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Development of Measures of Effectiveness for Marine Vehicles for Coast Guard Missions

Volume 1

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16. Abstract

The U.S. Coast Guard is presently studying candidate advanced marine vehicles (AMVs) to replace its aging cutters. Several programs have been initiated to evaluate marine vehicles that best fulfill required missions. These programs include development of decision aids, test and demonstration of existing AMVs, and development of state-of-the-art point designs.

The Research and Development Center has developed measures of effectiveness of AMVs in search and rescue, enforcement of laws and treaties, marine environmental protection, and military readiness missions. The MOEs are based on a probability of mission success and can be calculated based on existing data bases or test data. These MOEs provide a quantitative assessment of a craft's ability to perform a mission under specified operational and environmental constraints. An example is presented of how to use the MOEs in the process of evaluating candidate craft to replace existing cutters or procure new ones.

Craft characteristics of AMVs were updated based on state-of-the-art technology. They were then incorporated in the Cutter Resources Effectiveness Evaluation (CREE) computer model, which was converted from FORTRAN IV to BASIC to allow it to run on an HP-9845 interactive desktop computer. Volume II is a user's guide for the program.

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METRIC CONVERSION FACTORS

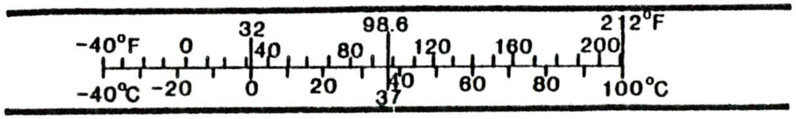
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	ml
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	ml^2
ha	hectares(10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report has been prepared for the U.S. Coast Guard by the Systems Integration Department of Analysis & Technology, Inc., under contract DTCG-39-81-C-80349. The principal author was Louis C. Tedeschi. Significant contributions by other A&T employees included Ralph L. Volk for MOE development, George E. Selecman for updating craft characteristics, and Chris Heidtman for the CREE model conversion.

This effort was coordinated for the Coast Guard by Clark Pritchett of the U.S. Coast Guard Research and Development Center, Avery Point. Coast Guard personnel who contributed significantly included Dave Motherway (R&DC); LT Tim W. Hylton (G-OSR-3); LT Richard Lang (G-OLE); LT Brian Hunter (G-OLE); and LCDR Dave Isbell (G-OMR).

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SECTION 1
INTRODUCTION

The objective of this report is to present proposed measures of effectiveness (MOEs) for the evaluation of conventional and advanced marine vehicles in support of U.S. Coast Guard missions. This final report completes the requirements of Contract Number DTCG-39-81-C-80349 by including the results of the three specified tasks:

1. Measures of effectiveness for four specified missions including the rationale for their development and guidelines followed. The utility of the MOEs was demonstrated by calculating numerical values based on existing data available from Coast Guard data bases and test results of advanced marine vehicles.

2. Craft characteristic data for conventional and advanced marine vehicles were updated and graphically presented in standard naval architecture convention consistent with CREE computer model application.

3. Conversion of the CREE computer model from FORTRAN IV to HP Extended BASIC on the HP 9845B desktop computer to provide interactive capability at the Office of R&D at Coast Guard Headquarters. This included preparation of the program tape and user's guide.

This report also focuses the application of present efforts in the CG Research and Development Center on the evaluation of advanced marine vehicles. These efforts include defining measures of effectiveness, conducting tests and operational demonstrations, and developing evaluation aids. An approach is proposed applying these MOEs to the evaluation of potential candidates to replace existing cutters or procure new ones.

SECTION 2
MOE DEVELOPMENT

2.1 INTRODUCTION

2.1.1 Objective

The objective for the development of measures of effectiveness (MOEs) is to provide a quantitative appraisal of performance as applied to a specified craft in fulfilling a Coast Guard mission. The "measurement" process is considered in the broadest sense as an evaluation process of a candidate marine vehicle's capability.

A multimission craft could be evaluated on the basis of the weighted sum of individual mission MOEs. The weights would be established by the cutter acquisition manager on the basis of operational requirements for the particular ship class such as WPB or WMEC.

2.1.2 Approach

The process followed in developing MOEs is defined below.

1. A draft of the proposed MOE development guidance was discussed with each of the above mission manager's staff and comments were solicited on the proposed approach. The resulting guidance is detailed in section 2.2.

2. Each mission and mission element was defined for the following four Coast Guard programs:

    a. Search and rescue (SAR),

    b. Enforcement of laws and treaties (ELT),

c. Marine environmental protection (MEP), and

d. Military readiness (MR).

3. Mission statements and proposed mission MOEs were reviewed by Coast Guard personnel.

4. Historical data, such as the SAR data base, was reviewed to provide a basis for each mission operational requirement.

5. Scenarios for each mission were considered and a statistical method of evaluating numerous scenarios was developed.

6. MOE relationships were developed.

7. MOEs were verified with sample calculations with empirical data from established data bases or sea trial.

2.2 MOE DEVELOPMENT GUIDANCE

The following guidance was adopted for the development of measures of effectiveness.

2.2.1 Structural Requirements

The proposed structure for mission MOEs should satisfy four considerations as follows:

1. Consistent across mission areas for later combination into craft multimission capability,

2. Supportable with available or measurable data,

3. Accurately reflect important mission factors, and

4. Capable of distinguishing between craft types.

2.2.2 Types of MOEs

Types of MOEs that could have been selected include:

1. Efficiency measures such as transport efficiency for a transit calculate the craft's ability to transport a given payload a specified distance within a specified time considering fuel utilized.

2. Probability of success which calculates the probability of a craft making a transit considering constraints on payload, time, distance, and fuel used.

3. Qualitative measures provide relative merit of capability based on subjective judgements of expert opinion.

Although all three measures could have been used, a heavy emphasis was given to probability of success as a measure of effectiveness in order to provide consistent measures for all missions and emphasize objective evaluations. Where subjective measures may be required, the broadest base of expert opinion will be utilized to minimize individual preference.

The combined effect of several measures will require development of weight factors based on judgements of management as to the relative emphasis to be placed on various program elements.

2.2.3 Hierarchical Structure

The MOEs will be structured in a hierarchy as depicted in figure 2-1.

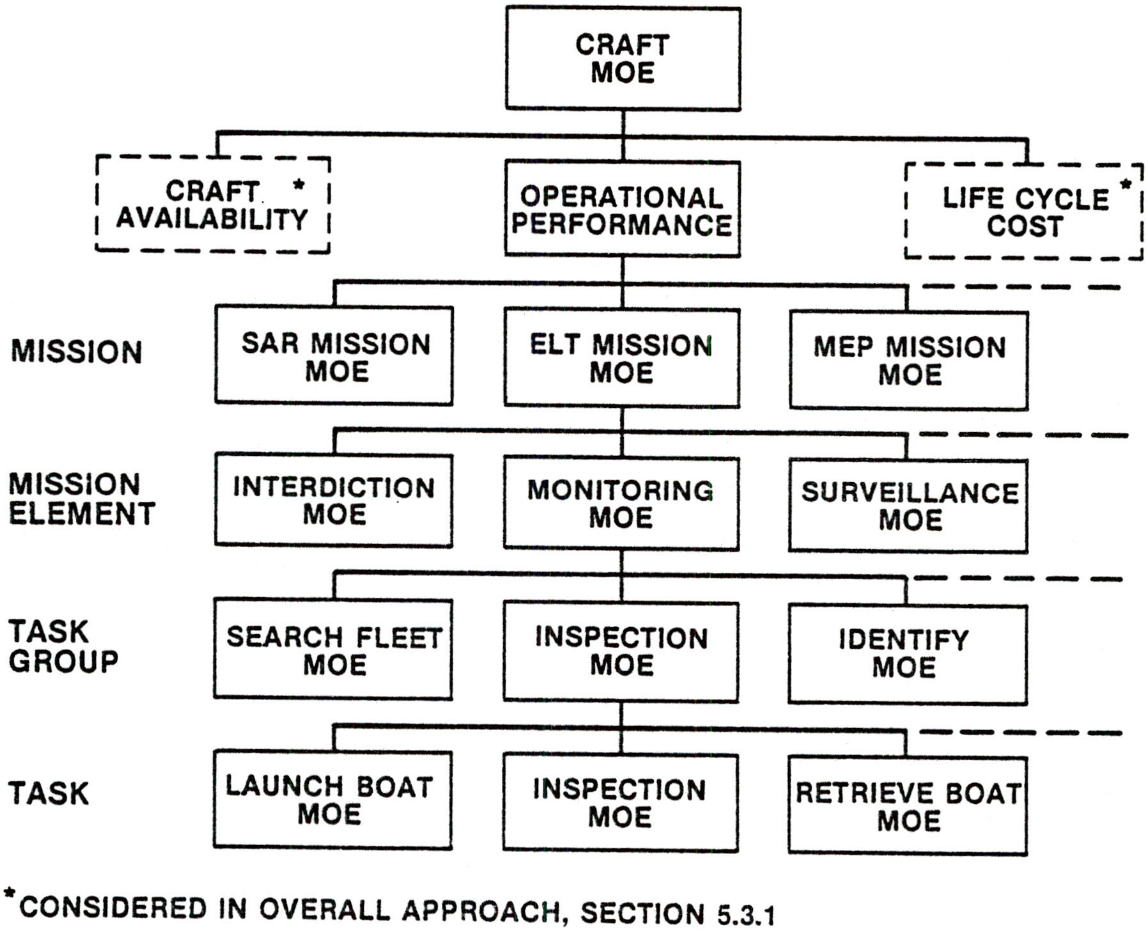


FIGURE 2-1. MOE HIERARCHICAL STRUCTURE

1. Overall Craft MOE. Overall measure of craft effectiveness when craft availability, operational performance, and life cycle costs are considered.

2. Mission MOE. Overall measure of mission effectiveness under constraints specified by operational requirements. Combines the total effect of mission element MOEs.

3. Mission Element MOE. Fundamental elements to be accomplished for performance of the mission. Elements for ELT mission are depicted in figure 2-2.

4. Scenario MOE. For each mission element, alternative scenarios which are representative of different operational concepts will be constructed. Several scenarios may be combined when a statistical data base is available.

5. Task Group MOE. A combination of individual task MOEs which occur frequently. Group MOEs are defined in the CREE model.

6. Task MOE. Measure of craft capability to accomplish each task. Task MOEs are the basic building blocks combined into group MOEs structured in a scenario which considers the operational constraints to calculate mission element/mission MOEs.

2.3 OPERATIONAL REQUIREMENTS

2.3.1 Definition

Operational requirements (ORs) as specified by the Coast Guard Headquarters Program Manager for each mission define "what" must be done to fulfill that mission and the constraints for getting it done.

	DISTINGUISHING CHARACTERISTICS		
MISSION ELEMENTS	CG OPERATIONAL CONCEPT	CG OPERATING REGION	CASELOAD TRAFFIC
<u>INTERDICTION</u> Drugs Immigration Customs	Barrier Patrol Seize & Escort	Assigned Fixed Area	Random Overall Traffic Known
<u>MONITORING</u> Foreign Fisheries Domestic Fisheries Endangered Species	Fixed Patrol Pattern Escort	Assigned Variable Area	Known
<u>SURVEILLANCE</u> Protection of Offshore Assets	Random Patrol Response to Call	Fixed Location	Random Unknown Caseload
<u>INVESTIGATION</u> Piracy Mutiny	Case Response Locate Investigate	Known Location/ Area	Random Rough Estimate of Cases

FIGURE 2-2. ELT MISSION ELEMENTS

ORs are independent of any craft/vehicle characteristics and are dictated only by nature, law, or policy. They provide the constraints for the development of MOEs and structuring of scenarios.

2.3.2 Scope

ORs may be further divided into the following elements:

1. Caseload. State of nature which cannot be controlled by Coast Guard such as:

    a. Number of responses required and distribution by number of lives saved, persons assisted, distance from shore of assist caller, and value of property saved based on SAR statistics and projections, or

    b. Distribution of drug traffic by numbers, size, and speed of smugglers.

2. Environment. Distributions of sea state and depth of water.

3. Time. Length of time personnel can survive in various sea conditions. Response time required to prevent loss of property, or mission duration of patrol.

4. Resources. Resource constraints to accomplish mission including operating personnel, fuel, and facilities.

5. Procedural. Constraints imposed by Coast Guard operating procedures such as obtaining statement of no objection (SONO) before boarding suspicious boats flying foreign flags.

2.4 SEARCH AND RESCUE MOE

2.4.1 SAR Mission

The primary mission of SAR is saving lives. The next most important effort, often concurrent with saving lives, is saving of property. This is followed by rendering assistance on water to personnel by providing less acute medical aid or by providing services such as towing disabled craft to a safe harbor.

2.4.2 Present SAR Measures

Several measures are presently included in the yearly SAR Statistics Report to help planners assess the performance of the SAR system:

$$A = \frac{280 \times (\text{lives saved}) + (\text{property loss prevented})}{(\text{operating costs in thousands of dollars})}$$

$$B = \frac{(\text{lives saved})}{(\text{lives saved}) + (\text{lives lost after CG notice})}$$

$$C = \frac{\text{persons otherwise assisted}}{\text{number of responses for station}}$$

$$D = \frac{\text{number of responses for station}}{\text{number of responses service wide}}$$

A productivity ranking for SAR stations/units is obtained by averaging the ranking for each of the four measures described above.

2.4.3 SAR Operational Requirements

The SAR requirements are well documented in the SAR data base and are available from yearly reports of SAR statistics prepared by G-OSR-3. The following information will be used as the basis for developing and evaluating SAR MOEs.

1. <u>Caseload</u>.

    a. Distribution of cases by distances from SAR station to scene (prior to start of search).

    b. Distribution of search distances based on search times and search speeds.

    c. Distribution of displacement of towed craft.

2. <u>Environment</u>.

    a. Distribution of sea states based on yearly averages and on distances from shore.

    b. Distribution of depth of water for each case.

3. <u>Time</u>.

    a. Average time to get underway.

    b. Probability of survival versus time to rescue after notification.

    c. Probability of property loss versus time to assist after notification.

4. <u>Resources</u>. SAR stations used as the basis for the aforementioned statistics are readily available. Closing of SAR stations can have a significant impact on distribution of distances to cases.

5. <u>Procedures</u>. A SAR unit must be held in a high readiness condition and dispatched on command. This affects availability requirements for craft and time to get underway after CG notification.

2.4.4 SAR MOE

1. Definition. In applying existing measures to the comparison of craft capabilities, the saving of lives predominates and hence can be used as the single distinguishing measure. This assumes, as discussed in section 5.3.2, that all candidate craft will be equally capable of saving property. The capabilities for towing, boarding, dewatering, and fighting fires will be specified as requirements that will be met by all point designs.

The SAR measure of effectiveness for a craft would then be defined:

SAR MOE = probability of saving lives given notification.

2. Calculation. The probability of success of saving lives can be determined by comparing the time-to-arrival-on-scene (total time) with the probability of no fatality occurring within the same arrival time.

The on-scene arrival times (total) can be calculated by summing the constant and variable times of the phases described in the following paragraphs.

The overall MOE is determined from statistical averaging based upon the time distribution of each individual phase.

Getting Underway Time (T_1)

Since getting underway can be assumed to be relatively constant from craft to craft, this constant time T_1 can be added to the other distributions shifting the mean and leaving the variance unchanged. It is assumed to be 15 minutes or .25 hour in this sample calculation.

Transit Time Distribution (f_T)

The distribution of transit times can be calculated from three known distributions and functions depicted in figures 2-3 and 2-4 for this sample calculation.

The first step in calculation of the transit times distribution is to determine the distribution of maximum velocities, f_V, from probability distribution of sea states, $f_{(SS)}$, by using a transformation on craft velocity versus sea state. The resultant probability distribution of velocities, f_V, is shown in figure 2-3c.

This distribution of velocities can be combined with the known distribution of possible case distances, f_D (figure 2-4) resulting in a joint probability distribution of transit times, f_T, shown in figure 2-5. This calculation uses the same Jacobian transformation as in the single variable case and the simple relationship:

$$T = D/V.$$

For discrete distributions, a simple computer sum is used rather than integration.

Search Time Distribution (f_S)

The distribution of search times can be calculated using search rates and a distribution of areas to be searched. In this example, the distribution of search times from SAR statistics depicted in figure 2-6 is used.

On-Scene Arrival Time Distribution (f_{Total})

Finally, the distribution of total on-scene arrival times (f_{Total}) can be calculated by summing the distributions of underway time, transit time, and search time as shown in figure 2-7.

Probability of No Fatality

In order to compare this total time distribution to the survival time, a survival probability was calculated. The survival probability is based on $1-P_F$ where P_F is the probability of any fatality. This distribution was calculated by G-OSR-3 based on SAR statistics and is shown in figure 2-8.

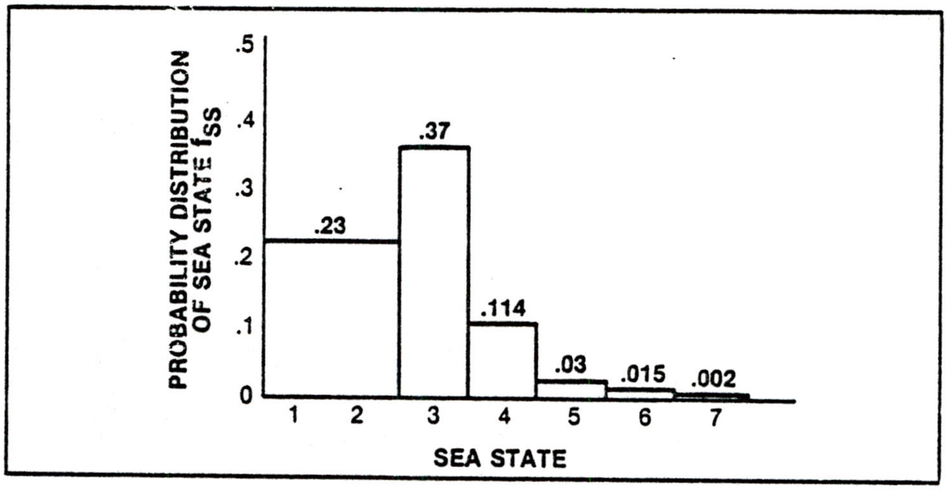


FIGURE 2-3A. DISTRIBUTION OF POSSIBLE SEA STATES

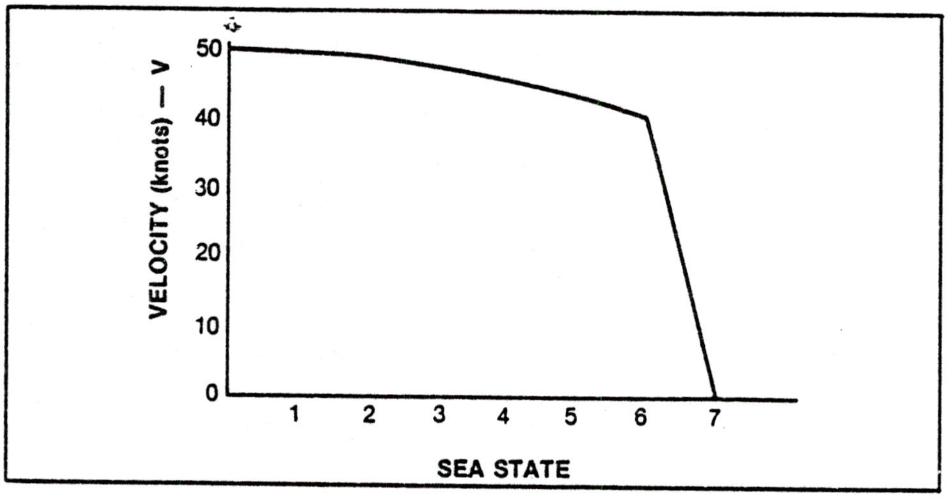


FIGURE 2-3B. CRAFT VELOCITY AS A FUNCTION OF SEA STATE

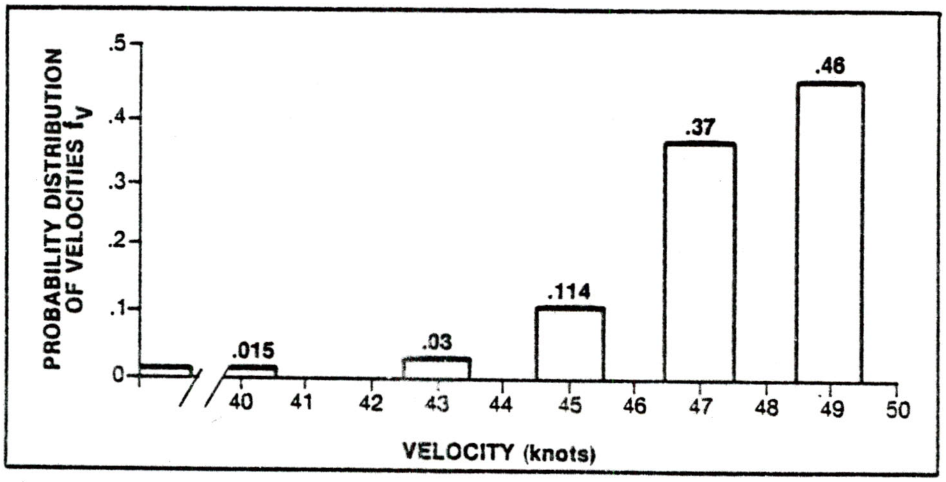


FIGURE 2-3C. DISTRIBUTION OF VELOCITIES

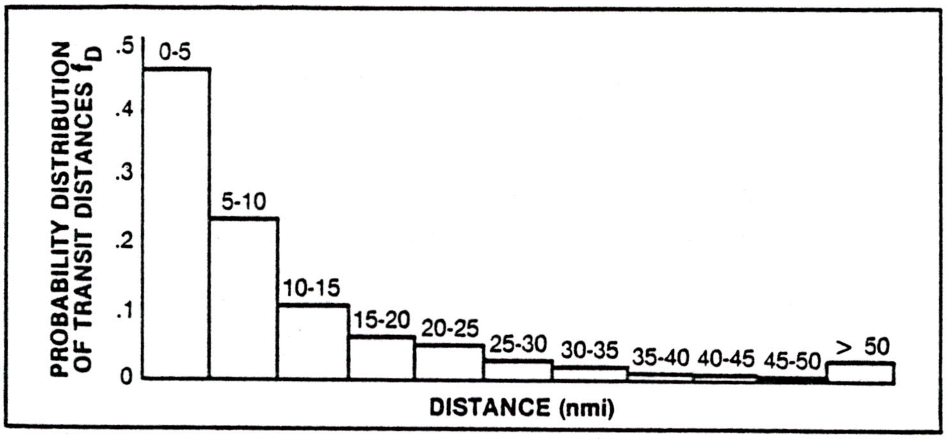


FIGURE 2-4. DISTRIBUTION OF POSSIBLE CASE DISTANCES

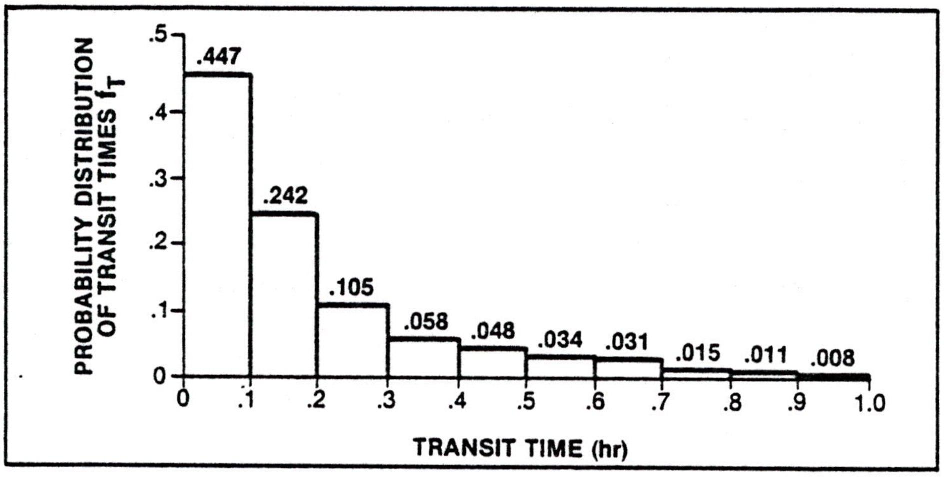


FIGURE 2-5. DISTRIBUTION OF TRANSIT TIMES

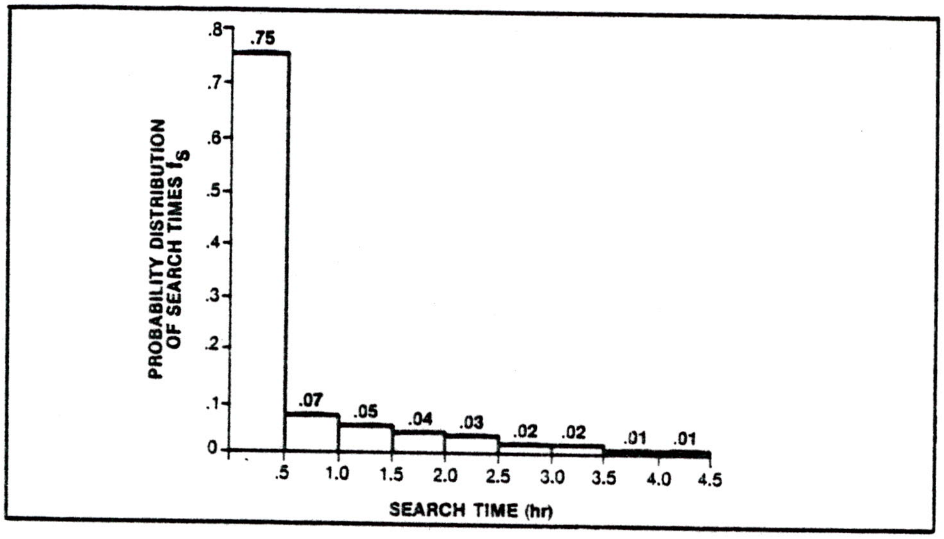


FIGURE 2-6. DISTRIBUTION OF SEARCH TIMES

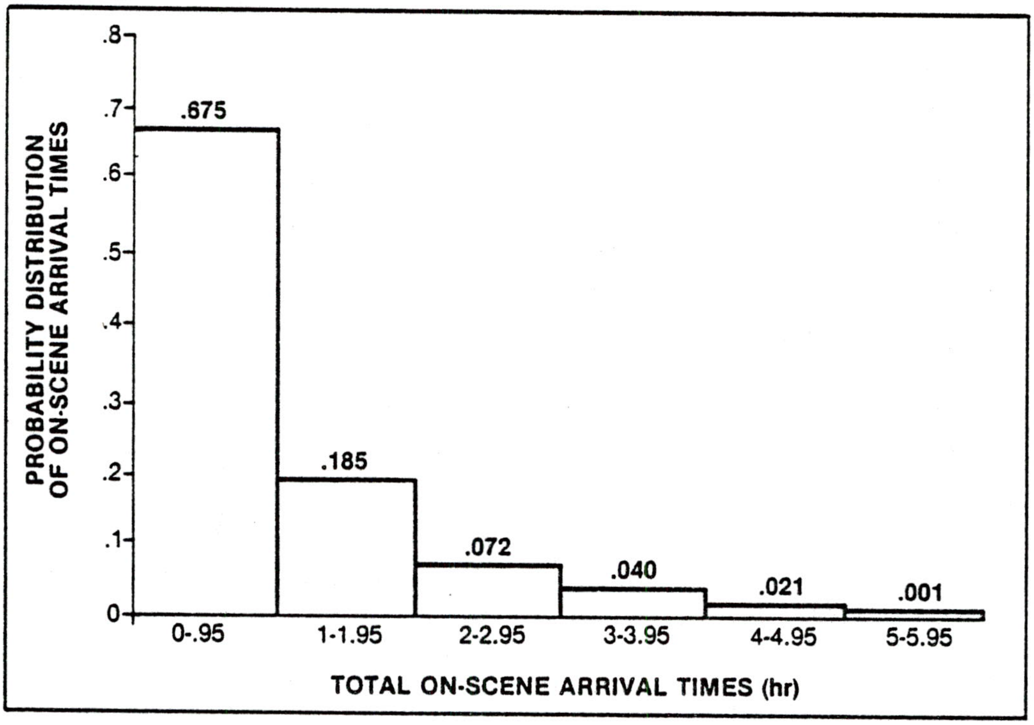


FIGURE 2-7. DISTRIBUTION OF TOTAL ON-SCENE ARRIVAL TIMES

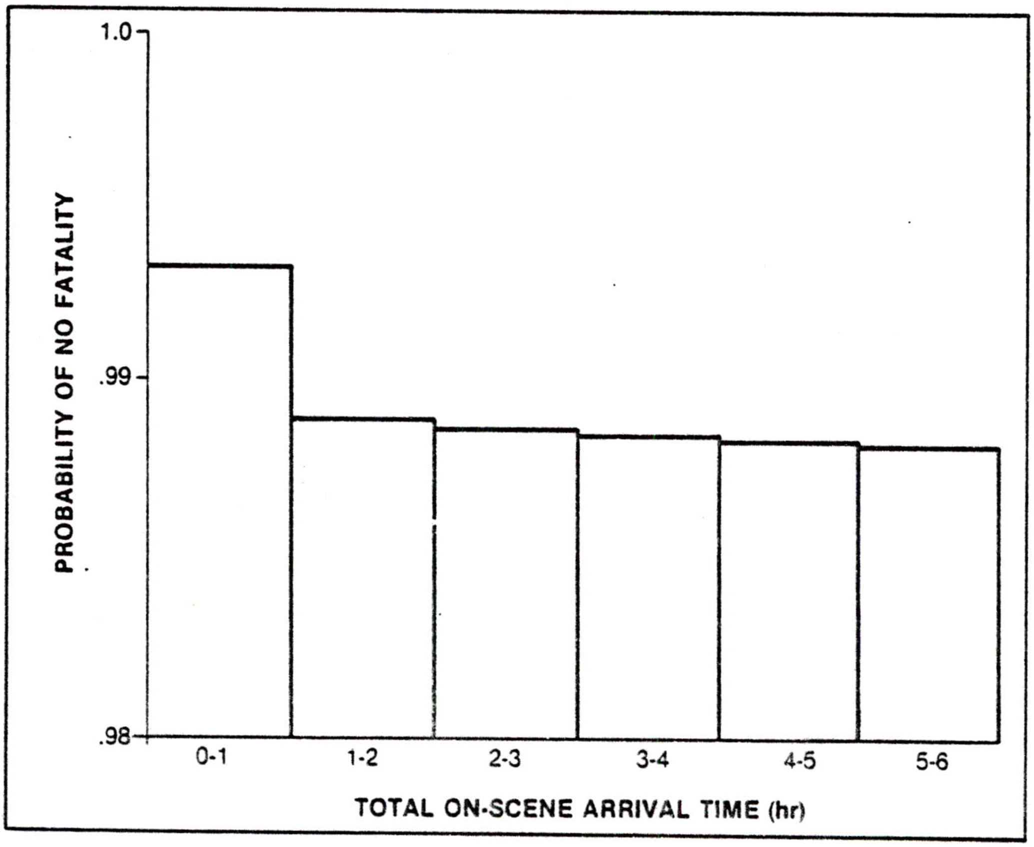


FIGURE 2-8. DISTRIBUTION OF SURVIVAL PROBABILITY

Probability of Saving Lives

Thus, for any one case, the probability of saving a life(s) can be determined by calculating the total time for arrival on scene and determining the probability of survival from figure 2-8. To consider all cases, the probability of each total on-scene arrival time can be multiplied by the related probability of no-fatality for that time. The normalized sum of these products thus provides a measure of probability of success. The value of the calculations for this data is:

MOE SAR = 98.9 percent probability of success for saving lives given notification.

This MOE is useful in planning when assessing the effectiveness of a vessel in the SAR system. Its usefulness at a resource level or its application on a case-by-case basis has not been established.

2.4.5 AMV Evaluation for SAR Mission

From the previous sample calculations, it can be seen that the resultant probability of success in saving lives is dependent on AMV speed in a seaway. The sensitivity of this speed for the SAR OR distributions selected is greatly influenced by the probability of no-fatality distribution. This distribution indicates that on-scene arrival time must be less than two hours to have any significant influence in saving lives.

The value of speed in a seaway for the SAR mission can also be measured by evaluating the impact of selectively closing SAR stations. This would increase the average response distance and hence response time. For faster cutters, the decrease in SAR MOE would be minimal when compared to slow craft.

Additional effort is required to refine distributions to be used and particularly to investigate the validity of the probability of no-fatality distribution. However, the proposed MOE <u>definition</u> is valid and has been verified by the sample calculations.

The decision that must be faced is determining the acceptable probability of success in saving lives. However, the evaluation of AMV candidates does not require determination of an absolute measure. When the two vehicles are compared, the greater value of MOE indicates a more capable vessel. Without a specified probability of success in saving lives, the acceptability of the AMV will not be known.

2.5 ENFORCEMENT OF LAWS AND TREATIES MOE

2.5.1 ELT Mission

Enforcement of laws and treaties covers a wide variety of tasks and may be further divided in mission elements as previously depicted in figure 2-3. These elements include:

1. Interdiction. Establishing a barrier patrol to detect, search, and seize vessels and personnel carrying contraband goods, drugs, or illegal aliens. Although the search area is established, traffic is random and unpredictable.

2. Monitoring. Conducting a patrol for the purpose of monitoring domestic and foreign fishing enterprises and protection of endangered species. The patrol pattern is well established and traffic is often predictable.

3. Surveillance. An increasing number of offshore assets such as oil rigs and sea-bottom mining operations require protection from domestic and foreign saboteurs. A patrol to establish presence and/or a rapid response for assistance may be required.

4. Investigation. Acts of piracy or mutiny require the investigation by law enforcement officers of the sea. Although unpredictable, such acts require immediate response by the Coast Guard to protect the safety of innocent personnel and avert more serious consequences.

5. Response to Intelligence. Rapid response by Coast Guard to reports of drug or alien smuggling.

2.5.2 Present ELT Measures

Two extreme viewpoints are often taken in evaluating the effectiveness of any law enforcement agency:

1. Deterrence. By maintaining a presence, lawbreakers are deterred from breaking the law and hence very few are apprehended. Thus, an effectiveness measure is time dedicated to patrolling an area.

2. Apprehension. When the violation rate is fairly constant and a good law enforcement agency apprehends law breakers. Hence, an effectiveness measure is the total number of offenders apprehended.

