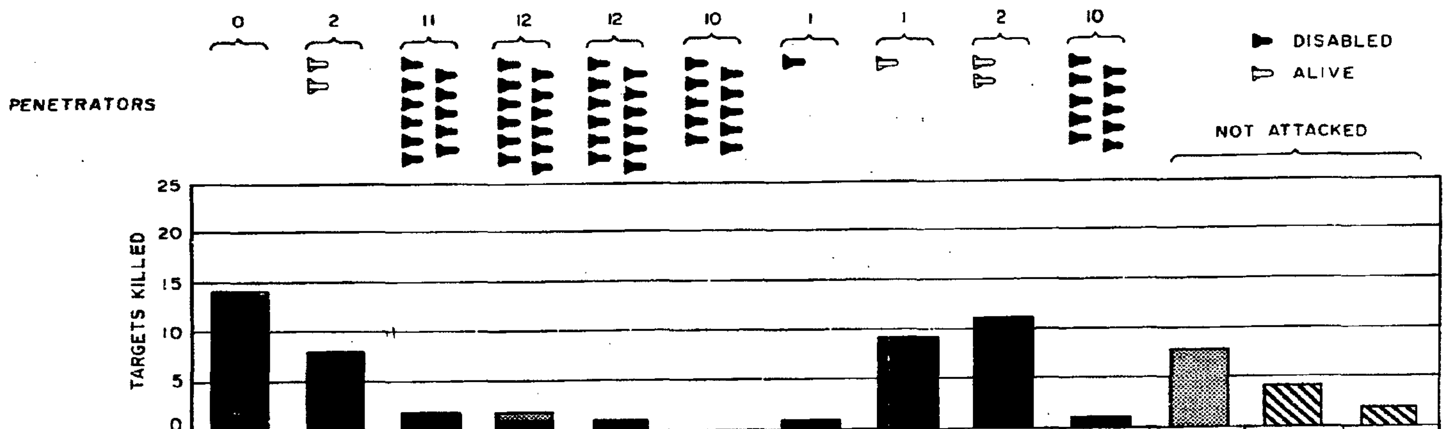
TOTAL PENETRATORS = 77

TOTAL SHIPS SURVIVING = 4

MAULER TALOS TERRIER TARTAR

RB-2167-1070

FIG. 5.38 TASK FORCE AAW EFFECTIVENESS: SEA MAULER CASE D




| WEAPON (S) | MAULER | MAULER | TERRIER AND MAULER | TALOS AND MAULER | TERRIER AND MAULER | TERRIER AND MAULER | TERRIER AND MAULER | MAULER | MAULER | MAULER | TARTAR TALOS & MAULER | TERRIER AND MAULER | TERRIER AND MAULER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SHIP POSITION | 0 | 1 | 6 | 5 | 3 | 7 | 9 | 2 | 4 | 8 | 11 | 10 | 12 |
| SHIP TYPE | AOE | CVA-59 | CVA-63 | CLG-3 | DLG-16 | DLG-16 | DLG-16 | DDG-2 | DDG-2 | DDG-2 | CG-10 | DLG-16 | DLG-16 |

| | KILLS | INTERCEPTS | SHOTS |
|---|---|---|---|
| MAULER | 48 | 130 | 145 |
| TARTAR | 0 | 0 | 8 |
| TERRIER | 6 | 9 | 18 |
| TALOS | 9 | 37 | 46 |
| TOTALS | 63 | 176 | 217 |

TOTAL PENETRATORS = 61

TOTAL SHIPS SURVIVING = 7

MAULER TALOS TERRIER TARTAR

RB-2167-1071

FIG. 5.39 TASK FORCE AAW EFFECTIVENESS: SEA MAULER CASE E

By the addition of the SEA MAULER units (Case B), there is remarkable increase in the task force defensive capability. The 100 percent increase in total firepower is due in part to the fact that a high-rate-of-fire weapon has been added to the force and in part to the fact that an additional five ships in the task force main body manage to survive the entire air battle, thereby providing an extended opportunity to engage the enemy. Such a "second-order" effect of a self-defense weapon system is perhaps of as much significance as the number of kills that may be directly attributed to that system.

It is interesting to note in Case C that, when the single-shot kill probabilities were lowered to more realistic values, the NTDS TEWA doctrine automatically compensated by increasing the task-force firepower. This is a direct result of the requirement for a larger number of assignments to be made to a given target before it is no longer considered for additional assignments. The number of enemy penetrations increased by nearly 50 percent over the previous case, although the number of ships disabled was actually reduced by 2. The difference in the number of ships disabled is attributable to end-game variability associated with a small sample size. This case is representative of the results that might be obtained with presently expected single-shot kill probabilities, given that a workable multiple-target home-on-jam guidance capability is developed.

By comparison, Cases D and E represent the expected game results if degraded home-on-jam intercept capability is experienced and some of the jamming aircraft survive the entire air battle. The number of shots fired is reduced from the previous case by about 35 percent, due largely to shorter radar detection, or burn-through ranges, however, firepower is still greater than in the non-MAULER situation (Case A). The number of penetrators increased by a factor greater than two as a compound effect of fewer intercepts (and, in turn, kills) and a larger number of ships being disabled. These two runs demonstrate the degree of degradation in task force AAW capability that would be inflicted by failure to obtain a good home-on-jam kill probability.

The task force did not appear to lose any significant advantage by the employment of the SEA MAULER batteries in an autonomous mode. In fact the total task force firepower differed by but one shot between run Cases D and E. This is due in part to the predominance of low-altitude attackers, against which the autonomous mode of operation inflicts the least degradation in firepower. Coupled with this is the fact that early warning of the raid and initial threat evaluation is provided by information from non-MAULER search and height-finding radars.

For all of the task force runs, it was assumed that SEA MAULER was equipped with an automatic launcher reload device that could replenish the launcher rack with nine missiles in one minute. A summary of the utilization of this capability is presented in Table 5.11. In Case C, better than one quarter of the SEA MAULER firepower resulted from launcher reload missiles. Case B, utilizing higher single-shot kill probabilities, required only one ship to reload (twice), accounting for less than 10 percent of the SEA MAULER firepower. In both Cases D and E, the system maximum intercept range was degraded by the survival of jamming aircraft resulting in fewer SEA MAULER assignments and, in turn, a lesser requirement for reload missiles.

Table 5.11

SEA MAULER RELOAD SHOT SUMMARY

| Case | Number of Ships Firing Reload Missiles | Number of Ships Requiring Indicated Number of Reload Cycles | | Number of Reload Missiles Fired From Each Reload Cycle | | Number of Reload Missiles Fired | Percentage of Total SEA MAULER Firepower |
|---|---|---|---|---|---|---|---|
| | | 1 Cycle | 2 Cycles | 1st Cycle | 2nd Cycle | | |
| A | - | - | - | - | - | - | - |
| B | 1 | 0 | 1 | 9 | 1 | 10 | 7.2 |
| C | 5 | 4 | 1 | 45 | 7 | 52 | 26.8 |
| D | 2 | 2 | 0 | 12 | 0 | 12 | 9.5 |
| E | 2 | 2 | 0 | 20 | 0 | 20 | 13.8 |

It is of interest to note that nearly all of the launcher reload requirements in these situations could have been met by a single reload cycle. Thus, with a full nine-missile magazine supplemented with a ready service, rapid reload supply of nine additional missiles per launcher, the task force could achieve essentially the same SEA MAULER firepower as with the unlimited, rapid reload capability assumed.

5.2.2.2.2 Summary of Findings

(1) The investigations of SEA MAULER effectiveness in an attack carrier task force environment reveal that it represents a potent air defense weapon if operating in conjunction with the more powerful, long-range 3T systems. It seems quite clear that SEA MAULER's performancewill be directly dependent on the ability of other naval SAM systems in a task force to:

(a) Force the enemy into low-level attacks (where SEA MAULER effectiveness is highest)

(b) Force the enemy into stand-off attacks with relatively large missiles (which can be engaged by SEA MAULER in their terminal approach to target)

(c) Destroy enemy jammers at relatively long ranges so as to minimize their effects on SEA MAULER performance

(2) The rather impressive effectivenss of SEA MAULER that emerges from this study further depends on the system's ability to achieve single missile salvo kill probabilities of the order predicted against ASM targets. If such single-shot kill probability values (even on the order of the latest BuWeps estimates) cannot be attained,the firing of multiple (two or three) missile salvos may be necessary in order to maintain an acceptably high level of defense effectiveness. In such an event, the importance of the automatic launcher reload capability would be evident

(3) It is, of course, to the Navy's advantage to develop missile systems with single-shot kill probabilities as high as attainable, as reflected in the defense performance in task force Case B. However, given lower single-shot kill probability values and knowledge of this fact

(i.e., realization), the NTDS TEWA doctrine tends to compensate by increasing over-all firepower of the task force, as in Case C.

(4) There is a pressing requirement for the development of a missile defense system of long range with a good multiple target home-on-jam kill capability. In the cases studied, the number of enemy penetrations suffered increased by more than two-fold when the defense failed to kill all of the jamming aircraft.

(5) In the task-force environment, the defense did not appear to lose any significant advantage by employing the SEA MAULER batteries in an autonomous mode. This is due in part to the predominance of low-altitude attackers, against which the autonomous mode of operation suffers the least degradation in the single-ship analysis, combined with the fact that the early warning and initial threat evaluation was provided in the task force cases by the ship's surveillance radars.

### 5.3 AEW Detection Capabilities

#### 5.3.1 Introduction

Throughout the present investigation of missiles system effectiveness in task force anti-air warfare, a need has arisen for a better understanding of how the characteristics and limitations of certain types of radar systems may affect the performance of the AAW complex as a whole. This need is particularly apparent in the area of airborne early warning (AEW) radar systems since limited detection capabilities on the outer fleet defense perimeter may have serious effect on the over-all task force operations. Therefore, this study was undertaken to investigate the effectiveness of the AN/APS-96 radar system which is aboard the E-2A, an early warning aircraft. The results and conclusions of the study are of value in the interpretation of task force runs, particularly in the area of interceptor vectoring, since the assignment doctrine for interceptors is strongly dependent on the range and information limitations of the AEW. Furthermore, the study demonstrates the utility of the computer program in the analysis of a single radar system, which, in this instance, happens to be an important element of the task force AAW complex.

5.3.2 Stand-off Jamming

The ability of the AN/APS-96 radar, as presently configured, to detect nonjamming attack aircraft being screened by stand-off jammers at various stand-off ranges and jamming power levels is considered in this section. The stand-off jammer is assumed to be on station throughout each run situation while the attacking aircraft appear at the radar horizon, close on the AEW position to a closest point of approach, and continue toward the task force center to a weapon-release point. As in the AAW effectiveness simulation work, target radar reflective area is computed as a function of target aspect angle at each scan of the radar. This cross section area is at its maximum value at the target's closest point of approach to the AEW position (i.e., when the beam aspect is presented to the radar).

Th phenomenon being investigated here is the ability of an airborne search radar to detect nonjamming attack aircraft, in its antenna main beam, while an enemy stand-off jammer is attempting to introduce enough noise jamming energy through the side-lobe structure of the radar antenna pattern to "out-shout" the target signal return. Obviously, the manner in which the side-lobe pattern is modeled is of critical importance to the outcome of such an analysis. Careful attention was given to obtaining valid antenna pattern gain data for the AN/APS-96 radar and to correctly simulating its effect as will be explained later in this section.

5.3.2.1 The Raid

The geometry used in this study is derived from what has already been described as a feasible task-force configuration (Part 5.2.2) and the enemy raid against which the detection capabilities of the AN/APS-96 are measured result from the employment of a reasonable set of attack tactics. From the AEW deployment analysis described in Part 5.4.2, it follows that a typical distance between AEW stations is approximately 280 nm. Typical enemy tactics to avoid detection would probably be a stright-line attack directly between two AEW's. Due to the symmetry of the situation, only one AEW was considered in the analysis. It is placed at a radial distance of 200 nm from task force center, at an angle of 45 degrees with respect to the raid path, and at an altitude of 35,000 ft (see Fig. 5.40).

The object of the study was to determine how effectively the stand-off jammer degrades the performance of the AN/APS-96 radar aboard the AEW. The jamming power was varied from 5 Mc to 500/Mc. The higher values are considered feasible only if directional jamming antennas are employed by the enemy. The position of the stand-off jammer was varied from 150 nm (approximately the point in the attack path closest to AEW) to 375 nm (just beyond the maximum unambiguous range of the AN/APS-96) from task force center.

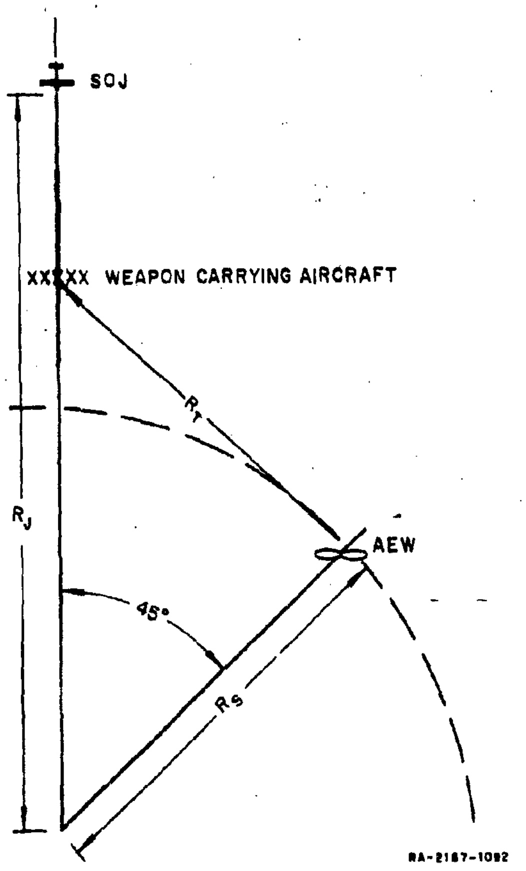



FIG. 5.40 AEW STATION LOCATION AND RAID DIRECTION

The raid consists of one stand-off jammer at an altitude of 50,000 ft and five weapon-carrying aircraft at 35,000 ft. The altitude of the stand-off jammer was selected to place it in the vertical main beam of the AN/APS-96 for as long as possible. Due to the earth's curvature the altitude of the stand-off jammer should decrease as its position in various runs approaches the point in the attack path closest to the AEW. In fact at that point, the altitude of the stand-off jammer should be 35,000 ft, the same as the five aircraft. However, two preliminary runs were made with jamming powers of 25 w/Mc and 50 w/Mc at 150 nm, from task force center (see Figs. 5.43 and 5.44) with the stand-off jammer at 35,000 ft. These runs indicate that although the jamming is slightly more effective at 35,000 ft, the qualitative results are essentially the same. Therefore throughout the study constant stand-off jammer altitude (50,000 ft) was assumed.

The stand-off jammer remains stationary during each run while the weapon-carrying aircraft proceed toward task-force center at a speed of 575 knots. The radar cross-sectional area of the aircraft varies from 15 $m^2$ (head-on) to 100 $m^2$ (beam aspect), depending on their position with respect to the AEW.

5.3.2.2 Acquisition Criteria

In most present-day radar systems, target detection and acquisition is determined by the judgment of the radar operator through intuition, experience, and knowledge of his environment. The operator attempts to distinguish the signal return of real targets from spurious signals arising from other sources.* He bases his judgment on both the appearance of the image on his PPI or A scope and on the persistence with

* Although these "other sources" include such important and diverse possibilities as sea clutter, rain clutter, etc.; the only noise elements considered in the study are broad-band barrage gaussian noise jamming and receiver ambient noise.

not to appear again, is considered a false target, while a blip that remains in position for several scans is judged to be a real target. In the latter case, target acquisition is assumed to have occurred. Should the target disappear in subsequent scans of the radar, acquisition is said to have been lost.

In the case of the AN/APS-96, however, the process of determining acquisition and loss of acquisition of targets, is automatic. For this purpose, some criterion must be established to replace the judgment normally exercised by the operator. This criterion, as in the case of the human operator, is determined on the basis of persistence of the potential target on the radar screen over several scans.

The selection of the number of scans to be considered and the number of detections within this group of scans necessary for acquisition is a compromise between the objective of not neglecting any real target while attempting not to misclassify any false target as a real target.

To prevent saturation of the radar, it is assumed that constant false alarm rate (CFAR) is incorporated within its circuitry. This technique essentially controls the radar receiver in such a manner as to keep the noise level at a constant figure, varying the level of incoming signal accordingly. Detection is then based upon whether signal plus noise exceeds a threshold built into the radar. Corresponding to each such possible threshold is a probability of false alarm. This false alarm probability is simply the probability that a given detection is fallacious.

It should be noted here that while it is apparent that raising this threshold will eliminate possible false detection; it will also tend to suppress the detection of real targets.

Finally, for a given radar system this threshold is fixed by the internal circuitry of that system, and so that the threshold must be considered in the construction of a meaningful acquisition criterion.

For the present analysis, two criteria governing automatic target acquisition and loss of acquisition were selected on the basis that they would be the likely ones to be used with the AN/APS-96. These were as follows:

Criterion I - Acquisition occurs with two detections out of the last three scans. Target loss occurs upon no target detection in the last 18 scans.

Criterion II - Acquisition occurs with three detections out of the last group of five consecutive scans. Target loss occurs upon no target detection in the last 18 scans.

It should be noted that Criterion I is less stringent than Criterion II in the sense that an acquisition under Criterion II always implies an acquisition under Criterion I.

5.3.2.3 Discussion of Results

Figures 5.41 through 5.48 represent the results of the study for the various jamming powers. Listed vertically on each figure is the position of the stand-off jammer for that run. On the horizontal axis is the slant range (distance from target to AEW). The slant range decreases from 240 nm (acquisition in clear environment occurs at an average of 236 nm) down to 140 nm (closest point of raid approach to AEW) and then increases to 200 nm (task force center). The five lines for each run represent period of acquisition for each of the five weapon carrying aircraft (numbered 1 through 5.) The dots shown in the figures reflect acquisition by the use of Criterion I, whereas the vertical pips correspond to acquisition by Criterion II. Gaps in the line represent periods of loss of target acquisition under both criteria.

In connection with Figs. 5.41 through 5.48, an important factor should be mentioned. The detection results being presented are statistical in nature and the figures shown represent the results of only one replication of a five-plane run-in against the task force for a particular stand-off jammer range and power. Since the five attacking aircraft are being

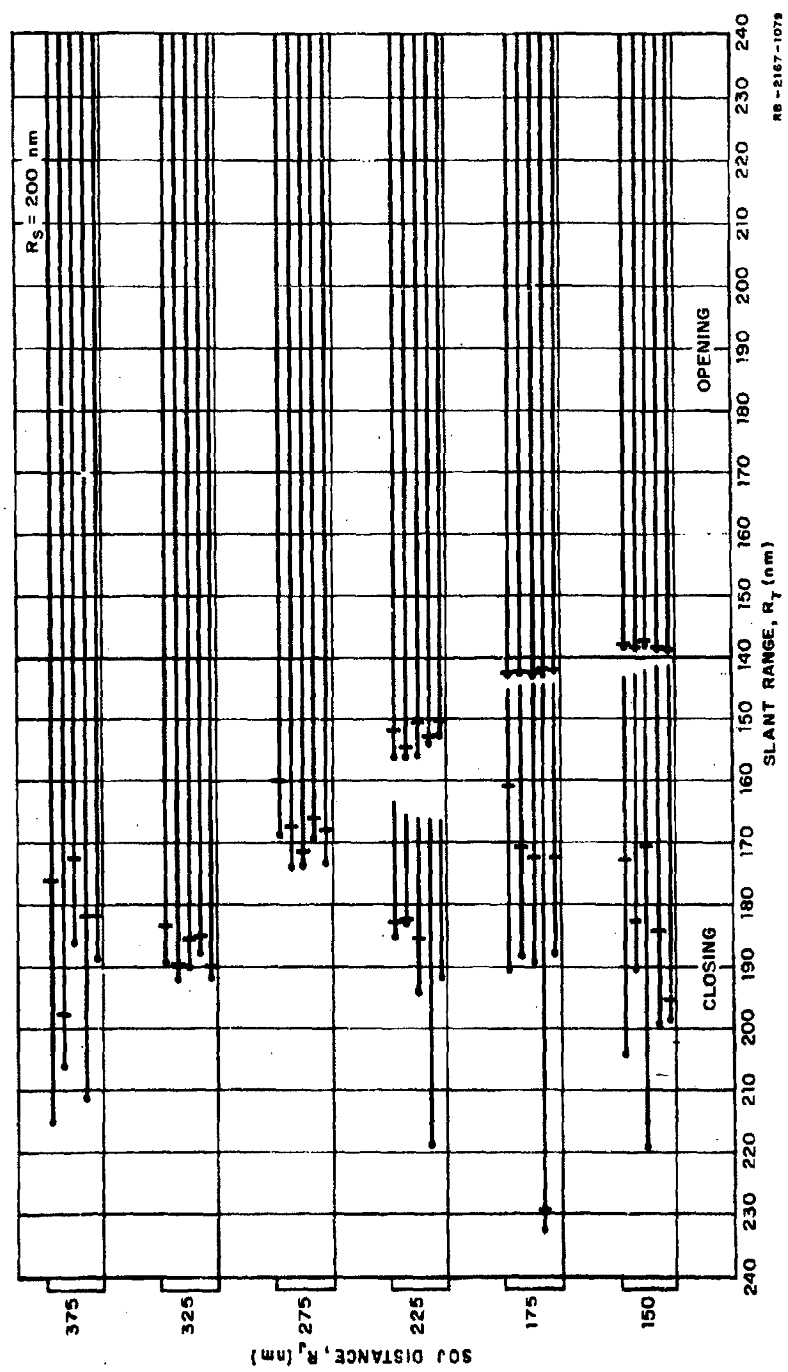



FIG. 5.41 AEW ACQUISITION PLOTS WITH STAND-OFF JAMMER POWER 5 w/Mc

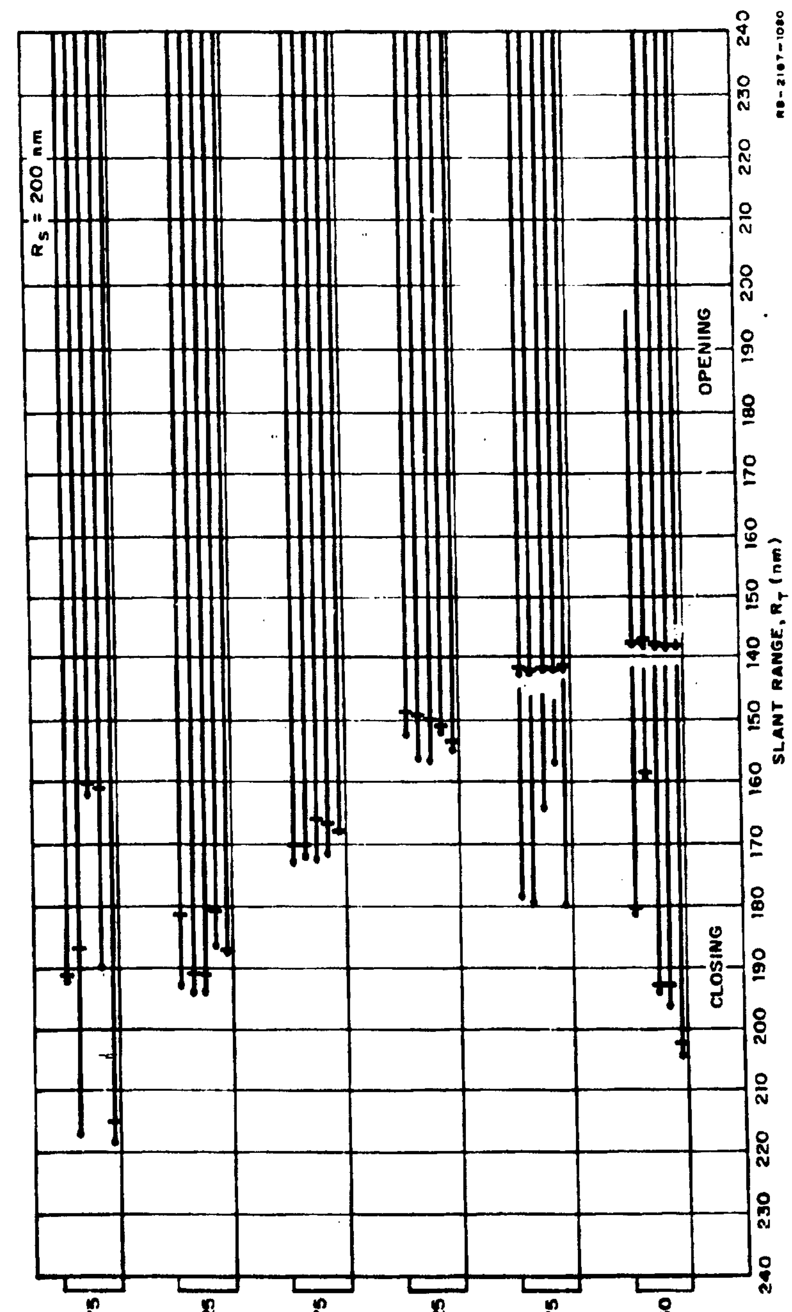



FIG. 5.42 AEW ACQUISITION PLOTS WITH STAND-OFF JAMMER POWER 15 w/Mc

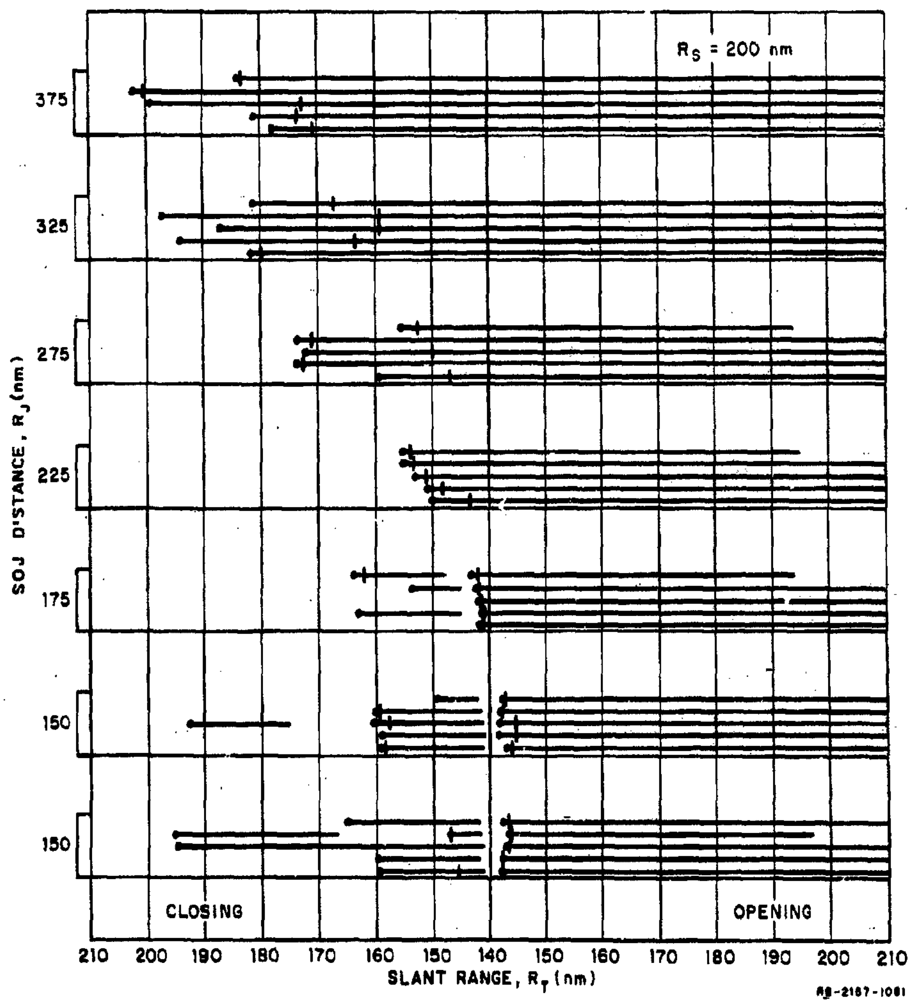



FIG. 5.43 AEW ACQUISITION PLOTS WITH STAND-OFF JAMMER POWER 25 w/Mc

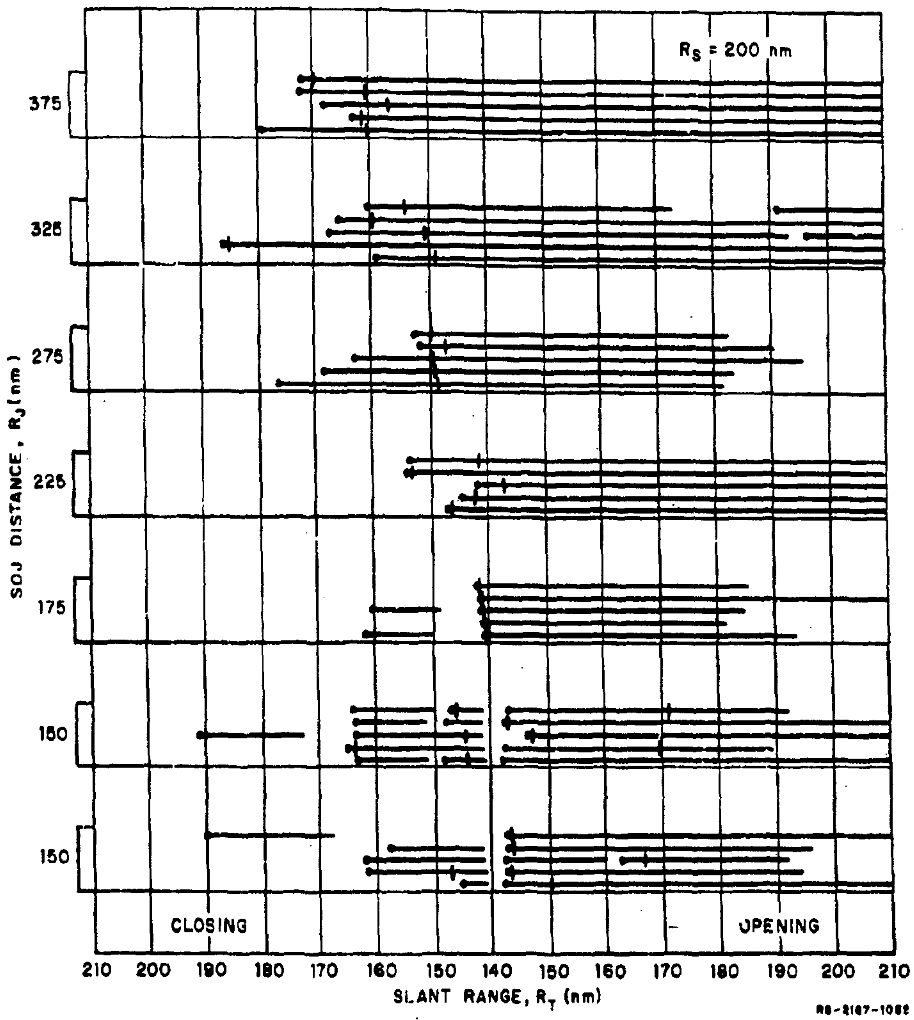



FIG. 5.44 AEW ACQUISITION PLOTS WITH STAND-OFF JAMMER POWER 50 w/Mc

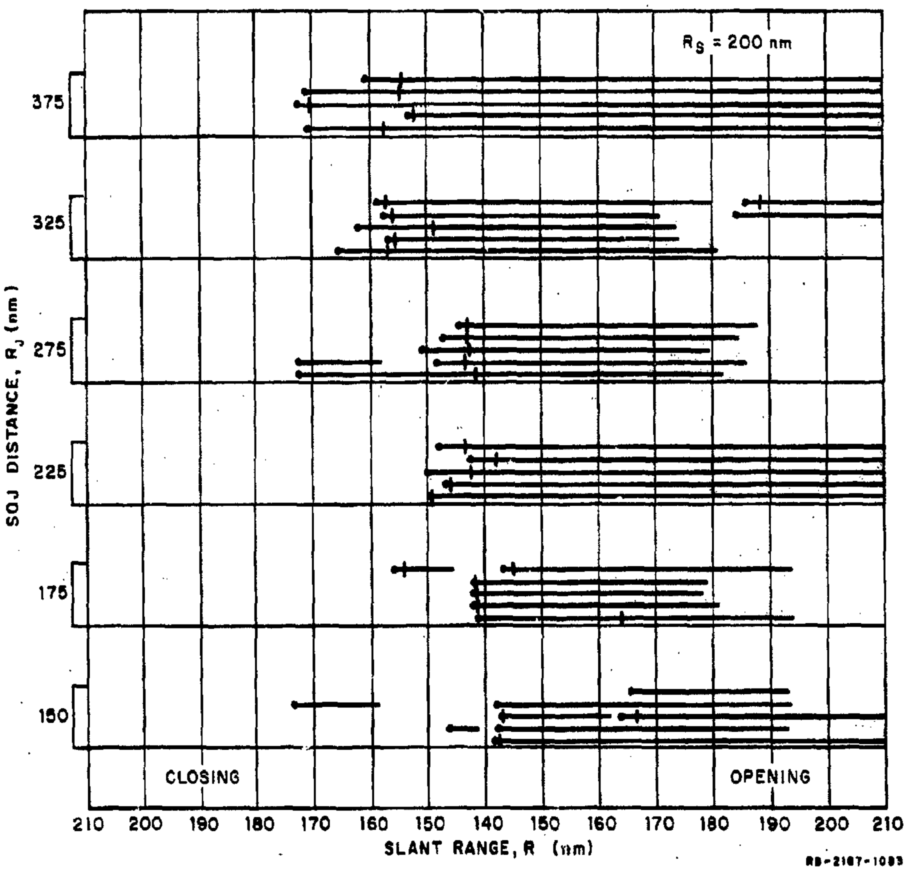



FIG. 5.45 AEW ACQUISITION PLOTS WITH STAND-OFF JAMMER POWER 75 w/Mc

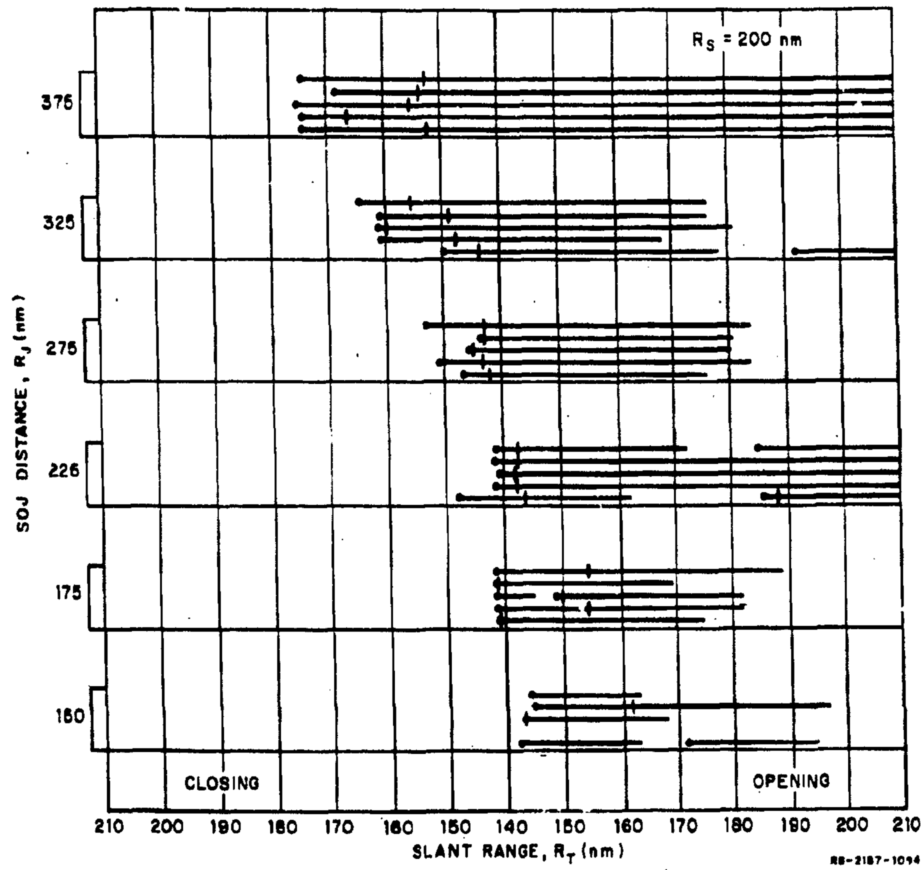



FIG. 5.46 AEW ACQUISITION PLOTS WITH STAND-OFF JAMMER POWER 100 w/Mc

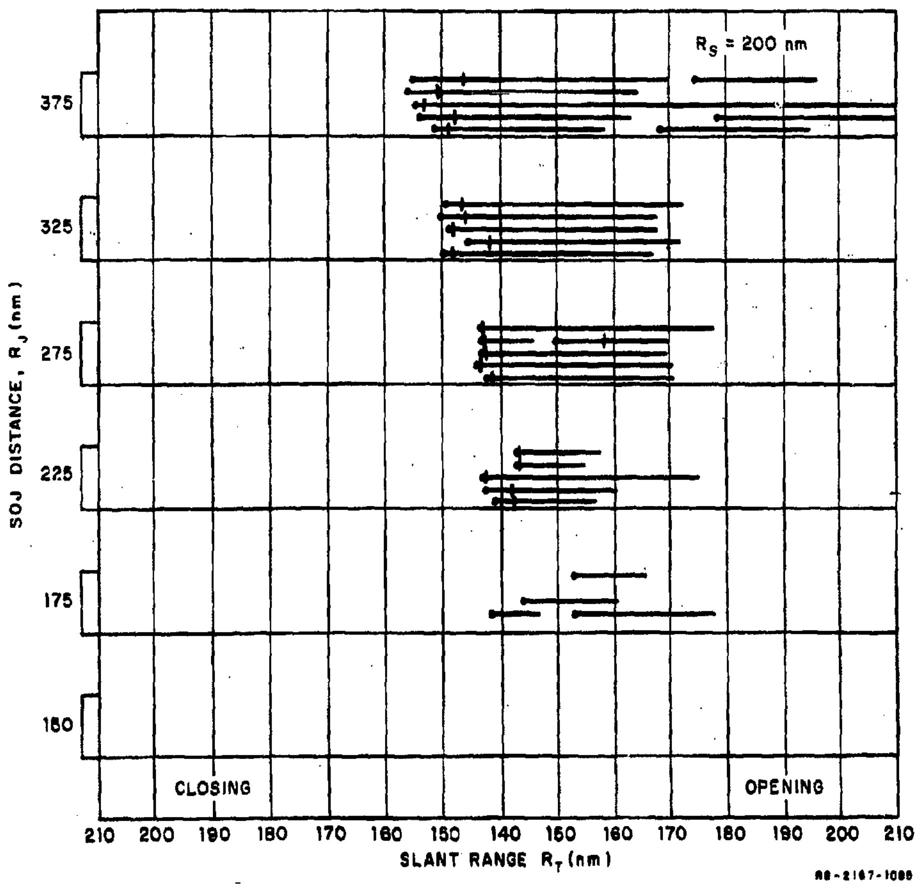



FIG. 5.47 AEW ACQUISITION PLOTS WITH STAND-OFF JAMMER POWER 250 w/Mc

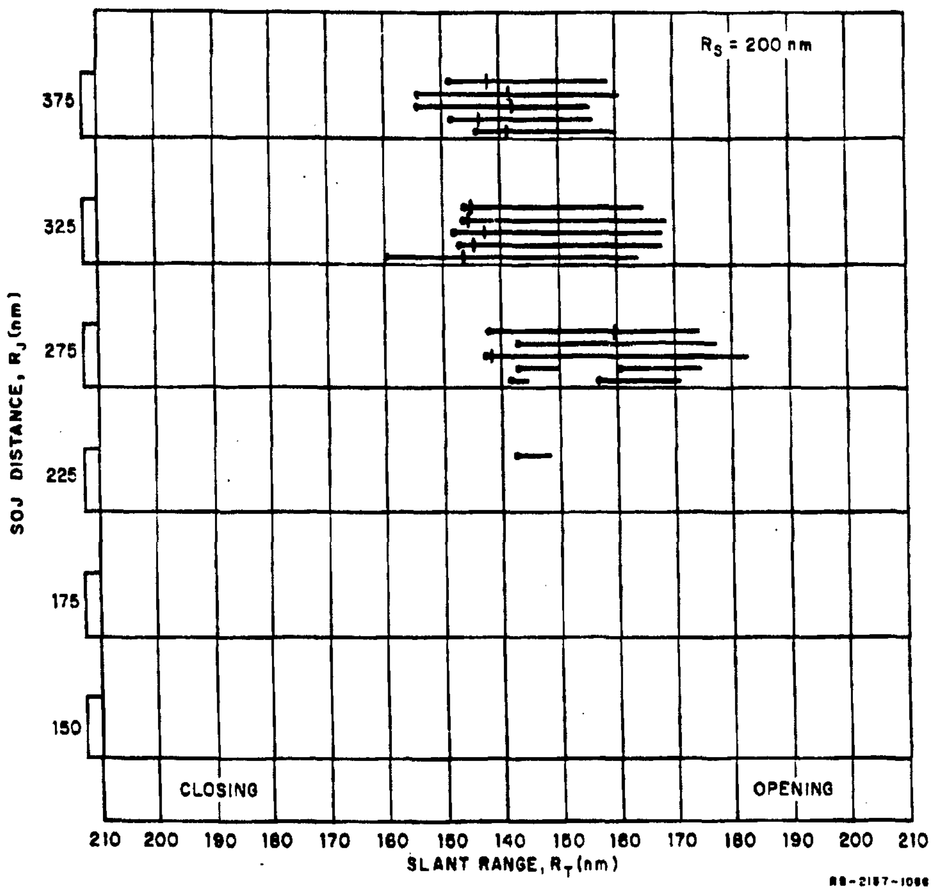



FIG. 5.48 AEW ACQUISITION PLOTS WITH STAND-OFF JAMMER POWER 500 w/Mc

resolved by the range resolution capabilities of the AN/APS-96, there are, in effect, five independent detection replications in each run being presented.

For a more meaningful interpretation of Figs. 5.41 through 5.48, a tabulation of relevant information is presented in Table 5.12. In the first and second columns are the stand-off jammer positions and the corresponding slant ranges. In the third column are the slant ranges of the targets at which the stand-off jammer enters and exits the main beam of the AN/APS-96. The fourth and fifth columns contain the associated slant ranges of the targets when the stand-off jammer is in the first and second side-lobe nulls, respectively.

