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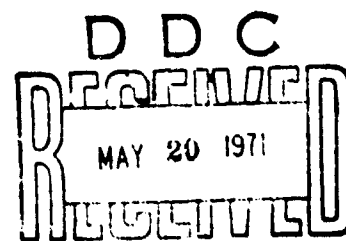
**SYSTEMS ANALYSIS OF AMPHIBIOUS LANDING CRAFT:
COMPARISONS OF PRELIMINARY DESIGNS
OF ADVANCED LANDING CRAFT**

By: J. I. STEINMAN A. R. GRANT P. S. JONES M. J. NIELSEN

Prepared for:

NAVAL SHIP SYSTEMS COMMAND AND
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WASHINGTON, D.C.

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11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Naval Ships Command Research and Office of Naval Research Washington, D.C.	
13. ABSTRACT This report describes the procedures that were used to evaluate the preliminary designs of advanced landing craft as part of the Navy's Advanced Amphibious Landing Craft Program. The procedures were applied initially to more than 30 different existing and proposed landing craft, and complete analysis was made for five advanced craft after screening out marginal craft at each stage of the analysis. Measures of effectiveness used were Force-Time Effectiveness, Time to Deliver 200,000 sq ft of Vehicles Ashore, Marine Forces or Cargo Lost, Response Time, Mean Productivity per Craft by Type, and Mean Cargo Transfer Rates. Standoff distances of 5 and 25 nautical miles were used. The computer programs used in the analysis were provided by SRI and the Naval Weapons Laboratory. Data are presented bearing on the effectiveness of each type of craft and each craft mix. A description also is given of the SRI program GAMUT, which is a simulation covering much the same ground as the STS-2 package but with a great reduction in the level of detail that is considered. It provides the means of rapidly and cheaply changing the input conditions and operating procedures used in the simulation. Selected preliminary results of the GAMUT model are given.			

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14	KEY WORDS	LINK A		LINK B		LINK C	
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PREFACE

This memorandum report compares the relative effectiveness of selected mixes of advanced amphibious landing craft. The comparison is part of the Systems Analysis of Amphibious Landing Craft, which is in turn a part of the Navy's Amphibious Assault Landing Craft Program (S14-17X). Measures of effectiveness used in this report were selected to permit objective comparisons of widely different types of potential landing craft. These measures are described in detail in the joint SRI, NWL (Naval Weapons Laboratory) Dahlgren report, "Analysis of Present Craft in Future Environments," dated February 1969.

The work described in this report was performed jointly by the technical staffs of SRI's Logistic Systems Research Program and the Warfare Analysis Division (Code KW) of NWL, Dahlgren, Virginia. However, the conclusions reported here are SRI's responsibility. Technical direction of this work is provided by Mr. James L. Schuler, NavShips Code 03412, Manager, and Mr. M. W. Brown, NSRDC Code H80, Technical Director, of the Navy's Assault Amphibious Landing Craft Program. Mr. Paul S. Jones of SRI is project leader of the Systems Analysis of Amphibious Landing Craft. Mr. Oliver F. Braxton, Head of NWL's Warfare Analysis Division, is responsible for the NWL work. Administrative direction of SRI's work is provided by Mr. J. R. Simpson, Acting Director, Naval Analysis Programs, Office of Naval Research, through the Institute's Naval Warfare Research Center.

Important technical contributions were made by the following analysts: Mr. Jerome I. Steinman was responsible for the computer runs and the analysis of results; Mr. Andrew R. Grant provided craft vulnerability data and assisted with the computer runs and the analysis of results; Mr. Michael J. Nielsen developed operating data for the advanced landing craft; and Mr. Albert A. Lynch, Jr., was responsible for the use of NWL's ship-to-shore computer simulation (STS-2).

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I INTRODUCTION

The objective of the Navy's Amphibious Assault Landing Craft Program (S14-17X) is to provide the design and development work needed to specify a new family of amphibious landing craft that is significantly more cost-effective and operationally flexible than the family of craft now in service. The landing craft of interest have advanced hull forms, advanced propulsion systems, advanced structures, or a combination of the three. They will be capable of very much better performance than is possible with today's craft. In addition, the new craft will be specifically designed for peak performance for the range of amphibious assault environments considered likely during the 1975 time period. This report describes analytic procedures used to identify the desired performance characteristics and design features of advanced landing craft.

The focus of attention here is a ranking of relative effectiveness and relative cost for mixes of advanced landing craft. To be meaningful these comparisons must relate similar functions for combinations of craft that are often dissimilar. Thus, when comparing displacement craft that carry cargo only as far as the beach line with amphibian craft capable of carrying the cargo across the beach line to firm soil, the analysis must consider all activities that occur until the cargo reaches firm soil. For comparison purposes, the scope of operations selected for study is broad enough to allow all operational features of all potential advanced landing craft and all alternative means for moving men and materiel ashore to be included in the measures of effectiveness. It includes loading craft at amphibious ships, travel of craft to or across the beach line, unloading vehicles and cargo from craft at or on the beach, and moving equipment and cargo to first inland destinations. Thus, the evaluation process encompasses the operations of conventional displacement craft, high speed planing or hydrofoil craft, air cushion craft, wheeled or tracked amphibious craft, and helicopters. In addition, attention has been given to force composition and embarkation of the force on amphibious ships because of the importance of these factors to craft loading operations.

For analytical convenience and in line with established doctrine, the amphibious operations have been divided into two phases, an assault and a general unloading phase. During the assault phase, all of the

serialized* materiel is scheduled for delivery ashore. The serialized materiel is made up almost entirely of mobile loaded vehicles--tracked vehicles, wheeled vehicles, and trailers. Each vehicle is assigned to a specific serial and moves ashore with that serial. During the general unloading phase nonserialized cargo and equipment are moved ashore. This is largely palletized cargo and skid-mounted equipment that must be lifted onto an off the landing craft.

The attention of this report has been focused on the assault phase for two important reasons:

- (1) The assault phase is the most critical phase of an amphibious operation in terms of tactical importance, craft performance requirements, and number of craft needed. Thus craft characteristics required to accomplish the assault phase are paramount. Requirements for the general unloading phase have a subordinate influence on craft characteristics.
- (2) Craft performance during the general unloading phase is heavily influenced by loading and unloading operations. Significant advances in materials handling equipment, as yet undefined, are needed before full advantage can be taken of advanced craft. Because craft characteristics are likely to affect materials handling equipment design greatly, it is appropriate to select the craft before formally addressing the equipment problem.

A mix of landing craft selected for study is defined to be a set of craft, which is composed of different numbers of two or more craft sizes and types, that is carried to an objective area by an amphibious fleet for the purpose of delivering part or all of a Marine assault force ashore. The performance of each selected craft mix is influenced by the size and composition of the Marine force, the ships of the amphibious fleet, the landing plan followed, the defensive actions taken by the enemy, the state of the weather, and a variety of other conditions.

* A serial is the smallest unit of the assault force that has both tactical and administrative integrity. For a description of the Marine force serialization, see Means, E. H. and D. E. Vaughn, "Marine Assault Forces and Amphibious Operation Plans (U)," (NWRC/LSR-RM42), Stanford Research Institute, Menlo Park, California, August 1967 (CONFIDENTIAL)

The sensitivity of present-day craft to different environmental conditions has been studied and is reported in the analysis of present craft in future environments.* The measures of effectiveness, sources of advanced craft designs, and environmental conditions used in this comparison of advanced craft are summarized below, together with a brief description of the analytical work.

Measures of Effectiveness

Landing craft effectiveness cannot be measured directly from craft performance parameters because the landing craft constitute only one part of much larger amphibious assault systems. Therefore, landing craft effectiveness is derived from amphibious assault effectiveness and should be measured in terms of amphibious assault parameters.

The specific measures of effectiveness that were adopted are intended to measure the contribution that different mixes of advanced landing craft makes to amphibious assault operations. Ideal landing craft effectiveness would enable the amphibious force commander to plan for and alter his attack, placing men and equipment where they are needed without giving any consideration to landing craft constraints. Unfortunately, flexibility is not an acceptable measure of effectiveness because it is extremely difficult to quantify. However, some measure of flexibility can be realized by measuring the speed with which the force can be delivered ashore and the time required to deliver a particular serial ashore once it has been requested.

In all, six measures of effectiveness have been adopted that express differences in performance between alternative mixes of craft. These are:

- (1) Force-time effectiveness. For any reference time, the force-time effectiveness measure is proportional to the size of the Marine force delivered ashore multiplied by the length of time that each unit has been ashore. This measure, expressed in vehicle-square-foot-hours, emphasizes the desirability of early delivery ashore. Each vehicle of the force makes a contribution to force-time effectiveness that depends on its size in square and on the time that it reached the shore.

* See Jones, P. S., J. I. Steinman, and A. A. Lynch, Jr., "Analysis of Present Craft in Future Environments," Stanford Research Institute, Naval Weapons Laboratory, Menlo Park, February 1969.

Thus, if the reference time is H+7 hours, a vehicle with an area of 100 square feet might make the following contributions to force-time effectiveness:

<u>Time Vehicle Delivered Ashore (hours)</u>	<u>Contribution to Force-Time Effectiveness (sq ft-hours)</u>
H+1	600
H+3	400
H+6	100
H+7	0

- (2) Time to deliver 200,000 square feet of assault vehicles ashore. A measure of time to complete the assault phase; 200,000 square feet was selected for comparability of runs.
- (3) Marine forces or cargo lost. The total area, in square feet, of vehicles on board landing craft sunk en route to the beach.
- (4) Response time. The elapsed time from the request for a particular Marine serial until all its components reach the beach, having been unloaded from all craft and are ready for use.
- (5) Mean productivity per craft by type. This measures the square feet of vehicles delivered ashore per square foot of outside craft area. It is accumulated up to a reference time. This is a measure of craft performance relative to the ship well area on shipdeck area that the craft occupy en route to the objective area.
- (6) Mean cargo transfer rates. Flow rates expressed in pallets per hour that describe cargo handling capacity at different points in the cargo flow network. They reflect the general unloading phase performance in terms of craft loading from ships, craft unloading at the beach, and moving cargo inland to the logistic support area.

To avoid misinterpretations, these measures of effectiveness must be supplemented with careful examination and understanding of the results of the computer simulations from which they are produced.

Advanced Landing Craft

Preliminary designs of the 32 different advanced landing craft listed in Table 1 were prepared by 11 companies under contract to NavShips (Naval Ship Systems Command) through Gibbs and Cox, Inc. These designs included preliminary layouts, machinery arrangements, structural analyses, preliminary selection of propulsion and power train equipment, control system design, and estimates of performance and cost. The preliminary designs were examined by a large technical review committee, which approved 18 for analytical studies. These 18 are identified in the last column of Table 1.

The number of advanced craft was further reduced by taking into account lessons learned in the base system analyses* and by a desire to represent consistently each craft size and type. Thus, where possible we avoided comparing a very optimistic design of one craft-type with a very conservative design of another. Specifically, it was found that craft with both bow and stern access ramps can be loaded with vehicles very much faster than craft with only bow access ramps. The advantage of stern ramps for drive on loading (as opposed to back-on) is so great as to mask many other characteristics.† Therefore, only advanced craft with bow and stern access were selected for analysis. Where two speed options were available for similar planing craft, we selected the higher speed option for the initial analysis. In one instance, the lower speed was also tested. By these and similar screening steps, the field of advanced craft was reduced first to six craft sizes and types and then to five for the initial comparisons. The dimensions, weights, and speeds of these craft are given in Table 2.

