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Volume III
SUBMARINE CAPABILITIES

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SUBMARINE WEAPON SYSTEM EMPLOYING GUIDED MISSILES FOR 1960-70



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A STUDY CONDUCTED FOR
THE OFFICE OF NAVAL RESEARCH
BY THE
GENERAL DYNAMICS CORPORATION
ELECTRIC BOAT DIVISION ★ CONVAIR - POMONA

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FOREWORD

This study has been performed to assist those who have decisions to make in the development and use of the submarine/guided missile system. It is assumed that the decision makers want to be advised, first, of certain scientific facts and conclusions which will be of use in policy setting; of secondary interest is the mathematics which support the facts and conclusions.

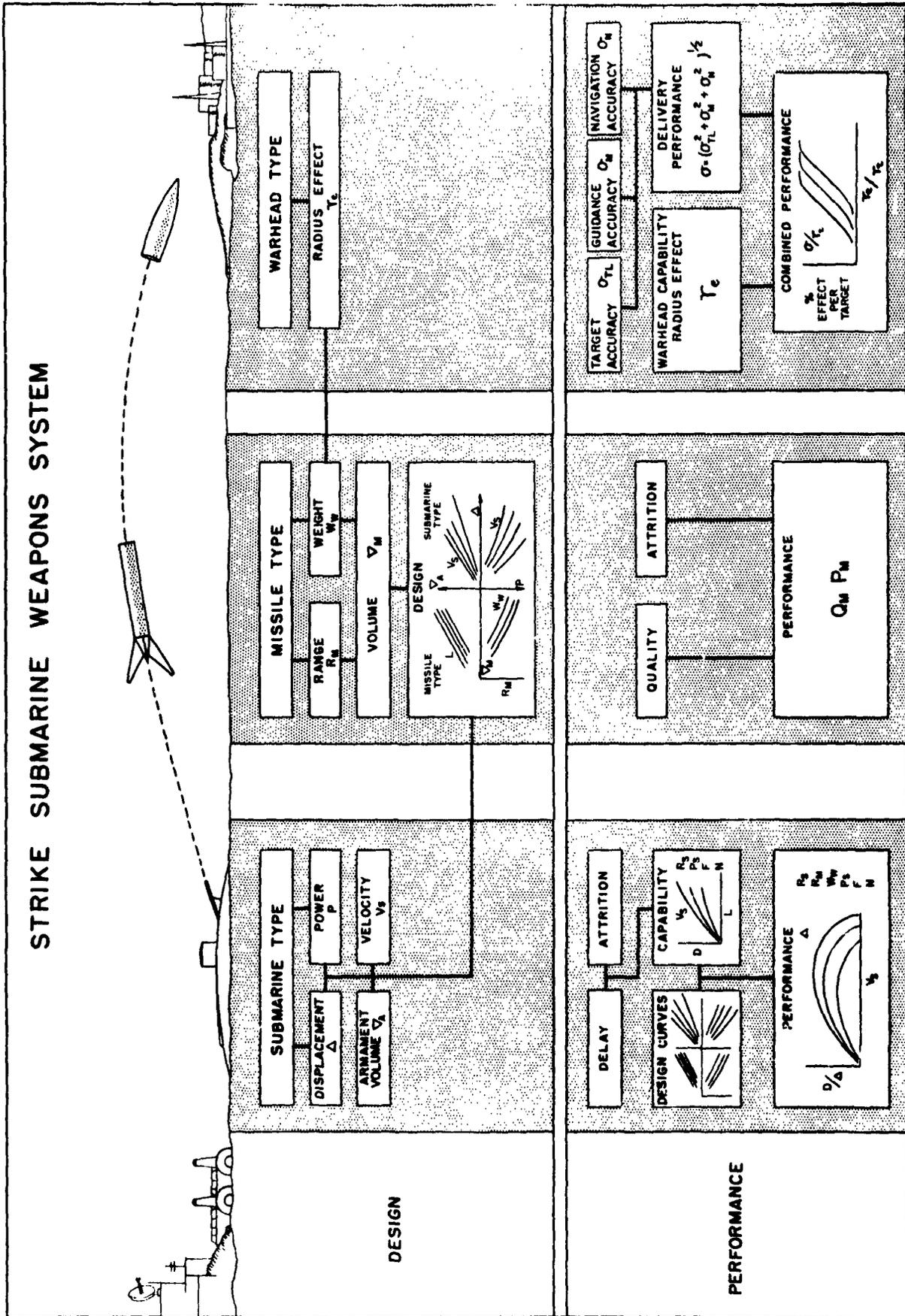
This report is a parametric development of the performance of the submarine/guided missile system in the execution of a representative task. It is, then, the basic purpose of this report to develop the scientific facts and to present the conclusions drawn from them. The supporting data are provided in the appendices of this report.

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STRIKE SUBMARINE WEAPONS SYSTEM



FRONTISPIECE STRIKE SUBMARINE WEAPONS SYSTEM PERFORMANCE

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SECTION 1

SUMMARY OF STUDY

This paper is a study in the development of a method to measure the possible physical performance characteristics of a Strike Submarine Weapons System (submarine launched guided missile) that is to be employed against coastal targets during the period 1960-70. It is part of a larger study that has as its purpose the development of a means to evaluate the effectiveness of such a system to accomplish military objectives.

Specifically, this study of system performance is to provide:

- a. the feasible configurations of such a system in terms of missile range, accuracy and warhead, and in terms of submarine speed, displacement and payload (number of missiles carried),
- b. a means for measuring the physical performance of the entire system which, in this study, is developed as the rate of missile delivery under certain given situations,
- c. a perspective of the general problem that this study serves to support, i.e., the problem of measuring the effectiveness of the several possible variations of the system to accomplish specific military objectives, and the cost to achieve this effectiveness.

In this study the words *performance* and *effectiveness* have discreet usages upon which an understanding of this work depends. *Performance* is used in the subjective sense as a capability to perform. *Effectiveness* is used in the objective sense as the satisfaction of the demands of a task or a strategy. *Performance* is an expected result under given conditions which can be controlled by the operator. *Effectiveness* is the expected result in respect to an end objective under conditions which are to some extent controlled by the opposition. Rate-of-fire is a measure of performance whereas exchange rate is a measure of effectiveness.

The conclusions of the study lie in the curves which demonstrate the performance capabilities of the system. These capabilities are measured in respect to a definite missile that is to be delivered at a certain defined series of launch points. This data is thus made available to be used to determine the system's effectiveness for a given military mission.

Complete calculations are made in the case of two missiles (100 mile and 1500 mile ranges) that are to be delivered at launch points which are 2000 miles and 6000 miles from base.

SECTION 2

DIMENSIONS OF SYSTEM PERFORMANCE

INTRODUCTION

A large range of system capabilities is inherent in the feasible configurations of submarine, missile, and warhead. It is, therefore, of importance to establish a measure of system capability to perform a task before determining the *best* or the *most effective* system for the task. However, capability is independent of the task. Capability merely defines what is available for use in the performance of the task.

DEFINITION OF SYSTEM PERFORMANCE

There are four major components of the strike system:

- a. the submarine,
- b. the missile,
- c. the warhead,
- d. navigation and guidance.

SECRET

Each of these components contributes one or several capabilities. The combined capabilities per component yield a component performance. The combined component performances yield system performance. The distinction made here between capability and performance is that which, in standard engineering usage, distinguishes an output from an efficiency or ratio of output to input.

Since the operation of the strike system involves sequential steps, *system performance is obtained as the product of component performances; i.e.,*

$$\text{System Performance} = \text{Submarine Performance} \times \text{Missile Performance} \times \text{Warhead Performance} \times \text{Navigation and Guidance Performance}$$

MEASURE OF PERFORMANCE

Implicit in the employment of a designed component, is its quality of reliability in operation and invulnerability to enemy opposition.

Consequently, the measure of component capability falls necessarily into two categories, *Physical* and *Statistical*.

The *physical factors* are measured in terms of the state-of-the-art of design and construction. They are characterized by the fact that, being under the direct control by the user, they can be described in concrete physical terms. The *statistical factors* which influence component capability must be defined in different terms since they must account for influences not under the direct control of the human operator. The system in operation encounters environments (enemy opposition, weather, geography) or is involved in situations (locating a target, obtaining a navigational fix, delivery of a missile in the vicinity of a target) where the outcome of the event is not predictable with certainty. Consequently, the language used to describe the event must be stated as an average and must indicate the degree to which the capability involved may be less than fully realized.

PHYSICAL DIMENSIONS OF PERFORMANCE

SUBMARINE PERFORMANCE

Table I is a breakdown of capability and performance by components. For a given displacement, the submarine can be designed for a range of capabilities that exhibit an interchange between power and armament volume. Consequently, the submarine is capable of a certain speed, range, and armament carrying capacity.