For an example of the use of Table 5.12 refer to Fig. 5.43 and a stand-off jamming distance of 150 nm (slant range of 141 nm). Aircraft 1 is acquired at a slant range of 149 nm for Criterion I. This slant range corresponds to the entrance of the jammer into the first side-lobe null (147 nm). Acquisition of Aircraft 1 is lost at 142 nm* and regained by both criteria at 142 nm. This loss of acquisition is due to main-beam jamming at 141 nm. Aircraft 3 is acquired for Criterion I when the jammer is in the third side-lobe null (187 nm) at approximately 193 nm and acquisition is lost at 175 nm. Aircraft 2 through 5 are acquired for Criterion I at 159 nm (jammer in second side-lobe null) and acquisition is lost when main-beam jamming occurs. All aircraft are acquired for Criterion II after the exit of the SOJ from the main beam but only 2, 3, and 5 are acquired for Criterion II with the SOJ in the second side-lobe null. This particular example well illustrates the dependency of acquisition on side-lobe structure. This relationship may not be as clear for greater stand-off jamming distances, since range limitations of the AN/APS-96 tend to minimize side-lobe effects at the greater ranges.

The fact that the AEW, as presently configured, cannot maintain acquisition of targets while it is being jammed in the main beam is illustrated in Fig. 5.41. For the stand-off jamming distances of 150 nm,

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* Indicates targets receding from point of closest approach to AEW.

Table 5.12

AEW ACQUISITION RUN SUMMARY

| Stand-off Jammer Distance from Task Force Center (nm) | Corresponding Slant Range of Jammer From AEW | Slant Range of Targets when SOJ Enters and Exits Main Lobe | Slant Ranges of Targets when SOJ in First Sidelobe Null | Slant Ranges of Targets when SOJ in Second Sidelobe Null | Slant Ranges of Targets when SOJ in Third Sidelobe Null |
|---|---|---|---|---|---|
| 150 | 141 | 144<br>141* | 147<br>143* | 159<br>152* | 187<br>170* |
| 175 | 145 | 151<br>142 | 157<br>141 | 178<br>144* | 229<br>155* |
| 225 | 164 | 178<br>154 | 192<br>149 | 245<br>142 | N/A<br>142* |
| 275 | 194 | 213<br>175 | 249<br>165 | N/A<br>150 | N/A<br>141 |
| 325 | 232 | N/A<br>200 | N/A<br>186 | N/A<br>161 | N/A<br>146 |
| 375 | 273 | N/A<br>232 | N/A<br>206 | N/A<br>172 | N/A<br>150 |

* Indicates targets receding from point of closest approach to AEW

N/A indicates targets are beyond maximum unambiguous range of AN/APS-96

175 nm and 225 nm, the AEW acquires the targets, loses acquisition when the stand-off jammer enters the main beam, and then reacquires when it exits the main beam. At jamming distances greater than 275 nm the range limits the radar from immediately acquiring after targets are clear of main-beam jamming. A quick glance at the remainder of the runs reconfirms the conclusion that the AN/APS-96 is not capable of acquisition when the jamming is in the mainlobe. However, the AN/APS-96 can produce some intelligent directional information when main-beam jamming occurs by passively using the receiving portion of the system. Therefore, two AEW's using methods described in Sec 4.2.3 and Appendix C (SYNTRAC) can, in many situations, passively locate targets that they cannot actively detect.

It was found that acquisition is particularly sensitive to doctrine when the detailed side-lobing structure is considered. If the jamming is in the side lobes, acquisition is dependent on the doctrine and the actual jamming power. For the lower jamming powers, acquisition occurs as soon as the jamming is out of the main beam (range permitting) since the average maximum side lobes are down 25 db. However, at higher jamming powers detection will occur only when the stand-off jammer is in one of the side-lobe nulls. Therefore acquisitions will occur only for the less stringent doctrines, since the number of scans in the period when the stand-off jammer is in the null is limited. This effect is accentuated for high jamming powers when the stand-off jammer position is closest to the AEW. An excellent example of this is shown in Fig. 5.44 with the stand-off jammer at 150 nm. This illustrates how Criterion I can take advantage of the side-lobe pattern. A further examination of the remainder of the results leads to the conclusion that Criterion I takes advantage of the nulls but Criterion II usually does not. However, this does not necessarily imply that Criterion I is superior in general, since this would have to be substantiated by further analysis on the probability of false targets.

Several comments are in order about the problems that arise in the foregoing analysis. The gain pattern of any radar is not constant. The pattern is usually a complex function depending on such variables as frequency, position of beam with respect to the principal axis of the radar platform, the position of the propellers (for an airborne radar), platform vibration, etc. As a consequence, the position of the nulls with respect to the axis of the main beam fluctuates as a function of these variables. A detailed examination of this phenomenon is beyond the scope of the present analysis. However, the problem was not ignored completely. Some experimental results on antenna gain were obtained. The gain function were plotted for the main beam in several positions with respect to the axis of the aircraft. For this analysis, the pattern generated when the main beam is pointing along the axis of the E-2A was chosen. The pattern is shown in Fig. 5.49. As can be seen, the gain at any off-axis angle is not constant. In the analysis, a high and a low envelope were fitted about this pattern (see Fig. 5.50). The gain in any direction was then established between these two values by Monte Carlo evaluation.

Although this is by no means a complete analysis of this problem, it can be expected that in actuality, the detection pattern of the AN/APS-96 will have the same characteristics as shown in Figs. 5.41 through 5.48. However, the actual ranges at which the detection gaps, shown in the figures, appear may be different. Since the analysis concerning acquisition criteria is based only on the fact that nulls do exist and not on their relative position, the conclusions are still valid.

5.3.3 Self-Screening Jamming

From the previous analysis of the stand-off jamming situation, it is obvious that if an enemy's sole consideration is to screen the approach of attacking aircraft, without regard to revealing his position by virtue of passive strobe triangulation techniques, he would attempt to introduce jamming noise into the main lobe of the AN/APS-96 radar antenna pattern continuously. This can be accomplished during the entire raid approach, rather than only during a few moments of target/stand-off jammer bearing coincidence, by employing self-screening jammers. These self-screening aircraft fly right along with the attack aircraft, or indeed, the weapon-delivery aircraft themselves may be fitted (payload capacity permitting) with broad-band barrage noise jammers to cover the AN/APS-96 frequency spectrum.

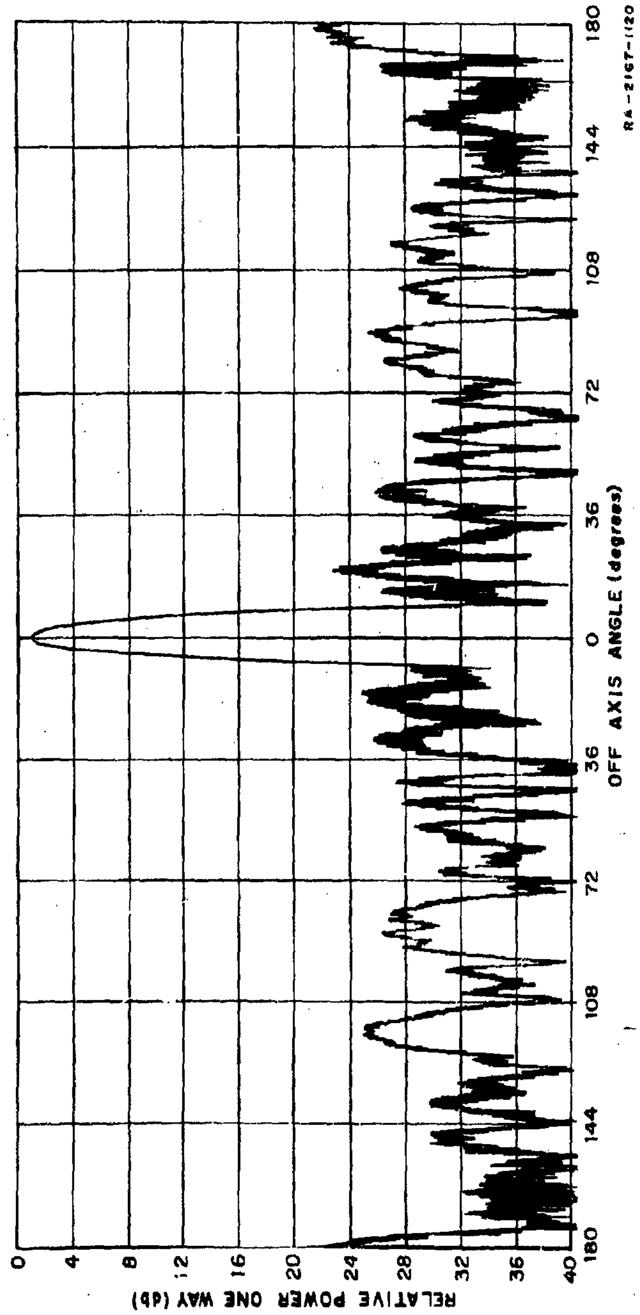


FIG. 5.49 MEASURED AN/APS-96 ANTENNA GAIN PATTERN

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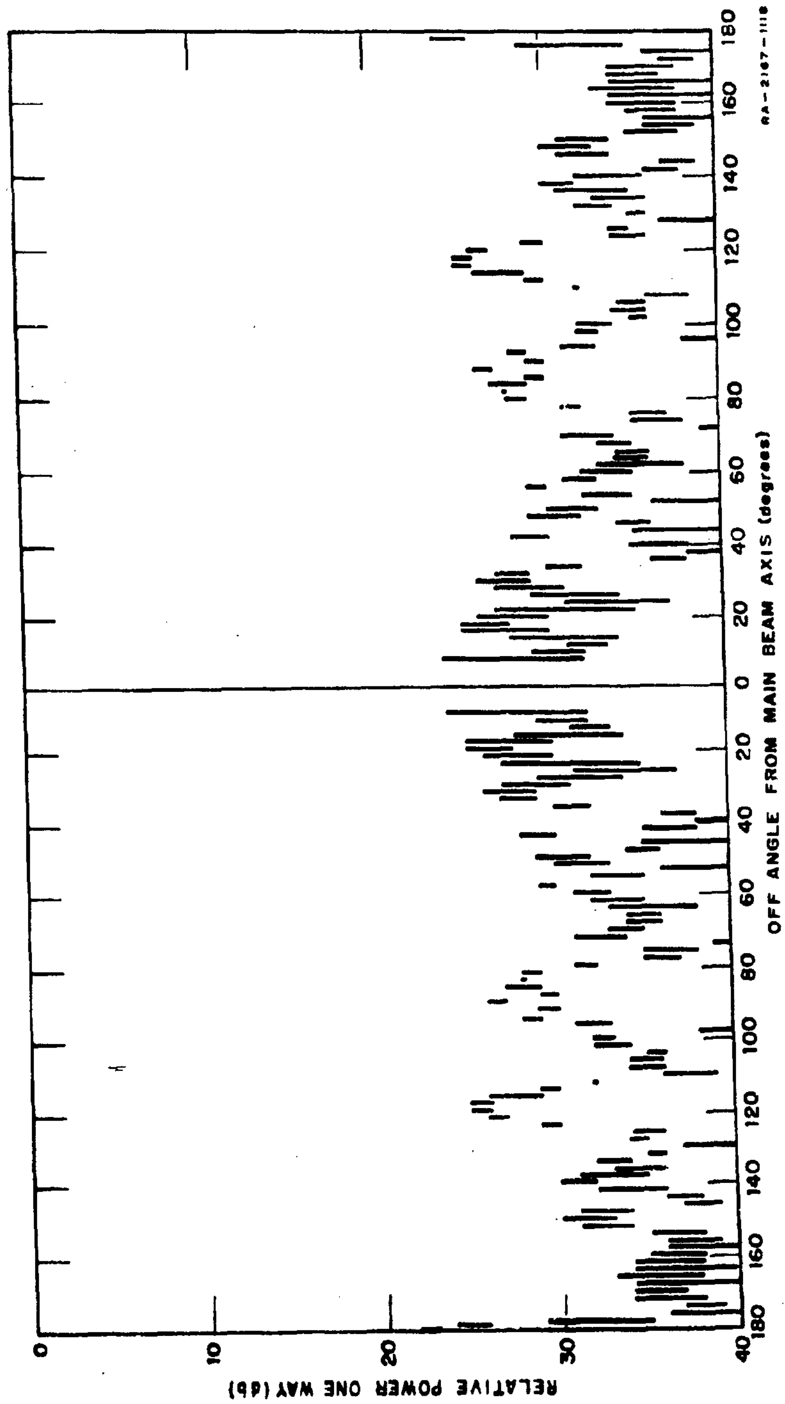


FIG. 5.50 SIMULATED AN/APS-96 ANTENNA GAIN PATTERN



SECRET

Since it is recognized that the performance of the AN/APS-96 radar is not satisfactory under conditions of main-lobe jamming, the question becomes, just how bad is this situation and to what extent must the radar performance be improved in order to achieve acceptable results?

Given a main-lobe jamming situation, the probability that a radar will detect a target is greatest at the closest point of approach, since signal return varies as the fourth power of radar to target range, whereas received jamming energy is proportional to the square of radar to jammer range. The fact that, in this case, target cross section area is also maximum at the closest point of approach serves to enhance further the detection probability at this point.

5.3.3.1 The Raid

Since, with normal target spacings under the conditions of Part 5.3.2.1, target resolution in range is being made by the AEW radar, it is sufficient to consider only a single jamming target in order to investigate the effects of main-lobe jamming.

Two target sizes, of $100m^2$ and $1000m^2$, are considered. Jamming power density is varied as a parameter over the range of 1 w/Mc to 500 w/Mc on the AN/APS-96 radar frequency band.

5.3.3.2 Effectiveness Measure

In the case of a self-screening jammer, the returned signal energy (from a constant cross section target) and the noise jamming energy received, each monotonically increase as functions of decreasing radar-to-target range. In this model, the target cross section does vary as a function of aspect angle, reaching a maximum value at the beam; for a crossing target, this aspect is presented to the radar at the target's closest point of approach. Thus, all factors contribute to a smoothly varying radar detection probability, which reaches a maximum value at the closest point of target approach. Since wild fluctuations in noise power received through the radar's side lobe structure do not occur, acquisition of a self-screening target, by either decision rule, is therefore directly related to the single-scan detection probability. For this reason, it is sufficient for this radar analysis to compute the single scan probability of detection of the self screening jammer, at closest point of approach, by the AEW aircraft, and to plot this data as a function of jamming power density. Such curves reflect the highest detection probabilities, and in turn the radar acquisition probabilities, which could be expected in a self-screening jammer environment.

Improvements in the AN/APS-96 radar are reflected most directly by changes in the value of a lumped radar constant used in the simulation program. This constant, $C_1$, is expressed as follows;

$$C_1 = \frac{P_T \tau G_T G_R \lambda^2 L_T L_R L_P L_A C_B}{(4\lambda)3}$$

$C_1$ = a constant performance factor for the radar (joule-meters2)

$P_T$ = Peak transmitted power (watts)

$\tau$ = Pulse width (seconds)

$G_T$ = Transmitting antenna gain in direction of maximum gain

$G_R$ = Receiving antenna gain in direction of maximum gain

$\lambda$ = Wavelength of radar signal (meters)

$L_T$ = Transmission line and duplexer loss on trnsmit

$L_R$ = Transmission line and duplexer loss on receive

$L_P$ = Pattern loss (effect of beam shape on pulse integration)

$L_A$ = Atmospheric attenuation

$C_B$ = Correction factor for nonoptimum band pass

If we define a term M to represent the ratio of $C_1$ for a new design of the AN/APS-96 radar to the present value of $C_1$, a family of curves may be developed and the effectiveness of such radar improvements in increasing detection capability may be examined in detail. Figures 5.51 through 5.54 are single-scan detection probability curves as a function of self-screening jammer power density for values of M of 1, 2, 4, 8, and 16, respectively. Each family of curves represents a fixed closest point of approach, either 140 to 70 nm, and a fixed beam cross section area of 100 or 1000 $m^2$. Thus, in each of the figures, the curve for M=1 represents the performance of the AN/APS-96 radar as presently configured. The curver for M=2 corresponds to an improvement in the factors that determine the value of the radar constant $C_1$, by a factor of two, and so on for the higher values of M.

5.3.3.3 Discussion of Results

Figure 5.51 represents the main-lobe jamming situation for the case considered in Part 5.3.2, that is, AEW station radius of 200 nm closest point of approach of 140 nm and target beam cross section of

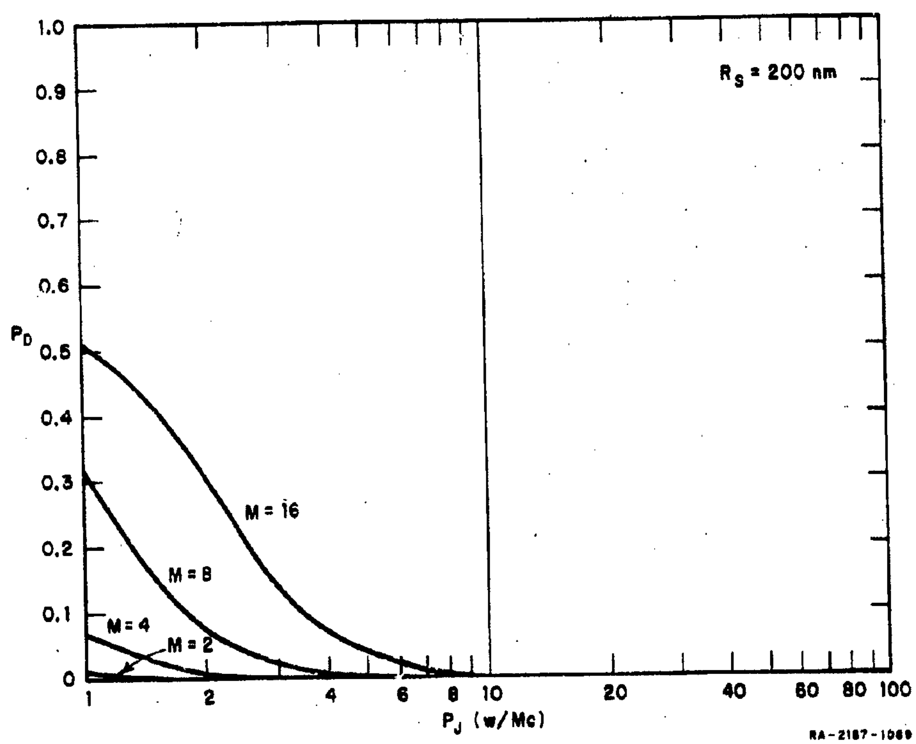


FIG. 5.51 SELF-SCREENING JAMMER $P_d$ CURVES: $R_T$ = 140 nm, $R_S$ = 200 nm, $\sigma$ = 100 $m^2$

100 $m^2$. It can be seen from the figure that even for the lowest jamming power density considered (1 w/Mc), the AN/APS-96 radar as presently configured (M=1) has no detection capability whatsoever. It is not until an eight-fold improvement in the radar performance is achieved that the single-scan detection probability rises to a high enough value (again at 1 w/Mc) to offer any hope of target acquisition. If the jamming power density is increased to 10 w/Mc, the detection capability of the radar is nonexistent, even for a sixteen-fold improvement in the radar characteristics.

The situation is considerably improved if the target beam cross section is much larger, for example 1000 $m^2$ as in Fig. 5.52.* The AN/APS-96 radar, as presently configured, now offers some hope of target acquisition for very-low jamming power densitites, i.e., less than 5 w/Mc. An improvement in the radar by a factor of two results in greatly increased detection capability; however, a jamming power density of 10 w/Mc is still adequate to counter such a radar.

Since the enemy can, with relative ease, deny target detection to the AEW stationed on a 200 nm radius circle, it could conceivably be to the advantage of the task force to place the AEW aircraft on a smaller station radius, forcing the attack aircraft to approach the AEW station positions more closely. The range from task force center at which detection would be accomplished would be correspondingly reduced; however, detection at a reduced range is presumably preferable to no early warning at all from the AEW aircraft. An alternate means of obtaining the goal of closer target to AEW approach would be to increase the number of AEW aircraft on station from the present four to perhaps eight. This is deemed to be impractical for an extended operation, due to the deck-space limitations of the aircraft carriers (see Part 5.4.2).

Figures 5.53 and 5.54 represent the AN/APS-96 detection capabilities when the AEW aircraft are stationed on a 100 nm radius circle,

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* Actual radar cross sectional area measurements at L band on a twin-engine medium bomber yield a median value of 1300 $m^2$ with cross-section scintillations varying from a few tenths of a square meter to 40,000 $m^2$ (Ref. 19).

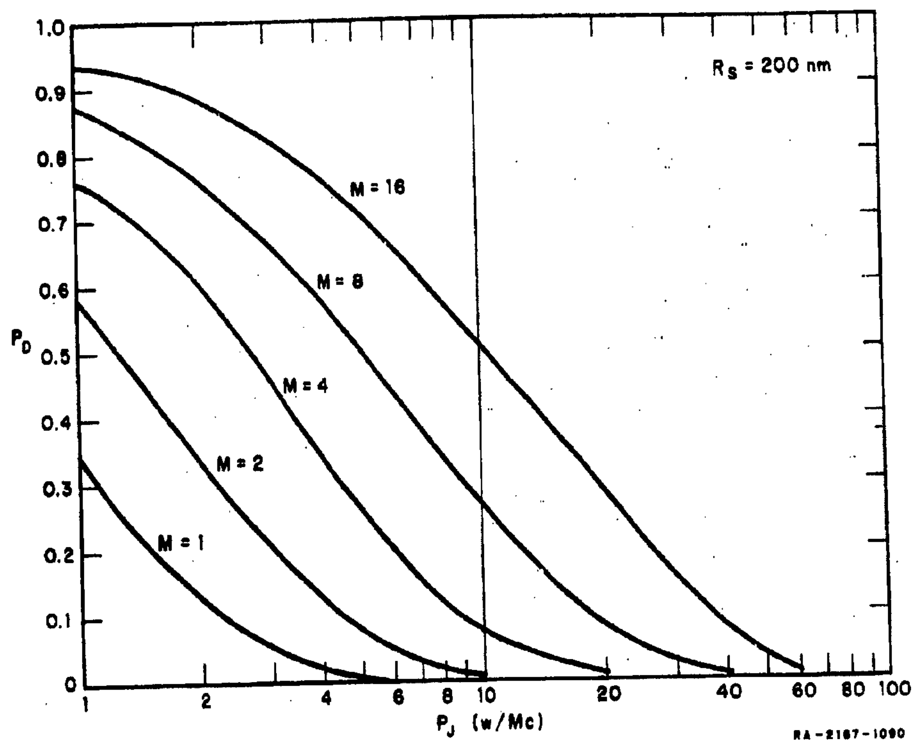


FIG. 5.52 SELF-SCREENING JAMMER $P_d$ CURVES: $R_T$ = 140 nm, $R_S$ = 200 nm, $\sigma$ = 1000 $m^2$

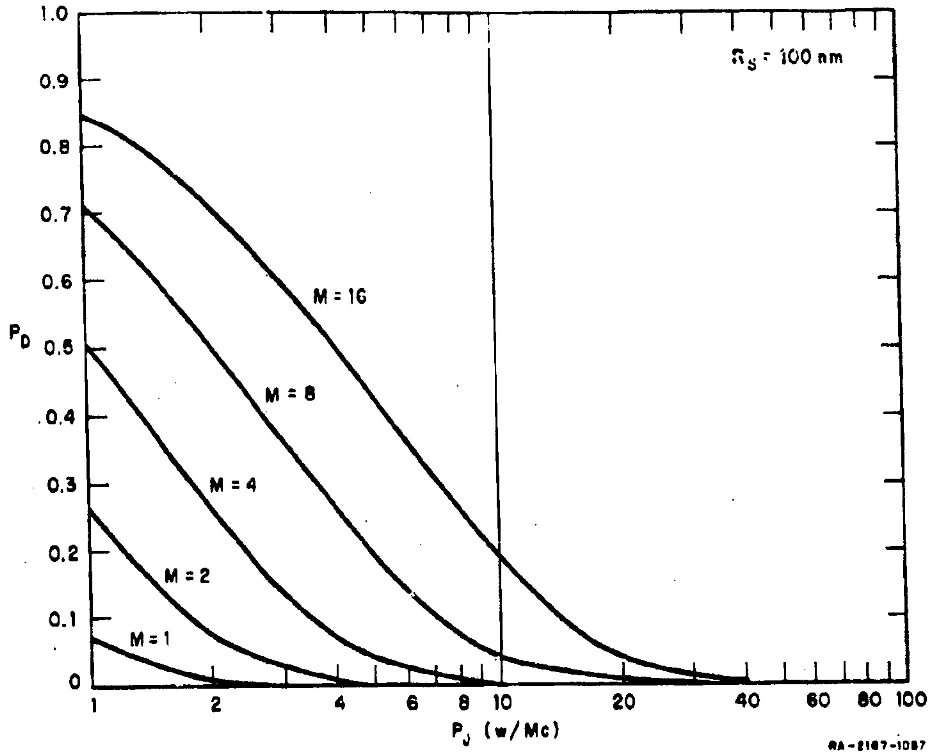


FIG. 5.53 SELF-SCREENING JAMMER $P_d$ CURVES: $R_T$ = 70 nm, $R_S$ = 100 nm, $\sigma$ = 100 $m^2$

corresponding to a target to AEW closest point of approach of 70 nm. For a target-beam cross section of 100 $m^2$ (Fig. 5.53) the presently configured AN/APS-96 radar detection capabilities are again totally inadequate, even for the lowest jamming power density considered. It is not until the radar performance factor, M, is increased four fold that even marginally acceptable single-scan detection probabilities result for the lower jamming power levels. The jamming power density required to counter such an improved rardar is, however, still moderate (less than 10 w/Mc).

Against a 1000 $m^2$ self-screening target at a range of 70 nm (Fig. 5.54), the present configuration of the AN/APS-96 radar shows good promise of detecting targets for jamming power densities of 10 w/Mc and less. Improvements in the radar performance under these favorable

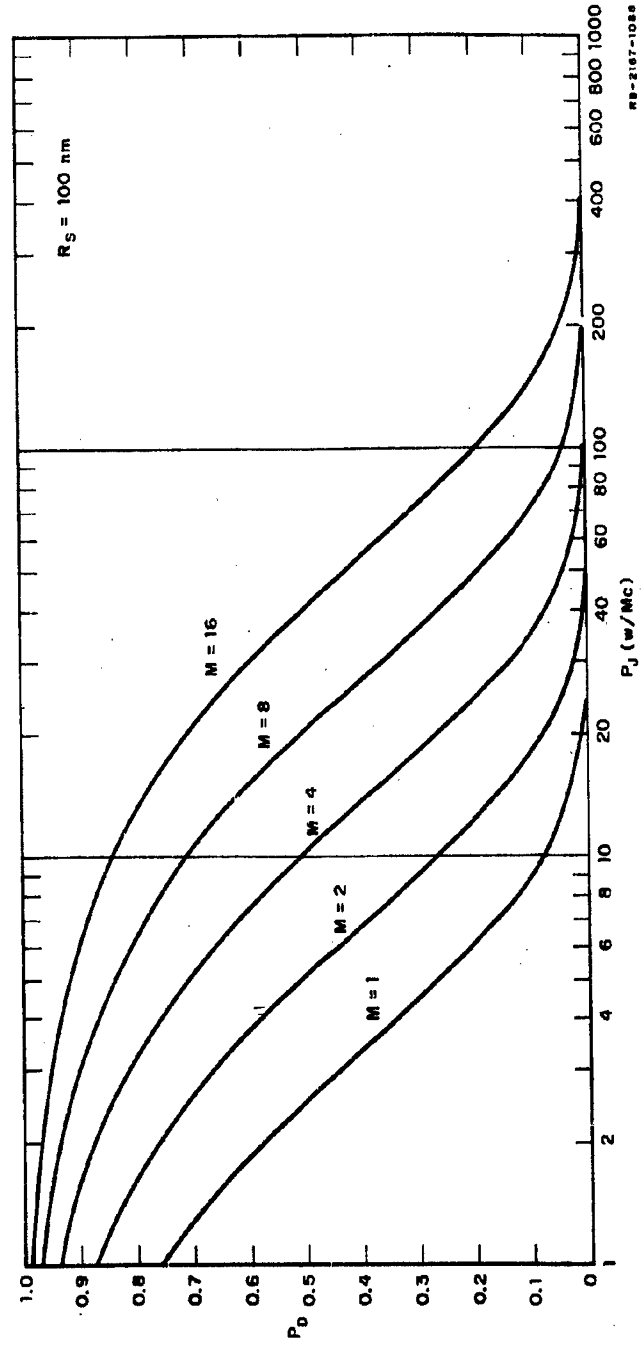


FIG. 5.54 SELF-SCREENING JAMMER $P_d$ CURVES: $R_T$ = 70 nm, $R_S$ = 100 nm, $\sigma$ = 1000 $m^2$

conditions are not required unless the enemy is able to employ self screening jammer power densities greater than 10w/Mc.

5.3.4 Summary and Findings

1. The analysis indicates the performance of the AN/APS-96 radar as being adequate, under the conditions studied, in a situation where there is no main beam jamming.

2. The performance of the AN/APS-96 radar is totally inadequate against self-screening jammers employing relatively low power densities of 5w/Mc and less. However, it is possible that under these circumstances, the AEW aircraft can obtain strobe bearing information on jamming aircraft to determine a passive position fix in the manner of SYNTRAC (Part 4.2.3, Appendix C). The attainment of this capability might be a consideration on the part of the enemy against using a self-screening jammer attack tactic unless the attack/jammer aircraft could be spread out over a wide enough front to introduce a large position error in the SYNTRAC method and/or present severe multiple intersection or ghosting problems.

3. The selection of an acquisition criterion can greatly improve or degrade the detection capabilities of the AN/APS-96 radar when the enemy employment of ECM is restricted to stand-off jamming. Unfortunately, the selection of an acquisition criterion is, of necessity, a compromise between ease of target acquisition and high false alarm rate. By considering relatively few radar scans for the acquisition decision process, the radar may be able to obtain occasional glimpses of its target while the jamming energy is entering the receiver through nulls in the antenna side lobe structure. However, at the same time, the occurrence of false target presentations in increasing correspondingly due to the fewer number of scans being considered for acquisition. When weighting this compromise, the various causes and effects of the time-variant characteristic of the antenna side lobe structure should be taken into account.

4. Detection capabilities of the AN/APS-96 radar against self-screening jammers can be greatly improved by increasing the lumped radar constant $C_1$ (see Part 5.3.3.2). While the manner in which such an increase

in radar performance could be implemented has not been analyzed in this study, it has been ascertained, for example, that a sixteen-fold increase in $C_1$ would be required to achieve a probability of detection of 0.5 against a jamming power density of 10w/Mc if the AEW aircraft is on a 200 nm station radius.

5. The detection capability of the AN/APS-96 radar against self-screening jammers can also be enhanced by forcing the enemy aircraft to approach the AEW station position more closely. This must be accomplished by reducing the interstation distance, either by a reduction in AEW station radius or by an increase in the number of AEW aircraft on station. In the former case, the range from task force center at which detection might occur would be correspondingly reduced.

## 5.4 Effectiveness of Future Fighter/AAM Systems

### 5.4.1 General

The simulation model went through two phases of development. The first of these was the clear model in which the role played by radars in the fleet, while included, was distinctly simplified. In particular, there was no provision made for the simulation of either ECM or less than perfect target resolution. Included in the clear model were simulations of the F-4B/SPARROW III and F-6D/EAGLE air-to-air systems. These systems were simulated with deterministic target detection ranges and a fixed unsophisticated employment doctrine. Although fairly unrealistic, this model provided the study group with both experience and a first approximation to the nature of the problems that would later be faced.

In fact, the various results derived from and shortcomings of the clear model led to the conception and development of the ECM model. As originally planned, this ECM simulation model was to treat all elements of the AAW complex, such as the surface-to-air missile systems and their associated shipborne search and fire control radars; the air-to-air missile systems consisting of fighter/interceptors, their missile armament and airborne intercept radars; the airborne early warning radar net organic to the task force and finally the data nets and fire coordination system (the command and control system) that directs and controls the activities of all AAW units during the air battle.

Programming of the air-to-air systems into the model proved to be a most difficult task mainly because of the following related factors:

1. The fighter/AAM systems, enjoying many degrees of freedom and the capability of high transit speeds, are generally assigned to intercept the enemy at relatively long ranges from the surface units being defended. This intercept process requires that enemy positions be at least roughly established prior to fighter assignment, so that the fighters know where to go. Surface ships, on the other hand, are the true focal points of enemy activity and, as such, have the advantage of the knowledge that enemy attack vehicles or weapons must close on the ships in order to accomplish the enemy objective of ship destruction or disablement. Of course, the ships must also be capable of locating enemy targets in order to intercept them but generally speaking, they are ultimately confronted with a "closing range" situation rather than with the nonconstrained situation, that, in a relative sense, prevails in the case of fighter/interceptors. Under conditions of enemy jamming, this factor alone affords SAM ships some advantage over fighters and their air-to-air missiles. Furthermore, since fighters fly out to meet their adversaries, they can be "spoofed" with relative ease by the enemy who can employ stand-off jammers or feinting attacks to draw the fighters out of position while pressing a determined attack against the fleet from some other quarter.

2. The air-to-air system intercept problem is more specifically compounded by the fact that airborne sensors must be both light and compact. It is current practice to fit airborne search radars on larger aircraft such as the E-2A with the intent of stationing such aircraft either over or at some distance from the surface force to provide the force with early warning of an impending attack. These aircraft are of relatively high endurance and can remain on station for several hours. The fighters that carry the air-to-air missiles, on the other hand, carry airborne intercept radars that are generally pencil-beam radars capable of rapid sector scans. As such, they possess limited search capability

and require that the fighter first be favorably positioned with respect to enemy targets by an air controller having access to search information from either shipborne or airborne search radars. Thus, unlike missile ships, the processes of initial detection on the one hand and target localization, fire control acquisition, and lock-on on the other hand, are split between two separate types of aircraft, which may be at widely differing locations at any point in time. Furthermore, present-day high-speed fighter endurance is relatively low.

Since equipment weight and size are characteristics that are so tightly controlled when the devices are to be installed in aircraft, airborne radar antenna size and radiated power are likely to be restricted. As a consequence, airborne radars of any type cannot be expected to perform as well as their shipborne counterparts. This is particularly true with respect to their ECCM capabilities when confronted by enemy jamming. Under these circumstances, it is relatively easy for the enemy to deny to the airborne search and intercept radars the range information required for vectoring and conversion. On the other hand, since fighters ultimately close with their targets prior to weapon launch, it is possible that at times the adverse jammer/radar power relationship can be overcome by a favorable fighter-to-target geometry.

3. The combination of factors briefly discussed in 1 and 2 above have made it extremely difficult to derive effective employment doctrines for fighters and their air-to-air missiles. The fact that these airborne weapons might play an important role in supplementing SAM capabilities under certain conditions has been recognized for some time. Without an extensive understanding of the many factors that affect air-to-air system effectiveness in an ECM environment as well as the complex interactions between AAM and SAM performance, it is virtually impossible to systematically tackle the problem of optimizing employment doctrine for the airborne weapon systems.

It was believed that the difficulty in achieving this prerequisite basic understanding could best be overcome by the development of an analytical tool that would make it possible to assess the effects of jamming as a stochastic process on all fleet radars, airborne or shipborne, as a function of time and geometry and would treat, in closed-loop fashion, the major SAM/AAM interactions during an air battle. The programming of the SAM systems was structured around the "nearest least engaged" fire doctrine associated with NTDS TEWA (Threat Evaluation and Weapon Assignment); however, it soon became apparent that no equivalent single doctrine could be effectively applied to the case of the air-to-air systems. The assignment options open to fighters under varying enemy attack conditions were numerous. This factor, when coupled with the degree of autonomy that must be allowed the fighter once it is assigned and the independence of the air-to-air missile once it is fired (because of limited guidance system resolution capabilities), made it impossible to program around any fixed form of assignment doctrine. Rather, it was decided that fighter assignment doctrine be programmed into the simulation model as a mtter of input option so that many different doctrines might be tested against some fixed mode of attack. This procedure would permit the systematic study of the consequences of choosing a specific assignment doctrine so that eventually it should be possible to establish a set of optima related to varying attack conditions. The criterion for optimization would be that of maximizing the AAW effectiveness of the whole task force (surface-to-air and air-to-air systems) rather than that of the airborne systems only.

A computer program simulating air-to-air systems embodying the features and structured on the ideas expressed in the preceding paragraphs has been completed and is operational.

Because of the considerable difficulties encountered both conceptually and technically in the construction of this air-to-air portion of the general simulation model, it has been impossible to complete the program of analysis described earlier in this section. It is felt that a useful analytical contribution to this problem has been developed but that its capabilities have yet to be fully realized.

Because of the small volume of work that has been completed on the general simulation model, it has been decided to include in this report a section on the work done with the clear model. While, as mentioned previously, the model makes certain simplifying assumptions, it is felt that the assumptions are not unreasonable in the situations to which that model has been applied.

5.4.2 Non-ECM Environment

5.4.2.1 Results

While the ECM model was being completed, a series of non-ECM runs were made using the clear model, which, as has been pointed out earlier, contained as subroutines in the weapon-assignment portion of the model simulations of two air-to-air systems, the F-4B/SPARROW III and the now defunct F-6D/EAGLE. Table 5.13 depicts the runs that were made

Table 5.13

CLEAR ENVIRONMENT RUN SUMMARY

| Defense Mix \ Threat | Low-Altitude Clear, HE[1] | Med-Altitude Clear, HE[2] |
|---|---|---|
| TYPHON Task Force | x | x |
| TYPHON Task Force + Cap LRMF | x | |
| TYPHON Task Force + Deck Launch LRMF | x | x |
| TYPHON Task Force + Cap F4B | x | x |
| TYPHON Task Force + Deck Launch F4B | x | |
| 3T Task Force | | |
| 3T Task Force + Cap F4B | x | x |
| 3T Task Force + Deck Launch F4B | x | x |

x denotes cases run. A blank indicates a case not examined

[1] 520 kt aircraft at 200 ft carrying four torpedoes launched at 10 nm from the ship under attack

[2] 1110 kt aircraft at 35,000 ft carrying two ASM's launched at 100 nm from the ship under attack

at that time. A complete analysis of the results obtained against the low-altitude threat can be found in "1970 - Era Task Force Anti-Air Warfare Effectiveness Against Low-Altitude Conventional Weapon Attacks (Non-ECM)".[7] A summary of these results is presented here along with the results of follow-on runs against a medium-altitude threat. The TYPHON and 3T task forces considered against the low- and medium-altitude threats are the same as those presented in Ref. 7 (shown in Figs. 5.55 and 5.56,*, respectively; Fig. 5.57 illustrates the disposition of the entire task force for both cases). The measure of effectiveness used in the analysis is Carrier Probability of Survival in which the raid size of a given threat is treated as a parameter. (See Part 4.1.2) The attack formations consisted of a single homogeneous wave (of varying size) of aircraft approaching the task force from a given direction. In the analysis, commitment doctrines allowing both CAP and deck-launched aircraft in the same run were not considered. Also only homogeneous compliments of interceptors were considered, i.e., no mixed deck loadings of F-4B and F-6D.

The problem of how many AEW stations and how many CAP stations a two-carrier task force can maintain was given considerable attention by the study group. The logistics model described in Part 5.3.1 was developed to analyze this problem. The numbers and placements of CAP and AEW aircraft used in imputs to the simulation model were derived from the results of this analysis. A summary of these results is contained in Tables 5.14 and 5.15. From Table 5.14, for example, it can be seen that with E-2A

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* The Task Force differs from the TYPHON Task Force discussed in Ref. 7 in these respects:

(1) The TYPHON cruiser is replaced by a CG-10 with two TALOS and two Improved TARTAR batteries.

(2) The two TYPHON frigates are replaced by two DLG-16's, each with two dual-rail Improved TERRIER batteries.

(3) Both carriers in the 3T Task Force are fitted with two dual-rail Improved TERRIER batteries (only one carrier is so fitted in the TYPHON Task Force).