10,400-Pound Planing Craft (10P)

The 20-knot Sparkman & Stephens design was selected, as submitted, for this craft size. This craft has no drive-through capability; however, drive-through capability is not considered essential for this size because it can carry only light vehicles whose back-on loading time is not drastically different from drive-on loading time. The Sparkman & Stephens design was selected over the Hydronautic's design because of its smaller external dimensions.

* See Jones, et.al., op.cit.

† See Nielsen, Michael J., "Vehicle Loading Test Results," NWRC/LSR RM51, Stanford Research Institute, Menlo Park, California, April 1969.

Table 1

ADVANCED CRAFT CHARACTERISTICS FROM PRELIMINARY DESIGNS

Designer	Hull Type	Nominal Payload (thousands of pounds)	Design Speed (knots)	Approved for Analysis
Aerojet-General Corporation	ACV	30	35	No
	ACV	125	50	No
	ACV	150	50	No
	ACV	320	35	No
Atlantic Hydrofoils, Inc.	HF	70	35	No
	HF	125	35	No
Bell Aerosystems Company	ACV	30	50	Yes
	ACV	125	35	Yes
	ACV	150	50	Yes
	ACV	320	50	Yes
J. E. Bowker Associates, Inc.	P	320	20	Yes
	P	320	35	Yes
Control Data Corporation, TRG Division	P	125	20	Yes
	P	320	20	Yes
General Dynamics Corporation, Electric Boat Division	ACV	10.4	50	No
	ACV	30	50	No
	ACV	70	50	No
	ACV	125	50	No
	ACV	150	50	No
	ACV	320	50	No
General Dynamics Corporation, Quincy Division	HF	70	35	Yes
	HF	125	35	Yes
Hydronautics, Inc.	P	10.4	35	No
MacLear & Harris	P	30	35	Yes
	P	125	20	Yes
Sparkman & Stephens, Inc.	P	10.4	20	Yes
	P	10.4	20	Yes
	P	125	20	Yes
	P	125	35	No
United Aircraft Corporation	P	70	20	Yes
	P	70	35	Yes
	P	150	20	Yes

• ACV = air cushion hull, HF = hydrofoil hull, P = planing hull.

Table 2

CRAFT CHARACTERISTICS FOR INITIAL COMPARISONS

	Payload (pounds)				
	10,400	30,000	125,000	150,000	320,000
Hull type	Planing	Air cushion	Planing	Air cushion	Planing
External dimensions (ft)					
Length	46.1	50.0*	73.8	104.0	140.0
Width	12.8	24.0*	24.0	44.0	32.0
Height	14.5	18.0/ 21.5 [†]	21.5	23.0/ 27.1 [†]	21.0 [‡]
Cargo well dimensions (ft)					
Length	29.0	37.0*	46.0	66.0	115.0
Width	8.0	12.0*	17.0	26.0	26.0
Drive-through capability	No	Yes	Yes*	Yes	Yes*
Ramp width (ft)					
Bow	8.0	12.0*	17.5	26.0	15.0
Stern	--	9.0	Gate only	13.0	Gate only
Draft (ft)					
Maximum	4.0	1.1	4.6	1.5	6.8
Bow, loaded	1.8	1.1	3.8	1.5	3.6
Weight (thousands of pounds)					
Light	21.8	34.0	81.0	127.6	386.0
Payload	10.4	30.0	125.0	150.0	320.0
Fuel	2.7	12.0	39.5	34.5	78.4
Gross	35.3	77.0	246.3	312.1	785.0

* Modified for analysis.

[†] Height off cushion/on cushion.

[‡] Mast down.

30,000-Pound Air Cushion Craft (30ACV)

To provide drive-through capability for this craft, the approved Bell design was abandoned in favor of the revised Aerojet General version of the 30,000-pound ACV. Because this craft has not been certified for analysis, only its dimensions are used. Performance characteristics are taken jointly from Bell and Aerojet General, with emphasis on Bell's conservatism.

70,000-Pound Planing Craft (70P)

This craft was dropped from the analysis before beginning the comparisons. The designers of the three approved craft selected cargo wells for the 70,000-pound craft as large as those suggested for the 125,000-pound planing craft. As a result these three designs are so close in size and performance to the 125,000-pound planing craft that the selection of a 70,000-pound craft represents a sacrifice of load-carrying capability. The comparative dimensions and weights* are:

Design	<u>70,000-Pound Payload Craft</u>			<u>125,000 Pound Payload Craft</u>		
	Length (ft)	Width (ft)	Displace- ment	Length (ft)	Width (ft)	Displace- ment
			Less Payload (1000 lb)			Less Payload (1000 lb)
United Aircraft	93	20	114	117	32	209
United Aircraft	93	20	135			
General Dynamics, Quincy	97	23	296	97	23	312
TRG				81	22	135
Sparkman & Stephens				74	24	121
MacLear & Harris				103	30	191

Note that both the TRG and Sparkman & Stephens 125,000-pound craft are smaller than all the approved 70,000-pound payload craft and weigh approximately the same without payload as the 70,000-pound craft.

* Weights are fully equipped including fuel but less payload.

125,000-Pound Planing Craft

We selected two versions of the Sparkman & Stephens craft as a basis for the 125,000-pound craft. The first has no drive-through capability, the second has. Initially, the 35-knot speed was selected for the following reasons.

- (1) We do not want to delete a basic craft size because of slow speed. Use of a speed below 35 knots would put planing craft at a disadvantage with respect to ACVs.
- (2) The Sparkman & Stephens craft has attractive length, height, cargo well area to gross area ratio, and payload to cargo well characteristics. It will also fit two abreast in a 50-foot well.

Later in the analysis the 20-knot speed was tested.

The 125,000-pound planing craft with drive-through capability was adopted by providing a ramp in well ships to allow trucks to enter at the poop deck level and drive down into the cargo well. This arrangement affects the layout of the spaces but appears to allow sufficient room for the machiner. A ramp will have to be provided by each well-type ship to bridge from the well to the poop deck. This could be stowed overhead and dropped into position. It will also be needed for the 320,000-pound planing craft.

150,000-Pound Air Cushion Craft

The Bell 150,000-pound payload, 50-knot speed design was selected. It was the only craft of this type approved for analysis.

320,000-Pound Planing Craft

The Bowker 320,000-pound payload, 35-knot speed design was selected. However, to allow it to fit in the forward part of an LHA well, its width was arbitrarily reduced to comply with the LHA well dimensions. The Bowker has stern access but not a stern ramp; stern loading depends on a ramp provided by the well-type ship.

Present-Day Landing Craft

Present-day landing craft were used in the analyses to provide a common reference and to evaluate the performance of mixes of present day and advanced craft. The present-day craft used in the base system analysis included LCM-6, LCM-8 (steel) and LCU (1637 class) craft. We also examined several of the more advanced amphibian vehicles now in service, including: LARC-15 and LCA. These vehicles can cross the beach line but have low speeds through the water. The characteristics of these present-day craft are summarized in Table 3.

Table 3

CHARACTERISTICS OF PRESENT-DAY CRAFT

Designation	Payload (thousands of lb)	Gross Weight (thousands of lb)	Water Speed (knots)	Amphibian	Outside Dimensions	
					Length (ft)	Width (ft)
LCM-6	68	139	9.0	No	56.0	14.0
LCM-8 (Steel)	120	260	9.0	No	73.5	21.0
LCU 1637	375	699	11.0	No	134.8	30.5
LCA	60	136	12.0	Yes	52.0	21.0
LARC-15	30	79	8.4	Yes	45.0	14.5

Source: NSRDL (Naval Ship Research and Development Laboratory) Prior Craft Review.

Method of Analysis

Carefully selected mixes of advanced craft, advanced craft and conventional craft, and conventional craft were compared by using computer programs and procedures that are described in the base system report. The computer programs and brief descriptions of each are listed in Table 4. The procedure followed to develop information on each craft mix is summarized below.

The set of computer programs was designed to simulate the performance of a specific mix of landing craft when delivering a given Marine

Table 4

COMPUTER SIMULATIONS

Marine Force Description (FORCE)

Essentially a data base designed for each modification. Punched cards with data for individual vehicles or items of cargo are assembled into serials, tactical units, and other organizational units.

Amphibious Ship Embarkation (EMBARK)

Loads the Marine force aboard ships of the amphibious fleet.

Landing Craft Selection (CRAFT)

Revision of the program SELECT described in the baseline system report. Selects landing craft of the most appropriate types to accommodate each serial of the Marine force.

Landing Craft Loading (PREBOAT)

Modification of the SELECT program. Fits serials that are to be preboated into the specific craft mix selected for a run.

REVISER

Checks the validity of the output from EMBARK and transforms it so that it is in the input format required by STS-2.

MERGER

Takes the STS-2 compatible output from REVISER and PREBOAT and merges it with hand-prepared input. The result can be used to run STS-2 without any further modification.

STS-2

Stimulates ship-to-shore movement and provides basic data for craft comparisons.

STSPAR

Revision of the program STSTAPE used previously. Reorders the STS-2 output for easy editing.

EDIT

Extracts data from the STS-2 output, combines them, and summarizes them to facilitate craft comparisons

PLOT

Program to display graphically the EDIT output in more easily interpreted form.

force ashore in a specified environment. The simulations produce the data necessary to calculate the measures of effectiveness for the craft mix. They also plot curves of performance versus time (see Appendix A for sample sets of curves). The principal inputs to the simulations are:

- The size and composition of the Marine force
- The types of landing craft to be used
- The ship types and number of each type in the amphibious fleet
- The environment*
- The embarkation.

In selecting the Marine force, it is only necessary to specify gross force composition. Using these inputs, the Marine Force Description Model (FORCE) completely defines the Marine force down to the characteristics of each individual vehicle and its combat load. The force is organized into serials for tactical and administrative integrity, and serials are associated in tactical units when it is desirable to load two serials onto the same ship or designate a specific ship or ship type for a serial.

A balanced craft mix for each run is selected from among the craft types specified. A balanced mix includes at least one craft capable of carrying the heaviest individual vehicle load in the force (the tank retrievers) and at least one craft that can be deck loaded on LKAs. In addition, the two or three craft types in each mix should complement one another with respect to operating characteristics and effective use of ship well areas.

The number of each craft type to be included in the mix is determined through an iterative process that includes the CRAFT and PREBOAT programs and hand fitting the craft into (or onto) amphibious ships. Initially, the CRAFT program is used to fit individual serials of the force dimensionally into the selected craft types. This program considers each serial in turn and selects for it the most efficient combination of craft to carry it ashore, based on the cargo well area occupied by the load. When all serials in the force have been examined, the total craft selected yields the proportion of each craft type that gives the most efficient transport for all serials. The selected craft

* Beach width and length, beach profile, anchorage area (or sea echelon area), standoff distance, sea state, and general landing tactics.

types are hand fitted into the available ships in a mix that efficiently uses the ships' carrying capability and closely approximates the proportions determined by CRAFT.

PREBOAT is used to fit serials designated for preboat loading into the specific craft mix that has been selected as a result of hand fitting craft into well-type ships. The preboat designated serials are assigned to craft in the order of their priority. Preboat serials are not designated for craft that will be transported to the objective on nonwell-type ships. No serial is partially preboat. When a poor fit occurs, adjustments are made in the priority of the preboat serials, of in the mix of the craft, or in both, and the process continues until a satisfactory stopping point is reached.