A third viewpoint considers lawbreakers as entrepreneurs who weigh the financial and personal risk of apprehension. It recognizes that there is some truth and a logical interdependency between the two previously discussed extreme views. This view may be stated as follows:

3. Increase Risk. A violator will continue to break the law until he perceives that his personal risk is unacceptable and that his return on investment could be greater through another enterprise.

Thus, an increased apprehension rate will make risks greater and slow the violation rate until the apprehension rate decreases to acceptable levels. This provides a dynamic situation where a fixed number of assets with constant capability may be excessively or insufficiently effective as the violation rate varies.

An ELT MOE derived from the last viewpoint is a specified global interdiction or apprehension rate that is commensurate with the return on investment:

$$\text{MOE ELT} = \frac{\text{number of apprehensions of violators}}{\text{estimate of total traffic of violators}} .$$

The effective numerical value considering personal risk is highly subjective. However, financial risk may be calculated for some elements such as drug smuggling by considering open-market value of seized goods, estimated costs for smuggling, and current market investment rates.

In applying the above measures to evaluation of AMVs and conventional vehicles, interdiction is the most representative element of ELT mission and is receiving the greatest emphasis at the present time. The following discussion will thus be focused on this mission element.

2.5.3 ELT Operational Requirements

Although the caseload distribution and other statistics for all ELT elements are available, interdiction is the most important. The barrier patrol is a representative scenario and is considered below as an example.

1. Caseload. For each barrier considered such as the Yucatan channel:
    a. Barrier length and/or area.
    b. Rate of traffic both legal and illegal.
    c. Distribution of distances from ports to barrier.
    d. Distinguishing characteristics of smugglers such as length or displacement.
2. Environment.
    a. Distribution of sea states during transit and at patrol area.
    b. Depth distribution during transit and at patrol area.

3. Time.

   a. Time to get underway.

   b. Mission duration.

   c. Distribution of boarding time including delays for statement of no objection.

4. Resources.

   a. Location of home ports.

   b. Refueling capability in operating area.

5. Procedural.

   a. Statement of no objection to boarding may be required before boarding suspicious vessels flying foreign flags.

   b. Additional personnel will be required as custody crew.

   c. Seized vessels will be escorted or towed back to home port.

2.5.4 ELT MOE

1. Definition. Given the OR specified in the previous section, a proposed mission measure of effectiveness for ELT can be defined as:

MOE ELT = interdiction rate achieved within some specific mission time.

The mission duration T_M is the sum of the following times:

T_T = time to transit to barrier,

T_P = patrol time on station, and

T_R = time to return to station.

The time to get underway (.25 hours) in the case of ELT is insignificant when compared to typical mission duration (240 hours).

T_M is usually a specified value for a given craft such as 10 days.

T_T can be calculated (as is the SAR case) given a distribution of distances to patrol area, sea states, and velocity versus sea state for craft.

T_R can be calculated similar to T_T, assuming the return speed is fixed by the requirement to tow and/or escort seized vessels:

Thus, patrol time $T_P = T_M - T_T - T_R$.

T_P is the most important parameter since on-station time determines the number of smugglers interdicted and number of patrol vessels required. The patrol time can be further subdivided into:

T_S = time spent searching, and

T_B = time spent boarding vessels, including standby time to obtain permission to board foreign-flag vessels,

where $T_P = T_S + T_B$.

For a given T_P available, there is a tradeoff between boarding and search efforts. An excessive amount of time spent boarding will reduce the time spent searching for other vessels to board. Conversely, interdiction cannot occur unless a vessel is boarded. The fraction of vessels interdicted can be defined as:

$$I = \frac{\text{Number of smugglers seized during } T_p}{\text{Number of smugglers entering barrier during } T_p} \quad .$$

2. Scenario. In order to calculate an interdiction rate, a barrier scenario will be described to define terms used in subsequent calculations.

Figure 2-9 illustrates the geometry and defines terms utilized. Figure 2-10 lists several formulations for probability of detection (POD) that can be used in the constraints specified. The choice of POD is dependent upon the search tactic employed. The optimum tactic for a specified set of conditions will be the subject of future discussion.

Figure 2-11 depicts a decision tree which illustrates the logical breakdown of events and subsequent results of a cutter on barrier patrol. Figure 2-12 summarizes the possible actions of the patrol vessels and barrier traffic. The values depicted are representative of actual practice and obtained from G-OLE.

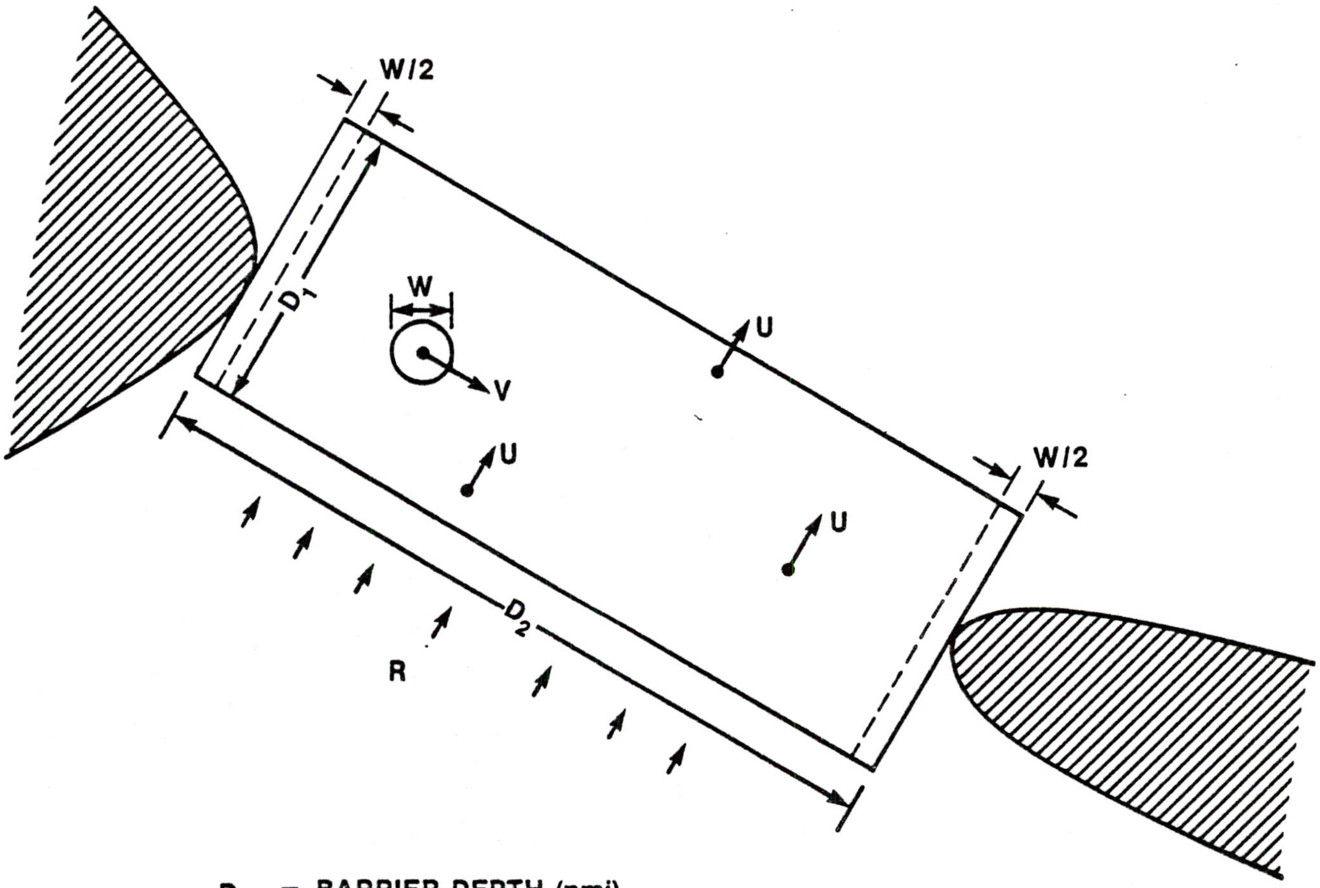
3. MOE Calculation. The overall measure of effectiveness for ELT should consider the long term results of several barrier patrols. Thus, an effective definition is:

ELT MOE = long-term interdiction rate I .

The interdiction rate, as previously defined, is given by:

$$I = \frac{\text{number of smugglers seized } (N_{SS})}{\text{total number of smugglers entering barrier } (N_{SP})} \quad .$$

The craft's interdiction rate while on scene will be derived below. The interdiction rate for each patrol will then be combined with time on scene to achieve the long term interdiction rate.



D_1 = BARRIER DEPTH (nmi)

D_2 = BARRIER LENGTH (nmi)

W = SEARCH VESSEL SWEEP WIDTH (nmi)

V = SEARCH VESSEL SPEED (knots)

U = PENETRATOR SPEED (knots)

R = PENETRATOR RATE (VESSELS PER HOUR)

BARRIER PARAMETERS

r = V/U SPEED RATIO

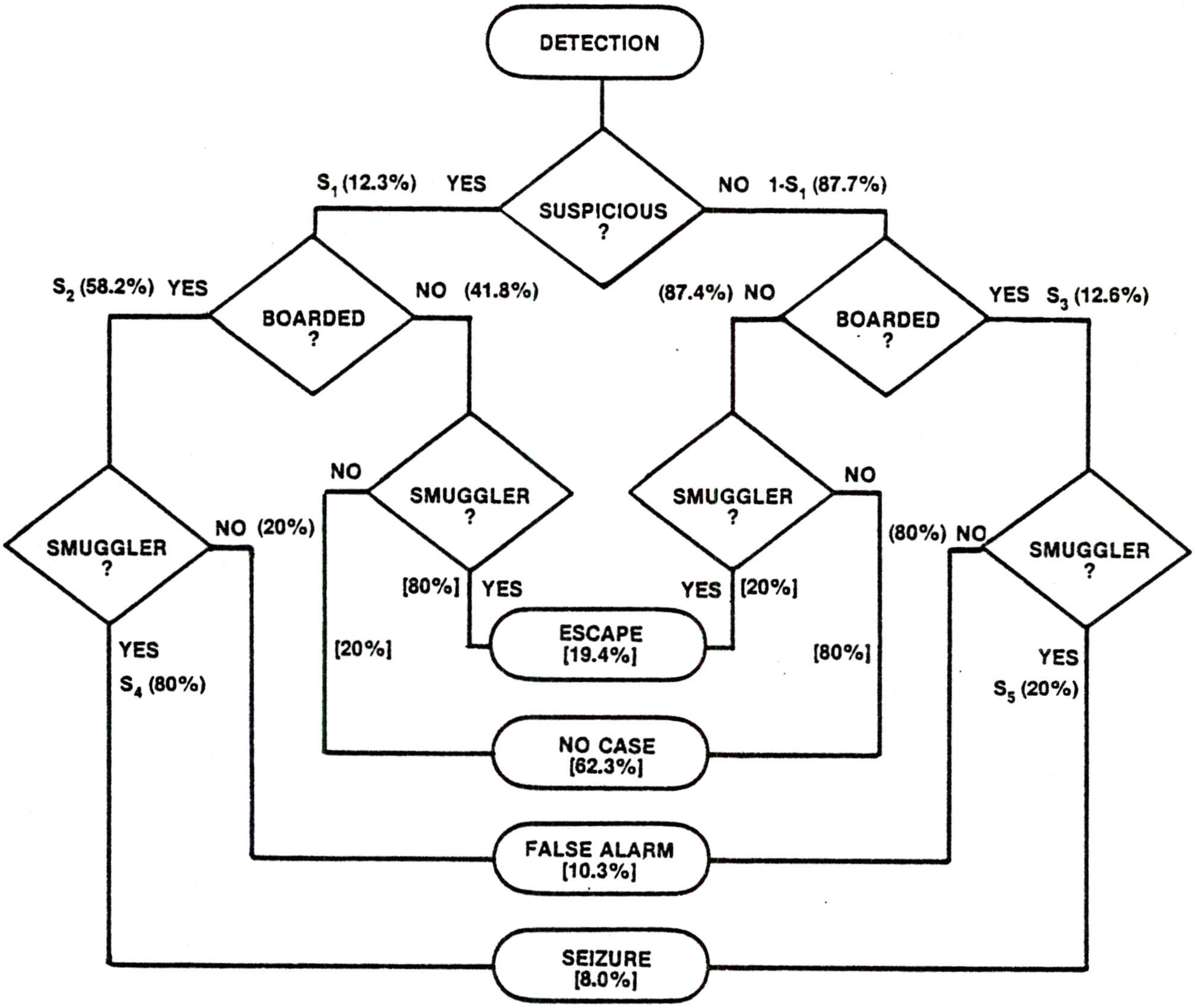
$\lambda = \frac{D_2 - W}{W}$ COVERAGE FACTOR

FIGURE 2-9. ELT BARRIER PATROL

TACTIC	POD	CONSTRAINT	REFERENCE
Area Search	$POD_R = \frac{r}{\lambda + 1}$	$r \leq \lambda$	2
Crossover ∞	$POD_{\infty_1} = \mathrm{MIN}\left[1 , \left(1 + \frac{r\sqrt{r^2-1}}{r + 1}\right) \frac{1}{\lambda + 1}\right]$ $POD_{\infty_2} = \frac{\sqrt{r + 1}}{\lambda + 1}$		1 1
Linear (Back & Forth) $\leftrightarrow$	$POD_{\leftrightarrow} = \begin{cases} \left[1 - \frac{\left(\lambda - \frac{\sqrt{r^2 + 1} - 1}{2}\right)^2}{\lambda(\lambda + 1)}\right] \\ 1 \end{cases}$	$r \leq 2\sqrt{\lambda(\lambda+ 1)}$ $r > 2\sqrt{\lambda(\lambda +1)}$	1
Relationships			
for r >> 1	$POD_{\infty_1} \rightarrow \left(\frac{r}{\lambda + 1}\right)$	$r \leq \lambda$	
for $r \simeq 1$	$POD_{\leftrightarrow} \simeq 0.4\left(\frac{r}{\lambda + 1}\right)$	$r \leq 2\sqrt{\lambda(\lambda+ 1)}$	

<u>REFERENCES</u>: 1. Naval Operations Analysis, United States Naval Academy, 1977.
2. Search and Detection, Alan R. Washburn, ORSA, May 1981.

FIGURE 2-10. PROBABILITY OF DETECTION (POD) FORMULAS



S_1 = FRACTION SUSPICIOUS GIVEN DETECTION

S_2 = FRACTION BOARDED GIVEN SUSPICIOUS

S_3 = FRACTION BOARDED GIVEN NOT SUSPICIOUS

S_4 = FRACTION SMUGGLER GIVEN BOARDING GIVEN SUSPICIOUS

S_5 = FRACTION SMUGGLER GIVEN BOARDING GIVEN NOT SUSPICIOUS

S_B = FRACTION BOARDED GIVEN DETECTION

S_{SB} = FRACTION SMUGGLERS GIVEN BOARDING

(XX%) = PERCENTAGES OF OCCURRENCE BASED ON PATROL REPORTS

[XX%] = ESTIMATED

FIGURE 2-11. ELT BARRIER PATROL DECISION TREE

	SMUGGLER	NOT SMUGGLER	TOTALS
BOARD	SEIZURE 8.0%	FALSE ALARM[2] 10.3%	18.3%
DON'T BOARD	ESCAPE[1] 19.4%	NO CASE 62.3%	81.7%
TOTALS	27.4%	72.6%	100.0%

NOTES: 1. Type I error.
2. Type II error.

FIGURE 2-12. SUMMARY TABLE FOR ELT BARRIER OPERATIONS

It is assumed that the penetrator rate R, which includes only small vessels of interest penetrating the barrier per hour, and speed of penetrators U are constant throughout the patrol period T_P. Then,

$$N_{SP} = RT_PS_{ST} \quad ,$$

where S_{ST} is the fraction of the vessels of interest which are smugglers approaching the barrier.

Calculation of N_{SS} requires an analysis of distribution of efforts between searching and boarding.

During a mission, the total time spent searching T_S may be calculated by:

$$T_S = N_F \, \bar{t}_S \quad ,$$

where

N_F = number of vessels found or detected, and

$\bar{t}_S$ = average time spent searching for each vessel.

The average time spent searching for each vessel detected which can also be considered as the time between detections is:

$$\bar{t}_S = \frac{1}{POD \times R} \quad .$$

PODs defined in figure 2-10 are a function of the speed ratio r and coverage factor λ only and are not affected by time. However, both r and λ will be affected by sea state, thus PODs will be a function of sea state and hence have a probability distribution of occurrence. To simplify calculations, POD may be taken as an average value. This will result in an average time for detection and average time spent searching, thus:

$$T_S = \frac{N_F}{POD \times R} \quad .$$

Similarly, the time spent boarding is:

$$T_B = N_B \, \overline{t}_B \quad ,$$

where

N_B = number of vessels boarded, and

$\overline{t}_B$ = average time spent boarding a vessel including closing vessel, delay times, and physically boarding.

The number of vessels boarded N_B is dependent on the particular tactics to be employed. The choices are:

a. Board all vessels detected ($S_2 = S_3 = 1$).

b. Board only suspicious vessels ($S_2 = 1$, $S_3 = 0$).

c. Board all suspicious vessels and some unsuspicious vessels ($S_2 = 1$, S_3 = specified).

The choice of tactics to be utilized depends on the vessel traffic and time required to board. As the barrier penetrator rate increases, the patrol vessel will be saturated. This may occur instantaneously by two closely spaced arrivals or continuously throughout the patrol.

The concept of saturation requires considerable discussion and further investigation. The following is an outline of the proposed approach. To simplify initial definition, the search vessel will be considered to be performing either of two mutually exclusive tasks: searching or boarding. Saturation will be defined as occurring when the average time to board is greater than the average time between detections when the search vessel is not boarding. Thus:

$$\overline{t}_B > \overline{t}_S = \frac{1}{R \times \text{POD}} \quad .$$

Therefore, the saturation penetrator rate R_S is given by:

$$R_S = \frac{1}{\overline{t}_B \times \text{POD}} \quad .$$

When R_S is exceeded, the patrol vessel is physically incapable of boarding all suspicious vessels penetrating the barrier during the patrol.

The general expression for relating numbers boarded to number detected can be calculated from figure 2-9 and is given by:

$$N_B = [S_2 \, S_1 + S_3 \, (1-S_1)] \, N_F \quad .$$

where S_1 is given from experience and S_2, S_3 are variables that depend on boarding tactics employed. Thus, time spent boarding:

$$T_B = N_B \, \bar{t}_B = [S_2 \, S_1 + S_3 \, (1-S_1)] \, N_F \, t_B \quad .$$

The total patrol time is then:

$$T_P = T_S + T_B = \frac{N_F}{\text{POD x R}} + [S_2 \, S_1 + S_3 \, (1-S_1)] \, N_F \, \bar{t}_B \quad .$$

Solving for the number detected/found:

$$N_F = \frac{T_P}{\frac{1}{\text{POD x R}} + [S_2 \, S_1 + S_3 \, (1-S_1)] \, \bar{t}_B} \quad .$$

The number of smugglers seized, based on boarding strategy, can now be related to the total number of vessels detected by utilizing figure 2-9:

$$N_{SS} = [S_1 \, S_2 \, S_4 + (1-S_1) \, S_3 \, S_5] \, N_F \quad .$$

The total number of smugglers seized is thus:

$$N_{SS} = \frac{[S_1\ S_2\ S_4 + (1-S_1)\ S_3\ S_5]\ T_P}{\frac{1}{POD \times R} + [S_2\ S_1 + S_3\ (1-S_1)]\ \bar{t}_B} .$$

The interdiction rate can now be expressed as the number seized divided by the total number of smugglers entering the barrier:

$$I = \frac{N_{SS}}{N_{SP}} = \frac{1}{RT_P\ S_{ST}} \left(\frac{(S_1\ S_2\ S_4 + (1-S_1)\ S_3\ S_5)\ T_P}{\frac{1}{POD \times R} + [S_2\ S_1 + S_3\ (1-S_1)]\ \bar{t}_B} \right)$$

$$I = \left(\frac{S_1\ S_2\ S_4 + (1-S_1)\ S_3\ S_5}{S_{ST}} \right) \cdot \left(\frac{POD}{1 + [S_2\ S_1 + S_3\ (1-S_1)]\ POD \times R \times \bar{t}_B} \right) .$$

For the case when only suspicious vessels are boarded, $S_2 = 1$, $S_3 = 0$.

$$I = \left[\frac{S_1\ S_4}{S_{ST}} \right] \times \left[\frac{POD}{1 + S_1\ (POD)\ Rt_B} \right] .$$

Utilizing some typical values for Yucatan channel and conventional WPB:

$D_2 = 97$ nmi $\qquad W = 15$ nmi $\qquad \lambda = 5.47$ nmi

$U = 8$ kts $\qquad V = 10$ kts $\qquad r = 1.25$

$POD_R = 0.19 \qquad POD_{\infty_1} = 0.22 \qquad POD_{\infty_2} = 0.25 \qquad POD_{\leftrightarrow} = 0.24$

$R = 1/2$ vessel/hr $< R_S \qquad S_1 = 0.123$

$\bar{t}_B = 2$ hours $\qquad S_4 = 0.80$

$S_{ST} = 0.274$

$$R_S \leq \frac{1}{POD \times \bar{t}_B} = \frac{1}{(.25)\ (2)} = 2 \text{ vessels/hour}$$

$$I = \frac{S_1 \; S_4}{S_{ST}} \left(\frac{POD}{1 + S_1 \; (POD) \; Rt_B} \right)$$

$$= \left(\frac{(0.123) \; (0.80)}{(0.274)} \right) \left(\frac{(.25)}{1 + (0.125) \; (0.25) \; (\tfrac{1}{2}) \; (2)} \right)$$

$$I = 0.088$$

Utilizing an AMV such as with $V = 32$ kts $r = 4$ $\lambda = 5.47$

$POD_R = 0.62$ $POD_{\infty_1} = 0.63$ $POD_{\infty_2} = 0.64$ $POD_{\leftrightarrow} = 0.57$

$$I = \frac{(0.123) \; (0.80)}{(0.274)} \quad \frac{0.64}{1 + (.125) \; (0.64) \; (\tfrac{1}{2}) \; (2)} = 0.216$$

Each patrol will have a different interdiction rate. For a series of patrols, each craft's ability to interdict will depend on its time on station. The long-term interdiction rate will depend on the ratio of the total number of smugglers seized, N_{SS}, to number entering barrier during the same time frame. Therefore,

$$\text{ELT MOE} = \text{long-term interdiction rate } I = \frac{N_{SS}}{N_{SP}}$$

For N patrols each with interdiction rate I_i

$$N_{SS} = \sum_{i=1}^{N} (N_{SP} I)_i = \sum_{i=1}^{N} (RT_p \; S_{ST} I)_i$$

if average values are used,

$$N_{SS} = n \; RT_p S_{ST} I$$

Then, the total number of smugglers depends on the sum total of times for each mission assuming that no gap exists between start of each mission.

$$N_{SP} = nRT_M S_{ST} \quad .$$

Therefore,

$$\text{ELT MOE} = \frac{n\ RT_P\ S_{ST} I}{n\ RT_M\ S_{ST}} = \left(\frac{T_P}{T_M}\right) I \quad .$$

The on-station patrol time T_P thus plays an important role in determining the overall mission MOE.

Given the distribution of sea states, velocity versus sea state for craft, and distances to barrier, transit time T_P and return time T_R can be calculated for the above example as was done for the SAR MOE. Thus,

$$\text{ELT MOE} = \frac{(T_M - T_T - T_R)}{T_M} \quad I$$

$$\text{ELT MOE} = \left(1 - \frac{(T_T + T_R)}{T_M}\right) I$$

When there are gaps in the start of a mission due to the unavailability of the craft, an availability factor A_0 must be included in the overall ELT MOE. Reduced availability decreases on-station patrol time and has the same effect as increasing the effective mission duration. Substituting

$$T_M = T_{MD} + T_D$$

where

T_{MD} = mission time when delay time considered

T_D = delay time in port

$$\text{ELT MOE} = \left(\frac{T_{MD} + T_D - T_T - T_R}{T_{MD} + T_D} \right) I$$

Since the availability factor A_0 is defined

$$A_0 = \frac{\text{uptime}}{\text{uptime + delay time}} = \frac{T_{MD}}{T_{MD} + T_D}$$

then

$$\text{ELT MOE} = \left[1 - A_0 \left(\frac{T_T + T_R}{T_{MD}} \right) \right] I$$

2.5.5 AMV Evaluation for ELT Mission

The above definition of ELT MOE provides a means of evaluating the relative worth of speed in a seaway of performance of the barrier scenario. Speed in a seaway provides a significant improvement in probability of detection and transit time to the barrier. The effectiveness of speed must be weighed against the average boarding time and vessel traffic.

The above measure is useful in providing the ability to perform sensitivity analysis for the above parameters, in defining craft characteristics such as the operating profile, and in determining total number of patrol vessels required for varying vessel traffic. These detailed tradeoffs are beyond the scope of this report, and should be pursued in the future.

2.6 MARINE ENVIRONMENTAL PROTECTION MOE

2.6.1 MEP Mission

The marine environmental protection (MEP) mission can be divided into two elements:

1. Preventative measures which require inspections in port and various shore facilities as well as port patrol, and

2. Corrective measures which require responsive action to limit contamination and clean up the environment.

The latter element is more relevant to the evaluation of AMVs and conventional cutters that would have multimission responsibilities including SAR and ELT. Thus, the analysis of the MEP mission will focus on the control of offshore oil spills and other hazardous materials.

There are three phases in the control of oil spills or removal of hazardous material after initial notification of the Coast Guard.

1. Response. During this phase, trained personnel and pollution control equipment are transported to the scene. The primary vehicle capabilities required are:

   a. Payload capacity for above personnel and supporting equipment, and

   b. Speed in seaway to minimize transit time.

2. Containment. During the next phase, containment booms are deployed and positioned to minimize dispersion of pollutant. Additional efforts may be required to stop or reduce dispersion rate of effluent. Local coordination of

effort and communication with shore command is required to appraise authorities of the current situation. The primary vehicle capabilities required are:

a. Deploy and position pollution response equipment.

b. Act as on-scene commander.

c. Support diving operations.

d. Support fire-fighting operations.

e. Support damage-control operations.

f. Refloat grounded vessels.

3. Removal. The final phase requires removal of the pollutant from the environment including transportation from the scene to a safe location for reprocessing/storage. The primary vehicle capabilities required are:

a. Pumping pollutant into containment vessel such as an inflatable bag or ship tanks.

b. Transportation of pollutant from the scene to reprocessing/storage center.

2.6.2 Present MEP Measures

At present, measures of effectiveness for MEP include the ability to contain and remove a specified size spill within a given time.

MOE MEP = probability of removing a XXX gal. offshore
oil spill within YY days

The stress on containment exceeds any necessary time constraints. Ability for timely removal is important only to the extent that it allows efficient removal of pollutant without threat to the environment.

2.6.3 MEP Operational Requirements

The operational requirements for MEP as they pertain to control of pollutant discharges at sea include:

1. Caseload
    - a. Number, types of spills, and distribution of their distances from response centers.
    - b. Quantity and flow rate versus time distribution.
2. Environment
    - a. Distribution of sea states transiting and on-site of spills.
    - b. Dispersion rate of effluent versus sea state.
    - c. Boom containment efficiency versus sea state.
3. Time
    - a. Time required to assemble response team.
    - b. Time to load pollution control equipment.
    - c. Dispersion rate of effluent versus time.

4. Resources

   a. Response centers and locations.

   b. Response team numbers and locations.

   c. Pollution control equipment available.

   d. Delivery equipment such as fast delivery sleds.

   e. Containment tanks/vessels.

   f. Storage and/or reprocessing centers.

5. Procedural

   a. Response team activation process.

   b. On-scene commander and reporting responsibilities.

2.6.4 MEP MOE

1. Definition. Based on the OR for MEP, a mission measure of effectiveness may be expressed in terms of probability of removing a pollutant from the environment, assuming a distribution of pollutant quantities, effluent flow rates, environmental conditions, and case distances from MEP response centers.

MEP MOE = probability of removing pollutant given alert, and

$$\mathrm{MEP}_{\mathrm{MOE}} = P_{R/A} \cdot P_{C/R} \cdot P_{X/C} \quad ,$$

where

$P_{R/A}$ = probability of responding given alert,

$P_{C/R}$ = probability of containment given response, and

$P_{X/C}$ = probability of removal given containment.

Each of these three conditional probabilities can be factored further as described in the following sections.

2. Calculations.

Response Probability ($P_{R/A}$)

$$P_{R/A} = P_{L/A} \cdot P_{T/L}$$

where

$P_{L/A}$ = probability of loading necessary equipment and personnel, and

$P_{T/L}$ = probability of transitting to scene of incident given equipment and personnel loaded aboard.

$P_{L/A}$ imposes a payload requirement on a vessel. In the approach proposed for evaluation, this would be expressed in terms of tons of payload capacity, deck space requirement, and cargo handling capability for craft design under consideration. If a fast delivery sled is to be employed, these requirements can be considerably reduced and tow requirements imposed.

$P_{T/L}$ can be treated in much the same manner as transit probability in SAR MOE, where the case distance and sea state distributions are combined with craft velocity versus sea state to obtain a distribution of transit time. For MEP, the craft velocity distribution may be modified to reflect a tow capability for the fast delivery sled or other equipment. Utilizing the fast delivery sled or deck loaded gear presents two possible scenarios that would require adaptation of $P_{L/A}$ and $P_{T/L}$ for each case.

Containment Probability ($P_{C/R}$)

$P_{C/R} = P_{A/R} \cdot P_{F/R}$

where

$P_{A/R}$ = probability of area containment given response, and

$P_{F/R}$ = probability of flow containment given response.

It will be assumed that both probabilities are independent. This will require an area dispersion rate as a function of time only and an effluent flow rate as an independent function of time.

$P_{A/R}$ will require a capability to deploy and maneuver the containment boom under a given sea state distribution at the scene. Both capabilities will be highly influenced by sea state, the deployment being a two-state variable, whereas the boom positioning and effectiveness being a continuous function of sea state. The calculation of probability of area containment will require the measurement of an effective area containment versus time so that it can be matched against dispersion rate as illustrated in figure 2-13. The resultant combination, when considering response time, would provide a probability of containing the effluent within a certain area.

$P_{F/R}$ may require a considerable number of capabilities including damage control, fire fighting, diving, and towing. Assignment of appropriate values for probability of success given occurrence is highly subjective and much more difficult.

Although this is a logical capability to be measured, in most practical instances flow cannot be controlled and hence a measure of the containment probability is directly related to area containment only.

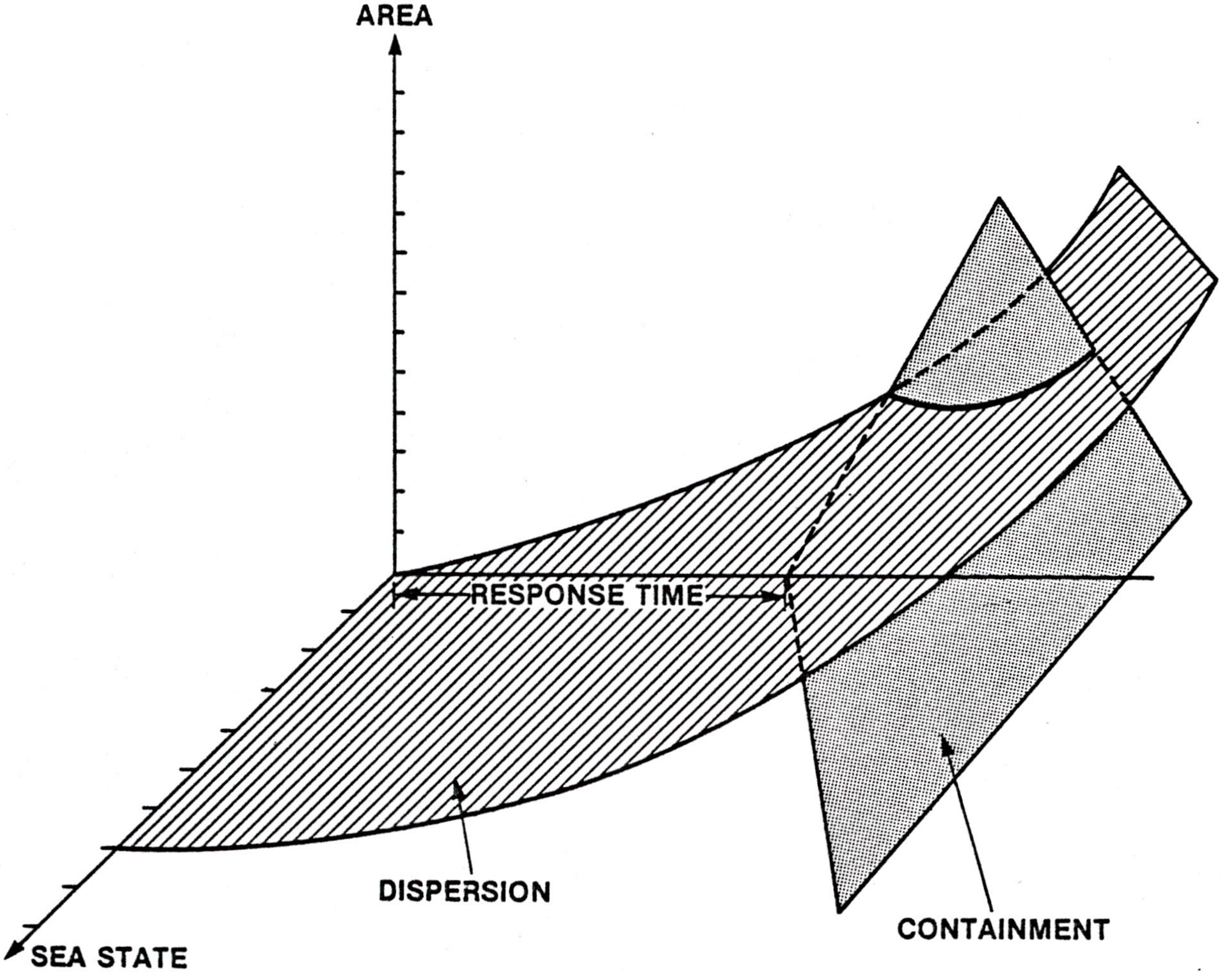


FIGURE 2-13. ABILITY TO CONTAIN A DISPERSING EFFLUENT

Removal Probability ($P_{X/C}$)

$$P_{X/C} = P_{P/C} \cdot P_{S/P}$$

where

$P_{P/C}$ = probability of pumping given containment, and

$P_{S/P}$ = probability of storage given pumping.