**TABLE I
DIMENSIONS OF SYSTEM COMPONENT PERFORMANCE**

Component	Independent Design Parameter	Design Capability	Component Performance
Submarine	Displacement (tons)	1. Armament Volume (cu.ft.) 2. Range (miles) 3. Velocity (knots)	$\frac{\text{Armament Volume}}{\frac{\text{Range}}{\text{Velocity}}} \times \text{Displacement}$
Missile	Unit Volume (cu.ft.)	1. Warhead Capacity (lbs.) 2. Range (miles) 3. Velocity	$\frac{\text{Warhead Capacity}}{\text{Unit (Missile) Volume}}$
Warhead	Weight (lbs.)	Effect (Area Coverage)	$\frac{\text{Effect}}{\text{Warhead Weight}}$
Guidance		Accuracy (Feet)	% times given effect (AREA COVERAGE) is produced

SECRET

Per ton of displacement;

$$\begin{aligned} \text{Submarine Performance} &= \frac{\text{Armament Volume}}{\frac{(\text{Range})}{(\text{Speed})} \times \text{Displacement}} \\ &= \frac{\text{Armament Volume}}{\text{Mission Time} \times \text{Displacement}} \end{aligned}$$

MISSILE PERFORMANCE

For a given range of missile the important performance characteristic is:

$$\text{Missile Performance} = \frac{\text{Warhead Weight}}{\text{Unit (Missile) Volume}}$$

WARHEAD PERFORMANCE

For a given type of warhead, there is a relationship between warhead weight and its delivered effect. Consequently,

$$\text{Warhead Performance} = \frac{\text{Effect (Area Coverage)}}{\text{Warhead Weight}}$$

PHYSICAL SYSTEM PERFORMANCE

The submarine and missile performances combine to yield, *RATE OF DELIVERING TOTAL WARHEAD WEIGHT PER TON OF SUBMARINE* (or some factor other than tons that is a cost common to all strike submarine weapons systems such as dollars or men). This can be seen by combining, dimensionally, the following product terms,

$$\begin{aligned} \text{Physical System Performance} &= \frac{\text{Armament Volume}}{\text{Time} \times \text{Displacement}} \\ &\quad \times \frac{\text{Warhead Weight}}{\text{Missile Volume}} \end{aligned}$$

Armament volume and missile volume combine to give the number of missiles carried aboard the submarine. As a result, the above product reduces to,

$$\begin{aligned} \text{Physical System Performance} &= \frac{\text{Number of Missiles}}{\text{Time} \times \text{Displacement}} \\ &\quad \times \text{Warhead Weight Per Missile} \end{aligned}$$

Warhead weight per missile combines further with the number of missiles to give,

$$\text{Physical System Performance} = \frac{\text{Total Warhead Weight}}{\text{Time} \times \text{Displacement}}$$

The final interpretation is therefore

$$\text{Physical System Performance} = \frac{\text{Rate of Delivering}}{\text{Total Warhead Weight Per Ton of Submarine}}$$

When this combined performance of submarine and missile is coupled with the warhead performance of effect per warhead weight, the result is

$$\text{Physical System Performance} = \frac{\text{Rate of Delivering}}{\text{Total Warhead Effect Per Ton of Submarine.}}$$

DIMENSIONS OF GUIDANCE PERFORMANCE

In addition to transporting and delivering the missile, the system is required to guide the missile to the target. This involves the following operations:

- a. obtaining a navigational fix,
- b. relating own position to position of target,
- c. relaying this information to the missile.

These operations combine to define a guidance performance in terms of accuracy. Consequently,

$$\text{System Operational Performance} = \text{Physical performance} \times \text{Guidance Performance}$$

The effect of guidance is to modify the system physical performance from a total warhead effect to one of average warhead effect since the guidance accuracy defines the percentage of times the total effect is produced and, consequently, the degree to which the total warhead effect may be less than fully realized.

TOTAL SYSTEM PERFORMANCE

By combining the results of physical system performance with the guidance performance, total system performance is obtained as follows:

$$\text{Total System Performance} = \frac{\text{Rate of Delivering Average Warhead Effect Per Ton of Submarine.}}$$

SYSTEM PERFORMANCE REQUIREMENTS

The foregoing dimensional analysis has served merely to describe the physical framework within which the system operates. Regardless of the level at which the system is being reviewed for its utility (strategic, tactical, or economic) the system is a transport and delivery agent for missiles that are capable of imposing an effect at a certain rate. Within the state-of-the-art of each component, namely, power and armament volume per ton of submarine, range and warhead capacity per pound of missile, damage effect per pound

SECRET

of warhead, many degrees of performance are possible. It is the purpose of the sections which follow to present a series of curves which incorporate the design and operational characteristics of the guided missile submarine as an integrated system. Study of these

curves will provide an opportunity to observe the quality of the separate component capabilities that combine to form system performance. This will lead to a more accurate description of and appreciation for the possibilities inherent within the system.

SECTION 3

PARAMETRIC PRESENTATION OF SYSTEM

GENERAL

The system's designed performance characteristics are outlined in the *system parameter nomogram* (Figures 1, 2, and 3). There, the parameters of missile range and payload are related to the submarine parameters of payload, speed, displacement and power. From this nomogram one can determine what parameters are required to create a system with certain desired characteristics.

GROWTH FACTORS

In studying the design nomogram, the differences in the state-of-the-art of the submarine and missile design is of significance. The development of major submarine components, with exception of the nuclear reactor, has extended over several decades, while missile component evolution is young and has been rapid. It can be expected that the missile will experience some reduction in size but of more importance to the total system performance is increase in reliability. On the other hand the submarine has accomplished reliable operation, and advances in the state-of-the-art for this craft should lead to a reduction in submarine vulnerability to enemy action.

SUBMARINE DESIGN FACTORS

A 700 foot operating depth was chosen because it represents the current state-of-the-art. Further analysis might indicate that 700 feet is either too large or too small. In the computation of the submarine parameters it was found that, with a 700 foot operating depth, every design was volume dependent.

The development of specific configurations for the submarine was not necessary to arrive at the parametric accuracy required. To estimate the submerged power requirements, a mean propulsive constant was assumed which is representative of twin screw, SSG performance.

The speed parameter used is that of maximum sustained speed. In the nuclear boats, all speeds are submerged speeds in that no tactics requiring surface speeds are anticipated. In the diesel boats, the speeds are surfaced speeds. The submerged speeds on diesel boats is considered to be constant at 7 knots, the battery capacity being varied to give a fixed requirement for the duration and frequency of battery charges.

MISSILE DESIGN FACTORS

The discussion of the missile design considerations is contained in a separate report.

SECRET

SECTION 4

INFLUENCE OF DEGRADATION ON SUBMARINE CAPABILITY

GENERAL

The purpose of this section is to discuss and emphasize the extent to which degradation of the submarine, while transporting and delivering missiles, can influence its potential capabilities.

The causes of degradation are attributed to two major influences:

- a. enemy opposition,
- b. natural hazards such as component malfunction and weather.

The price exacted by these influences is twofold:

- a. the probability of loss of the submarine itself,
- b. the loss of time in performing the mission.

The submarine's capabilities are most sensitive to the degrading influences which can be expected in the enemy dominated launch area. Here, the submarine will be subjected to a finite risk (attrition) per launching and to launching delay due to some of the following causes:

- a. time required to position the submarine tactically for launching the missile(s),
- b. time to travel to next launch point,
- c. time required for a navigational fix,
- d. time required for readying missiles.

The extent to which time delay and attrition reduce the designed capabilities of the submarine is graphically displayed in Figure 4. For contrast, the capability of the submarine (number of missiles launched

per month) is measured against the maximum capability it would have in the absence of delay or attrition. The curves exhibit the progressive reduction in capability, first, as the result of delay between launching, and then, as the result of increased risk per launch. The latter effect becomes marked when one attrition has the extreme value of 5 percent. The major reason for this reduction due to attrition is that the fate of the missiles aboard is so intimately connected with the attrition of the submarine, and, in attempting to launch successive missiles, the attrition effect is cumulative and eventually the system reaches a point where the potentials represented by the payload aboard is never realized.

The influence of the number of missiles fired per launching can be observed by comparing the sets of curves of Figure 4. This fire rate is subject to the physical limitations of the submarine in handling the missile and to the number of targets within reach. A higher fire rate is achievable with ballistic missiles than is achievable with cruise missiles because the ballistic missile is less cumbersome and complex and, hence, lends itself to relative ease of handling.

The attrition and delays incurred in the transit to and from the launch point modify the system's capability in direct proportion to their magnitude. The effect on the curves, therefore, would be one of a shift in scale. The form of the curves would remain unchanged.

Degradation due to natural hazards is of greatest significance in turn-around-time where preventive maintenance delays the operation. One day in port for every three days at sea is assumed in the computation of curves illustrated in Figures 4, 5, 6, and 7.

SECRET

SECTION 5

DEVELOPMENT OF SUBMARINE PERFORMANCE

GENERAL

Section 2 defined system capability as system output, while performance is an efficiency or ratio of input to output. The group of curves in Figure 5 illustrates the output of a submarine measured in missiles launched per month as a function of various design and mission parameters. These parameters (number missiles, submarine speed, submarine radius of operation, etc.) serve as a specification for the submarine design in that they define the submarine's capability. They do not account for the price for the system's performance which, in these curves, is chosen to be *submarine displacement*.

The curves of Figure 6 and 7 combine the system specification or output with the design input, displacement, as a measure of submarine performance. This performance is plotted as a function of submarine speed for various values of displacement. Considering

a given displacement a fixed volume is defined to house the submarine functions. The performance of a submarine is dependent on the utilization of this volume. For instance, this volume at one extreme could be given totally to missile stowage leaving no space for propulsion, and as a consequence, would have zero speed. At the other extreme, the space could be consumed by propulsion equipment to gain maximum speed. This, then, results in a zero payload and also zero performance. Between these extremes is an optimum balance which, in turn, defines an optimum speed.

With no degradation and unlimited mission requirements, the optimum submarine would have the largest displacement that was feasible. With an increase in the distance between the launch points, the optimum submarine displacement will be decreased below that which is the optimum from a purely transportation viewpoint.

SECTION 6

MISSILE PERFORMANCE

GENERAL

The missile physical performance has been defined for a given range and mach number as the ratio of its warhead capacity and packing volume. In the case of the cruise type missile the packing volume is strongly dependent on the arrangement of the aerodynamic surfaces and boosters. Consequently the values of missile size for various ranges may deviate substantially from those used in the curves of Figures 1, 2, and 3. On the basis of this physical ratio, the cruise missile will have a higher performance above ranges of 600 to 800 miles.

Missile type can have a marked effect on submarine performance as noted in Section 4. Potentially, the ballistic missile affords less restriction to operations since remote launching, submerged launchings, and multiple launchings are possible.

Current programs indicate that missile reliability should be of primary concern. Reliability is a function of design, craftsmanship, handling, servicing, and stowage conditions. Design evolution and experience should improve missile reliability with time. The new element added in the strike submarine operation is the possibility of suffering depth charge attacks with missiles in stowage. This time function of reliability is purely speculative, and consequently a reliability factor of 72% successful detonations at target is selected resulting from 90% passing checkout and 80% experiencing successful flight.