The EMBARK model follows PREBOAT and loads the balance of the force, i.e., the nonpreboat serials, into the amphibious ships. It recognizes ship preferences and makes assignments to specific hull numbers as required. Ships are described to EMBARK in terms of the areas available in each ship for carrying portions of the force and limitations on the type of vehicles or cargo that can be carried in each area. Broken stowage factors that reflect the physical layout of the area are used for each area of a ship. EMBARK spreads the serials among the ships of the fleet to provide a maximum number of parallel loading stations throughout the assault. The results of EMBARK are recorded on magnetic tape and run through REVISER for verification and conversion to STS-2 compatible format. Additional input data for STS-2 are prepared by hand. These data include craft performance characteristics, loading and unloading rates, and attrition factors. A geographical description of the landing is developed to include ship locations, beach width (including number of unloading stations), and other data. The sea state is reflected in the craft performance characteristics. The MERGER program assembles all the necessary input data onto a single tape for transmission to NWL, Dahlgren.

The STS-2 model accounts for all the important landing craft-related events in the movement of Marine assault force from the ships of the amphibious fleet to its first destination beyond the assault beach. A separate version of STS-2 also accounts for helicopter lift of vertical assault forces and the subsequent movement of cargo by helicopter. The STS-2 program keeps track of ship positions and movements and simulates craft-loading operations, including queues of craft awaiting loading stations. It simulates beach unloading operations, including queues of craft awaiting unloading positions and cargo queues (beach dumps) awaiting movement inland. Landing craft damage and destruction are simulated by attrition of landing craft at rates that depend on the individual craft's position and vulnerability and on the time since the assault was launched.

Selected STS-2 output is transmitted to SRI for further processing. The data are first checked and packed onto one or two magnetic tapes for more efficient storage. The tapes are edited to extract specific data of interest from the standard STS-2 tables to provide time histories for items of interest, to compute rates and other values, and to tabulate selected distributions. Finally, some data are displayed graphically by the PLOT program for ease of interpretation. The measures of effectiveness are extracted from edited data and graphs.

Amphibious Environments

Two amphibious environments have been used for the comparisons of advanced landing craft. These were carefully selected from the results of the base system analysis to give a moderately severe test of alternative landing craft. The environments differ only in the mean distance offshore (standoff distance) from which the assault is launched. In the first environment, standoff distance is nominally 5 nmi. This distance was selected to test the advanced craft in an environment that is particularly favorable to present-day craft. In the second environment, the standoff distance is nominally 25 nmi. This distance was selected to measure the importance of speed to advanced craft. Other environmental features common to both standoff distances are summarized below.

Marine Force

The base system analysis revealed that landing craft performance is not particularly sensitive to variations in Marine force composition. Therefore, the advanced craft comparison runs were based on the unaugmented MAF (Marine Amphibious Force).*

Amphibious Fleet

The principal difference between the amphibious fleet used in the advanced craft comparison runs and the fleet used in the base system runs is in the addition of LHA-type ships to the former fleet. The addition of LHA type has an important influence on the numbers and types of landing craft that can be carried by the fleet.

* See Means and Vaughn, op.cit.

Landing Plan

Because landing craft performance is relatively insensitive to changes in landing plans, the basic plan used in the base system analysis was selected for the close-in assault (5-nmi standoff distance). Some variant of a sea echelon formation is indicated for the long standoff distance because of water depths at this distance. However, an amphibious assault has not been launched from a sea echelon since World War II. Existing doctrine on sea echelon formations does not reflect the full range of defensive weapons available to a potential enemy today. Furthermore, although fleet dispersion poses enormous communication and navigation problems, it need not significantly increase the distances traveled to individual craft. Therefore, in the analysis, we merely displaced the existing formation 25 nmi offshore without changing relative ship positions.

Beach Characteristics

Approximate beach dimensions and operation of the beach dumps are discussed in Appendix B. Beach characteristics were assumed to be favorable to displacement and planing craft, even though these conditions do not occur frequently worldwide. A beach slope of 2 percent was assumed, with no sand bar or other offshore obstacle. Easy access from the beach to hard ground was assumed for ACV and other amphibian craft.

Sea State

Sea state 2 was selected for the analyses, because it offers challenge to the advanced craft but does not prevent planing craft from operating in planing mode. We discarded the notion of examining a range of sea states, because data on advanced craft performance in different seas are judged inconsistent for the different designs.

Landing Craft Attrition

The comparisons of advanced landing craft used attrition factors calculated for enemy action (by geographical location), mechanical failure, and personnel error. These attrition factors, based on the best available information are reported elsewhere.* Similar attrition factors were calculated for existing craft for comparative purposes.

* See Grant, Andrew R., "Vulnerability of Landing Craft," NWRC/LSR RM-52, Stanford Research Institute, Menlo Park, California, April 1969.

Performance Characteristics

Landing craft performance information for specific operating circumstances was calculated from the performance data provided by the different craft designers. Maneuvering time in and out of ships' well was calculated, together with time to beach and retract. The assumptions concerning craft and ship actions are given in Appendix B.

The time required to load vehicles and cargo into craft from different ships to unload them later onto the beach were estimated from observations of amphibious exercises and from tests conducted by the Marine Corps.[†]

When selecting the amphibious environment and calculating craft performance characteristics, the study team deliberately favored planing craft over air cushion craft; that is, planing craft were generally given the benefit of any doubt, and air cushion craft were not. The selection of a 2-percent beach gradient without sand bar favors planing craft. The procedures outlined in Appendix B for ballasting and deballasting well-type ships favor mixes of all planing craft. It was assumed that the beam of the 320P could be reduced so that it could fit into the forward part of an LHA well. Furthermore, the maneuvering times assigned to air cushion craft do not reflect the maneuverability that might be available with advanced designs. This conservative approach was adapted to mitigate the enthusiasm that has been directed toward air cushion craft and to assure that advanced planing craft are given every opportunity for selection.

System Costs

Amphibious landing craft system costs were estimated by using an AACOST model that was developed for this purpose.* Following the requirements of the DOD programming system, the model computes and sums: (1) research, development, test, and engineering (R,D,T, & E) costs; (2) initial investment costs; and (3) annual operations costs to compute 10-year systems costs. The specific cost categories in the model are listed in Table 5.

[†] See Nielsen, op.cit.

Summary of Analytical Work

Two sets of simulation runs were made to identify the advanced craft designs that are worthy of further consideration. The first runs used the close-in environment and sought to determine:

- (1) Whether advanced craft are significantly more effective than present-day craft in an environment that favors present-day craft
- (2) Whether any of the advanced craft sizes are significantly less attractive than other sizes
- (3) The best mixes of advanced craft
- (4) The improvement in effectiveness achieved by replacing one or two of the present-day craft with advanced craft types
- (5) The potential role for LCA and LARC amphibians.

The second set of runs used the long standoff environment and sought to determine:

- (1) Whether present craft can play an effective role in long standoff amphibious assaults
- (2) The relative performance of long standoff assaults versus close-in assaults when advanced landing craft are used.
- (3) Whether a specific set of "best advanced landing craft" can be identified at this time.

The procedure by which specific runs were selected is described in Chapter III. The results of the investigations are presented in Chapter IV and summarized in Chapter II.

* See Jorgensen, David G., "Cost Model and Cost Estimates," NWRC-LSR RM, Stanford Research Institute, Menlo Park, California, March 1969.

Table 3

COST CATEGORY DEFINITIONS

Chart of Accounts	Definitions
R&D&L	
1. Engineering & development support	Initial design engineering and support costs
2. Initial tooling and prototype fabrication	Tool design and fabrication, plus complete construction cost of first craft
3. Test and evaluation	Contractor test and evaluation including planning, instruction, operating costs, and data analysis
Initial Investment	
1. Sustaining engineering	Design modifications, systems integration, shop and vendor liaison, and so forth
2. Sustaining tooling	Tool planning, jigs, fixtures, and so forth
3. Fabrication	Complete cost to build total craft required for one MAF; summation of account items 4, 5, and 6 below
1. Hull fabrication	Total procurement cost for hull only (Cost Category 1)
5. Propulsion	Turbines, transmission, shafting, lifting, lift or foils, propellers (Category 2)
6. Other construction	Electric plan, communications and control, auxiliary systems, outfit and furnishings (Categories 3-6)
7. Initial spares	Pipeline and depot spares to complement initial craft procurement
8. Support equipment and modification	Support requirements and modifications to fleet caused by new craft
9. Initial training	Training to obtain proficiency in new specialties required by introduction of a new craft
10. Program management	Operations liaisons offices, documentation, and the like
Annual Operations	
1. POL	Consumption of petroleum, oil, and lubricants
2. Support costs	Engineering changes and improvements
3. Peacetime attrition	Operational losses
1. Operating personnel	Military pay and allowances and support costs of craft operators
5. Annual Training	Annual, transitional, and replacement training; schools, and instructor pay
6. Shipboard maintenance: labor	Field level corrective, preventive, and servicing maintenance
7. Shipboard maintenance: material	Field level replacement spares
8. Overhaul maintenance	Depot overhaul of structure, engines and all other systems
9. Support equipment	Maintenance of equipment that was installed on ships to handle the advanced craft
10. Depreciation	Wearing out of conventional craft

II CONCLUSIONS

The comparisons of preliminary designs of advanced landing craft have clearly established that the advanced craft are potentially much more effective in the support of amphibious assaults than are any of the present-day craft. When one compares direct ratios of the weighted sum of effectiveness measures divided by ten-year amphibious system costs* advanced craft are significantly more cost-effective than present-day craft. Table 6 lists weighted effectiveness values and effectiveness

Table 6

EFFECTIVE AND EFFECTIVENESS-COST COMPARISONS

Run Number	Craft Mix	Standoff Distance (nmi)	Weighted Effective- ness Factor	Effectiveness/ Cost Ratio
17	125P, 150ACV, 320P	5	1.413	1.23
13	10P, 125P, 320P	5	1.356	1.14
8	30ACV, 125P, 320P	5	1.333	1.12
Baseline	LCM-6, LCM-8, LCU	5	1.000	1.00
20	30ACV, 150ACV, 320P	25	2.490	2.18
19	30ACV, 125P	25	2.356	1.98
26	30ACV, 150ACV	25	2.210	1.97
23	125P, 150ACV, 320P	25	2.336	1.97
Baseline	LCM-6, LCM-8, LCU	25	1.000	1.00

* The amphibious system includes, in addition to landing craft, the ships of the amphibious fleet and the Marine force being carried. It does not include fire support ships or naval units engaged in protecting the amphibious fleet.

cost ratios for the baseline system and for the most attractive of the advanced craft mixes at both 5 nmi and 25 nmi standoff distances. It is significant that the advanced craft mixes are 33 to 41 percent more effective in supporting close in amphibious assaults (5 nmi) than are baseline craft. Even when cost is taken into account, advanced craft are 12 to 23 percent more attractive. At long standoff distances (25 nmi), the dominance of advanced craft over baseline craft is overwhelming.

The performance of present-day craft in long standoff assaults is unacceptable by any reasonable set of criteria. From 25 nmi off the beach, present craft require 2-1/2 hours to deliver the preboated loads ashore. Round trip times for subsequent loads require 6-1/2 to 7-1/2 hours. With these delivery times, response to changing conditions ashore is almost impossible during the critical stages of the assault phase. Thus, for long standoff assaults, it is essential that advanced landing craft be developed.

The most effective and most cost-effective landing craft mixes (see Table 6) contain two or three of the following four craft:

30,000-lb payload air cushion craft

125,000-lb payload planing craft

150,000-lb payload air cushion craft

320,000-lb payload planing craft.

Because of uncertainties of cost and performance data and uncertainties about the operating procedures assumed for the analysis, the differences among mixes of these four craft are not significant.