$P_{P/C}$ requires the ability to carry pumps with necessary capacity and to maneuver over the dispersion area or along the containment boom to collect spilled effluent. The evaluation of $P_{P/C}$ will require consideration of current MEP hardware capabilities including skimming barriers with some containment and pumping capacity.

Required rate of removal will depend on total containment, effluent rate, and time available for removal. The time available is in turn dependent on influence of sea state on removal rate, crew effectiveness, and vehicle maneuverability as well as craft on-station endurance.

$P_{S/P}$ requires a storage capacity and ability to transfer on-site storage to a permanent relocation such as reprocessing center or waste disposal tank. There are two alternate approaches to provide this capability. The first is to utilize storage capacity within the craft; the other is to utilize external storage tanks such as rubber inflatable systems or vessels of opportunity. The probability of success for this phase is dependent on the survival of the craft and/or external tanks in a sea state and/or the ability to tow and reach the final destination in given environmental conditions.

2.6.5 AMV Evaluation for MEP Mission

The above analysis of MEP mission provides some insights into craft characteristic requirements. The sensitivity of the MOE to craft payload, speed, seakeeping, maneuvering, and towing is dependent upon the specific OR requirements expressed in terms of distributions of distances of incidences from response centers, sea states, containment quantities, and effluent rates.

It would appear that high containment quantities and effluent rates will require large conventional ships, whereas long distances, smaller quantities, and moderate seas would favor advanced marine vehicles. A quantitative analysis is required to establish specific vehicle sizes and crossover values. This analysis is beyond the scope of this report and should be addressed at a later date.

2.7 MILITARY READINESS MOE

2.7.1 MR Mission

During war, hostilities, or under other special conditions, the U.S. Coast Guard may be requested to support the U.S. Navy in naval military operations. Mission areas and required operational capabilities (ROCs) for each class of Coast Guard cutters are defined in OPNAV INSTRUCTION C3501.2E and a recent COMMANDANT DIRECTIVE.

Each warfare area such as antiair warfare (AAW) and antisubmarine warfare (ASW) is further divided into specific required capabilities. Some of these capabilities require personnel skills while others require both equipment and personnel. The AMV evaluation method described in section 2 proposes to specify a common mission payload including equipment and personnel for all AMV candidates, thus the area of interest is craft sizing and performance to accomplish the required missions. Specifically, only ROCs that affect craft characteristics need be considered for MOE development.

In addition, many warfare missions have an affect on craft performance requirements very similar to noncombatant missions such as SAR and ELT. These MOEs, in addition to those of a strictly military nature, can be used to establish the total measure of military effectiveness of a Coast Guard cutter.

2.7.2 Present MR Measures

Present measures for MR are concerned with training and overall cutter performance evaluation during fleet exercises. These measures are based on existing cutter designs.

In initial cutter designs, the military requirements are established through dialogue with OPNAV based on available payload and potential capabilities of cutters sized on the basis of nonmilitary requirements. Weapons are selected based on weapons suites on similar size naval vessels. Thus, effectiveness studies, when conducted, are based on those of similar size naval vessels.

2.7.3 MR Operational Requirements

The operational requirements for MR are listed as ROCs and projected operational environment (POE) as discussed in section 2.6.1. Since the specific capabilities of ships are classified, figure 2-14 is presented to illustrate notional capabilities required for a new cutter.

Figure 2-14 illustrates the relationship between ROCs and related MOEs such as those developed for ELT and SAR. It indicates whether ROCs affect ship personnel, equipment, or operational characteristics. The majority of the ROCs selected affect only personnel and/or equipment. The ROCs which affect ship characteristics are predominately influenced by improved sea state capability and a related MOE can be applied.

2.7.4 MR MOE

ROCs selected in figure 2-14 are oriented towards a smaller cutter that does not require a significant ASUW or ASW capability. All requirements that affect craft characteristics are covered by the SAR or ELT MOEs. To calculate MOEs for each warfare mission area requires:

REQUIRED OPERATIONAL CAPABILITY	RELATED MOE	SHIP IMPACT			REMARKS
		PERSONNEL	EQUIPMENT	CHARACTERISTICS	
ANTIAIR WARFARE					
Recognize and identify aircraft by sight		o			
ANTISURFACE WARFARE					
Detect and track surface contacts with radar	ELT	o	o	o	Craft motions will affect sweep width in seaway.
Detect and track surface contacts visually	ELT	o	o	o	Craft motion and visibility affect sweep width.
Identify surface contacts		o	o		
AMPHIBIOUS WARFARE					
Conduct spotting for naval gunfire and artillery		o	o		
MINE WARFARE					
Destroy floating mines		o	o		Minor caliber gun required.
Install and maintain a precise navigation system		o	o		
Navigate precisely in MCM environment		o	o		
Navigate precisely in mine-laying environment		o	o		
MOBILITY					
Steam at full power	SAR	o	o	o	Endurance affected by speed in seaway.
Steam with split plant operations		o	o		
Control fire, flooding, electrical, structural hull casualties		o	o		
Counter and control NBC contaminants/agents		o	o		
Maintain security against unfriendly acts		o	o		
Provide damage control security/surveillance		o	o		
Navigate under all conditions of geographic location, weather, and visibility	SAR	o	o	o	Seakeeping and visibility.
Conduct precision anchoring		o	o		
Get underway, moor, anchor and sortie with duty section in safe manner		o	o		
Abandon/scuttle ship rapidly		o	o		
Provide life boat/rafts		o	o		
Tow or be towed (towing engine not required)	SAR	o	o	o	Seakeeping limitation.
Operate day & night and under all weather conditions	ELT	o	o	o	Seakeeping.
Deploy with organic allowance within designated time period		o	o		
Ensure the operation of the potable water system in a manner consistent with accepted sanitary conditions		o	o		
COMMAND, CONTROL, AND COMMUNICATIONS					
Function as on-scene commander for SAR operations		o	o		
Carry out emergency destruction of classified matter and equipment rapidly		o	o		
Provide tactical voice communications		o	o		
Maintain visual communications		o	o		
Process message traffic		o	o		
Relay visual communications		o	o		
INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE					
Collect electronic intelligence information		o	o		
Collect photographic intelligence information		o	o		
Conduct overt surveillance and reconnaissance	ELT	o	o	o	Similar to barrier operations.
Conduct in-shore harbor defense patrols	ELT	o	o	o	Similar to barrier operations.
LOGISTICS SUPPORT					
Provide small boat services		o	o		
FLEET SUPPORT OPERATIONS					
Conduct towing operations	SAR	o	o	o	Affected by motion in seaway.
Conduct rescue operations	SAR	o	o	o	Affected by motion in seaway.
Recover man overboard		o	o	o	Maneuverability and seaway motion.
Identify, equip, and maintain first aid spaces		o	o		
Train crew members in first aid		o			
NONCOMBAT OPERATIONS					
Provide messing facilities		o	o		
Provide personnel for living space maintenance		o			
Provide organizational-level maintenance		o	o		
Collect and disseminate meteorlogical information		o	o		
Provide emergency flooding/fire-fighting assistance		o	o		
Conduct harbor patrol	ELT	o	o	o	Similar to barrier operations.
Provide physical protection of port facilities					
Detect and identify noncombatant vessels	ELT	o	o	o	Similar to barrier operations.
Conduct boarding and inspection of noncombatant vessels	ELT	o	o		
Provide surveillance and protection of maritime resources	ELT	o	o		
Conduct peacekeeping/disarmament operations		o	o		

FIGURE 2-14. NOTIONAL U.S. COAST GUARD CUTTER REQUIRED OPERATIONAL CAPABILITIES

1. Definition of threat and environment for cutter operation.

2. Selection of appropriate sensors and command/control equipment to counter threat.

3. Determination of personnel requirements to operate and support above systems aboard ship.

4. Establishment of appropriate scenario for evaluation.

5. Developing an MOE for scenario.

For example, the antisurface warfare (ASUW) ROCs are very similar to the ELT mission, and the MOE ELT definition can be used with the following constraints:

1. The potential threat may not be smugglers as previously defined but fast patrol boats. Hence, the values of the penetrator speed U may be considerably higher.

2. Detection on the barrier may be restricted to passive systems without electromagnetic radiation, hence the sweep width W may change considerably.

3. Noise radiation at high patrol speeds may be a consideration for threats posed, hence very high patrol speeds may be restricted.

4. Identification of targets may require EW equipment not normally carried aboard.

5. Boarding may not be required.

6. All vessels may be considered "suspicious" for a specified barrier.

Although values of the parameters in the MOE ELT definition need to be modified for the ASUW mission, the present definition can be used to evaluate the ASUW mission ROCs. In like manner, other ROCs can be related to SAR or ELT MOEs as noted in figure 2-14.

2.7.5 AMV Evaluation for MR Mission

Military requirements affect large cutter design to a greater degree than small cutters. The greatest effect of the MR mission on craft characteristics is that of mission payload. Whether all military equipment is installed or only space and weight provided, the payload capability is the single most influential factor. Since other missions such as MEP require substantial payload capability, an alternate mission capability appears feasible for small cutters. Thus, the cutter could be configured to load pollution control equipment or missile cannisters. The controlling factor for sizing cutters under this approach is the minimum built-in command-control capability that is required.

As described in section 2.7.4 above, many ROCs can be evaluated with other mission MOEs by appropriately modifying the parameters in the definition. This approach leads to a minimum number of measures and focuses attention on the operational requirements and scenarios. Thus, to evaluate the impact of MR on total craft MOE, the same measure can be used to evaluate whether it imposes more demanding requirements or is less demanding than other missions such as peacetime ELT.

SECTION 3
CUTTER RESOURCES EFFECTIVENESS EVALUATION (CREE) MODEL

3.1 BACKGROUND

The CREE model was developed by personnel in the Coast Guard R&D Center and Transportation System Center in Cambridge, Massachusetts as a result of a planning requirement issued by the Office of Operations at Coast Guard Headquarters in June 1976. These objectives for the CREE project were:

1. To determine the mission-related capabilities, limitations, and operational and support requirements of high-performance watercraft and of conventional Coast Guard vessels (with and without aircraft), present and future.

2. To develop a method which provides a quantitative description of the costs and effectiveness of AMV and conventional vessels and which presents a quantitative evaluation of the craft considered in task, program, and multi-program mission performance, singly, comparatively, and within a mix of resources.

3. As an end product, to provide the Office of Operations with a theoretical model, implementing computer programs, and documentation which satisfy the above objectives, with sufficient flexibility so that the user may tailor the computational procedures to his operational or analytical requirements.

The resultant model whose overall structure is depicted in figure 3-1 was developed in FORTRAN IV for the IBM mainframe computer at the Transportation Department.

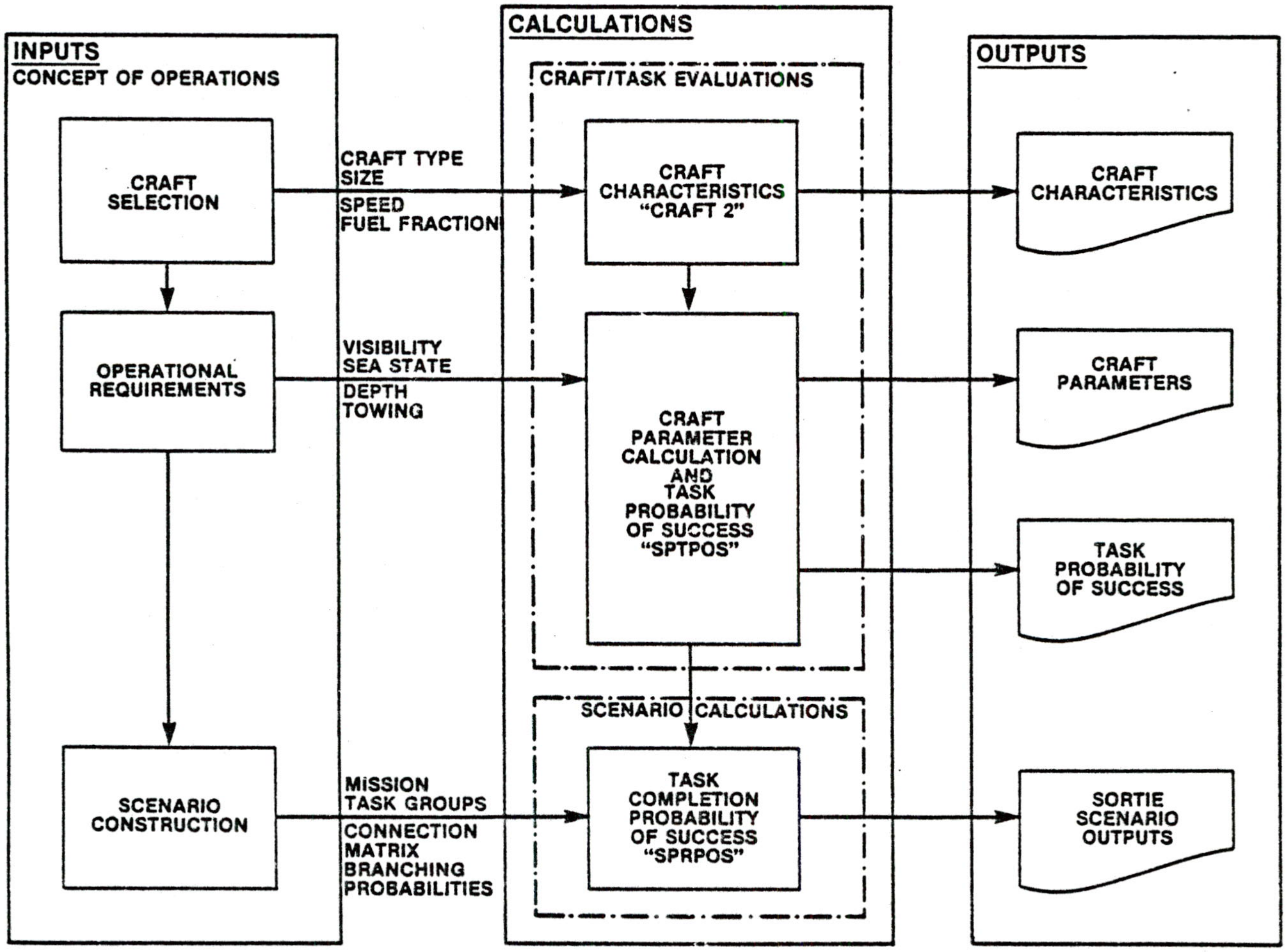


FIGURE 3-1. CREE MODEL STRUCTURE

3.2 STRUCTURE OF THE CREE MODEL

The CREE model can be used to evaluate various craft. A conventional vessel or an advanced marine vehicle, and a set of operational requirements and a scenario, are necessary inputs to the model. They are described in the following paragraphs.

1. Inputs

   a. Craft. Select the type of craft to be evaluated, craft size, maximum speed, and fuel fraction. Available craft are listed in figure 3-2.

   b. Operational Requirements. Select sea state, visibility, depth, and towing distributions appropriate to scenario from tables such as figure 3-3.

   c. Scenario Construction. Select the appropriate mission to be evaluated and the appropriate task groups. Define the interrelationships between task groups in a connection matrix and describe the branching probabilities between each task group. A typical SAR scenario construction is depicted in figures 3-4 through 3-6.

2. Calculations

   a. Craft Characteristics. Algorithms resident in the program will calculate the craft characteristics based upon the user inputs. A detailed discussion of these algorithms and their update is included in section 4.

   b. Craft Parameters. Craft characteristics and operational requirement inputs are combined by normalization procedures and algorithms into craft parameters.

Advanced Marine Vehicles

Hydrofoil, Submerged Foil
Hydrofoil, Surface Piercing Foil
ACV - Air Cushion Vehicle, low cushion pressure to length ratio
ACV - Air Cushion Vehicle, high cushion pressure to length ratio
SES - Surface Effect Ship
Planing Craft
Catamaran
Hybrid Vessel
Conventional Craft

Existing Coast Guard Craft

MRB 26'	Motor Rescue Boat
PWB 32'	Port and Waterways Boat
UTB 41'	Utility Boat
MLB 44'	Motor Life Boat
MLB 52'	Motor Life Boat
ANB 55'	Aids to Navigation Boat
ANB 63'	Aids to Navigation Boat
WPB 82'	Patrol Boat
WPB 95'	Patrol Boat
WMEC 210'	Medium Endurance Cutter
WMEC 270'	Medium Endurance Cutter
WHEC 378'	High Endurance Cutter

FIGURE 3-2. CRAFT CHARACTERISTICS AVAILABLE IN CREE MODEL

SS DISTRI-BUTION NUMBER	AVERAGE OF SEA STATE DISTRI-BUTION-SS	SEA STATE					
		0-1	1-2	2-3	3-4	4-5	5-6
1	0.5	1.0	0	0	0	0	0
2	1.0	.55	.40	.05	0	0	0
3	1.5	.20	.60	.15	.05	0	0
4	2.0	.20	.30	.35	.10	.05	0
5	2.5	.10	.30	.30	.15	.10	.05
6	3.0	.05	.15	.25	.40	.10	.05
7	3.5	.05	.10	.10	.35	.20	.15
8	4.0	0	.05	.15	.25	.35	.20
9	4.5	0	0	.05	.20	.45	.30
10	5.0	0	0	0	.10	.30	.60

FIGURE 3-3A. SUMMARY OF SEA STATE PROBABILITY DISTRIBUTION

DISTRIBUTION NUMBER DESCRIPTION		GOOD	FAIR	POOR
1	Very Good	0.9	0.1	0
2	Good	0.7	0.2	0.1
3	Good to Fair	0.5	0.3	0.2

FIGURE 3-3B. VISIBILITY PROBABILITY DISTRIBUTION

TOW DISTRIBUTION NUMBER	CUMULATIVE PROBABILITY OF TOW					
	0.0	0.2	0.4	0.6	0.8	1.0
1	.5	1.0	2.5	7.0	10	50
2	.7	2.0	4.0	10	30	100
3	1.0	4.0	7.0	20	60	500
4	2.0	6.0	20	50	80	1000
5	10	20	50	100	300	10,000

FIGURE 3-3C. DISTRIBUTIONS FOR DISPLACEMENT OF TOWED CRAFT (TONS)

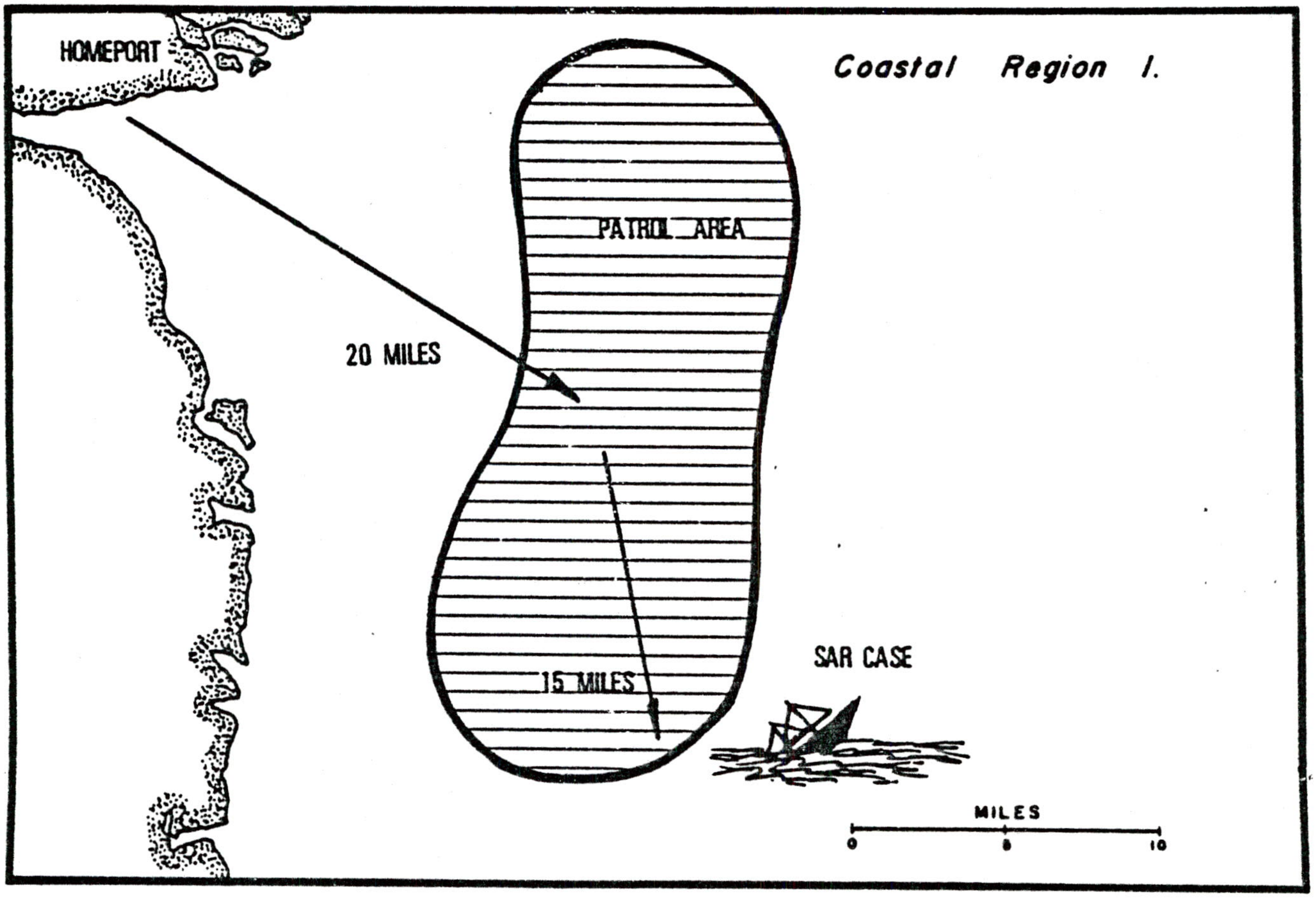


FIGURE 3-4. OPERATIONAL AREA FOR SAMPLE SAR SEARCH

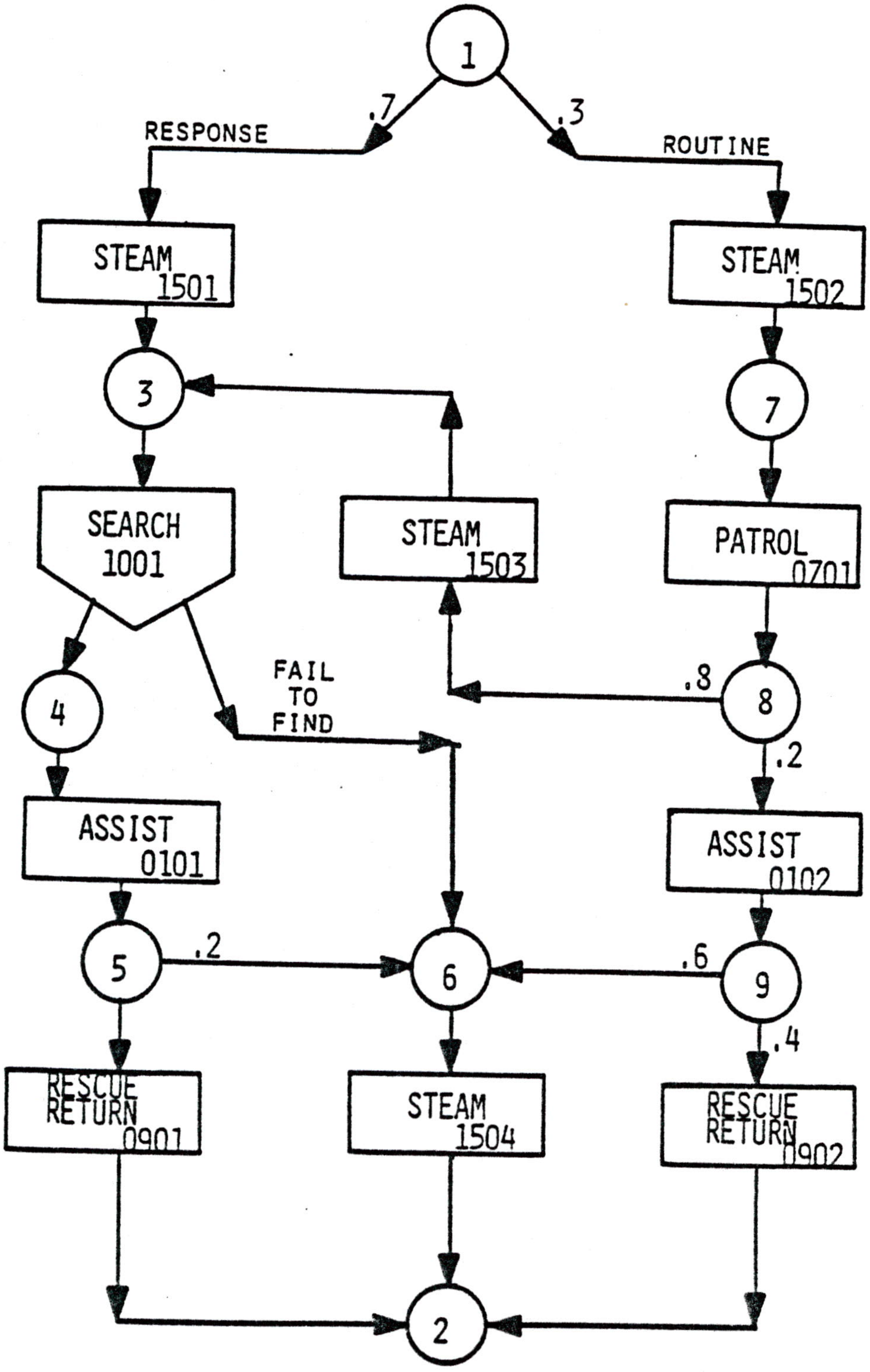


FIGURE 3-5. TYPICAL SAR SCENARIO CONSTRUCTION

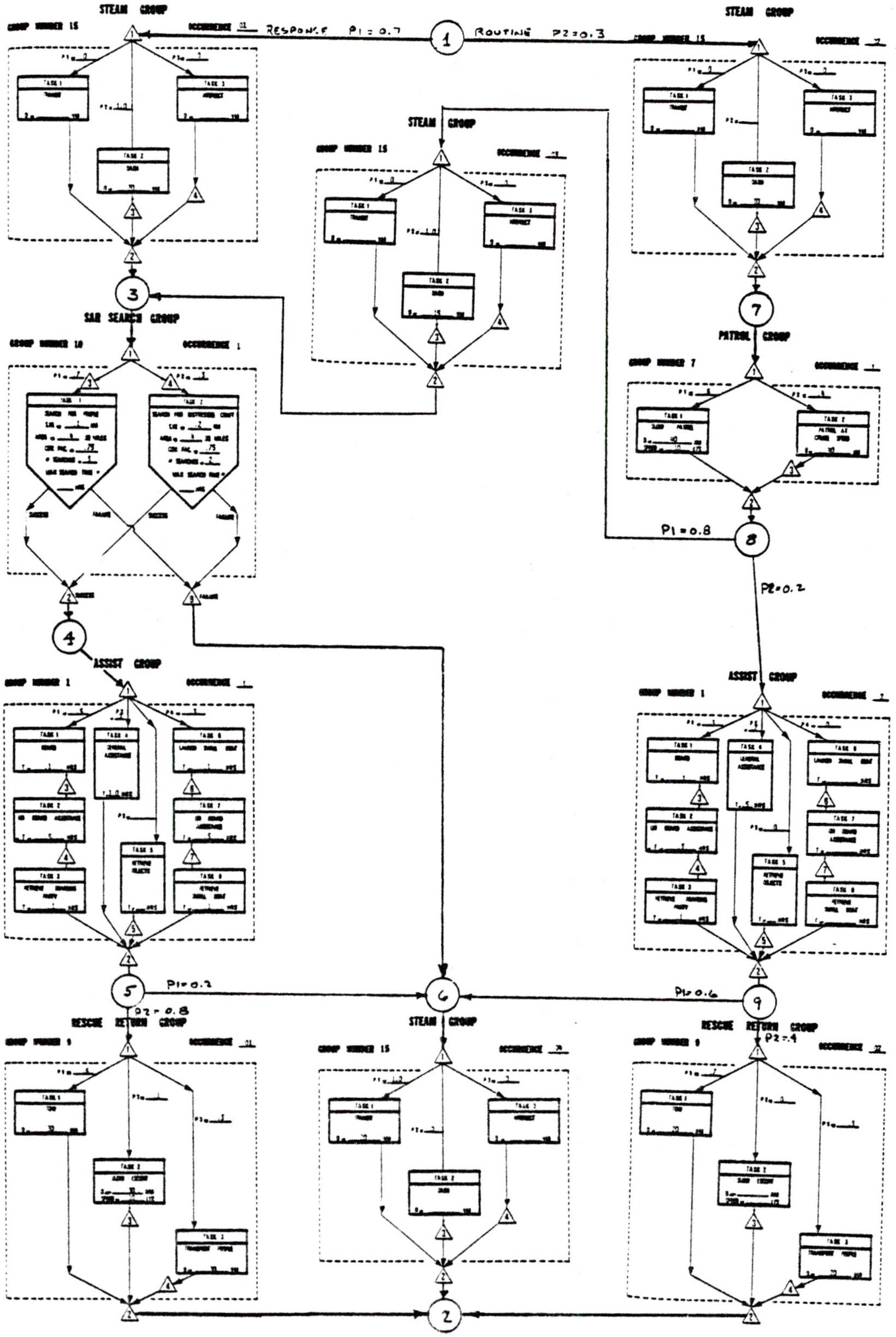


FIGURE 3-6. FUNCTIONAL GROUPS IN CREE MODEL

c. Tasks Probability of Success. A probability of success for each standard task is calculated based on craft parameters.

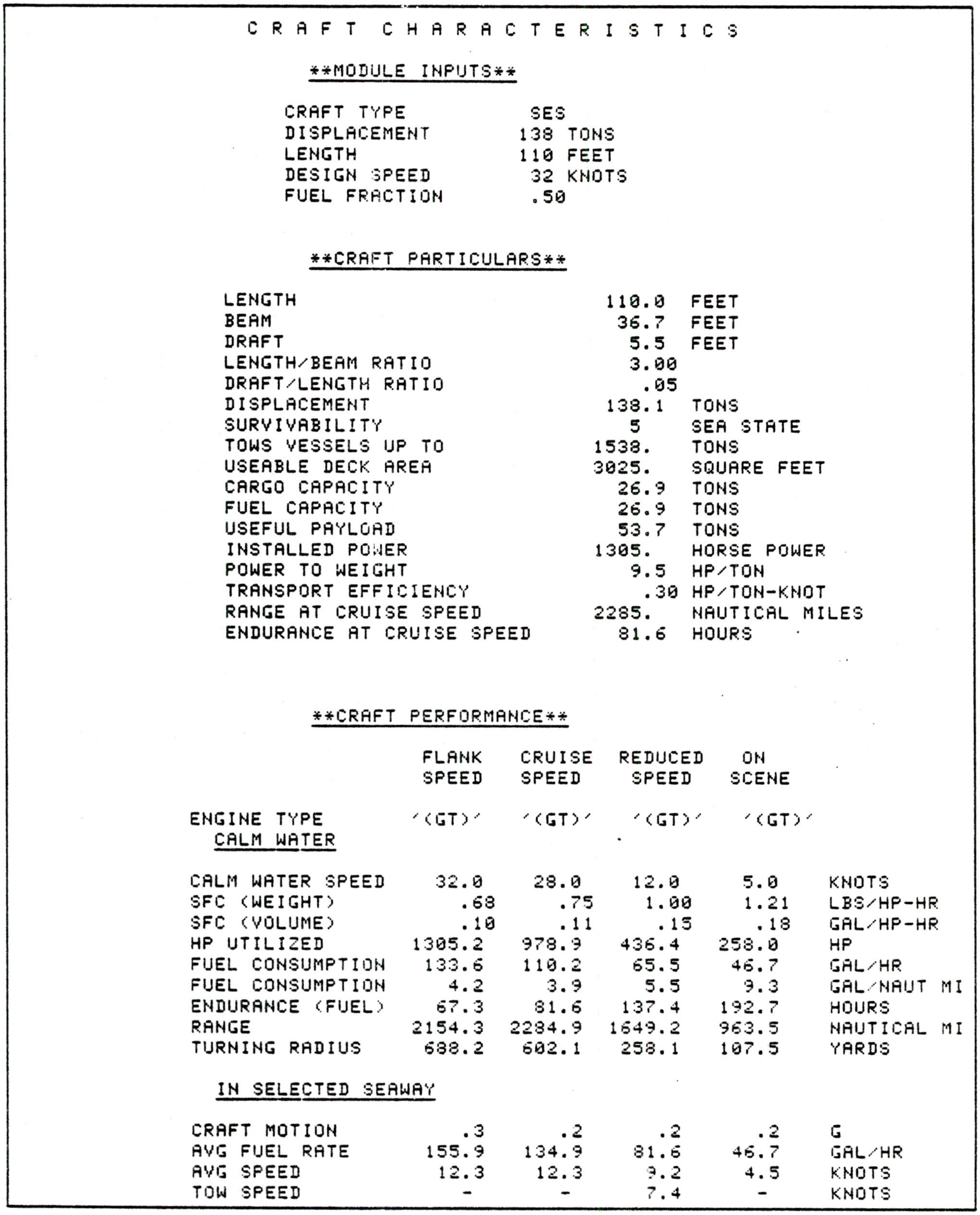
d. Task Completion Probability of Success. Based upon the scenario constructed, the probability of success is calculated for each sortie. Each possible path through the scenario (called a sortie) is evaluated. The probability of successfully completing a sortie depends on two factors. The first is the probability that the sortie path will occur, and the second is the probability of accomplishing all the tasks encountered on the path. Sorties may be aborted because of fuel or time limitations. Only successfully completed sorties are calculated, but all attempts are counted.