The high speeds presently achievable in the missile (mach 3.5 or better) make the problem of enemy counter so difficult that certain survival of missile in flight has been assumed throughout this report.

SECRET

SECTION 7

PERFORMANCE OF WARHEAD AND GUIDANCE SYSTEM

INTRODUCTION

The purpose of the present chapter is to demonstrate the method for combining:

- a. component accuracies to give guidance accuracy,
- b. guidance accuracy with warhead effect to give guidance performance.

DELIVERY OF MISSILE

The submarine enters the launch area equipped with a missile of given range and warhead effect. Having selected its target, the submarine is required to perform the following operations:

- a. position itself either by means of a piloting or a celestial fix,
- b. relate the target position to its own position,
- c. relay this information to the missile either before or after firing.

Associated with each of these operations is a discrete error. The nature and magnitude of these errors play a dominant role in this phase of the strike cycle.

WARHEAD PERFORMANCE

The amount of damage that a given weight and type of warhead can inflict on a target has not been studied in great detail for the purposes of this study for several reasons. The information available on warhead effect is highly classified, and the state-of-the-art is developing at such a rate that existing data will soon become obsolete. Moreover, the subject entails political and military considerations that are beyond the province of the present study. Consequently, the warhead effect has been treated simply as a physical circle that can cover a certain percentage of a target of given size. It has been assumed that some relationship exists that relates warhead weight and the corresponding radius of warhead effect.

GUIDANCE PERFORMANCE

The accuracy with which the missile is guided to the target depends upon the following component accuracies:

- a. submarine navigation,
- b. target location,
- c. missile guidance.

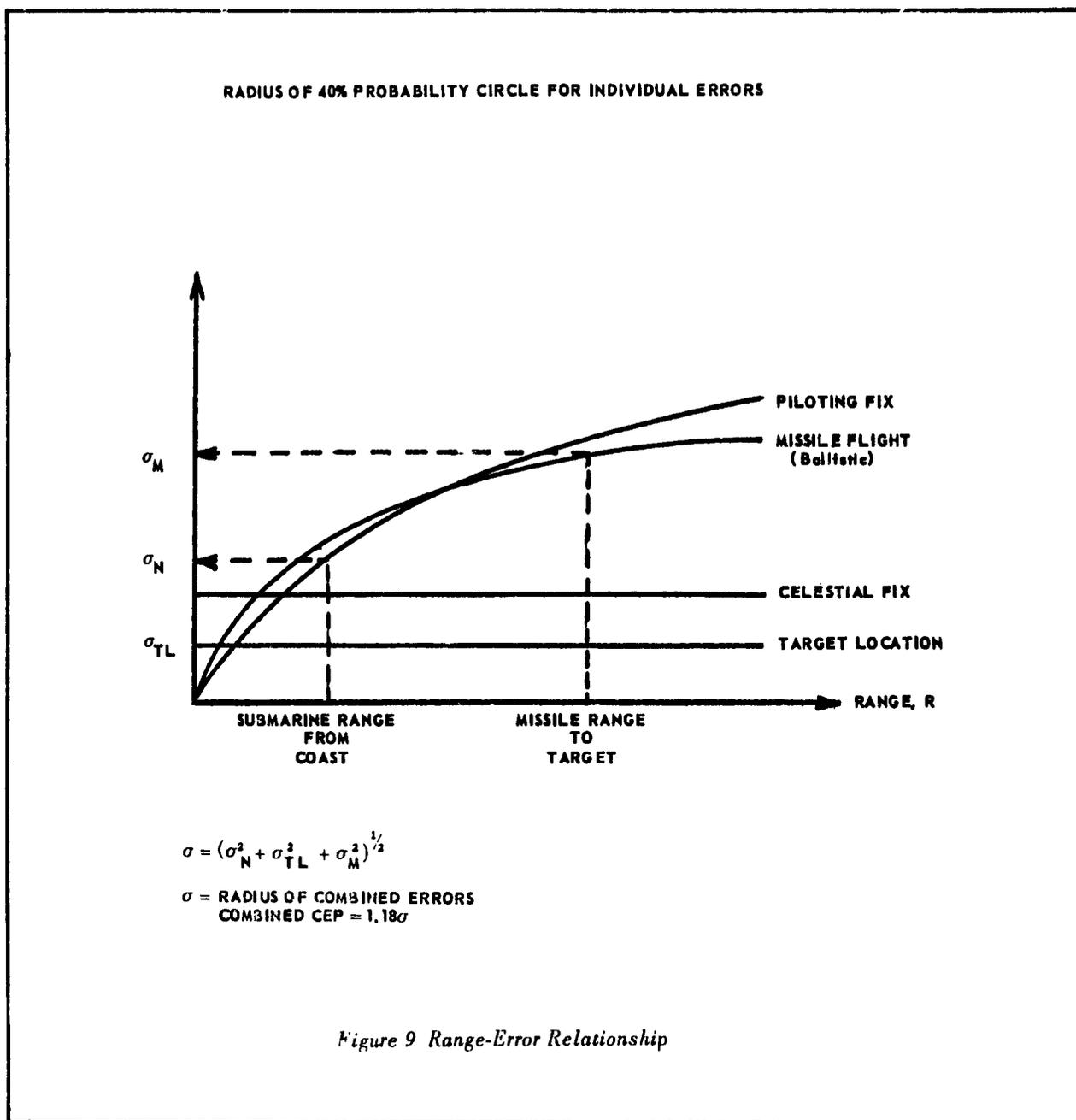
Each of these component accuracies is of sufficient magnitude as to be the subject of a separate and detailed study. An exploratory study of the order of magnitude of submarine navigation and target location accuracies for a variety of systems has been made and is appended to this report.

The total guidance error is computed by means of the following relationship:

$$\sigma^2 = \sigma_N^2 + \sigma_{TL}^2 + \sigma_M^2$$

where σ_N , σ_{TL} , and σ_M are the submarine navigation, target location, and missile guidance errors respectively. For simplicity of mathematical treatment, all errors have been assumed to be circular normally distributed. The advantage of this simplification is that it keeps the task of computing the effect of errors from becoming unnecessarily complex. It has become standard practice to describe the errors in terms of the symbol *CEP*. By definition, a *CEP* of given magnitude is the radius of the circle within which fifty percent of the missiles can be expected to fall. This definition provides a convenient measure for discussing errors.

For the purpose of illustrating the method for treating component errors, the following diagram is presented. It is purely suggestive and is intended to exhibit the possible relationship that might exist between errors and range.



GUIDANCE AND WARHEAD PERFORMANCE

Given the warhead and guidance capabilities, represented symbolically by r_0 and σ , the final step is to relate these to the physical dimensions of the target (r_t) and obtain a measure of guidance and warhead performance. This has been done and the results are incorporated in Figure 8. These curves show the relationship between (r_0/r_t) and the following defined measures:

- a. *Average Coverage* – The average percent of overlap between the warhead effect radius r_0 and the target circle of radius r_t .
- b. *Probability of Total Coverage* – The percentage of times that the warhead circle completely encloses the target circle.

By means of these curves, the quality of the warhead performance can be readily assessed. The graphs can be used for a variety of inputs depending upon the problem at hand. For example, if it were of interest to

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know the size of warhead effect (r_e) to build into the missile in order to deliver a certain effect against a given size target (r_t) for known system accuracy (σ), it would involve entering the ordinate of plot, reading over to the appropriate (σ/r_t) curve and noting the corresponding value of (r_e/r_t). Conversely, this procedure could be reversed if it were of interest to determine the order of accuracy required with a given

warhead effect against various sizes of target. If the required accuracy were greater than that presently obtainable, it would require further investigation into the nature of the total error in order to establish which of the component errors could be improved.

The use of the curves is dictated by the type of mission that the system would be required to perform.

SECTION 8

IMPLICATIONS OF THIS STUDY

The implications of the performance curves deserve careful analysis since some of the results are not those that would be intuitively expected. As an example it is observed that:

- a. For a given submarine displacement, there is an optimum speed/payload balance.
- b. For an increase in displacement, there is an increase in optimum speed.
- c. Beyond a certain displacement, any increase in displacement provides negligible increases in performance.
- d. Optimum displacement is sensitive to attrition, operational delays, and the submarine radius of action.

- e. For a given task, as the displacement increases, performance appears to be more sensitive to operational delays than to attrition.
- f. The attainable fire rate for a 100 mile ballistic missile strike submarine weapons system appears to be such as to warrant consideration of the use of the system for non-nuclear warheads. This is illustrated by the curves of Figure 6 where it can be seen that three, 3000-ton submarines can maintain a continuous fire rate on one target of four missiles a day, each missile carrying a 1000 pound warhead of either chemical explosive or of napalm. This has important implications in localized and limited warfare.