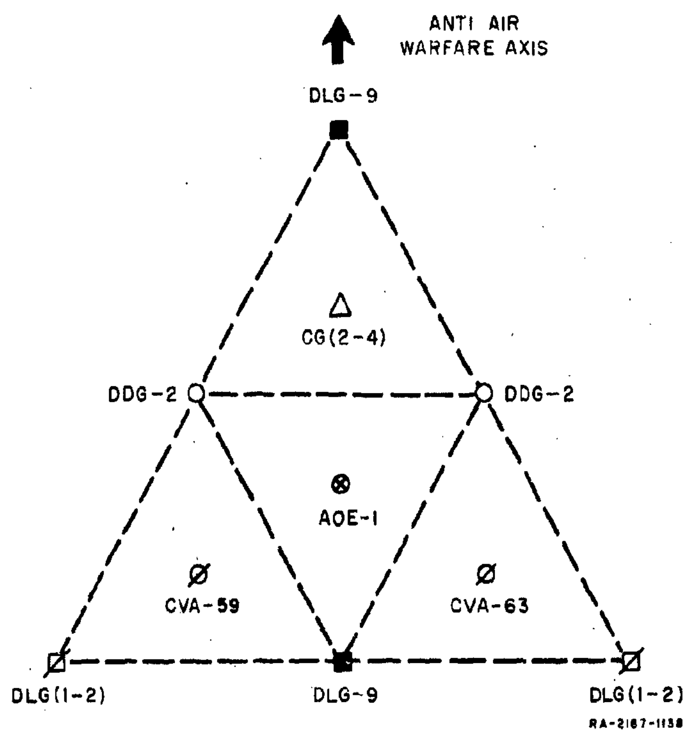



FIG. 5.55 TASK FORCE MAIN BODY FORMATION III

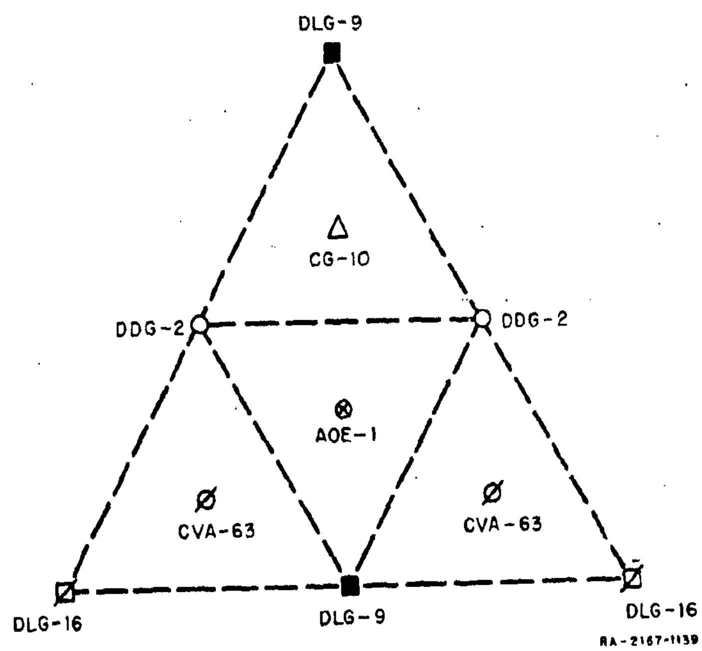



FIG. 5.56 TASK FORCE MAIN BODY FORMATION IV

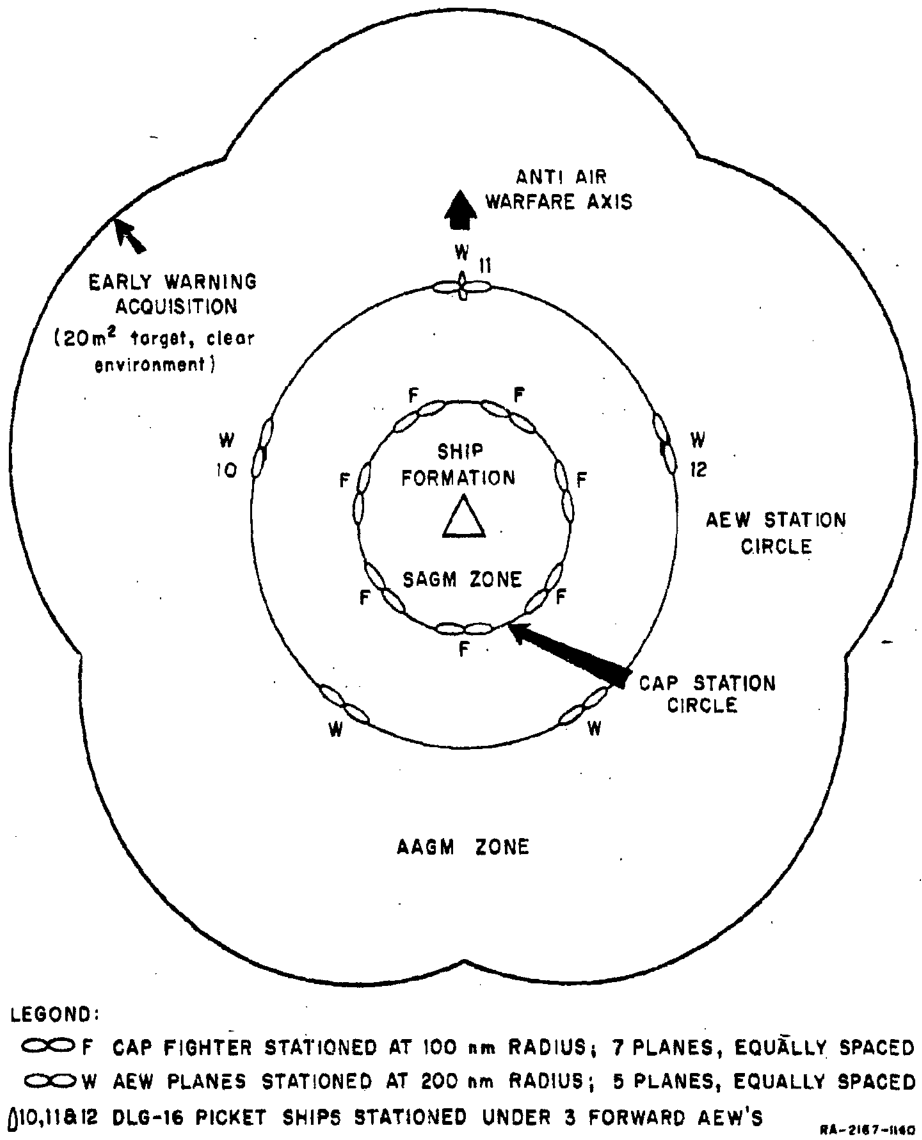



FIG. 5.57 TASK FORCE DISPOSITIONS — FORMATIONS III AND IV

Table 5.14

SUMMARY OF MAXIMUM NUMBER OF STATIONS POSSIBLE
FOR F-6D AND F-4H CAP AIRCRAFT

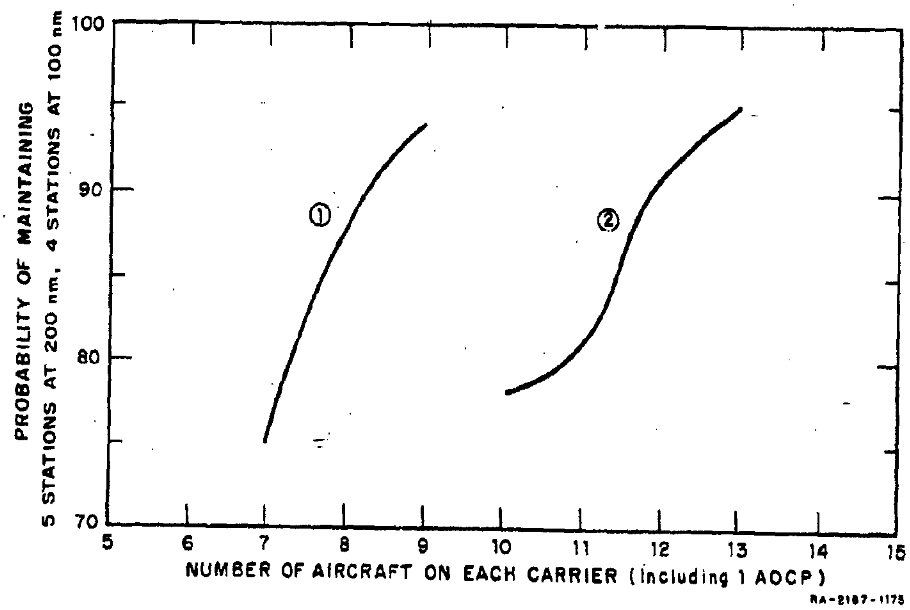
| Deployment (nm) | | Maximum Number of Stations | Number of A/C on Each Carrier* | Number of Maintenance Spots | Launch Frequency (hours) | Number A/C Per Launch Per CVA | Probability |
|---|---|---|---|---|---|---|---|
| Interceptor | E-2A | | | | | | |
| F-6D: | | | | | | | |
| 170 | 200 | 8 | 13 + 1 = 14 | 6 | 4.0 | 4 | 0.8961 |
| 135 | 200 | 8 | 13 + 1 = 14 | 6 | 4.2 | 4 | 0.9139 |
| 100 | 200 | 8 | 13 + 1 = 14 | 6 | 4.4 | 4 | 0.9361 |
| 70 | 200 | 8 | 13 + 1 = 14 | 6 | 4.57 | 4 | 0.9500 |
| F.C. | 200 | 8 | 13 + 1 = 14 | 6 | 4.68 | 4 | 0.9557 |
| 100 | 100 | 10 | 16 + 2 = 18 | 7 | 4.4 | 5 | 0.9364 |
| 70 | 100 | 10 | 16 + 2 = 18 | 7 | 4.57 | 5 | 0.9520 |
| F.C. | 100 | 10 | 16 + 2 = 18 | 7 | 4.68 | 5 | 0.9578 |
| F-4H (with 600 gals. e.t. fuel) | | | | | | | |
| 200 | 200 | 4 | 16 + 2 = 18 | 7 | 1.43 | 2 | 0.9944 |
| 170 | 200 | 5 | 16 + 2 = 18 | 7 | 1.50 | 2/3 | 0.9025 |
| 135 | 200 | 6 | 16 + 2 = 18 | 7 | 1.66 | 3 | 0.9137 |
| 100 | 200 | 6 | 16 + 2 = 18 | 7 | 1.82 | 3 | 0.9432 |
| 70 | 200 | 6 | 16 + 2 = 18 | 7 | 1.91 | 3 | 0.9626 |
| F.C. | 200 | 6 | 16 + 2 = 18 | 7 | 2.11 | 3 | 0.9835 |
| 100 | 100 | 8 | 20 + 2 = 22 | 9 | 1.82 | 4 | 0.9326 |
| 70 | 100 | 8 | 20 + 2 = 22 | 9 | 1.91 | 4 | 0.9569 |
| F.C. | 100 | 8 | 20 + 2 = 22 | 9 | 2.11 | 4 | 0.9827 |
| F-4H (with 1340 gals. ext. fuel) | | | | | | | |
| 200 | 200 | 6 | 16 + 2 = 18 | 7 | 1.95 | 3 | 0.9604 |
| 170 | 200 | 6 | 16 + 2 = 18 | 7 | 2.07 | 3 | 0.9839 |
| 135 | 200 | 6 | 16 + 2 = 18 | 7 | 2.21 | 3 | 0.9898 |
| 100 | 200 | 7 | 16 + 2 = 18 | 7 | 2.35 | 3/4 | 0.9289 |
| 70 | 200 | 8 | 16 + 2 = 18 | 7 | 2.47 | 4 | 0.8957 |
| F.C. | 200 | 8 | 16 + 2 = 18 | 7 | 2.65 | 4 | 0.9349 |
| 100 | 100 | 10 | 20 + 2 = 22 | 9 | 2.35 | 5 | 0.9038 |
| 70 | 100 | 10 | 20 + 2 = 22 | 9 | 2.47 | 5 | 0.9314 |
| F.C. | 100 | 10 | 20 + 2 = 22 | 9 | 2.65 | 5 | 0.9590 |

* Totals include both available and AOCP aircraft, e.g., 13 + 1 means 13 available A/C plus 1 AOCP.

Table 5.15

PROBABILITY OF MAINTAINING REQUIRED NUMBER OF E-2A STATIONS
(Varying number of aircraft on each of two CVA's)

| Desired Number of Stations | No. of A/C on Each Carrier (including AOCP) | No. of Maintenance Spots | Launch Frequency (hours) | No. of A/C Per Launch | Probability | Deployment |
|---|---|---|---|---|---|---|
| 4 | 6 + 1 = 7 (1) | 3 | 4.7 | 2 | 0.7465 (1) | 100 |
| 4 | 7 + 1 = 8 (1) | 3 | 4.7 | 2 | 0.8759 (1) | 100 |
| 4 | 8 + 1 = 9 (1) | 3 | 4.7 | 2 | 0.9409 (1) | 100 |
| 5 | 9 + 1 = 10 (2) | 4 | 4.0 | 2.5 | 0.7785 (2) | 200 |
| 5 | 10 + 1 = 11 (2) | 4 | 4.0 | 2.5 | 0.8104 (2) | 200 |
| 5 | 11 + 1 = 12 (2) | 4 | 4.0 | 2.5 | 0.9115 (2) | 200 |
| 5 | 12 + 1 = 13 (2) | 4 | 4.0 | 2.5 | 0.9478 (2) | 200 |



stationed at 200 nm, eight F-6D's can be maintained on station at any station radius from 0 to 170 nm. The total number of F-6D per CVA is 14. At the beginning of each CAP cycle each carrier launches four of its complement of F-6D aircraft. The frequency of launches required decreases as station radius decreases due to the longer time on station at shorter range from the CVA.

In the TYPHON task force analysis, four AEW aircraft were stationed symmetrically on a 200 nm circle about task force center. The interceptor compliment in this case consisted of 36 F-4B's, or 28 F-6D aircraft. Of these aircraft, 30 F-4B's or 24 F-6D's are available for deck-launch operation. In CAP operation seven F-4B's may be maintained on 100 nm stations, or eight F-6D's may be maintained on CAP at any station radius less than 200 nm from task force center.

For the 3T task force analysis, three AEW aircraft were stationed on a 100 nm radius about task force center. In this case, the F-4B complement was increased to 44 aircraft, of which 38 are available for deck-launch operation. In CAP operation, ten stations were maintained at 70 nm from task force center. The F-6D was not considered with the 3T task force. (For a complete analysis of the derivation of the above values, see Ref. 16.)

While operating on CAP, the F-4B aircraft were required to complete any engagements outside of the surface-to-air missile zone (SAGM zone) and were not permitted to fly inside the SAGM zone once enemy aircraft had entered and were being taken under engagement by the SAM's. This same restriction also applied to F-4B deck-launch operations. On the other hand, the F-6D aircraft were permitted to operate within the SAGM zone. This distinction was imposed because of the different aircraft characteristics, i.e., the F-4B operating at high speed and with a short-range missile having to close intimately with the raid, a condition obviated by the long-range AAM aboard the slow-flying F-6D.

In deck-launch operation, after initial detection of an incoming raid by any task force search radar, a 90-sec delay was allowed for threat evaluation. Two minutes after this, the first aircraft was launched. This second delay time is to allow for engines to be started, the carrier to be turned into the wind, if necessary, and target assignments to be made. It was further assumed that there are two catapults per aircraft carrier available for launching interceptors, and that each catapult is able to launch one aircraft per minute.

It is important here to stress again that primary interest should focus on the relative comparisons of the results presented. Too much reliance should not be placed on absolute values because the assumptions one makes for the purposes of analysis will not necessarily pertain in a real-life situation.

Figure 5.58 shows the relative effectiveness of three different AAW mixes versus the medium-altitude threat. The mixes are the TYPHON task force unaugmented by any AAM systems, the same task force with CAP F-4B available, and also with deck-launched F-6D available. As can be seen from Fig. 5.58, the unaugmented TYPHON force has a 90 percent probability of survival of at least one CVA against a 94-plane raid approaching directly along the AAW axis. CAP F-4B's increase the raid size that can be tolerated with a 0.90 probability of survival by only two aircraft, i.e., to a raid size of 96, an insignificant amount. The reason that the size CAP F-4B contributes so few kills on the average is mainly because of their being excluded from the SAGM zone. Because of this, and the fact that the CAP were placed symmetrically to afford 360-degree coverage, only the three CAP stations nearest the raid approach path have sufficient time and fuel available to make an intercept, and in general, can make only one engagement each. (It should be noted that the TYPHON task force used in this phase of the analysis employed Long-Range TYPHON, and, hence, the SAGM zone is roughly 400 nm in diameter against a medium-altitude threat.) Because of this same restriction, it was not possible for deck-launched F-4B to make any intercepts against this threat. That is, allowing for the aforementioned 3.5-min delay after initial raid detection by the AEW aircraft, deck-launched aircraft did not have sufficient time to intercept the raid prior to its penetrating the zone of fire of the SAM's.

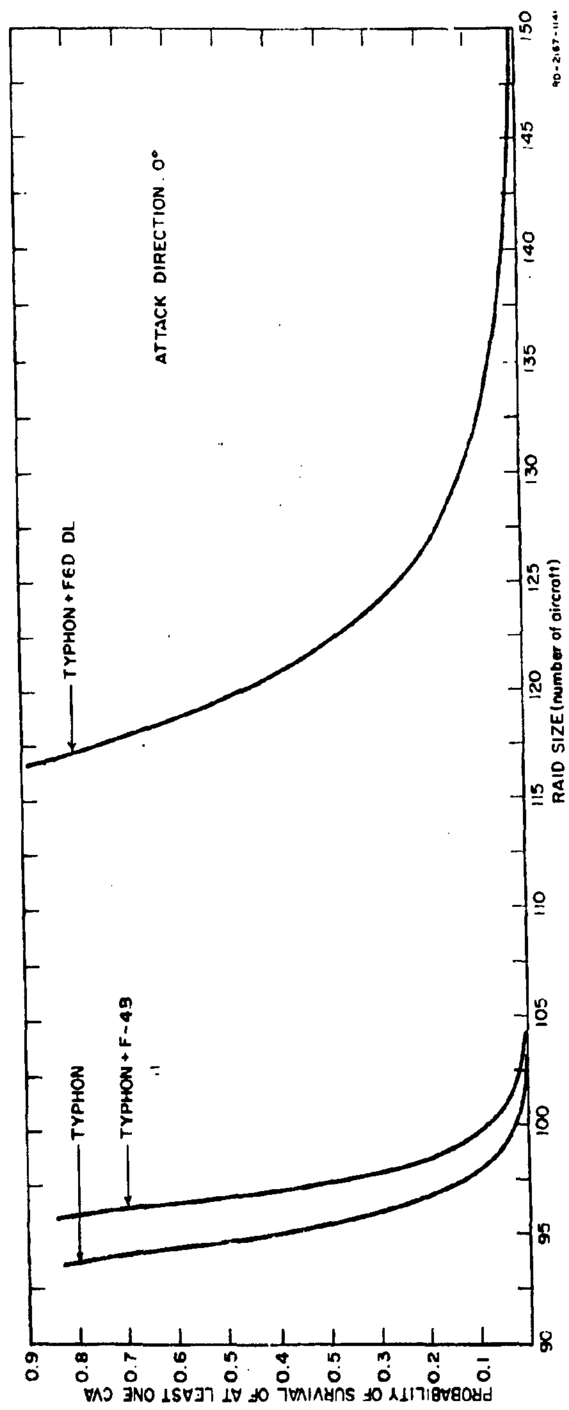



FIG. 5.58 RELATIVE EFFECTIVENESS OF THREE TYPHON AAW MIXES (*Medium-altitude* ASM *attacks*)

An indication of the SAGM zone restriction upon F-4B effectiveness can be seen in Fig. 5.59 which presents the probability of survival curves for the same threat against a 3T task force both SAM's alone and SAM's augmented by CAP and deck-launched F-4B. The longest-range SAM in this force is 100 nm TALOS; thus, in this case, the fighter-exclusion zone is correspondingly decreased from the previous case. Also the CAP radius decreases, permitting more aircraft to be maintained on station. The consequences of this are brought out in Fig. 5.59. Again the raid approaches along the AAW axis. The 3T force alone has a 90 percent probability of survival against a raid size of 22. With F-4B aircraft on CAP, the number of aircraft that can be tolerated is approximately 31. This is caused by the greater number of CAP aircraft that can be brought to bear on the raid and the fact that several of those CAP near the raid path can make second engagements. In this case, deck-launch operation of F-4B is also possible. Although the AEW stations are closer to the task force, the warning they afford is still sufficient to allow approximately ten aircraft to be launched and make intercepts outside of the SAGM zone. However, there is not sufficient time to allow re-engagements. This accounts for the fact that with deck-launched F-4B, the combined SAM and AAM for ce has a 0.9 probability of survival against a 29-plane raid, or a somewhat smaller raid size than in the CAP case.

One further case was examined, namely, the TYPHON task force augmented by deck-launched F-6D aircraft. F-6D used on CAP were not examined. As can be seen from Fig. 5.58, the F-6D in this case increased the raid size that can be tolerated with a 0.9 probability of survival from 94 to 117. It should be remembered that the F-6D were permitted within the SAGM zone. Even so, there was not sufficient time available to launch and bring to bear all the available F-6D aircraft.

The probability of survival curves for several different weapon systems mixes versus the low-altitude threat are presented in Fig. 5.60. The two task forces and numbers of available interceptor aircraft are the same as treated against the medium-altitude threat.

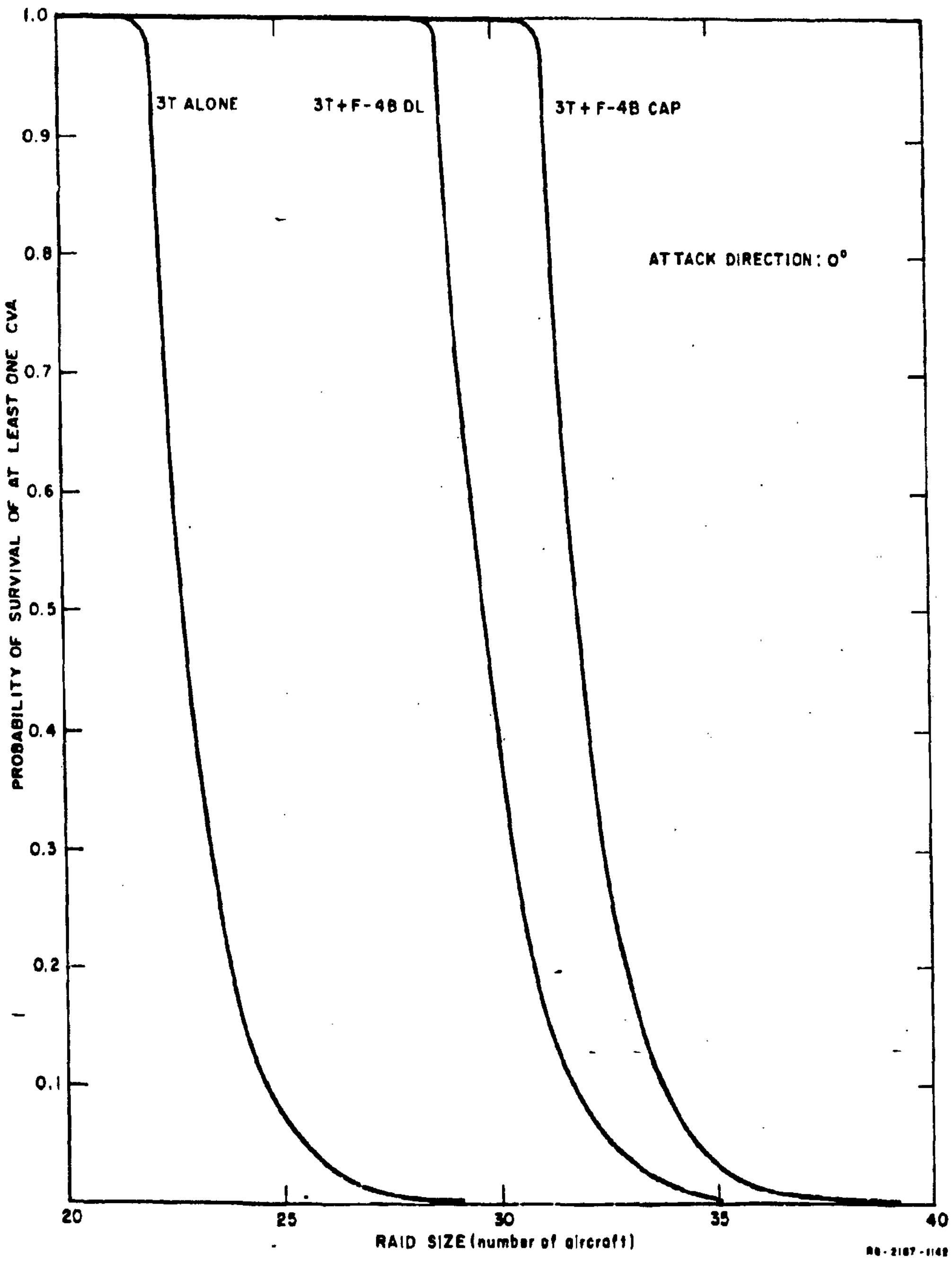



FIG. 5.59 RELATIVE EFFECTIVENESS OF THREE 3T AAW MIXES
(Medium-altitude ASM attacks)

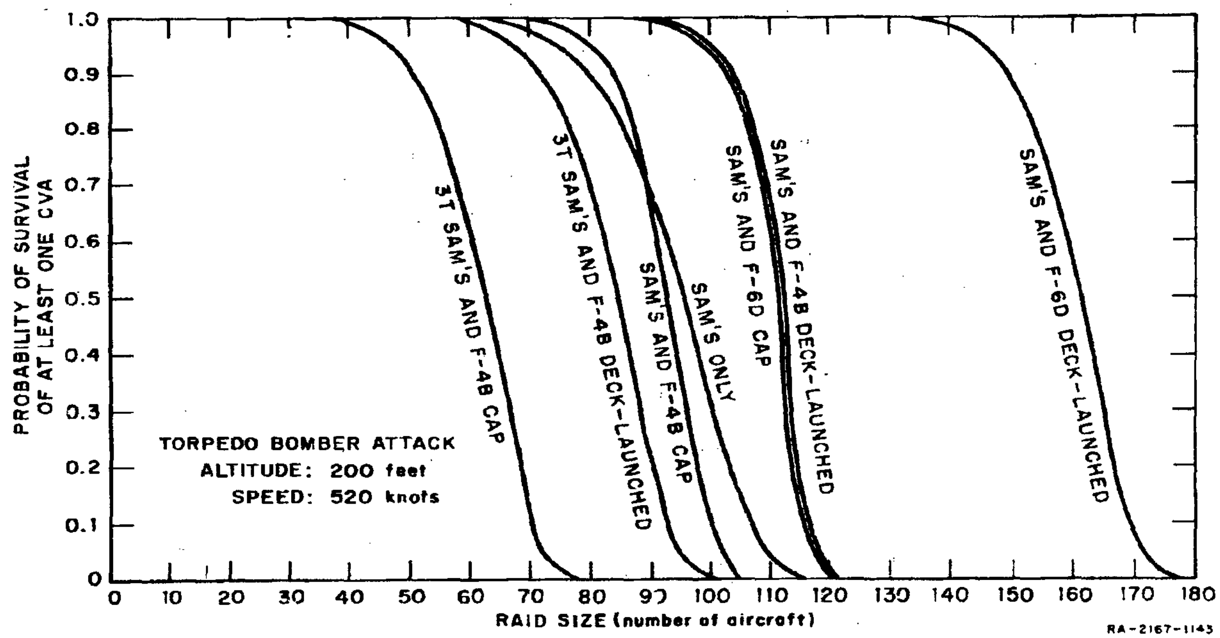



FIG. 5.60 RELATIVE EFFECTIVENESS OF SEVEN 3T AND TYPHON AAW MIXES (Low-altitude torpedo bomber attacks)

Against a target with a 200-ft altitude, a ship's radar horizon is approximately 26 nm. Consequently, in this case, the SAGM zone shrinks to a circle of roughly 40-nm radius about task-force center. Warning times are such that exclusion from the SAGM zone is not a constraint in this case, i.e., against the low-altitude threat considered, all available interceptors can be brought to bear prior to the raid entering the SAM zone of the main body of the task force.

As can be seen from Fig. 5.60, the TYPHON task force alone has a probability of survival of 0.9 against a raid size of 80 approaching along the AAW axis. The CAP F-4B contributes about three kills on the average, again, a statistically insignificant amount. The F-4B in deck-launch operations does better, raising the raid size that can be tolerated with a 0.9 probability to 103 aircraft. One point should be mentioned. As pointed out above, against this particular threat all available F-4B can be brought to bear against the raid. However, due to sea-clutter problems in its AI radar (AN/APQ-72), the F-4B in the simulation was restricted to either co-altitude attack considered in these runs, pilot rather than airframe limitations were assumed to be dominant. Thus, at low altitude, target and F-4B speed were taken to be the same. Without a speed advantage, each F-4B could make only one attack.

The F-4B contribution to a 3T task force versus this threat was also examined. The 3T task force alone was not run. However an analysis of the runs using the F-4B show that the 3T's contributed on the order of 35 to 40 kills against this threat. The CAP F-4B contributed on the order of six kills, and in the deck-launch mode the F-4B contributes approximately 25 kills. (The higher number of kills in the 3T case is due to the fact more F-4B are available than in the TYPHON case because of the smaller number of AEW required.)

The relative contribution of F-4B aircraft in this case is sizable. In the deck-launch mode, the F-4B contribution is better than half as large as the SAM's ships contribution and even in CAP mode is about one-sixth of the SAM's. This capacity represents the F-4B operating against the type of raid for which it is best suited and in which the limitations of SAM systems affords the best opportunity for contribution by fighters.

The 3T force augmented by interceptors still does not reach the level of the TYPHON force unaugmented by any fighter aircraft. In the former case, using deck-launched F-4B, the force can tolerate a raid of 72 aircraft with a 90 percent probability of survival. The TYPHON force alone can tolerate a raid of 79 aircraft with the same survival probability.

The TYPHON task force augmented by F-6D CAP and deck-launch aircraft was also considered against the low-altitude threat. The eight F-6D operating on CAP contribute about 22 kills, raising the raid size that can be tolerated with a 0.9 probability from 80 in the TYPHON-alone case up to 103. An indication of the advantages of the multiengagement capability of the F-6D is that the lesser number of CAP F-6D have the same effectiveness as the deck-launched F-4B. In deck-launch operations, the F-6D raise the raid size that can be tolerated with a 0.9 probability from 80 to 149. In this case, the number of kills by SAM's and AAM's is approximately the same.

5.4.2.2 Summary of Findings

The results described in Part 5.4.2.1 and in Ref. 7 seem to indicate:

1. Air-to-air systems, both the long-range systems of the EAGLE variety and the shorter-range SPARROW, contribute most to task force defense against low-altitudes attacks where horizon and system limitations reduce SAM firepower. In this case, deck-launch operation of aircraft is superior to CAP operation.

2. The air-to-air systems contribute relatively less against higher-altitude threats primarily because of greater target speeds at altitude and, in the case of the F-4B, because of an increase in size of the figher exclusion (or SAGM) zone with altitude.*

* The study assumed operation of the F-4B at 35,000 ft against the medium-altitude threat.

Both CAP and deck-launched operations were found to yield essentially the same results against the medium-altitude threat. The SAM systems, however, are tending to achieve the fall measure of their firepower capability at these higher altitudes.

3. Against the particular medium-altitude threat considered in Part 5.4.2, and in a TYPHON task force with a large fighter exclusion zone, the F-4B contributes a negligible amount toward task-force AAW. It should be remembered that the clear environment model had associated with it certain inherent assumptions whose effects can seriously alter these conclusions. First, all radars operated in an undegraded manner, allowing maximum warning time to fighter aircraft, and also permitting the SAM's to achieve a maximum number of kills. Furthermore, the problem of radar resolution was not considered, that is, perfect resolution was assumed. A consequence of this assumption was that perfect target/missile pairings (both AAM and SAM) were made, eliminating the problem of aborts and/or overkills, which has subsequently turned up in the more sophisticated ECM model, and which, in fact, can be expected to occur in actual battle. Another effect of this assumption was, in effect, to allow the task force a perfect count of the raid, permitting optimum allocation of aircraft. That is, a task force commander, not having an accurate raid count and wishing to protect his force against enemy feinting and spoofing tactics, might not wish to commit all of his available aircraft immediately, as has been done in the foregoing analysis.

Another point to bear in mind is that, in the clear environment, all aircraft pose essentially the same threat to the task force. Interceptors are essentially weapon-limited as to number of missiles. Further restrictions--such as exclusion zones or limited warning time--limit the number of aircraft that can be brought to bear on a given raid. For this reason, air-to-air systems in general will do less than SAM systems on a pure kill-for-kill basis. In an ECM environment, however, a small number of enemy jammers may seriously degrade the performance of the SAM's, and the interceptors, by eliminating these jammers, might greatly increase

SAM kill capability. In other words, in a more realistic ECM environment, a large number of interceptor kills is not necessarily of importance, but rather the particular type of aircraft killed.

5.4.3 ECM Environment

5.4.3.1 Results

The work that has been done on the complete ECM task force model is presented below. The results are incomplete and are not presented as formal conclusions, however, they do point to some provocative possibilities. The major possibilities are:

(1) The F-4B used with an effective employment-deployment doctrine and restricted by only a small or moderate SAGM zone may add a surprisingly great contribution to AAW.

(2) The employment-deployment doctrine used is of critical importance to the ultimate success of the fighter in the role of an interceptor.

In the following analysis a one-carrier striking force consisting of four missile ships (including the CVA) has been postulated and against this force the enemy has been assumed to launch a 21- plane attack. Two of the aircraft are standoff jammers (BEAR Strike Command Aircraft) and one aircraft accompanies a high-altitude (50,000 ft) four-plane attack element (all BLINDER's) against the force as a screening jammer. The remaining fourteen BLINDER aircraft attack the task force (selecting the cruiser and carrier as prime targets) from low altitude (200 ft) being guided on their run-in by the BEAR Strike Command Aircraft. All nonjamming aircraft (18 in number) carry air-to-surface missiles with maximum ranges of 100 nm. The attack and the defense are more fully described below. Following this description is a discussion of the results.

5.4.3.2 Attack Description

The enemy raid considered in these runs consists of three groups of aircraft with their associated armament and ECM gear. These aircraft are all assumed to be approaching the task force along its air defense axis. The composition of the raid is:

Two BEAR's--These are flying abreast and spaced at 2 nm. They serve as stand-off jammers and each carry equipment to barrage-jam on the following bands.

| Band | Power Density (w/Mc) |
|---|---|
| P | 5 |
| L | 5 |
| S | 15 |
| C | 40 |
| X | 2 |

They fly in at 435 knots at 50,000 ft until they arrive within 200 nm of the task force. Upon reaching this point they orbit, serving as information bathers, while attempting to screen the remaining attack[8] elements.

Five BLINDER I's-- Four of these carry one AS-4I apiece. They fly abreast spaced at 65 yards. Trailing behind them at 3 nm is the fifth BLINDER carrying ECM gear to barrage-jam the following bands.

| Band | Power Density (w/Mc) |
|---|---|
| P | 5 |
| S | 15 |
| C | 40 |
| X | 2 |

These aircraft approach at 680 knots passing the 200 nm mark six minutes after the BEAR's have arrived at that position. When they approach to within 110 nm of the task force, they launch their ASM and begin their return flight. Each ASM dives to 200 ft and continues to its target at that altitude with a speed of 925 knots. Upon reaching its target each ASM makes its terminal dive and impacts.

Fourteen BLINDER I's--These fly abreast at a 65-yard spacing. They fly with a speed of 475 knots at 200 ft, and are phased to pass the 200-nm point with its orbiting BEARs, four minutes after the five high flying BLINDER's have passed that point. at 80 nm from the task force each of these BLINDER's climbs to 3000 ft momentarily to locate a target and launch the single AS-2 it carries as armament. The AS-2's proceed in maintaining a 200 ft altitude until their terminal dive is executed upon reaching their respective targets.

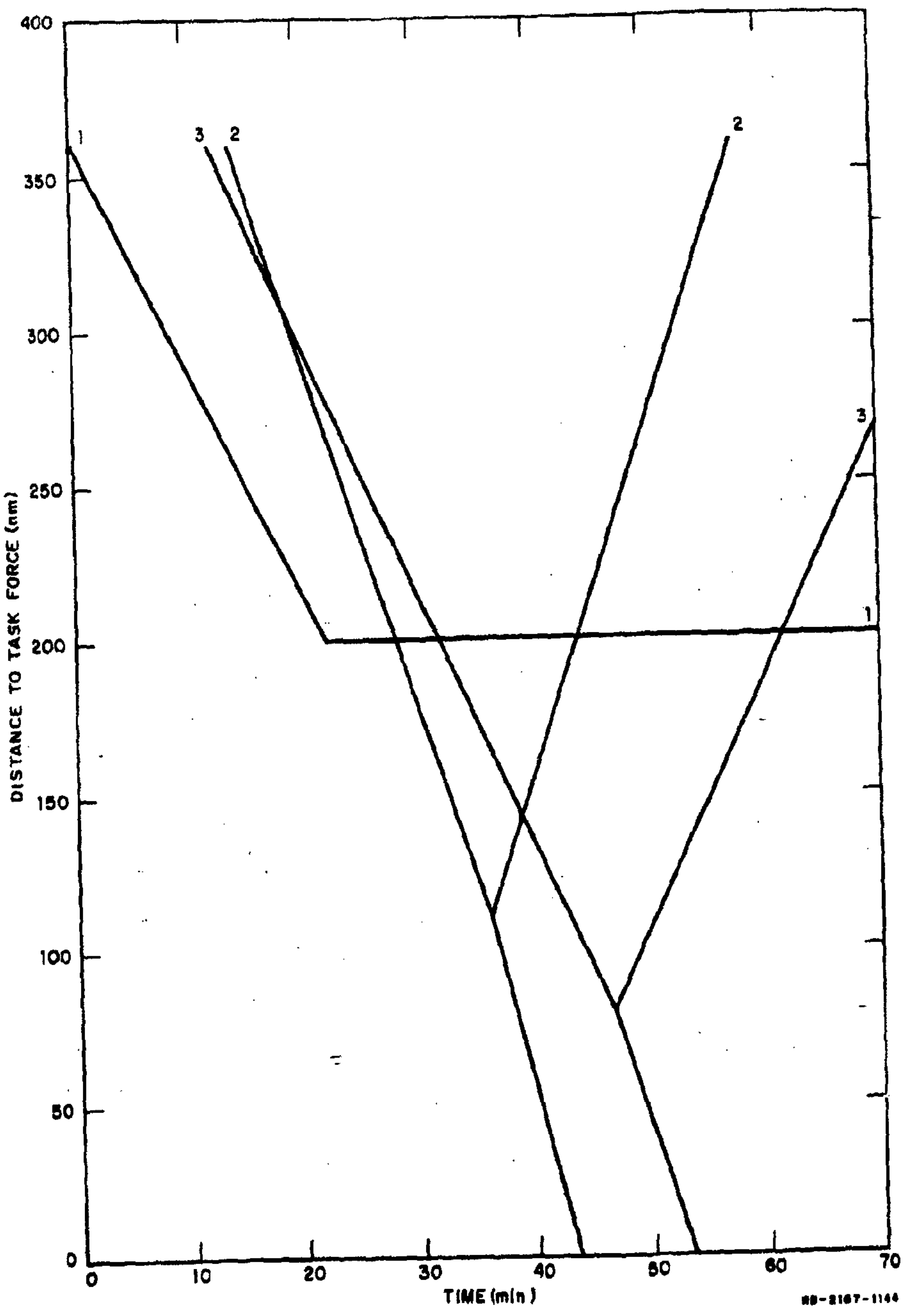



FIG. 5.61 ATTACK RAID-TIME PLOT

Figure 5.61 illustrates the time schedule that the raid follows. The abcissa is time in minutes, while the ordinate is in nm from the task force. It should be noted here that the phasing of the sections of this raid result in the SAM component of the task force being presented with two distinct threats. In fact the time between the impact of the AS-4I of the high-altitude BLINDER's and the launch of the AS-2 of the low-altitude BLINDER's is three minutes with an additional four minutes of elapsed time before the AS-2's come over the radar horizon of the surface ships of the task force.

Parameter values used as inputs to the model for the attack described above are shown in Table 5.16.

5.4.3.3 <u>Task Force</u>

The Task Force postulated for this exercise is composed of the following:

(1) One CVA-63

(2) One CLG-3

(3) Two DDG-2

These ships constitute an Air Strike Module (as described in Ref 9); their deployment is illustrated in Fig. 5.62

The screening is provided by four destroyers, with capabilities for ASW, surface warfare, and deception. For this simulation, the anti-air warfare capability of the screening ships is considered insignificant and they do not appear in Fig. 5.62.

The Task Force AAW armament is best defined in two parts as the airborne detection-intercept complement and the SAM complement.

The airborne complement consists of one squadron of E-2A aircraft for AEW service, and two squadrons of F-4B interceptors. This complement is sufficient to maintain two E-2A aircraft on 100 nm AEA station, three F-4B interceptors on 100 nm CAP as illustrated in Fig. 5.63, and, in addition, maintain twelve F-4B's ready for deck launch. The armament consists of four SPARROW III missiles aboard each of the F-4B interceptors.