It is not clear at this time whether two or three new advanced craft are needed. The effectiveness-cost analysis suggests that a mix comprising three craft types is both more effective and more cost-effective than a mix comprising only two craft types. However, both Run 19 (30ACV and 125P) and Run 26 (30ACV and 150ACV) were attractive at long standoff distances but not as attractive as Run 20 (30ACV, 150ACV, 320P). Because development costs are not a dominant fraction of ten-year life cycle costs, the two craft mixes are not significantly cheaper than the three craft mixes. However, it is clear that at least two new craft types should be provided: (1) a craft suitable for deck-loading aboard LKAs and (2) a craft capable of carrying the largest items of Marine Corps cargo (at present the M51 tank retriever weighing 60 tons) and also operating in heavy weather. The 125P may be capable of filling both roles; however, it is likely that a larger craft will be needed.

It is clear that whatever number of new craft types are finally selected, these craft should not be supplemented with present-day craft in the performance of an amphibious mission. By occupying critical loading and unloading positions, present craft severely impede the operations of advanced craft and cause reductions in the effectiveness of the mix as a whole. Even at a nominal 5 nmi standoff distance, craft mixes made up of both existing and advanced craft are substantially less effective and less cost-effective than mixes made up entirely of advanced craft. Furthermore, mixes of existing and advanced craft are only marginally more attractive than mixes made up entirely of present-day craft. These results suggest that the Navy would materially compromise the entire landing craft program unless a full set of advanced craft were developed.

Figure 1 summarizes the results of simulation runs for the baseline system and the more attractive advanced craft mixes at both 5- and 25-nmi standoff distances. Each of the advanced craft mixes is significantly more effective than present-day craft in all measures of effectiveness at both the 5- and 25-nmi standoff distances except in the square feet of Marine vehicular cargo lost during the assault phase. With respect to this measure, the baseline system ranked third after two of the advanced craft mixes at 5 nmi and ranked second after one advanced craft mix at 25 nmi. However, because of the baseline system's poor performance relative to the other runs, less Marine Corps cargo was exposed to loss in the baseline runs. Attrition time suggests that for comparable amounts of cargo, the baseline systems would be less effective than most advanced craft mixes. Moreover, total cargo lost is still a small fraction of the Marine force, even in the worst case.

Despite smaller quantities of preboated cargo because of smaller ratios of cargo well area to gross craft area, advanced craft mixes were distinctly superior to the baseline systems in force-time effectiveness. At 5 nmi standoff, advanced craft mixes (with one exception) had 6 to 42 percent higher measures of force-time effectiveness than the baseline system. At 25 nmi standoff distance, all advanced craft mixes except one had at least twice the force-time effectiveness of the baseline system. In terms of the time to off-load 200,000 square feet of vehicles from 5 nmi, the best craft mix was 40 percent more effective than the baseline system, and the poorest advanced craft mix was as effective as the baseline system. From 25 nmi the best advanced craft mix could off-load 200,000 square feet of vehicles four times as fast as the baseline system.

The landing craft mix has a very important influence on the amount of Marine cargo that can be preloaded in the craft carried aboard well-type ships. Variations of 2 to 1 in the square feet of preboated vehicles were observed. These variations suggest a corresponding variation in

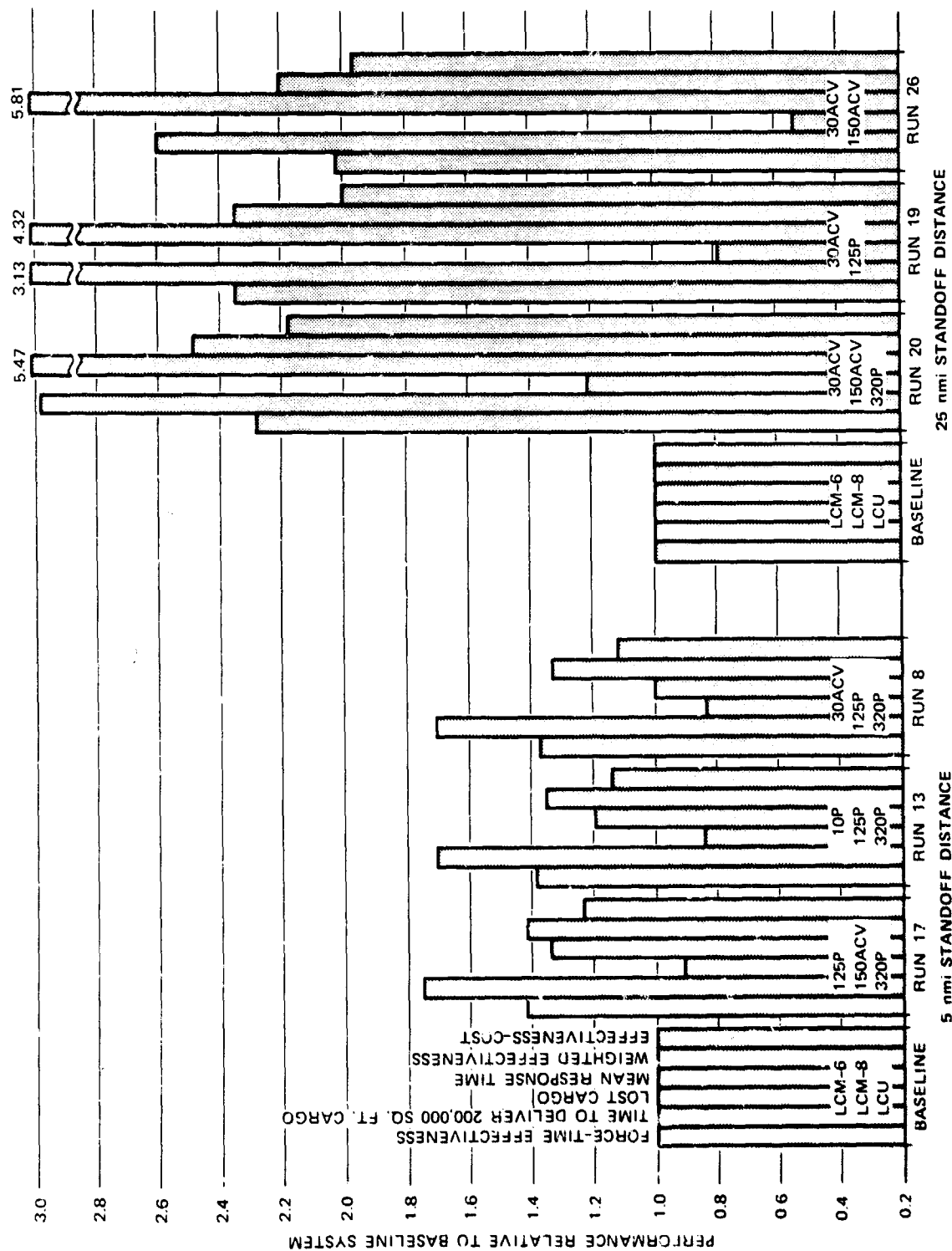


FIGURE 1 EFFECTIVENESS AND EFFECTIVENESS-COST FACTORS FOR SELECTED RUNS

the number of Marine Corps serials that can be preboated for fast response to urgent calls. With advanced craft mixes, it will not be possible to preboat all on-call serials as is the practice with present craft. As a result, some on-call serials will be aboard ship when called ashore. Mean response time measures the delay in getting these serials ashore. Mean response times as long as 43 minutes were observed for mixes of advanced craft. Craft mixes with two ACV-type craft gave the best response to urgent calls for nonpreboated cargo. It is significant that mean response times for advanced craft at 25 nmi standoff are less than 50 percent longer than mean response times at 5 nmi standoff.

Despite its good performance in Run 13, the 10P craft (10,400-pound LCVP size) is distinctly inferior to the other advanced craft. In all the runs, 10P craft were included in large numbers (68 to 114), but these craft made very small contributions to the amphibious assault as a whole. Figure 2 shows the cumulative force-time effectiveness for all craft in Run 13. At H+7 hours, the 83 10P craft have contributed 7-1/2 percent of the force-time effectiveness and a like fraction of the vehicles delivered ashore. In fact, at 5 nmi standoff distance, the 10P contributed less to the simulated amphibious assaults than any other craft, advanced or present day, except for the LARC 15. Furthermore, all but one of the craft mixes that included the 10P craft (Run 13) showed relatively poor performance. Therefore, we recommend that the 10,400-pound planing hull craft be dropped from further consideration.

Mixes of advanced craft are more effective and as cost-effective, in supporting an amphibious assault launched from 25 nmi offshore than present craft are in supporting an amphibious assault launched from 5 nmi offshore. The relative performance of the best advanced craft mixes from 25 nmi and the baseline system from 5 nmi are listed below:

Run Number	Craft Mix	Force-Time Effective- ness	Time to Deliver 200,000 ft of Cargo (hrs)	Last Cargo (sq ft)	Mean Response Time (min.)
Baseline	LCM-6, LCM-8, LCU	780	8.4	5,590	43
20	30ACV, 150ACV, 320P	829	6.7	4,002	34
19	30ACV, 125P	854	6.4	6,134	43
22	30ACV, 125P, 320P	899	6.5	6,126	50

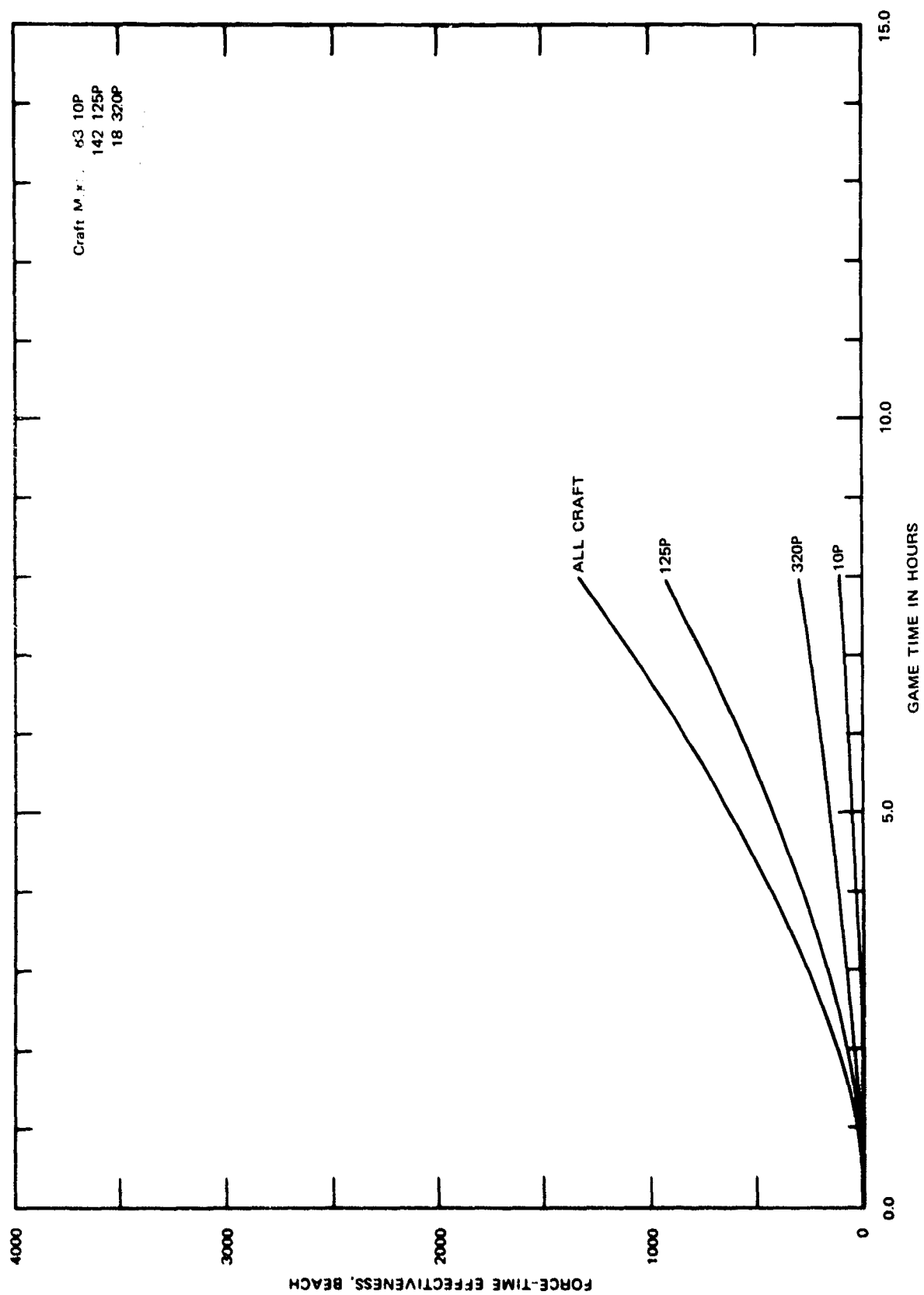


FIGURE 2 FORCE-TIME EFFECTIVENESS ADVANCED RUN 13

When these factors are combined to yield composite effectiveness and divided by cost, the results are:

	<u>Effectiveness Factor</u>	<u>Cost Factor</u>	<u>Effectiveness/ Cost Ratio</u>
Baseline	1.000	1.00	1.00
Run 20	1.195	1.14	1.05
Run 19	1.114	1.19	0.94
Run 22	1.118	1.19	0.94

It is not possible to draw significant conclusions about the relative attractiveness of individual advanced craft. As indicated above, no clearly superior craft mix emerged. Performance differences between attractive mixes are less than the uncertainties about craft characteristics and operating procedures. Nonetheless, some observations can be made that may be of value in guiding future work. Some insight can be gained by exploring the productivity of each craft in terms of the amphibious ship well space that each one occupies. Table 7 lists relative craft productivity per square foot of well space occupied for advanced and

Table 7

MEAN CRAFT PRODUCTIVITY AT 5 AND 25 NMI
STANDOFF DISTANCES

<u>Craft Type</u>	<u>Mean Productivity</u>	
	<u>5 nmi Standoff</u>	<u>25 nmi Standoff</u>
10P	1.69	
30ACV	2.32	2.18
125P	2.97	2.08
150ACV	2.21	2.21
320P	2.80	2.62
LCM-6	1.88	0.71
LCM-8	2.11	1.03
LCU	2.48	1.13
LCA	1.85	
LARC-15	1.06	

present-day craft at 5 nmi and at 25 nmi standoff distance. Craft productivity is measured in terms of the square feet of vehicles delivered ashore and represents all runs in which each craft participated. At 5 nmi each advanced craft shows a small advantage over the comparable sized present-day craft. However, at 25 nmi, the baseline craft clearly drop out of the picture. The two ACV craft appear marginally superior to the 125P and inferior to the 320P. However, it is well to bear in mind that the success of the 320P depends on successfully reducing its width so that it can fit in the forward part of an LHA well. Further insight can be gained by investigating the degradation in performance of craft while increasing standoff distance from 5 to 25 nmi. As listed below, present-day craft show a very marked degradation with increased standoff distance. The performance of advanced planing craft is degraded by almost one-fifth while air cushion craft show almost no degradation.

	Percent of <u>Degradation</u>
Present craft	56%
Advanced planing craft	18
Advanced air cushion craft	1

The performances of LCA and LARC-15 craft were disappointing even at short standoff distance. The LCA was about 20 percent less effective than the 30ACV, and the LARC-15 was the least effective of all craft examined. This work suggests that the LCA is substantially more effective than the LARC vehicles, but it is still substantially less effective (particularly at long standoff distances) than any of the advanced craft.

The strong case made above is supported in subsequent chapters for the continuation of the advanced landing craft program (S14-17). Advanced craft clearly have great potential if naval tactics include long standoff amphibious assaults. Even if naval tactics do not include long standoff amphibious assaults, advanced craft are potentially superior to baseline craft and existing experimental and developmental craft. Preferences among advanced craft types are clouded by the uncertainties of craft data. Therefore, definitive comparisons cannot be made among the 30ACV, 150ACV, 125P, and 320P craft. We strongly recommended further design work to better define each of these craft. If a vastly improved 30P craft can be devised, this size might also be included. If one

craft is to be singled out for accelerated development, it should be the 150ACV for the following reasons:

- (1) Because of their superior performance at long standoff distances and their potential for crossing beaches and marginal terrain, it is felt that the advanced craft mix should include at least one air cushion type.
- (2) The 150ACV represents the greatest technological advance of any of the advanced craft proposed. As a result, the development of this craft is likely to take the longest time and, therefore, should begin first.

However, it would be a gross error to develop the 150ACV to the exclusion of the other craft. Therefore, SRI endorses the program plan by which development is proceeding on the 150ACV and by which the other sizes are given another round of preliminary design effort.

III SELECTION OF RUNS

The selection of runs was a key part of the comparison of advanced craft because of the need to keep the number of runs to a minimum. As was noted in the baseline system report, each simulation of a complete assault phase requires about 230 minutes of computer time at a cost of about \$1,100. Also, four to six weeks are needed to complete a set of runs, including data transmission between Menlo Park and Dahlgren. Thus, unless great care were used in the selection of runs, the comparison of advanced landing craft would exceed both the available time and the available funds.

To limit the number of runs, two simplifying conventions were adopted. First, the study team decided to simulate each craft mix and environment only once. The work with the baseline systems supported the contention that there are sufficient craft and a sufficient number of craft trips in each assault phase simulation to avoid making repetitive runs to calculate estimators for the different measures of effectiveness.* Thus the result of each single run does represent the particular mix of craft and environment being tested. Second, it was decided to perform the craft comparisons in two sets. Each set was carefully selected to answer specific questions that would narrow the field of potentially attractive advanced craft.

For Set One the close-in assault (5 nmi standoff distance) was selected. By this choice, the advanced craft could be tested in an environment in which they have the least advantage over existing craft. Because of short distances, craft cycle time and thus performance is dominated by loading and unloading activities. Therefore, the environment is ideal for answering the following questions:

- (1) Are advanced craft always more effective than present craft?
- (2) Are one or more of the advanced craft significantly less attractive than the others?

* Subsequent investigations with the GAMUT model described in Chapter V revealed that the standard deviations of the measures of effectiveness are about 1 to 2 percent.

- (3) Are combinations of advanced craft and present craft attractive?

For Set Two, the long standoff distance (25 nmi) was selected. This set of runs was intended to test the attractiveness of the different advanced craft speeds. It also compared advanced craft performance from long standoff with present-day craft performance close in and provided evidence on the feasibility of long standoff assaults with present craft. With this set of runs we hoped to realize a large differentiation among the craft types within the limits of accuracy of design, performance, and operating data.

Set One Runs

After performing the analyses described in Chapter I, five advanced craft types remained to be tested: 10P, 30ACV, 125P, 150ACV, and 320P. The characteristics of these craft are summarized in Table 2. We were interested in mixes of both three craft types and two craft types. However, for Set One, we selected only mixes of three craft types, since these provide more comparative data than mixes of two craft types. There are ten possible combinations of these five craft when they are considered in sets of three. All ten are displayed in Table 8. Since some results

Table 8

ALL POSSIBLE COMBINATIONS OF FIVE ADVANCED CRAFT (Three Craft at a Time)

<u>Run Number</u>	<u>Craft Mix</u>	<u>Reason for Not Running</u>
7	10P, 30ACV, 125P	
11	10P, 30ACV, 150ACV	
12	10P, 30ACV, 320P	
--	10P, 125P, 150ACV	Poor performance of 10P in other runs
13	10P, 125P, 320P	
2,3	30ACV, 125P, 150ACV	
8	30ACV, 125P, 320P	
1	30ACV, 150ACV, 320P	
9	125P, 150ACV, 320P	
--	10P, 150ACV, 320P	Poor performance of 10P in other runs

of earlier runs were available before the entire first set of runs was completed, it was possible to eliminate two of the ten possibilities on the basis of the consistently poor performance of the 10P craft.

The Set One analysis also included the present-day operational craft--LCM-6, LCM-8, and LCU--as well as two existing developmental craft--the LCA and LARC-15. Enough runs were made with the three present-day craft to reach firm conclusions regarding their effectiveness when employed in combination with advanced craft. The LCA and LARC-15 were included in only one run each. The results of these runs clearly suggested that no further analysis was needed. The complete set of runs, together with the number of each craft type used in the simulation is listed in Table 9.

The run numbers are not continuous because two planned runs were found to be unnecessary. Run 14 was a repetition of the baseline system using the new amphibious fleet (with LHA-type ships) and using the results of the craft vulnerability analysis. In Run 9 the smallest craft, the 125P, was not deck-loaded aboard the LKAs because of its size. However, further investigation revealed that each LKA 113 class ship could carry a maximum of five 125Ps. Therefore, the run was repeated as Run 17 with the addition of the deck-loaded 125Ps. Run 18 uses the same craft mix as Run 3, but in Run 18 the 125P craft speed was limited to 20 knots.

Set Two Runs

After analysis of Set One results, four advanced craft types remained for further analysis (the 10P craft had been discarded). The four remaining craft were combined in all four of the possible sets of three craft. In addition, three of the six possible sets of two craft were analyzed. Also, a hypothetical 30,000-pound payload planing hull craft, designated the 30P, was added and examined in two of the Set Two runs.

Table 10 lists the craft mixes used in the Set Two runs, together with the number of craft of each type. Run 24 uses present-day craft. Because of their poor close-in performance, the LCA and the LARC-15, were not simulated at long standoff distance.

Table 9

SET ONE SIMULATION RUNS
(5 nmi Nominal Standoff Distance)

Run Number	Small Craft		Medium Craft		Large Craft		Total Craft
	Type	Number	Type	Number	Type	Number	
1	30ACV	95	150ACV	37	320P	19	151
3	30ACV	68	125P	76	150ACV	32	176
4	LCM-6	142	150ACV	35	LCU	24	201
6	30ACV	126	LCM-8	54	150ACV	28	208
7	10P	114	30ACV	104	125P	104	322
8	30ACV	92	125P	93	320P	26	211
9	125P*	67	150ACV	26	320P	21	114
10	10P	69	125P	94	150ACV	30	193
11	10P	68	30ACV	102	150ACV	38	208
12	10P	100	30ACV	160	320P	30	290
13	10P	83	125P	142	320P	18	243
14	LCM-6	147	LCM-8	56	LCU	41	244
15	LCA	100	150ACV	39	320P	15	154
16	LARC-15	114	150ACV	46	320P	18	178
17	125P	80	150ACV	32	320P	24	136
18	30ACV	68	125P [†]	76	150ACV	32	176

* No craft deck-loaded on LKAs.

† 125P speed limited to 20 knots.