3. Outputs. Sample outputs resulting from the above calculations are described below:

a. Craft Characteristics. An SES ship of length 110 feet, design speed of 32 knots, and fuel fraction of 0.5 (figure 3-7) has been selected.

b. Craft Parameters and Task Probabilities of Success. Figures 3-8 through 3-13 are based upon visibility distribution 2, tow distribution 3, depth distribution 1, and sea state distribution 6. The average sea state is 3.

c. Sortie Outputs. A sample output for 1 of the 14 sorties is shown in figure 3-14. These sorties are based on scenario inputs described in figure 3-15. The scenario selected is the SAR 7 scenario of figure 3-6 with maximum time on scene of 12 hours, a range fraction of 0.9, and 180 days total of operation. The results of the sorties are summarized in figure 3-16.



```
                    C R A F T   C H A R A C T E R I S T I C S

                         **MODULE INPUTS**

                      CRAFT TYPE           SES
                      DISPLACEMENT        138 TONS
                      LENGTH              110 FEET
                      DESIGN SPEED         32 KNOTS
                      FUEL FRACTION        .50


                         **CRAFT PARTICULARS**

                 LENGTH                            110.0  FEET
                 BEAM                               36.7  FEET
                 DRAFT                               5.5  FEET
                 LENGTH/BEAM RATIO                   3.00
                 DRAFT/LENGTH RATIO                   .05
                 DISPLACEMENT                      138.1  TONS
                 SURVIVABILITY                       5    SEA STATE
                 TOWS VESSELS UP TO               1538.   TONS
                 USEABLE DECK AREA                3025.   SQUARE FEET
                 CARGO CAPACITY                     26.9  TONS
                 FUEL CAPACITY                      26.9  TONS
                 USEFUL PAYLOAD                     53.7  TONS
                 INSTALLED POWER                  1305.   HORSE POWER
                 POWER TO WEIGHT                     9.5  HP/TON
                 TRANSPORT EFFICIENCY                .30  HP/TON-KNOT
                 RANGE AT CRUISE SPEED            2285.   NAUTICAL MILES
                 ENDURANCE AT CRUISE SPEED          81.6  HOURS


                         **CRAFT PERFORMANCE**

                               FLANK    CRUISE   REDUCED    ON
                               SPEED    SPEED     SPEED    SCENE

              ENGINE TYPE      '(GT)'   '(GT)'   '(GT)'   '(GT)'
                CALM WATER

              CALM WATER SPEED   32.0     28.0     12.0      5.0     KNOTS
              SFC (WEIGHT)        .68      .75     1.00     1.21     LBS/HP-HR
              SFC (VOLUME)        .10      .11      .15      .18     GAL/HP-HR
              HP UTILIZED      1305.2    978.9    436.4    258.0     HP
              FUEL CONSUMPTION  133.6    110.2     65.5     46.7     GAL/HR
              FUEL CONSUMPTION    4.2      3.9      5.5      9.3     GAL/NAUT MI
              ENDURANCE (FUEL)   67.3     81.6    137.4    192.7     HOURS
              RANGE            2154.3   2284.9   1649.2    963.5     NAUTICAL MI
              TURNING RADIUS    688.2    602.1    258.1    107.5     YARDS

                IN SELECTED SEAWAY

              CRAFT MOTION         .3       .2       .2       .2     G
              AVG FUEL RATE     155.9    134.9     81.6     46.7     GAL/HR
              AVG SPEED          12.3     12.3      9.2      4.5     KNOTS
              TOW SPEED            -        -       7.4       -      KNOTS
```

FIGURE 3-7. SAMPLE OUTPUT (SES)

```
                   C R A F T   P A R A M E T E R S


                   CRAFT TYPE      SES
                   DISPLACEMENT    138  TONS
                   LENGTH          110  FEET
                   DESIGN SPEED     32  KNOTS
                   FUEL FRACTION    .50

                       VISIBILITY DISTRIBUTION NO. 2
                       TOW DISTRIBUTION NO. 3
                       DEPTH DISTRIBUTION NO. 1
                       SEA STATE DISTRIBUTION NO. 6
                       (AVERAGE SEA STATE =3.0)


           TASK  CARGO DRAFT MANEUV  SEA   TOW
           CODE  CPCTY               STATE


                   CC     DF     MN     SS     TW


       ON SCENE:
           ASST     --     1.00   .92    .96    --    ASSIST
           BORD     --     1.00   .92    .96    --    BOARD
           MNAC     --     1.00   .92    .96    --    MONITOR ACTIVITIES
           RTRV     --     1.00   .92    .94    --    RETRIEVE
           WAIT     --      --    --     .96    --    WAIT
           WEQD     --     1.00   --     .94    --    WORK EQUIPMENT @ DRIFT
           WEQP     --     1.00   .92    .94    --    WORK EQUIPMENT @ POSITION

       REDUCED SPEED:
           SDIU     --     1.00   --     .92    --    SEARCH FOR DISTRESSED UNIT
           SESC     --      --    --     .92    --    SLOW ESCORT
           SPAT     --     1.00   --     .92    --    SLOW PATROL
           SPEO     --     1.00   --     .92    --    SEARCH FOR PEOPLE
           TOWS     --      --    .50    .92   1.00   TOWS

       CRUISE SPEED:
           ESCT     --      --    --     .88    --    ESCORT
           IDNT     --      --    .95    .88    --    IDENTIFY
           PATL     --      --    --     .88    --    PATROL
           STGT     --     1.00   --     .88    --    SEARCH FOR TARGET
           TRPT   0.00      --    --     .88    --    TRANSPORT
           TRST     --      --    --     .88    --    TRANSIT

       FLANK SPEED:
           RSPD     --      --    --     .51    --    RESPOND


       *** DEPENDENT UPON SCENARIO (E.G., FOOTPRINT AND WEIGHT OF CARGO)
```

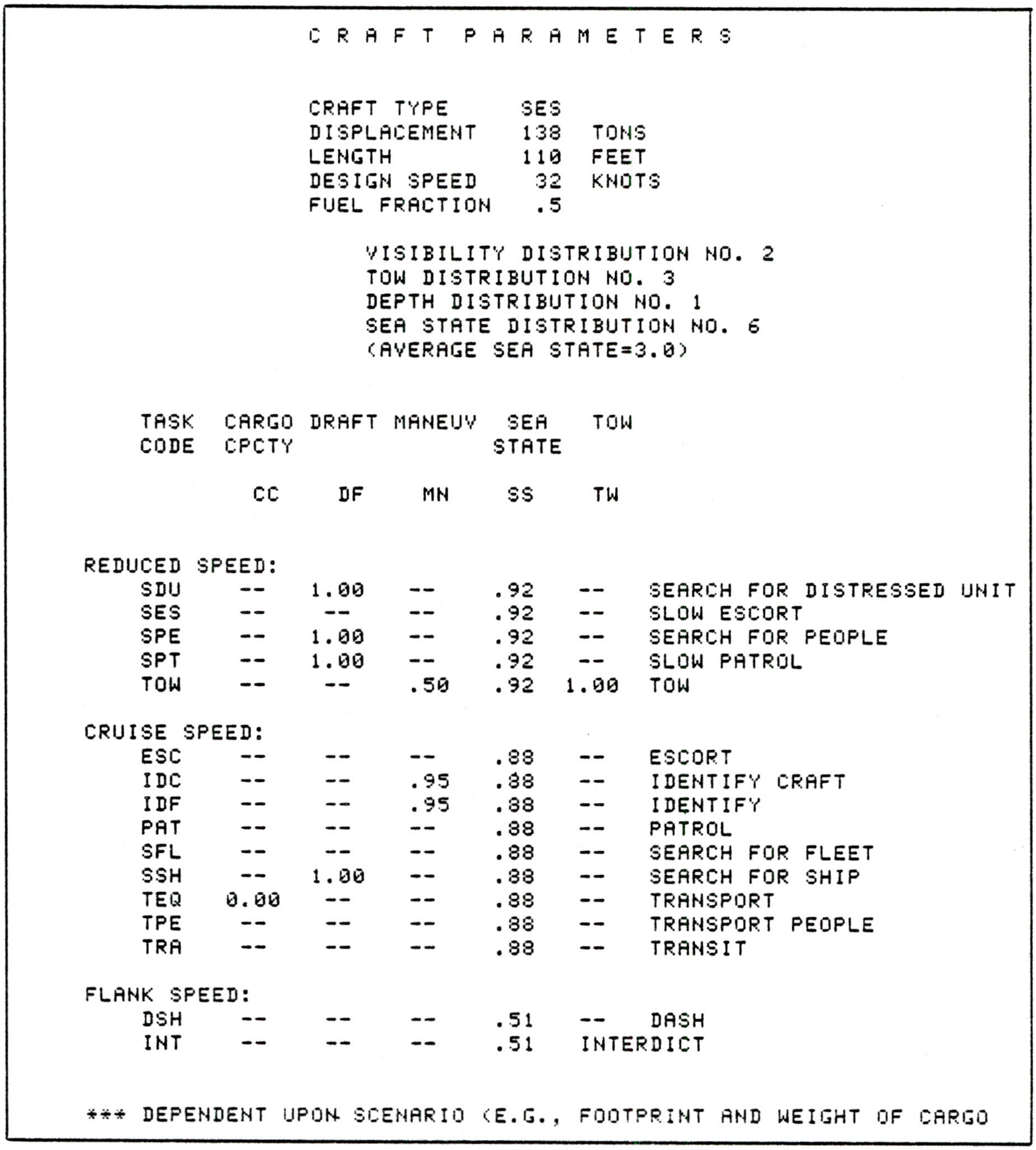
FIGURE 3-8. SAMPLE OUTPUT

```
   T A S K   P R O B A B I L I T I E S   O F   S U C C E S S


            CRAFT TYPE       SES
            DISPLACEMENT     138   TONS
            LENGTH           110   FEET
            DESIGN SPEED      32   KNOTS
            FUEL FRACTION     .50

                VISIBILITY DISTRIBUTION NO. 2
                TOW DISTRIBUTION NO. 3
                DEPTH DISTRIBUTION NO. 1
                SEA STATE DISTRIBUTION NO. 6
                (AVERAGE SEA STATE =3.0)


    TASK    TASK PROB     TASK
    CODE    OF SUCCESS


ON SCENE:
    ASST       .883      ASSIST
    BORD       .883      BOARD
    MNAC       .883      MONITOR ACTIVITIES
    RTRV       .868      RETRIEVE
    WAIT       .960      WAIT
    WEQD       .943      WORK EQUIPMENT @ DRIFT
    WEQP       .868      WORK EQUIPMENT @ POSITION

REDUCED SPEED:
    SDIU       .922*     SEARCH FOR DISTRESSED UNIT
    SESC       .922      SLOW ESCORT
    SPAT       .922      SLOW PATROL
    SPEO       .922*     SEARCH FOR PEOPLE
    TOWS       .461      TOWS

CRUISE SPEED:
    ESCT       .875      ESCORT
    IDNT       .830      IDENTIFY
    PATL       .875      PATROL
    STGT       .875*     SEARCH FOR TARGET
    TRPT      0.000      TRANSPORT
    TRST       .875      TRANSIT

FLANK SPEED:
    RSPD       .513      RESPOND


  *   THIS IS THE P.O.S OF THE ABILITY TO SEARCH CRAFT´ SUCCESS
      IN FINDING THE OBJECT OF THE SEARCH IS DEPENDENT UPON
       SCENARIO (E.G., SEARCH AREA)
***** DEPENDENT UPON SCENARIO (E.G., FOOTPRINT AND WEIGHT OF CARGO)
```

FIGURE 3-9. SAMPLE OUTPUT

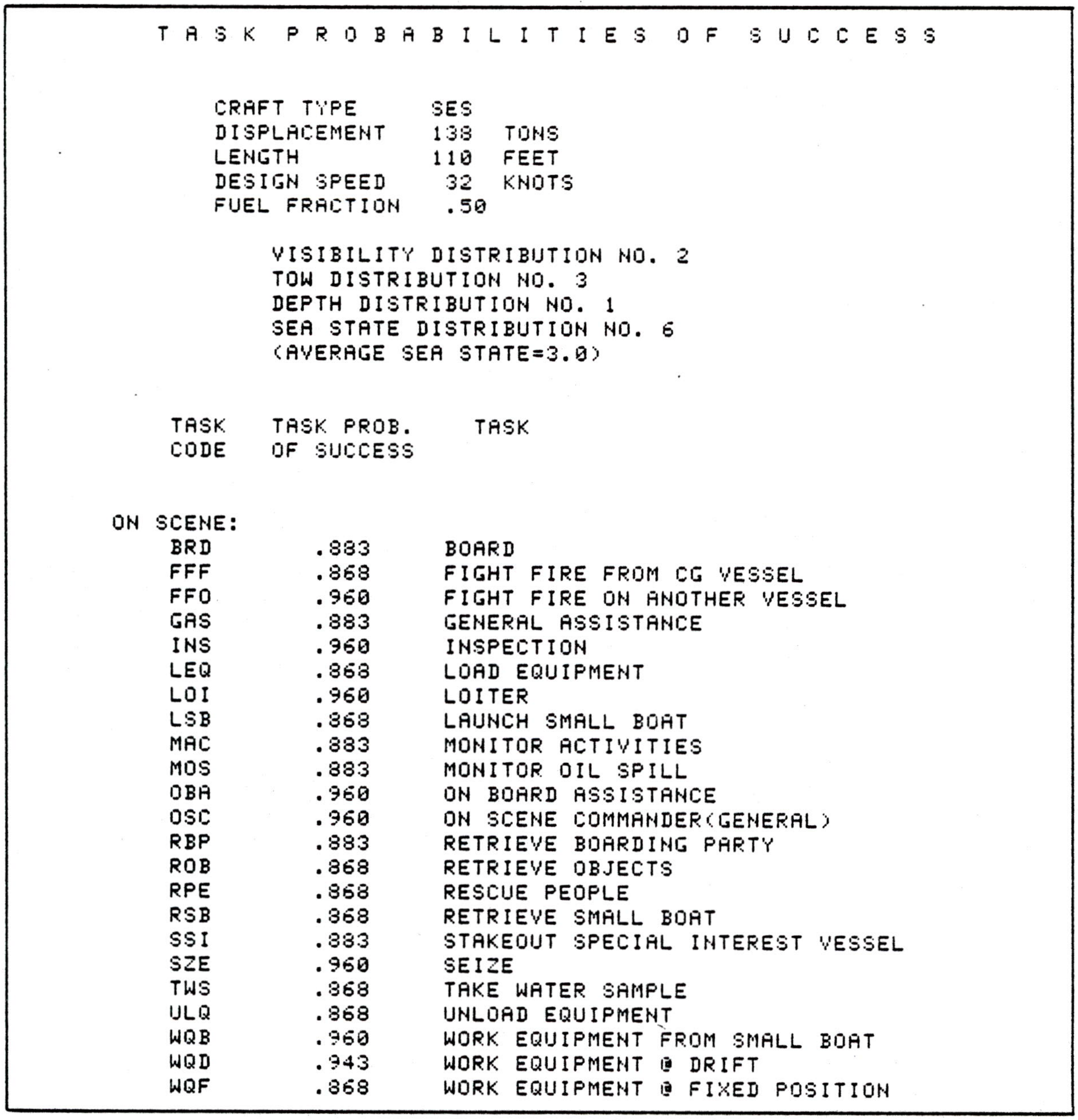
```
                C R A F T   P A R A M E T E R S


                CRAFT TYPE     SES
                DISPLACEMENT   138  TONS
                LENGTH         110  FEET
                DESIGN SPEED    32  KNOTS
                FUEL FRACTION   .50

                    VISIBILITY DISTRIBUTION NO. 2
                    TOW DISTRIBUTION NO. 3
                    DEPTH DISTRIBUTION NO. 1
                    SEA STATE DISTRIBUTION NO. 6
                    (AVERAGE SEA STATE =3.0)


    TASK  CARGO DRAFT MANEUV  SEA  TOW
    CODE  CPCTY              STATE

            CC    DF    MN    SS   TW


ON SCENE:
    BRD    --   1.00   .92   .96   --   BOARD
    FFF    --   1.00   .92   .94   --   FIGHT FIRE FROM CG VESSEL
    FFO    --    --    --    .96   --   FIGHT FIRE ON ANOTHER VESSEL
    GAS    --   1.00   .92   .96   --   GENERAL ASSISTANCE
    INS    --    --    --    .96   --   INSPECTION
    LEQ    --   1.00   .92   .94   --   LOAD EQUIPMENT
    LOI    --    --    --    .96   --   LOITER
    LSB    --   1.00   .92   .94   --   LAUNCH SMALL BOAT
    MAC    --   1.00   .92   .96   --   MONITOR ACTIVITIES
    MOS    --   1.00   .92   .96   --   MONITOR OIL SPILL
    OBA    --    --    --    .96   --   ON BOARD ASSISTANCE
    OSC    --    --    --    .96   --   ON SCENE COMMANDER(GENERAL)
    RBP    --   1.00   .92   .96   --   RETRIEVE BOARDING PARTY
    ROB    --   1.00   .92   .94   --   RETRIEVE OBJECTS
    RPE    --   1.00   .92   .94   --   RESCUE PEOPLE
    RSB    --   1.00   .92   .94   --   RETRIEVE SMALL BOAT
    SSI    --   1.00   .92   .96   --   STAKEOUT SPECIAL INTEREST VESSEL
    SZE    --    --    --    .96   --   SEIZE
    TWS    --   1.00   .92   .94   --   TAKE WATER SAMPLE
    ULQ    --   1.00   .92   .94   --   UNLOAD EQUIPMENT
    WQB    --    --    --    .96   --   WORK EQUIPMENT FROM SMALL BOAT
    WQD    --   1.00   --    .94   --   WORK EQUIPMENT @ DRIFT
    WQF    --   1.00   .92   .94   --   WORK EQUIPMEN @ FIXED POSITION
```

FIGURE 3-10. SAMPLE OUTPUT



```
                C R A F T   P A R A M E T E R S


                CRAFT TYPE     SES
                DISPLACEMENT   138  TONS
                LENGTH         110  FEET
                DESIGN SPEED    32  KNOTS
                FUEL FRACTION   .5

                    VISIBILITY DISTRIBUTION NO. 2
                    TOW DISTRIBUTION NO. 3
                    DEPTH DISTRIBUTION NO. 1
                    SEA STATE DISTRIBUTION NO. 6
                    (AVERAGE SEA STATE=3.0)


    TASK  CARGO DRAFT MANEUV SEA    TOW
    CODE  CPCTY              STATE

            CC    DF    MN    SS    TW


REDUCED SPEED:
    SDU    --   1.00   --    .92   --   SEARCH FOR DISTRESSED UNIT
    SES    --    --    --    .92   --   SLOW ESCORT
    SPE    --   1.00   --    .92   --   SEARCH FOR PEOPLE
    SPT    --   1.00   --    .92   --   SLOW PATROL
    TOW    --    --   .50    .92  1.00  TOW

CRUISE SPEED:
    ESC    --    --    --    .88   --   ESCORT
    IDC    --    --   .95    .88   --   IDENTIFY CRAFT
    IDF    --    --   .95    .88   --   IDENTIFY
    PAT    --    --    --    .88   --   PATROL
    SFL    --    --    --    .88   --   SEARCH FOR FLEET
    SSH    --   1.00   --    .88   --   SEARCH FOR SHIP
    TEQ   0.00   --    --    .88   --   TRANSPORT
    TPE    --    --    --    .88   --   TRANSPORT PEOPLE
    TRA    --    --    --    .88   --   TRANSIT

FLANK SPEED:
    DSH    --    --    --    .51   --   DASH
    INT    --    --    --    .51  INTERDICT


*** DEPENDENT UPON SCENARIO (E.G., FOOTPRINT AND WEIGHT OF CARGO
```

FIGURE 3-11. SAMPLE OUTPUT

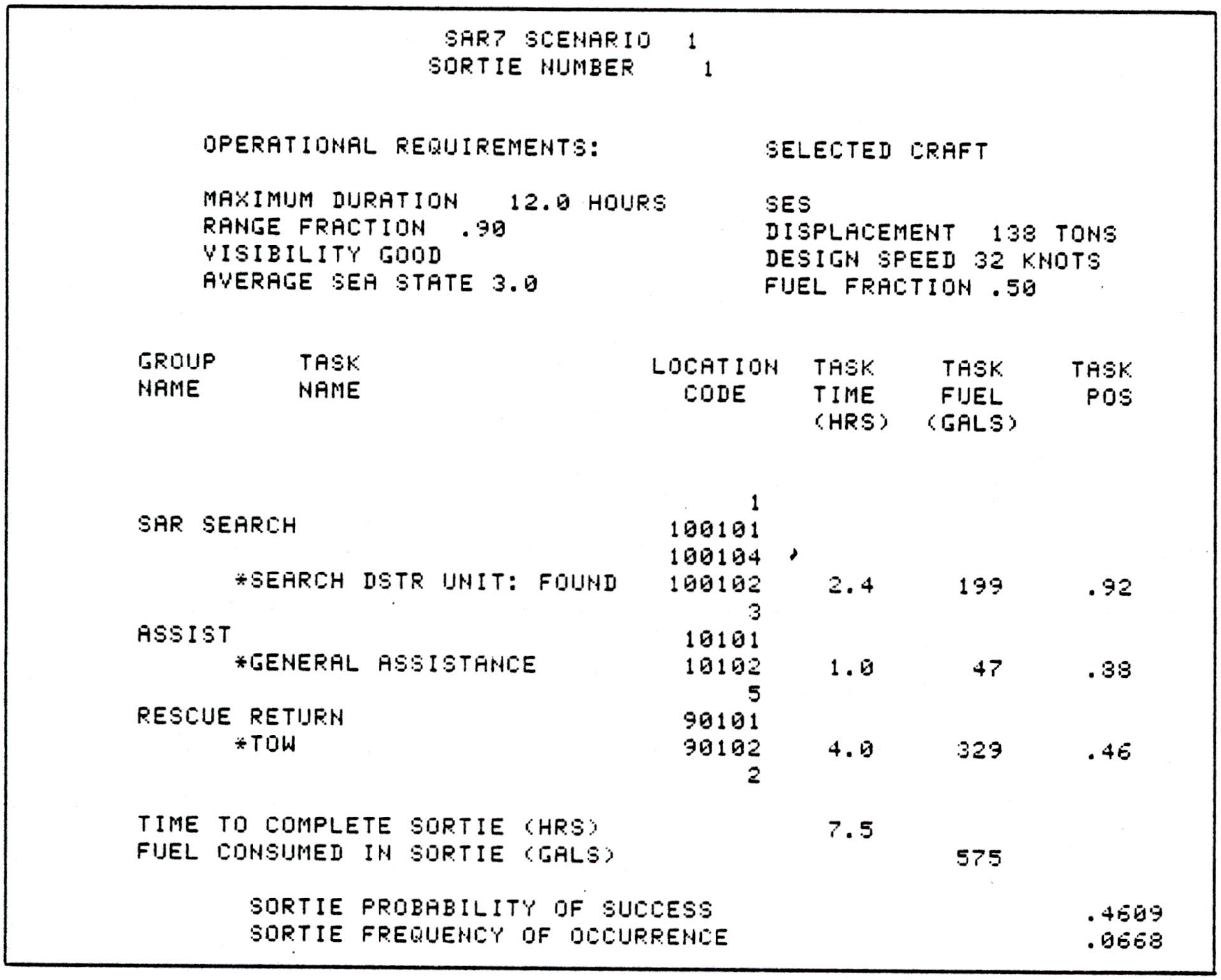


```
          T A S K   P R O B A B I L I T I E S   O F   S U C C E S S


              CRAFT TYPE      SES
              DISPLACEMENT    138  TONS
              LENGTH          110  FEET
              DESIGN SPEED     32  KNOTS
              FUEL FRACTION   .50

                  VISIBILITY DISTRIBUTION NO. 2
                  TOW DISTRIBUTION NO. 3
                  DEPTH DISTRIBUTION NO. 1
                  SEA STATE DISTRIBUTION NO. 6
                  (AVERAGE SEA STATE=3.0)


          TASK   TASK PROB.     TASK
          CODE   OF SUCCESS


      ON SCENE:
          BRD         .883      BOARD
          FFF         .868      FIGHT FIRE FROM CG VESSEL
          FFO         .960      FIGHT FIRE ON ANOTHER VESSEL
          GAS         .883      GENERAL ASSISTANCE
          INS         .960      INSPECTION
          LEQ         .868      LOAD EQUIPMENT
          LOI         .960      LOITER
          LSB         .868      LAUNCH SMALL BOAT
          MAC         .883      MONITOR ACTIVITIES
          MOS         .883      MONITOR OIL SPILL
          OBA         .960      ON BOARD ASSISTANCE
          OSC         .960      ON SCENE COMMANDER(GENERAL)
          RBP         .883      RETRIEVE BOARDING PARTY
          ROB         .868      RETRIEVE OBJECTS
          RPE         .868      RESCUE PEOPLE
          RSB         .868      RETRIEVE SMALL BOAT
          SSI         .883      STAKEOUT SPECIAL INTEREST VESSEL
          SZE         .960      SEIZE
          TWS         .868      TAKE WATER SAMPLE
          ULQ         .868      UNLOAD EQUIPMENT
          WQB         .960      WORK EQUIPMENT FROM SMALL BOAT
          WQD         .943      WORK EQUIPMENT @ DRIFT
          WQF         .868      WORK EQUIPMENT @ FIXED POSITION
```

FIGURE 3-12. SAMPLE OUTPUT

```
      T A S K   P R O B A B I L I T I E S   O F   S U C C E S S


          CRAFT TYPE       SES
          DISPLACEMENT     138   TONS
          LENGTH           110   FEET
          DESIGN SPEED      32   KNOTS
          FUEL FRACTION     .50

              VISIBILITY DISTRIBUTION NO. 2
              TOW DISTRIBUTION NO. 3
              DEPTH DISTRIBUTION NO. 1
              SEA STATE DISTRIBUTION NO. 6
              (AVERAGE SEA STATE=3.0)


       TASK    TASK PROB     TASK
       CODE    OF SUCCESS


   REDUCED SPEED:
       SDU         .922*     SEARCH FOR DISTRESSED UNIT
       SES         .922      SLOW ESCORT
       SPE         .922*     SEARCH FOR PEOPLE
       SPT         .922      SLOW PATROL
       TOW         .461      TOW

   CRUISE SPEED:
       ESC         .875      ESCORT
       IDC         .830      IDENTIFY CRAFT
       IDF         .830      IDENTIFY FLEET
       PAT         .875      PATROL
       SFL         .875      SEARCH FOR FLEET
       SSH         .875*     SEARCH FOR SHIP
       TEQ        0.000      TRANSPORT EQUIPMENT
       TPE         .875      TRANSPORT PEOPLE
       TRA         .875      TRANSIT

   FLANK SPEED:
       DSH         .513      DASH
       INT         .513      INTERDICT

     *   THIS IS THE P.O.S. OF THE ABILITY TO SEARCH. CRAFT´S SUCCESS
         IN FINDING THE OBJECT OF THE SEARCH IS DEPENDENT UPON
         SCENARIO (E.G. SEARCH AREA)

   ***** DEPENDENT UPON SCENARIO (E.G., FOOTPRINT AND WEIGHT OF CARGO)
```

FIGURE 3-13. SAMPLE OUTPUT

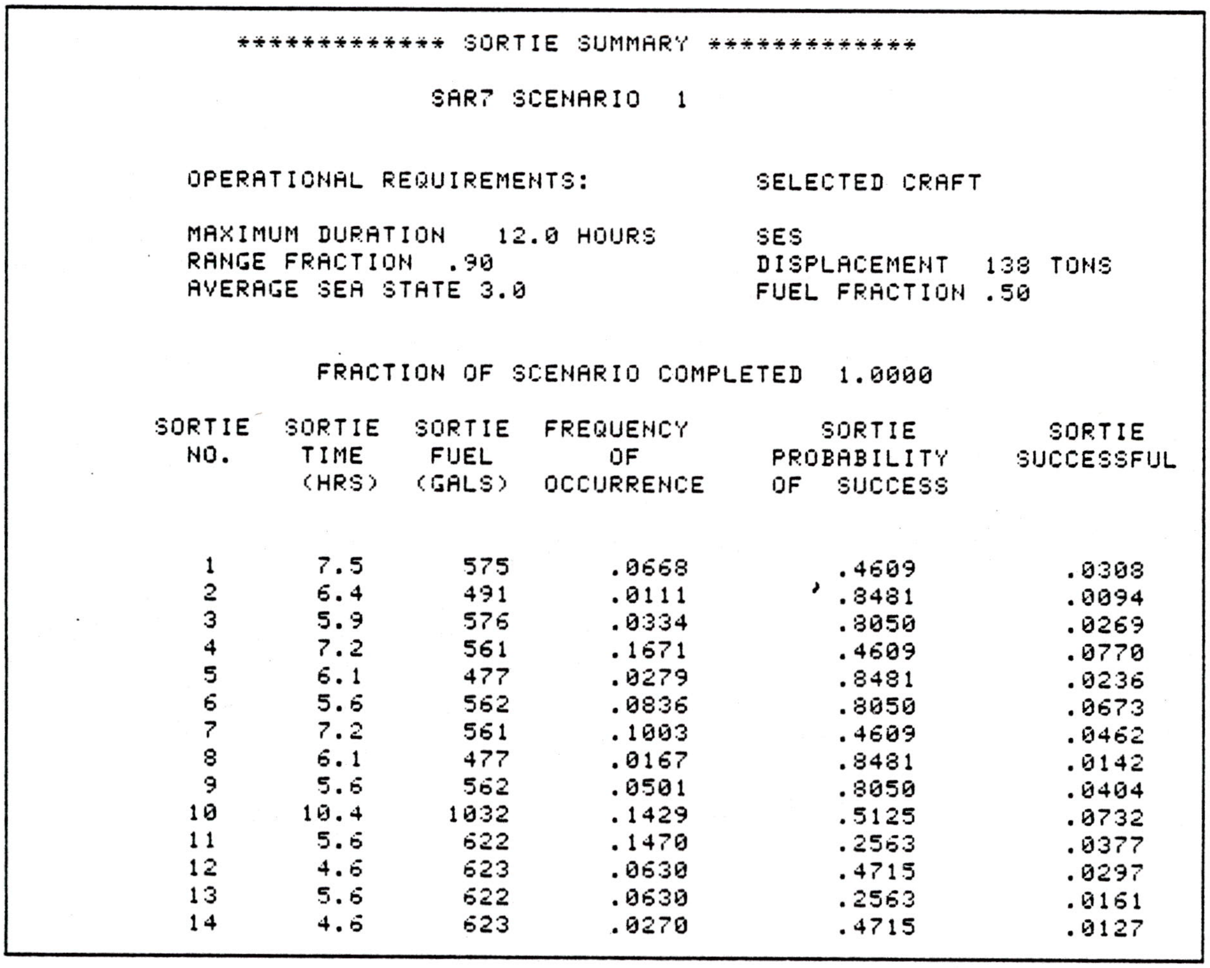


```
                       SAR7 SCENARIO  1
                      SORTIE NUMBER    1

     OPERATIONAL REQUIREMENTS:            SELECTED CRAFT

     MAXIMUM DURATION   12.0 HOURS        SES
     RANGE FRACTION  .90                  DISPLACEMENT  138 TONS
     VISIBILITY GOOD                      DESIGN SPEED 32 KNOTS
     AVERAGE SEA STATE 3.0                FUEL FRACTION .50

 GROUP     TASK                         LOCATION  TASK    TASK      TASK
 NAME      NAME                          CODE     TIME    FUEL       POS
                                                  (HRS)  (GALS)


                                              1
 SAR SEARCH                              100101
                                         100104
      *SEARCH DSTR UNIT: FOUND           100102    2.4     199       .92
                                              3
 ASSIST                                   10101
      *GENERAL ASSISTANCE                 10102    1.0      47       .38
                                              5
 RESCUE RETURN                            90101
      *TOW                                90102    4.0     329       .46
                                              2

 TIME TO COMPLETE SORTIE (HRS)                     7.5
 FUEL CONSUMED IN SORTIE (GALS)                            575

        SORTIE PROBABILITY OF SUCCESS                                .4609
        SORTIE FREQUENCY OF OCCURRENCE                               .0668
```

FIGURE 3-14. SAMPLE OUTPUT

```
** SCENARIO DATA **

 CG PROGRAM=SAR7
 SCENARIO NO. = 1
 MAXIMUM TIME=  12.0
 RANGE FRACTION= .90
  NO. DAYS OF OPERATION= 180
 4                   11
 4                   4
 3                   5
 3                   4
 2                   8
 2                   4
 NUMBER OF IMPORTANT TASKS= 6
 411 404 305 304 208 204
 NODES= 7
 CONNECTION MATRIX=
  0.0    0.0     .7     .7    0.0     .3    0.0
  0.0    0.0    0.0    0.0    0.0    0.0    0.0
  0.0    0.0    0.0    0.0    1.0    0.0    0.0
  0.0    1.0    0.0    0.0    0.0    0.0    0.0
  0.0    1.0    0.0    0.0    0.0    0.0    0.0
  0.0    0.0    0.0    0.0    0.0    0.0    1.0
  0.0    1.0    0.0    0.0    0.0    0.0    0.0
 GROUP PLACEMENT MATRIX=
   0     0  1001  9001     0  1501     6
   0     0     0     0     0     0     0
   0     0     0     0   101     0     0
   0  1502     0     0     0     0     0
   0   901     0     0     0     0     0
   0     0     0     0     0     0   102
   0   902     0     0     0     0     0
 &GROUP DATA=
   1.00   1.00   .50   .20  0.00   .30   .10   .50   .10  1.00   .20   .10   .50
   .10  0.00  0.00  0.00  0.00  0.00  0.00
   1.00   2.00   .30   .70  0.00  0.00   .10   .30   .10   .50  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00
   9.00   1.00   .60   .10   .30 30.00 30.00 10.00 30.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00
   9.00   2.00   .70  0.00   .30 20.00  0.00  0.00 20.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  10.00   1.00  0.00  1.00  0.00  0.00  0.00  0.00  0.00   .10  4.00  3.00   .75
  8.00  0.00  0.00  0.00  0.00  0.00  0.00
  15.00   1.00  0.00  1.00  0.00  0.00 30.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00
  15.00   2.00  0.00  1.00  0.00  0.00 30.00  0.00  0.00  0.00  0.00  0.00  0.00
  0.00  0.00  0.00  0.00  0.00  0.00  0.00
 &END
 NUMBER OF PRINTOUTS=  1
 OUTPUT FORMAT=1
```

FIGURE 3-15. SCENARIO INPUTS



```
          ************* SORTIE SUMMARY *************

                      SAR7 SCENARIO  1

      OPERATIONAL REQUIREMENTS:               SELECTED CRAFT

      MAXIMUM DURATION    12.0 HOURS          SES
      RANGE FRACTION  .90                     DISPLACEMENT  138 TONS
      AVERAGE SEA STATE 3.0                   FUEL FRACTION .50


              FRACTION OF SCENARIO COMPLETED  1.0000

    SORTIE  SORTIE  SORTIE  FREQUENCY        SORTIE          SORTIE
     NO.     TIME    FUEL      OF         PROBABILITY      SUCCESSFUL
            (HRS)   (GALS)  OCCURRENCE    OF  SUCCESS


      1       7.5     575     .0668           .4609           .0308
      2       6.4     491     .0111           .8481           .0094
      3       5.9     576     .0334           .8050           .0269
      4       7.2     561     .1671           .4609           .0770
      5       6.1     477     .0279           .8481           .0236
      6       5.6     562     .0836           .8050           .0673
      7       7.2     561     .1003           .4609           .0462
      8       6.1     477     .0167           .8481           .0142
      9       5.6     562     .0501           .8050           .0404
     10      10.4    1032     .1429           .5125           .0732
     11       5.6     622     .1470           .2563           .0377
     12       4.6     623     .0630           .4715           .0297
     13       5.6     622     .0630           .2563           .0161
     14       4.6     623     .0270           .4715           .0127
```

FIGURE 3-16. SAMPLE OUTPUT

d. Scenario Overall Results. The overall results of the SAR 7 scenario are illustrated in figures 3-17 and 3-18. The probability of success for each mission can be the results of several scenario calculations and should be tabulated separately. The combined value for several missions to give an overall craft assessment is left to the evaluator. This value will be based on the relative weights assigned for each mission.