Table 5.16

ATTACK PARAMETERS

| | Attack Aircraft |
|---|---|
| **BEAR** | |
| Speed: | 435 kts |
| Altitude | 50,000 ft |
| Nose-on radar cross section (L-Band): | $20m^2$ |
| **BLINDER** | |
| Speed: | 680 kts; 475 kts |
| Altitude | 50,000 ft; 200 ft |
| Nose-on radar cross section (L-Band): | $15m^2$ |
| Armament: | One AS-4I or one AS-2 |

| | Attack Weapons |
|---|---|
| **AS-2** | |
| Speed: | 725 kts |
| Altitude | 200 ft |
| Max Release Range: | 125 nm |
| Nose-on radar cross section (L-Band): | $1/2m^2$ |
| Warhead Weight: | 2000 lb |
| $P_k$ (anti-ship) | 0.25 |
| **AS-4I** | |
| Speed: | 925 kts |
| Altitude: | 200 ft |
| Max Release Range: | 150 nm |
| Nose-on radar cross section (L-Band): | $1/2m^2$ |
| Warhead Weight: | 2000 lb |
| $P_k$ (anti-ship): | 0.25 |

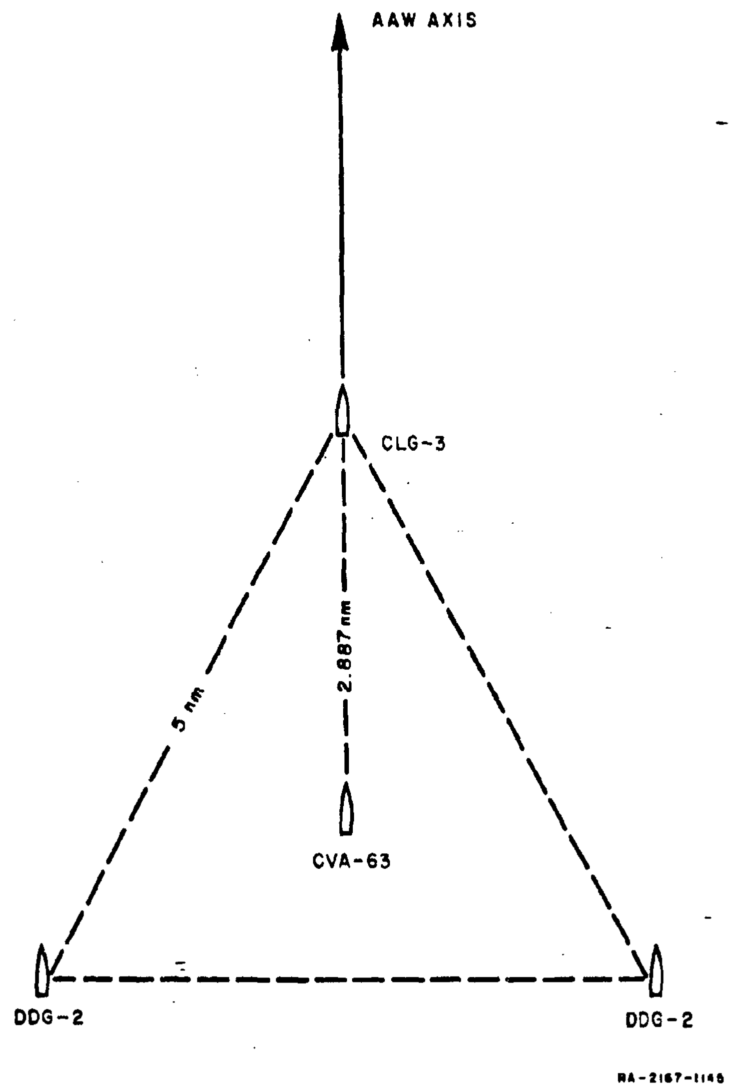



FIG. 5.62 TASK FORCE FORMATION V

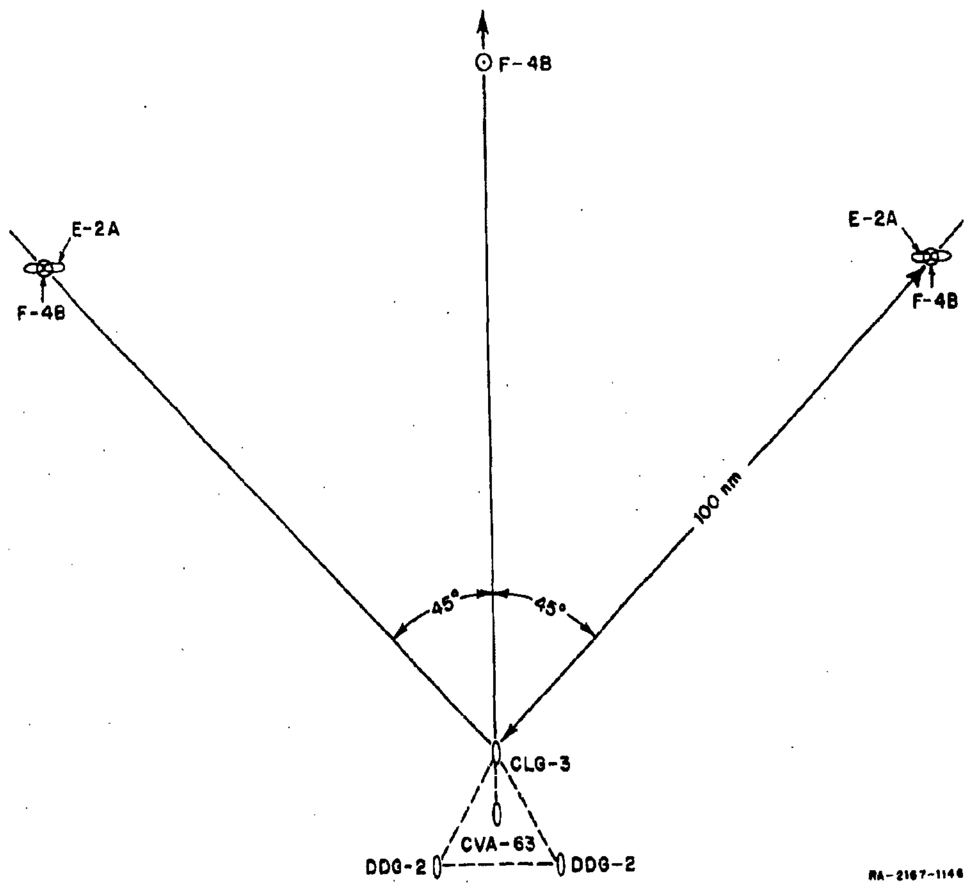



FIG. 5.63 TASK FORCE DISPOSITION — FORMATION V

The SAM complement consists of two TERRIER dual-rail launchers aboard the CVA, one TALOS dual-rail launcher aboard the CLG-3, and one TARTAR single-rail launcher aboard each of the DDG's.

The radar systems simulated are shown below.

| SHIP | RADAR | FUNCTION |
|---|---|---|
| CVA | AN/SPS-17 | Search |
| CVA | AN/SPG-55A | TERRIER Guidance |
| CLG-3 | AN/SPS-37 (large) | Search |
| CLG-3 | AN/SPG-56 | TALOS Guidance |
| DDG | AN/SPS-37 (small) | Search |
| DDG | AN/SPG-51 | TARTAR Guidance |
| **AIRCRAFT** | **RADAR** | **FUNCTION** |
| E-2A | AN/APS-96 | Search |
| F-4B | AN/APQ-72 | Search - Tack |
| F-4B | AN/APA-157 | SPARROW III Guidance |

Parameter values for the AAW systems are shown in Table 5.17.

Table 5.17

AAW SYSTEM PARAMETER

| Air-to-Air Systems | |
|---|---|
| SPARROW III | |
| Max Range | 9.4 nm |
| Min Range: | 1.6 nm |
| Salvo Size: | 2 |
| $P_k$ (single shot): | 0.5 |

SURFACE-TO-AIR-SYSTEMS

| | TERRIER HT-3 | Improved TARTAR | TALOS 6C1 |
|---|---|---|---|
| Max Range: | 20 nm | 17 nm | 100 nm |
| Launcher Reload: | 35 sec | 10 sec | 45 sec |
| Track Acq. Time: | 20 sec | 20 sec | 20 sec |
| Kill Assessment Time: | 8 sec | 8 sec | 8 sec |
| Salvo Size: | 1 | 1 | 1 |
| $P_k$ (anti-ASM): | 0.67 | 0.67 | 0.67 |

5.4.3.4 Discussion of Results

Four different AAW situations were examined with one run apiece. In two of the four cases, the fighters were excluded from the defense, and the surface force met the enemy attack with SAM firepower only. The remaining two cases dealt with the combined firepower of task force ship-launched and air-launched weapons against the same attack. A summary of results is presented in Tables 5.18 through 5.21. The case of the SAM-only defense is discussed first.

The two runs of "SAM-only' situations were made to explore degree to which the task force could defend itself against the posulated attack, without airborne assistance other than Early Warning from two E-2A aircraft. The attack and defense are the same for these two runs, except for a variation in the value of the low-to-medium threat threshold in the NTDS TEWA doctrine. The results shown in Table 5.18 correspond to the use of a value of 0.125 for this parameter while those in Table 5.19 are related to the use of a zero value for the parameter. As can be seen by comparing Table 5.18 and 5.19 reduction in the threat threshold value increases the maximum number of SAM assignments allowed to any particular target or tack, and hence increases total shots fired.

In the two cases under discussion, the SAM's were unable to intercept any of the ASM delivery aircraft, the stand-off jammers (Strike Command BEAR's), or the self-screening jammer (BLINDER) since the enemy ASM's were all released outside of task force SAM range and the jammers never came within maximum range of the task force SAM systems. However, the AN/APS-96 radars aboard the E-2A succeeded in burning-through the enemy jamming and detecting the ASM's shortly after they were launched. These ASM's were subsequently detected by the surface force and taken under engagement as they crossed the various ship radar horizons (a distance of approximately 26 nm from the task force center for ASM's approaching at an altitude of 200 ft).

The first wave of four ASM's was destroyed in both cases. In the first case where the low-to-medium threat threshold was non-zero, eight SAM shots were fired against the first wave attack and in the

Table 5.18

SUMMARY, SAM DEFENSE ONLY,
NTDS TEWA THRESHOLD VALUE 0.125

| Fire Unit | Weapon Type | Kills | | | | | Misses | | | | Shots |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | JAM | MPL | ASM | PAR | Total | JAM | MPL | ASM | Total | |
| 0 | TERRIER | 0 | 0 | 3 | 0 | 3 | 0 | 0 | 1 | 1 | 4 |
| 1 | TALOS | 0 | 0 | 5 | 0 | 5 | 0 | 0 | 2 | 2 | 10 |
| 2 | TARTAR | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 3 |
| 3 | TARTAR | 0 | 0 | 4 | 0 | 4 | 0 | 0 | 0 | 0 | 4 |
| | Total | 0 | 0 | 14 | 0 | 14 | 0 | 0 | 3 | 3 | 21 |

PENETRATOR SUMMARY

| Ship | Status | ASM's |
|---|---|---|
| 0 | Alive | 4 |
| 1 | Alive | 0 |

Table 5.19

SUMMARY, SAM DEFENSE ONLY,
NTDS TEWA THRESHOLD VALUE ZERO

| Fire Unit | Weapon Type | Kills | | | | | Misses | | | | Shots |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | JAM | MPL | ASM | PAR | Total | JAM | MPL | ASM | Total | |
| 0 | TERRIER | 0 | 0 | 5 | 0 | 5 | 0 | 0 | 3 | 3 | 8 |
| 1 | TALOS | 0 | 0 | 5 | 0 | 5 | 0 | 0 | 3 | 3 | 12 |
| 2 | TARTAR | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 2 | 2 | 6 |
| 3 | TARTAR | 0 | 0 | 3 | 0 | 3 | 0 | 0 | 2 | 2 | 6 |
| | Total | 0 | 0 | 14 | 0 | 14 | 0 | 0 | 10 | 10 | 32 |

PENETRATOR SUMMARY

| Ship | Status | ASM's |
|---|---|---|
| 0 | Alive | 4 |
| 1 | Alive | 0 |

second case, with a zero threshold value, twelve shots were fired. The increase in the number of missiles fired resulted from the lowering of the threat threshold. In the first case six of the eight shots intercepted targets, resulting in four kills and two misses. The remaining two missiles fired were aborted, since all targets were destroyed before the missiles could achieve intercept. In the second case, there were nine intercepts (five misses and four kills) and three missiles aborted due to lack of targets.

Again the second wave of 14 ASM's, 11 shots were fired when the threat threshold was non-zero. These shots all resulted in intercepts of which ten were kills and one a miss. Four ASM's penetrated over the CVA. With the threat threshold reduced to zero 18 shots were fired. Of these ten resulted in kills, five misses, and three were aborted. In this case four ASM's also penetrated over the CVA.

One should be aware of the fact that this simulation contains many stochastic elements, such as the assessment of individual missile intercepts by Monte Carlo techniques. Consequently in any single play of a game, the number of kills can differ from the expected number of kills based on missile single shot kill probabilities. Several replications of a given situation are required for reliable estimates of the stochastic elements in the game. In the first case run of the 11 shots, 10 resulted in kills--an inordinately high number. This accounts for the fact that in the two cases the same number of penetrators occurred even though there was a marked difference in number of shots fired.

Total number of shots fired, missile kill probabilities, number of intercepts achieved, number of aborted assignments, and the threat level thresholds are all interrelated in a complicated manner. Because of the stochastic nature of the model, one run of a case is insufficient to really explore their interactions, as can be seen in the above example. However, such analysis of the interactions is possible and the NTDS threat thresholds and other aspects of the TEWS procedure can be optimized.

It can be concluded, that against this particular raid, the SAM's alone are likely to be inadequate in preventing enemy penetrations.

A discussion of the runs wherein the defense consists of both surface-to-air and air-to-air weapons now follows.

Two runs were made of the combined SAM/AAM defense against the same enemy attack. The surface-to-air systems were augmented by CAP and deck-launched F-4Bs fitted with four SPARROW III missiles each. Certain aspects of interceptor employment doctrine were varied between these runs to see what effect these might have on interceptor effectiveness.

The computer simulation model provides for the assignment of fighters in either a controlled (by airborne or shipborne aire controller) or autonomous mode. For the present set of runs, it was decided to give preference to the autonomous mode of assignment in light of the vulnerability of fleet search radars and communication links to enemy jamming.

It is a rather common belief that one of the primary objectives of CAP aircraft is to destroy jamming aircraft in order to clear the environment for other AAW elements. In the first run of this set, the doctrine used for the employment of CAP aircraft was to vector* and launch missiles against any available strobe targets. Range information for these passive assignments was provided by triangulation from AEW. The deck-launched aircraft vector and fire at any available enemy tracks. The reults of this run are presented in Table 5.20.

These results paradoxically appear to indicate that the fighters decrease task force AAW capability, since there are twice as many penetrators over the force in this instance than in the two cases run with SAM's alone. The CAP aircraft in attempting to shoot down jamming aircraft were firing at strobes even though they had succeeded in burning-through and detecting other targets. The open-fire range used by the

* "Vector" as used herein implies not only the guidance of the fighter by air controller, but also includes the possibility of independent control of the aircraft based soley on internally generated target information.

Table 5.20

SUMMARY, SAM + AAM DEFENSE, AAM DOCTRINE:
VECTOR AND LAUNCH AGAINST AVAILABLE STROBE TARGETS

| Fire Unit | Weapon Type | Kills | | | | | Misses | | | | Shots |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | JAM | MPL | ASM | PAR | Total | JAM | MPL | ASM | Total | |
| 0 | TERRIER | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 1 | 1 | 3 |
| 1 | TALOS | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 4 | 4 | 7 |
| 2 | TARTAR | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| 3 | TARTAR | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 3 |
| SAM Total | | 0 | 0 | 6 | 0 | 6 | 0 | 0 | 6 | 6 | 15 |
| | SPARROW | 3 | 8 | 0 | 4 | 15 | 7 | 13 | 0 | 20 | 44 |
| SAM and AAM Total | | 3 | 8 | 6 | 4 | 21 | 7 | 13 | 6 | 26 | 59 |

PENETRATOR SUMMARY

| Ship | Status | ASM's |
|---|---|---|
| 0 | Dead | 3 |
| 1 | Alive | 5 |

aircraft in these passive assignments was based on triangulation. The jammer geometry was such that the range estimate obtained in this manner was in error by approximately 30 nm. As a consequence of this, the CAP aircraft fired all their missiles but achieved no intercepts.

On the other hand, the doctrine for deck-launched fighters was to fire at targets of opportunity as they were detected, with second preference given to strobes. With this doctrine the deck-launched aircraft succeeded in killing the high-altitude missile planes prior to the launching of their ASM's. Later they burned-through and killed all jamming aircraft. However the interceptors did not detect the low-flying component of the attack prior to the launching of their ASM's, and so the SAM's were required to defend the surface force against the entire second wave of 14 ASM's. In this run the low-to-medium threat thresholld for the SAM TEWA was again set at 0.125. Twelve SAM shots were fired, resulting in six kills and six misses, with eight penetrating ASM's. As can be seen from the examination of the "SAM's-only" results, the interceptors killed those targets (jammers and high-altitude missile planes) that the surface systems could adequately cope with, and did not kill any targets in that part of the attack that saturated the SAM defenses.

For the second SAM/AAM run, certain doctrinal changes were made in the hope that these would increase over-all effectiveness. The CAP doctrine was changed to vector against strobes, but launch missiles against tracks in preference to strobes. The doctrine for the deck-launched interceptors was not changed. In addition, an interceptor with no track or strobe visible on its own AI radar was permitted to receive additional vectoring information from an AEW, if communications with that AEW were not jammed. The results of this run are shown in Table 5.21.

Table 5.21

SUMMARY, SAM + AAM DEFENSES, AAM DOCTRINE: VECTOR STROBES, LAUNCH AGAINST TRACKS

| Fire Unit | Weapon Type | Kills | | | | | Misses | | | | Shots |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | JAM | MPL | ASM | PAR | Total | JAM | MPL | ASM | Total | |
| 0 | TERRIER | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -4 |
| 1 | TALOS | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 2 | 2 | 6 |
| 2 | TARTAR | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 3 |
| 3 | TARTAR | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 3 |
| SAM Total | | 0 | 0 | 4 | 0 | 4 | 0 | 0 | 3 | 3 | 16 |
| | SPARROW | 3 | 14 | 0 | 12 | 29 | 6 | 11 | 0 | 17 | 44 |
| SAM and AAM Total | | 3 | 14 | 4 | 12 | 31 | 6 | 11 | 3 | 20 | 60 |

PENETRATOR SUMMARY

| Ship | Status | ASM's |
|---|---|---|
| 0 | Alive | 0 |
| 1 | Alive | 0 |

In this run, the combined systems were able to kill all enemy targets and the task force suffered no penetrations. This marked reversal was directly related to the aforementioned doctrinal changes. In this case the CAP aircraft vectored out toward the jammers and initially burned-through on the two BEAR's. Firing on burn-through information, they succeeded in killing the BEAR's at 240 nm from the task force. The CAP then proceeded toward the jamming BLINDER burning-through on the high-altitude missile planes and killing three of these before exhausting their missile supply. Now, deck-launched fighters vectored toward the remaining jamming BLINDER since the low-altitude component of the attack was still being screened from them. The first two deck-launched aircraft burned-through on the jammer and the one remaining high-altitude missile plane, killing both. At this point all jamming and high-altitude missile planes have been killed, as in the previous game. In contrast with that game, however, the CAP aircraft were able to contribute several kills. Once all jammers had been destroyed, the deck-launched interceptors received vectoring information from the AEW and proceeded to attack the low-flying missile planes. In this case, eight of these attacking aircraft were killed before they came within release range of the task force. The interceptors also succeeded in killing two ASM's after they were launched. There may be some question as to the actual capability of the SPARROW III to intercept and destroy a target of this type, but no restrictions were placed on the system for these runs. The only targets finally remaining for the SAM's to engage were four ASM's. The SAM's had sufficient firepower to kill these remaining targets.

### 5.5 Implications of AAW Systems Effectiveness Findings

The purpose of this part of the report is to integrate the effectiveness findings of the various studies presented in Sec. 5 into a more general, meaningful set of conclusions pertaining to future carrier task force AAW. This is done on the premise that certain advanced system concepts are being considered by the Navy at the present time that are, in many ways, similar to the surface- and air-launched weapon system concepts analyzed in this study. Thus, it seems fitting than an attempt be made to interpret the specific study findings of Parts 5.2 through 5.4 in more general terms to establish, at least, the direction to be taken in future AAW system development efforts.

5.5.1 Comments on an Advanced Surface-to-Air Missile System (ASMS)

If the size and nature of the future limited war threat is to be as postulated in Part 3.4.2, it seems quite clear from the analysis work performed in Part 5.2.2 that the 3T family of missiles cannot provide a task force of the 1970 era with an adequate AAW capability. A follow-on surface-to-air system of greater effectiveness is required. Here again, the systems analysis work presented in this report points to certain conclusions relative to an effective follow-on system to the 3T family of ship-launched weapons. The most critical factors involved in the effectiveness of SAM systems appear to be:

(1) Maximum system intercept range,
(2) System rate of fire, and
(3) Guidance subsystem ECCM characteristics.

5.5.1.1 Range

The attainment of longer system intercept ranges is usually considered desirable for the following reasons:

(1) The maximum range characteristic enters directly into the determination of firepower according to the following relationship:

$$\text{Firepower (no. of shots fired/engement)} = \text{avg. rate of fire} \times \frac{\text{(Max-Min) intercept range}}{\text{target velocity}}$$

A long-range system, e.g., TALOS, will usually exhibit higher firepower against medium and high-altitude targets than its shorter-range contemporaries (TERRIER, TARTAR) even though its average rate of fire is somewhat less due to longer launcher cycle times (resulting from increased size and weight of the missile) and longer guidance radar tie-up times (due to the longer missile times-of-flight to intercept).

(2) Intercepts at longer ranges provide a margin of safety for the task force in that they allow for sequential engagements of a target and can tolerate longer target "times-to-die."

(3) Perhaps of greatest importance is the fact that, in the era of stand-off weapon attacks, a long-range system may perhaps be able to engage missile delivery aircraft prior to weapon launch. In this manner, a multiple threat potential might be destroyed before it is given an opportunity to compound the defense problem. Even if the AAW system fails to intercept enemy missile planes before they launch their weapons, but succeeds, instead, in killing enemy aircraft while they are attempting to return to their base, it is raising the attrition levels on an important element of an enemy's future attack potential. It is also the general belief that long-range SAM systems also have a better chance of eliminating harassing elements of an enemy attack, such as stand-off jammers or "spoofers" (aircraft involved in feinting tactics).

(4) Range is a missile system parameter which in a noise jamming environment can be traded off for a home-on-jam capability against the jamming source. The trade-off commences whenever jamming forces the SAM system to other than minimum energy trajectories.

5.5.1.2 Rate of Fire

As in the case of system range, discussed above, system rate of fire has a direct bearing on firepower. Average rate of fire is governed in a target-range-dependent manner by either guidance channel tie-up time or launcher reload cycle time. At short engagement ranges, for example, launcher reload time is the dominant factor in determining the system rate of fire.

Rate of fire becomes an extremely important factor in low-altitude attack situations where the engagement range is limited by the radar horizon. With a truncated range capability, a high rate of fire is a required system characteristic if adequate firepower is to be maintained against low-flying targets.

5.5.1.3 ECCM Characteristics

Simply stated, the SAM radar subsystems should incorporate ECCM features that will minimize the performance degradations experienced by the system in the face of likely enemy electronic countermeasures. Results of the present study corroborate the fact that this goal becomes more and more difficult to achieve in the face of enemy noise jamming as maximum missile range increases.

There are three basic concepts that can permit the attainment of an AAW kill capability at long ranges from task force center, recognizing from the discussion under 5.5.1.1, above, that such a capability may be a desirable one.

These are:

(1) The employment of long-range (100 to 200 nm) SAM's.

(2) The employment of fighters armed with air-to-air missiles.

(3) The remote positioning of missile ships fitted with short or medium range SAM's.

The outlying placement of missile ships with SAM systems of shorter range [Concept (3)] can provide the task force main body with fire-power at long range from task force center. This scheme, however, places the pickets in a vulnerable position with respect to their self-defense capability should they be subjected to attacks by the enemy. Furthermore, the enemy can evade picket ship firepower unless these ships are present in large enough numbers to provide overlapping missile system fields of fire.

Concepts (1) and (2), on the other hand, warrant careful consideration. With respect to long-range SAM systems [Concept (1)], the present study has revealed the following:

(1) These systems have firepower versus altitude of attack curves (against wave attacks) that invariably reflect poor to moderate performance at low altitude, exhibiting spectaculer increases in firepower with increasing attack altitude.

The most extreme case studied was that of the long-range TYPHON (200 nm) in which firepower against a particular type of target (ASM) rose from 8 to 40 shots fired as the attack altitude increased from 200 ft to 60,000 ft. Such a system characteristic, once known to an enemy, should compel him to attack at low altitude.

(2) That an enemy can successfully avoid the loss of weapon delivery aircraft to long-range SAM systems when attacking the fleet with stand-off air-to-surface missiles. This he can do by appearing over the radar horizon only long enough to obtain a radar fix on the target he wishes to attack (two to three minutes), after which he launches an anti-radiation air-to-surface missile with inertial mid-course guidance. In the task force analyses performed for this study (see Part 6.2.2.1) the long-range system consistently failed to intercept attacking aircraft prior to weapon release, even though they appeared over the radar horizon within SAM range for a short period of time. Several such aircraft were intercepted <u>after</u> weapon release, however, while retreating from their weapon release positions but the number of such interceptions was small. They were made by SAM's that had been assigned to the weapon-delivery aircraft while the aircraft were closing on the task force, prior to the release of their ASM's.

(3) That much of the spectacular firepower performance exhibited by the long-range SAM systems against attacks delivered from the higher altitudes is lost to the system under conditions of moderate to severe enemy stand-off jamming. This effect is shown in the results of Part 6.2.1.1. Under conditions of moderate noise jamming, the performance of a 200 nm system may be degraded to less than that of a 100 nm system operating in a non-ECM environment.

(4) The single-ship results obtained in an ECM environment demonstrate that an enemy gains little or nothing by employing stand-off jamming to screen low-altitude attacks. If he should resort to self-screening jamming in the delivery of low level attacks, advanced fire control radars of the AN/SPG-59 type will generally burn through the jamming at the short engagement ranges that are involved in such attacks.

Concept 2, the employment of fighters armed with air-to-air missiles for the achievement of long-range intercepts, appears to be quite feasible, even though a more thorough analysis than that performeed for this study is required to demonstrate fully the existence of this capability under conditions of enemy jamming. The effectiveness of airborne missile systems in meeting this task will be enhanced by the following:

(1) The developement of a long-range air-to-air missile (approximately 30 to 50 nm) that will permit the accommodation of larger fleet passive ranging errors in an ECM environment.

(2) The developement of an effective home-on-jam capability in the air-to-air missile system that will make it possible to achieve passive intercepts under conditions of steady or intermittent noise jamming (blinking jamming).

(3) The existence of a simultaneous multiple target engagement capability, which would enhance AAM system firepower in both ECM and non-ECM environments.

(4) The incorporation of guidance subsystem ECCM characteristics that will ensure reasonable missile system performance in a "burn-through" mode when confronted with likely levels of enemy noise jamming in the 1970-75 era.

(5) The development of a fleet passive ranging technique that will permit the location of enemy targets in a noise jamming environment with a degree of precision that matches AAM system range performance, so that fighter assignments can be made in a passive mode with a reasonable assurance of engagement success.

(6) The provision of adequate fleet early warning to permit the assignment of CAP or deck-launched fighters to approaching enemy attack units while these units are still at relatively long ranges from rask force center (approximately 400 to 500 nm).

Airborne system improvements of the type outlined above would improve air-to-air missile system performance to a significant degree. These systems, however, are missile supply-limited by (a) the number of fighter aircraft stationed on an attack carrier; (b) the percentage of these aircraft that can be brought to bear against any given attack; and (c) the relatively small number of missiles carried per aircraft. While fighter/AAM systems could be used to make long-range intercepts for the task force, it seems quite clear that a ship-launched missile back-up will generally be required in order to yield effective levels of fleet AAW capability.

Combining all of the factors expressed in the foregoing paragraphs leads to the following rationale:

Long-range SAM systems seem to be incapable of intercepting enemy aircraft delivering stand-off weapons against fleet units, prior to weapon launch. More often than not, the long-range SAM system will be forced to engage enemy weapons rather than aircraft. The firepower vs. attack altitude characteristics of these systems in either an ECM or non-ECM environment are such as to cause an intelligent enemy to favor low-level attacks against fleet units if his losses are to be minimized. A SAM system of moderate maximum range (such as 40 nm) can be developed to deliver high firepower against low-altitude attackers. These missiles are smaller and lighter than their long-range counterparts and thus can be handled and launched more rapidly. Since launcher reload cycle time is a critical parameter in the low-altitude attack situation, the 40 nm system will generally outperform one of longer maximum range (i.e., 100 or 200 nm) when operating against such attacks.

It is important that the system being proposed include surveillance and tracking/guidance radars with ECCM characteristics that will permit virtually undegraded system performance in the presence of enemy ECM, even though the attainment of this objective dictates the use of a radar that would be considered over-designed for the system in a non-ECM environment. Firing on "burn-through" only, if radar burn-through ranges against likely levels of enemy jamming are such to afford intercepts at near-maximum missile range, would be one way of minimizing system ECM degradation in a noise jamming environment. In general, such invulnerability to counter-measures can more readily be achieved with a system that includes a missile of more modest maximum range than the 100 or 200 nm ranges associated with some of the proposed systems of the past.

It is also imperative that the guidance radar subsystem provide for a multiplicity of missile-guidance channels so that several missile target engagements can be carried out simultaneously. In this manner the firepower at low altitude (and, for that matter, at all altitudes) can be maintained at a high level, despite the fact that the system range is relatively short. A guidance technique that relies upon a series of electronically scanned beams generated by the tracking radar for midcourse guidance of the missile and the short-term utilization of an illuminator for terminal guidance, appears to provide the highest firepower capability short of the highly complex guidance system associated with TYPHON.

Such a SAM system would exhibit relatively constant firepower with altitude of attack, or perhaps, a slight increase in firepower with increasing altitude. It would presumably retain these characteristics even under high levels of expected ECM. This SAM system should be complemented by an advanced airborne missile system whose major roles would be raid reconnaissance and the long-range engagement of weapon-carrying aircraft, stand-off jammers, and "spoofers." If the air-to-air systems are to be excluded from the surface-to-air guided missile zones, a SAM system of more moderate range will, in addition, provide greater freedom of action for the fighters through a reduction in the size of this zone of exclusion.

A cost analysis and additional effectiveness studies are required to provide further validation of the above rationale. Nevertheless, it is believed that the combination of systems being proposed represents an effective division of defense responsibility and the most efficient utilization of defense resources.

5.5.2 Comments on Point-Defense Surface-to-Air Missile Systems

It was established in Part 5.2.2.3 that a point-defense system such as the proposed SEA MAULER provided a highly significant measure of AAW capability against low altitude attacks. This was true if the point-defense system operated in an environment that included longer range systems of the 3T variety. In short, it was found that the 3T and the point-defense systems could effectively complement each other. If, for example, the longer-range TALOS, could force the enemy to stand-off jamming or if the 3T systems as a group could destroy incoming self-screening jammers, the short-range quick-reacting point-defense system would be allowed to exercise its high firepower against low-flying targets in an undegraded manner. The study performed in Part 6.2.2.3 does emphasize the need for an effective multiple-target HOJ kill capability in the 3T systems, if the point-defense system is to make a reasonable AAW contribution; otherwise, the persistence of enemy jamming could sharply degrade its performance. On the other hand, granting the availability of an effective 3T HOJ capability, the analysis of Part 6.2.2.3 has revealed that a point-defense SAM system can significantly assist in closing the low-altitude effectiveness gap that exists with the current 3T weapons.

It is worth noting that the true value of point-defense systems in the task force may go beyond the increase in the number of targets killed by the systems in a typical air battle. When, for example, these systems are installed aboard a 3T missile ship for the purpose of "last ditch" self-defense, they enhance ship survivability, thereby providing an extended opportunity for target engagement by all ship weapon systems. This "second order" effect is of perhaps as much significance as the number of target kills achieved by the point-defense system during the air battle.

An effectiveness indifference to either coordinated or autonomous operation of SEA MAULER was noted in Part 6.2.2.3 as long as the attack was predominantly directed against the task force from low altitude and as long as early warning and initial threat evaluation was provided by other elements of the task force AAW complex.

5.5.3 Comments on Airborne Early Warning (AEW)

The group of task force analyses presented in this section provide evidence of the value of the AEW concept in anti-air warfare. The use of elevated platforms, displaced from force center, for the early detection of an approaching enemy, has been found to provide the task force with a high level of surveillance coverage, obtained with a relatively small number of deployed sensors. This is most true in the case of low altitude attacks. Early detections made by the AEW aircraft are used to vector friendly CAP or deck-launched fighters against the attack and to alert the SAM systems of impending enemy action. It has been ascertained, however, that larger numbers of AEW aircraft (E-2A) will be required aboard each CVA in a two-carrier striking force of the 1970 era than are presently provided. This increased requirement stems from the fact that higher attack vehicle speeds will be encountered in this time period making it necessary to employ larger AEW station radii. Coupled with this is the probable requirement for a full 360 degrees of early warning coverage by the time the task force reaches its operating area.

No effort has been made in the current study to assess the vulnerability of the E-2A aircraft to enemy air attacks. There is reason to believe that the value of the function that these aircraft perform for the task force would be recognized by an enemy so that an attempt to destroy the E-2A's either prior to or during an air attack against the force might well be expected. It should be recognized, of course, that destruction of the AEW aircraft would in itself constitute a form of early warning. Furthermore, much would depend on the ultimate proximity of advanced elements of the task force to enemy air bases. Attacks against AEW stations would most likely be carried out by enemy fighters. Because of the greater range of task force strike aircraft, it may be possible in many instances to keep advanced elements of the force outside of enemy fighter range while conducting strike operations. Should this not be possible, or should the enemy choose to use heavier aircraft of longer range in attacking the AEW stations, defense of the latter can be accomplished by arming the AEW aircraft with air-to-air missiles, by providing them with CAP fighter protection or by positioning the AEW aircraft over guided missile picket ships as discussed in Part 3.5.

Even though the AN/APS-96 radar has been found to be highly vulnerable to mainlobe jamming (Part 5.3.3.3), the possibility of obtaining strobe bearing information on jamming aircraft under main lobe jamming conditions is an extremely important one. This capability has been assumed for the radar in deriving the snythetic tracking (SYNTRAC) procedure described in Appendix C. In fact, as is pointed out in Appendix C, it would be highly desirable to at least equip the E-2A with passive receivers in C and X bands. In this manner decisions to launch SAM's or AAM's with C or X band passive homing capabilities respectively, can be based upon valid passive ranging information from the E-2A aircraft, should the enemy choose to assign jamming frequencies to various attack aircraft in a non-uniform manner. This passive ranging capability on jamming frequency bands other than L-band has also been assumed for the E-2A in this study.

Performance of the AN/APS-96 radar against attacks being screened by stand-off jammers only was found to be adequate in that jamming power densities of 50 w/Mc or more and relatively short stand-off ranges were required to successfully screen the incoming enemy raid.

5.5.4 Comments on Air-to-Air Missile Systems

The present study does not present a complete picture of air-to-air system effectiveness. More analysis of air-to-air systems--particularly long-range AAM's such as PHOENIX--interacting with SAM's in an ECM environment, is required to round out the effectiveness picture for the airborne weapon systems. Nevertheless, certain facts about AAM systems have emerged both from the task force analyses described in Parts 5.4.2 and 5.4.3 and from the effort to develop the computer simulation models for the airborne AAW systems. These will be identified and discussed below.

The full realization of the significance of employment doctrine to the effectiveness of AAM systems did not come about until the attempt was made to develop the fighter ECM model, nor were the difficulties to be encountered in realistically defining such doctrines* fully appreciated until that time. In the non-ECM or clear environment model, briefly discussed in Part 4.2.2, perfect resolution was assumed for all radars, and fighters (or more specifically, AAM's) were assigned to targets in accordance with the NTDS TEWA doctrine in very much the same manner as the SAM's. Furthermore, the detection capabilities of fighter AI radars were not directly simulated in this model, but were implicitly introduced in the form of a combined probability of detection, conversion and lock-on for each fighter Airborne Missile Control System (AMCS) as a function of initial fighter-to-target approach angle.

With the introduction of enemy ECM into the problem, it became clear that there could be no weapon assignment doctrine for ATDS that was comparable to the NTDS TEWA with respect to the way in which the latter generates missile-to-target pairings. From the outset it seemed that, at best, ATDS could only commit interceptors to battle. For one thing, the SYNTRAC scheme for passive ranging with AEW aircraft, described in Appendix C, only provides the approximate location of jamming raids. This SYNTRAC passive ranging solution is used in the analysis as the point toward which fighter aircraft were vectored when clear detections of the raid cannot be made by the task force because of enemy jamming. The AEW aircraft lack sufficient detailed sensor information at this point to make air-launched missile-to-target parings. Once the fighters are vectored toward the raid, it is highly likely that they will find themselves in a more favorable position to obtain better raid information (raid size, raid formation, target type, etc.) than is available to the controller who initially assigned them to the attack. Thus, it appears as if a certain degree of autonomy must realistically be allowed the fighter aircraft in their final choice of targets to be engaged. The fact that communications links between fighters and AEW aircraft or surface control units may eventually be jammed by the enemy in a typical air battle serves to further support the case for fighter autonomy.

* The study group has never been successful in uncovering a definition of the assignment doctrine for ATDS.

What the fighter can and will do, once it is successfully vectored into the vicinity of the raid, is strongly dependent upon the detection and resolving capabilities, as well as the ECCM features of its AI radar. Thus, it became necessary to fully simulate the performance of these radars in the model. At the same time, it was decided to introduce fighter assignment and AAM firing doctrines into the model as a matter of input option, as described in Part 4.2.3. It was hoped, in this manner, that the effects of doctrinal variations on effectiveness could be systematically explored. Unfortunately, there has been insufficient opportunity to exercise the complete task force model at the time of this writing, although a strong sensitivity of task force effectivenss to fighter doctrine has been demonstrated in Part 5.4.3.

The results of Part 5.4.2 point to the relative strength of fighters against low altitude attacks in a non-ECM environment. These results were based on enemy low-level torpoedo attacks, which bring the attacking aircraft to within 10 nm of the ship being attacked, presenting better targets to the fighters than would, for example, a group of ASM's following a low altitude terminal trajectory. Despite the fact that a thorough investigation of fighter low altitude capabilities has not been made, particularly under conditions of enemy jamming, there is reason to believe that air-to-air and surface-to-air missile systems will significantly complement one another in defending a task force against low flying aircraft. The ability of fighters to engage low altitude ASM's with air-to-air missiles is not well defined but is believed to be quite marginal.

For the 35,000 ft (medium altitude) attacks in which the enemy aircraft launched 100 nm ASM's, the fall-off in fighter effectiveness for both the F-6D) was primarily due to an increase in enemy speed at the higher altitude (1110 kt). The F-4B, however, suffered an additional degradation because of the fact that it was excluded from the SAGM zone, whereas the F-6D, because of its slower speed and its long range AAM, was not. Inplicit in the medium altitude analysis was the assumption that the F-4B would operate at the same altitude as the attackers (35,000 ft). This assumption, in turn, carried with it the larger SAGM exclusion zones for the F-4B aircraft. The possibility of allowing the F-4B to operate at much lower altitudes, employing a snap-up maneuver to fire its SPARROW III missiles, was not analyzed in the study. Under these circumstances, of course, the exclusion zone could be reduced considerably with perhaps an attendant increase in effectiveness.

An advanced air-to-air system, as exemplified by EAGLE in this study, shows promise of having a decided effectiveness advantage over the current F-4B/SPARROW III. This advantage is chiefly attributable to the longer range of the advanced AAM and the capability in the advanced system for the simultaneous engagement of multiple targets. It is interesting to note that the Long Range Missile Fighter never finds itself at a disadvantage because of its subsonic speed (M = 0.8). In fact, it appears as if endurance is more important in AAW than the capability for operating at supersonic speeds if, of course, the aircraft is armed with a long range, high performance missile. With a slower, larger missile fighter, firing missiles of longer range, there is a greater likelihood, in a non-ECM environment, of permitting the fighter to operate in the SAGM zone, which enhances the effectiveness of the AAM systems considerably by allowing for a longer opportunity to engage the enemy. The F-6D/EAGLE was treated accordingly in the analysis of Part 5.4.2. It is not at all clear, however, if violation of the SAGM zone by fighter aircraft of any kind can be accepted under conditions of enemy jamming where close control and identification of friendly aircraft could become very difficult if not impossible. Since a future enemy can be expected to employ ECM in attacking a task force, it is perhaps more realistic to plan on the exclusion of fighters from the SAGM zone, except for the establishment of safety corridors through the zone to permit fighters to return to the aircraft carriers.

There are two possibilities for the operation of fighters within SAM range of the task for ce in an ECM environment which were recognized in the course of the study but never analyzed. One calls for remote engagements of the enemy by CAP aircraft in addition to those deck launched aircraft that can be vectored through the SAGM zone before the SAM's open fire on the raid. Any additional aircraft available for deck launch can be positioned over task force center, if armed with an advanced long-range AAM, where they can support the SAM's in their terminal engagement of the attack. If the enemy employs long range stand-off weapons (i.e., ASM's of 50 to 100 nm or more), the AAM system must have the capability of intercepting such weapons for the tactic to be worthy of consideration. There is also the possibility that the aircraft stationed over force center could still interfere with SAM firepower being delivered against enemy weapons in their terminal flight phase. Another scheme which permits the unrestricted employment of fighters is based on a form of sector control wherein fighters are assigned the exclusive coverage of a specified angular sector within the region of task force AAW effectiveness. The SAM systems would be restricted from firing in this sector. It is not clear, however, that this AAW tactic offers any distinct advantage over the method of assigning zones of responsibility to the AAM and SAM systems in a uniform manner around the task force, as analyzed in the study. In fact, if this scheme can only be implemented at the expense of denying the SAM sector of responsibility any fighter coverage, it is more likely to degrade the AAW effectiveness of the task force.

In general, it has been found that the most important interaction between AAM and SAM systems has to do with the ability of the former to clear the atmosphere of jamming by the time the latter go into action against the enemy. The ability of an airborne system to affect a reduction in enemy jamming levels will depend strongly on an effective home-on-jam capability in the air-to-air missile if jamming on AI radar frequency is too high to permit AAM firing on "burn-through." Reliabile means for providing the task force with passive ranging information on jamming raids will also be required.

Largely in its favor is the fact that the fighter enjoys many degrees of freedom. Thus, in order to effectively countermeasure air-to-air missile systems with noise jamming, an enemy is likely to be forced to onmidirectional radiation with an attendant drop in jamming power density. At the same time the fighter can approach a target from a direction other than head-on, benefiting from the larger radar cross sections that are presented. Both factors increase the likelihood of AI radar burn through.

The analysis work performed on airborne missile systems in this study is by no means complete. Nevertheless, it appears to point toward promising effectiveness contributions to be made by the AAM systems, particularly an advanced system with longer range, a high power AI radar and a multiple simultaneous engagement capability. The attainment of high endurance by an advanced fighter at perhaps the expense of a supersonic speed capability appears to favor the effectiveness of the aircraft in an AAW role.

## 6. THE ROLE OF AIRBORNE PLATFORMS IN FUTURE TASK FORCE ANTI-AIR WARFARE

### 6.1 Introduction

Analytical studies indicate that the surface-to-air guided missile, though currently beset by engineering development problems inherent in large, complex, interrelated systems, is potentially the dominant contributor to the AAW effectiveness of a future task force. Some of the more advanced SAM systems that are technically feasible, perhaps will not be implemented because of their high cost and complexity or because of changing roles and missions in future warfare. In the event the more advanced SAM systems are not implemented, an even larger portion of the total AAW burden may fall upon the fighter-AAM systems. Furthermore, Navy fighters are designed and procured to perform multiple missions, including strike and reconnaissance, as well as AAW.

This section examines, first, some of the fundamental physical resource considerations that limit the use of fighter AAM and SAM Anti-air warfare weapon systems. Next, ways are examined in which fighter AAM systems can complement the SAM systems to augment over-all fleet AAW capability. In this context are examined also the serious problems of meeting the fighers' tactical information requirements. Finally, the utility and feasibility of airborne ECM directed against enemy force-localization radar is explored. The fighter is considered along with some other platforms for use with this type of ECM system.

### 6.2 Mass, Energy, and Time Considerations

Considerations of mass, energy, and time illuminate some major differences between the concepts of the SAM and the fighter-launched AAM. The F-4B fighter weighs about 43,000 lb at take-off, including 15,000 lb of fuel. The normal armament load is four SPARROW III missiles carrying 65-lb warheads, for a total warhead weight of 260 lb. Normally, aircraft maneuverability is restricted to about 3-4g's during target engagement. At 1000 knots ($V_{max}$ is in excess of 1200 knots) this results in a turning radius of 5.2 nm.

At maximum power, nearly two minutes and 4000 lb of fuel are required to climb to 35,000-ft altitude from take-off, and 7.5 minutes are required to fly out to 100 nm range. In each nautical mile traversed at maximum power at 35,000 ft, the aircraft consumes about 50 lb of fuel.