Table 10

SET TWO SIMULATION RUNS
(25 nmi Nominal Standoff Distance)

<u>Run Number</u>	<u>Small Craft</u>		<u>Medium Craft</u>		<u>Large Craft</u>		<u>Total Craft</u>
	<u>Type</u>	<u>Number</u>	<u>Type</u>	<u>Number</u>	<u>Type</u>	<u>Number</u>	
19	30ACV	167	125P	100			267
20	30ACV	95	150ACV	37	320P	19	151
21	30ACV	68	125P	76	150ACV	32	176
22	30ACV	92	125P	93	320P	26	211
23	125P	80	150ACV	32	320P	24	136
24	LCM-6	147	LCM-8	56	LCU	41	244
25	30P	101	150ACV	46	320P	18	165
26	30ACV	135	150ACV	40			175
27	30P	186	125P	138			324
28	125P	90	150ACV	43			133

IV RESULTS

The measures of effectiveness selected for comparing the performance of mixes of advanced landing craft are based on total system performance during the assault phase of a selected amphibious operation. The measures of effectiveness do not bear direct relationships to the specific performance of a particular craft or a particular type of craft. Thus, each of the advanced craft performed especially well in at least one mix and performed relatively badly in at least one mix. Therefore, the task of selecting the most favorable craft or, alternatively, of eliminating the least favorable craft is one of consensus ranking.

Presented first in the results of the analyses of both sets of runs are data and curves on the assault and on the individual measures of effectiveness for each set. Next we present the ranking procedure used to draw the conclusions stated in Chapter II. Because the analyses were limited to assault phase operations only five of the six measures of effectiveness were used: (1) force-time effectiveness, (2) time to deliver 200,000 square feet of cargo ashore, (3) square feet of Marine cargo lost, (4) response time, and (5) mean productivity per craft by type.

Set One Runs

Before statistical analyses can be meaningful, it is important that the analyst understand the simulated results for each run and that he be willing to accept the simulation as a representation of a hypothetical amphibious assault. Figures 3 and 4 show graphically the development of the landings. In these figures the cumulative square feet of vehicles offloaded from the ships of the amphibious fleet are plotted against time after H-hour. The y-axis intercepts of these curves show the amount of cargo that was preboated on the landing craft carried in ships' wells (LSD, LPD, and LHA types). Note that the amount of preboated cargo varies from a low of 52,000 square feet for Run 11 to a high of 100,000 square feet for Run 8. These values reflect three different measures of efficiency: (1) the efficiency with which Marine cargo can be loaded in craft cargo wells, (2) the ratio of craft cargo-well area to total craft outside area for the individual craft of the mix, and (3) the efficiency with which craft can be fitted into the well-type ships. By adopting more or less standard cargo-well dimensions, the effect of the first

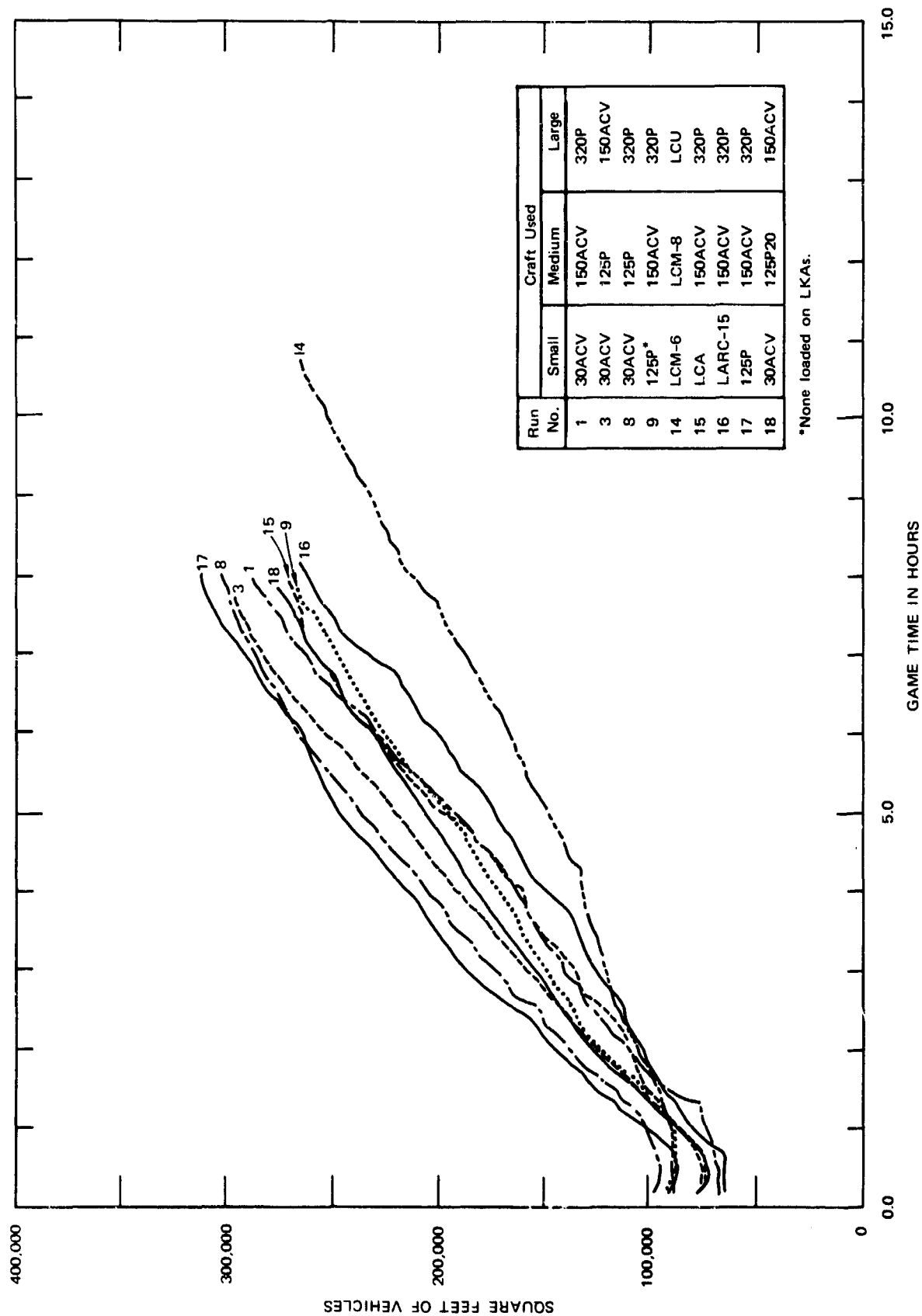


FIGURE 3 VEHICLES OFF-LOADED FROM SHIPS — baseline and 8 advanced runs at 5 nmi

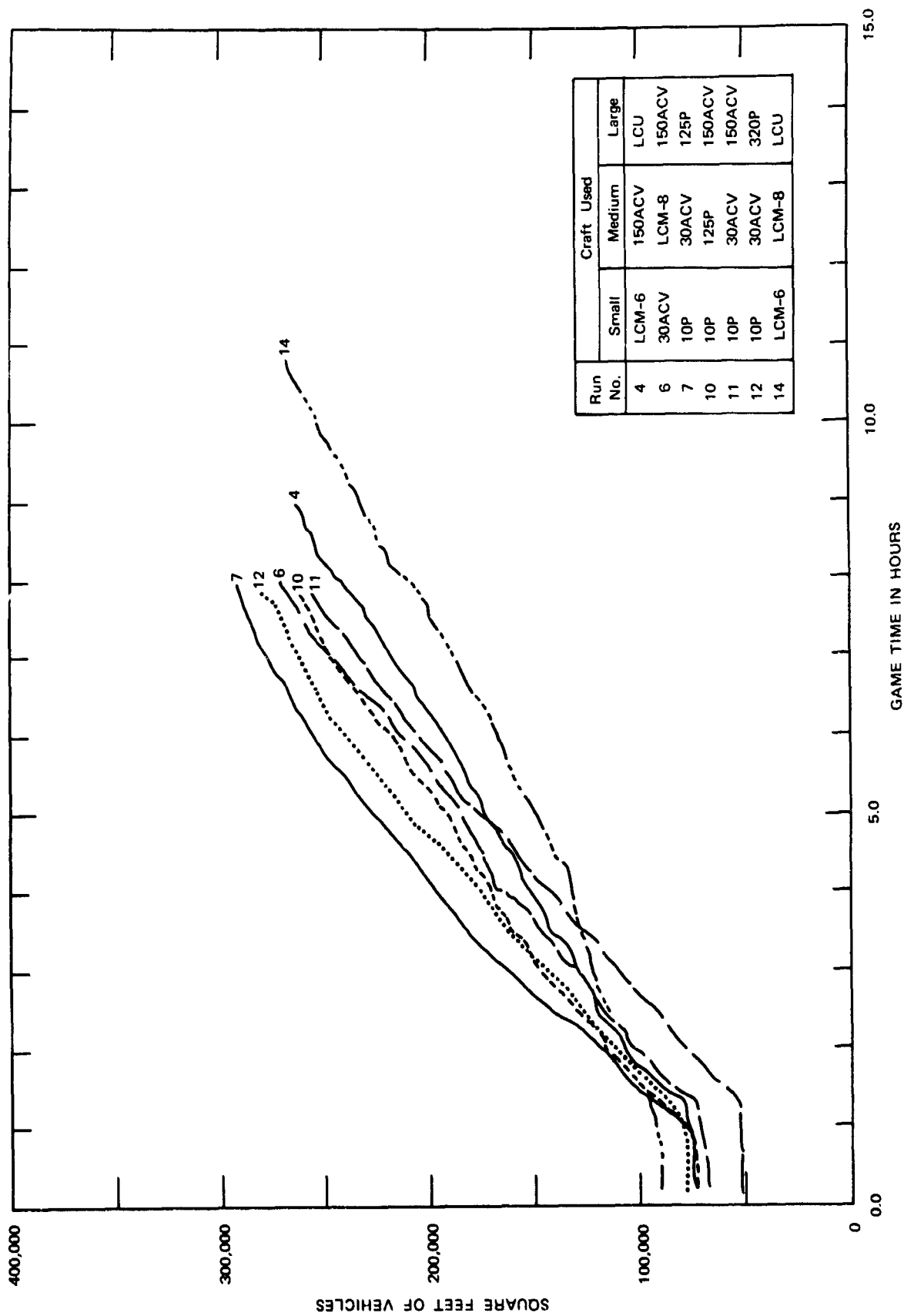


FIGURE 4 VEHICLES OFF-LOADED FROM SHIPS — baseline and 6 advanced runs at 5 nmi standoff distance

efficiency measure was standardized over all runs. The second measure is a function of craft design. The fraction of usable cargo area is higher for planing craft than for air cushion craft and is higher for large craft than for small craft. Specific values of this measure for the five advanced craft and five present-day craft are listed below:

Cargo-Well Area/
Total Rectangular Area

Advanced Craft

10P	0.393
30ACV	0.370
125P	0.442
150ACV	0.375
320P	0.667

Present Craft

LCM-6	0.532
LCM-8	0.427
LCU	0.434
LCA	0.500
LARC-15	0.368

A study of Figures 3 and 4 reveals that the craft mixes with the largest amounts of preboated cargo are combinations of efficient craft.

The slopes of the curves in Figures 3 and 4 represent the rate at which Marine cargo is off-loaded from ships. This rate depends on (1) the number of craft available (which varies over time because of attrition); (2) craft operating cycles, including loading and unloading time, maneuvering time at ships and at the beach, and transit time to and from the beach; and (3) the time craft spend in queues at the ships and at the beach. The influence of each of these factors can be illustrated using the curves of Figures 3 and 4. Runs 9 and 17 include the same number of craft in ships' wells, but Run 9 does not include 125P craft deck loaded on LKAs. Note that the y-axis intercepts of these two runs are the same (same amount of preboated cargo) but that the slopes are dramatically different, the difference being the added delivery capability of the additional 125P craft in Run 17. The craft operating cycles for Run 14 (baseline system) are longer than those for Run 17, principally because of longer transit times. Therefore, the delivery curve for Run 17 has a very much steeper slope (i.e., much faster delivery rate) than the curve for Run 14.