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SSWS PARAMETRIC CURVES

MISSILES
BALLISTIC, SINGLE & MULTISTAGE

SUBMARINES
SSG, TWIN SCREW, NUCLEAR

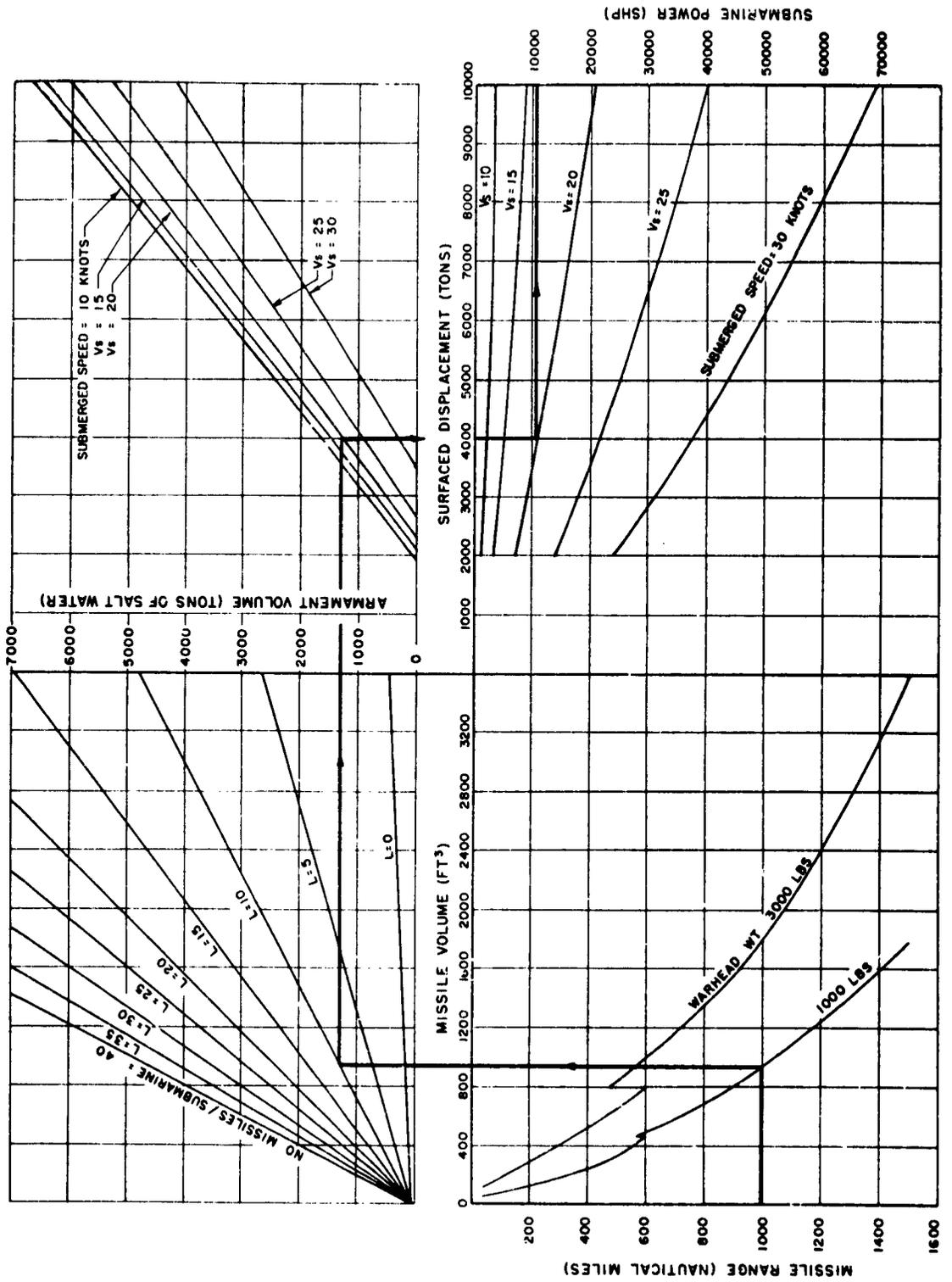


FIGURE 1 SSWS PARAMETRIC CURVES (BALLISTIC - NUCLEAR)

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SSWS PARAMETRIC CURVES

MISSILES
BALLISTIC, SINGLE & MULTISTAGE

SUBMARINES
SSG, TWIN SCREW, DIESEL-ELECTRIC

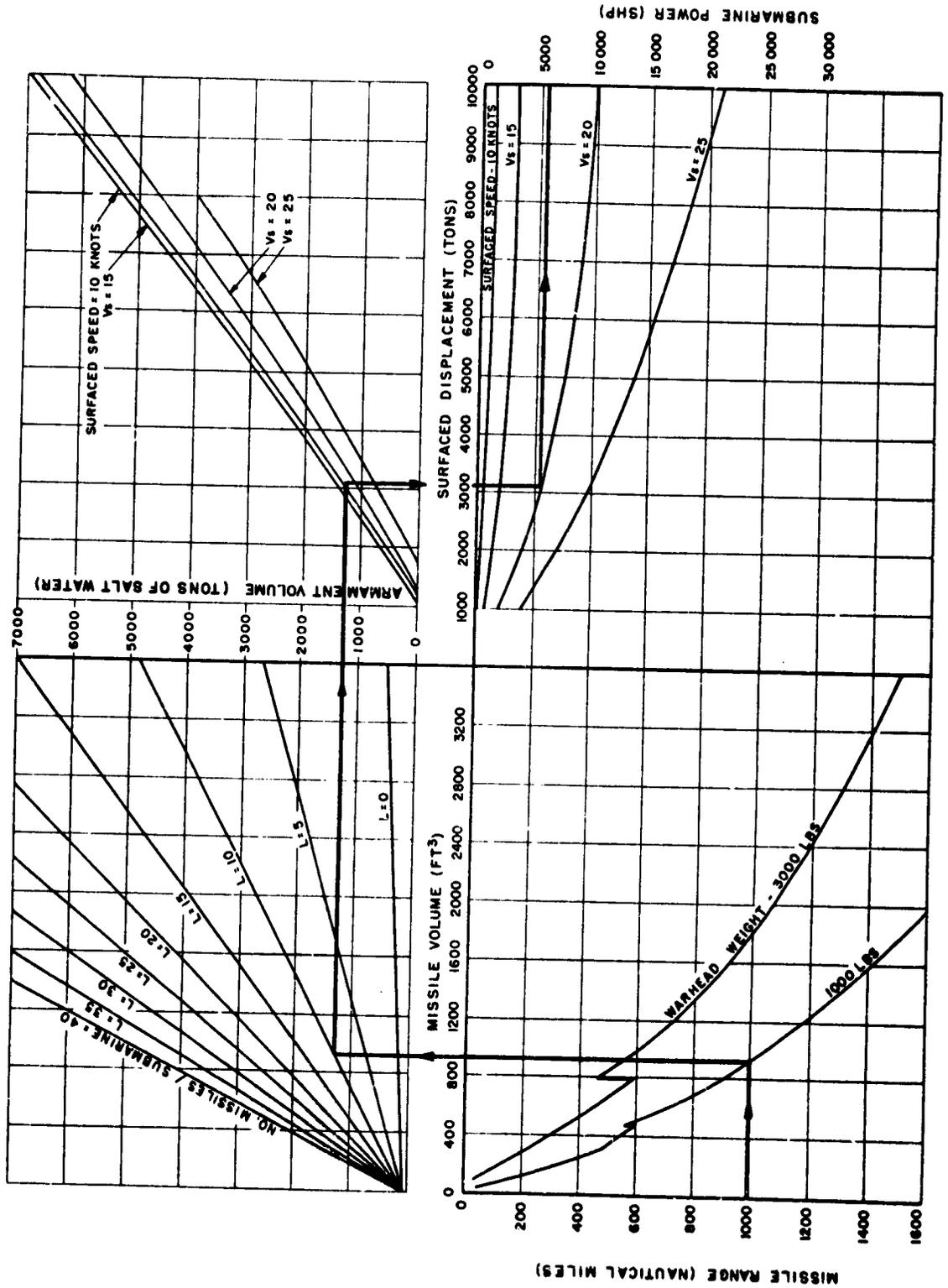


FIGURE 2 SSWS PARAMETRIC CURVES (BALLISTIC-DIESEL)

SSWS PARAMETRIC CURVES

SUBMARINES
SSG, TWIN SCREW, NUCLEAR

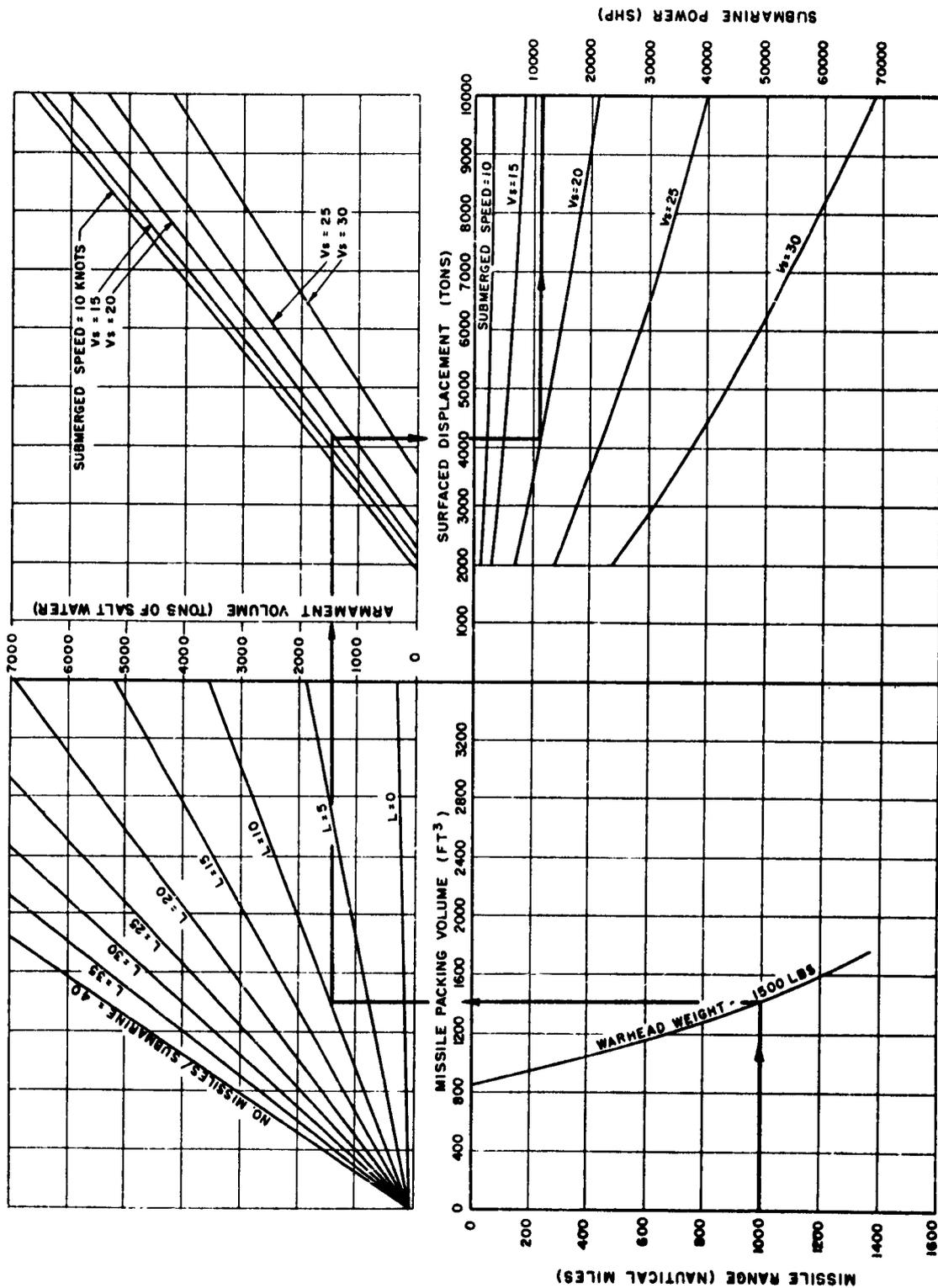


FIGURE 3 SSWS PARAMETRIC CURVES (CRUISE - NUCLEAR)