Instead of relying upon deck launching in response to an incoming raid, the fighters can be prepositioned in the air (CAP operation), directly over the task force or at some range distant in the direction of expected attack. This reduces take-off and climb response time and may reduce intercept closure time, if the raid approach direction is favorable to the station locations. However, the F-4B aircraft must expend fuel to remain aloft at the rate of 4500 lb per hour. Furthermore, a minimum of 44 aircraft are required to achieve at least a 90 percent probability of maintaining 10 stations over a 72-hr period. Each aircraft normally carries four missiles (some load configurations carry more missiles, at the expense of speed, range, and endurance). Only one target can be engaged at a time but sequential engagements may be possible if warning time is adequate and if the fighter has sufficient speed advantage.

By contrast, the TALOS 6C1 missile with a maximum range of 100 nm, weighs 7700 lb and carries a 420-lb warhead. Maneuverability at 35,000 ft is 12 g's and flight time to 100 nm is 4.3 minutes. A missile ship may be configured with one or two dual-rail TALOS launchers. Each launcher is provided with 40 missiles. Also associated with each launcher are two tracking radars, permitting the simultaneous engagement of two targets. SAM performance envelope size in combinations with system reaction and delay times will generally permit the sequential engagement of targets falling within system field of fire. It may be noted that a single TALOS missile delivers more warhead weight than available from the entire missile complement of the F-4B aircraft.

These fundamental comparisons, of course, do not fully represent the relative effectiveness of the two system concepts, since more factors than these enter into that measure. Measures of relative AAW effectiveness have been the objective of the simulation studies described elsewhere in this report.

To represent the air-launched missile concept, we have chosen a high-performance interceptor firing a short-range missile, primarily because that is the kind of system that the Navy is procuring. It is illuminating to think of an air-launched weapon system as comprising a delivery vehicle and a weapon, the aircraft and missile (including fire-control system), respectively. It becomes apparent that system performance is some function of the performance of these two components, and that, conceptually, at least, a given system performance level could be achieved by different combinations of performance level in each component. By the same token, the over-all weapon system performance can be changed by varying the performance level of either component. The level of performance in either component and hence in the over-all system is constrained by technology and also by resource costs.

Over-all system performance does not necessarily increase linearly with component performance, especially when cost constraints are considered. The familiar phenomenon of diminishing returns becomes evident as, for example, aircraft speeds are increased.

The matrix below classifies three Navy AAM weapon systems according to relative levels of performance in the delivery vehicle and the missile system. The F-4B is now in fleet service, the F-111B is in preliminary design, while the F-6D was cancelled before procurement.

| Delivery Aircraft Performance Level | Missile System Performance Level | |
|---|---|---|
| | High | Low |
| High | F-111B, PHOENIX | F-4B, SPARROW III |
| Low | F-6D, EAGLE | -- |

Both of the high-performance missile systems are capable of simultaneously engaging six targets, and their missile launch ranges are greater than 50 nm. The SPARROW III system by contrast is capable of engaging only one target at a time; its range is less than 15 nm. The maximum speed of the F-4B aircraft is about Mach 2.1 that of the F-111B slightly higher; the F-6D was to be subsonic.

Analysis has shown that effectiveness of F-6D EAGLE against a low-altitude* raid was never constrained by the low speed of the aircraft. The high performance of the missile system (long range, high speed, multiple simultaneous engagement capability) reduced the need for aircraft speed. Other problems, such as the need for external information for early warning, vectoring, and inter-fighter fire coordination do, however, constrain the effectiveness of an AAW system. Higher aircraft speed can reduce the need for early warning of approaching attack, but may increase the problems of vectoring and coordination. Clear environment early warning capability of the E-2A system is adequate; early warning in the presence of enemy ECM can be obtained passively, but the problems of vectoring fighters and assigning them to targets are extremely difficult to solve in an ECM environment. These problems impose the major constraints on fighter/AAM effectiveness and thus, with a high performance AAM system, higher aircraft speed is of questionable value.

## 6.3 The Complementary Role of the Fighter

In a clear environment, where enemy countermeasures do not seriously degrade airborne radar systems, the fighter-launched AAM's appear to complement the SAM's. Against low-altitude targets, the SAM systems' range is limited by the radar horizon. The fighter, however, can exploit its vertical mobility to eliminate the horizon constraint, and thus can provide a significant contribution to AAW against a low-altitude attack†, provided some additional conditions are met.

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* The low-altitude raid is of major importance in the evaluation of AAM systems. The radar horizon masks the raid from the SAM batteries; AAM systems operating at altitude avoid this constraint.

† Current SAM systems are weak against low-altitude attack due basically to the raid's short time of exposure to SAM firepower. This weakness could be overcome by increasing the number of targets that can be killed by the total SAM defense in the limited time available during a low-altitude attack. This increase in turn can be accomplished by increasing the sustained firing rate of each SAM battery, the number of SAM batteries in the force, the kill probability of each missile fired, or by any combination of these.

### 6.3.1 The Target Information Problem

First, early warning of approaching raids is needed to provide adequate time for fighter response. Second, externally derived vectoring instructions must be provided to direct the fighter until it is close enough to the target to use its own acquisition radar. Third, efficient allocation of fighters to multiple targets depends heavily on the resolution of individual targets and coordination of fighter-target assignments. These resolution and coordination capabilities are not fully defined at this time, nor are the consequences of different levels of capability. Imperfect target resolution has been found to contribute significantly to the high percentage of aborted surface-to-air missile shots (see Part 5.2.2), but the limited quantitative data available at this time will not support a comparison between SAM's and AAM's with respect to this factor.

Against medium- and high-altitude targets, the SAM capability is not constrained by the radar horizon. But the higher target speeds at these altitudes and the larger zones of exclusion reduce the fighter's capability to the extent that its contribution to total firepower is generally less than that of the SAM's.

#### 6.3.1.1 Stand-Off Jamming

When the enemy uses remote stand-off noise jammers in conjunction with nonjamming attack aircraft, AAM system performance may be degraded. The radars aboard the E-2A early warning and control aircraft and aboard the fighters could be jammed by the stand-off jammers, and might not detect the approaching attackers. Analysis has shown the AN/APS-96 radar to be quite insensitive to sidelobe jamming, such as might result from stand-off jammers. Jamming power levels on the order of 75 to 100 w/Mc and fairly short stand-off ranges were required to degrade the radar's performance seriously. But short stand-off ranges ease the task of destroying the stand-off jammers with fighters or radiation-homing missiles. This outcome is indeed fortunate, since AN/APS-96 detection ranges on nonjamming attackers were sharply reduced under these jamming conditions.

If the AN/APS-96 radar were unable to burn through the stand-off jammers' noise, this noise would at least provide warning of the jammers' presence and of possible hostile enemy intentions. The possibility of feinting to activate the defense spuriously cannot be dismissed. Conceivably fighters could be dispatched on the basis of such detections and vectored in the direction of the stand-off jammers. Perhaps the fighters could, while enroute, burn through the jamming and detect the attackers. Since reflected radar signal increases inversely with the fourth power of range from fighter to nonjamming attacker while jamming power received increases inversely with the square of range from fighter to jammer, there is a reasonable chance for burn through if the flight path to the jammers carries the fighters near the approaching raid. Because of their necessarily small size and low weight, airborne radars of any type cannot be expected to perform as well as their shipborne counter-parts. To say more than this requires further analysis of specific situations.

The threat posed to AAM systems by stand-off jammers suggests that destruction or disablement of these jammers yields high payoff to the defense by subsequently allowing air-to-air missile systems to function in an ECM-free environment. Whether this payoff can consistently be realized is questionable. In order that fighters can proceed to engage attacking aircraft in an environment free of the effects of remote jamming, the jammers must first be destroyed. The long response time of fighters leaves in doubt their ability to clear the environment by destroying jammers early enough so that other fighters (or perhaps the same ones) can engage the nonradiating attackers before these attackers launch their weapons.

The destruction of remote jammers by fighters is of little or no use in enhancing the capability of SAM systems defending against low-altitude attack. This has been demonstrated in the analysis of task force AAW capability against the complex, coordinated low-altitude ASM attack, described in Sec 5.2.2. The low-altitude ASM's cross the ship's radar horizons at such short ranges that tracking-radar burn through occurs immediately; hence, the jammers do not significantly degrade SAM defenses.

6.3.1.2 Self-Screening Jamming

The AN/APS-96 was found to be quite vulnerable to mainlobe jamming by self screeners and will require considerable ECCM improvement if a burn through capability is to be achieved against even low jamming power density levels. Even though it is difficult to burn through self screeners with the AN/APS-96, the strobes created by such jammers allow the use of passive ranging.

6.3.1.3 Passive Detection of Radar Emissions from the Attack Aircraft

Although we may be able to burn through stand-off jamming and may passively detect self-screening emissions, the high stakes involved in modern warfare justify consideration of still another means of detecting and tracking attack aircraft. These aircraft are very likely to carry target location radars; emissions from these radars could be detected passively if the fleet ships and aircraft were properly equipped with receiving equipment. Enemy efforts to avoid detection of these emissions will hamper the conduct of the attack by degrading the quality and reducing the quantity of targeting information available to the attackers.

6.3.2 Vectoring of Fighters

While the E-2A may be capable of vectoring fighters, the present study has revealed that it cannot handle fighter/target pairings in an ECM environment. In fact, even in the absence of jamming, the general inability of the AN/APS-96 radar to resolve individual targets limits the capability of the E-2A to control fighter activities closely in the target-engagement phase. Therefore, it cannot effectively allocate to individual targets those fighters that have burned through the jamming to detect the attackers. This lack of coordination could result in a situation where the fighters attack only a few targets, leaving all others unengaged.

The foregoing descriptive analysis implies that airborne radars will often be on the losing side in the ECM/ECCM battle. The reactive nature of the balance between measures, countermeasures, on out to $(\text{counter})^n$

measures has been manifested in many ways. The reasonable assumption is that any relative invulnerability that airborne radars might enjoy would, at best, be temporary.

6.3.3 Implications of High-Firepower SAM Systems

Analyses have shown that, even against low-altitude raids, the fire-power of SAM systems employing the multiple-channel TYPHON radar and short-cycle-time launchers would be difficult to match with fighter/AAM systems. This fact holds even in the absence of the vectoring and coordination problems discussed above. AAW effectiveness may prove to be maximized by allocating additional available resources to high-fire-rate SAM systems with large simultaneous-engagement capacity, rather than to fighter-AAM systems. A definite answer to this question involves consideration of resource requirements as well as effectiveness. This study has considered only effectiveness and has not addressed the question of costs.

6.3.4 Multiple Capabilities of Fighters

It must be borne in mind that naval fighter aircraft--such as the current F-4B and the coming F-111B--are capable of performing multiple missions, including strike and reconnaissance as well as AAW. In some circumstances, the fighters will be the preferred vehicle for the execution of these non-AAW missions. The fighters' presence in the fleet does not depend solely upon the over-all effectiveness of their AAM weapon systems. One relevant consideration in evaluating the fighters as a task force AAW weapon is the alternative uses that would be foregone by employing fighters in their AAW role. Given that fighters are present in the task force, the relevant question is: How would these fighters best be used? This question of the relative importance of AAW and other missions that the fighters can perform is outside the scope of this study, but it will in any event depend crucially upon particular situations. If none of the other missions make conflicting demands on the fighter, then it becomes clear that the fighters should be used for AAW in whatever way they can best contribute. However, if use of the fighter in AAW requires that some alternative use be foregone, then a choice between these conflicting uses must be made on the basis of which role contributes most to the larger objectives of the task force. That question, as well as that of costs, is outside the scope of this study.

## 6.4 Airborne ECM

The limitations of the AAM systems in an ECM environment, the potentially high effectiveness of advanced SAM systems against even low-altitude threats, and the fact that fighters will nonetheless be in the fleet because of roles other than AAW, gives rise to a search for new ways to use fighters to complement SAM's for over-all enhancement of fleet AAW.

### 6.4.1 The Utility of Fix-Denial ECM

The use of airborne platforms for ECM against enemy force-localization radars has been examined and found both feasible and useful as a complement to ECM from ships in the task force. Countermeasures against this radar deny the enemy use of his preferred means of ship location and force him to employ secondary means such as passive fixing on ship emissions which are less reliable since they are controlled by the defense. Furthermore, we impose a drain upon the enemy's resources by forcing him to develop and implement the passive capability.

Soviet ASM-delivery aircraft are equipped with target-localization radar used for accurate force-localization and identification in order to launch weapons. Countermeasures against enemy radar, to be useful, need only delay the launch of enemy weapons by creating confusion and uncertainty in locating the force ships with precision sufficient for weapon launching. By delaying weapon launch, ECM increases the enemy bombers' exposure time to task force AAW firepower. Because the AAW systems can then shoot at slower, larger bombers instead of fast, small ASM's, more shots can be fired and each will have higher kill probability.

The usefulness of ECM directed against enemy target-spotter radars is contingent upon enemy need for the data provided by those radars. Intelligence estimates indicate Soviet plans for the inclusion of target-spotter radars in ASM-delivery aircraft. Fundamentally, there are two ways for the enemy to eliminate or reduce dependence upon these target-spotter radars: to develop missiles that can operate without benefit of the pre-launch data provided by the radar, or to acquire the needed pre-launch data by other means.

6.4.2 ASM Homing Systems

It is conceivable that anti-ship ASM's could be designed to operate without benefit of information from target-spotting radars. If enemy reconnaissance systems can locate the force to within 15 to 50 nm, as indicated in Sec. 3.1.3, and if enemy ASM terminal homing systems (e.g., active radar, or passive infrared or microwave homing) can detect, acquire, and home in on ships located within an uncertainty region of this magnitude, then enemy dependence upon target-localization data is greatly reduced. Under these circumstances, the detriment to the enemy from denial of target localization would be his need to use area fire upon targets of opportunity instead of specific target/ASM pairings before launch.

It must be borne in mind that this assessment is conjectural, for its conclusions depend upon future Soviet capabilities and intentions that are unknown. The extent of damage that could be inflicted upon the fleet by future Soviet weapons operating without benefit of pre-launch individual target localization cannot at this juncture be determined except by gross supposition about the existence and performance of such weapons. Nonetheless, anti-ship weapons capable of operations without benefit of pre-launch target localization are readily conceivable within known technology. Should the denial of pre-launch target localization data (e.g., by means of ECM as here proposed) prove to be highly detrimental to Soviet attackers, that in itself would motivate the development of weapons capable of operation without prelaunch localization. Such reaction is inherent in the dynamic nature of military technology, in which each technical measure elicits a countermeasure. By the same token, countermeasures against the postulated homing systems can be conceived.

6.4.3 Surface vs. Airborne ECM Platforms

If the usefulness of a anti-fix ECM is granted, the question of surface or airborne platforms can be addressed. The Navy has shipboard fix-denial ECM equipment, such as the AN/SLQ-12 noise jammer and the AN/ULQ-6 echo enhancer. The SINEWS study being conducted by NEL for the Bureau of Ships includes studies of shipborne ECM.

#### 6.4.3.1 Operational Advantages Unique to Airborne Platforms

Airborne ECM platforms offer at least two operational advantages that cannot be obtained with shipborne platforms. For example, spot jamming requires measurement of the frequency and direction of enemy signals. Continuous receiving while jamming is difficult in a shipboard system because the receiving and transmitting antennas are coupled by the radio-reflective properties of the ship and the sea surface. As a result, jamming emissions must be interspersed with monitoring periods. But continuous receiving is important against a rapid-tuning radar, such as might be encountered in the 1970 period. Operational airborne jammers have been built with antennas that reduce coupling to acceptable levels.

The second advantage has to do with the fact that an airborne raid approaching surface targets that are emitting jamming noise or false targets can deduce approximate range to these targets by descending to determine the radar horizon altitude. From this information the range to the emitting surface objects can be deduced by a single aircraft.* If the ECM emitters are airborne at substantial altitudes, range estimates deduced in this way will be grossly in error unless the enemy knows the altitude of the emitters, which is even more unlikely. This feature, by itself,

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* Approximate range to a ship that is emitting microwave radiation can be determined from a single receiver-equipped aircraft by varying flight altitude to find the radiation horizon; range can be computed from $R = K\sqrt{h}$ , where h = the altitude below which the radiation is masked and K is a coefficient to account for refraction and earth curvature. This technique is subject to ambiguities arising from propagation anomalies and requires furthermore a priori knowledge that the emitter is on the surface. It should be noted that a distant elevated emitter could produce the same horizon altitude as a closer emitter on the surface. Consequently, accurate range deduction by a single aircraft is highly problematical. However, triangulation by two or more aircraft is not uncommon.

is not a decisive advantage, because two or more receivers can deduce range by triangulation without changing altitude. Triangulation requires communication between widely separated enemy attack elements and these communications are difficult to jam. Directional antennas, buffering, and other techniques permit highly jam-resistant communications.

6.4.3.2 Operational Flexibility at Lower Cost

Airborne platforms can disperse ECM devices at various locations about the task force at lower cost than can ships. Placing the ECM device ahead of the defended ships in the task force, in the direction of the approaching attack aircraft, dispersed in azimuth, offers some operational benefits not readily obtainable with devices located within the force. These advantages arise from radial distance and azimuthal dispersion, and do not depend upon platform elevation. Hence, one or more ships placed at these forward locations could secure the same ECM benefits as airborne platforms that are so located, but the airborne platform is far less costly. A ship can carry more powerful ECM gear, but some operational advantages accrue from having numerous dispersed sources of ECM emission, and here the airborne platforms cost advantage becomes important.

Very small ships can carry substantial amounts of ECM gear. In fact, the minimum ship size for an ECM platform would be governed by endurance and sea-worthiness of the ship, which must be capable of sustained operation with the task force at sea. The destroyer is the smallest ship type envisioned for task force use. Several destroyers could be deployed in the forward locations as ECM platforms. The destroyer, however, is a multipurpose ship. To optimize its placement for ECM purposes is likely to compromise its effectiveness in, say, ASW. Airborne ECM platforms appear to afford a more efficient use of task force resources. Small auxiliary surface vessels, carried aboard larger ships in the force and launched and recovered as needed, might be envisioned as ECM platforms. However, the operational problems of launch and recovery at sea make such a scheme unattractive.

An ECM device positioned between defended ships and the approaching raid requires less power than a device aboard the defended ships, for a given screening effect. Reflected signal return increases inversely with the fourth power of range from the radar to the screened ship, while jamming power received increases inversely with the square of range from radar to jammer. This results in a screening advantage to the remote jammer over that attainable through self screening from the ship. These relationships are shown in Fig. 6.1 for jammers of a given power, located aboard the ship being screened, and, for comparison, the same jammer aboard a remote platform stationed nearer the radar by a distance $R_{sj}$. This advantage is overshadowed by some of the others discussed here, since the power of systems aboard the defended ships could be rather readily increased to offset most of any practical benefit from this source.

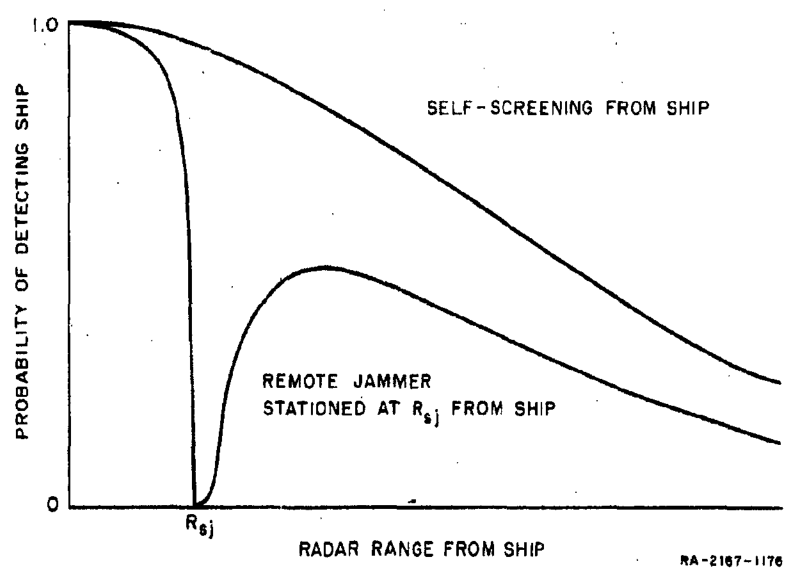


FIG. 6.1 DEFENSE JAMMER EFFECTIVENESS

Noise jamming from a self-screening ship denies range but yields bearing data to the enemy, from which ship position can be deduced by triangulation. Jamming platforms remote from the ships but within the radar's search field can produce strobes at spurious locations and thereby frustrate enemy efforts to deduce ship position.

Deception images from shipborne repeaters can be made to appear only at ranges greater than the ship, if the radar has rapid frequency tuning, which is to be expected in the 1970 era. From this fact the enemy could deduce range to a self-screening ship. Furthermore, since sidelobe deception is not feasible, because of high peak power and image intensity-matching problems, repeaters aboard a defended ship would yield to the enemy bearing information as well. Remote platforms, on the other hand, can be stationed ahead of the ships to be screened and at various bearings within the radar search field. These platforms can produce false images ahead of, behind, and at false bearings from the defended ships.

Airborne ECM platforms can accomplish all of these purposes of remote location and do so at lower costs than ECM ships.

### 6.4.4 Joint Operation of Ship-Based and Airborne ECM

It is unlikely that the Navy would or should rely upon airborne ECM alone, abandoning ship-based devices. For that reason this appraisal of airborne ECM is based upon the joint operation of ship-based and airborne ECM.

Enemy aircraft, by changing altitude as they approach the task force, could discriminate between emissions coming from airborne ECM devices and emissions or radar returns from surface ships, provided that the approximate positions of the ships in the area were known to the enemy by prior reconnaissance, as in fact we expect. It is believed that propagation anomalies as well as the time necessary to acquire and interpret the information obtained in this manner would make the scheme difficult to implement and would degrade its reliability.

This scheme could be countered by operating the airborne platforms at both high and low altitudes, at several locations, and by placing an airborne platform at high altitude near some or all of the ships. At the same time it remains necessary to control emissions from ship-based radars in order to avoid disclosing ship positions as discussed in Part 6.4.8. This control can be less strict for narrow beam than for broad beam emissions. Jamming or deception emissions from ships appear feasible if conducted simultaneously with ECM emissions from airborne platforms in the manner described above.

### 6.4.5 Considerations for Airborne ECM Platform Characteristics

#### 6.4.5.1 Capability to Stay With the Fleet

The ECM device, of course, registers upon enemy radar scopes. Discernible motions uncharacteristic of the fleet being screened would render the countermeasure ineffective. Furthermore, the ECM device must remain within the radar search field, which is likely to be confined to the area where enemy external reconnaissance sources have located the fleet's approximate position (estimated to be about 15 to 50 nm in extent). Thus, the important characteristics in this regard are ability to hold altitude while maintaining the same net motion as the fleet. This requirement tends to favor a helicopter. A fixed wing aircraft would have to confine its orbiting motions to a region less than the radar beam width, which for a 2 degree beam is about eight nm when the radar is 240 nm distant and which drops to about two nm when the radar is at 60 nm. This orbiting flight pattern would also impose problems of steering a directional ECM antenna in the raid direction.

#### 6.4.5.2 Noninterference With Other Missions

Airborne ECM is a complement to, not a substitute for, AAW. The ECM platform should therefore not interfere with AAW, strike, or other missions of the fleet. Such interference is more likely if:

- The ECM platform is a carrier-based fixed wing aircraft requiring deck and hangar space and catapult launching.
- The ECM platform role is performed by an aircraft that also has active AAW or strike capability.

These considerations favor a platform that does not require carrier launch, recovery and storage, and that is not more useful in other roles at the time it is needed for ECM. A helicopter capable of operation from ships as small as destroyers could fill this requirement.

6.4.5.3 Speed

High speed appears to be less important to the ECM mission than are the two characteristics just named. For CAP operations, high speed is less important than endurance and reliability in sustained operation. Launching the ECM aircraft in response to an approaching raid may be feasible if the fleet has reliable AEW aircraft on CAP station. Consider the following circumstances: AEW aircraft detect an approaching raid 425 nm from the fleet. The attackers are moving at high subsonic speed, at 50,000 ft, so that their radar horizon to the fleet is about 275 nm. It is sound doctrine, if not imperative, that our ECM platforms be in position by the time the raid reaches the fleet radar horizon. This permits from 15 to 17 minutes to get the ECM platforms into position. A helicopter averaging 90 knots could travel 22 to 25 nm in this time.

6.4.5.4 Payload

The platform should be capable of carrying at least 1000 pounds of ECM equipment. This payload would allow an average output power of 8-10 kw, and we believe that anything much less than this is not attractive.

6.4.5.5 Cost

Cost of the airborne ECM platform is an important consideration. The question is: What is its true cost? If the ECM platform interferes with other missions, then the value of the alternative missions sacrificed is a valid cost of the ECM role. If the ECM role can be performed by aircraft that are in the fleet for other purposes, and that are not needed for those other purposes at the time the ECM mission arises, then those aircraft are essentially free to the ECM mission. A platform procured specifically for the ECM mission should entail resource costs no greater than the benefits that result from this use. Optimum allocation dictates that resources be applied to the ECM mission only if no alternative uses would produce greater benefits. Unfortunately, the benefits of use are not measurable in the same terms as the resource costs; hence, the question of how much of our resources should be devoted to the ECM mission must be answered on the basis of human judgment.

### 6.4.6 Some Potential Platforms

#### 6.4.6.1 Light Helicopters

We have indicated that in some respects a helicopter might have attractive features; for example, its ability to stay with the fleet and its ability to operate off smaller ships and therefore not tie up carrier space. Carrier space and launching capability is a costly commodity in terms of total resources consumed. Fixed-wing aircraft used as ECM platforms consume some of that scarce carrier capacity. A helicopter that can operate from smaller ships in the force consumes none. For example, helicopters operating from destroyers would tie up none of the scarce carrier capacity. Manned helicopters have been successfully operated from destroyers in the North Atlantic, by the Canadian Navy, using a winch-down recovery system. The helicopter platforms measure about 35 X 75 ft. The British have demonstrated helicopter operations from destroyer-size ships in various sea states using pilot technique alone, unaided by cables or other devices.

Helicopter aircraft appear quite promising for the airborne ECM application. Payload and endurance requirements can both be met by helicopters. The investment cost of feasible helicopters is lower than that of fighters such as the F-111B. The helicopter may be able to perform multiple functions and this fact strongly favors use of a demountable ECM pod. Consequently the marginal cost of the ECM role for the helicopter might be less than the total cost of the helicopter. If a helicopter procured for other purposes is used as an ECM platform, the relevant cost of such use is the value of other uses that need to be foregone, or else it is the cost of performing those other missions by alternative means. But if helicopters are procured expressly for the ECM role, then their whole cost represents a net resource demand that would otherwise not arise.

One proposed helicopter design that appears feasible for the ECM platform role has the characteristics tabulated below.

Characteristics of a Small-Ship Helicopter

| | |
|---|---|
| Payload Capacity | |
| Weight | 1300 lb |
| Internal Storage Compartment | 4.5 X 4 X 6 ft |
| Endurance | 2.6 hours at cruise speed |
| | 1.2 hours loiter at 50 nm from ship |
| Cruise Speed | 86 kts |
| Rotor Diameter | 35 ft |
| Overload Gross Takeoff Weight | 4300 lb |
| Normal Gross Takeoff Weight | 3900 lb |
| Fuel Load | 600 lb |

ECM payload capacity is 1300 lb; the internal storage compartment has about 100 $ft^3$ capacity; such a helicopter could be operated from a platform with a minimum dimension of 35 ft. Design studies indicate that extensive modification of hull or superstructure would not be required for operation from destroyers that would be operational with the 1970 task force. Two of these helicopters can be stowed aboard and operated from a present-day FRAM destroyer. A prototype of this helicopter has been flown. This helicopter is powered by a single Pratt & Whitney PT6 turbo-shaft engine rated nominally at 550 shaft horsepower, which exceeds the power required for lift and propulsion. Sufficient excess power (about 150 horsepower) is available at cruise flight condition to drive an ECM package with 10 kw average output power.

The estimated cost of this helicopter is about $125,000 with tooling and other nonrecurring costs allocated over a hundred units. This cost includes navigation and communication equipment required for night VFR operations, but does not include the costs of the ECM package. The ECM package cost is estimated to be on the order of $100,000, so the cost of an ECM-equipped helicopter would be about $225,000-$250,000. Thus, one million dollars would buy four ECM-equipped helicopters, and the price of a single F-111B would buy about 25 of these helicopters.

6.4.6.2 F-111B Interceptor

The F-111B is also considered as an ECM platform largely because of its imminent procurement as a multipurpose, carrier-based aircraft for the late 60's and 1970 era. This aircraft has a normal AAW missile payload of 6,000 lb. The F-111B (TFX) work statement specifies six missiles weighing 1000 lb each, at least two of which must be stowed internally. The envelope dimensions of the missile are 13 X 2 X 2 ft, so that two missiles would occupy about 50 $ft^3$ of internal stowage space. It is reasoned that ECM equipment would be an alternate weapon load displacing the missiles only and that the missile fire control system would remain in the aircraft. A suggested approach is to replace the two internally stowed missiles by the ECM package, bearing in mind the probable need for antennas mounted in a location more suitable than the fuselage missile bay. The ECM antennas are expected to consume little space and might be permanently installed in the fuselage or in a separate mountable pod. The four externally stowed missiles could remain, yielding dual capability in one aircraft. Alternatively, additional ECM pods could replace some of the external missiles, in whole or in part.

The F-111B requires carrier space for stowage and catapults for launching. Furthermore, because it is a multipurpose aircraft, it may be needed for a weapon-delivery role in either AAW or strike missions at the very time that it is also needed in its ECM role. Its high speed, which makes it a useful weapon system for many other missions, may be a handicap in the ECM mission where the objective is to simulate a group of ships and where the ability to move at 30 knots is therefore more useful.

6.4.6.3 COD Aircraft

The requirement for noninterference with other AAW or strike missions and the absence of a requirement for high speed suggest that the Carrier Onboard Delivery (COD) aircraft, which are a part of every carrier's complement, are perhaps better suited than most carrier-based aircraft for the ECM platform role. It does not appear likely that these COD aircraft would be required for other missions at the time when they are needed for the ECM role.

6.4.7 A Conceivable Airborne ECM System

Ref. 20 reports the results of a study of the feasibility of airborne ECM. Included in that study are the estimated technical and performance characteristics of the expected future Soviet target spotter radar, analysis of the technical requirements for the ECM system, and the physical, technical, performance, and operational characteristics of a feasible ECM system.

6.4.7.1 Enemy Radar Characteristics

On the basis of intelligence data and technical projections, an estimate is formed of the 1970 Soviet target spotter radar. The characteristic parameters are estimated as follows:

Frequency--8000 Mc ± 500 Mc
Peak power--250 kw
Average power-- 1 kw
Pulse width--16 µsec
Pulse compression factor--80
PRF--250 pps
Horizontal beamwidth--1.5 deg
Vertical beamwidth--3 deg
Antenna gain--37 db
Scan rate--1 to 10 sec/cycle

These parameters are used in this study as a plausible threat in the time period. It is recognized that there are many uncertainties regarding the path of development of future radars.

6.4.7.2 Weight and Volume

By means of empirical relationships formulated from actual airborne ECM devices, it has been calculated that a 1000-lb ECM package could produce an output of 8-10 kw of broadband noise.* The same device could incorporate repeater deception capability. The package is regarded to be feasible within known technology for operational use in the 1970 time period.

The 1000-lb package is proposed for development as a basic ECM module (a demountable pod is one likely configuration) suitable for use even with aircraft having small payload capacity. Multiple packages could be used with aircraft having larger payload capacity. This 1000-lb module is expected to occupy a volume of about 40 $ft^3$, based upon actual designs of similar airborne ECM equipment.

6.4.7.3 Cost

The cost of such a device will depend upon many factors (including the number procured) that are highly fluid at this stage of investigation. An estimate of $100 per pound is considered to be a reasonable extrapolation from past experience with airborne ECM equipment. This estimate must be used with some caution because of the wide variability in past data and because of the technical differences among devices. Applying the estimate to the 1000-lb device here postulated results in projected cost of $100,000. Combining this device with a $125,000 helicopter would result in the $225,000 total cost.

6.4.7.4 The Airborne Noise Jammer

The airborne jammer system would consist of an antenna system to measure the angle of arrival of the radar signal to within perhaps a twelve degree azimuth sector, an associated receiving system which would measure the frequency to within 10 Mc, and a barrage noise transmitter that would jam a 20 Mc band over the same sector.

The jammer performance in screening various ships in the fleet will depend upon many conditions. These conditions include the geometric relationships between the attackers and the airborne jammers, the radar cross sections of the ships, and the number of attackers and jammers in

* By comparison, 10 kw output power is representative of shipborne jammers in current planning.

the engagement. However, to illustrate the capabilities of a single airborne jammer as described, consider a jammer situated over and protecting an aircraft carrier from detection by a single aircraft using an advanced target spotting radar. The jammer is radiating 10 kw over a 20 Mc frequency band, producing a noise power spectral density of 500 w/Mc and radiating this power from an antenna with 25 db gain. The antenna is designed for a circular polarization and has a beam pattern that is 6 degrees vertical by 12 degrees horizontal. The radar's probability of detecting the ship on a single scan under these conditions will be less than 50 percent for ranges greater than 50 nm. As the aircraft approach to within 50 nm from the fleet, the use of noise jamming to obscure the fleet will become ineffective because the radiant intensity received from the jammers will be much less than the radiant intensity backscattered from the ships. This kind of performance on advanced radars indicates that single airborne jammers will be restricted to handling threats at relatively long ranges (in this example, greater than 50 nm) from the fleet unless more power or antenna gain is available, or unless the jammer is deployed differently.

6.4.7.4.1 Receiver

The receiver of the jammer would detect the presence of radar signals and measure their frequencies and angles of arrival. This analysis operation would most likely be done when the jammer was not radiating, although continuous reception (look-through) has been used in some airborne jammers. Either a scanning or a monopulse system could be used to measure arrival angle, in order to determine the sector to jam. A scanning system would be preferable to reduce the number of components. The antenna system postulated switches at a high rate between six antennas each with a conservative 10 db gain; in fact, a 25 db gain appears quite feasible. Microwave diodes are available now to perform the scanning function electronically, at a rate fast enough (0.1 $\mu$sec switching time between sectors) to achieve detection on a single pulse arriving from any azimuth angle. At this rate, all six sectors could be scanned in 0.6 sec. Switching among these sectors produces a loss estimated conservatively at 8 db. Losses less than 4 db are regarded feasible by 1970. The postulated broadband receiving system would cover 1 Gc within X-band, using a low-noise receiver (3 db noise figure), which also appears reasonable for the 1970 period.

The range at which enemy radar signals can be detected by a jammer of this type is an important parameter. Against a high-performance enemy radar, detection of the electromagnetic emission is not a difficult task. At a range of 300 nm, the main beam of the enemy radar would produce, at the jammer receiver, a signal level of -43 dbm. This represents an adequate safety margin, which should ensure that all modern airborne radars capable of detecting the fleet can be detected by the jammer within line-of-sight range.

After the radar pulses are detected, the signal might be passed through a bank of filters each with a bandwidth of 10 Mc or a Q of about 1000, which is feasible in X-band. Detectors on the outputs of these filters would indicate the frequency of the enemy signal.

6.4.7.4.2 Transmitter

After the direction and frequency of the incoming signal has been determined, the jammer control unit would select the antenna required to jam the desired sector and adjust the frequency and bandwidth of the jamming transmitter. Perhaps jammer power-spectral-density might also be selected upon the basis of receiver measurements of the amplitude of signals detected and the amount of power available.

One technique for frequency and bandwidth adjustment, used in the AN/ALQ-27, takes noise generated at low level and passes it through the same filters that received the signals. After the noise spectrum is shaped in this manner, the low-level noise power is amplified in a TWT chain to increase the power to effective levels. In this way, frequency differences between the transmitter and the measuring equipment can be avoided. In the two-tuple method the transmitter is a carcinotron which is set on frequency by using the frequency measuring equipment to supply feedback. Atlthough the AN/SLQ-12 uses a fixed bandwidth, a method for adjusting bandwidth could be developed.

If the enemy radar does not use rapid frequency tuning, the jamming receiver can monitor the incoming signals for a short time--of the order of 10 milliseconds--measuring the directions and frequencies of the enemy signals. After this look-through period, the control unit will select the sectors and frequency bands required to counter the enemy signals. In addition, the unit might select a distribution of power over the frequency bands chosen, based on power measurements of the received signals. When these measurements and control functions have been performed, the jammer will radiate the desired noise spectrum over the spatial regions selected for a variable period on the order of one second and then return to the listening mode to recycle through this sequence.

Rapid frequency tuning of the enemy radar--such as pulse-to-pulse frequency agility or pulse chirping--can be expected in the 1970 period. This will require provision for continuous look-through and rapid adjustment of the jamming power. Although continuous receiving while jamming is a difficult if not impossible task for shipboard equipment, operational airborne jammers have been built with this feature. With an airborne platform the antenna system might be designed to reduce, to acceptable levels, the coupling between the transmitting and receiving antennas.

### 6.4.7.5 The Airborne Deception Repeater

Airborne ECM platforms can be employed in another mode of operation to confuse the enemy and impede the process of target evaluation. By concentrating the radiated power in pulse packets similar to those reflected from ships, the ECM system might simulate ship echoes on the airborne radar display. The task may be easier if the ships are employing equipment such as the AN/ULQ-6 to obscure their natural echoes and cause all to appear as large capital ships. The airborne ECM system would receive radar signals and repeat amplified copies of these signals at time delays corresponding to targets at longer ranges.

In its simplest configuration, a deception repeater would consist of a receiver, a delay circuit, and a transmitter. The receiver would detect the radar pulse, delay the signal varying amounts to form multiple targets, and then retransmit it to the radar. The same power tube could be used in two different modes of operation for both jamming and deception.

The deception device can produce on the scope of an advanced offensive radar false target indications that will resemble those produced by an aircraft carrier for ranges from 30 nm to the radar horizon if peak powers of 25 kw are available. If the airborne deception device is in front of the fleet, it can produce false targets in front of the fleet even in the face of pulse coding that prevents generation of false targets ahead of the deception device.

The number of targets that the device could produce would depend on the ranges of the aircraft from the device. At a maximum peak power of 25 kw, the device could generate pulses every 2.67 nm in range and maintain a short term average power of less than 10 kw. This would produce about 35 targets in a 90 nm interval behind the device. Images appearing at longer ranges would require less than the maximum peak power. Consequently, for reasonable peak and average power, on the order of a hundred false targets could be generated to appear in a 250 nm interval for each attack radar under typical tactical conditions.

6.4.7.5.1 Design Characteristics

Consider a deception system collocated with an aircraft carrier and using an omnidirectional receiving antenna with a gain $G_r$ of 2 db. The effective antenna aperture, A, is $2 \times 10^{-4}$ $m^2$, from the relationship $A = G_r (\lambda^2/4\pi)$, 97 db below the aircraft carrier cross section. At a range of 300 nm, the main beam of the enemy radar would produce at the deception receiver a signal level of -43 dbm, adequate for detection by the deception receiver. If this signal were delayed various times and retransmitted, apparent echoes at several ranges beyond the location of the deception repeater would be generated. To simulate the cross section of an aircraft carrier, a deception transmitter gain of about 97 db over the incoming signal would be required to generate false targets near the deception repeater.

With the radar at 300 nm distant, the required deception pulse power would be only 250 w. As the radar closed to a range of 30 nm from the repeater, pulse power of 25 kw would be required to simulate an aircraft carrier.

6.4.7.5.2 Intensity Matching

Matching the intensity of false targets produced on the radar scope to that which would result from true targets at corresponding ranges will be a task of some difficulty. With the deception device 30 nm from the radar and producing targets distributed in range from the location of the deception device to 90 nm behind the device, matching will require reducing the power of 24 db from the leading pulse to the trailing pulse. However, with good intelligence data, the range of the radar probably can be estimated with enough accuracy to match the false target intensity to the required level to within 10 db. The effect of this matching error on the ability of the offensive radar operator to discriminate between real and false targets is not well understood. Certainly, sophisticated processing equipment could make use of this discrepancy to reject false targets, but how many real targets would be rejected also could only be determined by simulation and field testing to verify the simulation.

6.4.7.5.3 Sidelobe Deception

By transmitting only when signals are received on the main beam of the radar, the azimuths of the false targets are fixed and cannot be varied. That is, the false targets generated by one deception device will appear on the offensive radar scope along an azimuth line in the direction of the deception device. Perhaps this regularity in the pattern of false targets could be used to discriminate between false and real targets. One possibility for avoiding this pattern regularity is the use of sidelobe deception. In sidelobe deception, the power transmitted is increased to compensate for reduction in the receiving gain of the radar antenna in a side lobe. Transmitting enough power into the side lobe gives the appearance of false targets along the azimuth direction in which the main beam is pointing. Thus false targets could be generated in both azimuth and range.

One limit on the use of this technique to produce false targets is peak power. A side lobe of 20 db below the main beam could be detected at 300 nm and would require a gain-power product of 45 dbw to simulate an aircraft carrier (61 $dbm^2$). For omnidirectional deception antennas of 2 db gain, this would require 50 kw peak power. For sidelobe levels of 30 db below the main beam, which are more likely for advanced radars, detection would not occur until ranges of 90 nm or less. At this range, a gain-power product of 66 dbw is required or a peak power of 2.5 Mw with a deception antenna gain of 2 db. Even with deception antenna gains of 10 db, peak power of 400 kw would be required. Hence, high peak powers and large antenna gains are required to transmit realistic false targets of large cross section into the side lobes of advanced radars.

False target intensity matching is expected to be even more difficult for sidelobe than for mainlobe deception.

From these considerations, it is concluded that sidelobe deception of advanced radars will not be effective. To generate false targets dispersed in azimuth, airborne platforms could be deployed at various azimuths. Increasing the number of aircraft appears to be the feasible way of generating false targets dispersed in azimuth.

6.4.8 Operational Considerations for ECM Platforms

The ECM platforms should be positioned within the enemy's radar search field. If his external reconnaissance sources disclose fleet position within 15 to 50 nm, the enemy will search with his target fix radars a region perhaps twice that dimension. ECM stations 30 nm ahead of the ships are reasonable. Against a raid operating 10 target spotter radars at any one time, five ECM platforms in the jamming mode would hold single-scan detection probability to about 0.25; in the deception mode sufficient power would be available to create about 125 false targets on each radar scope.

Platforms operating in the noise-jamming mode could be located on the same azimuths as the ships, as well as at other azimuths. Those on the same azimuth could deny range on the ships, while those at other azimuths would produce spurious strobes to frustrate enemy triangulation. Platforms operating in the deception repeater mode could be similarly placed, which is convenient since we propose to combine both jamming and deception capabilities in the same ECM package.