Delivery rates (slope) are also influenced by the number of unloading areas available to landing craft. Because ACV-type craft cross the beach and unload at inland points, craft mixes containing ACV-types have more unloading areas available. Thus the delivery rates for the runs with two ACV-type craft (Runs 1 and 3) are slightly steeper than the rates for runs with only one ACV-type craft (Runs 8 and 17). Runs with a mix of ACV and planing hull craft may provide more delivery capability in a limited beach width situation and thus more flexibility in selecting landing areas.

Examples of Craft Performance

Figures 5 through 14 illustrate the performance of each of the advanced craft and present-day craft types examined in Set One. The curves for each craft type show the cumulative fraction of time that craft spent in different activities as the assault progressed. These curves of necessity are taken from different runs, but each is generally representative of its craft type. However, it is important to note that the performance of each craft type depends on the other craft present in the mix and the relative numbers of each craft type. Complete sets of curves for Runs 17 and 20 are presented in Appendix A.

10P Craft. Figure 5 illustrates the performance of the 10P craft. In this Run (13), 83 10P craft operated with 142 125P craft and 18 320P craft at a nominal standoff distance of 5 nmi. The 83 10P craft contributed less than 10 percent of the force-time effectiveness and delivered less than 10 percent of the vehicles ashore. Sixty-five percent of the 10P craft were deck-loaded on LKAs and carried no preboated cargo. The balance were carried in the well-type ships filling voids that could not accommodate the larger planing craft of the mix. These latter craft were loaded with Marine cargo. Immediately after H-hour* the preloaded craft began moving toward the beach. The first group arrived at H+20 minutes and unloading began. In the meantime, the craft from the LKAs reported to the boat pool and awaited loading assignments. At H+40 minutes the first of these craft had moved to loading stations and began receiving cargo. As the assault phase proceeded, all the 10P craft received assignments and the fraction of time spent in the boat pool decreased. By H+2 hours, all craft were occupied. After H+6 hours, the cumulative time in

* H hour or zero game time on the graph is the time at which the final scheduled wave reaches the beach.

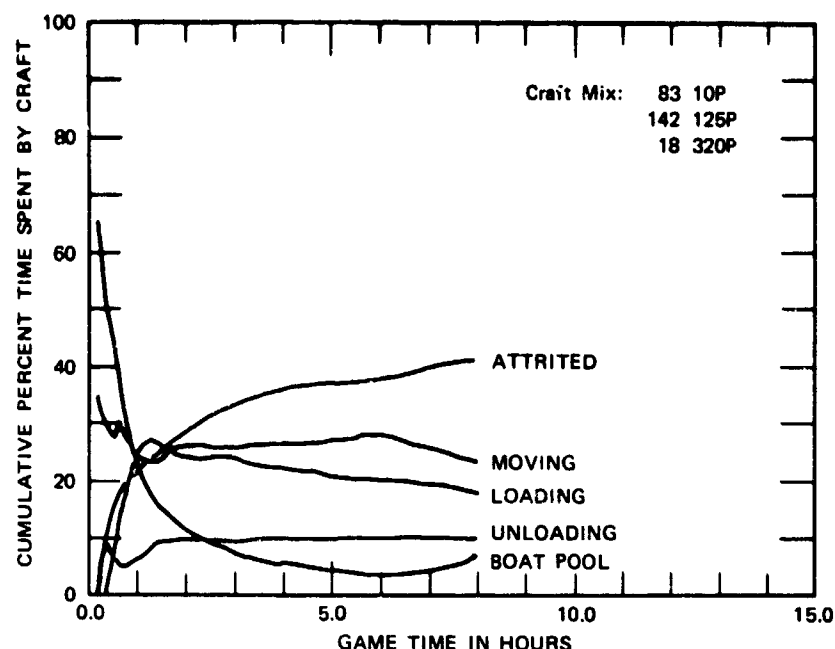


FIGURE 5 DISTRIBUTION OF CRAFT TIME — 10P, RUN 13, 5 nmi STANDOFF DISTANCE

the boat pool again increased. It is evident from the early rise in this curve that 10P craft were the first to be diverted to the boat pool as the assault phase neared completion. The fraction of time out of action rises sharply from the time that the first craft approaches the beach until about H+1 hour when the rate of increase slows. By H+5 hours the distribution of craft time to different activities begins to stabilize at about the following percentages:

Moving	28%	Unloading	10%
Loading	21	Boat pool	4
		Attrited	37

Thereafter, craft activities are influenced by the completion of the assault phase.

30ACV Craft. Figure 6 illustrates the performance of the 30ACV craft in terms of Run 3. The craft mix for this run consisted of 68 30ACV, 76 125P, and 32 150ACV. The assault was launched from a 5 nmi nominal standoff distance. The 30ACV craft accounted for one-sixth of the force-time effectiveness and almost one-fifth of the vehicles delivered ashore. Fifty-four percent of the 30ACVs were deck-loaded on LKAs and carried no preboated cargo. The balance were carried in ship wells and contained preboated Marine cargo. Initially, the preboated craft

headed for the beach, and the empty craft reported to the boat pool. The sequence of activities for the 30ACV craft is the same as that described for the 10P craft. By H+6 hours, the distribution of craft time stabilized at the following percentages:

Moving	18%	Boat pool	2
Loading	31	Attrited	35
Unloading	14		

Because of its higher speed, the 30ACV spends less time moving than the 10P and, proportionately, more time loading and unloading.

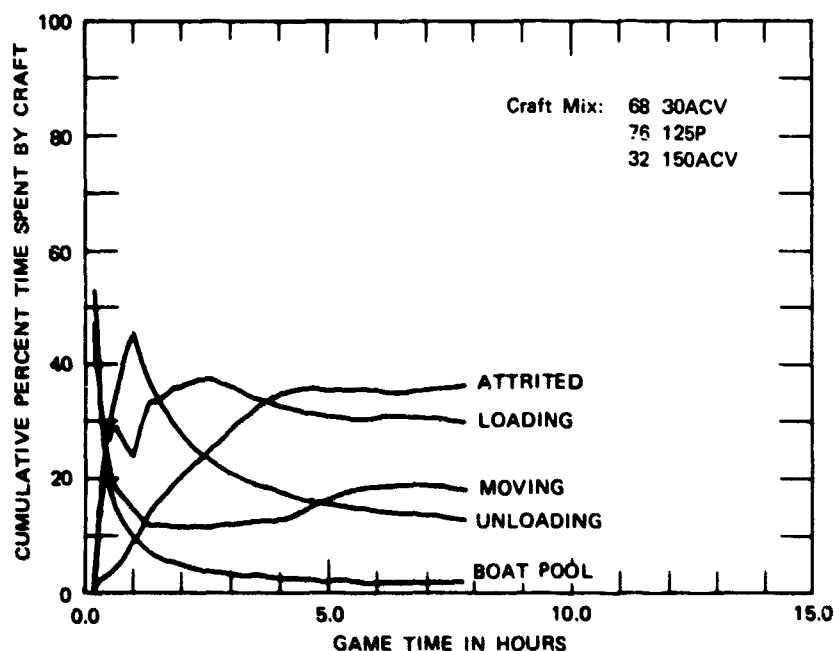


FIGURE 6 DISTRIBUTION OF CRAFT TIME — 30ACV, RUN 3, 5 nmi STANDOFF DISTANCE

125P Craft. Figure 7 illustrates the performance of the 125P craft in Run 17 from a nominal standoff distance of 5 nmi. The craft mix was made up of 80 125Ps, 32 150ACVs, and 24 320Ps. The 125P craft accounted for more than 35 percent of the force-time effectiveness and more than 40 percent of the vehicles delivered ashore. The imbalance reflects the early inactivity of the craft deck-loaded aboard the LKAs. In this run, 45 percent of the 125Ps were deck-loaded on LKAs without preboated cargo. These craft entered the boat pool at H-hour while the preboated craft moved toward shore. Craft activities for the first few hours after H-hour were similar to those described for the 10P and 30ACV. However, the cumulative fraction of time out of action continues to rise rather

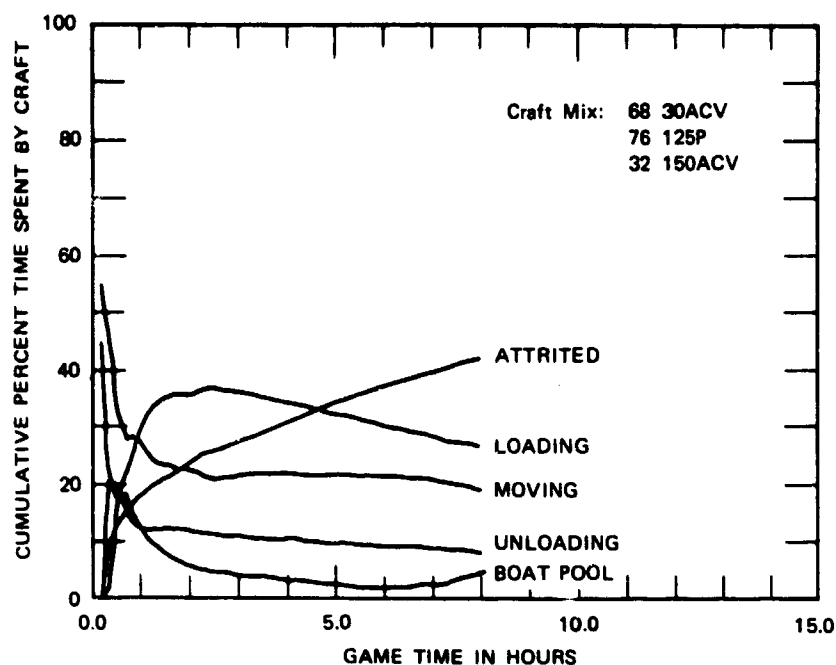


FIGURE 7 DISTRIBUTION OF CRAFT TIME — 125P, RUN 17, 5 nmi STANDOFF DISTANCE

than stabilizing after H+5 hours. This is due largely to mechanical failures and long repair times. Both factors are subject to careful review and revision during later design phases. However, it is important to note that a rising attrition curve is not characteristic of 125P craft in all the advanced craft mixes. At H+5 hours, the approximate breakdown of 125P craft activities is in percent:

Moving	22%	Boat pool	3%
Loading	32	Attrited	34
Unloading	9		

Note that this distribution of time falls between the 10P and the 30ACV craft.