3.3 CONVERSION

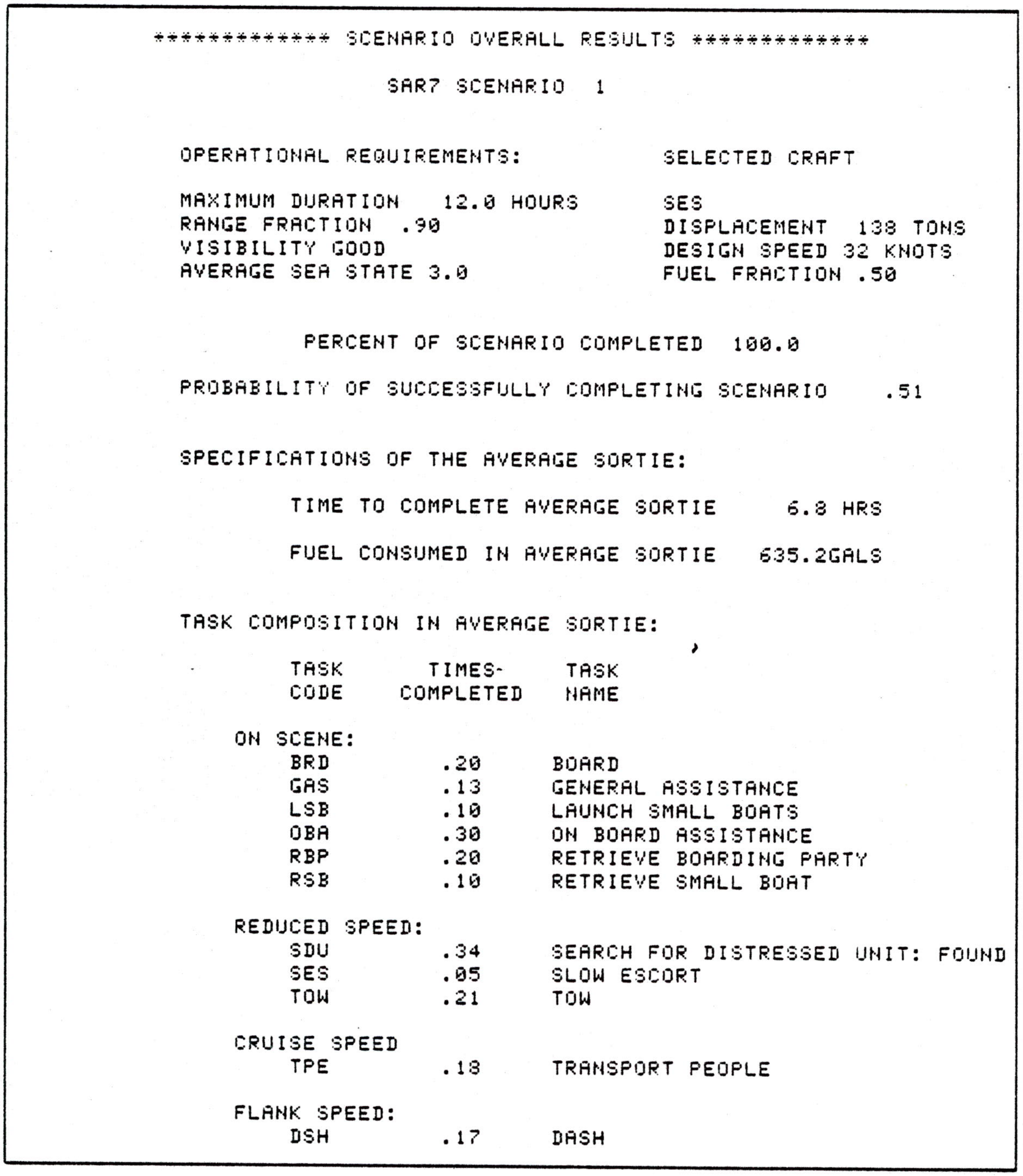
In order to provide greater accessibility to decisionmakers at Coast Guard headquarters, the CREE model was converted to HP Extended Basic so that it can be used on an interactive desktop computer (HP 9845B) with CRT display. This capability will allow a high degree of flexibility in constructing scenarios, evaluating various craft, and observing the sensitivity of mission probability of success to various operational requirements and craft characteristics.

In addition, the HP 9845B has a highly flexible edit capability to rapidly modify the basic program, subroutines, and craft characteristics algorithms.

It is anticipated that this capability can be developed into an effective tool for evaluation and establishing requirements for new classes of Coast Guard cutters.

3.4 HP 9845B CREE MODEL UTILIZATION

A user's guide has been prepared and is included as Volume II for ready reference to assist the user of the CREE Model on the HP 9845B. The information contained in the user's guide supplements the original CREE model guidance contained in "A Guide for Users and Analysts," Report No. CG-D-98-78. Although the program is self-explanatory and guides the user through its execution, the procedure is outlined below for ready reference:



```
************* SCENARIO OVERALL RESULTS *************

                SAR7 SCENARIO  1

  OPERATIONAL REQUIREMENTS:             SELECTED CRAFT

  MAXIMUM DURATION   12.0 HOURS         SES
  RANGE FRACTION  .90                   DISPLACEMENT  138 TONS
  VISIBILITY GOOD                       DESIGN SPEED 32 KNOTS
  AVERAGE SEA STATE 3.0                 FUEL FRACTION .50


           PERCENT OF SCENARIO COMPLETED  100.0

  PROBABILITY OF SUCCESSFULLY COMPLETING SCENARIO    .51


  SPECIFICATIONS OF THE AVERAGE SORTIE:

          TIME TO COMPLETE AVERAGE SORTIE     6.8 HRS

          FUEL CONSUMED IN AVERAGE SORTIE   635.2GALS


  TASK COMPOSITION IN AVERAGE SORTIE:

          TASK      TIMES-     TASK
          CODE    COMPLETED    NAME

      ON SCENE:
          BRD          .20      BOARD
          GAS          .13      GENERAL ASSISTANCE
          LSB          .10      LAUNCH SMALL BOATS
          OBA          .30      ON BOARD ASSISTANCE
          RBP          .20      RETRIEVE BOARDING PARTY
          RSB          .10      RETRIEVE SMALL BOAT

      REDUCED SPEED:
          SDU          .34      SEARCH FOR DISTRESSED UNIT: FOUND
          SES          .05      SLOW ESCORT
          TOW          .21      TOW

      CRUISE SPEED
          TPE          .18      TRANSPORT PEOPLE

      FLANK SPEED:
          DSH          .17      DASH
```

FIGURE 3-17. SAMPLE OUTPUT

```
         ************* SCENARIO EVALUATION *************
                       SAR7 SCENARIO  1


OPERATIONAL REQUIREMENTS:             SELECTED CRAFT

MAXIMUM DURATION   12.0 HOURS         SES
RANGE FRACTION  .90                   DISPLACEMENT  138 TONS
VISIBILITY GOOD                       DESIGN SPEED 32 KNOTS


   IMPORTANT TASKS COMPLETED IN  180 DAYS OF OPERATION


        TASK       TIMES      TASK
        CODE     COMPLETED    NAME

    ON SCENE:
        GAS           24     GENERAL ASSISTANCE
        OBA           54     ON BOARD ASSISTANCE

    REDUCED SPEED:
        SPT            0     SLOW PATROL
        TOW           37     TOW

    CRUISE SPEED:
        PAT            0     PATROL
        TPE           32     TRANSPORT PEOPLE

    FLANK SPEED:
        NO IMPORTANT TASKS SPECIFIED
```

FIGURE 3-18. SAMPLE OUTPUT

1. Place the data tape cartridge in T14 tape drive to the left of the HP 9845B and the program tape cartridge in T15 tape drive.

2. Start loading the program by typing GET "MAIN" and press the EXECUTE button.

3. Start the program by pressing the RUN button.

4. Follow instructions displayed on CRT to select options and continue inputting information. The last input will be selection of the desired sea state distribution.

5. The program will now run linking with information on the data tape. Approximately 15 minutes are required for this operation before the computer is ready for output. The run light on the bottom right-hand corner of the CRT will be lit during this operation.

6. The first output will be "craft characteristics." A hard-copy output may be selected. To continue outputs, press the CONT button as instructed on the screen.

7. At the end of the task probability of success outputs, a scenario must be selected. Type the name of the scenario file desired such as SCEN1, which presently describes the SAR 7 scenario discussed in section 3.3 above. To create another scenario, follow the detailed instructions in the user's guide.

8. The computer will run for approximately five minutes after selecting a scenario. The outputs will then be sortie and scenario evaluations.

9. The program may be rerun at the completion of the scenario outputs to evaluate the same craft in various scenarios or different craft for the same scenario.

SECTION 4
CRAFT CHARACTERISTICS

4.1 INTRODUCTION

In order to provide current technical information for the evaluation of AMVs, the craft characteristics relationships in the CREE model were reviewed and updated. This process included:

1. Identification of state of the art design practices and criteria such as those found in the Hydrofoil Analysis and Design Evaluation (HANDE) computer model,

2. Analysis of comparative data for various AMVs such as that found in the Advanced Naval Vehicles Concepts Evaluation (ANVCE) Study,

3. Expansion of data bases to include AMVs produced on the drawing board,

4. Statistical curve fitting to update design relationships such as that between displacement and length for each vehicle type, and

5. Consideration of standard presentation of data reflecting current naval architectural practices.

It is recognized that the current program described in the following sections is a highly simplified conceptual design tool. However, it is useful for first-order approximations when comparing the performance of different vehicles in various missions. Future refinements can be done by using outputs from more sophisticated design tools, such as HANDE, as inputs to the CREE model.

4.2 APPROACH

The general approach to updating the craft characteristics models in the CREE program was a simple one. A great deal of new information available about AMVs was researched, tabulated, and plotted. Least-square curves were fitted to this empirical data set and these curves, along with their limits of applicability, form the updated craft characteristics models.

4.2.1 Existing CREE Model Module

The module in the CREE model that estimates the characteristics of proposed craft (both advanced craft and conventional craft) is described diagrammatically in figure 4-1. The figure shows the flow of data in the craft characteristics module from the user-supplied inputs, through the detailed models describing craft particulars and performance, to the final outputs of the module. An effort has been made to retain the order of inputs, processing, and outputs from the program in the diagram, so that the data flow through the program can be traced using the figure.

The craft characteristics fall naturally into two categories. The first category describes the overall characteristics of the craft such as length, displacement, and installed power, and can be called the craft particulars group. The second category can be called the craft performance group and contains descriptions of the speed dependence of selected craft performance factors such as fuel consumption, range, and craft motions. The efforts in this update were concentrated on the craft particulars group. It was the most logical and tractable place to begin to include the large amounts of new information available on the advanced vehicles since the original models were formulated.

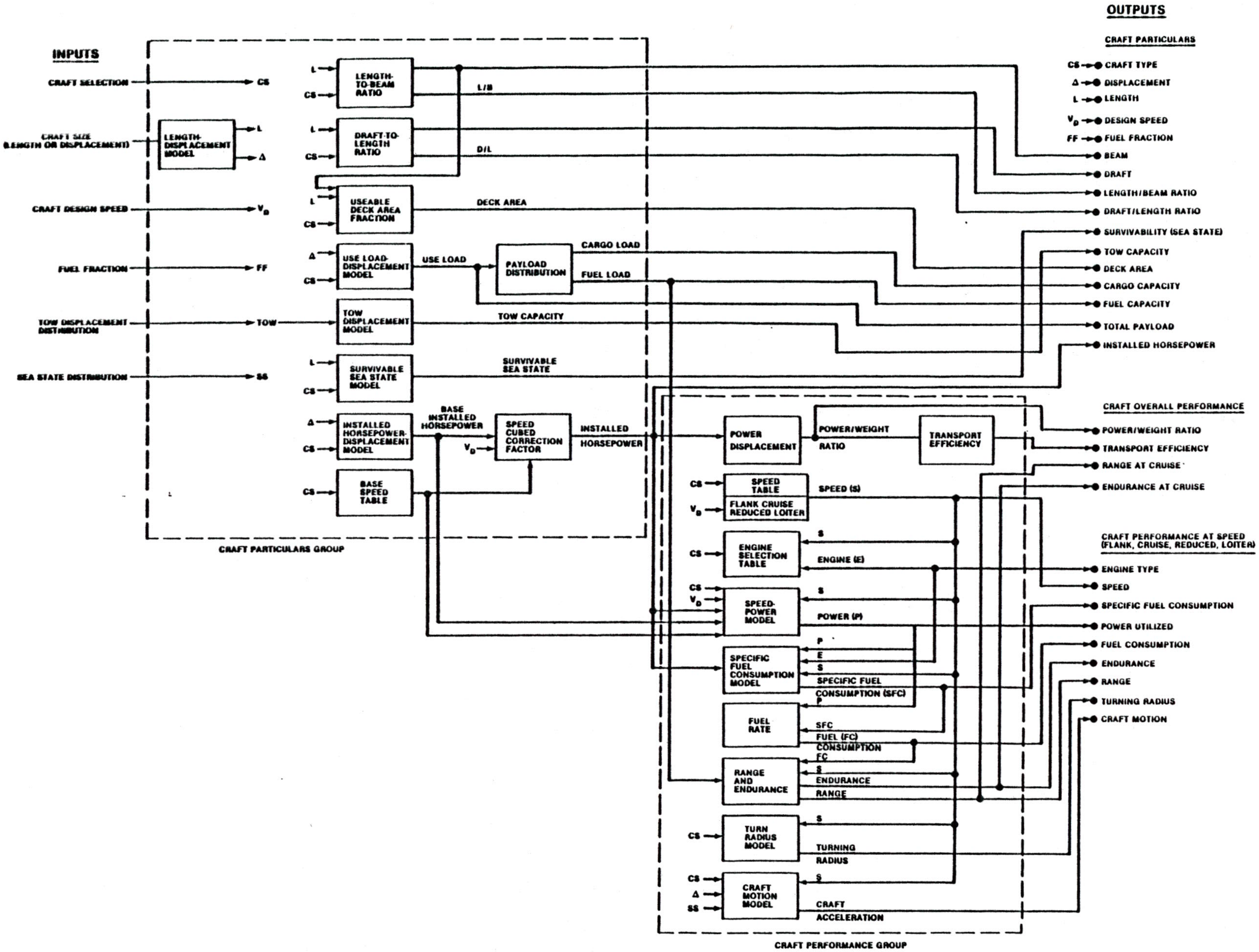


FIGURE 4-1. CRAFT CHARACTERISTICS MODULE

4.2.2 Current Design Data Base

The original design data base was limited by the small number of available craft and designs in many of the classes chosen for the study. The current data base of actual craft and point designs has grown considerably from that which was available several years ago, and many of these new designs have been used to extend the range of applicability of the models in the craft characteristics module. For example, the Soviet Union has placed considerable emphasis on hydrofoil development, and as such many new and old Soviet designs have been included in the data base, predominantly in the surface piercing foil category. As another example, the original SWATH models included data from one craft and three point designs, where the new models include data from five craft and seven point designs. Although dramatic improvements in the design data base have been made, it should be noted here that insufficient data is currently available to isolate the effects of many of the unique design features which might otherwise segregate different types of designs within a class of AMVs. As such, the models developed from this data base are somewhat oversimplified, but do represent the general trends applicable to the given AMV technology.

4.2.3 Recommended Data Formats

Originally, the small size of the available data base only justified linear curve fits across the very limited range of dependent variables within the data set. With the expanded data set currently available, however, this approach becomes difficult to implement. As such, a different data format has been implemented for the update. Using displacement as the fundamental independent variable, it quickly became apparent that in order to compare data from the wide variety of sizes which were available, a logarithmic presentation would be necessary. Since the independent variables also varied widely, a logarithmic presentation was also used for them. This log-log format provides two major benefits. First is that data from a wide variety of craft sizes can be compared on a single graph. This facilitates development of a predictive model. The second advantage is that a straight line fit through the data represents a power law relationships between the two variables. Since many relationships among naval architectural variables follow power law relationships, this was considered advantageous.

4.3 UPDATED CHARACTERISTICS

The following sections describe those models in the craft characteristics module which have been updated to reflect some of the new information available in the advanced marine vehicles data base. The data and models are described, and a sample plot presented. Graphs of the data for each craft appear in appendix A. In those cases for which insufficient new information was available, the existing models were retained.

4.3.1 Length Versus Displacement

The length-displacement relationship is a fundamental description of the size of a class of craft. For example, figure 4-2 shows the length-displacement data for surface piercing hydrofoils and the least-squares curve fit established for it. It should be anticipated that the length of the craft should increase approximately as the cube root of the displacement, and this behavior is shown, approximately, in the data. Figure 4-3 lists the new length-displacement models developed from the data presented in appendix A, figures A-1a through A-1j.

4.3.2 Installed Horsepower Versus Displacement

Describing the variation of installed horsepower with displacement for a given class of craft is more complex than length because installed horsepower is a strong function of design speed. As such, the data has been reduced using speed cubed scaling (Reynolds scaling) to a single base speed representative of the nominal design speed for the class. The limitations of using

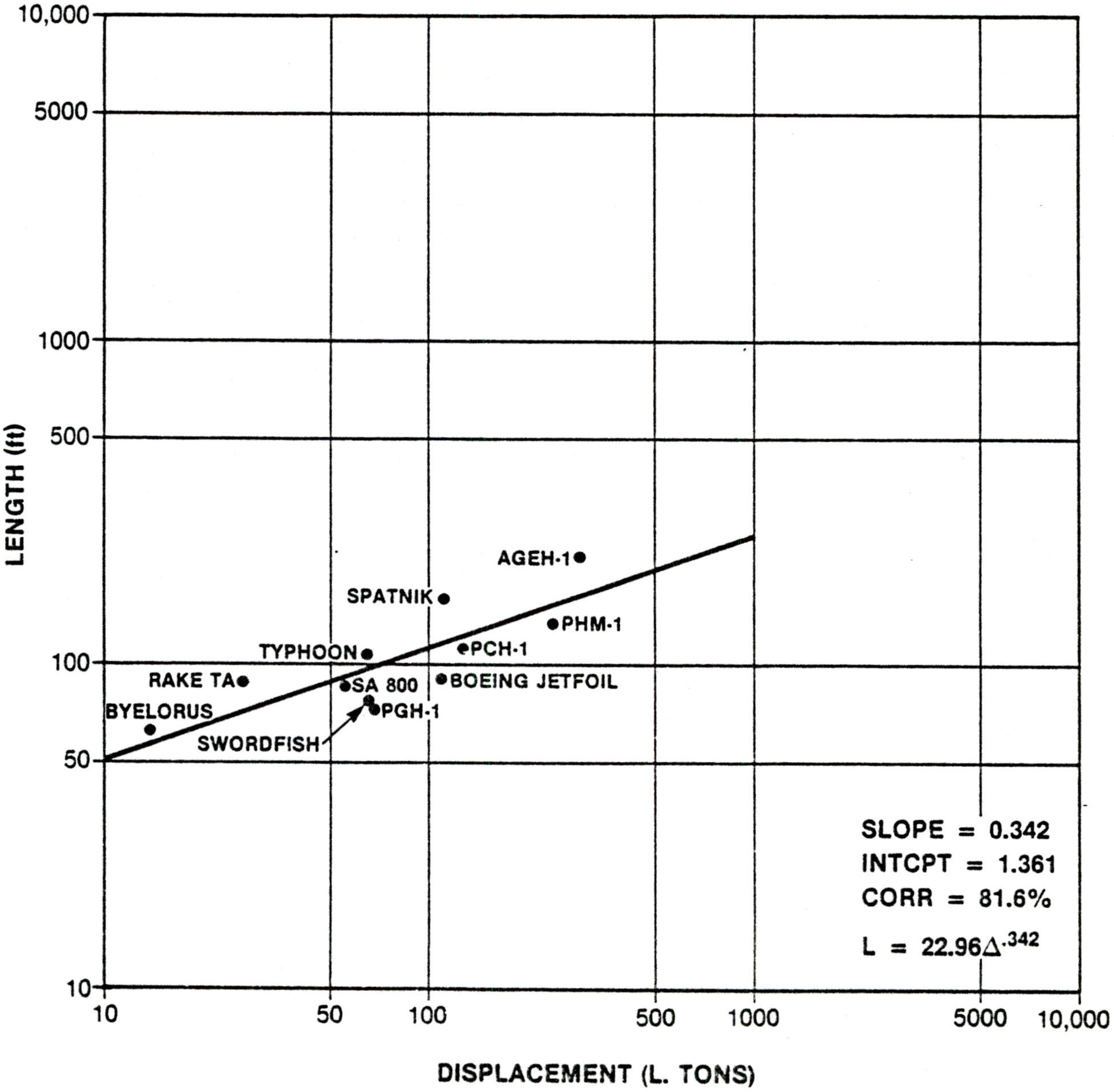


FIGURE 4-2. LENGTH VERSUS DISPLACEMENT

CRAFT DESIG-NATION	CRAFT	MODEL	DISPLACEMENT LIMITS (LT)	LENGTH LIMITS (FT)
10	Hydrofoil (submerged)	$L = 23.0*\Delta^{0.342}$	10-1000	50-250
11	Hydrofoil (surface piercing)	$L = 25.1*\Delta^{0.324}$	10-1000	50-250
20	ACV (low cushion Density)	$L = 20.8*\Delta^{0.358}$	10-1000	50-250
21	ACV (high cushion density)	$L = 12.1*\Delta^{0.447}$	10-1000	30-350
30	SES	$L = 19.4*\Delta^{0.352}$	10-10,000	40-500
40	Planing Craft	$L = 16.9*\Delta^{0.396}$	10-1000	40-250
50	CATAMARAN	[1]$L = 0.657*\Delta + 33$	10-140	40-125
60	SWATH	$L = 14.6*\Delta^{0.357}$	10-10,000	30-400
70	HYBRID	[1]$L = 0.657*\Delta + 33$	10-140	40-125
80	CONVENTIONAL	[1]$L = 110*\log \Delta - 120$ $356*\log \Delta - 859$	30-1000 1000-3500	40-210 210-400

[1] Old Model Retained

FIGURE 4-3. UPDATED LENGTH-DISPLACEMENT MODELS this very crude scaling law in estimating the powering requirements of advanced marine vehicles are recognized, but the implementation and validation of more sophisticated scaling rules, individually tailored to each craft, was beyond the scope of this effort. This problem should be the major focus of any further effort to update the CREE craft characteristics module.

Figure 4-4 shows the data describing the relationship between installed horsepower at base speed (in this case, 50 knots) and displacement, and the linear least-squares (log-log) curve fit to that data. Figure 4-5 lists the installed power-displacement models developed from curve fits to the data for each class of craft.

4.3.3 Useful Load Versus Displacement

Since the useful load has significant affect upon the range and other mission capabilities of the craft, this relation was also selected for update. Figure 4-4 shows the data and describes the results of the log-log-linear curve fit performed for the submerged foil hydrofoil data. Figure 4-7 lists the empirically derived models for the other proposed craft.

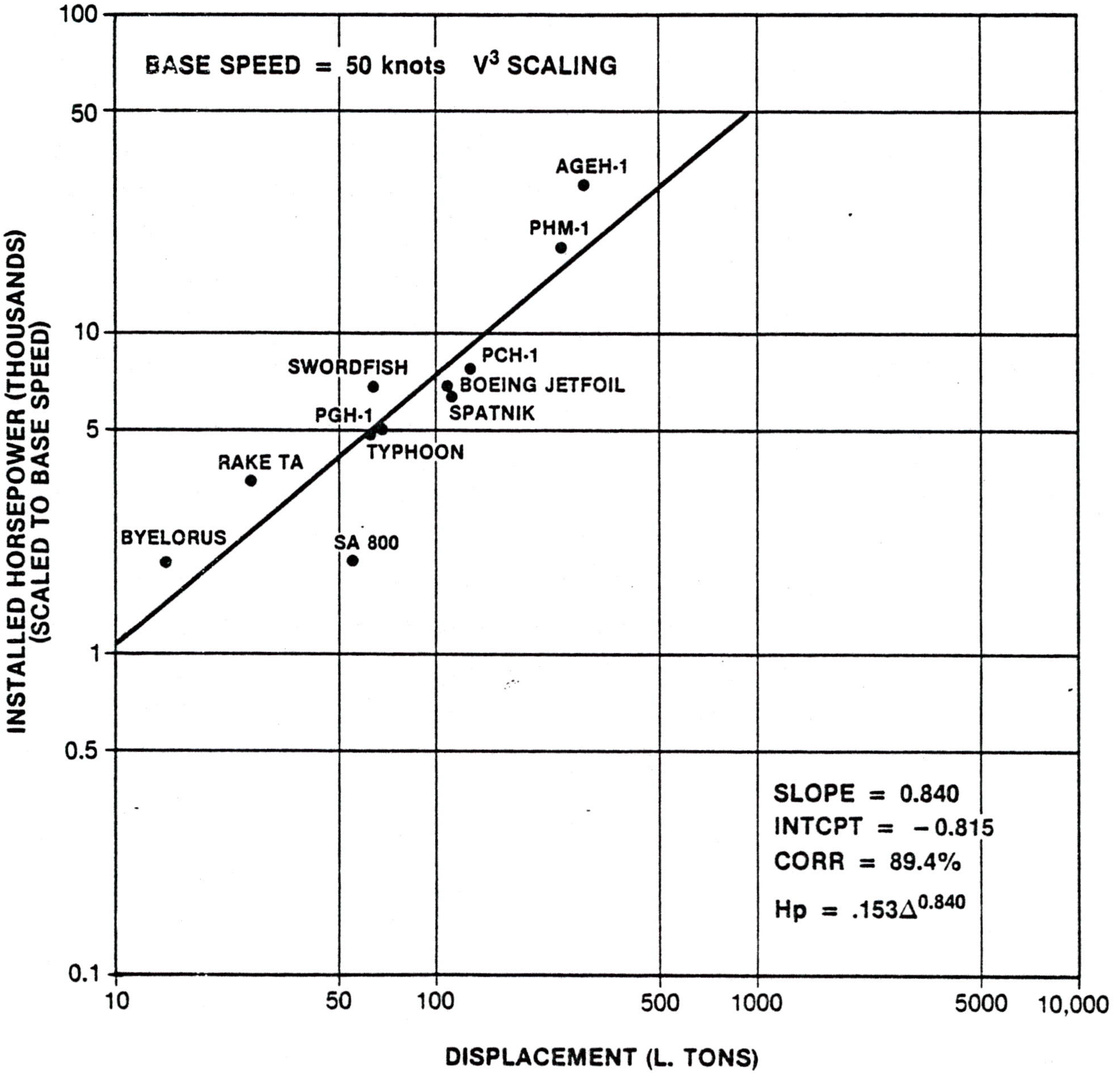


FIGURE 4-4. INSTALLED HORSEPOWER VERSUS DISPLACEMENT

CRAFT DESIGNATION	CRAFT	MODEL	BASE SPEED (KTS)
10	Hydrofoil (submerged)	$H_p = 0.153*\Delta^{0.840}$	50
11	Hydrofoil (surface piercing)	$H_p = 0.086*\Delta^{0.869}$	40
20	ACV (low cishion density)	$H_p = 0.139*\Delta^{0.710}$	50
21	ACV (high cushion density)	$H_p = 0.094*\Delta^{0.869}$	50
30	SES	$H_p = 1549*\Delta^{0.528}$	60
40	Planing Craft	$H_p = 548*\Delta^{0.682}$	45
50	CATAMARAN	[1] $H_p = 20*\Delta + 2120$	30
60	SWATH	$H_p = 115*\Delta^{0.582}$	20
70	HYBRID VESSEL	[1] $H_p = 35*\Delta - 107$	40
80	CONVENTIONAL	[1] $H_p = 184*\Delta^{0.659}$	25

[1] Old model retained.

FIGURE 4-5. UPDATED INSTALLED POWER - DISPLACEMENT MODELS

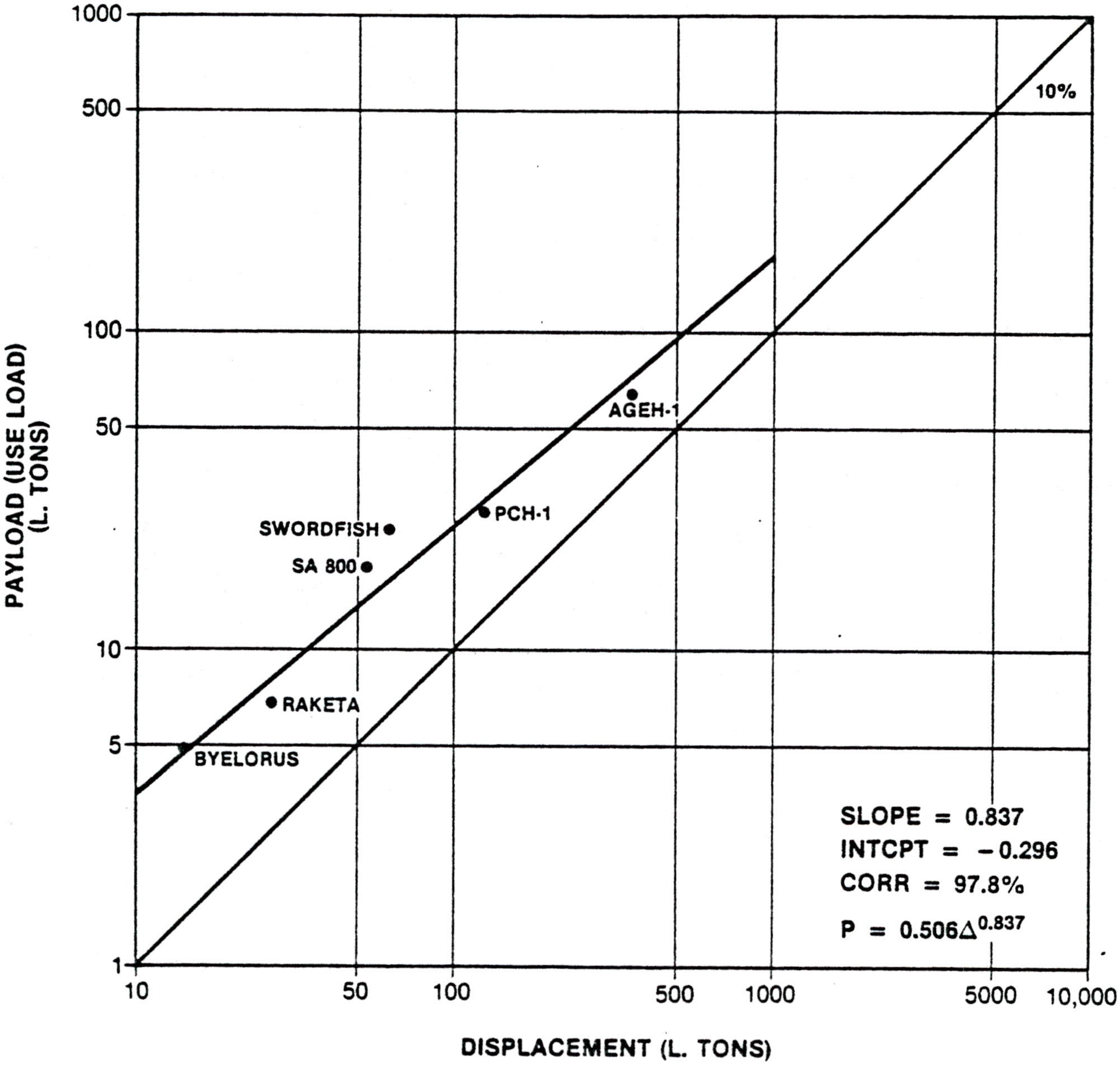


FIGURE 4-6. USEFUL PAYLOAD VERSUS DISPLACEMENT

CRAFT DESIGNATION	CRAFT	MODEL
10	Hydrofoil (submerged)	$P = 0.506*\Delta^{0.837}$
11	Hydrofoil (surface piercing)	$P = 0.169*\Delta^{1.08}$
20	ACV (low cushion density)	$P = 0.316*\Delta^{1.04}$
21	ACV (high cushion density)	$P = 1.07*\Delta^{0.843}$
30	SES	$P = 0.179*\Delta^{1.074}$
40	Planing Craft	[1]$P = 0.525*\Delta - 7.5$
50	CATAMARAN	[1]$P = 0.289*\Delta + 2.0$
60	SWATH	[1]$P = 0.296*\Delta - 7.0$
70	HYBRID VESSEL	[1]$P = 0.244*\Delta + 2.0$
80	CONVENTIONAL	[1]$P = 0.333*\Delta - 0.2$

[1] Old model retained.

FIGURE 4-7. UPDATED USEFUL LOAD - DISPLACEMENT MODELS

SECTION 5
CUTTER EVALUATION

5.1 INTRODUCTION

To illustrate the approach proposed in the previous sections, a current need to replace existing cutters will be analyzed. The required steps to implement this procedure will be outlined to provide the basis for further comprehensive calculations.