To increase enemy confusion, platforms could be located both near the surface and at altitudes up to about 2,000 ft. This measure would help frustrate enemy attempts to discriminate ships from spoofers by noting which images appear and disappear when he changes altitude.

Unless the fleet exercises strict control over electromagnetic emissions, the enemy can locate the force by passive detection and triangulation, and our jammers, ship or airborne, cannot deny this avenue of position fixing. At 100 nm, direction finders with 1-degree beamwidth can locate a radiating ship to within about 2 nm error. The uniqueness of individual ship emission signatures might even permit identification of the force and its constituent ships. These passive methods may be less convenient, slower and less accurate than target localization radar, and, of course, they require both passive listening and strobe-passing capability, but neither of these impose prohibitive requirements, and both are likely capabilities for aircraft that could attack the fleet.

One possible remedy for the defense is to rely upon AEW radars for warning and maintain ship radar silence until bombers are within engagement range of defensive missiles. In this circumstance missile-launching fighters can play an important kill role because they can attack the raid without disclosing fleet position. The picture then is this:

(1) Fix-denial ECM and fleet EMCON delays enemy weapon release.

(2) Meanwhile, fighters attack the raid with air-launched missiles, without disclosing ship positions. (Our AEW aircraft on station at 100 nm or more from the fleet need not be silenced, so that they can detect a distant approaching raid and alert the fleet and direct fighters.)

(3) When the raid has closed to within range of the majority of our SAM batteries, then open fire with SAMs against the delivery aircraft.

These operations may require coordination between surface and airborne elements beyond what is presently implemented.

6.4.9 Summary

1. ECM against enemy target localization radar can deny or delay enemy weapon release and increase exposure to AAW firepower thus forcing the enemy to rely upon area fire on targets of opportunity, which is less effective and more vulnerable to countermeasures.

2. Airborne ECM complements ship-borne ECM in that it:

(1) Creates noise-jamming strobes at spurious bearings to frustrate enemy triangulation efforts

(2) Projects deception images ahead of the ships and at false bearings

(3) Denies range deduction from ship horizon altitude determination

(4) Promises continuous ECM receiver look-through against advanced radars.

3. Fixed-wing carrier-based aircraft, such as the F-111B are less attractive for use as airborne ECM platforms than are helicopters. The helicopters do not interfere with strike missions because they can operate from small ships, can hover, and are relatively low in cost.

4. The F-111B could attempt the airborne ECM mission as another part of its multipurpose capability, but many of its features, such as high speed, would not be justified in the ECM role. High speed would hamper the ECM role; the ECM role might, in turn, interfere with the primary missions of the F-111B.

5. A 1000-lb, demountable pod, fix-denial ECM package appears feasible for use as a basic airborne ECM module suitable for employment with fixed-wing or helicopter aircraft, singly or, where weight and space constraints permit, in multiples. Such a device might occupy 40 ft$^3$ of space and combine capability for either pulse-repeater deception, with peak power on the order of 25 kw, or 10 kw broad-band noise jamming.

In short, it appears that airborne ECM can enhance fleet survival at low cost.

# Appendix A

## BASIC RADAR EQUATIONS USED IN THE NWRC COMPUTER SIMULATION

## Appendix A

### BASIC RADAR EQUATIONS USED IN THE NWRC COMPUTER SIMULATION

Equations are utilized in the simulation program which enable the computation of received signal energy and received noise power per cps bandwidth. From this data, the probability of detection of the target, or group of unresolved targets, is computed from a third equation which takes into account additional radar factors; e.g., false alarm rate and number of pulses integrated. These equations are constructed so that they may be used in the same manner for both the jammed and clear environments. The equations must be modified for each radar by changing five "radar constants" and selecting appropriate functions to describe the three-dimensional antenna patterns. In addition, each radar has a limitation on maximum range caused by its instrumentation that should be considered as a "scope limit."

The radar signal energy returned from a target may be computed as

$$E_{T_c} = \frac{C_1 \sigma_{50} F(\theta)^2}{R_{T_c}^4} \qquad (A.1)$$

where

$E_{T_c}$ = Signal energy returned from a target within resolution cell c (joules)

$\sigma_{50}$ = Median radar cross-section of target (Computed as a function of aspect angle)

$\theta$ = Elevation angle of target

$R_{T_c}$ = Slant range to target

and

$$C_1 = \frac{P_T \tau G_T G_R \lambda^2 L_T L_R L_p L_A C_B}{(4\pi)^3} \qquad (A.2)$$

where

$C_1$ = a constant performance factor for the radar (joule - meters$^2$)

$P_T$ = Peak transmitted power (watts)

$\tau$ = Pulse width (seconds)

$G_T$ = Transmitting antenna gain in direction of maximum gain

$G_R$ = Receiving antenna gain in direction of maximum gain

$\lambda$ = Wavelength of radar signal (meters)

$L_T$ = Transmission line and duplexer loss on transmit

$L_R$ = Transmission line and duplexer loss on receive

$L_p$ = Pattern loss (effect of beam shape on pulse integration)

$L_A$ = Atmospheric attenuation

$C_B$ = Correction factor for nonoptimum bandpass .

The parameter $F(\Theta)$ takes into account the variation in antenna gain with elevation angle. This variation is important for accurate computation of radar performance because it is quite large for many of the surveillance radars. Fortunately, the patterns of all the radars to be used in the simulation can be described with only three pattern equations.

The noise power per cycle measured at the input of the radar receiver consists of two parts. First is the receiver noise, a constant for each radar, where:

$$N_o = kT\overline{NF} = C_2 \tag{A.3}$$

$N_o = C_2$ = Noise power per cycle at input of radar receiver without jamming

$k$ = Boltzmann's constant ($1.380 \times 10^{-23}$ joule/degree K)

$T$ = Temperature, assumed to be 290°K

$\overline{NF}$ = Radar noise figure, not including transmission line and duplexer losses.

The jamming noise power seen by the radar may be caused by the jamming efforts of several targets. Since the individual jammers are independent, their contributions can be computed separately and then added together. The noise power per cycle seen at the input to the radar receiver due to a noise jammer $J_i$ is:

$$N_{J_i} = \frac{P_{J_i} G_{J_i} G_R \lambda^2 L_R (L_P L_A)^{1/2} F(\theta) F(\phi) F(x)}{B_{J_i} (4\pi)^2 R_{J_i}^2} \qquad (A.4)$$

where

$N_{J_i}$ = Noise power per cycle at input of radar due to noise jammer $J_i$ (watt/cycle)

$P_{J_i}$ = Radiated jamming power (watts)

$G_{J_i}$ = Antenna gain of jammer in the direction of the radar

$\theta$ = Angle between $J_i$ and look direction in the horizontal plane

$F(\phi)$ = Antenna pattern of radar as a function of $\varphi$

$x$ = Angle between $J_i$ and look direction in the vertical plane [pencil beam radars only for a fan beam $F(x) = 1$]

$F(x)$ = Antenna pattern of radar as a function of $x$

$B_{J_i}$ = Bandwidth of jamming noise (cps)

$R_{J_i}$ = Slant range between jammer and radar (meters).

For convenience, define the constants

$$C_3 = \frac{G_R \lambda^2 L_R (L_P L_A)^{1/2}}{(4\pi)^2} \quad , \quad \text{a radar constant} \quad ; \qquad (A.5)$$

and

$$K_{J_i} = \frac{P_{J_i} G_{J_i}}{B_{J_i}} \quad . \tag{A.6}$$

Then

$$N_{J_i} = \frac{C_3 K_{J_i} F(\theta) F(\phi) F(x)}{R^2_{J_i}} \quad . \tag{A.7}$$

The method used to determine detection probability depends on the radar design. It has been assumed that all radars in use during the 1965-70 time period will have CFAR receivers. Thus, the signal-to-noise ratio of importance is

$$\frac{E}{N} = \frac{\sum_{c} E_{T_c}}{N_o + \sum_{i} N_{J_i}} \quad . \tag{A.8}$$

For this class of receiver, the mean probability of detection $P_d$ for a slowly-fluctuating signal* has been shown to be approximated by the relationship.

$$P_d \approx \exp - \left[ \frac{\lambda_p - m + 1}{m \frac{E}{N} + 1} \right] = \exp \left[ \frac{C_4}{C_5 \frac{E}{N} + 1} \right] \tag{A.9}$$

for $m(E/N) \gg 1$.[22]

$m$ = number of pulse integrated after detection

$\lambda_p$ = Threshold level, dependent on m and desired false alarm probability.[22]

---

* Radars with pulse-to-pulse frequency diversity should be considered to have rapidly fluctuating signals.

For convenience, define the constants

$$C_4 = m - 1 - \lambda_p$$

$$C_5 = m \qquad \text{(A.10)}$$

Using the equations developed thus far, the detection probability for each target, jamming or quiet, may be determined. Assumptions made are as follows:

(1) A pattern loss $L_p$ of 1.6 db was used, to correct for the fact that not all of the pulses received between half-power points are the same strength. This is derived and discussed by Blake[23,24]

(2) An atmospheric loss $L_a$ due to attenuation by atmospheric oxygen was used. This loss is a function of range and elevation angle but was assumed a constant for each radar on the basis of the loss at the estimated free space detection range and the curves developed by Blake[25]

(3) Transmission line losses were estimated assuming about 100 feet of line and using the Attenuation of Transmission Lines Chart[26]

(4) Radars using an intensity modulated display were assumed to have a 3-db loss on receive due to collapsing loss, scope nonlinearity and "operator loss"

(5) A bandwidth correction factor $C_B = 1/1.2$ was assumed to correct for the unmatched characteristic of receiver bandpasses

(6) Constants given for radars which have search and track modes are computed on the basis of the search mode. All of these radars will track at least as far as they can acquire.

It was convenient to define the following functions:

$$f_1(\theta,h,\lambda) = \left[\sin \frac{h}{\lambda} 2\pi \sin \theta\right]^2 \qquad \text{(A.11)}$$

where

h = height of radar antenna from sea level.

This function is useful for describing the elevation antenna pattern for horizontally polarized antennas with frequency below 500 Mc. It assumes that the sea is a perfect reflector.

$$f_2\ (x,a) = \left[\frac{\sin \frac{2.783x}{a}}{\frac{2.783x}{a}}\right]^2 \qquad (A.12)$$

where

$a$ = the antenna 3 db beamwidth.

This function is used to describe the pattern in bearing $F(\phi)$ for all the radars and to describe the function $F(x)$ for the pencil-beam radars. It is probably an accurate approximation for the main-lobe.

$$f_3\ (x,a,b) = \frac{a \csc^2 x}{\csc^2 b} \qquad (A.13)$$

This function is useful for describing a portion of the antenna pattern for the fan beam radars.

The functional description of off-boresight gain $[F(\phi), F(x)]$, gives a sidelobe rejection of only 13.2 db, which is not as good as the actual antenna patterns. If it is desirable to include the effects of sidelobe jamming, it might be desirable to modify these equations to improve the sidelobe characteristics.

Appendix B

# SIMULATION OF AN AUTOMATIC THREAT EVALUATION PROCEDURE APPLICABLE TO ECM AND NON-ECM ENVIRONMENT SITUATIONS

Appendix B

SIMULATION OF AN AUTOMATIC THREAT EVALUATION PROCEDURE
APPLICABLE TO ECM AND NON-ECM ENVIRONMENT SITUATIONS

## B.1 Introduction

The Threat Evaluation and Weapon Assignment (TEWA) procedure used in the NWRC computer model was tailored to simulate, as nearly as possible, the doctrine scheduled for use in the NTDS equipment. Although the procedure for assigning target priorities and making weapon assignments to "clear" or fully detected targets was reasonably well defined for the NTDS at the time of the model development effort, there was not available a comparable doctrine for the engagement of jamming strobe targets prior to radar burn-through. Since home-on-jam capabilities were to be included in the missile guidance systems and since a determined enemy could deny radar burn-through until relatively short ranges, it was decided that a necessary supplement to the TEWA routine would be a procedure for the engagement of jamming strobe targets on the basis of passive data. Ideally, such a procedure should be in keeping with the spirit of the doctrine established for the engagement of fully detected targets, while at the same time not giving a priori assignment preference to either fully detected or jamming strobe targets, since knowledge by the enemy of any such preference could be used to his advantage.

The threat evaluation procedure simulated is based on the "nearest, least engaged" concept of target selection wherein two main factors are considered for target ordering. These factors are:

(1) The target's time to close on a defended area constructed about the ships of the task force and,

(2) The target's probability of surviving the current missile assignments made to it.

Actual target position, course, and speed information and command guidance missile assignments are used in determining the relative threat posed by fully detected targets. Jamming strobe targets are rated on the basis of synthetic target position and speed data, and on missile assignments made in the home-on-jam guidance mode. The application of these factors to the threat evaluation procedure will be more fully explained in the following sections.

Several additional factors in the NTDS TEWA procedure have not been included in the simulation program. These include the estimated target hostility (targets are assumed to be confirmed hostile upon radar detection in the simulation program), the estimated raid size (reflected in the computer model by the number of occupied radar resolution cells), and the time the targets will be in range and subject to engagement by the surface-to-air guided missile systems.

The TEWA procedure defined for use in NTDS has undergone periodic revision since the computer simulation program was developed by NWRC. Thus, the routine does not necessarily reflect the latest TEWA procedure in detail; nonetheless, it has been found to be a workable doctrine, providing task force AAW effectiveness in a complex ECM environment.

B.2 Threat Evaluation for Fully Detected Targets

Fully detected targets, that is, those whose three-dimensional position information is known, are separated into three "threat queues," HIGH, MEDIUM, and LOW according to target probability of survival. The boundaries, or thresholds, between threat queues are adjustable and provide a means of exerting control over the automatic threat evaluation procedure.

Unfortunately, perfect identification and resolution of individual targets within a multiple aircraft raid is limited by the resolving capabilities of the ship surveillance radar sets. The ships of the task force will therefore be dealing most of the time with groups of unresolved targets referred to as "tracks" or "target blobs." Thus, the targets that are visible to a ship are grouped into resolution cells, the size and shape of which are determined by the characteristics of the ship's surveillance radar. The probability that a track will survive the current missile assignments made to it by each ship in the task force may be termed the track's partial threat number. Thus,

$$\theta_{t/s} = (1 - p_{k1})_{ts} \cdot (1 - p_{k2})_{ts} \cdot (1 - p_{k3})_{ts} \cdots (1 - p_{kn})_{ts} \tag{B.1}$$

where $\theta_{t/s}$ is the partial threat number of track t with respect to ship s, and $(1 - p_{kn})_{ts}$ is the probability that the track will survive the $n^{th}$ current missile assignment made to it by ship s. In the case of fully detected targets, only command guidance missile assignments are considered in computing the partial threat number. The ship, of course, does not have knowledge of the number of aircraft within the track and must compute a single threat number to represent all the aircraft, based on the number and kill probabilities of surface-to-air missile assignments made to the track.

The effective, or over-all, threat number of a track with respect to a particular ship, b, is defined as the probability that the track will survive those current missile assignments made to it, of which ship b is aware. Thus, the threat number of track t is derived by combining the partial threat number from all ships with which ship b can communicate:

$$\theta_{tb} = \prod_{s=1}^{S} \theta_{t/s} \tag{B.2}$$

where $\theta_{t/s} = 1$ for all ships which cannot communicate with ship b, and S is the total number of ships in the task force. These "track" threat numbers are then used to divide the targets among the three threat queues mentioned earlier.

Within the HIGH and MEDIUM threat queues, the targets are further ordered by their time-to-close on a defended zone. (Missile assignments are not made to LOW threat targets). Figure B.1 shows how such a zone might be constructed about the ships in the main body of the task force, where $R_s$ is the radius of the defended zone circle about ship s. The importance of certain ships within the force may be reflected by adjusting the magnitude of the corresponding $R_s$. It should be noted that the size of the defended zone circles do not necessarily bear any relationship to the SAM performance boundaries.

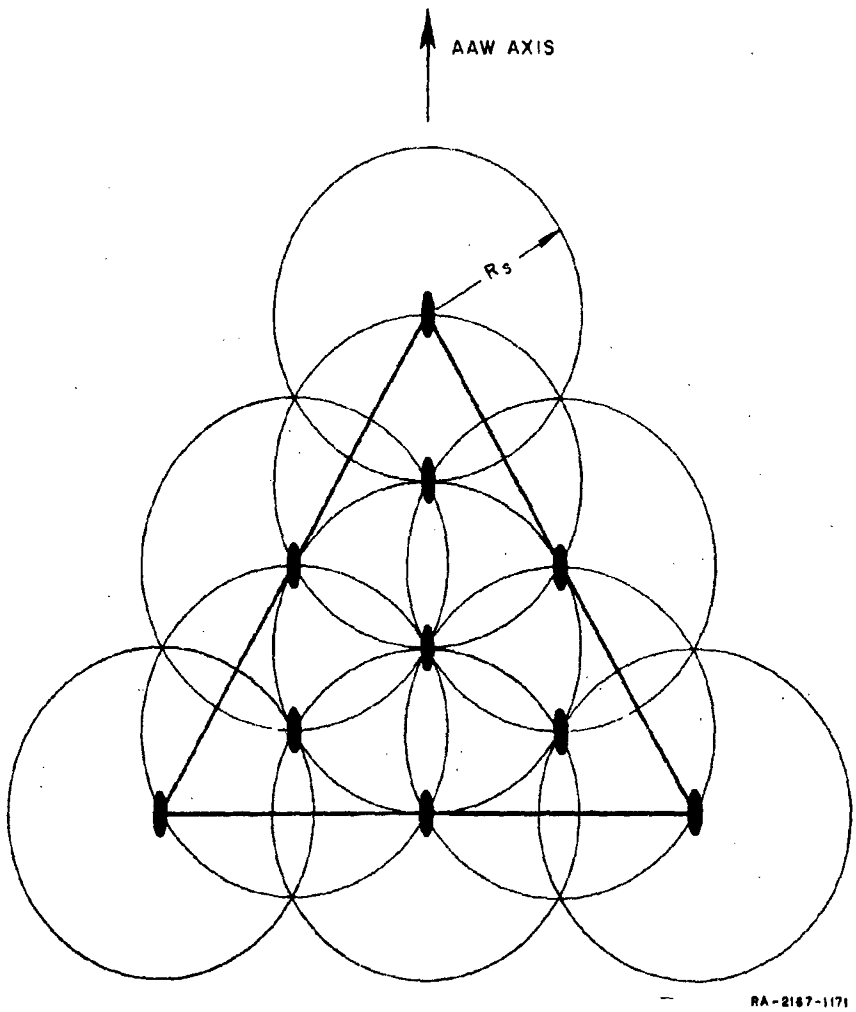


FIG. B.1 DEFENDED ZONES

In the computer program, a single target is selected from within each "track" and its course and speed is assigned to the track for the purpose of computing the time-to-close on the defended zone. As shown in Fig. B.2, the target is projected along its present course until its path intersects the defended zone, at point A. The time at which the target would reach point A is called the "time-of-closing" and that time minus the current game time is the "time-to-close" for that target. Targets whose projected flight paths do not intersect the defended zone

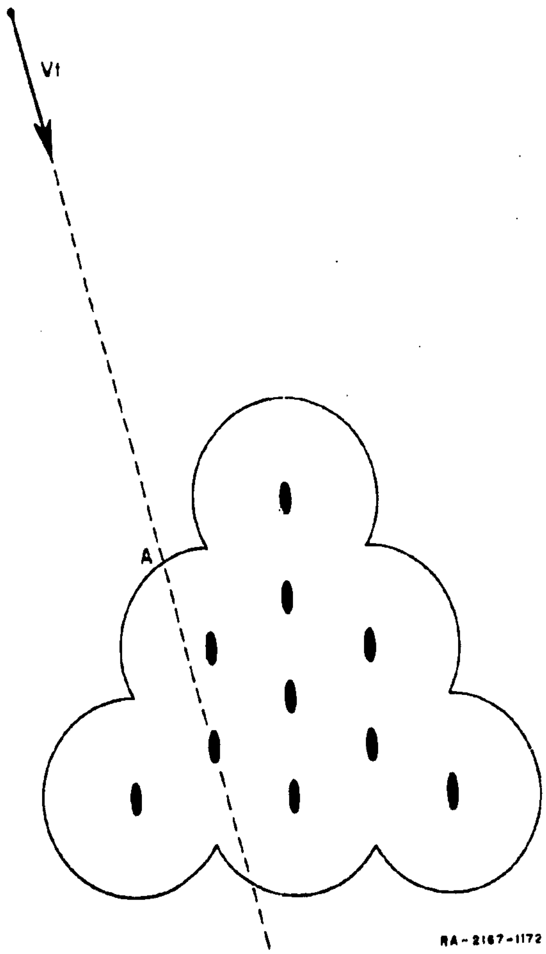


FIG. B.2 TARGET INTERSECTION WITH DEFENDED ZONE are given infinite times-to-close and are not further considered for possible weapon assignments.

The "track" within the HIGH threat queue with the shortest time-to-close is the first target to be considered for possible missile assignment. If it cannot be engaged or if additional weapons are available aboard the ship being considered, the target with the next shortest time-to-close is then selected, and so on, until the HIGH threat queue is exhausted. Thereafter, the targets in the MEDIUM threat queue are considered for possible missile assignments in the same manner of selection.

## B.3 Threat Evaluation for Jamming Strobe Targets

The procedure for determining the threat posed by jamming strobe targets is very much the same as that used for fully detected targets with three important differences;

(1) The range and range rate associated with a jamming strobe target is derived from the synthetic track (SYNTRAC) data.

(2) Strobe target threat numbers are derived from the probability of surviving current missile assignments made in the home-on-jam guidance mode.

(3) There is no intership coordination of jamming strobe target engagements since correlation of strobe data, for this purpose, is considered to be prohibitively difficult.

A jamming strobe target is defined to be a continuous jammed sector as seen by the surveillance radar of the ship being considered. In the case of ships having more than one search radar type, data from the radar with the most narrow beamwidth is used for this purpose. Adjacent jamming targets separated by more than one beamwidth of the ship's surveillance radar would fall in different strobe target groups. Thus, as in the case of the fully detected "track," a single strobe target may contain any number of enemy jamming aircraft, up to the total number present in the raid.

In order to rank the strobe targets by time-to-close, a reference line (SYNLINE) is derived from the SYNTRAC data as shown in Fig. B.3.

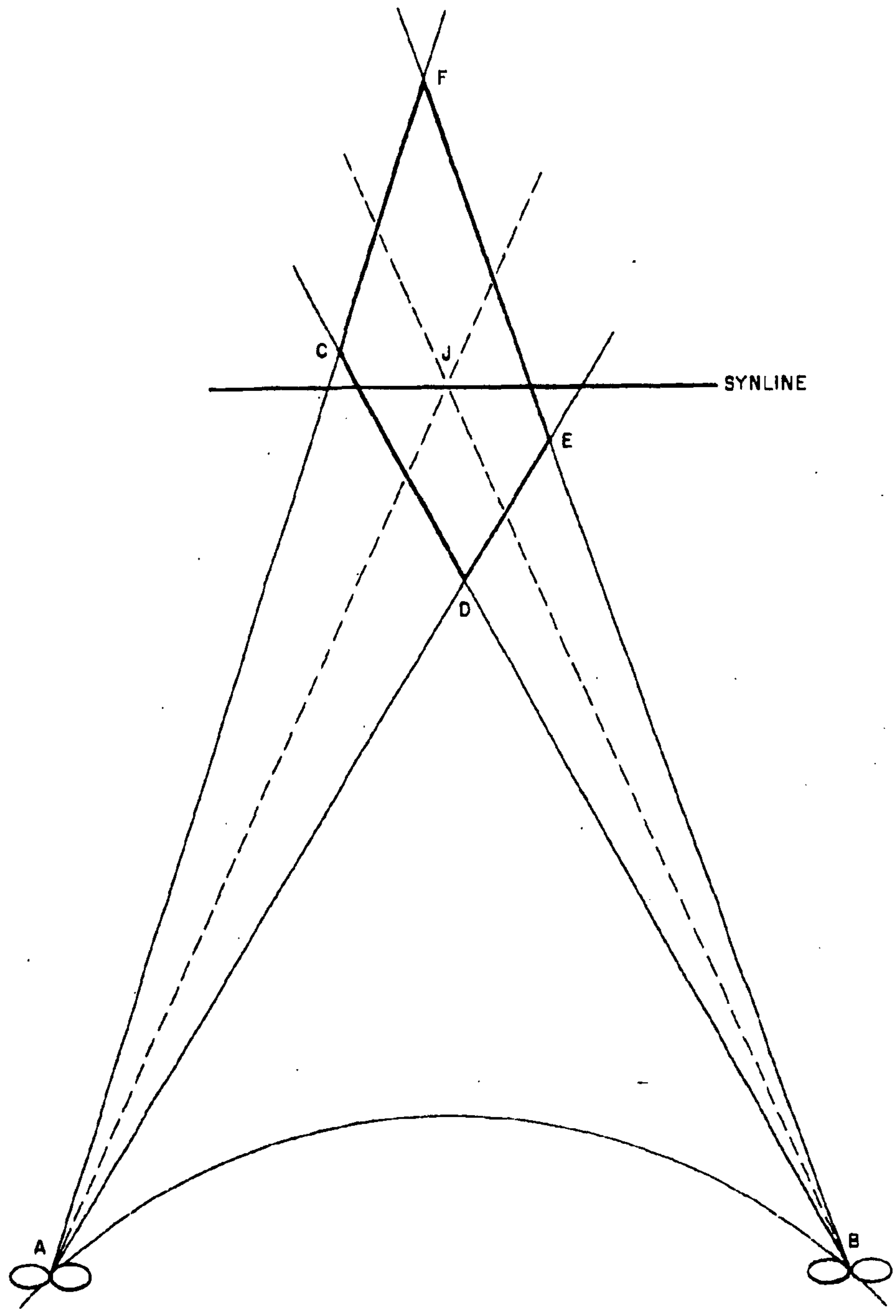


FIG. B.3 DERIVATION OF SYNLINE

This line is established by bisecting the angle formed by the intersection of the AEW jammed sector bisectors, AJ and BJ.

Figure B.4 illustrates a ship, s, which has two jamming strobe targets. The center bearing of each of these strobe targets intersects the SYNLINE at points $P_1$ and $P_2$, respectively. Within each strobe group, it is considered that there exists one target, located at point P, with a velocity vector directed toward the ship, s, of magnitude equal to the range rate solution derived by the SYNTRAC routine. Based on this synthetic target position and velocity data, the time at which the target would penetrate the defended zone, at point A, is computed. From this, a synthetic time-to-close is derived for each jamming strobe target.

The partial threat number of a jamming strobe group, g, is defined as before:

$$\theta_{g/s} = (1 - p_{k1})_{gs} \cdot (1 - p_{k2})_{gs} \cdot (1 - p_{k3})_{gs} \cdots (1 - p_{kn})_{gs} \tag{B.3}$$

where $\theta_{g/s}$ is the partial threat number of strobe group target g with respect to ship s, and $(1 - p_{kn})_{gs}$ is the probability that the strobe will survive the $n^{th}$ current home-on-jam missile assignment made to it by ship s. There may, of course, be any number of jamming targets within a strobe group. The strobe group threat number reflects the number and kill probabilities of home-on-jam surface-to-air missile assignments made in the direction of the strobe by the ship being considered.

Since there is no intership coordination of strobe target assignments in this program, the effective threat number of a jamming strobe group target with respect to a particular ship, b, is the same as the partial threat number with respect to that ship:

$$\theta_{gb} = \theta_{g/s}, \quad \text{where } s = b \quad . \tag{B.4}$$

These strobe group threat numbers are then used to divide the jamming targets among the same three threat queues used for the fully detected "tracks."

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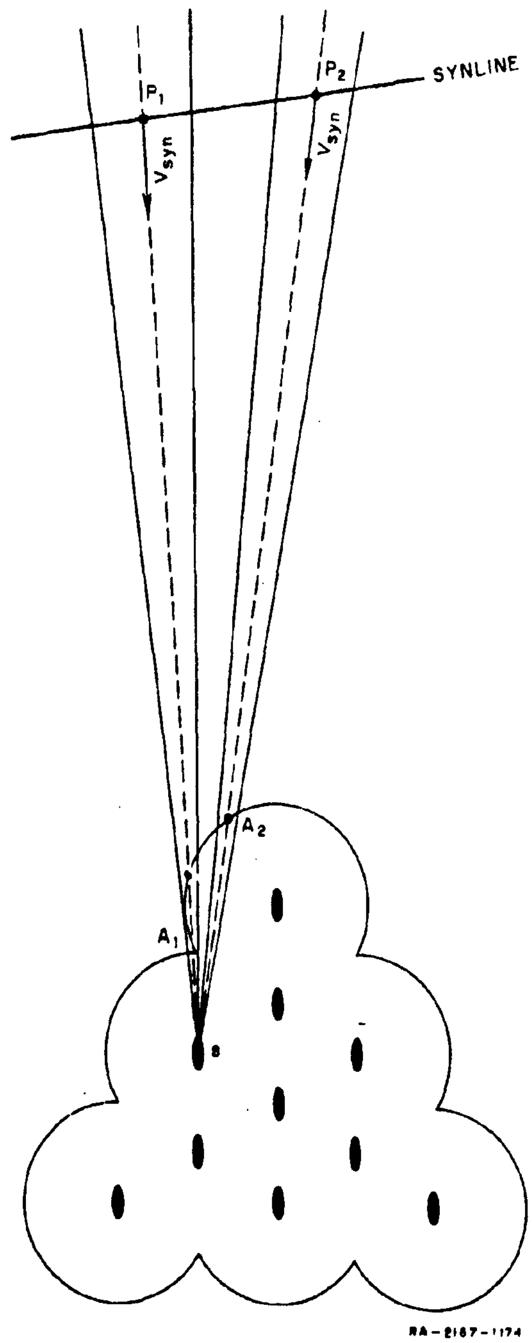


FIG. B.4 SHIP WITH TWO STROBE TARGETS



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Within the HIGH and MEDIUM threat queues, the targets (both strobes and tracks) are further ordered by their time-to-close (real or synthetic) on the defended zone. The target within the HIGH threat queue with the shortest time-to-close is the first target considered for possible missile assignment. In the case of jamming strobe targets, the weapon control station is presented with the azimuth and approximate range of the jamming target to be engaged, along with an indication that this is a strobe target.

It should be noted that the electronic environments of the surveillance and tracking radars may be quite different and that therefore, the surveillance radar status (fully detected or jamming strobe) of a target presented for possible missile assignment does not necessarily determine the guidance mode to be used. The following four combinations of surveillance/tracking radar detection status are possible:

(1) Surveillance detected - Tracking detected
(2) Surveillance strobe - Tracking detected
(3) Surveillance detected - Tracking strobe
(4) Surveillance strobe - Tracking strobe

Different tracking radar lock-on delay times are allowed for each of these four possible combinations with the shortest time normally associated with the fully detected condition (1). The missile guidance mode to be used depends, of course, on the tracking radar detection status.

Appendix C

A PROCEDURE FOR SYNTHETIC TRACKING (SYNTRAC) OF JAMMING AIRCRAFT
TO PROVIDE PASSIVE RANGE AND RANGE RATE INFORMATION

Appendix C

## A PROCEDURE FOR SYNTHETIC TRACKING (SYNTRAC) OF JAMMING AIRCRAFT TO PROVIDE PASSIVE RANGE AND RANGE RATE INFORMATION

### C.1 Introduction

The synthetic tracking routine (SYNTRAC) of the NWRC computer simulation model provides a method for deriving passive range and range rate data pertaining to noise jamming targets in an ECM environment. Briefly, strobe information from selected AEW aircraft is combined by central control ships to obtain a triangulation solution of gross jamming aircraft position, and by maintaining a time history of the solution, to obtain range rate information. This data may then be used by missile control systems having a home-on-jam capability to establish rough open fire range. Air controllers may also use this information to vector interceptor aircraft toward the general area of the jamming sources, with a reasonable amount of confidence in the range to the targets.

A necessary assumption for this method of range solution is that the radar sets employed be configured so as to be capable of obtaining "clean" strobe data, i.e., well-defined strobes in the direction of the jamming aircraft and no erroneous strobes resulting from jamming energy entering the sidelobe structure of the radar antenna pattern. This capability has been advised for the AN/APS-96 radar elsewhere in this report.

An attacking enemy force is not, of course, constrained to the employment of identically configured jamming aircraft, but may well utilize space diversity among jammers on different frequency bands in an attempt further to confuse or deceive the force units under attack. Under such conditions, the passive ranging solution obtained from surveillance radar data (L band, for example) may not at all represent the position of the aircraft jamming on other frequency bands (such as the fire control frequencies in C and X band). The decision to launch surface-to-air missiles with passive homing capability on C band against jamming targets, based on information derived from L band strobe data, may obviously be in error.

Thus, it is highly desirable to have available on the radar platforms being used to provide jamming strobe data (normally AEW aircraft) passive listening equipment operating on other frequency bands, particularly on the fire control and AI radar frequencies, with accurate direction finding capabilities. In this study, such an equipment capability has been imparted to the E-2A aircraft by assumption, and the various weapon systems have been allowed access to the most pertinent jammer position information available from the synthetic tracking routine.

Although surface vessels may be used to provide the necessary jamming strobe data, the AEW aircraft provide a much more desirable platform for this mission by virtue of four factors:

(1) For all target altitudes, the normal platform elevation (35,000 ft) of the AEW aircraft affords an increase in the distance to the radar horizon of over 200 nm as compared with surface platforms. Vast areas of overlapping passive listening coverage may be obtained with but a few AEW aircraft.

(2) The displacement of the AEW station positions, forward of the Task Force Center, serves to further extend the distance at which jamming aircraft may be detected and a passive ranging solution obtained.

(3) The separation of the AEW aircraft on adjacent stations (typically on the order of 100-250 nm, depending on the station radius and interstation angular spread) provides a relatively large base line for the triangulation solution, thus reducing the effects of strobe direction measurement errors.

(4) The loiter altitude and displacement combinations of AEW aircraft are such that one-way line-of-sight communication links can generally be maintained from the AEW to the control ships. Since the SYNTRAC solution is generated aboard surface vessels, there is no real requirement (for this triangulation scheme) to have available a surface-to-AEW communication link. The data requirements are such that even a voice radio net in broadcast mode of operation would be acceptable for the triangulation solutions obtained manually aboard the control ships.

Since the AEW are positioned and configured so as to provide the first radar early warning of an approaching attack force, it is likely that the AN/APS-96 radar frequency band would be the first to be subjected to jamming efforts by the enemy. For this reason alone, it would be desirable to have the capability to derive jammer position information from AEW radar strobe data.

C.2 Method of Solution

The disposition of a Two Carrier Task Force might be typically as shown in Fig. C.1. The station radius and the number of AEW aircraft deployed depend on the radar early warning coverage desired as well as on the number of early warning aircraft available to the force. For full 360-degree coverage, from four to six aircraft on station would be required.

If the task force is subjected to an attack force as shown in Fig. C.2, and if some of the attacking aircraft are using active noise jamming devices radiating on the frequencies of operation of the AEW aircraft, then at some time, two or more of the AEW will obtain jamming strobes in the direction of the raid. E-2A No. 1 is receiving jamming energy in the sector bounded by the left and right strobe lines, AF and AE respectively. Similarly, E-2A No. 2 experiences a jammed sector bounded by BC and BF. The quadrilateral of intersection, CDEF, contains all the jamming planes in the raid. Intersection point D is of special interest, since it defines the closest point to the task force that a jamming aircraft could be located.

Since the quadrilateral of intersection is likely to be somewhat large, especially in the direction DF, it is desirable to define and keep a time history of some point within the quadrilateral. Such a point may be considered to be the effective location of the jamming aircraft for the purpose of making an open fire decision or for vectoring interceptor aircraft. Figure C.3 shows one way in which such a point could be defined; that is, as the intersection point, G, of the diagonals of the quadrilateral. This method requires construction of the quadrilateral and would be difficult to implement for machine solution since the solution becomes discontinuous as the raid crosses the AEW station base line, AB.

A simpler method is to track the intersection point, J, of the bisectors, AH and BI, of the jammed sectors, as shown in Fig. C.4. This solution can be implemented with just one piece of information from each of the AEW aircraft, that is, the direction of the center line of the jammed sector. Knowledge of the closest possible jammer location, D,

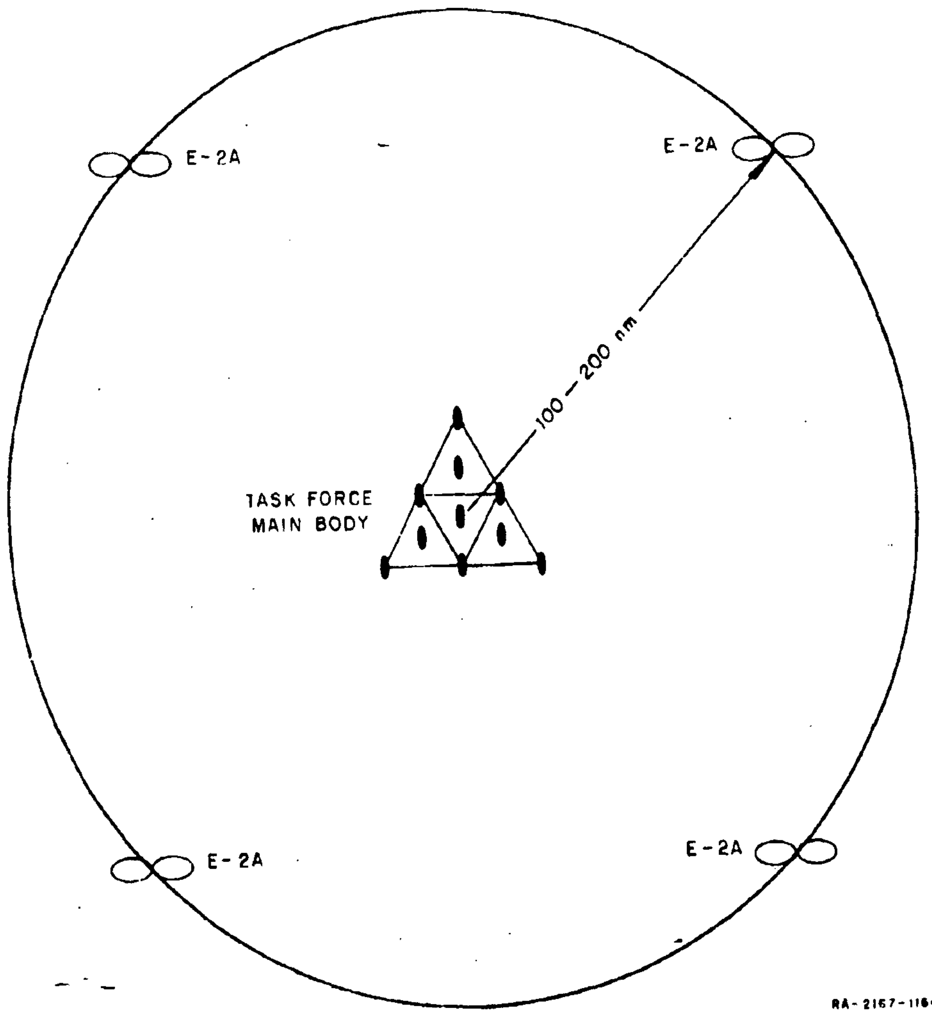


FIG. C.1 TYPICAL DISPOSITION OF TWO-CARRIER TASK FORCE

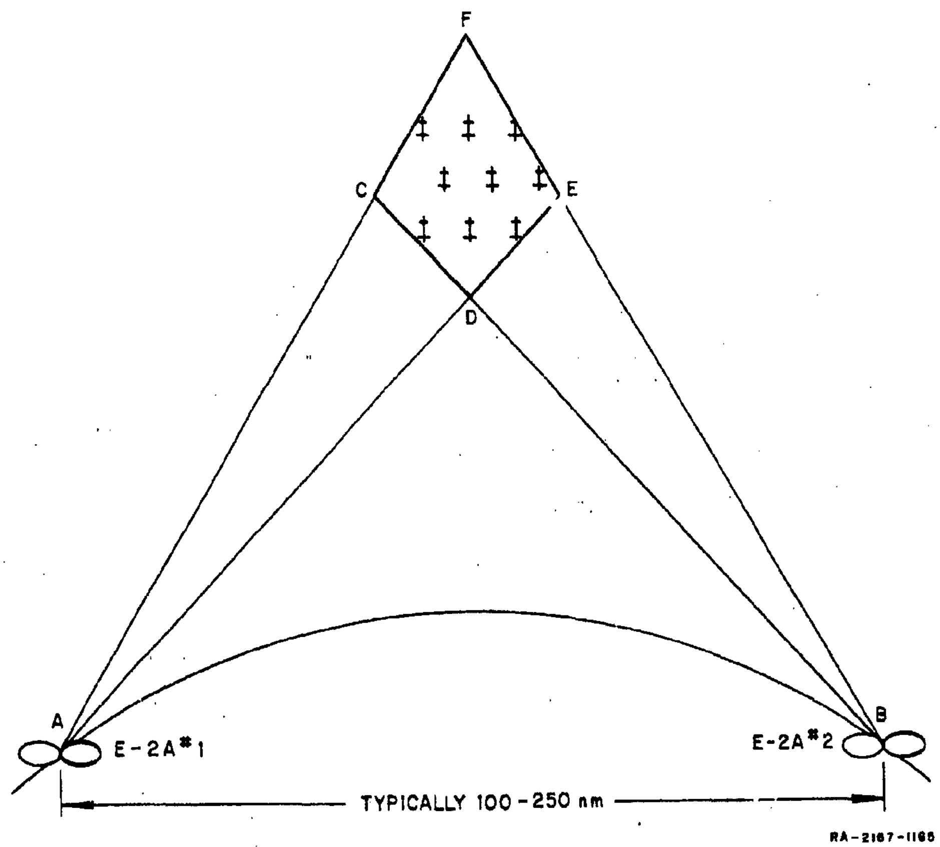


FIG. C.2 NOISE JAMMING ATTACK AGAINST TASK FORCE

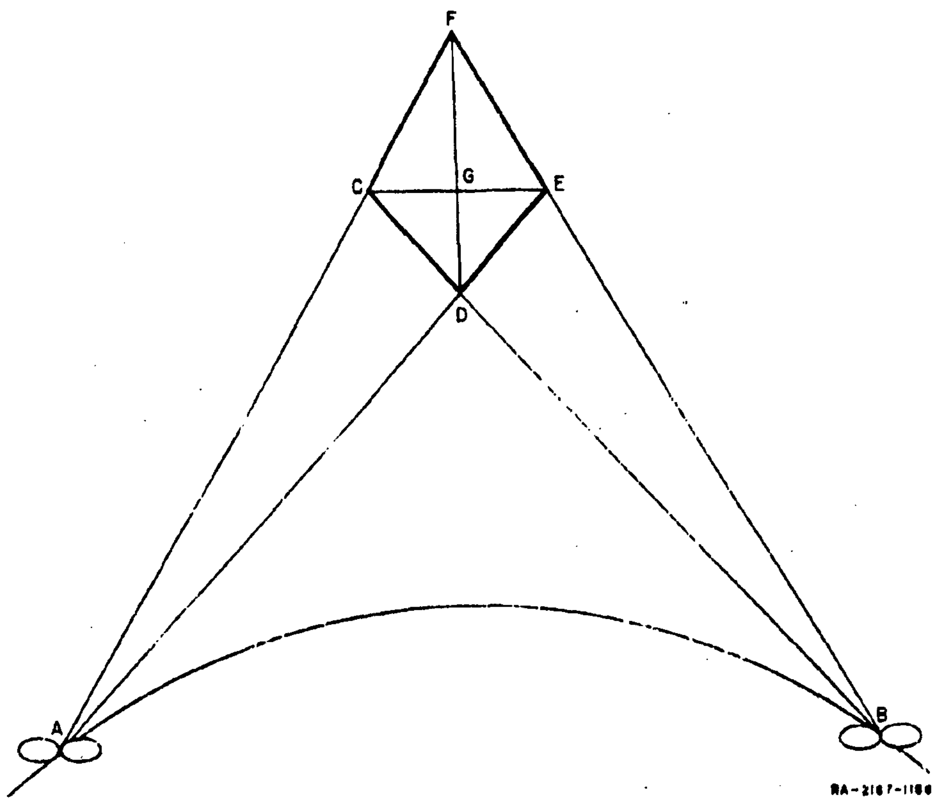


FIG. C.3 DIAGONAL INTERSECTION

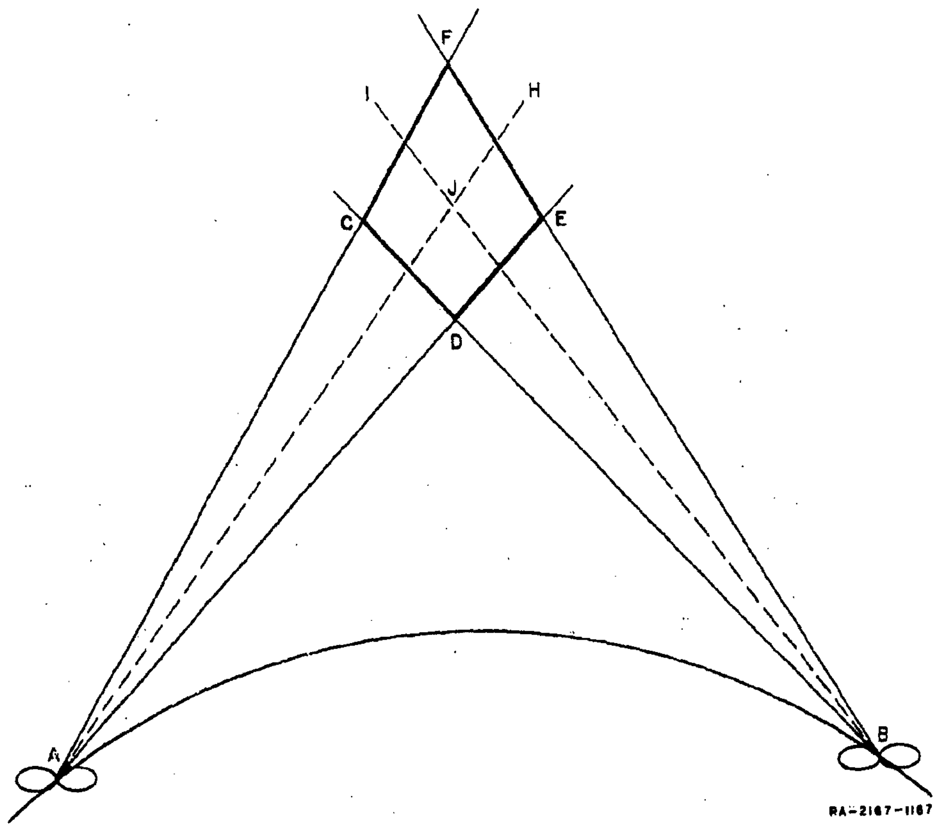


FIG. C.4 BISECTOR INTERSECTION

would then be available only if conditions permitted transmission of complete jammed sector information and the combination of the appropriate strobe sector boundaries.