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INFLUENCE OF DEGRADATION ON SUBMARINE CAPABILITY

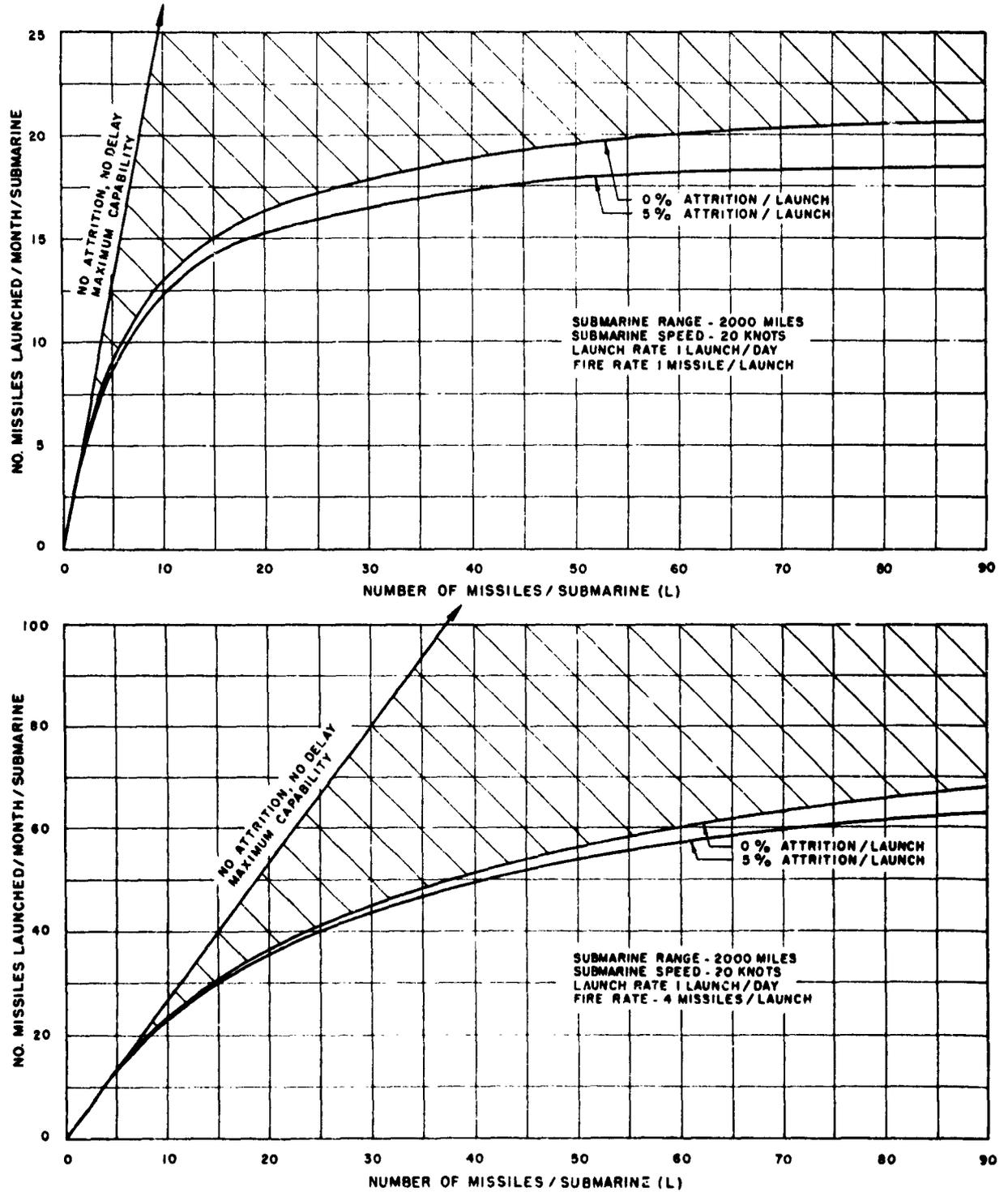


FIGURE 4 INFLUENCE OF DEGRADATION

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SUBMARINE CAPABILITY CURVES

ATTRITION - 1% / LAUNCH
LAUNCH RATE - 1 LAUNCH / DAY
FIRE RATE - 4 MISSILES / LAUNCH

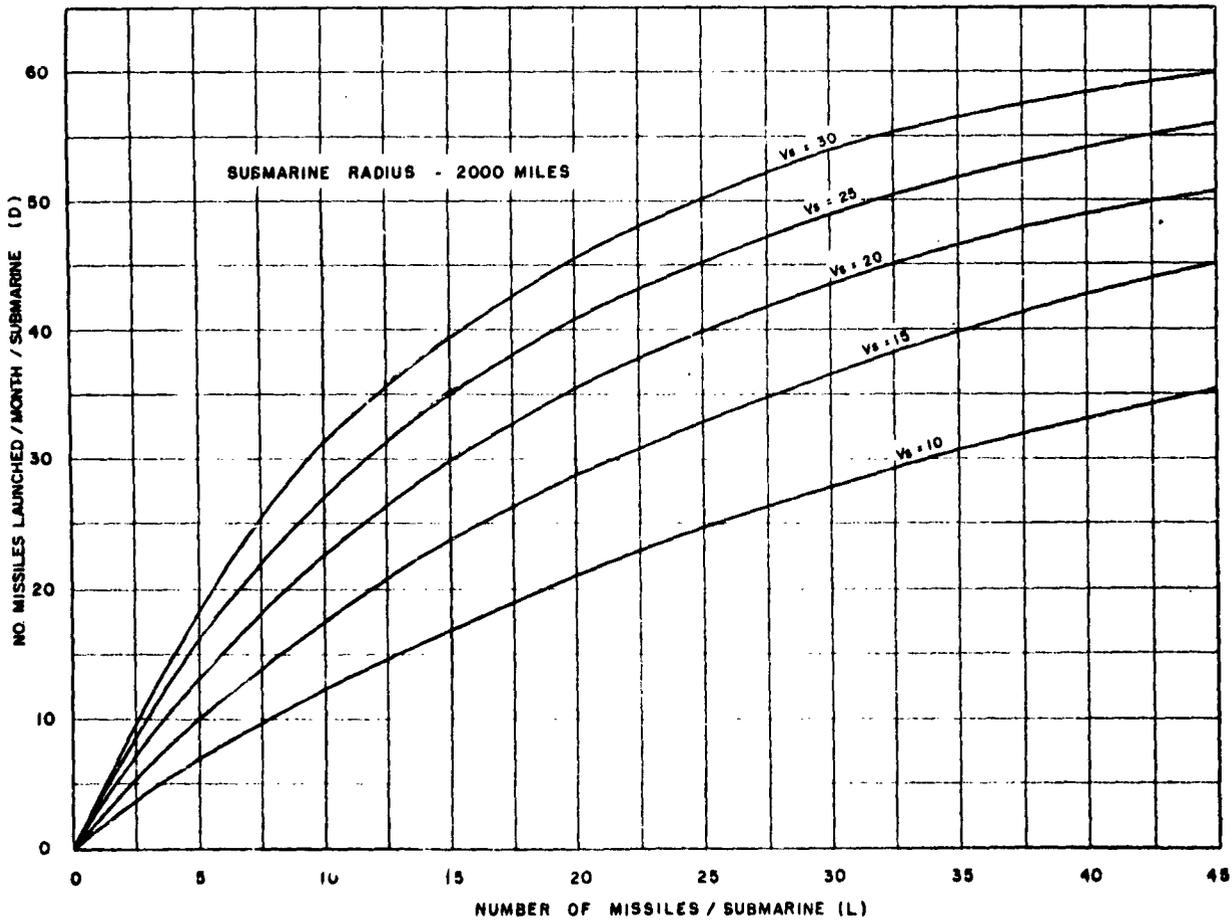
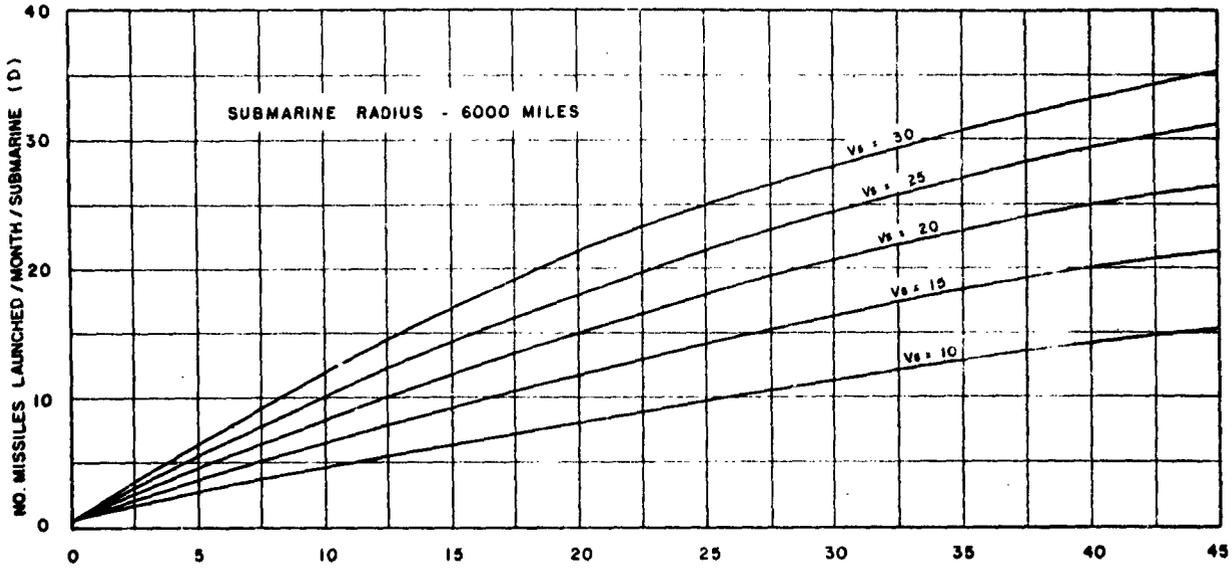