5.2 BACKGROUND

5.2.1 Coast Guard Evaluation of Advanced Marine Vehicles

Several projects are presently underway under direction of the Coast Guard Headquarters R&D Division to evaluate the effectiveness of current advanced marine vehicles (AMVs) in Coast Guard missions. These projects may be categorized into three areas: effectiveness analysis, vehicle demonstrations, and point designs.

1. Effectiveness Analysis. Four mission areas including SAR, ELT, MEP, and MR are presently being analyzed to develop measures of effectiveness that can be applied to the evaluation of specific vehicles in meeting the requirements for each of the above missions. The mission operational requirements are also being analyzed to assess the constraints and demands that they place on craft. In addition, mathematical models are being developed to measure the relative impact of specific craft characteristics on craft effectiveness to perform tasks in support of the specified missions. Finally, a previously developed computerized Cutter Resources Effectiveness Evaluation (CREE) Model is being adapted to a desktop computer to provide interactive capability in assisting the decision maker in evaluating various vehicles in specified scenarios. The craft characteristic data for AMVs used in the CREE model is also being updated to represent current technology.

2. Vehicle Demonstrations. Several operational demonstrations of AMVs including hydrofoils and air-cushioned vehicles have been conducted in the past. The most recent evaluation includes the operational demonstration of the 110-foot Bell Halter SES and tests on the RHS200 Rodriguez surface piercing hydrofoil. All these efforts provide a qualitative assessment of craft performance and quantitative data that can be used in the effectiveness analysis described above.

3. Point Designs. In order to maintain a current technology base, several designs of AMVs similar to existing CG craft such as a WPB are being prepared by DTNSRDC. The designs embody what is possible within the current state of the art for each AMV type.

5.2.2 Application to Cutter Replacement Program

Efforts described above can be integrated to support the decision of which craft type can be the most effective replacement for the existing Coast Guard cutters. The numerous factors which must be considered in reaching such a decision are embodied in the proposed evaluation approach described in the following sections. They may be categorized as operational, technical, and economic factors.

1. Operational Factors. Operational factors include requirements which are imposed by the need to perform specified missions; the operational requirements are descriptive of the state of nature and the capabilities of personnel and mission equipment. In the evaluation of conventional and AMV candidate craft, operational factors are "given" and equally applicable to all vehicles.

2. Technical Factors. Technical factors include platform performance capabilities, supportability by the Coast Guard logistics support system, and reliability. The technical factors affect overall availability which will have a significant effect on total number of craft required. These factors

are the core of the evaluation. Some are presently being assessed by vehicle demonstrations and all are embodied in point designs.

3. Economic Factors. Economic factors include unit acquisition cost and life cycle cost. Although the two are directly related, their individual importance in acquisition programs is totally independent. Product affordability must be considered in light of total number of craft required and total budget available for acquisition. Unless improved performance results in reduced numbers, increased unit costs are often difficult to justify. Thus, both acquisition and support costs are necessary evaluation factors.

5.3 APPROACH

5.3.1 Overall Approach

The overall approach which integrates the various efforts and considers the factors described above is depicted in figure 5-1. The inputs, outputs, and evaluation process are outlined in this section and described in detail for an application of this approach to a specific cutter replacement in subsequent sections. This is a general approach for the acquisition of any type of cutter. The example with the WPB is included to help make the process clear.

1. Inputs. The inputs to the evaluation process include:

   a. Mission and mission elements that define general functions which the craft must perform. The mission elements may be futher defined as required operational capabilities. In the evaluation process, their impact on equipment and personnel will be assessed.

   b. Test and evaluation data that result from vehicle demonstrations verifies craft performance parameters and ability to perform required tasks. These results are used to calculate task MOEs and establish a craft performance envelope.

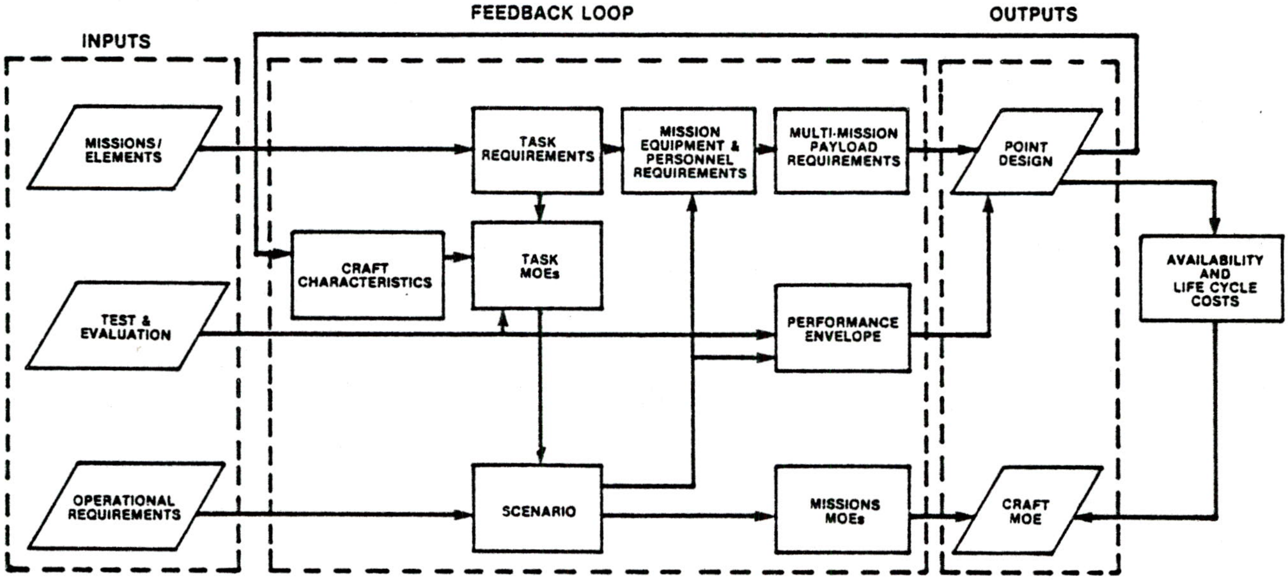


FIGURE 5-1. OVERALL APPROACH

c. Operational requirements describe the state of nature which defines the caseload and provides the constraints for the fulfillment of mission requirement. This information is necessary for the development of realistic scenarios.

2. Evaluation Process. The evaluation process includes several interrelated functions:

a. Task requirements which are a further refinement of mission and mission element definitions. Standard task descriptions were defined during CREE model development. Examples of standard tasks are shown in figure 5-1.

b. Mission equipment and personnel requirements that are derived as a result of analyzing the Task Requirements.

c. Multimission payload requirements which combine the total needs from all missions and includes the personnel and shipboard support.

d. Craft characteristics which are derived from the point designs or existing craft to be evaluated.

e. Task measures of effectiveness (MOEs) evaluated based on craft characteristics. Task MOEs are evaluated in the CREE model discussed in section 3.

f. Scenario calculations that evaluate the craft's ability to perform tasks in a typical operational environment. Scenarios may be constructed to conform to MOE definitions developed in section 2 or as described in the CREE model in section 3.

g. Mission measures of effectiveness which provide an evaluation of each candidate craft's ability to perform a specified mission in various scenarios.

h. Performance envelope resulting from scenario calculations which defines limiting relationships between endurance, speed, and sea state and provides a major input to sizing the required craft.

3. Outputs. The resulting outputs of the evaluation process include:

a. Point designs which embody all the payload requirements for a craft to accomplish the specified missions in the scenarios selected.

b. Availability and life cycle cost which are derived from point designs and provide an important input to the evaluation of the overall craft measure of effectiveness. These factors require further development, but are beyond the scope of this report.

c. Craft measure of effectiveness which provides a comparative quantitative measure for evaluating the relative worth of candidate vehicles including both AMVs and conventional platforms. Craft MOEs combine the MOEs for all specified missions with craft availability and life-cycle cost to obtain an overall measure.

5.3.2 Interface with Point Designs

1. Need for Point Designs. Existing AMV craft are of varying sizes and capabilities which may not fully support the specified multimission craft requirements. In order to develop an equitable comparison of various AMV candidates, vehicles that are responsive to the same basic requirements must be designed. These include:

a. Mission Equipment. Mission equipment will be the same for all crafts. Only effects of the platform on sensor interaction will be considered. For example, the same search radar will be specified and only the effect of seakeeping on detection ranges and other equipment operational characteristics will be considered.

b. Personnel. Personnel manning for mission equipment is the same. Only unique platform manning requirements will be considered. Personnel capability and training will be the same. Only effects of craft motion on crew performance and special training requirements will be considered.

c. Required Performance Envelope. Performance requirements such as the mission duration and speed histogram for each sea state will be prescribed for all candidates based on mission requirements and the result of scenario calculations.

d. Design Standards. Design standards for such factors as survivability, crew endurance, structural loads, and powering calculations will be specified to provide consistent ground rules for candidate designs.

2. Interfaces Defined. The process which interfaces with point designs is depicted in figure 5-2. This figure expands on the overall approach of figure 5-1 and describes some of the information required to provide adequate interfaces.

a. Equipment Characteristics. A matrix of mission equipment and weight, space, power, and cooling requirements will be specified.

b. Personnel Support. A matrix of space and weight required for personnel and their support will also be specified.

c. Speed Profile. A histogram of number of hours at each speed and given sea state will be specified to form the basis for powering calculations and determination of fuel requirements.

d. Performance Envelope. The output from the point designs which directly affects the scenario calculations is a craft performance envelope which defines the speed capability of the craft in

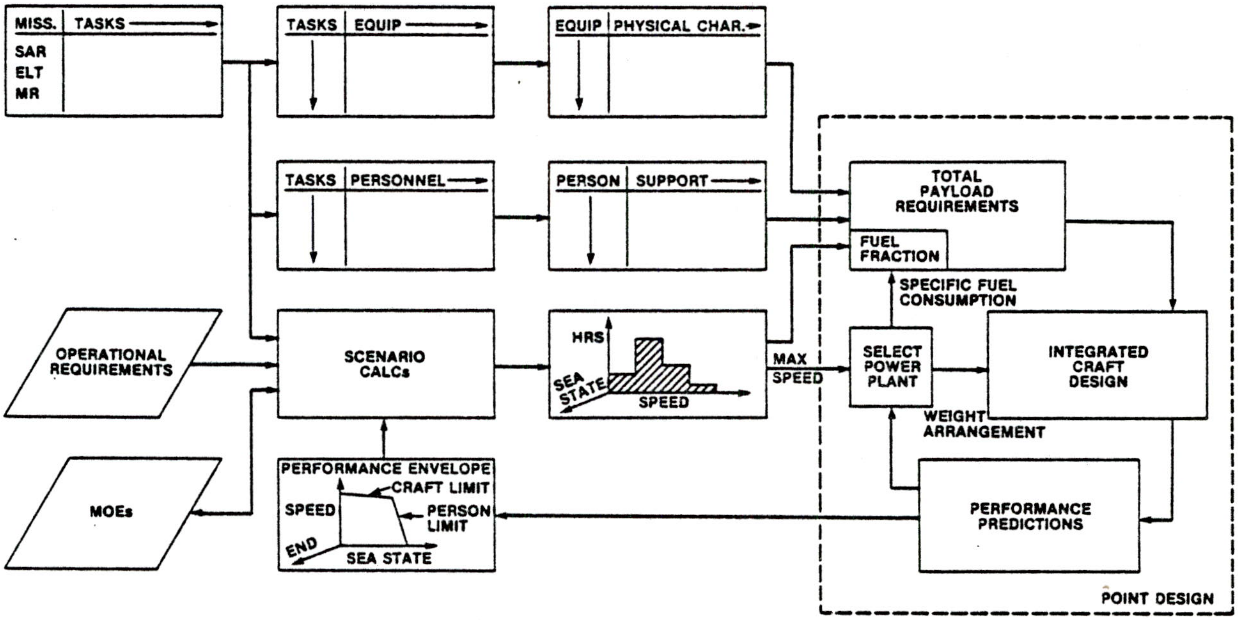


FIGURE 5-2. MOE-POINT DESIGN INTERFACE

a specified sea state as well as its endurance for a given speed and sea state. This envelope includes personnel as well as craft endurance limits for a given craft response in a sea state.

5.3.3. Interface with Test and Evaluation Program

1. General Test Plan. A general test plan for testing of marine vehicles has been prepared by LCDR M. J. Goodwin of the CG R&D Center. This plan describes the parameters to be measured and procedures. It provides general guidance that must be applied to each candidate vehicle for the collection of experimental trial data.

2. Verification of MOEs. As a result of trials conducted on AMVs such as the Bell Halter SES, specific data has been collected. This data will assist in verifying the fact that MOEs, as defined, can be measured. In addition, MOE definitions also provide requirements for collection of specified parameters during test and evaluation of craft. For example, speed in a seaway has been demonstrated to be an important input to SAR and ELT MOE evaluation. Present procedures require measurement of maximum vertical acceleration at certain points on the craft as an indication of craft endurance. However, personnel endurance criteria also require measurement of frequency as well as acceleration amplitude. Thus, a frequency spectrum should be measured for ride quality vice a single maximum vertical acceleration.

3. Point Design Interfaces. Collection of data on existing AMV craft can assist in verifying predictive algorithms. Direct applicability to point designs may require careful extrapolation/interpolation of experimental data.

5.4 CUTTER MISSIONS

5.4.1 Mission Need Statement

The starting point for any cutter design is the missions which are specified for that particular class of cutter. As an example, the following missions and capabilities assigned to the WPB replacement in the Mission Need Statement (MNS) approved by the Commandant on 27 July 1981 are summarized below.

1. Enforcement of Laws and Treaties

   - Conduct boardings and make seizures of sailing, fishing, and other powered vessels.
   - Provide a five-person custody crew to sail a seized vessel up to 24 hours while escorting the vessel and custody crew.
   - Intercept, overtake, and maintain hot pursuit of waterborne craft used for illicit operations for at least 24 hours at a minimum speed of 30 knots.
   - Carry suitable armament for exerting force for ELT duties.

2. Search and Rescue

   - Search and render assistance including, but not limited to, rescue of personnel in the water, dewatering vessels, and towing vessels up to 500 tons displacement.
   - Have the communications and surveillance ability to act as On-Scene Commander, and communicate and operate with other Coast Guard and DOD vessels, aircraft, and shore units.

3. Supporting Missions

- o Military Preparedness (MP). Carry suitable armament for exerting force and maintain space and weight reservations for additional weapons systems for contingency military operations commensurate with the size of the craft.
- o Recreational Boating Safety (RBS). Conduct overnight regatta patrols for up to 36 hours.
- o Waterways Management (WWM). Enforce traffic separation schemes in areas not covered by boats.
- o Short-Range Aids to Navigation (SRA). Minor servicing of aids to navigation in the absence of a buoy tender.
- o Marine Environmental Protection (MEP). Test or monitor pollution, aid in cleaning spills, patrol remote harbor areas, and survey special vessels.

4. Mission Duration. Perform multimission patrols of coastal waters with a minimum endurance of five days.

5. Environment. Carry out all described activities in 10-foot-high sea conditions and be able to operate at a reduced performance level in 25-foot seas and 60-knot winds.

5.4.2 Required Operational Capabilities

Based on the above MNS, an initial set of required operational capabilities (ROCs) can be established. A more detailed analysis of military capability tradeoffs can be conducted after initial sizing of cutter payload. Figure 2-14 can be used as a notional set of ROCs to illustrate this evaluation approach.

5.4.3 Task Requirements

Figure 5-3 relates mission requirements to tasks to be performed. The tasks are basic building blocks for construction of scenarios and evaluation of specific craft capabilities. They also represent an interim step for the development of mission equipment, personnel, and support requirements. The tasks listed in figure 5-3 are based on standard task groups developed during CREE model development and program conversion to BASIC for operation on an interactive desktop computer as discussed in section 3.

5.5 MISSION PAYLOAD

The mission payload includes equipment, personnel, and necessary support to perform tasks specified in figure 5-3. It does not include fuel load and platform-related requirements. The fuel load will be calculated on endurance and speed requirements, which will be based on various scenario calculations.

5.5.1 Mission Equipment

Figure 5-4 relates tasks to mission equipment. Equipment selected is based on current equipment approved for service use in the U.S. Navy and/or equipment common to current Coast Guard cutter acquisition programs such as WMECs.

Figure 5-5 is a sample form that would provide design information on equipment specified to calculate total military payload weight, volume, and support requirements.

5.5.2 Personnel Requirements

Personnel manning requirements are driven by cutter operational and maintenance policy, mission requirements, and equipment operational and maintenance

MISSIONS	TASKS																															
	TRANSIT OPAREA				ON SCENE																						RETURN TO BASE					
					SEARCH							C^3N		NON-COMBAT										COMBAT								
	Load Stores/Equip	Get Underway	High Speed Transit	ECON Speed Transit	SAR Search	Sensor Search	Search Fleet	Patrol	Identify	Monitor	Standby	On-Scene CMDR	Precise Navigation	Assist	Inspect	Rescue	Seize	Fight Fire	Transfer Equip	Work Equip	UNREP	VERTREP	Transfer by Boat	Covert OPS	Project Force	Destroy Threat	High Speed Transit	ECON Speed Transit	Escort	Tow	Moor	Offload
Search and Rescue (SAR)																																
Enforcement Laws & Treaties (ELT)																																
Marine Environmental Protection (MEP)																																
Military Readiness (MR)																																
(from ROCs)																																
Antiair Warfare																																
Antisurface Warfare																																
Amphibious Warfare																																
Mine Warfare																																
Special Warfare																																
Mobility																																
Command, Control, and Communications																																
Intelligence, Surveillance, and Reconnaissance																																
Logistic Support																																
Fleet Support Operations																																
Noncombat Operations																																

FIGURE 5-3. MISSIONS/TASKS FOR WPB REPLACEMENT

EQUIPMENT	TASKS																															
	TRANSIT OPAREA				ON SCENE																						RETURN TO BASE					
					SEARCH							C^3N		NON-COMBAT										COMBAT								
	Load Stores/Equip	Get Underway	High Speed Transit	ECON Speed Transit	SAR Search	Sensor Search	Search Fleet	Patrol	Identify	Monitor	Standby	On-Scene CMDR	Precise Navigation	Assist	Inspect	Rescue	Seize	Fight Fire	Transfer Equip	Work Equip	UNREP	VERTREP	Transfer by Boat	Covert OPS	Project Force	Destroy Threat	High Speed Transit	ECON Speed Transit	Escort	Tow	Moor	Offload
SENSORS																																
AN/SPS-64 Radar																																
Infrared Imaging Sensor																																
Low Light Level TV																																
EW																																
High Intensity Searchlight																																
COMMAND-CONTROL																																
MINICOMDAC																																
COMMUNICATIONS																																
UHF Transceiver																																
VHF Transceiver																																
Secure Voice																																
NAVIGATION																																
SATNAV																																
LTN 211 OMEGA																																
AN/URD-10 UHF-D/F																																
WEAPONS																																
Emerlec 30mm Twin Mount																																
Penguin Missile (Space & Weight)																																
Small Arms																																
SPECIAL EQUIPMENT																																
High Speed Rescue Craft																																
Pollution Control Boom & Equip (S&W)																																
Dewatering Pumps																																
Fire Monitor																																
Towing Hawser																																

FIGURE 5-4. EQUIPMENT/TASKS FOR WPB REPLACEMENT

EQUIPMENT	TOTAL WEIGHT (lbs)	VOLUME	DESIGN INFORMATION						
			ELECTRICAL POWER				ENVIRONMENTAL CONTROL		
		MAX. DIMENSIONS W H D VOL. CU FT	TYPE	HZ	PHASE	TOTAL KW	COOLING TYPE BTU/HR	VENTILATION BTU/HR	AIR COND BTU/HR

FIGURE 5-5. EQUIPMENT DESIGN INFORMATION

requirements. Figure 5-6 proposes crew requirements based on mission equipment suite provided and tasks to be accomplished. Manning requirements are greatly affected by endurance and special functions such as the need to provide custody crews during ELT missions.

5.5.3 Support Requirements

The direct mission equipment and personnel requirements discussed previously generate support requirements not normally required by the platform including its power plant. These requirements are tabulated in figure 5-5 and include weight, volume, energy, and environmental control. The generation of support requirements is not to be confused with equipment specifications. The systems and equipment specifications are the result of an integrated ship design process conducted during the development of point designs. During this process, total vessel requirements are integrated such that electrical power generation, for example, can be specified.

5.6 SCENARIO CALCULATIONS

5.6.1 MOE Sensitivity Analysis

Each of the MOEs developed in section 2 can be related to craft characteristics. For a given scenario, or set of scenarios, the craft characteristics may be varied to attempt to optimize the MOE. If an optimum cannot be obtained, tradeoff curves can be developed. For example, the SAR MOE can be calculated as a function of the speed versus sea state curve for a hypothetical cutter. If it can be determined that the incremental gain in SAR MOE is insignificant beyond a given speed versus sea state capability, then that capability can be cited as a requirement for point design.

PERSONNEL REQUIREMENTS	TASKS																															
	TRANSIT OPAREA				ON SCENE																						RETURN TO BASE					
					SEARCH							C^3N		NON-COMBAT										COMBAT								
	Load Stores/Equip	Get Underway	High Speed Transit	ECON Speed Transit	SAR Search	Sensor Search	Search Fleet	Patrol	Identify	Monitor	Standby	On-Scene CMDR	Precise Navigation	Assist	Inspect	Rescue	Seize	Fight Fire	Transfer Equip	Work Equip	UNREP	VERTREP	Transfer by Boat	Covert OPS	Project Force	Destroy Threat	High Speed Transit	ECON Speed Transit	Escort	Tow	Moor	Offload
<u>C^3N</u>																																
Commanding Officer																																
OOD																																
Helmsman																																
Navigator																																
Communicator																																
Sensor Operator																																
<u>WEAPONS</u>																																
Gun Crew																																
<u>ENGINEERING</u>																																
Propulsion Control																																
Eng. Plant Monitor																																
Plant Maintenance																																
<u>DAMAGE CONTROL</u>																																
Fire Party																																
Flood Control																																
<u>SUPPORT SERVICES</u>																																
Line Handling																																
Replenishment																																
Cleaning																																
<u>SPECIAL FUNCTIONS</u>																																
Boat Handling																																
Boat Crew																																
Boarding Party																																
Prize Crew																																

FIGURE 5-6. PERSONNEL REQUIREMENTS/TASKS FOR WPB REPLACEMENT

5.6.2 Operational Requirements Envelope

For several missions, and consequently scenarios, a composite curve of required craft characteristics will result. The envelope describing the maximum requirements will be used to size the craft. For example, SAR may impose the highest speed requirements, whereas ELT may impose the greatest endurance requirements. However, these requirements may be traded off in sizing the craft. Since the SAR mission does not require as great a payload as ELT, the craft may achieve the higher speeds at lighter displacement. This is a less stringent requirement than imposing maximum speed at maximum displacement.

5.6.3 Specified Speed Histogram

For every scenario created either through the MOE development approach of section 2 or through the CREE model, the time required at each speed and sea state occurrence can be calculated. The resulting horsepower distribution can be used to calculate horsepower requirements for a given craft size and, consequently, fuel consumption. These calculations lead to a determination of the total fuel required for the scenario. Considering the envelope of requirements as discussed in section 5.6.2 above, the fraction of the craft's total payload that will be required for fuel can be determined.

5.7 POINT DESIGN

5.7.1 Power Plant Selection

As a result of MOE sensitivity analysis and establishment of operating envelope discussed above, the basic requirements for selecting a power plant have been specified. The following specific design points can be calculated when a specific hull form is assumed:

1. Maximum power is based on maximum speed requirements and/or appropriate design margins for craft such as hydrofoils which have a "hump" in the relationship between power and speed at takeoff. The percent of time the craft will operate at full power is important when considering combined plants such as gas turbines and diesels to minimize total plant weight.

2. Cruise power is based on speed at which craft will operate the greatest percent of time. This is the power that requires maximum plant efficiency to reduce craft's overall fuel consumption.

3. Special requirements such as power required for towing vessels of specified size; or propulsive control to maintain near-zero relative speeds to tend pollution control booms.

The selection of the power plant, as in craft selection, must consider availability and life cycle costs. Performance alone cannot be the sole criteria since an adverse impact on craft's availability, due to lack of trained personnel or critical parts, can have a more severe effect on the craft's overall value.

5.7.2 Fuel Load Calculations

Having selected a specific hull form and power plant, the specific fuel consumption, as a function of speed, can be calculated. When this curve is combined with the speed and time requirements, fuel loads can be calculated for each scenario. The maximum fuel load is used to size tankage. Fractional fuel loads may be offset by additional payload or increased speed requirements.

5.7.3 Total Payload

The total payload includes the mission payload and fuel. It may be divided into two: the fixed payload, which includes installed equipment and basic personnel requirements, and the variable payload, which includes fuel, additional personnel, and equipment requirements. The variable payload is mission- and even scenario-oriented. The minimum amount of mission equipment common to all scenarios should be installed as to provide maximum flexibility and minimum craft size.

5.7.4 Design Standards

Design standards may be stated in terms of what requirements are to be imposed on all craft designs or they may detail how such requirements are to be implemented. Habitability, survivability, and ability to launch and retrieve a small boat are examples of standards that specify the requirements, whereas detailed procedures for power calculations specify how these standards are to be implemented.

In addition, design standards/guidance vary in detail and in effect on the design. During conceptual and preliminary design only those standards that significantly affect craft size need be considered.

5.7.5 Craft Sizing

Determining the craft dimensions and displacement is an iterative process. An initial estimate may be made by first determining maximum mission payload and assuming this to be 10 percent of gross displacement. Approximate dimensions may then be established for generic hull form selected and preliminary distribution of weights by weight groups may be estimated from design algorithms.

The power plant may then be sized as discussed in section 5.7.1 above and fuel loads calculated as per section 5.7.2. Upon completion of calculation of fuel loads, the total payload may be determined and compared with initial estimates. This calculation will provide the basis for a second iteration on preliminary craft size. Before detailed arrangements are developed, sensitivity analysis on various parameters may be performed to optimize the platform performance.

The above outline is intended to be a brief overview of the design process. The actual conceptual design requires considerably more detail in arriving at stability calculations, compartment spacing, scantling estimates, and numerous hydrostatic and hydrodynamic calculations.

5.7.6 Interactive Design

To minimize the time required to complete a creditable conceptual design, interactive computer programs have been developed for conventional and some AMV types. One such computer program is the Hydrofoil Analysis and Design Evaluation (HANDE).

When such programs exist, the craft evaluation process can take on a new dimension. The output of a computerized craft design module can output data to be input directly into a computerized operational analysis module such as the CREE program. This link facilitates dialogue between operations analyst and ship designer. It provides a craft design fully responsive to operational requirements and visible correlation between operational demands and resulting craft characteristics.

5.8 CRAFT MOEs

5.8.1 Total Performance MOEs

The evaluation of multimission crafts requires the combination of several performance MOEs for each mission and scenarios within each mission. Development of the combination process was beyond the scope of this report. However, the effect of various missions on operating requirements was discussed in section 5.6. It is important to note also that optimization techniques should be focussed on the combined craft MOE rather than individual MOEs. For example, craft characteristics resulting from an optimum SAR MOE may result in "suboptimization" for total craft requirements.

5.8.2 Availability and Life Cycle Cost

Availability and life cycle costs were not developed in this report but are also of considerable importance in developing overall craft MOE.

Availability, which includes reliability, maintainability, and logistic supportability, directly affects the number of craft required and hence on fleet life cycle costs. The unit life cycle cost must be weighed both from initial investment and continued support. Higher reliability may be obtained at higher initial costs. If it can be achieved through redundancy, it may improve availability when parts are common and readily obtainable. Thus, availability and life cycle costs are closely interdependent and significant considerations.

5.8.3 Cost Effectiveness Measures

The final comparisons between craft can be made based on cost effectiveness. In the process described above, every mission, scenario, or craft MOE will have a craft life cycle cost associated with it. The comparison may be made between craft types or for incremental changes in MOEs for the same craft. These procedures provide quantitative appraisals that can aid decision makers, but in the last analysis, human judgment will be required to determine the absolute worth of performance improvements: How much can the Coast Guard invest to increase the probability of saving lives from 98.6 to 99.0 percent?

APPENDIX A

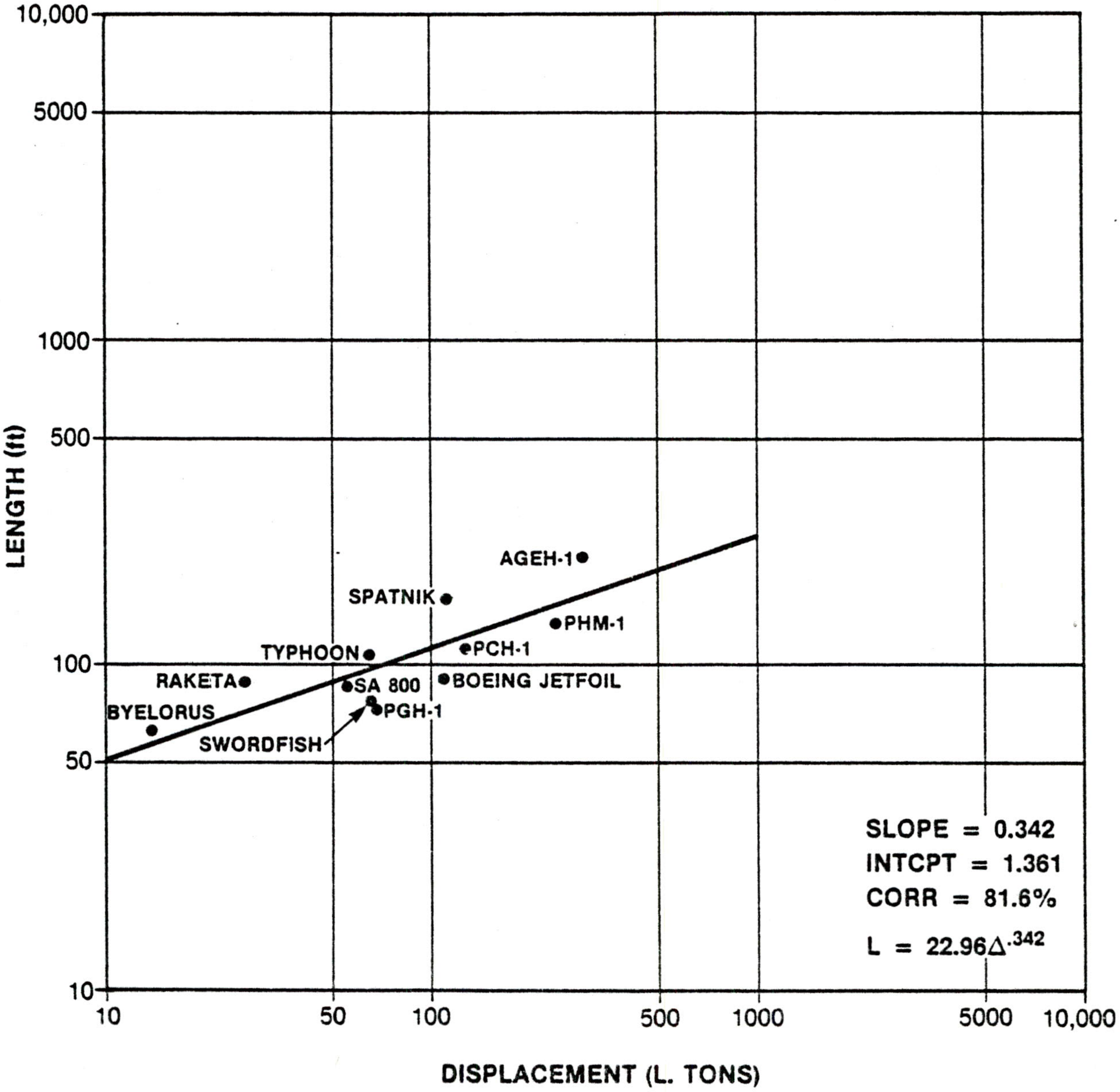


FIGURE A-1A. CRAFT LENGTH VERSUS DISPLACEMENT (HYDROFOIL, SUBMERGED)

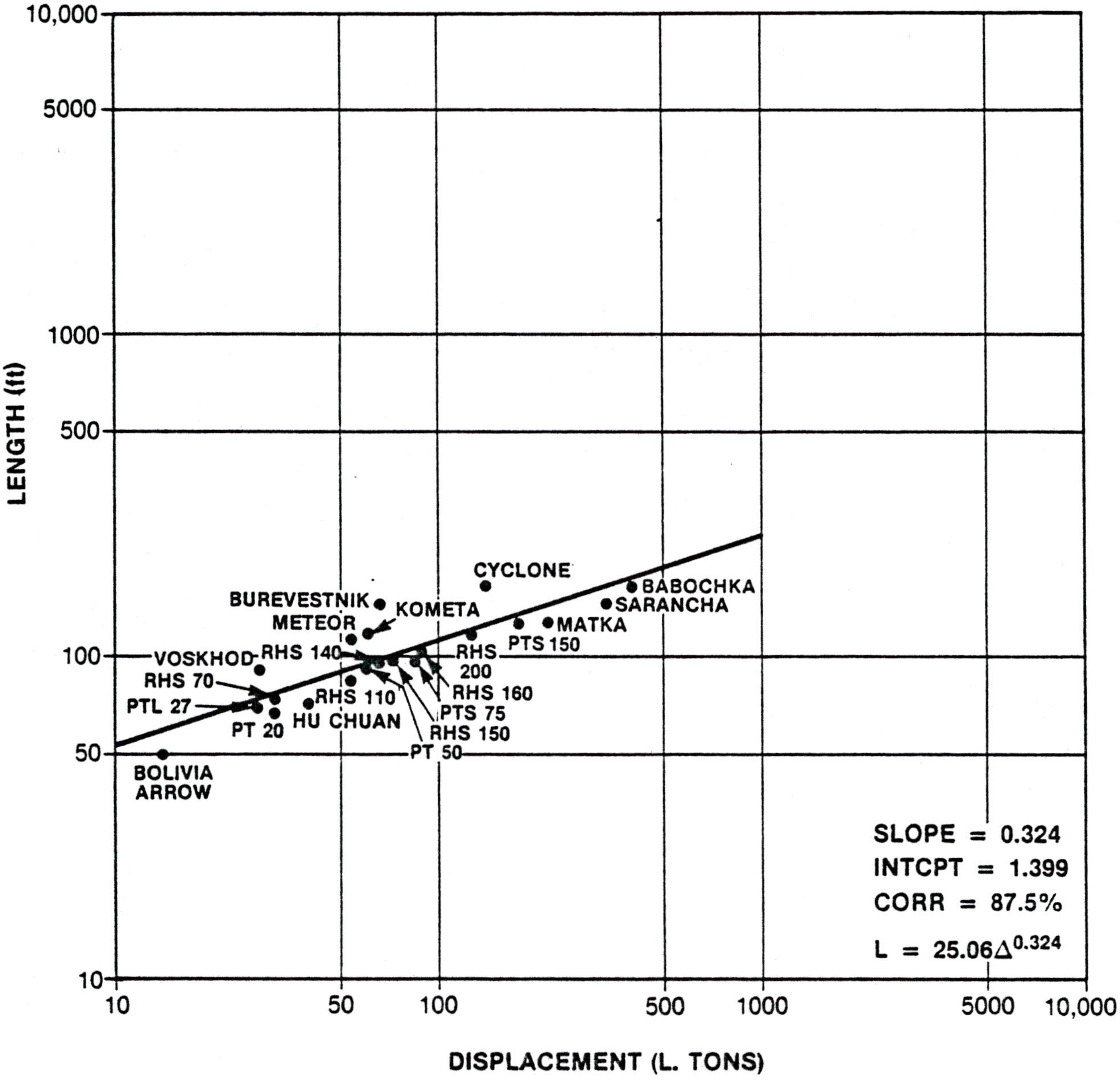


FIGURE A-1B. CRAFT LENGTH VERSUS DISPLACEMENT (HYDROFOIL, SURFACE PIERCING)