If strobe direction finding equipment is available on several frequencies aboard the AEW aircraft, separate synthetic track solutions could be kept for each frequency band. Then SAM systems could determine open fire information based on the C band solution, while the interceptor aircraft are committed on the basis of the X band jamming solution.

### C.3 Limitations and Special Cases

Consider a raid formation composed of two distinct segments separated in range, axially, as shown in Fig. C.5. By straightforward application

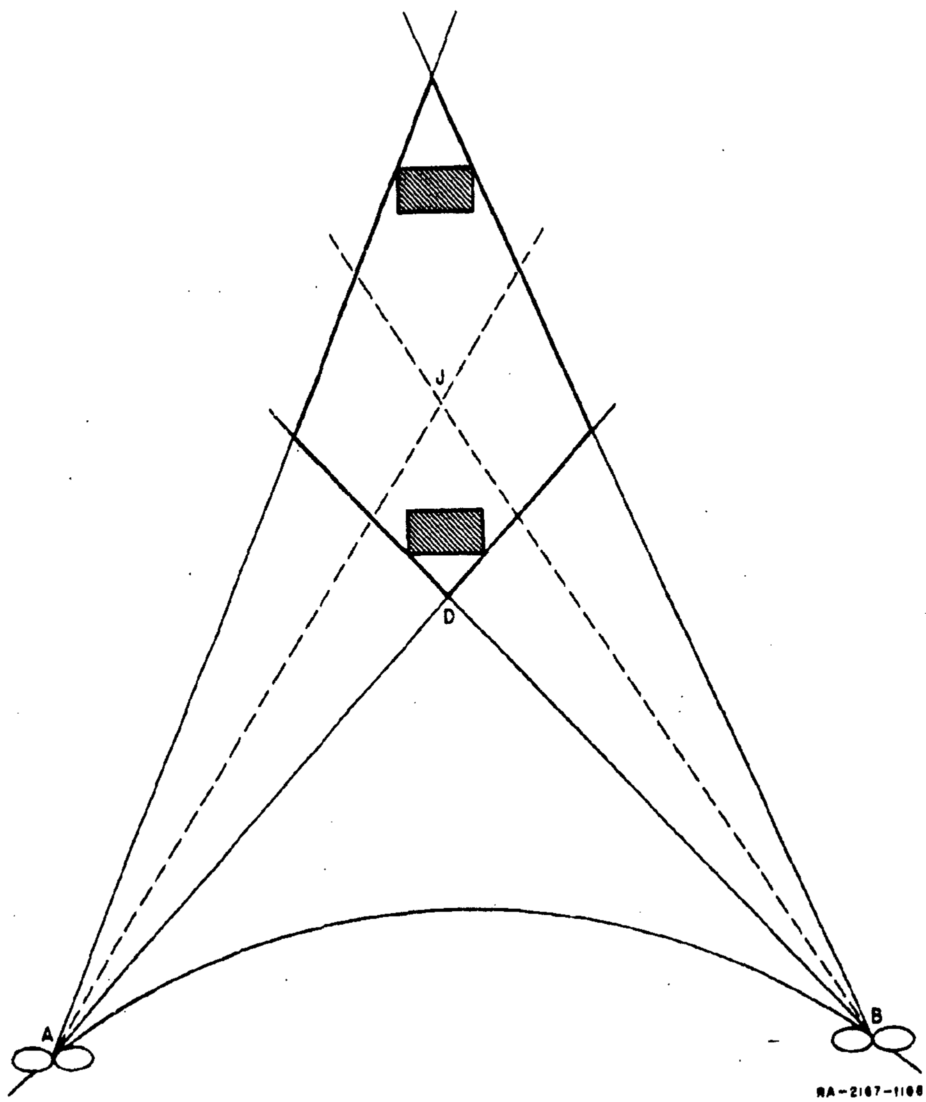


FIG. C.5 TWO-SEGMENT RAID

of the foregoing solution methods, a SYNTRAC point would be derived about midway between the two segments, where no aircraft exist. Such position information would be of little usefulness, particularly for interceptor vectoring purposes. The closest possible jammer position, D, might still be used effectively for open fire determination. An operator well trained in obtaining SYNTRAC solutions should also be able to derive additional information about the raid size and disposition from the size, shape, and time history of the quadrilateral of intersection.

If the raid segments are separated sufficiently to present the AEW aircraft with distinct, resolvable strobe groups, then multiple intersection points may be obtained as in Fig. C.6. The "ghost" intersections at points K and M are familiar to the multiple-target triangulation problem. However, by working with groups of targets and widely separated strobe groups, the number of such ghosts is reduced to manageable proportions. The number of intersection points obtained is simply the product of the number of strobe groups visible to each of the AEW being used for the SYNTRAC solution. Deghosting can be facilitated by the employment of a third radar platform location, ideally another AEW aircraft stationed directly over Task Force Center.

Figure C.7 illustrates the case of an enemy force approaching the task force from two widely separated attack directions. Here again, a ghost problem exists, however to a lesser extent. Since strobes AK and BM diverge, their intersection need not be considered and by inspection, the intersection point L is very probably a ghost; this again could easily be confirmed with strobe data available from a third radar platform.

The success of this method of passive triangulation depends upon several conditions and implicit assumptions. Included among these are:

(1) The employment by the enemy of broadband barrage noise jammers, which allows the strobes of one AEW to be correlated with those of another AEW.

(2) The use of steady noise jammers rather than blinking noise jammers; blinking jammers could perhaps be accommodated, however, increased confusion and solution complexity would result.

(3) Enemy attack formations of reasonably compact size, or widely separated groups of such compact formations.

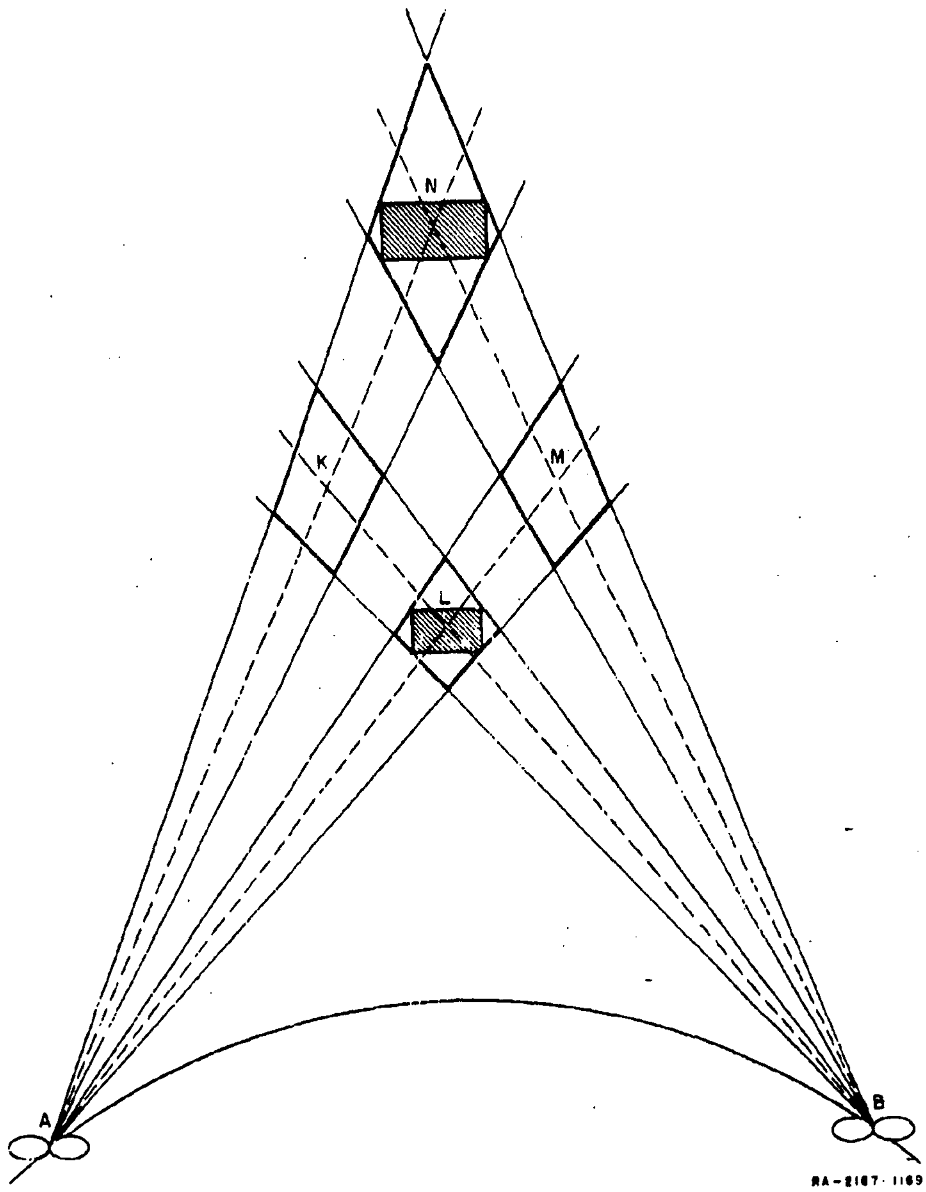


FIG. C.6 ILLUSTRATION OF "GHOSTING"

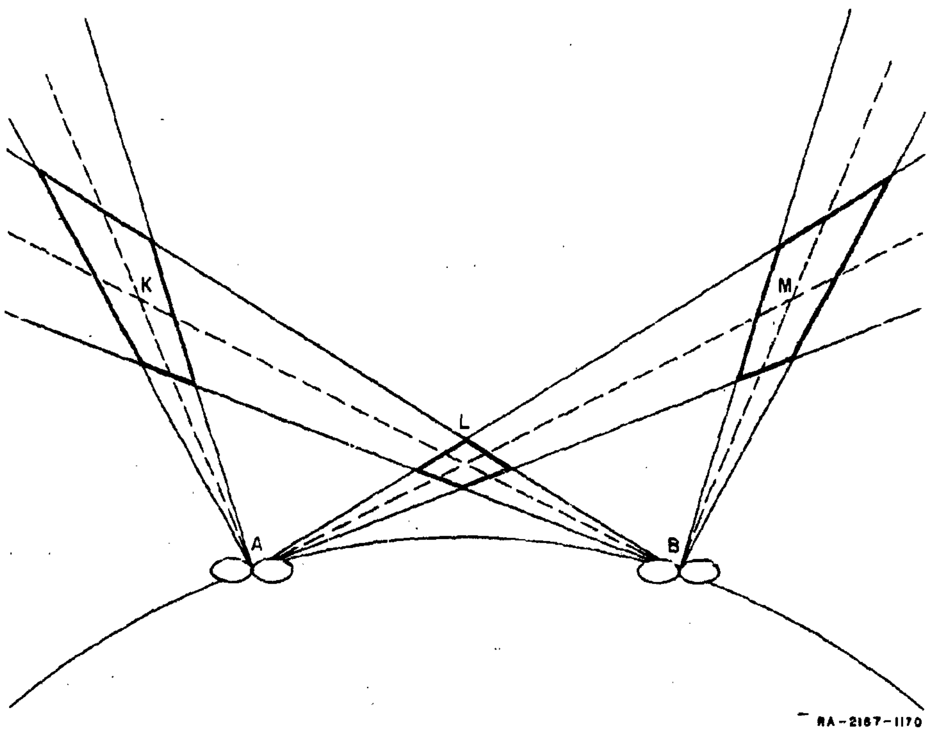


FIG. C.7 "GHOSTING" IN A WIDELY SEPARATED ATTACK

(4) Nonjamming aircraft being screened by stand-off jammers are not located by this method; however, interceptor aircraft may be vectored to counter the stand-off jammer aircraft.

The SYNTRAC method, of course, requires some shipboard personnel and equipment to derive the triangulation solutions; however, the expected payoff in an ECM environment should be well worth the investment. There is also the requirement placed on the AEW aircraft to obtain and transmit jamming strobe data to the surface control ships. It should be recalled that in some ECM conditions, the AEW will have available nothing but strobe information.

Finally, some mention of the vulnerability of the AEW aircraft to enemy roll-back attack tactics should be made. If the Airborne Early Warning aircraft is a prime source of detection and position finding information in the ECM as well as the clear environment, then it is even more likely to be selected as a priority target by the attacking forces. For this reason, it would be very desirable to provide the AEW aircraft with some measure of AAW protection. This might be accomplished by one or a combination of the following:

(1) Arming the AEW aircraft with an Air-to-Air missile system,

(2) Providing Combat Air Patrol protection for the AEW and,

(3) Stationing guided missile picket ships directly under the AEW loiter positions.

Appendix D

TASK FORCE ANTI-AIR WARFARE SYSTEMS DESCRIPTIONS

Appendix D

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## D.1 SAM Systems Descriptions

### D.1.1 General

The SAM Systems analyzed in this study are briefly described in this section. The SEA MAULER and Advanced TARTAR systems are described in more complete detail since they are system configurations specifically derived to investigate new design concepts.

Over-all single-shot kill probabilities for all SAM systems considered are shown below in Table D.1. These probabilities include missile-in-flight reliability, probability of successful fuzing, and the probability of a warhead "K" kill. For this study, all missile battery components are assumed to be fully operable. Three sets of $P_k$ data are shown in Table 4.1. Set I represents early estimates of missile kill capabilities. Sets II and III reflect the latest BuWeps estimates of these values. Set III, however, includes assumed reductions in the home-on-jam kill capabilities of the various systems. Each of the analyses discussed in Sec. 5 identifies the applicable set of $P_k$ values used therein.

Table D.1

SAM SYSTEMS KILL PROBABILITY VALUES

| Weapon Type | Set I | | | Set II | | | Set III | | |
|---|---|---|---|---|---|---|---|---|---|
| | $P_{k1}$ | $P_{k2}$ | $P_{k3}$ | $P_{k1}$ | $P_{k2}$ | $P_{k3}$ | $P_{k1}$ | $P_{k2}$ | $P_{k3}$ |
| SEA MAULER | 0.50 | 0.53 | 0.53 | 0.36 | 0.38 | 0.38 | 0.36 | 0.38 | 0.19 |
| TARTAR | 0.59 | 0.62 | 0.62 | 0.34 | 0.36 | 0.36 | 0.34 | 0.36 | 0.18 |
| ADVANCED TARTAR | 0.59 | 0.62 | 0.62 | 0.59 | 0.62 | 0.62 | 0.59 | 0.62 | 0.31 |
| TERRIER | 0.53 | 0.55 | 0.55 | 0.35 | 0.37 | 0.37 | 0.35 | 0.37 | 0.18 |
| M.R. TYPHON | 0.59 | 0.62 | 0.62 | 0.59 | 0.62 | 0.62 | 0.59 | 0.62 | 0.31 |
| TALOS | 0.53 | 0.55 | 0.55 | 0.39 | 0.41 | 0.41 | 0.39 | 0.41 | 0.10 |
| M.C. TALOS | 0.53 | 0.55 | 0.55 | 0.39 | 0.41 | 0.41 | 0.39 | 0.41 | 0.10 |
| I.R. TYPHON | 0.53 | 0.59 | 0.59 | 0.55 | 0.58 | 0.58 | 0.55 | 0.58 | 0.29 |
| L.R. TYPHON | 0.53 | 0.59 | 0.59 | 0.55 | 0.58 | 0.58 | 0.55 | 0.58 | 0.29 |

$P_{k1}$--Over-all single shot kill probability in command-guidance mode against air-to-surface missile-type targets.

$P_{k2}$--Over-all single shot kill probability in command-guidance mode against aircraft-type targets.

$P_{k3}$--Over-all single shot kill probability in passive-homing mode against jamming aircraft-type targets.

A delay time corresponding to initial threat evaluation was used in each situation analyzed. For the single ship analyses this delay was 20 sec for TERRIER, TALOS, TARTAR and Advanced TARTAR; and 10 sec for SEA MAULER and all versions of TYPHON. Thus, the time from first detection by any search radar aboard the firing ship to the initiation of a launch order for the first missile fired could be no less than this delay.

The corresponding threat evaluation delay in the task force analyses was taken to be 90 sec. No defensive action could be initiated until this period of time had elapsed from the time of first active radar detection or generation of a passive triangulation solution by the fleet.

A description of each of the SAM systems is presented below.

D.1.2 TERRIER System Description

TERRIER is a medium-range, solid-rocket propelled, radar-guided missile designed primarily for fleet defense against aircraft and air-supported missiles, and secondarily for attack of surface and shore targets. The TERRIER will be installed as a primary antiaircraft battery in destroyers, frigates, carriers, and some cruisers, and as a secondary antiaircraft battery in other cruisers.

The TERRIER missiles (BT and HT--Mach 2.0, 70,000-ft maximum altitude, 20 nm range) feature four fixed dorsal fins for aerodynamic lift and four independently movable tail fins for stabilization and directional control. All TERRIERs use a separable, solid-fuel booster rocket for launch and acceleration to cruise velocity, and an integral solid-fuel sustainer rocket for maintenance of cruise velocity during a large portion of the remainder of the flight. The BT missile uses a beam-riding guidance system, whereas the HT missile uses a semiactive homing-all-the-way guidance system. Dual-simplex guidance is provided by two target track-illuminating radars (AN/SPG-55A) per launcher. The TERRIER missiles are launched in single missile salvos (in this study) from dual rail launchers (MK 10).

An Advanced TERRIER corresponding to that defined in the TERRIER HT-3 Performance Extension Program (Mach 2.0 to 3.4, 100,000-ft maximum altitude, 40 nm range) is the version of TERRIER analyzed in this study.

D.1.3 TALOS System Description

TALOS is a long-range, ramjet propelled guided missile designed primarily for fleet defense against aircraft and air-supported missiles, and secondarily for attack of surface and shore targets. The TALOS weapon system is intended for installation in cruisers and larger combatant ships as a primary battery. The TALOS system will be used as a primary anti-aircraft weapon in the "Defense in Depth" concept, extending the coverage provided by the short- and medium-range surface-to-air systems.

The TALOS weapon is a high-performance, air-supported, wing-controlled missile with a separable booster. The TALOS, 6 cl (Mach 2.0-2.47, 70,000-ft maximum cruise altitude, 100 nm range) with a continuous-rod warhead, a proximity fuze, and a semiactive seeker was the only version of this missile considered in this study. Dual-simplex guidance is provided by two tracking and illuminating radar sets (AN/SPG-49) and two guidance transmitter radar sets (AN/SPW-2) per missile launcher. The TALOS missiles are launched in single missile salvos (in this study) from dual rail launchers (MK7 or MK12 as appropriate).

D.1.4 TARTAR System Description

The TARTAR system is to be installed as a primary battery in destroyer types (DDG's) and as a secondary battery in cruiser types [CG's and CG(N)'s]. It is to be usable in task force operations as a principal antiaircraft weapon in the concept of "Defense in Depth," complementing and supplementing the coverage provided by guns and rockets, by medium- and long-range missiles, and by manned interceptors.

TARTAR is a high-performance, tail-controlled, air defense missile with an integral booster. Propulsion is obtained from an integral, dual-thrust, solid fuel rocket motor designed to provide both booster and sustainer thrust. A CW Doppler semiactive-homing guidance system is provided, which incorporates an acceleration-feedback autopilot for missile control and employs proportional navigational principles for target intercept. The missile configuration features four fixed dorsal fins for aerodynamic lift and four independently movable tail fins for stabilization and directional control. The warhead is of the continuous-rod type and is fitted with an influence-type fuze having a fixed radiation pattern. Dual-simplex guidance is provided by two target track-illumination radars (AN/SPG-51) per launcher. The TARTAR missiles are launched in single missile salvos from single rail launchers (MK 13). The Improved TARTAR missile (Mach 2.0, 70,000-ft maximum altitude, 18 nm range) was considered in this study (see also Advanced TARTAR and MR TYPHON system descriptions).

D.1.5 TYPHON System Description

The TYPHON Weapon System comprises an advanced fixed array radar (AN/SPG-59), which performs search and fire control functions; a long-range missile (LR TYPHON--Mach 3.0 to 4.0, 100,000-ft maximum altitude, 200 nm range); a medium range missile (MR TYPHON--Mach 1.25 to 4.0, 90,000-ft maximum altitude, 40 nm range); associated launching, handling, and magazine equipment; and a central control system, which provides data processing.

The radar has sufficient power and data-processing capability to operate effectively in a heavy countermeasure environment; it also has high capacity tracking and guidance, which permits rapid fire. For this study, channel availability constraints for TYPHON were computed in accordance with the following rules:

(1) Ten track-while-scan (TWS) channels are required for a TYPHON missile in terminal guidance, as opposed to one for midcourse guidance

(2) A maximum of 100 TWS channels are available

(3) No more than 30 missiles can be guided in flight at any time

(4) The terminal guidance phase is of 18 sec duration prior to intercept.

The maximum number of guidance channels (midcourse and terminal) available to the system at any point in time, or the constraints imposed by (2) and (3) can be expressed as follows:

$$10\,(\text{Terminal}) + \text{Midcourse} \le 100$$
$$\text{Terminal} + \text{Midcourse} \le 30$$

The normal mode of TYPHON guidance consists of a command midcourse phase and a ground controlled semiactive homing phase.

The Long-Range TYPHON missile is, in fact, the SUPER TALOS, which has a cruciform delta wing configuration with control flippers located at the wing trailing edges. The missile is ram-jet propelled and is boosted to flight speed by a solid propellant booster of approximately 362,000 lb-sec total impulse. The missile is fitted with either a continuous rod high explosive warhead or nuclear warhead weighing 150 lb. Only the HE warhead version was considered in this study. This missile is fired from a modified dual-rail MK 10 TERRIER launcher.

The Medium-Range TYPHON missile, or SUPER TARTAR, is of standard TARTAR aerodynamic configuration. This missile is also fitted with a 150-lb warhead. Propulsion is provided by a dual-thrust, solid propellant rocket motor. The missile is launched from a modified single-rail MK 13 TARTAR launcher.

A third variant of the TYPHON missile was considered for this study. This missile has a maximum range of 100 nm and a maximum altitude of 100,000 ft, envisaged as an MR TYPHON with a solid rocket sustainer and a separable booster. In the study it is identified as the Intermediate Range TYPHON or IR TYPHON and is fired from the MK 10 TERRIER launcher.

The study further considers an alternate employment of the LR TYPHON missile wherein the missile is limited to line-of-sight trajectories and is provided with two-channel-simplex guidance by AN/SPG-553 radar.

D.1.6 Advanced TARTAR System Description

The Advanced TARTAR System concept analyzed in this report represents one of several system configurations that were being considered for ships of DD size and up. The system, as briefly described below, was derived in part from "Report of Ship Missile Study Group"[10] and a General Dynamics/Pomona Memo." It is neither an optimal nor minimal system from the effectiveness standpoint, although, since it incorporates the Rotating Phased Array Radar (ROPAR), it tends to stand rather high on the performance scale within the spectrum of possible Advanced TARTAR systems.

Briefly, the hypothetical Advanced TARTAR System analyzed in Sec. 5 of this study consists of the MR TYPHON missile employing TYPHON Ground Based Command Homing Guidance, a single MK-13 TARTAR launcher and the ROPAR radar with which are associated four CW illuminators. The ROPAR radar operates with a 40-channel track-while-scan system. For midcourse guidance, a missile requires one command/sec, whereas in terminal homing ten commands/sec must be provided. These commands are sent over a ship-to-missile command link.

The illuminators are positioned by TWS information coming from the ROPAR radar and are only needed for the terminal-homing phase of missile flight, which is assumed to be of 18 sec duration. The continuous illumination of the target during the missile terminal-flight phase provides the ship with missile target closing-rate information. Range errors as derived from the ROPAR radar once every second and Doppler errors, as derived from the semiactive missile seeker, are entered into the ship-based guidance computer. As stated above, homing commands are computed and sent to the missile at the rate of 10/sec when the missile is in its terminal homing phase.

This method of operation leads to the following constraints (exclusive of launcher constraints) on the maximum number of missiles that can be in the midcourse or terminal mode at any point in time:

$$\text{Terminal} + \text{Midcourse} \le 40$$
$$\text{Terminal} \le 4$$

System delay times incorporated into the analysis were as follows:

The time from first detection by any search radar aboard the firing ship to the initiation of a launch order for the first missile fired was no less than 20 sec. The launcher reload cycle time was 10 sec and the time for track and evaluation on the ROPAR radar was 1.1 sec. As in the case of SEA MAULER, it was assumed the illuminator tie-up continues one second beyond intercept to provide a safety margin for error in computed intercept time. Kill assessment is performed by the ROPAR radar.

The synthesis of the Advanced TARTAR described above was performed before any one system concept had been selected for development. The inclusion of an analysis of such a system in the present study was solely for the purpose of providing a comparison of one of the feasible, more advanced small-ship system concepts with SEA MAULER and the Improved TARTAR going aboard the DDG.

D.1.7 SEA MAULER System Description

The following brief description of SEA MAULER is based upon "Preliminary Technical Development Plan, Weapon System WW-028, MAULER Surface-to-Air Weapon System,"[12] and data provided by General Dynamics, Pomona, California in December, 1962. While the description basically pertains to the Army MAULER, variations arising from considerations of naval applications will be noted.

The SEA MAULER weapon pod consists of a launcher, which contains nine ready-service missiles, an L-band, pulse Doppler acquisition radar, and X-band CW Track-Illuminating Radar, a digital computing system, a weapon control console, a launch order computer and an IFF System. It weighs about 8000 lb. Several shipboard installation concepts are currently under study. These range from the installation of integrated MAULER pod units to the distribution of system elements over the ship. The current study implies the retention of the weapon pod as a unit that contains the launcher, the radars, the computers, the power supply and the operators. Off-mount magazine capacity per launcher has been assumed at 36 MAULER rounds.

The missile rack is reloaded only after all nine ready-service missiles have been fired. Manual reload time is estimated to be about fifteen minutes for each reload of nine missiles. An alternate, hypothetical automatic reload scheme is considered in the present study, which can perform the reload function for nine missiles in one minute.

MAULER missiles may be fired in salvos of one, two or three. The minimum time interval between shots in a multi-missile salvo is 1.25 sec. In the present study, single missile salvos only were considered. Each MAULER fire unit can engage only one target at a time, since there is only one tracking-illuminator channel associated with a unit. The acquisition (search) radar has an approximate detection range of 19.8 km (22,000 yd) against a $0.1m^2$ target with a detection probability of 0.85. It generates 1200 w of average power in the 1300-1400 Mc frequency-band. This radar has a field of view of 65 degrees above the horizontal, resulting in a blind zone of 25 degrees from the vertical. Only target detection and designation are affected by this blind zone. Targets can be intercepted within this zone if they were detected by the MAULER acquisition radar while outside the zone, or if acquisition is performed by other radars aboard the ship or elsewhere in the task force.

The track-illuminating radar has a detection capability of 17 km (19,000 yd) against a $0.1m^2$ target ($P_d$ = 0.85) and transmits 2 kw at 10.30-10.55 Gc. The illuminator imposes a limit on lead angle of 45 degrees at the time of missile launch. Antenna height is approximately 19 ft above the deck.

The MAULER missile weighs 115 lb and is fitted with a 19.5-lb warhead. It employs a semiactive homing-all-the-way mode of guidance and has a home-on-jam capability. Its time-of-flight to its maximum horizontal range of 10 km (11,000 yd) is 15 sec and its minimum intercept range is about 500 meters (550 yd). The missile flight envelope is shown in Fig. D.1 and missile times of flight to intercept at varying ranges and altitudes are shown in Fig. D.2.

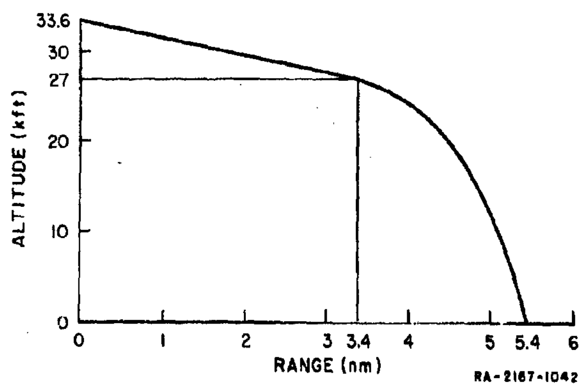



FIG. D.1 MAULER PERFORMANCE ENVELOPE

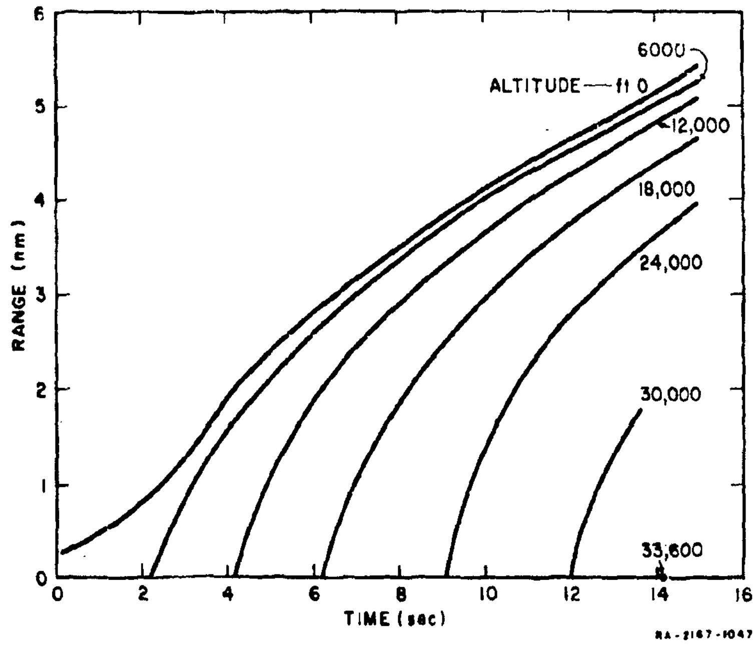



FIG. D.2 MAULER TIME-OF-FLIGHT CURVES

The mean value of turntable slew time is estimated to be 1.4 sec. This figure is based upon Army operations, where targets presumably may arrive from several directions. It was not included in the present study in view of the target arrival patterns being considered in Sec. 3.

Illuminator lock-on, lead computer solution and missile lock-on require a combined total of 2.4 sec, at the end of which time the missile leaves the launcher. Illuminator tie-up continues through missile intercept and one second beyond. The illuminator is then released for another engagement. The final second of illuminator tie-up is not for kill assessment, but rather is a safety margin for error in computed intercept time.

A kill assessment scheme employing the acquisition radar is used with MAULER. The illuminator is released as described above to engage a new target. The acquisition radar (which can track eight targets simultaneously) continues tracking the target for five seconds after computed intercept time. If the track has not vanished in that time, the target becomes eligible for reassignment.

Missile envelopes and time-of-flight data are presented in Figs. D.3 through D.13.

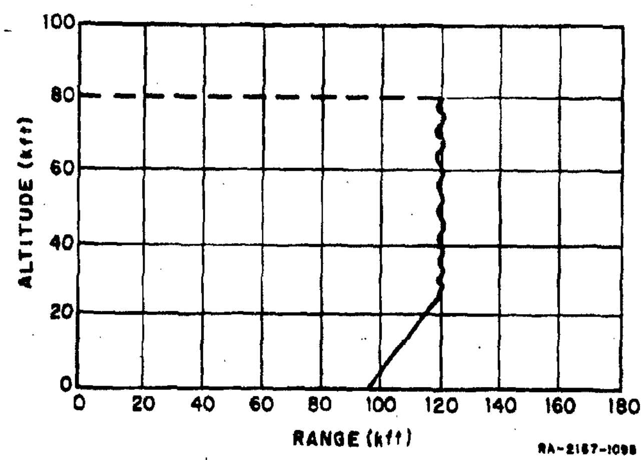



FIG. D.3 TERRIER HT-3 PERFORMANCE ENVELOPE

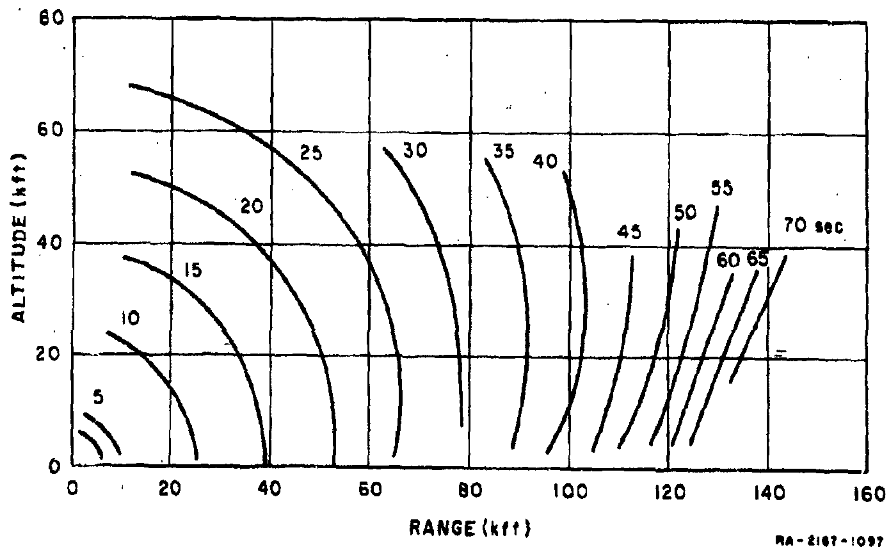



FIG. D.4 TERRIER BT-3 AND HT-3 TIME-OF-FLIGHT CURVES

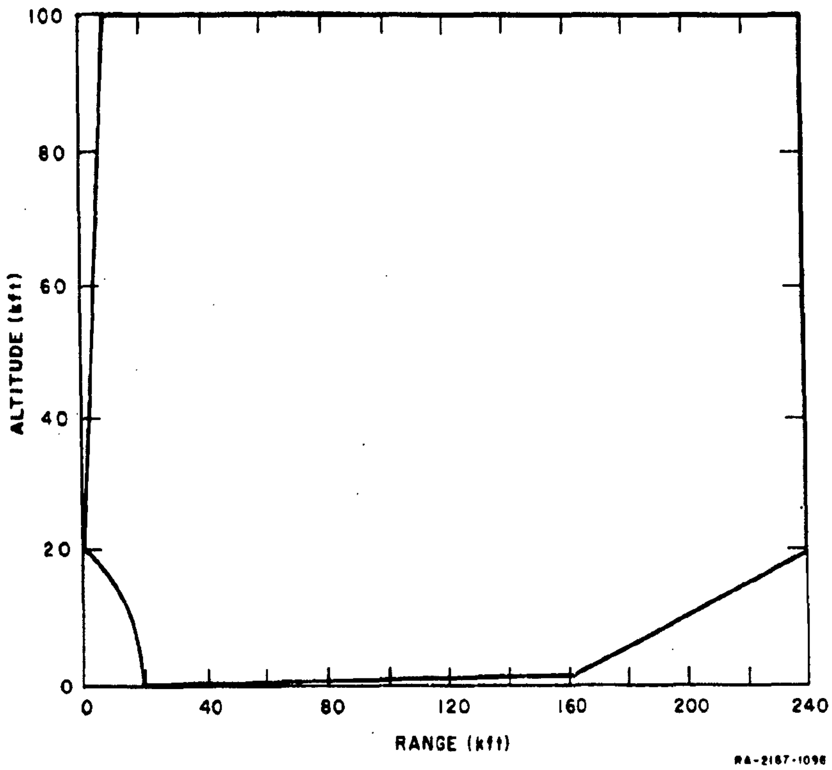



FIG. D.5 ADVANCED TERRIER PERFORMANCE ENVELOPE

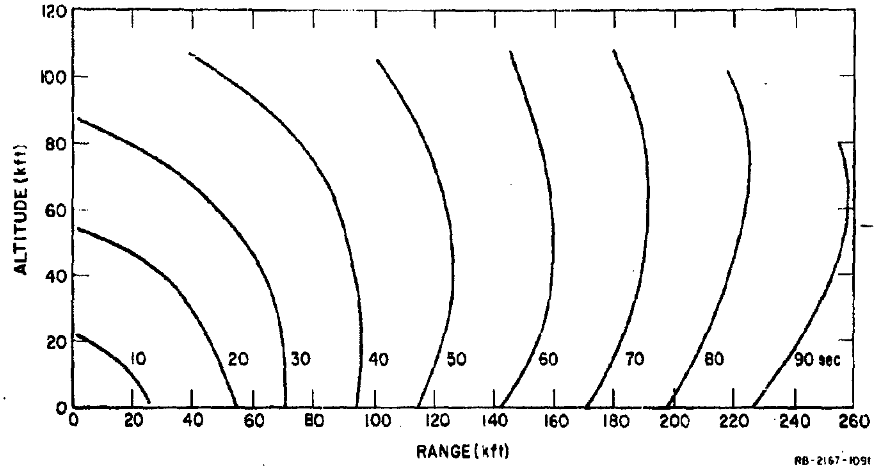



FIG. D.6 ADVANCED TERRIER TIME-OF-FLIGHT CURVES

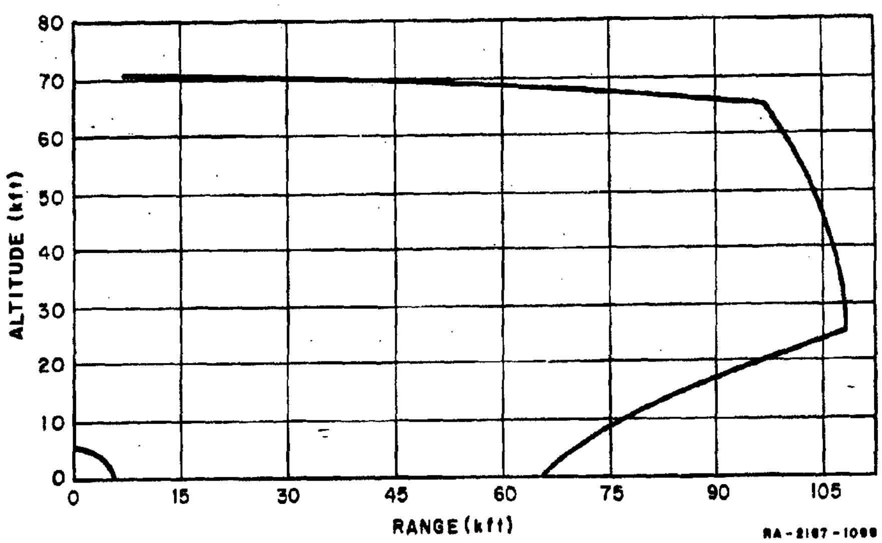



FIG. D.7 IMPROVED TARTAR PERFORMANCE ENVELOPE

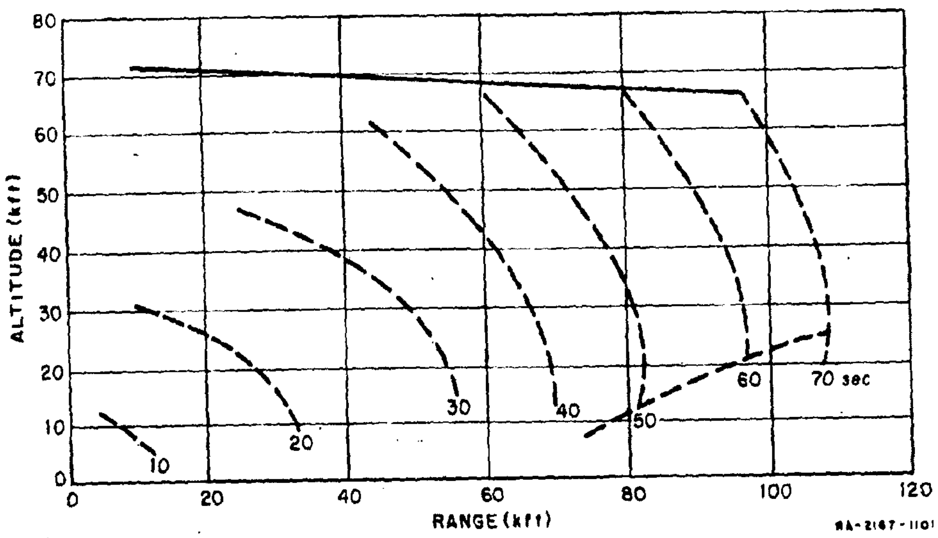



FIG. D.8 IMPROVED TARTAR TIME-OF-FLIGHT CURVES

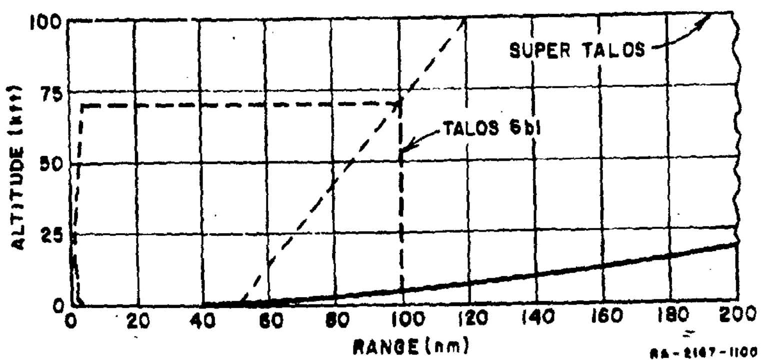
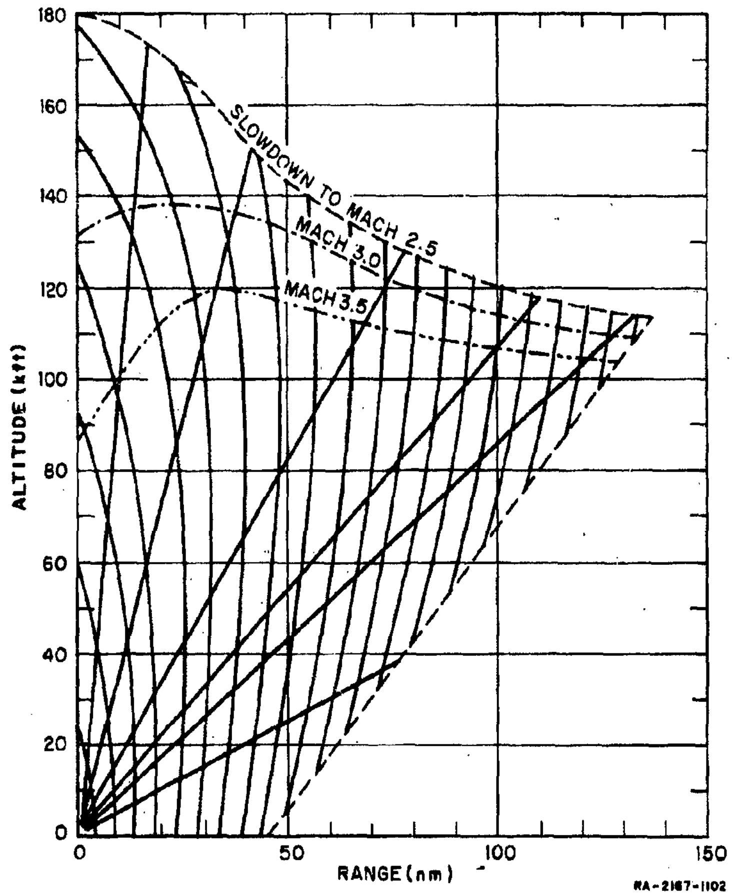