FIGURE 5 SUBMARINE CAPABILITY CURVES

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SUBMARINE PERFORMANCE CURVES

MISSILE RANGE - 1500 MILES
MISSILE TYPE - BALLISTIC
SUBMARINE TYPE - NUCLEAR
ATTRITION - 1% / LAUNCH
LAUNCH RATE - 1 LAUNCH / DAY
FIRE RATE - 4 MISSILES / LAUNCH

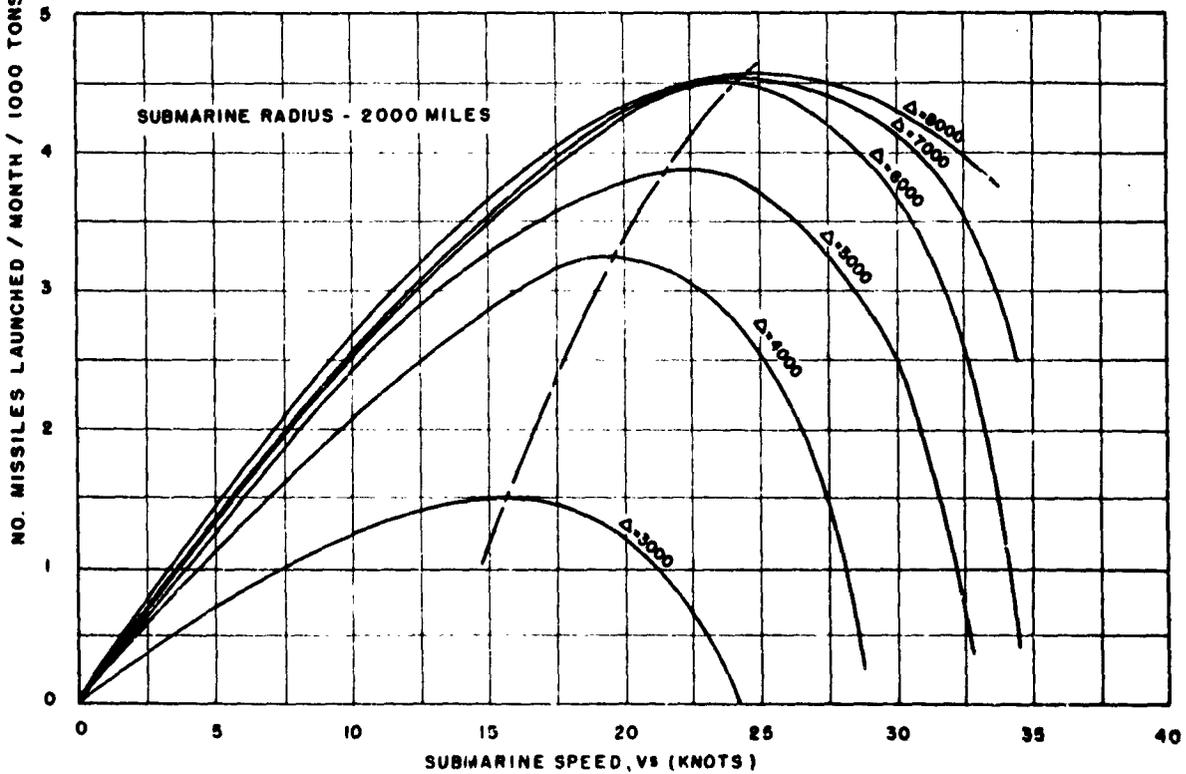
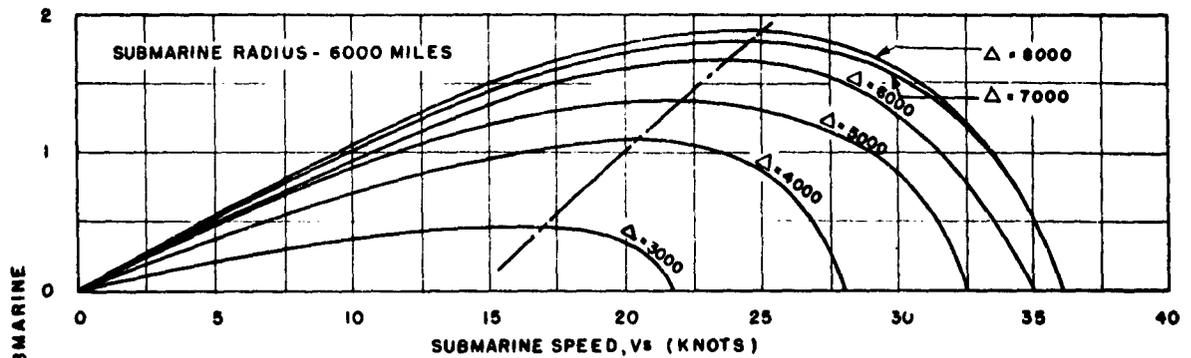


FIGURE 7 SUBMARINE PERFORMANCE CURVES (1500 MILE BALLISTIC)

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WARHEAD - GUIDANCE PERFORMANCE CURVES

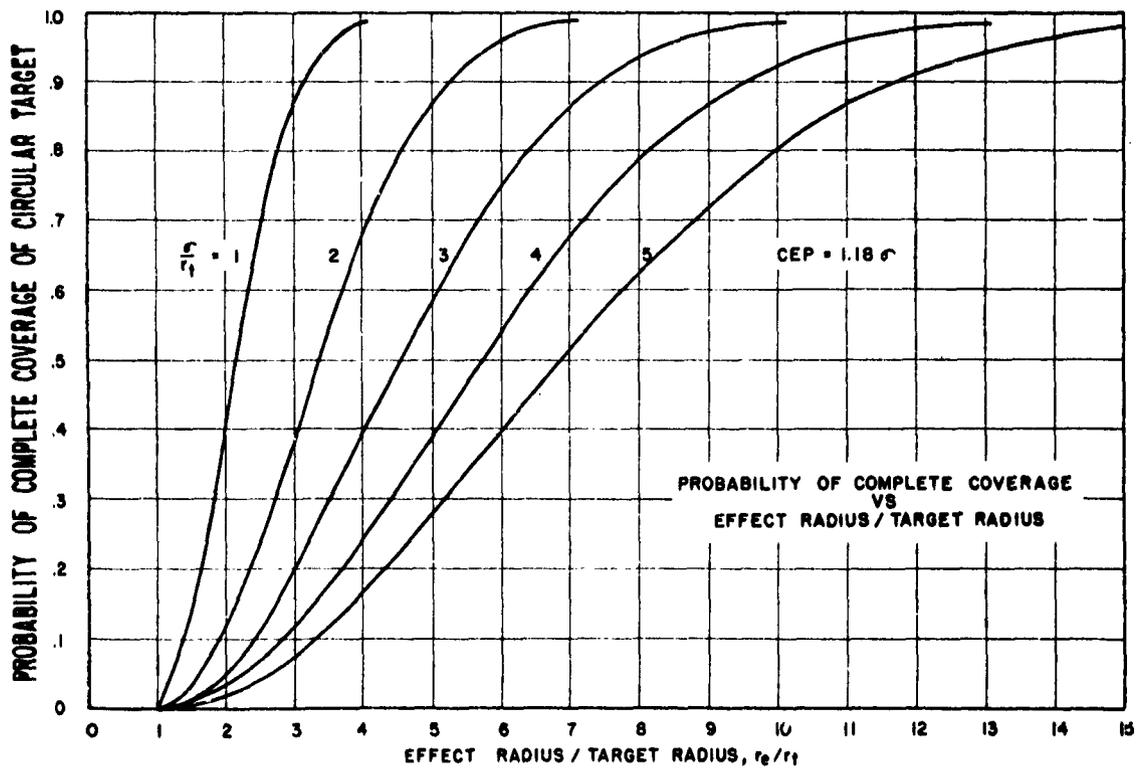
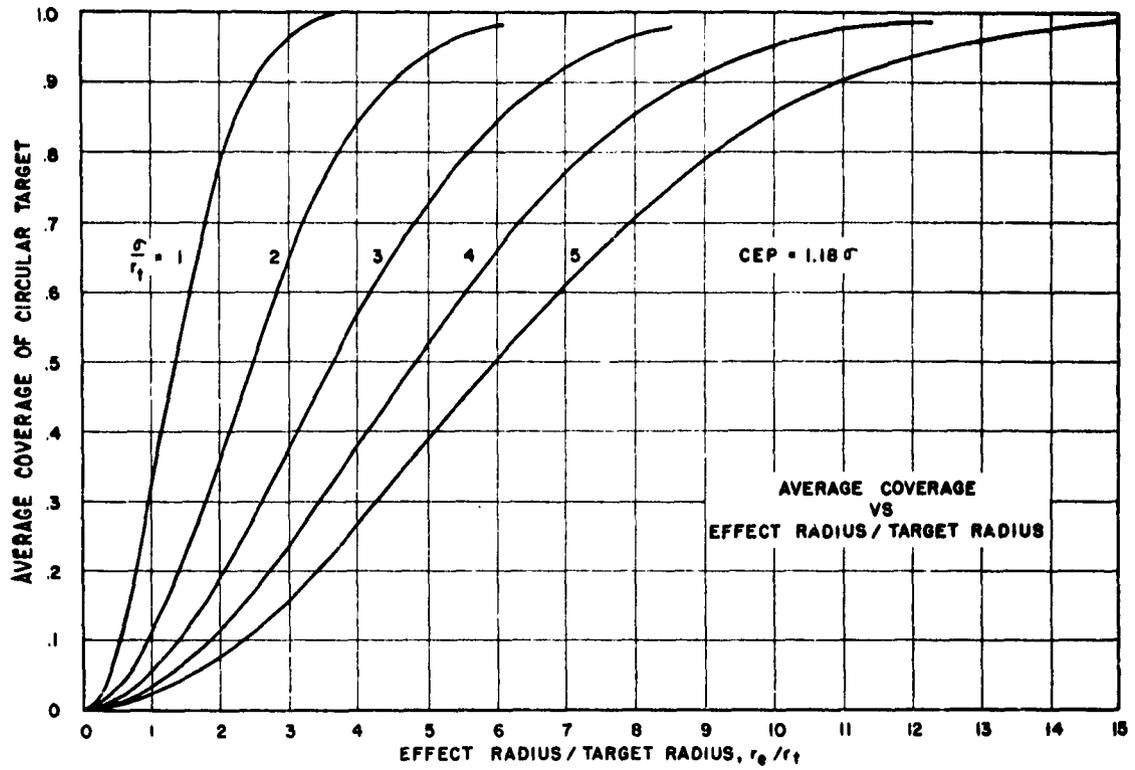