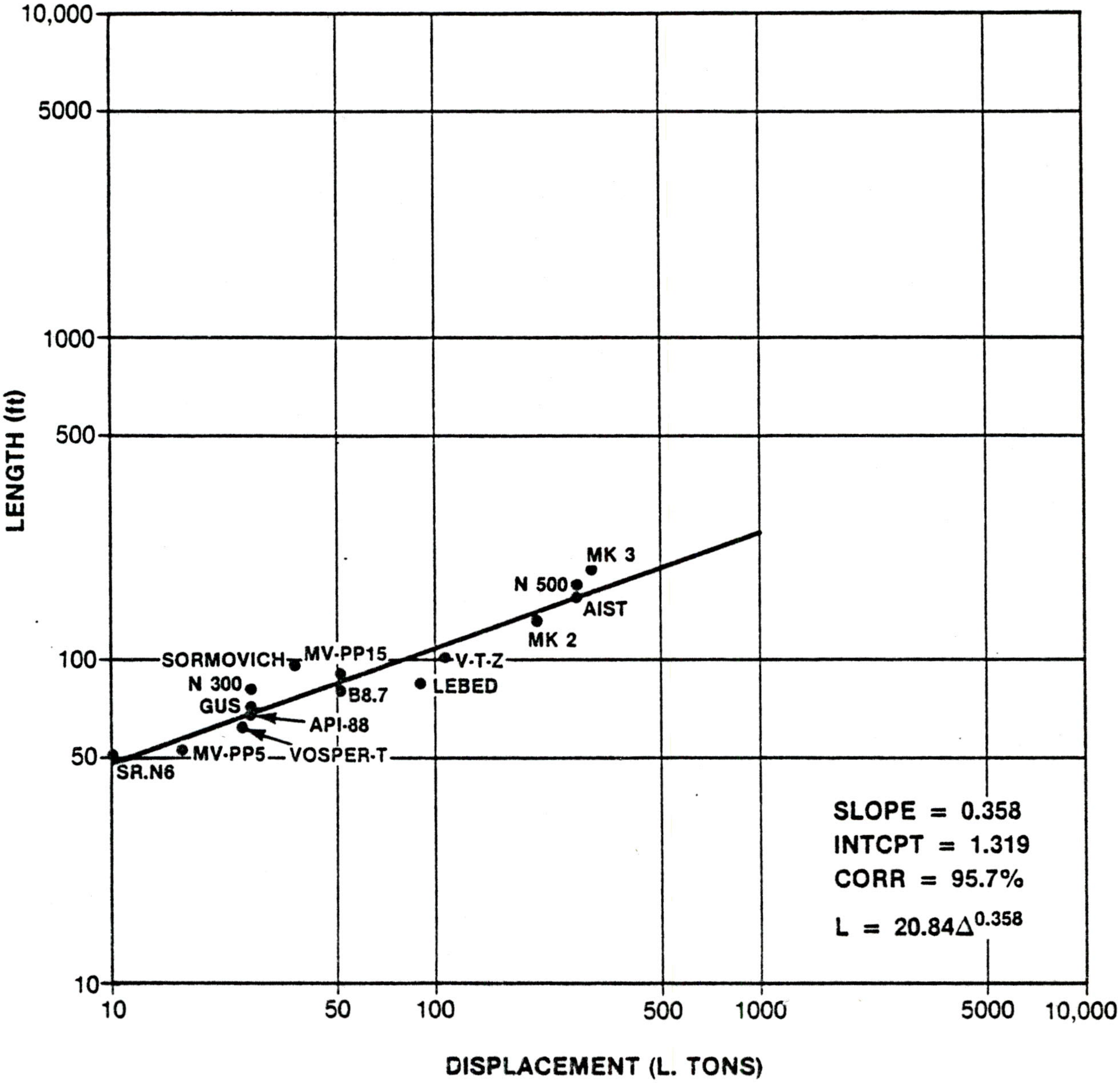


FIGURE A-1C. CRAFT LENGTH VERSUS DISPLACEMENT (ACV, LOW CUSHION DENSITY)

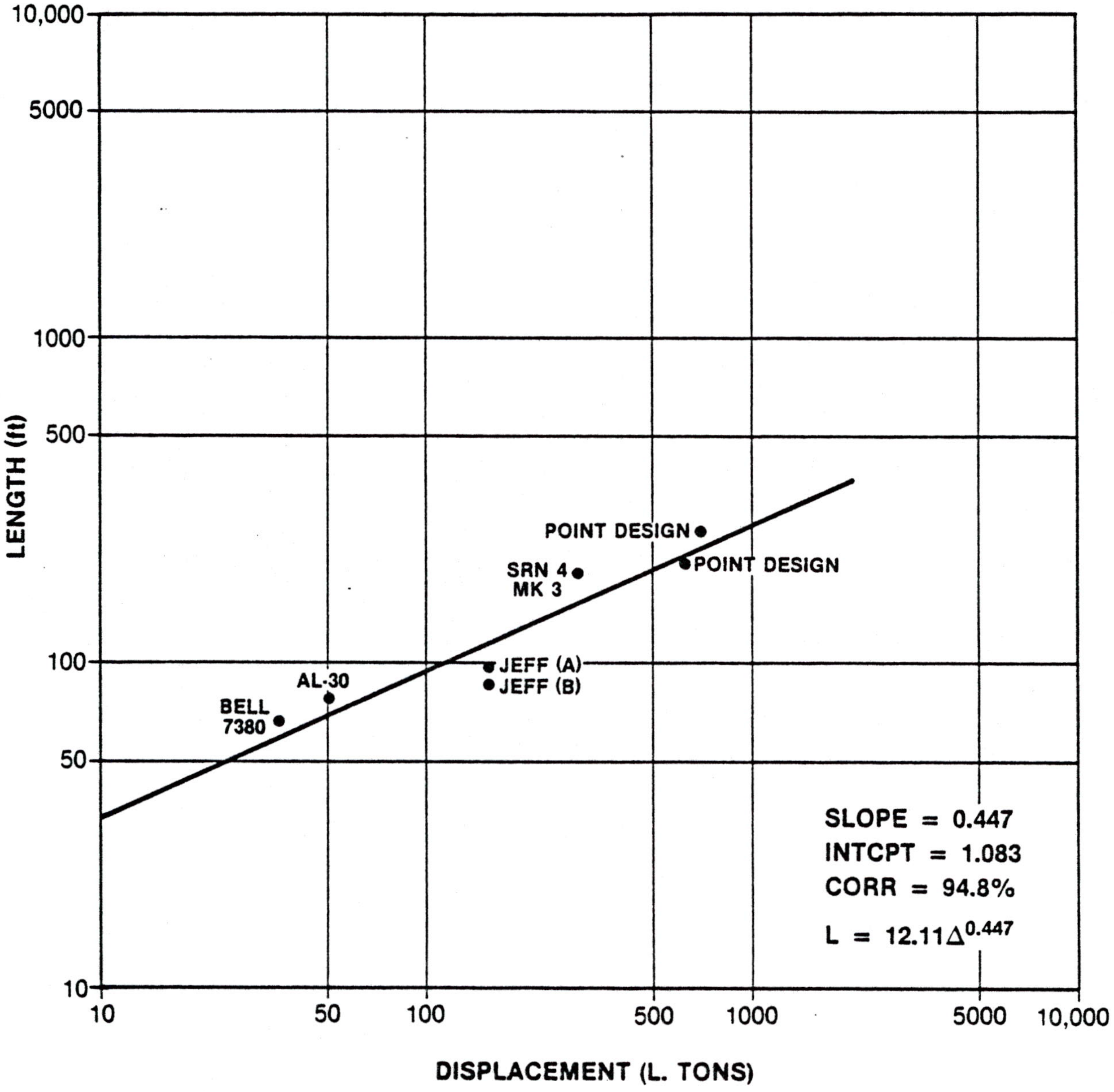


FIGURE A-1D. CRAFT LENGTH VERSUS DISPLACEMENT (ACV, HIGH CUSHION DENSITY)

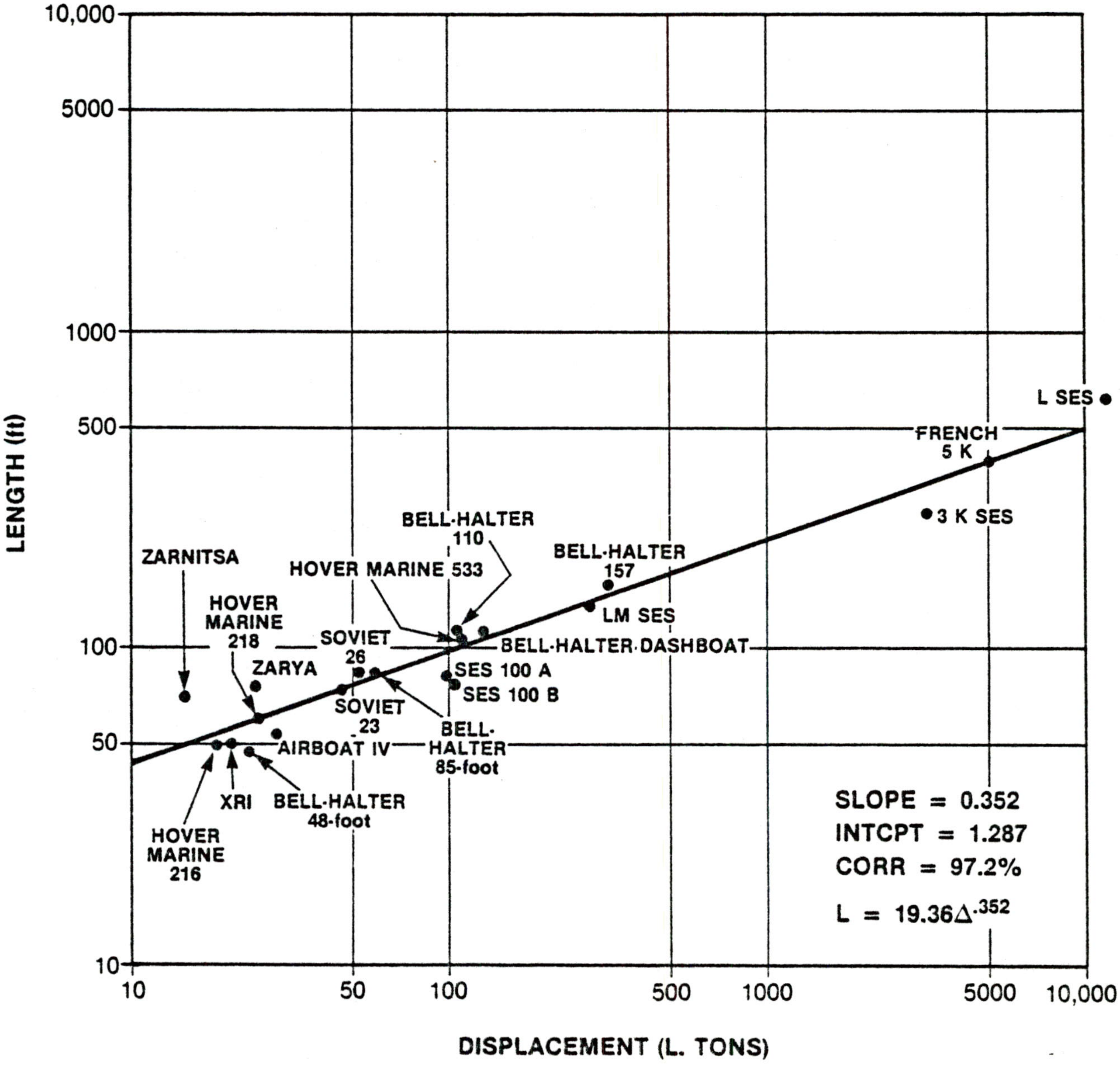


FIGURE A-1E. CRAFT LENGTH VERSUS DISPLACEMENT (SES)

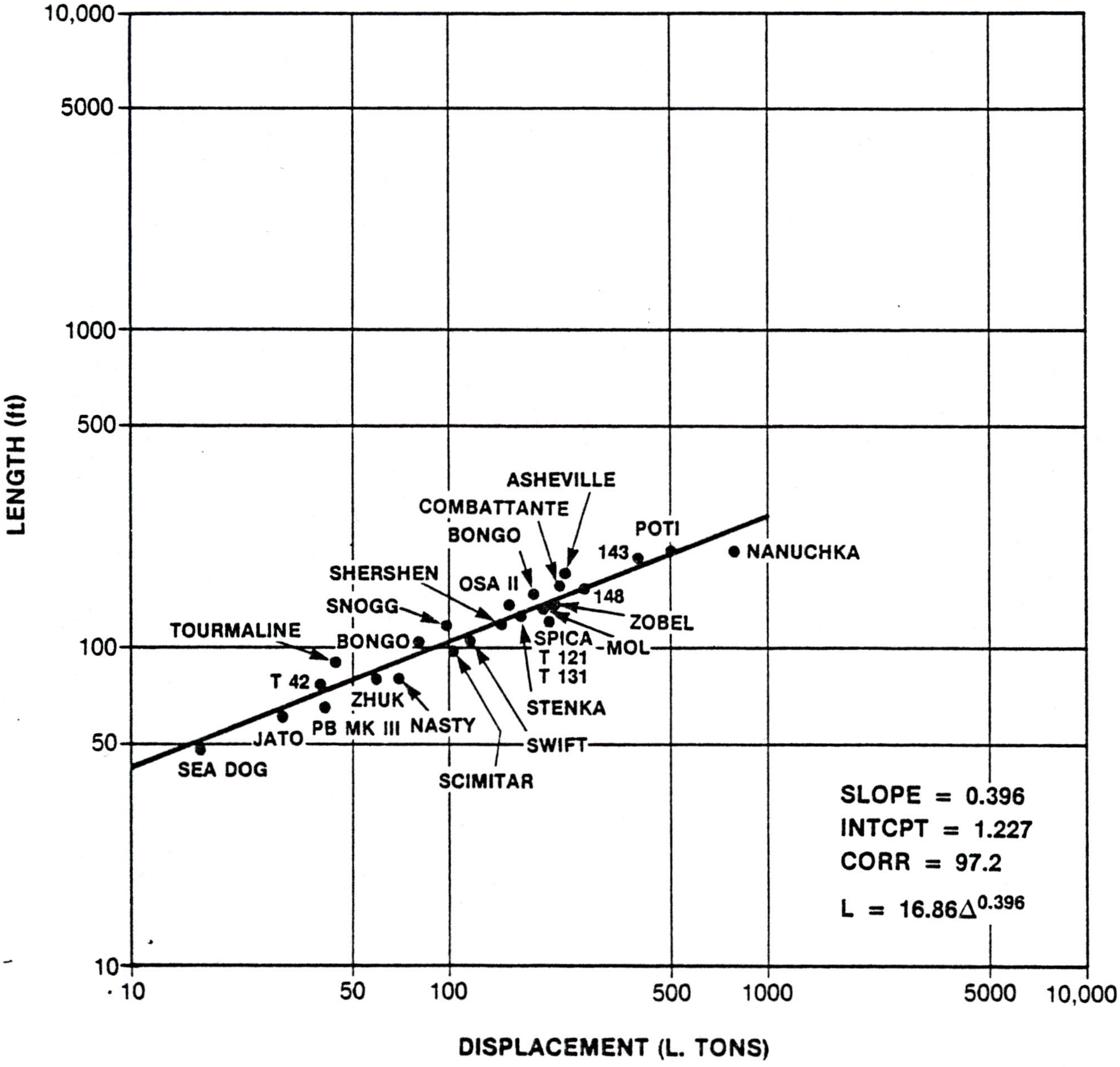


FIGURE A-1F. CRAFT LENGTH VERSUS DISPLACEMENT (PLANING CRAFT)

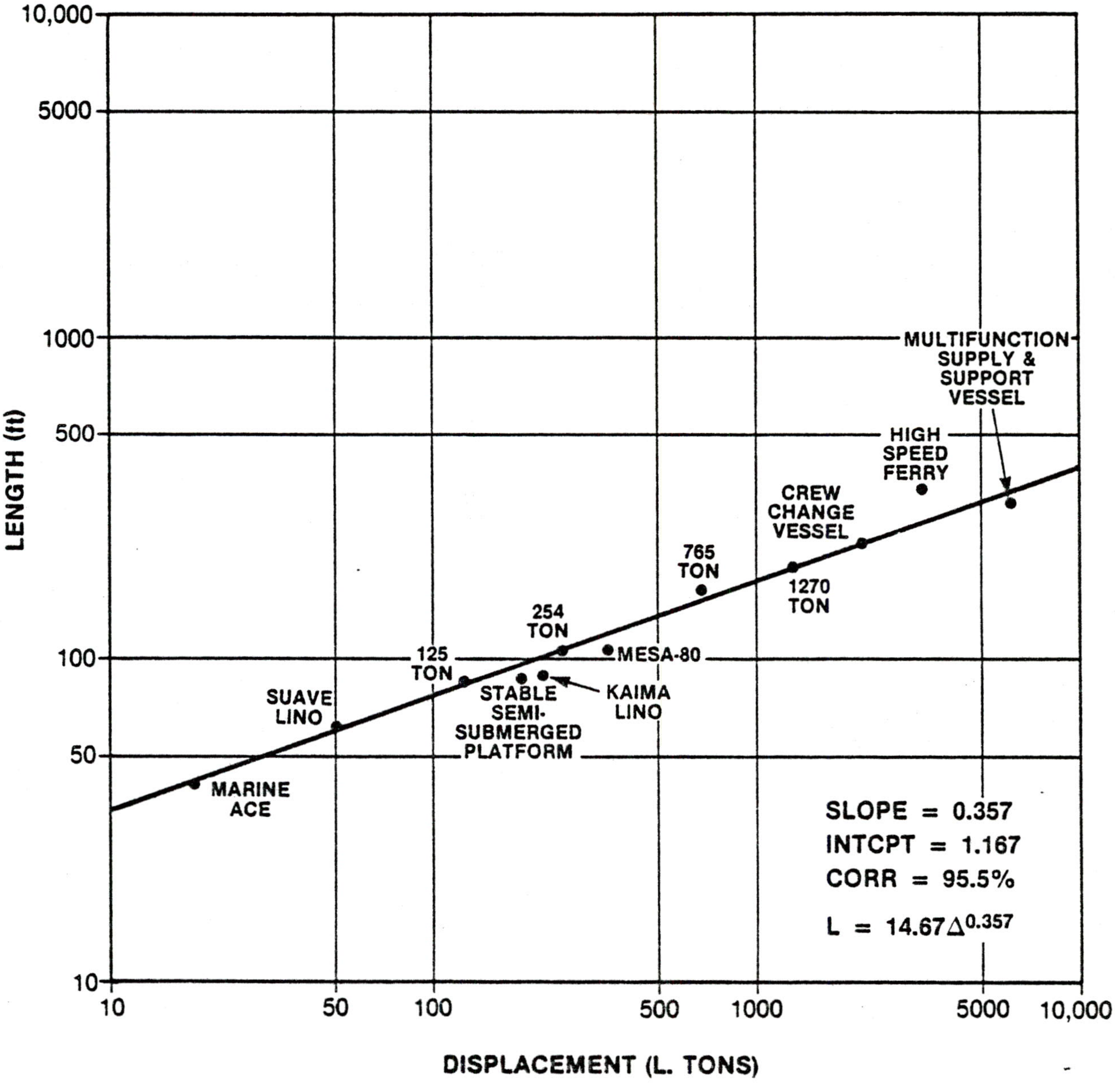


FIGURE A-1G. CRAFT LENGTH VERSUS DISPLACEMENT (SWATH)

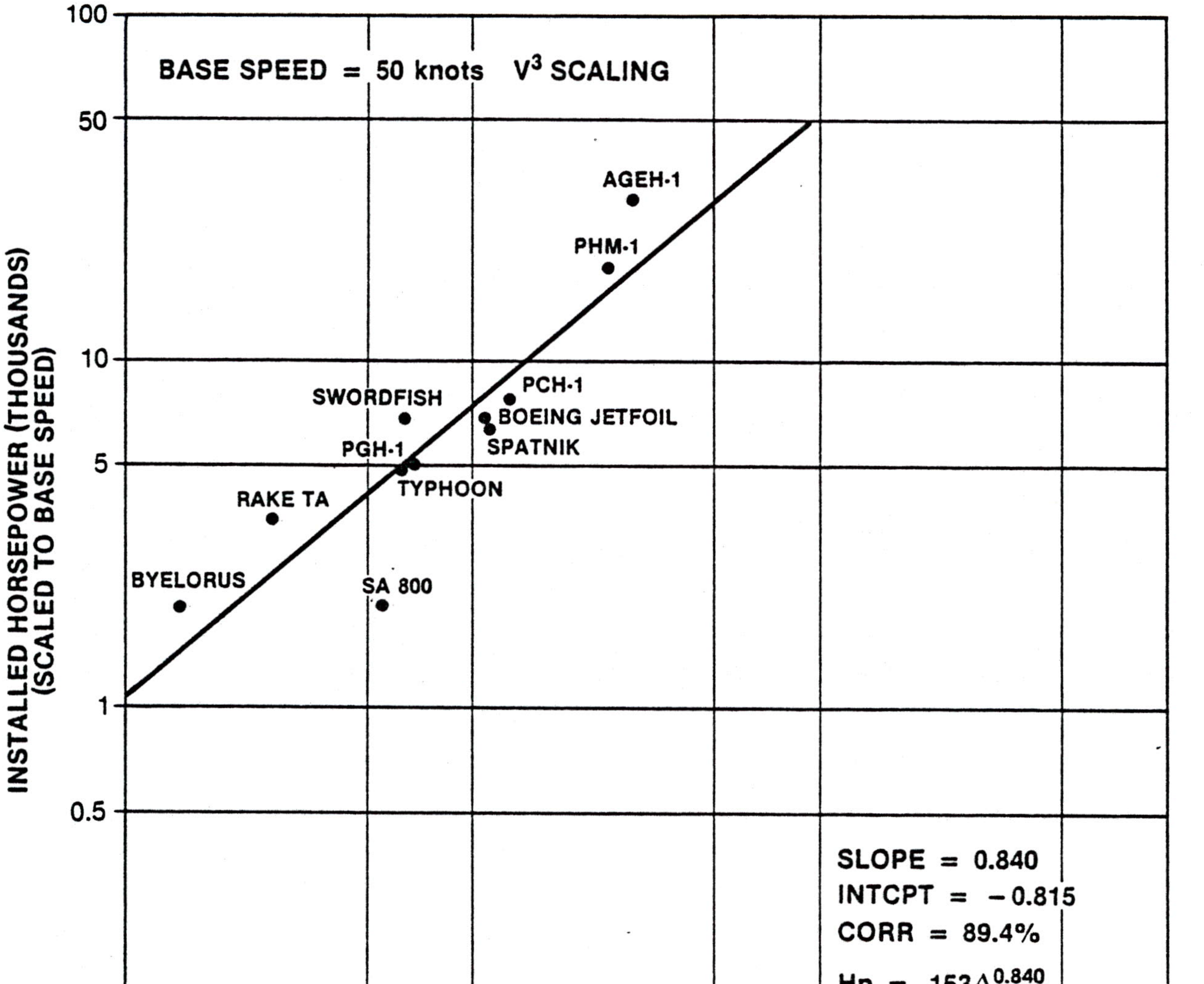


FIGURE A-2A. INSTALLED HORSEPOWER VERSUS DISPLACEMENT (HYDROFOIL, SUBMERGED)

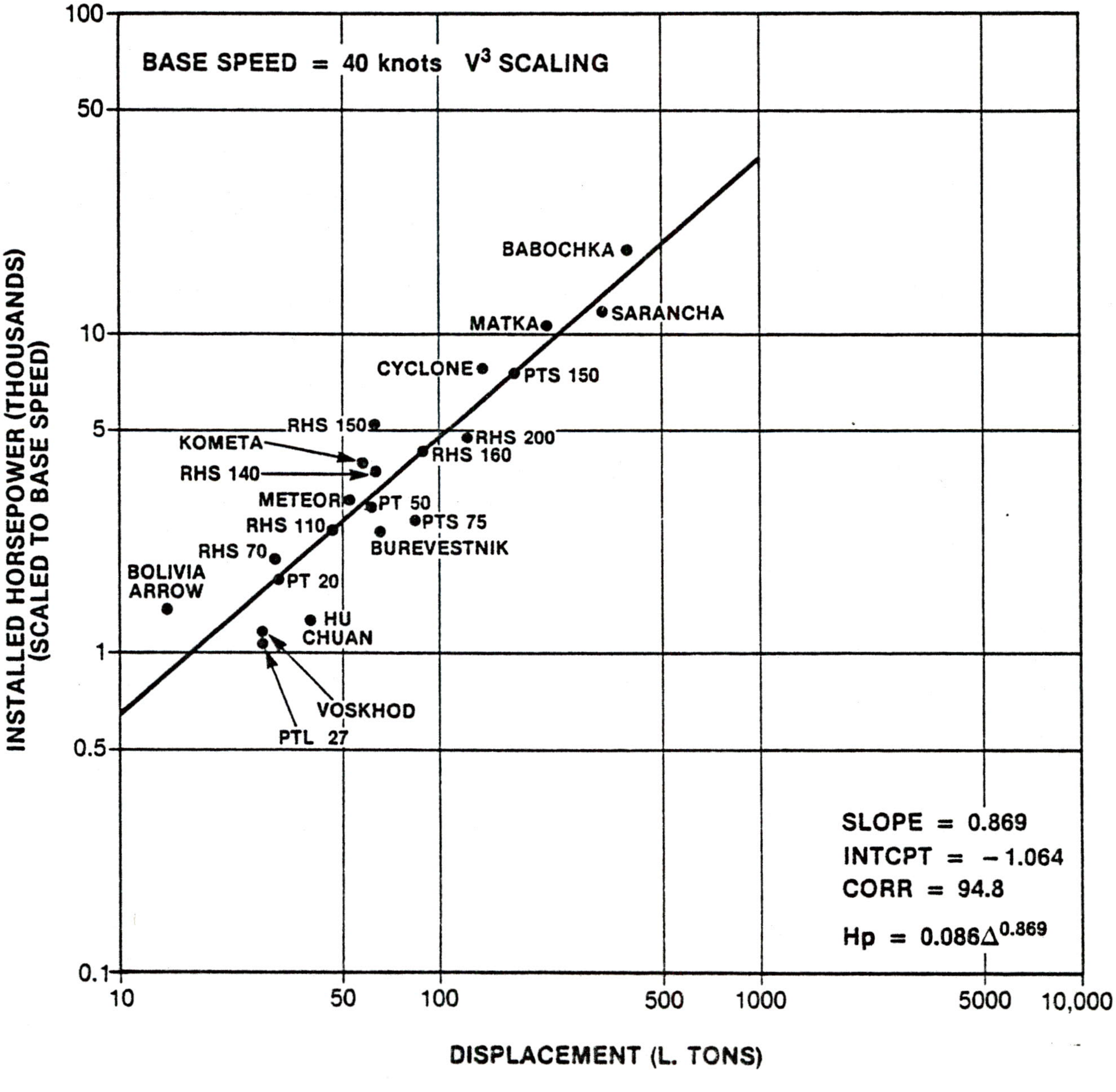


FIGURE A-2B. INSTALLED HORSEPOWER VERSUS DISPLACEMENT (HYDROFOIL, SURFACE PIERCING)

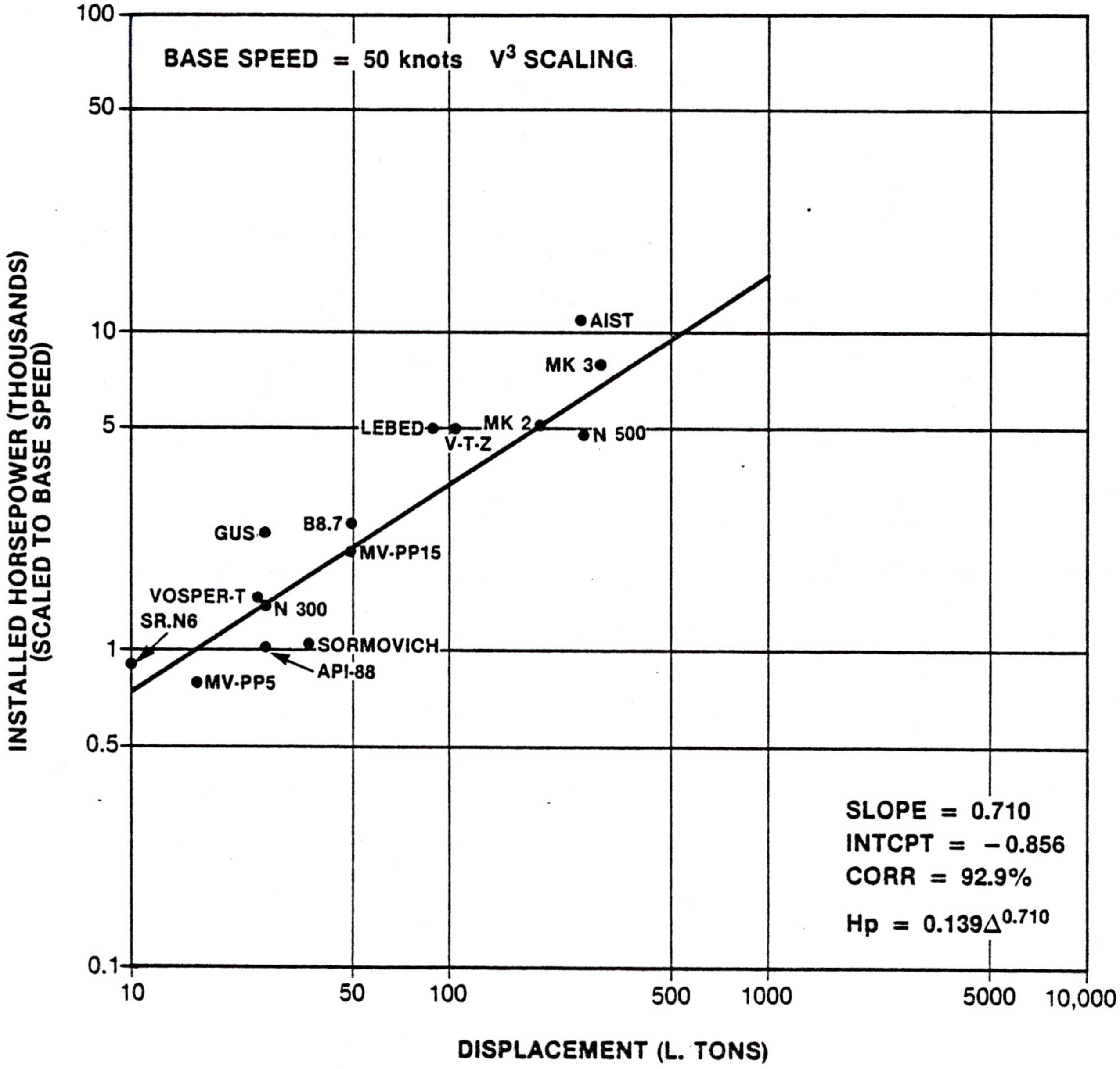


FIGURE A-2C. INSTALLED HORSEPOWER VERSUS DISPLACEMENT
(ACV, LOW CUSHION DENSITY)