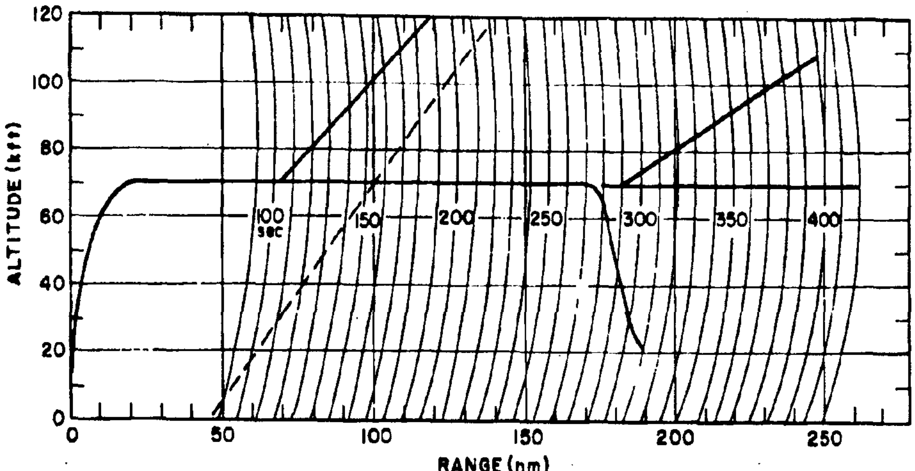

FIG. D.9 TALOS PERFORMANCE ENVELOPE




NOTE: 1) TIME LINES CORRESPOND TO END POINTS OF TRAJECTORIES

2) MAXIMUM RANGE NOT IMPLIED

FIG. D.10 SUPER TALOS (Long-Range TYPHON) TIME-OF-FLIGHT CURVES (Line-of-sight trajectory)




NOTE: 1.) TIME LINES CORRESPOND TO END POINTS OF TRAJECTORIES
2.) MAXIMUM RANGE NOT IMPLIED

FIG. D.11 SUPER TALOS (Long-Range TYPHON) TIME-OF-FLIGHT CURVES (Type L trajectory)

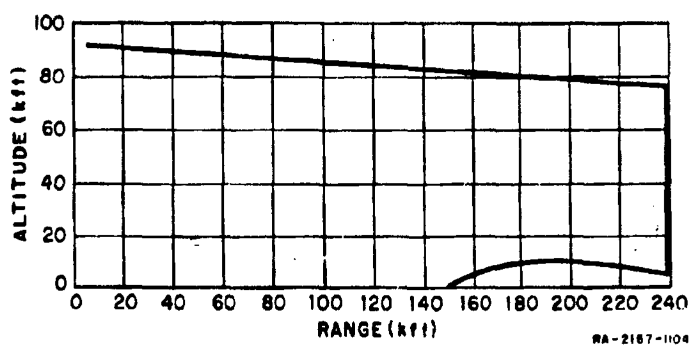



FIG. D.12 SUPER TARTAR (Medium-Range TYPHON) PERFORMANCE ENVELOPE

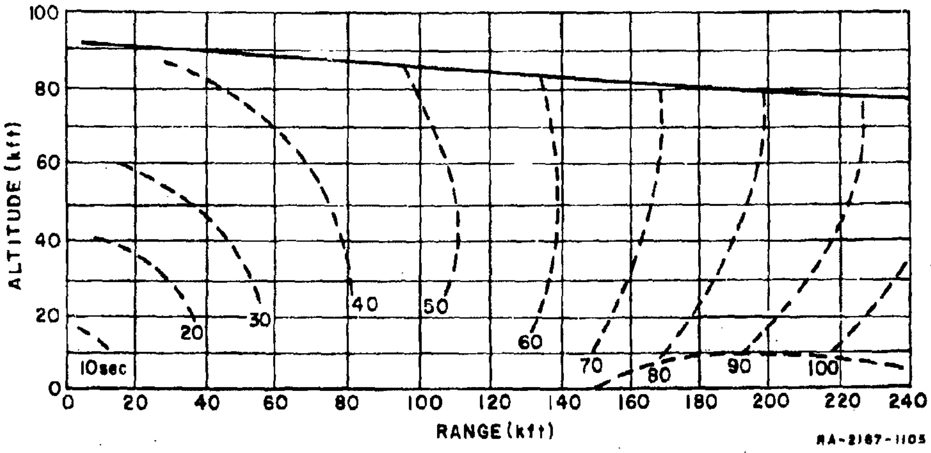



FIG. D.13 SUPER TARTAR (Medium-Range TYPHON) TIME-OF-FLIGHT CURVES

A summary description of the guided missile ships analyzed in this study and their weapon systems is presented in Table D.2.

## D.2 AAM Systems Descriptions

The air-to-air missile systems employed in this study consisted of the limited performance F-6D aircraft equipped with long-range EAGLE missiles, and the high-performance F-4B aircraft equipped with short-range SPARROW III missiles. The description of each system is presented in a separate section.

### D.2.1 F-6D/EAGLE System Description

The F-6D/EAGLE AAM system consisted of the F-6D aircraft equipped with a complement of six EAGLE missiles. This system is only used in clear environment situations and many approximations were employed. The system description is presented as separate definition of the aircraft, missile, and operating constraints.

#### D.2.1.1 F-6D Aircraft Description

The F-6D aircraft was envisioned as having relatively low speed capability while having long endurance capability. As used in the model, the aircraft was considered as flying at a constant velocity of Mach 0.7 at an altitude of 35,000 ft. Since the aircraft was considered to have

Ta

SAM SYSTEMS P

| Weapon System | Ship Class | Air Search Radar (primary) | $Z_s$-ft (nm) | Missile Guidance Radar | $Z_{FC}$-ft (nm) | New Assign $T_{FC}$-Sec (hrs) | Reassign $T_{FC}$-Sec |
|---|---|---|---|---|---|---|---|
| 1 | DLG-9 | AN/SPS-29 | 82.0 (0.01367) | AN/SPG-55A (2) | 53.0 (0.00883) | 20.0 (0.00556) | 5.0 (0.00139) |
| | CVA-63 | AN/SPS-29 | 130.0 (0.02166) | AN/SPG-55A (4) | 53.0 (0.00883) | 20.0 (0.00556) | 5.0 (0.00139) |
| -- | CVA-62 | AN/SPS-29 | 130.0 (0.02166) | -- | -- | -- | -- |
| (a) 2 (b) | DLG-16 | AN/SPS-37 (large) | 86.0 (0.0143) | AN/SPG-55B (4) | 58.0 (0.00967) | 20.0 (0.00556) 20.0 (0.00556) | 5.0 (0.00139) 5.0 (0.00139) |
| 3 | DDG-2 | AN/SPS-37 (small) | 82.0 (0.0137) | AN/SPG-51 (2) | 44.0 (0.00733) | 20.0 (0.00556) | 5.0 (0.00139) |
| 4 | DLG-32 | AN/SPS-43 | 82.0 (0.0137) | AN/SPG-59 (1) (small) | 75.0 (0.0125) | 0 0 | 0 0 |
| 5 | CLG-3 | AN/SPS-37 (large) | 100.0 (0.0167) | AN/SPG-56 (2) | 60.0 (0.01) | 20.0 (0.00556) | 5.0 (0.00139) |
| 6 | CG-10 | AN/SPS-37 (large) | 86.0 (0.0143) | AN/SPG-51 (4) AN/SPG-56 (4) | 44.0 (0.00733) 60.0 (0.01) | 20.0 (0.00556) 20.0 (0.00556) | 5.0 (0.00139) 5.0 (0.00139) |

NOTES

1. The Long-Range TYPHON aboard DLG-16 is restricted to line-of-sight trajectc

| Symbol | Definition |
|---|---|
| $Z_s$ | Air search radar antenna height above the ship water line |
| $Z_{FC}$ | Average missile guidance radar antenna height |
| $t_{FC}$ | Missile guidance radar pre-firing acquisition and tracking time |
| $t_A$ | Target kill assessment time |
| $\theta$ | Maximum elevation angle limitation on either missile guidance radar or |

1

Table D.2

SAM SYSTEMS PARAMETER VALUES

| ewAssign FC-Sec (hrs) | Reassign $T_{FC}$-Sec | $T_A$-Sec (hrs) | θ-deg | Launcher (No. and Loc.) | Rails (No.) | $T_L$-Sec (hrs) | $T_C$-Sec (hrs) | Φ | Missile | η |
|---|---|---|---|---|---|---|---|---|---|---|
| 20.0 (0.00556) | 5.0 (0.00139) | 8.0 (0.00222) | 85 | MK10-0 (1-aft) | 2 | 35.0 (0.00972) | 2.0 (0.00056) | 40 | TERRIER HT-3 | 0.80 |
| 20.0 (0.00556) | 5.0 (0.00139) | 8.0 (0.00222) | 85 | MK10-3,4 (2-P/S) | 2 | 35.0 (0.00972) | 2.0 (0.00056) | 40 | TERRIER HT-3 | 0.80 |
| -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 20.0 (0.00556) | 5.0 (0.00139) | 8.0 (0.00222) | 85 | MK10-5,6 (1-fwd, 1-aft) | 2 | 35.0 (0.00972) | 2.0 (0.00056) | 40 | L.R. TYPHON (L.O.S.) | 0.80 |
| 20.0 (0.00556) | 5.0 (0.00139) | 8.0 (0.00222) | 85 | MK10-5,6 (1-fwd, 1-aft) | 2 | 35.0 (0.00972) | 2.0 (0.00056) | 40 | TERRIER | 0.80 |
| 20.0 (0.00556) | 5.0 (0.00139) | 8.0 (0.00222) | 85 | MK13-0 (1-aft) | 1 | 10.0 (0.00278) | 2.0 (0.00056) | 40 | TARTAR (Improved) | 0.80 |
| 0 | 0 | 8.0 (0.00222) | 90 | MK10-0 (1-fwd) | 2 | 35.0 (0.00972) | 2.0 (0.00056) | 40 | L.R. TYPHON | 0.85 |
| 0 | 0 | 8.0 (0.00222) | 90 | MK13- (1-fwd, 1-aft) | 1 | 10.0 (0.00278) | | 40 | M.R. TYPHON | 0.85 |
| 20.0 (0.00556) | 5.0 (0.00139) | 8.0 (0.00222) | 85 | (1-aft) | 2 | 45.0 (0.01250) | 2.0 (0.00056) | 40 | TALOS | 0.85 |
| 20.0 (0.00556) | 5.0 (0.00139) | 8.0 (0.00222) | 85 | MK13-0 (1-fwd, 1-aft) | 1 | 10.0 (0.00278) | 2.0 (0.00056) | 40 | TARTAR (Improved) | 0.80 |
| 20.0 (0.00556) | 5.0 (0.00139) | 8.0 (0.00222) | 85 | (1-fwd, 1-aft) | 2 | 45.0 (0.01250) | 2.0 (0.00056) | 40 | TALOS | 0.85 |

ıe-of-sight trajectories only

| | Symbol | |
|---|---|---|
| : line | $t_L$ | Launcher loading cycle time |
| racking time | $t_c$ | Firing delay time (Transfer from external to missile internal electrical power) |
| | Φ | Missile magazine capacity per launcher |
| guidance radar or Launcher | η | Launcher operability factor |

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an endurance capability much greater than the expected duration of an air battle, fuel consumption was not considered as a system operational constraint.

The radar system was considered effective to the maximum missile range, since only clear environment situations were to be encountered. The radar system is capable of providing guidance to six missiles concurrently, provided the targets are in a spherical sector of 30 degrees in the horizontal plane and 5.8 degrees in the vertical plane.

D.2.1.2 EAGLE Missile Description

The EAGLE missile was envisioned as having a range capability from 15 to 100 nm relative to the launching aircraft. For the simulation runs the missile speed was 1680 knots.

D.2.1.3 F-6D/EAGLE Weapon System Interactions

The interactions between the launching aircraft and its launched missiles are as follows:

(1) The aircraft is constrained to maintain the missiles and targets within its sector of radar coverage

(2) The delay between successive launching of missiles must be greater than five seconds.

D.2.2 F-4B/SPARROW III System Description

The F-4B/SPARROW III AAM system simulated in this study consisted of the F-4B aircraft equipped with a complement of four SPARROW III missiles. Since this system was employed in both the clear and the ECM environment models, its description contains more detail than the F-6D-EAGLE AAM system description. The description is presented in parts as the aircraft, the missile, and specification of the interactions.

D.2.2.1 F-4B Aircraft Description

The F-4B is a high-performance aircraft developed to extend the radius of fleet air defense beyond that provided by the SAM systems. To satisfy this objective, the vectoring of the interceptor to the target area is dependent upon information from both surface and airborne surveillance radar systems. Location of a target upon reaching the target area is accomplished with the AN/APQ-72 AI radar system.

The F-4B is a two-place, supersonic interceptor manned by a pilot and a radar operator. The power is provided by two J79 turbojet engines with a total rated sea-level thrust of 30,000 lb. The aircraft fuel capacity is 2264 gallons internal, and external fuel-loading configurations of either 600 or 1340 gallons.

The simulation of the aircraft performance characteristics is approached from the composite representation of: Maximum level flight Mach number vs Altitude (Fig. D.14); Mach number vs Time to accelerate (Fig. D.15); Fuel Consumption vs Speed (Fig. D.16), and specification of

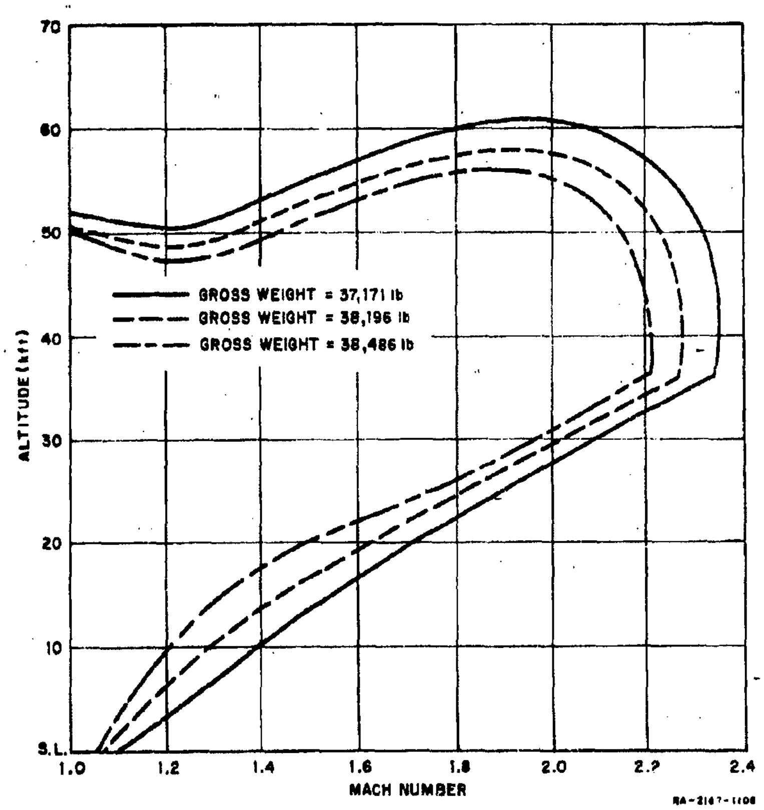


FIG. D.14 F-4B MAXIMUM LEVEL FLIGHT MACH NUMBER

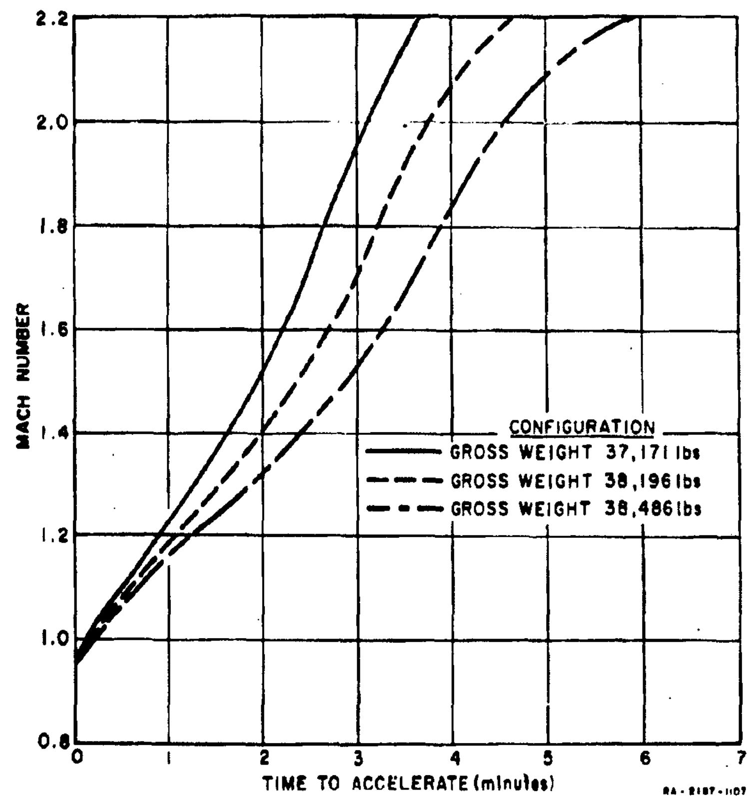


FIG. D.15 F-4B TIME OF FLIGHT TO ACCELERATE TO VARIOUS SPEEDS

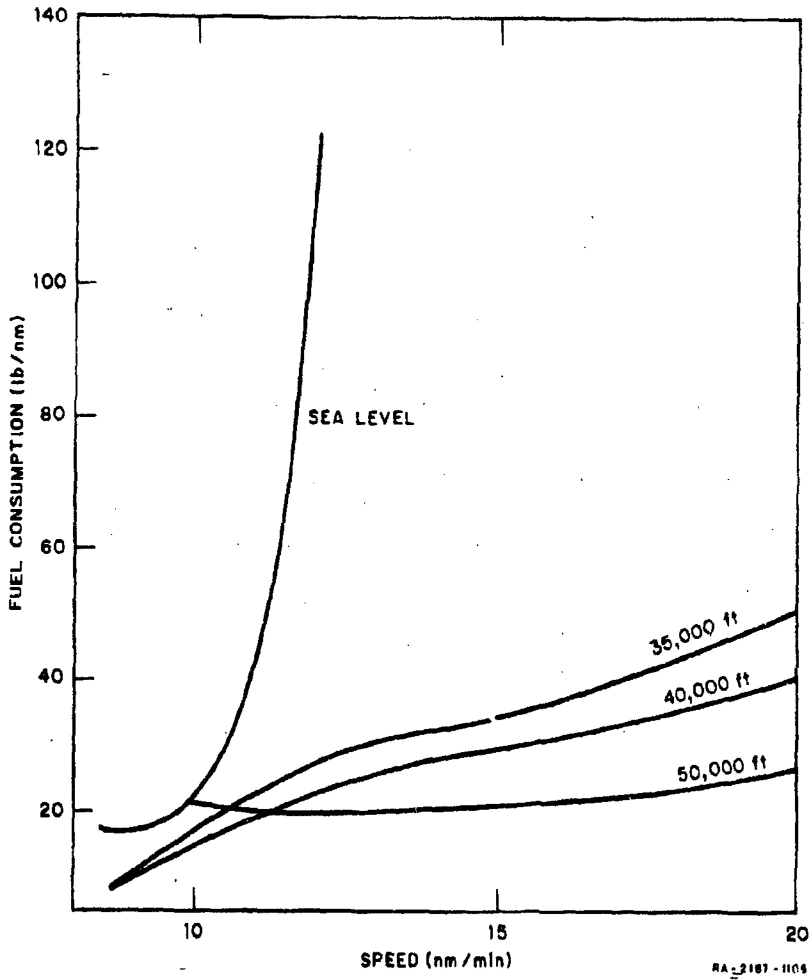


FIG. D.16 F-4B FUEL CONSUMPTION CHARACTERISTICS operational constraints. The simulation of the AI radar, on the other hand, is accomplished by specification of certain parameter and represented by performance equations.

D.2.2.2 F-4B Operational Constraints

The constraints specified are not necessarily the absolute limitations of the aircraft capabilities, but simply a statement of the restrictions imposed in the simulation.

(1) Normal acceleration restricted to values between -0.5g and +4g.

(2) External fuel loading is used by CAP aircraft only.

(3) Combat fuel reserve, defined as the necessary fuel for five-minutes operation at maximum thrust and 50,000 ft altitude: 4235 lb.

(4) The AI radar is effective against targets with closing velocities of less than 2500 knots and opening velocities of less than 800 knots.

D.2.2.3 SPARROW III Missile Description

The SPARROW III is an air-launched, boost-glide missile using semi-active radar guidance. The guidance system homes the missile on target-reflected X-band CW energy, with illumination provided by the interceptor transmitter. The missile flies a proportional navigational course in which the ratio of rate-of-change-of-missile-heading to rate-of-change-of-line-of-sight is maintained proportional to the ratio of closing speed to missile speed. The initial heading error is reduced by a biasing control applied during the boost phase of flight.

The thrusting during the boost phase is provided by a prepackaged liquid engine of 9000-lb thrust with a nominal duration of two seconds. This provides the missile with a speed relative to the launching aircraft of approximately 1600 ft/sec.

The internal electrical power for seeker operation is provided by a solid-fuel gas turbine alternator. The hydraulic power for control surface actuation is furnished by a hydraulic accumulator.

The warhead is of the continuous rod type with a total weight of 65 lb. Upon detonation, the warhead expands to a radius of 25 feet before breakup, causing both rod and blast damage to the target.

The launch envelope is defined by equations for the maximum and minimum launch ranges as defined below:

D.2.2.4 Launch Envelope Equations

$$R_{max} = R_1(h) + T_1(h)(V_c - V_{Tas}) \leq 50{,}000 \text{ ft}$$
$$R_{min} = R_2(h) + T_2 V_c$$

where:

$R_{max}$ = maximum launch range-(ft)

$R_{min}$ = minimum launch range-(ft)

$R_1(h)$= 11,000 + 0.5h-(ft) for $0 \leq h \leq 72{,}000$

h = launch altitude-(ft)

$$T_1(h)=\begin{cases} 11 \text{ sec for } V_c > V_{Tas} \\ 4.6 + 0.00011\ h\text{-(sec) for } V_c < V_{Tas} \end{cases}$$

$V_c$ = Closing speed (ft/sec)

$V_{Tas}$ = Interceptor true air speed (ft/sec)

$$R_2(h)=\begin{cases} 2000 + 0.0666h - \text{(ft) for } 0 \leq h \leq 30{,}000 \\ 4000 + 0.2143h - \text{(ft) for } 30{,}000 \leq h \leq 72{,}000 \end{cases}$$

$T_2$ = 4.3 sec.

D.2.2.5 SPARROW III Operational Constraints

(1) Normal acceleration is limited to 14 g's in any plane either by control restriction, or altitude reduction in control surface effectiveness.

(2) Delays:

  (a) Hydraulic power available 0.25 sec after launch

  (b) Target lock on 1.2 sec (nominal), after launch.

(3) The missile warhead is not armed until it has travelled at least 600 ft from the interceptor.

(4) Situations that result in warhead detonation:

  (a) Impact on target

  (b) Target proximity

  (c) Loss of target illumination and missile is within 0.6 mile of the target.

D.2.2.6 F-4B/SPARROW III Weapon System Interactions

After the interceptor acquires a target, it initiates a conversion maneuver to a position and heading suited for missile launch. During this maneuver, the missile seeker is aimed at the target by slaving it to the AI radar. Before missile launch, the interceptor to target steering error is minimized by an interceptor pursuit course maneuver.

After the missile is launched and prior to impact, the target is illuminated by CW energy from the interceptor transmitter. This constrains the admissible interceptor flight paths to those that maintain the target within the gimbal limits of the AI radar.

When the aircraft reaches the minimum missile launch range, a breakaway maneuver is initiated. This maneuver commands a 4g turn in order to maintain a distance from the target and possible debris by a minimum of 1000 ft.

D.2.2.7 Airborne Radar Characteristics

The characteristics of the AN/APS-96 Airborne Early Warning radar and the fighter AI radars analyzed in this study are shown in Tables D.3 and D.4 respectively.

Table D.3

AEW RADAR CHARACTERISTICS (AN/APS-96)

| | |
|---|---|
| Frequency (Band) | L |
| (mc) | 400-450 |
| Average Transmitted Power (kw) | 3.8 |
| Peak Pulse Power (kw) | 1000 |
| Pulse Length (μsec) | 12.8 |
| PRF (pps) | 300 |
| Beamwidth in degrees | |
| Horizontal | 7.1 |
| Vertical | 15.0 |
| Gain (db) | 22 |
| Scan Rate (rpm) | 6 |
| Side Lobe (db) | -23 |
| Receiver Noise Figure (db) | 5.5 |
| Anti-Jam Features | Pulse Compression<br>Coherent Moving Target Indication<br>Sensitivity Time Constant |

Table D.4

AIRBORNE INTERCEPT RADAR CHARACTERISTICS

| Parameter | AN/APQ-72 | AN/APQ-81 |
|---|---|---|
| Frequency (Band) | X | C |
| Frequency (Mc) | 9345-9405 | 5250-5650 |
| Peak Power (Kw) | 160 | 20 |
| Avg. Power (Kw) | 0.298 | 2.0 |
| Pulse Length ($\mu$sec) | 0.4 or 1.75 | 1.6 |
| PRF (pps) | 1060 | 56,800<br>62,500<br>69,500 |
| Duty Cycle | 0.00186 | 0.1 |
| Beamwidth in degrees<br>Horizontal<br>Vertical | <br>2.8<br>2.8 | <br>2.7<br>2.7 |
| Antenna Gain (db) | 34.5 | 37.2 |
| SCAN Patterns | $2.5^{\circ} \times 120^{\circ}$ (2 sec)<br>$2.5^{\circ} \times 30^{\circ}$ (1 sec) } 1 bar<br>$10^{\circ} \times 120^{\circ}$ (4 sec)<br>$10^{\circ} \times 30^{\circ}$ (1 sec) } 3 bar | $5.5^{\circ} \times 33^{\circ}$ (2 sec) - 2 bar |
| Side lobe (db) | -27 | -23 |
| Raster Pattern<br>Elevation | <br>±60 degrees | <br>+40 degrees, -35 degrees |
| Azimuth | ±60 degrees | ±60 degrees |
| Receiver Noise Figure (db) | 11.3 | 8.0 |

D.3 Guided Missile Ships

The ship types considered in the study are shown in Table D.5. It will be noted that the list includes some ships that are not ordinarily fitted with missiles. The various missile configurations assumed for each ship type are shown in Table D.6. SEA MAULER pods are assumed to replace 3"/50, 5"/38, and 5"/54 gun mounts, except in CVA-63, which has no guns. Fore and aft launchers are assumed to be centerline mounted.

Table D.5

SHIPS STUDIED

| Ship Type | Surveillance Radars | | Size | | | Speed |
|---|---|---|---|---|---|---|
| | Early Warning Two-Coordinate | Three-Coordinate | Displacement (tons) | Length (ft) | Beam (ft) | (Kts) |
| DDG-2 | AN/SPS-37 (small) | AN/SPS-39 | 4,500 | 432 | 47 | 32.5 |
| DLG-9 | AN/SPS-29 | AN/SPS-39 | 5,350 | 513 | 50 | 34.5 |
| DLG-16 | AN/SPS-43 (large) | AN/SPS-39 | 7,650 | 533 | 53 | 33 |
| DLG (T) | AN/SPS-43 (large) | None | | | | |
| CLG-3 | AN/SPS-43 (large) | AN/SPS-39 | 15,142 | 610 | 66 | 30.6 |
| CG-10 | AN/SPS-43 (large) | AN/SPS-39 | 18,340 | 674 | 71 | 31.5 |
| CG (T) | AN/SPS-43 (large) | AN/SPS-39 | | | | |
| CVA-63 | AN/SPS-43 (large) | AN/SPS-39 | 76,700 | 1,046 | 249 | 32 |
| CVA-59 | AN/SPS-29 | AN/SPS-39 | 75,900 | 1,040 | 252 | 31 |
| AOE-1 | AN/SPS-40 | None | 51,000 | 770 | 107 | 26 |

Table D.6

ASSUMED GUIDED MISSILE ARMAMENT CONFIGURATIONS

| Ship | Missile Type | Fire Control Radar | Launchers No. | Launchers Position | Missiles per Launcher | Remarks |
|---|---|---|---|---|---|---|
| DDG-2 | Improved TARTAR | AN/SPG-51 | 1 | aft | 40 | Basic configuration |
| | Improved TARTAR | AN/SPG-51 | 1 | aft | 40 | |
| | SEA MAULER | Pulse Doppler Acq (L band) | 2 | fore and aft | 36 | CW Track/Illumination radar (X band) |
| | SEA MAULER | Pulse Doppler Acq (L band) | 1 | aft | 36 | CW Track/Illumination radar (X band) |
| | SEA MAULER | Pulse Doppler Acq (L band) | 2 | fore and aft | 36 | CW Track/Illumination radar (X band) |
| | Advanced TARTAR | ROPAR | 1 | aft | 40 | Command homing |
| | 5"/54 gun mounts | GFCS Mk 68 | 2 | port and starboard | -- | Special gun--only configuration |
| DLG-9 | TERRIER HT-3 | AN/SPG-55A | 1 | aft | 40 | Basic configuration |
| DLG-16 | TERRIER HT-3 | AN/SPG-55A | 2 | fore and aft | 40 | Basic configuration |
| | TERRIER HT-3 | AN/SPG-55A | 2 | fore and aft | 40 | |
| | SEA MAULER | Pulse Doppler Acq (L band) | 2 | port and starboard | 36 | CW Track/Illumination radar (X band) |
| | LR TYPHON | AN/SPG-55B | 2 | fore and aft | 40 | LOS mode |
| | Advanced TERRIER | AN/SPG-55B | 2 | fore and aft | 40 | |
| DLG-(T) | LR TYPHON | AN/SPG-59 | 1 | fore | 40 | DLG (1-2) |
| | MR TYPHON | AN/SPG-59 | 2 | aft | 40 | |
| | IR TYPHON | AN/SPG-59 | 1 | fore | 40 | DLG (1-2)* |
| | MR TYPHON | AN/SPG-59 | 2 | fore and aft | 40 | |

Table D.6 (Concluded)

| Ship | Missile Type | Fire Control Radar | Launchers No. | Launchers Position | Missiles per Launcher | Remarks |
|---|---|---|---|---|---|---|
| DLG-(T) | MR TYPHON | AN/SPG-59 | 3 | 2 fore and 1 aft | 40 | DLG (0-3) |
| | MR TYPHON<br>SEA MAULER | AN/SPG-59<br>Pulse Doppler Acq (L band) | 3<br>2 | 2 fore and 1 aft<br>port and starboard | 40<br>36 | 3400-element radar |
| CLG-3 | TALOS 6cl | AN/SPG-49 | 1 | aft | 40 | Six guidance channels (tracking radars and guidance transmitters |
| | TALOS 6cl<br>SEA MAULER | AN/SPG-49<br>Pulse Doppler Acq (L band) | 1<br>1 | aft<br>fore | 40<br>36 | Six guidance channels<br>CW Track/Illumination radar (X band) |
| CG-10 | TALOS 6cl<br>Improved TARTAR | AN/SPG-49 | 2<br>2 | fore and aft<br>port and starboard | 40<br>40 | Basic configuration |
| | TALOS 6cl<br>Improved TARTAR<br>SEA MAULER | AN/SPG-49<br><br>Pulse Doppler Acq (L band) | 2<br>2<br>2 | fore and aft<br>port and starboard<br>port and starboard | 40<br>40<br>36 | CW Track/Illumination radar (X band) |
| CG-(T) | LR TYPHON<br>Improved TARTAR | AN/SPG-59<br>AN/SPG-51 | 2<br>4 | 1 fore and 1 aft<br>fore, aft, port, starboard | 40(f),80(a)<br>40 | |
| CVA-59 | SEA MAULER | Pulse Doppler Acq (L band) | 4 | 2 port and 2 starboard | 36 | |
| CVA-63 | TERRIER HT-3 | AN/SPG-55A | 2 | port and starboard | 40 | Basic configuration |
| | TERRIER HT-3<br>SEA MAULER | AN/SPG-55A<br>Pulse Doppler Acq (L band) | 2<br>2 | port and starboard<br>port and starboard | 40<br>36 | CW Track/Illumination radar (X band) |
| | Advanced TERRIER | AN/SPG-55B | 2 | port and starboard | 40 | |
| AOE-1 | SEA MAULER | Pulse Doppler Acq (L band) | 4 | 2 port and 2 starboard | 36 | CW Track/Illumination radar (X band) |

Table D.7 tabulates pertinent characteristics of the surveillance radars considered in the simulation studies. The anti-jam features listed with each type of set are those reported to be planned for incorporation into production radar sets. In order to reduce false-target presentations in ECM environment, to achieve clear strobes upon noise jamming for passive angle acquisition and tracking, to detect clear targets in the presence of side-lobe jamming, and to achieve timely development of radar simulation, it was necessary in the simulation to impute to all surveillance radars the following features:

(1) CFAR

(2) Side-lobe blanking cancellation of side-lobe signals by auxiliary antenna, receiving channel and comparison network

(3) Side-lobe suppression by primary antenna beam shaping

(4) Clutter rejection

(5) No detection loss

(6) Continuous noise jamming

(7) Target cross-section invariance with illumination frequency.

Table D.7

SURVEILLANCE RADAR CHARACTERISTICS

| Parameter | AN/SPS-29 | AN/SPS-37 (small) | AN/SPS-39 | AN/SPS-40 | AN/SPS-43 (large) |
|---|---|---|---|---|---|
| Weight (lb) | | | | | |
| Topside | 1000 | 1300 | 2800 | 1100 | 5000 |
| Below Deck | 3000 | 3000 | 8500 | 2650 | 3000 |
| Antenna Size (ft) | | | | | |
| Height | 8.5 | 8.5 | 12 | 8.5 | 10 |
| Width | 17.5 | 17.5 | 9 | 17.5 | 41.5 |
| Primary power required | 18kva | 20kw | 60kw | 30kva | 20kw |
| Frequency (Band) | P | P | S | L | P |
| (Mc) | 215-225 | 215-225 | 2910-3090 | 420-450 | 205-225 |
| Average Transmitted Power (kw) | 2.25 | 10.8 | 3.3-28.5 | 3.6 | 10.8 |
| Peak Pulse Power (kw) | 750 | 180 | 1000-2000 | 2000 | 180 |
| Pulse Length (μsec) | 10 | 200* | 4 2 | 6 | 200* |
| PPS (pps) | 300 | 300 | 3565 3565 to or to 495 820 | 300 | 280-300 |
| Beamwidth in degrees | | | | | |
| Horizontal | 18.0 | 18.0 | 2.4 | 10 | 7 |
| Vertical | 27.5 | 27.5 | 3.0 | 20 | 20 |
| Gain (db) | 18.5 | 18.5 | 32-34 | 23 | 23 |
| Scan Rate (rpm) | 7.5, 15 | 7.5, 15 | 15, 5 | 7.5, 15 | 5, 10 |
| Side-lobe (db) | -27 | -27 | -16 | -30 | -27 |
| Vertical Scan Coverage (degrees) | 27 | 27 | 50, 90 | 19 | 25 |
| Receiver Noise Figure (db) | 4 | 4 | 9 | 6 | 4 |

Table D.7 (Concluded)

| Parameter | AN/SPS-29 | AN/SPS-37 (small) | AN/SPS-39 | AN/SPS-40 | AN/SPS-43 (large) |
|---|---|---|---|---|---|
| Anti-jam Features | FTC<br>HVP<br>STC | ANL<br>CFAR<br>FTC<br>HVP<br>PC<br>STC | CV<br>FTC<br>NCMTI<br>PD<br>SLS<br>STC | CMTI<br>FTC<br>HVP<br>LR<br>NCMTI<br>PC<br>RT<br>STC | ANL<br>CFAR<br>CMTI<br>FTC<br>LR<br>NCMTI<br>PC<br>PR<br>RT<br>SSS<br>STC |

* Compressed to 6 μsec in receiver

| | |
|---|---|
| ANL | Automatic Noise Levelling |
| CFAR | Constant False Alarm Rate |
| CMTI | Coherent Moving Target Indication |
| CV | Coincidence Video |
| FTC | Fast Time Constant |
| HVP | High Video Pass |
| LR | Log Receiver |
| NCMTI | Noncoherent Moving Target Indication |
| PC | Pulse Compression |
| PD | Passive Detection |
| PR | Panoramic Receiver |
| RT | Rapid Tuning |
| SLS | Side Lobe Suppression |
| SSS | Signal Strength Strobe |
| STC | Sensitivity Time Constant |

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This report presents the results of a study program conducted by NWRC, SRI, in the area of future carrier task force anti-air warfare. The report presents a brief history of the research effort, the development of the limited war operating environment for future carrier task forces, a description of the analytical techniques employed by the study group and the results of analytical investigations pertaining to the effectiveness of the shipborne and airborne elements of a task force AAW complex. In addition the report examines the desirability and feasibility of the employment of airborne platforms in an Electronic Warfare role, complementing The Ship Integrated Electronic Warfare System (SINEWS) currently under development. Conclusions derived from these study efforts, pertaining to AAW operations and AAW system technology, are presented.

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