FIGURE 8 WARHEAD - GUIDANCE PERFORMANCE CURVES

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APPENDIX A
MATHEMATICAL DEVELOPMENT OF THE
ELEMENTS IN THE PHASE I PERFORMANCE STUDY

STRIKE SUBMARINE WEAPONS SYSTEM PARAMETRIC CURVES - (Figures 1, 2, and 3)

Submarine Characteristics - (Quadrant I, IV)

The two following empirical equations were used in the development of the weight and volume relationships for the family of SSG's:

WEIGHT EQUATION

$$\Delta = C_1 \Delta + C_2 \Delta^{2/3} + C_3 \Delta^{1/3} + C_4 P + M_{\Delta} + A_{\Delta} + C_5 \quad (1)$$

VOLUME EQUATION

$$\Delta = C'_1 \Delta + C'_2 \Delta^{2/3} + C'_3 \Delta^{1/3} + C'_4 P + M_{\nabla} + A_{\nabla} + C'_5 \quad (2)$$

The constants of these equations were evaluated using the following assumptions:

- The SSG will require ship's equipment similar to the advanced attack submarine of today.
- The hull will be designed for at least 700 feet operating depth.
- Fifteen percent reserve buoyancy will be supplied; i.e., $1.15 \Delta_{\text{surf}} = \Delta_{\text{sub}}$.
- The ship's personnel will vary as $\Delta^{1/3}$ a 2000 ton vessel carrying 80.
- The diesel SSG will be essentially a double hull craft.
- The nuclear SSG will have a greater portion of single hull.
- Defense armament will include 2 swimout tubes and 4 counter-measure torpedos.

Next, the power-displacement - speed relationships were considered. For submerged speed, the admiralty equation noted below was employed:

$$P = K V_3^3 \Delta_{\text{sub}}^{2/3} \quad (3)$$

For the diesel SSG, the diesel-electric power plant is rated on the basis of surfaced speed which represents its greater speed capability. To obtain surface characteristics, a geometric series of the fleet hull was developed and referred to Taylor's Standard Series.

Assumptions used in power calculations:

- The diesel SSG will be able to operate surfaced for sufficient time to justify the use of a good surfaced hull form.
- The SSG's considered are of twin screw design.
- The roughness correction for the coefficient of friction will be 1.0×10^{-3} .
- To recognize the more adverse configurations anticipated for the cruise missile carrier a K of .0055 was selected in contrast to the .0050 for the ballistic missile boat.

The results of the evaluation of the power-displacement-speed relationship are illustrated in the fourth quadrant of Figures 1, 2, and 3.

The power plant weight and volume characteristics were then developed. The nuclear plant characteristics are derived from a series of preliminary designs varying in power from 6000 to 60,000 SHP. This family is representative of the likely operational plants for 1960 through 1965. Fundamentally, these reactor plants are heterogeneous using either high pressure water or sodium as primary coolant:

The diesel-electric plants are based on the use of supercharged diesel engines obtaining fuel rates in the order of 0.37 and 0.80 pounds of fuel per BHP hour. No increase in performance of storage batteries is predicted. The Guppy II battery is used as a basis for battery characteristics. Two sets of criteria were used in sizing the batteries giving two snorkel cycles, 2 charges per day and 3 charges per day. For each case the 7 knot battery discharge rate was used and a minimum level of charge of 60 per cent. Maximum charging rate was allowed with 600 volts per battery being the charge cut-off point.

Fuel oil capacity is set for all vessels by a range of 12,000 nautical miles at 12 knots.

The final presentation of the relationship between volume available for armament, submarine speed, and displacement as shown in quadrant I of the curves is developed through the combination of the above functions. Systematically considering values of speed and displacement, the corresponding power requirements

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are obtained and converted to power plant weight and volume requirements. These weight and volume values are then substituted with displacement in equations (1) and (2) respectively. This allows the solution of weight and volume available for the missile installation. Comparing the weight and volume available with expected packing density it can be determined whether the designs are weight or volume controlled. For the cases presented in the curves, the designs are volume dependent and consequently in first quadrant submarine displacement is plotted against armament volume for various speeds.

Relationship of Missile Size to Submarine Armament Volume - (Quadrant II)

To allow a rough approximation of the influence of missile size on the submarine without developing detailed arrangements, missile loading functions were developed based on the following assumptions:

- a. The missiles would be stowed internally.
- b. The submarine will be of single hull construction in way of the missile stowage.
- c. Framing requires approximately 13% greater volume than the base compartment volume (inside framing).
- d. Two thirds, or 9% of this framing volume is charged as waste; the remainder will be utilized as compensation tankage.
- e. Missile service equipment space allowance is equivalent to a 10' x 10' x 8' volume.
- f. Compensation tankage volume is equal to the volume of the missile weight equivalent of salt water plus 5%.
- g. A missile packing factor of 2.75 times the missile cylindrical volume is required to allow for stowage arrangements.
- h. Handling and loading space is considered equal to the volume of 4 ballistic missiles or 2 cruise missiles.
- i. The missile density band on cylindrical packing volume is 62 pounds per cubic foot for ballistic missiles and 8.2 for cruise missiles.

These assumptions lead to the following equations:

BALLISTIC MISSILES

$$A_V = (1.09 + .03) [25 + 1.05 \times .0156 \rho I_v + 2.75 I_v + 4v]$$

substituting $\rho = 62 \text{ LB/FT}^3$

$$A_V = 28 + 4.48 v + 4.22 I_v \quad (4)$$

A_V is measured in tons of salt water.

CRUISE MISSILES

Letting $\rho = 8.2 \text{ LB/FT}^3$

$$A_V = 28 + 2.24 v + 3.23 I_v \quad (5)$$

These functions are plotted in the second quadrant of Figures 1, 2, and 3

Missile Characteristics - (Quadrant III)

The missile characteristics are developed in the missile parametric study section of the Strike Submarine Weapons report.

SUBMARINE CAPABILITY CURVES - (Figures 4 and 5)

General Expression

Submarine capability is defined as the rate of delivering missiles per submarine. Capability is a function of the dimensions of the task, characteristics of the submarine, and degradation factors (natural and enemy opposition). In general terms capability can be expressed as follows:

$$\text{Delivery Rate} = \frac{\text{Missiles Successfully Delivered}}{\text{Mission Time}} \quad (6)$$

The model presented herein is not an exact expression but a first approximation useful in an exploratory analysis.

Missiles Successfully Delivered

A submarine is equipped with L missiles and fires N missiles per launch. If the submarine attempts to launch all of its missiles successively and is subject to a constant risk $1-P_s$ per launch, then the average or expected number of successfully completed launchings is the sum of the probabilities of completing successive launchings, i.e.,

$$E(L/N) = P_s + P_s^2 + P_s^3 + \dots + P_s L/N \quad (7)$$

$$D' = \frac{P_s (1 - P_s L/N)}{1 - P_s} \quad (8)$$

Then the number of missiles successfully delivered is

$$N \frac{P_s (1 - P_s L/N)}{1 - P_s} \quad (9)$$

Mission Time

Mission time is considered in three parts:

- a. Time at base, t_B , for loading, repair, etc.
- b. Time in transit, t_T , including return trip if charged to the mission and evasive delays.
- c. Time in launch area, t_L , for evasion, navigation, reading, and movement between launch points.

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Time at base is considered to be a direct function of time at sea or

$$t_B = a (t_T + t_L) \quad (10)$$

Time in transit is a function of the distance from the operating base to the launch area, R_s , and the submarine speed of advance, $f V_s$. For a continuing operation this term would be expressed as follows:

$$t_T = \frac{R_s}{f V_s} + \frac{N D' R_s}{L f V_s} \quad (11)$$

If the mission is only concerned with on-station delivery rate t_T will be zero. The factor f is the percentage of maximum speed, V_s , made good.