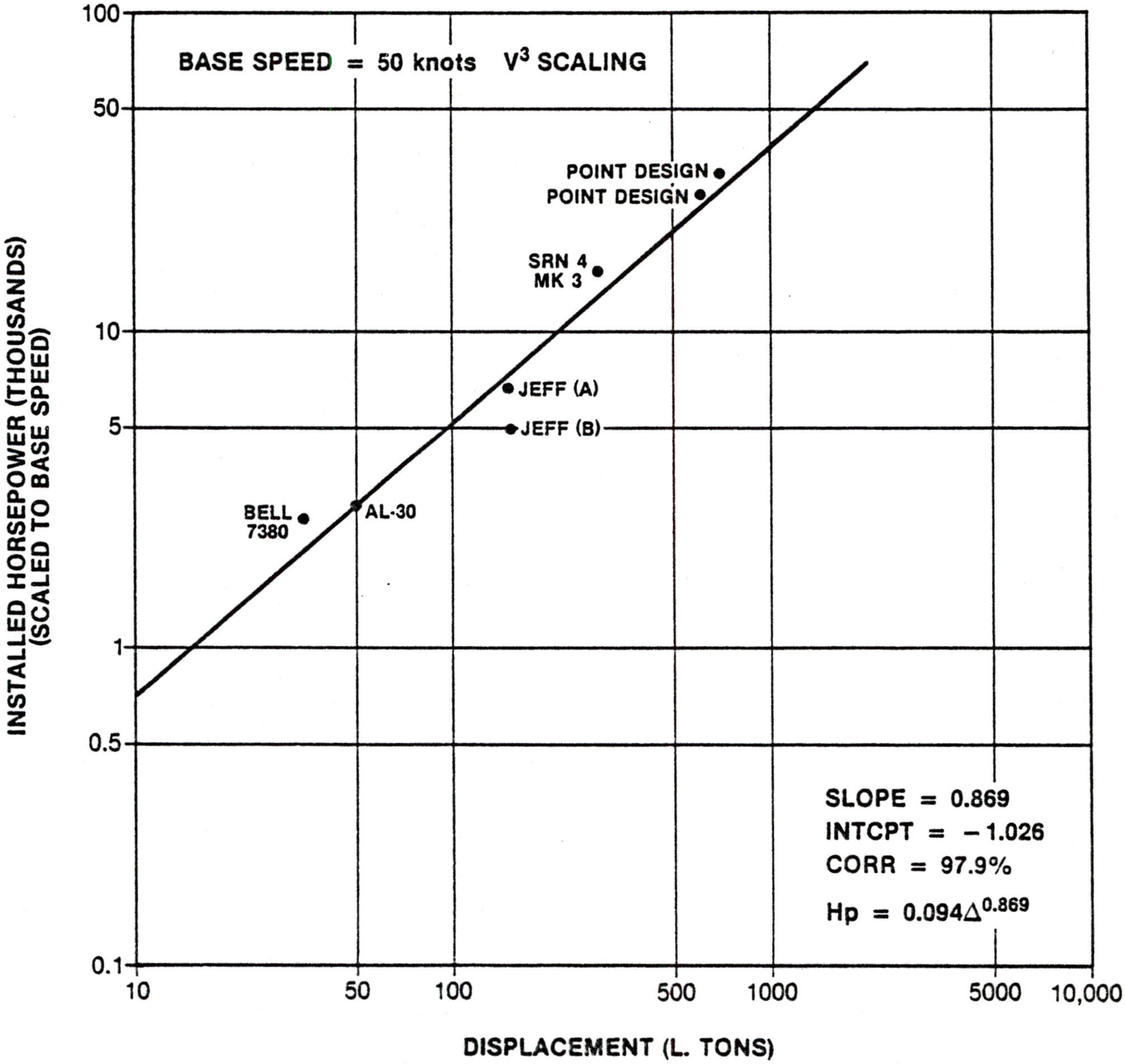


FIGURE A-2D. INSTALLED HORSEPOWER VERSUS DISPLACEMENT (ACV, HIGH CUSHION DENSITY)

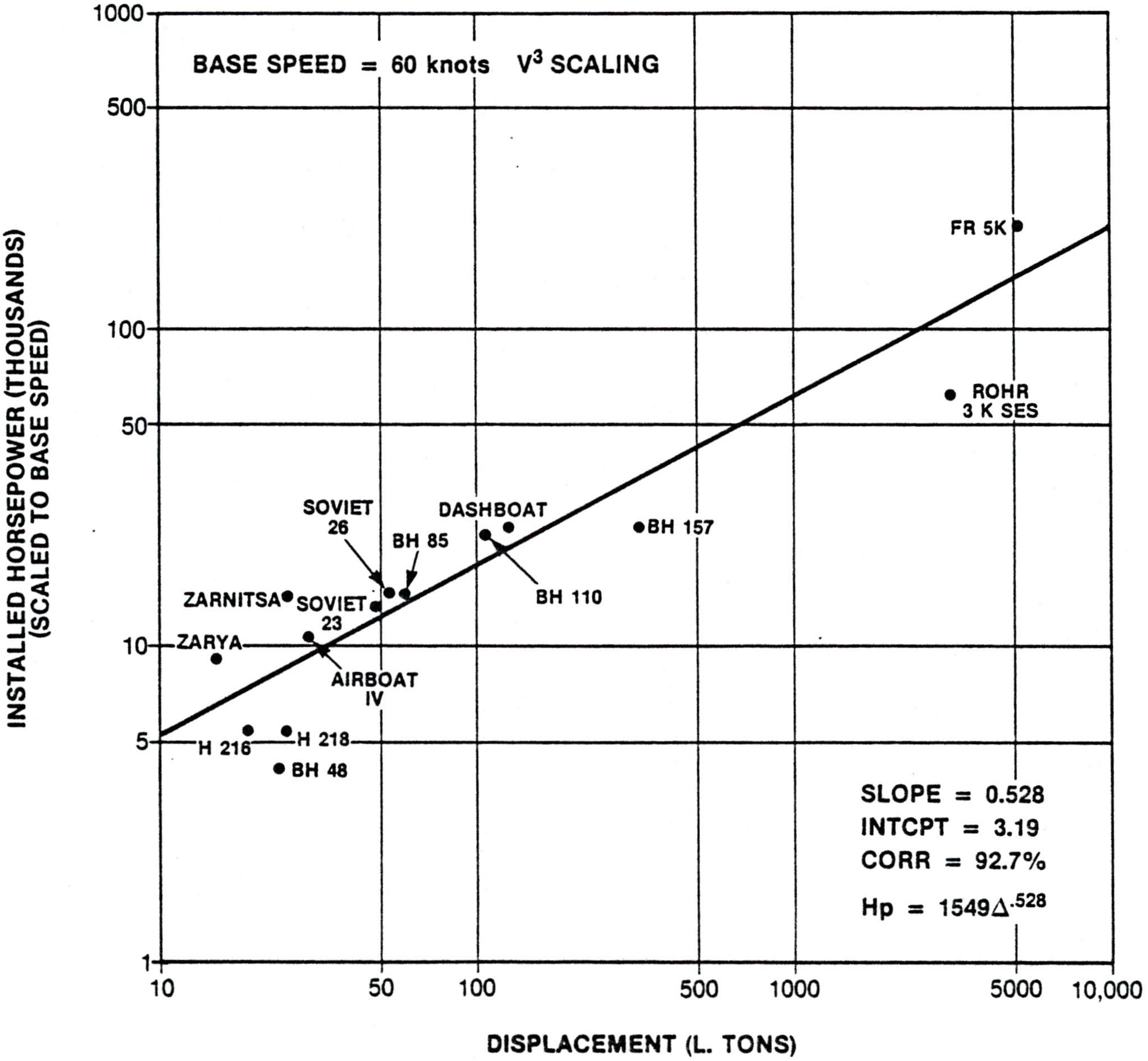


FIGURE A-2E. INSTALLED HORSEPOWER VERSUS DISPLACEMENT (SES)

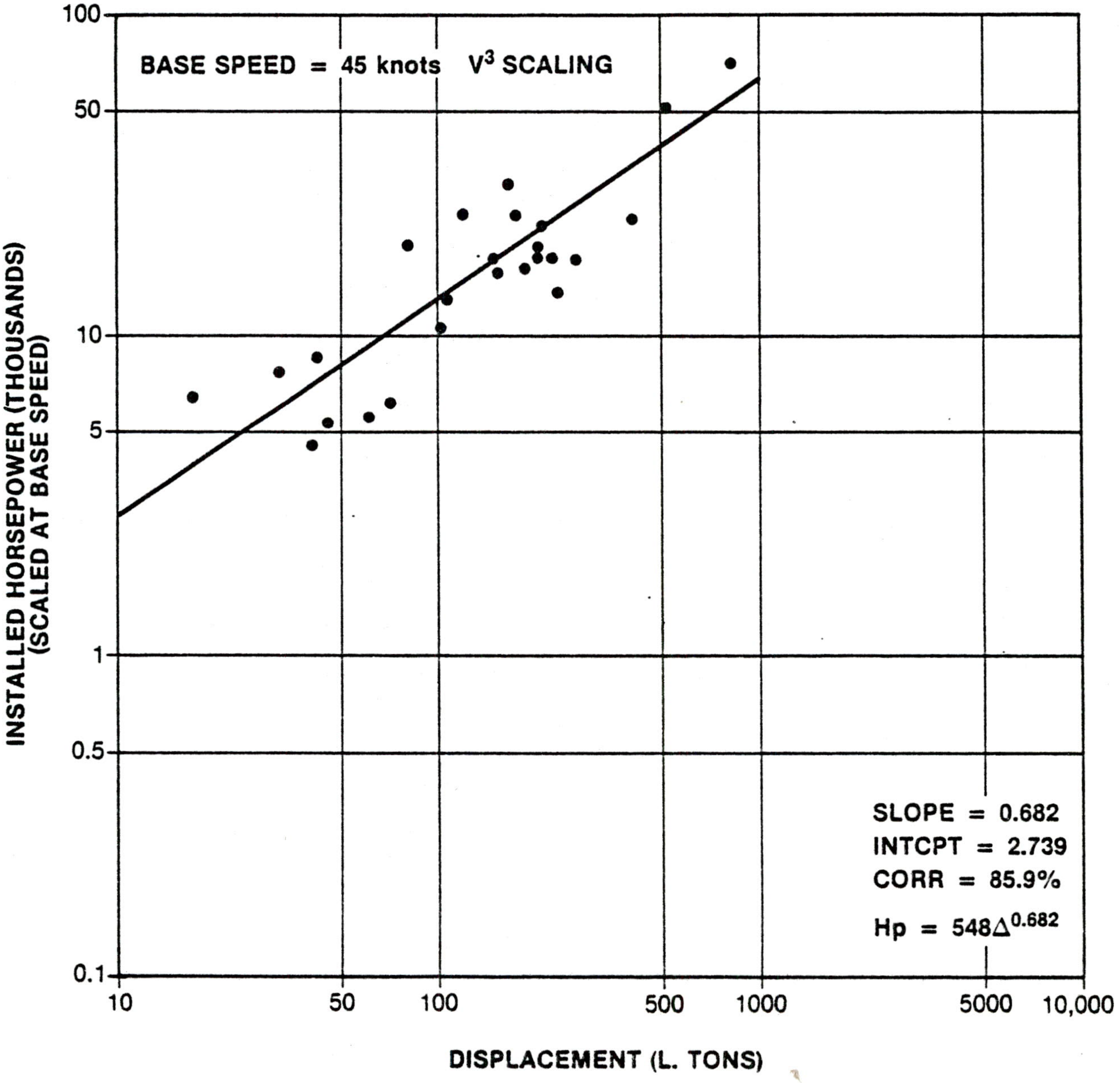


FIGURE A-2F. INSTALLED HORSEPOWER VERSUS DISPLACEMENT (PLANING CRAFT)

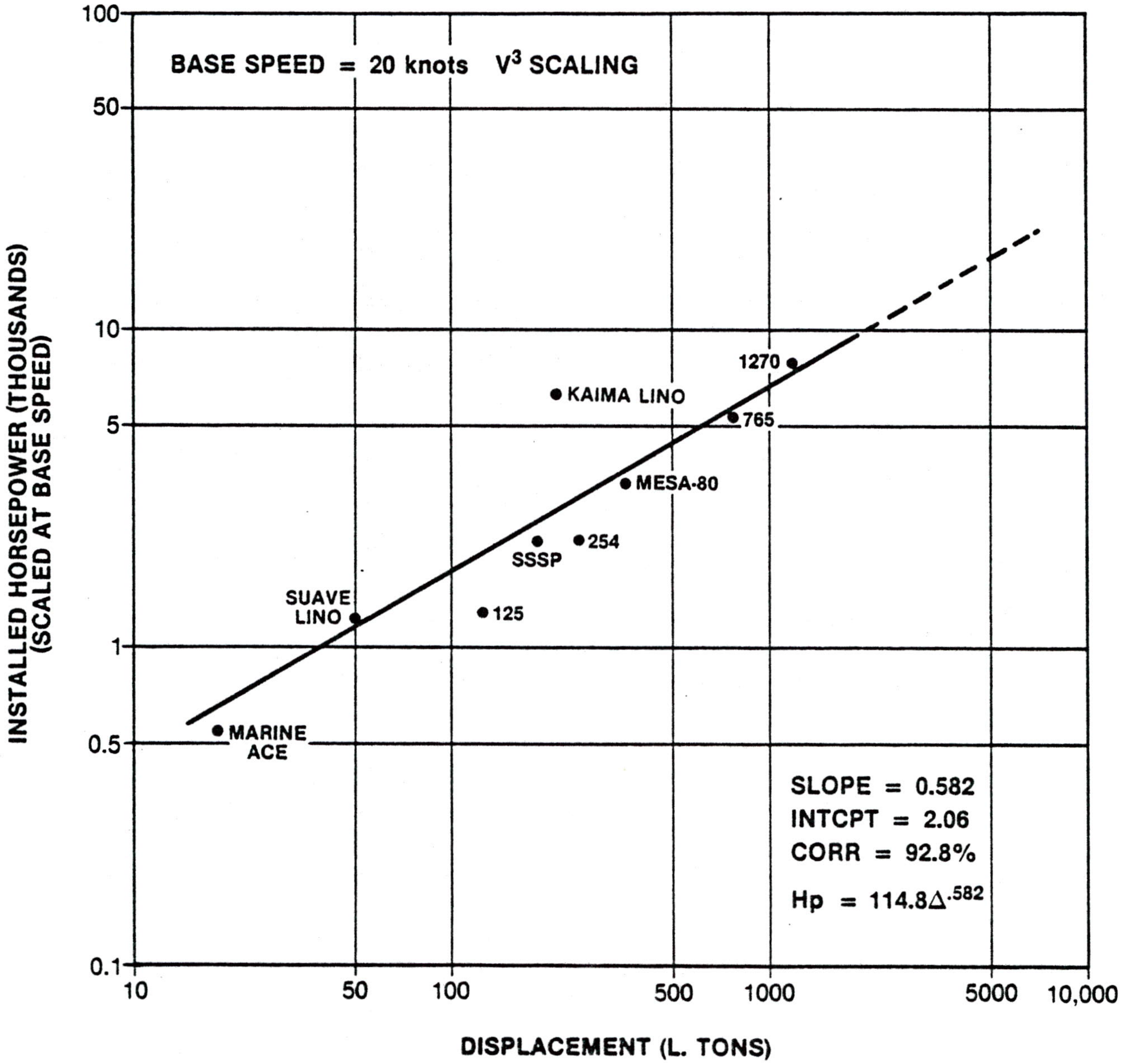


FIGURE A-2G. INSTALLED HORSEPOWER VERSUS DISPLACEMENT (SWATH)

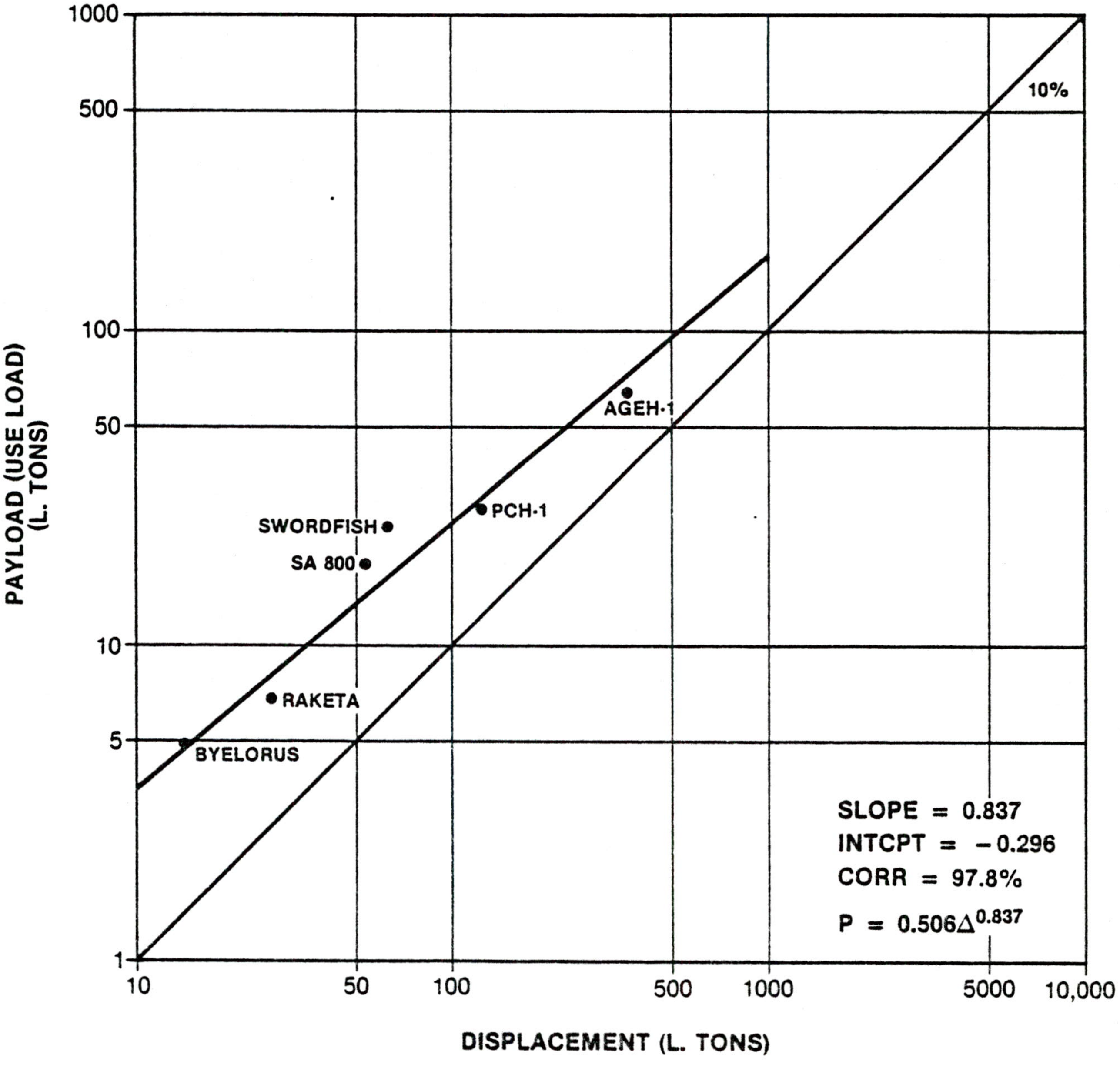


FIGURE A-3A. USEFUL PAYLOAD VERSUS DISPLACEMENT (HYDROFOIL, SUBMERGED)

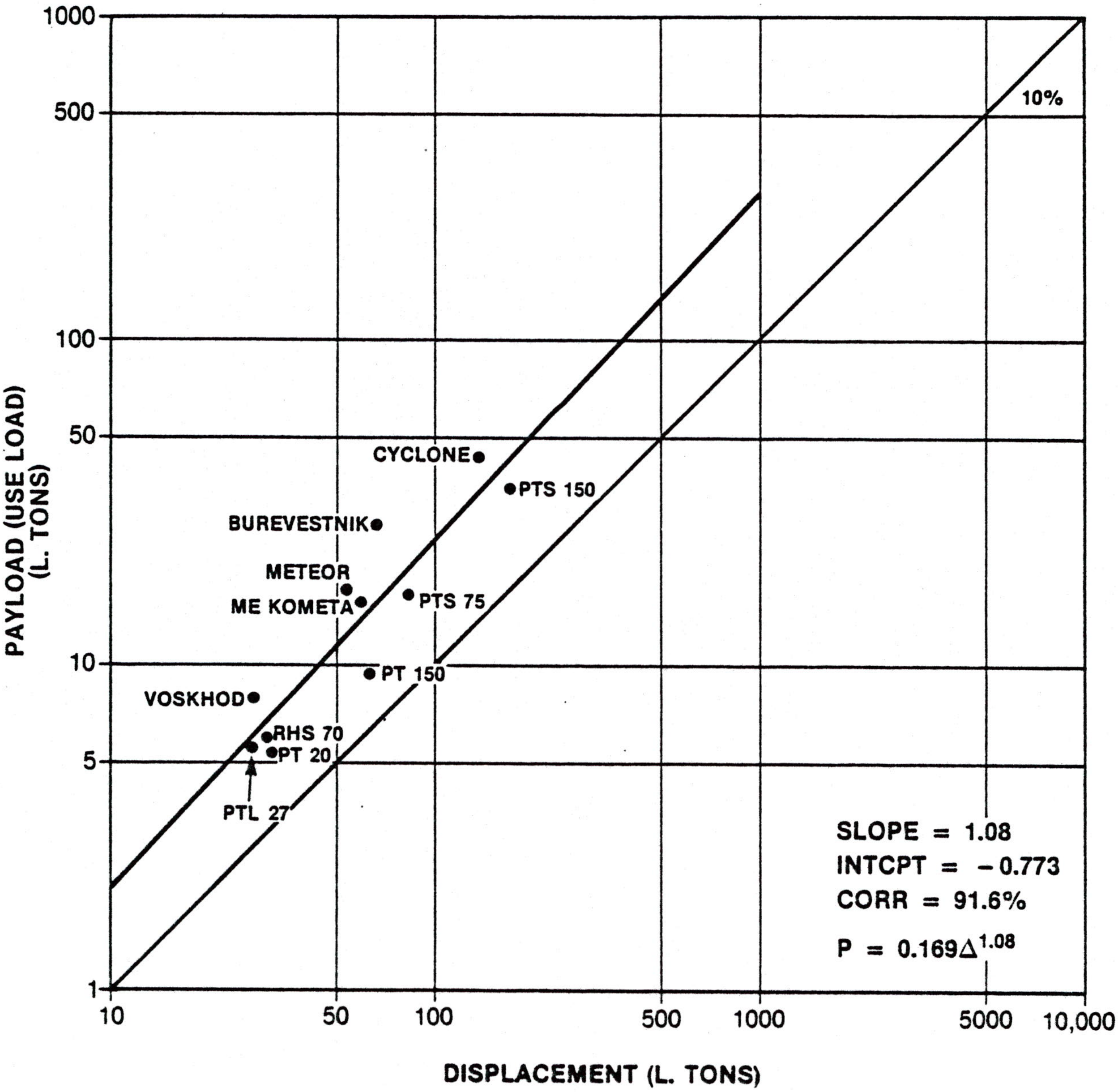


FIGURE A-3B. USEFUL PAYLOAD VERSUS DISPLACEMENT (HYDROFOIL, SURFACE PIERCING)

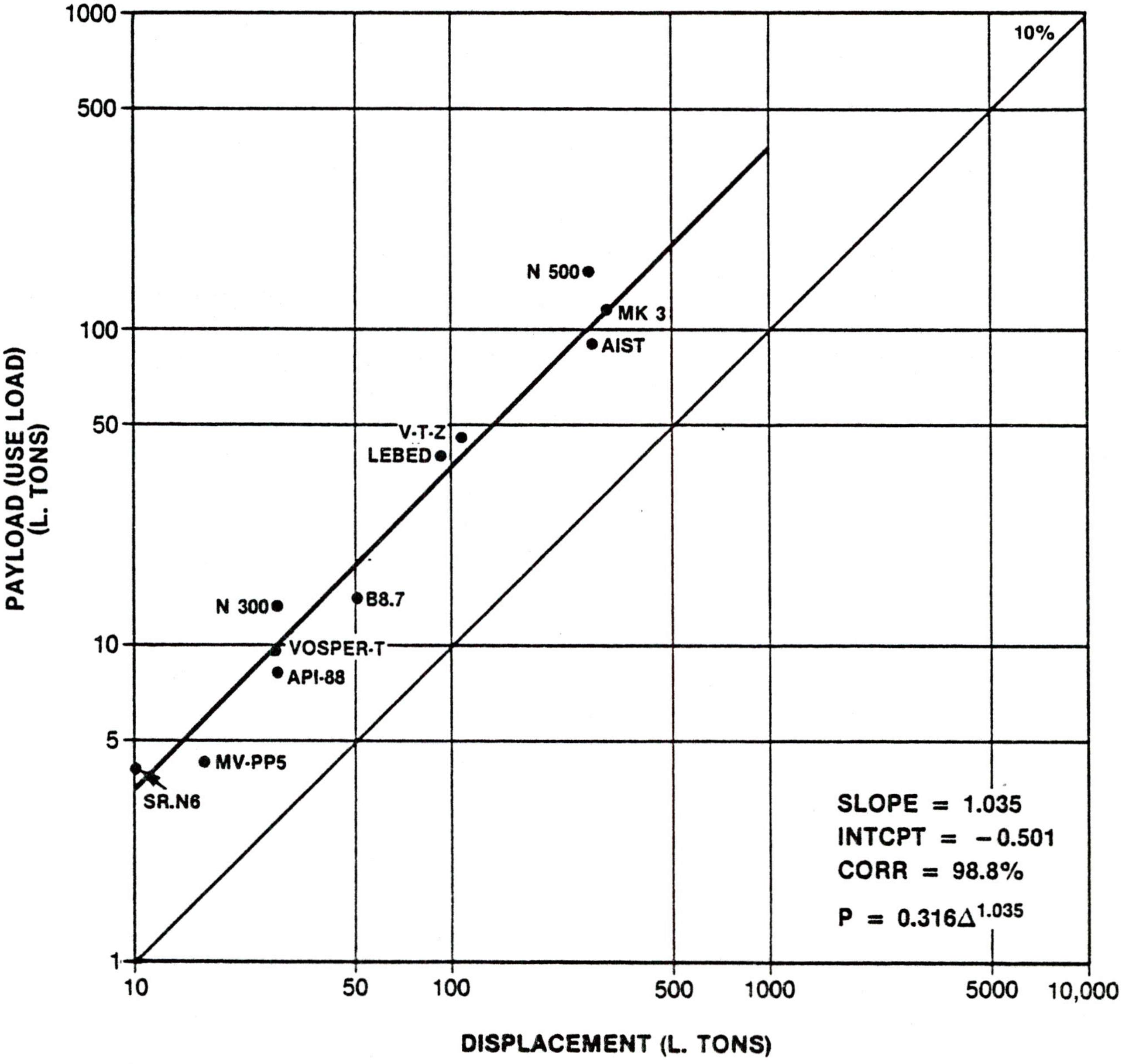


FIGURE A-3C. USEFUL PAYLOAD VERSUS DISPLACEMENT (ACV, LOW CUSHION DENSITY)

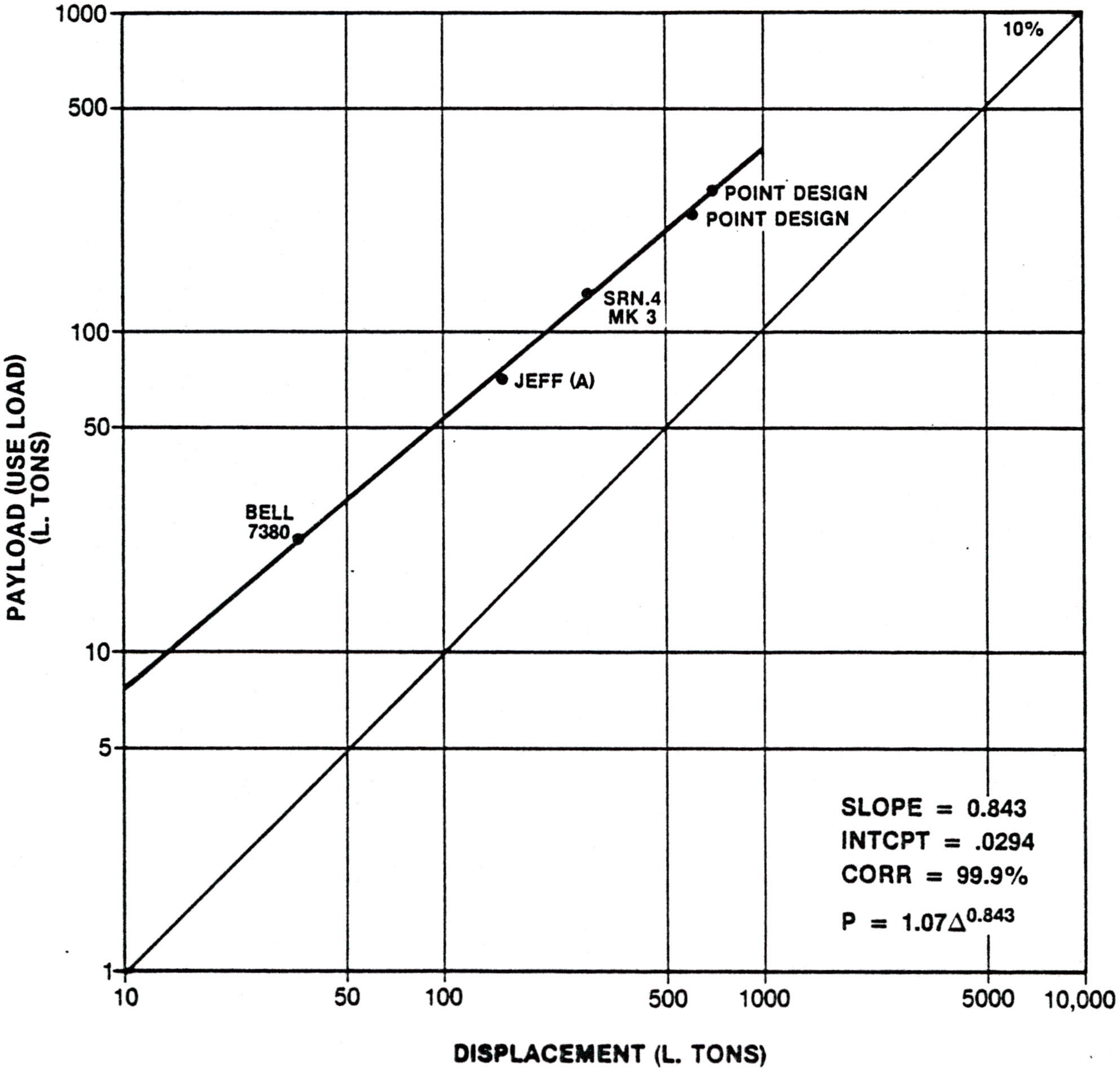


FIGURE A-3D. USEFUL PAYLOAD VERSUS DISPLACEMENT (ACV, HIGH CUSHION DENSITY)

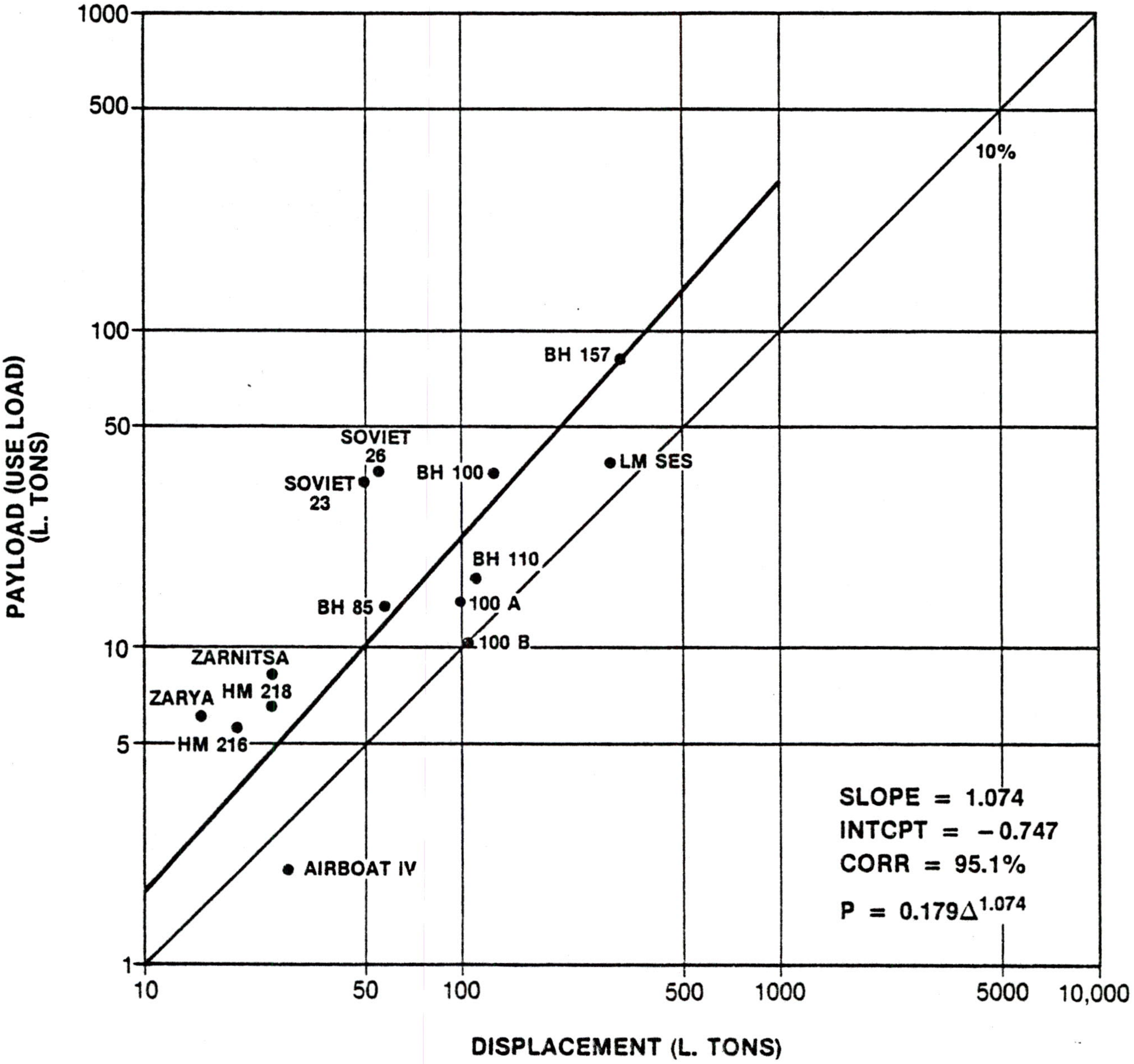


FIGURE A-3E. USEFUL PAYLOAD VERSUS DISPLACEMENT (SES)

GLOSSARY

AAW	antiair warfare
AMV	advanced marine vehicle
ASUW	antisurface warfare
ASW	antisubmarine warfare
CG	Coast Guard
CREE	Cutter Resources Effectiveness Evaluation
CRT	cathode ray tube
DTNSRDC	David Taylor Naval Ship Research and Development Center
ELT	enforcement of laws and treaties
HANDE	Hydrofoil Analysis and Design Evaluation
HP	Hewlett Packard
MEP	marine environmental protection
MLB	motor life boat
MNS	mission need statement
MOE	measure of effectiveness
MP	military preparedness
MR	military readiness
MRB	motor rescue boat
OR	operational requirement
POD	probability of detection
POE	projected operational environment
PWB	ports and waterways boat
RBS	recreational boating safety
ROC	required operational capability
SAR	search and rescue
SES	surface effect ship
SONO	statement of nonobjection
SRA	short-range aids
SWATH	small waterplane twin hull
UTB	utility boat
WHEC	high-endurance cutter
WMEC	medium-endurance cutter
WPB	patrol boat
WWM	waterways management