Time in the launch area is a function of the launch rate, fire rate, and number of successful launchings. The number of launchings is D' as defined by equation (8). t_L can then be expressed as follows:

$$t_L = \bar{L} (D' - 1) \quad (12)$$

Combining these three components of mission time:

$$\text{MISSION TIME} = t_B + t_T + t_L \quad (13)$$

$$t_M = a(t_T + t_L) + (t_T + t_L)$$

$$t_M = (a + 1) \left[\frac{R_s}{f V_s} + \frac{N D' R_s}{L f V_s} + \bar{L} (D' - 1) \right]$$

Model

The combined expression becomes

$$D = \frac{N D'}{(a + 1) \left[\frac{R_s}{f V_s} + \frac{N D' R_s}{L f V_s} + \bar{L} (D' - 1) \right]} \quad (14)$$

For this study $(a + 1)$ was considered equal to $\frac{1}{2}$ and f equal to 1.

SUBMARINE PERFORMANCE CURVES (Figures 6 and 7)

The submarine performance curves are developed through the following procedure:

- a. For a given submarine type, missile type, war-head size, and missile range enter Figures 1, 2, or 3 with a constant displacement and various speeds to determine the number of missiles carried per submarine, L .
- b. Then entering the appropriate curve of Figure 5 with L and the corresponding submarine speed, V_s , find the delivery rate capability, D .
- c. The delivery rate is then divided by the submarine displacement measured in kilotons and plotted as a function of submarine speed and displacement.

NOMENCLATURE

- Δ = Submarine surfaced displacement.
- Δ_{sub} = Submarine Submerged displacement.
- P = Ship's complement, officers and men.
- $A\Delta$ = Missile installation weight.
- $A\nabla$ = Missile installation volume.
- $M\Delta$ = Machinery installation weight.
- $M\nabla$ = Machinery installation volume.
- K = Admiralty equation coefficient.
- P = Maximum continuous SHP.
- ρ = Missile density based on cylindrical packing volume.
- v = Missile cylindrical packing volume.
- L = Number missiles carried per submarine.
- \bar{L} = Launch rate - Launches/unit time.
- $1-P_s$ = Risk of submarine attrition per launch.
- D' = Expected number of successfully completed launchings
- N = Fire rate - Missiles/launch.
- t_B = Submarine time at base.
- t_L = Submarine time in launch area.
- t_T = Submarine time in transit.
- t_M = Submarine mission time.
- a = Ratio of time at base to time at sea.
- f = Percentage of maximum continuous speed made good.
- V_s = Maximum continuous speed of the submarine.
- R_s = Distance the submarine travels from base to launch area.

- C_1, C_2, C_3, C_4, C_5 = Weight constants.
- $C_1', C_2', C_3', C_4', C_5'$ = Volume Constants.

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APPENDIX B

100 MILE MISSILE

SUPPORTING CALCULATIONS FOR STRIKE SUBMARINE WEAPONS SYSTEM

PROBLEM

To optimize the strike submarine weapons system satisfying the approximate parameters, given below, with respect to the current measure of effectiveness:

- a. Missile range, $R_m = 100$ miles
- b. Yield = 1 megaton
- c. Total CEP error. = 1 mile
- d. Guidance - completely passive and self-contained
- e. Launching from submerged submarine
- f. Two submarine capabilities:
 - (1) Range radius, $R_s = 2000$ miles
 - (2) Range radius, $R_s = 6000$ mileseach including a capability of cruising continuously for 600 miles submerged at non-cavitating speeds
- g. Missile type - ballistic
- h. Capability of the system
 - (1) against 50 targets
 - (2) against 100 targets

APPROACH

The approach to the problem is consistent with the methods outlined in the report, *A Study of the Performance Possibilities of a Strike Submarine Weapons System*. The measure for system optimization set forth in this study is weapon system performance which is defined as the rate of delivering an effect per 1000 tons of submarine.

SUBMARINE CONSIDERED

The task indicates a vessel of closed cycle capabilities. The phase I Strike Submarine Weapons Systems study has been limited to consideration of diesel-electric and nuclear power plants. For this reason the nuclear vessel was selected for consideration in this problem.

The parametric study results as presented in the system parametric curves (Figures 1, 2, and 3) are based on mean submarine propulsive characteristics, i.e. twin screw and average powering requirements. The size and type of missile for this problem will allow

good hydrodynamic design and consequently displacement and power values noted will be conservative.

Also this missile size and type should preserve the tactical degrees of freedom of the submarine. The following typical operational factors are chosen:

- a. Attrition/launching = 1%
- b. Attrition/mission other than per launching = 3%
- c. Launch rate = 1 launch/day
- d. Fire rate = 4 missiles/launch

Note that the launch rate can be influenced by enemy opposition, target distribution, navigational delay, and readying delays.

Note the nuclear submarine speeds quoted are maximum, continuous, submerged speeds. Also the speed optimization is on the basis of efficient use of the submarine envelope as a transport vehicle. The optimum speeds related to evasion and consequently survival have not been established by this portion of the study.

WARHEAD CONSIDERED

A one megaton warhead effect is desired. It is understood that a 1000 pound nuclear warhead will satisfy this requirement. The megaton yield may be converted to a radius of effect, r_e , of 4.0 miles giving an over pressure of 4 psi at the outer perimeter (reference - figure 59, page 123, OpNav Instruction 003 400.1).

MISSILE CONSIDERED

The missile considered was a single stage, inertially guided vehicle using solid propellant. This type has the advantage of ease in handling and checkout, and has a good payload/volume ratio. The assigned values for missile reliability are as follows:

- a. Missiles passing checkout = 90%
- b. Missiles surviving flight and successfully detonating = 80%

TARGET CONSIDERED

A target radius, r_t , of 1.5 miles was used in this example.

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SUBMARINE PERFORMANCE

Considering that the submarine will be employed in a continuing campaign, the round trip capabilities for a range of submarine parameters (velocity, missiles carried per submarine, and submarine operating radius) are computed and presented in the curves of Figure 5. Combining these capabilities with the parametric design curves (Figures 1, 2, and 3) through the common parameters, the performance curves (Figure 6) are developed as a function of submarine velocity, displacement, and operating radius.

Note in Figure 6 that the submarine performance ever increases with submarine displacement. This indicates that some practical limit be set. Arbitrarily, for this example, the submarine payload is limited to twenty (20) missiles.

As missile payload is not a parameter presented in Figures 6 and 7 a trial and error procedure is undertaken:

In Figure 6, $R_s = 2000$ mi., consider $\Delta = 2500$ T. The optimum transport speed is 14 K. Entering the curves of Figure 1 with 2500 tons and 14 knots it is found that the submarine will have a payload of approximately 35, 100-mile missiles.

Repeating consider $\Delta = 2250$ T. The optimum transport speed is 10 knots. It is found that these parameters satisfy the payload specification of 20 missiles. The corresponding performance for these parametric values from Figure 6 is 7.5 missiles delivered/month/1000 ton of submarine. When multiplied by the kiloton displacement and the mission attrition, the optimum submarine capability for a submarine range of 2000 miles is as follows:

$$7.5 \times 2.250 \times 0.97 = 16.4 \text{ missiles/month}$$

Now, considering the 6000 mile mission in similar fashion, it is found that a 2300 ton, 13 knot vessel is optimum within the specification. The performance for these characteristics from curve of Figure 6 is 3.3 miss./mon./1000 T. The optimum capability for the 6000 mile mission becomes:

$$3.3 \times 2.300 \times 0.97 = 7.38 \text{ missiles /month}$$

To summarize the optimum submarine characteristics considering a 20 missile load cutoff, the following values are listed:

OPERATING RADIUS = 2000 MILES

Displacement	= 2250 tons
Speed	= 10 knots
Payload	= 20 missiles
Performance	= 7.5 miss./mon./1000 T.
Capability	= 16.4 miss. delivered/month

OPERATING RADIUS = 6000 MILES

Displacement	= 2300 tons
Speed	= 13 knots
Payload	= 20 missiles
Performance	= 3.3 miss./mon./1000 T.
Capability	= 7.38 miss. delivered/month

COMBINED WARHEAD AND GUIDANCE PERFORMANCE

The radius of delivery CEP and radius of effect compare with the radius of target as follows:

$$CEP/r_t = 1.0/1.5 = 0.67$$

$$r_e/r_t = 4.0/1.5 = 2.67$$

Entering the curves of Figure 8, The following performance estimates are noted:

- The average coverage of a circular target = 97%.
- The probability of complete coverage of a circular target = 95%

MISSILE STATISTICAL PERFORMANCE

The missile statistical performance is measured by the following assumed values:

- Missiles passing checkout = 90%
- Missiles surviving flight and successfully detonating = 80%.

SINGLE SUBMARINE SYSTEM CAPABILITY

The submarine capability of delivering missiles must be degraded by 10% of the missiles not passing checkout. This results in single submarine system capabilities as follows:

OPERATING RADIUS = 2000 MILES

- The single submarine launches 14.8 miss/month.
- 80% of these missiles reach the target.
- Each missile reaching the target achieves 97% average coverage.

OPERATING RADIUS = 6000 MILES

- The single submarine launches 6.65 miss/month.
- 80% of these missiles reach the target.
- Each missile reaching target achieves 97% average coverage.

FORCE REQUIREMENTS

The following force requirements are computed below:

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OPERATING RADIUS = 2000 MILES

50 Targets/Month

$$\text{Force} = \frac{50}{0.80 \times 14.8} = 5 \text{ submarines}$$

100 Targets/Month

$$\text{Force} = \frac{100}{0.80 \times 14.8} = 9 \text{ submarines}$$

OPERATING RADIUS = 6000 MILES

50 Targets/Month

$$\text{Force} = \frac{50}{0.80 \times 6.65} = 10 \text{ submarines}$$

100 Targets/Month

$$\text{Force} = \frac{100}{0.80 \times 6.65} = 19 \text{ submarines}$$

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