150ACV Craft. Figure 8 shows the performance of the 150ACV in terms of Run 17. The craft mix is the same as that described above for the 125P. The 150ACV craft account for 32 percent of the force-time effectiveness and 28 percent of the vehicles delivered ashore. Thus 32 150ACVs are slightly less productive than 80 125Ps. All of the 150ACV craft are carried preloaded in ships' wells. Thus after the final scheduled wave, all the craft are ready to move toward the beach. The first craft reaches the beach at H+0.2 hour and begins unloading. The fraction of time spent unloading increases, and the fraction of time spent moving declines until

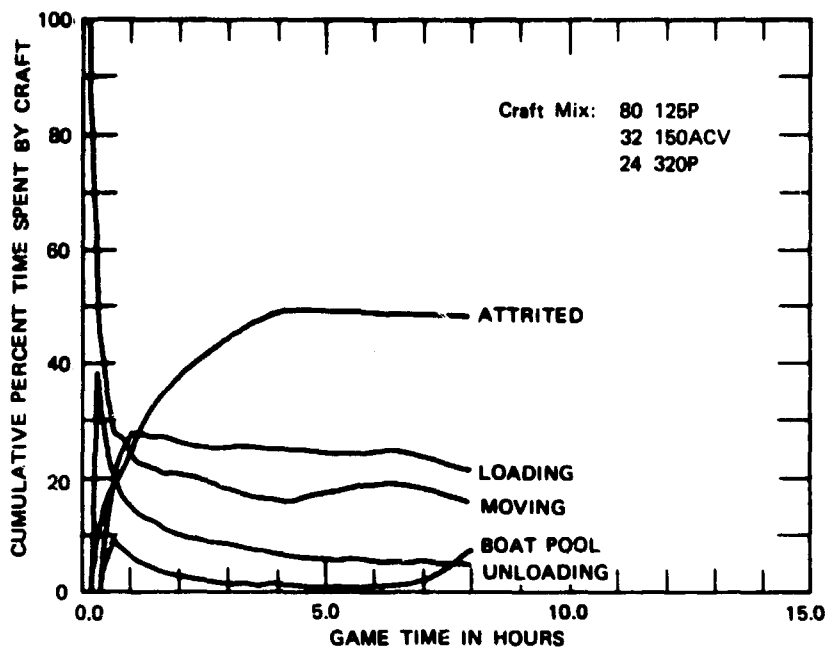


FIGURE 8 DISTRIBUTION OF CRAFT TIME — 150ACV, RUN 17, 5 nmi STANDOFF DISTANCE

all craft are unloaded at H+0.4 hour. At H+0.4 hour, the first of the emptied craft reaches a ship ready to begin loading. Some 150ACV craft cannot be accommodated at ship loading stations and report to the boat pool. By H+0.6 hour all returned craft have been given loading assignments and the cumulative fraction of time in the boat pool begins to decline. Attrition by enemy action, mechanical failure, and personnel error first enters at H+0.2 hour and becomes increasingly important with the passage of time. After H+4 hours and fraction of time spent in the different activities stabilizes, and at H+5 hours the time distribution is at about the following levels in percent:

Moving	18%	Boat pool	2%
Loading	25	Attrited	49
Unloading	6		

320P Craft. Figure 9 illustrates the performance of the 320P craft in Run 17. The 24 320P craft account for almost 32 percent of the force-time effectiveness and 30 percent of the vehicles delivered ashore. In the close-in environment, the 24 320Ps are slightly more productive than the 32 150ACVs despite a payload advantage of more than 2 to 1 and cargo well area advantage of slightly less than 2 to 1. Note also that 320P craft are given priority in loading assignments by the craft selection routine, and therefore no craft time is spent in the boat pool until

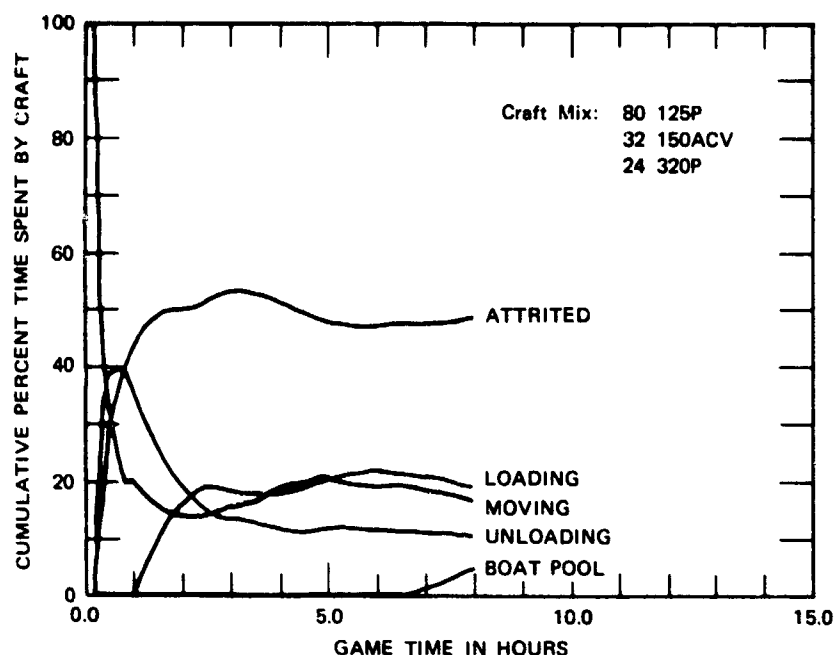


FIGURE 9 DISTRIBUTION OF CRAFT TIME — 320P, RUN 17, 5 nmi STANDOFF DISTANCE

H+6.5 hours when the assault phase is nearing completion. Since all these large planing craft carried preloaded cargo, 100 percent of the craft were moving toward the beach as soon as the scheduled waves had landed. At H+0.2 hour, the first craft reached shore and followed a pattern similar to that described for the 150ACV. The distribution of time among activities for the 320P differed from that for the 150ACV because of the 320Ps lower speed and larger cargo well and load capability and because of the disadvantages of off-loading through the water. By H+5 hours, the distribution of 320P time among activities was, in percent:

Moving	20%	Boat pool	0%
Loading	20	Attrited	48
Unloading	12		

LCM-6 Craft. Figure 10 shows the activity curves for the LCM-6 in Run 14. The craft mix for this run was made up entirely of present-day craft including 147 LCM-6s, 56 LCM-8s, and 41 LCUs. The LCM-6s made up 60 percent of the craft mix but accounted for only 30 percent of the force-time effectiveness and 35 percent of the vehicles delivered ashore. As with other small craft, this disparity is accounted for partly by the slow start of the deck-loaded craft but principally by the small cargo load that LCM-6s carry. About 37 percent of the LCM-6s were deck-loaded

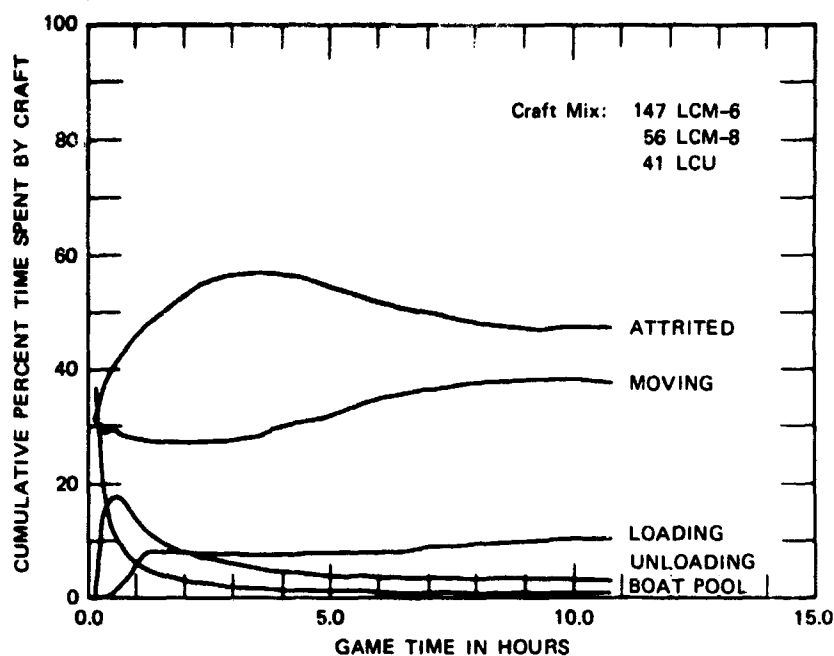


FIGURE 10 DISTRIBUTION OF CRAFT TIME — LCM-6, RUN 14, 5 nmi STANDOFF DISTANCE

on LKAs and initially reported to the boat pool for assignment. The balance was preloaded and proceeded to the beach as quickly as space could be made available for them. Note the especially heavy attrition losses early in the assault. Roughly half the LCM-6s are attrited during their first run to the beach. This results largely from slow speed that provides long exposure to enemy gunners. Craft activities, other than attrition, are dominated by moving, which again, is a result of slow speed. By H+9 hours, the distribution of craft time had settled down to the following percentages:

Moving	39%	Boat pool	1%
Loading	10	Attrited	47
Unloading	3		

LCM-8 Craft. Figure 11 illustrates LCM-8 activities for Run 14. The LCM-8s represented 23 percent of the craft mix, and they accounted for 22 percent of the force-time effectiveness and 21 percent of the vehicles delivered ashore. All LCM-8s are carried in well decks with preloaded cargo. The performance of this mix was sufficiently disappointing that the alternative of deck-loading LCM-8s on 113 class LKAs was not investigated. The LCM-8s also suffered about 50 percent loss on the initial trip. Thereafter, the attrition rate rose, declining after H+3 hours. As with the LCM-6s, moving time dominated LCM-8 activities but

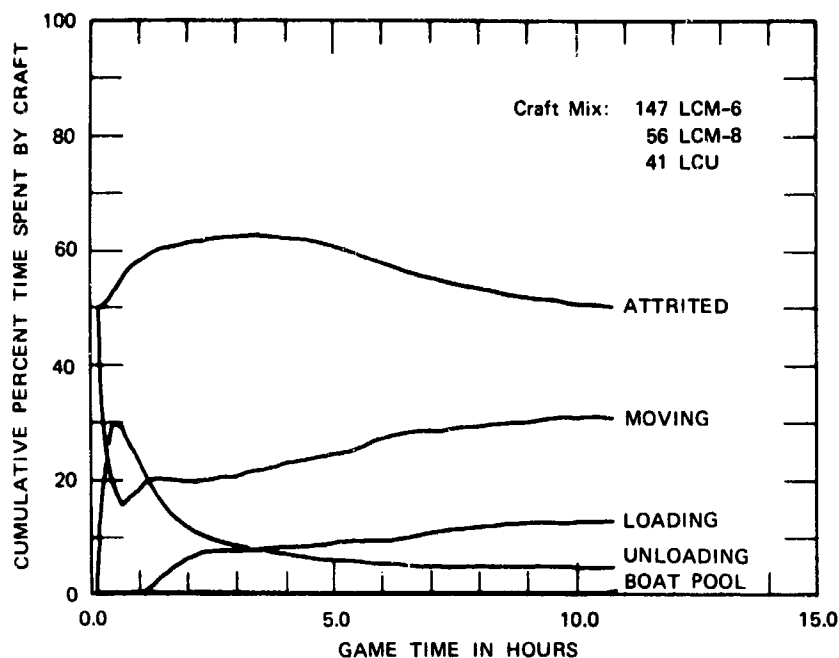


FIGURE 11 DISTRIBUTION OF CRAFT TIME — LCM-8, RUN 14, 5 nmi STANDOFF DISTANCE

loading times were higher than for the LCM-6 because of the LCM-8's larger cargo well. By H+9 hours, craft time was distributed as follows in percent:

Moving	30%	Boat pool	0%
Loading	13	Attrited	52
Unloading	5		

The high attrition rates and slow speeds both contribute to low boat pool residence. In general, sufficient loading and unloading stations are available to accommodate all craft until the assault phase begins to end.

LCU Craft. LCU craft activity is shown in Figure 12. The 41 LCU craft perform the bulk of the work in Run 14. They account for 46 percent of the force-time effectiveness and deliver 43 percent of the vehicles ashore. Their high productivity is due principally to their large size. First run attrition rates for these craft are only 39 percent, significantly less than for the LCM craft. This is due to the LCU's greater versatility in surf and quicker, easier retraction from the beach. However, the LCU's large size and slow speed contribute to a peak attrition of 66 percent at H+3 hours. Thereafter, enemy action is reduced (as friendly forces advance) and the fraction of craft time spent attrited declines. Similar to other present craft, at H+9 hours craft activity is dominated by attrition and moving, as shown below in percent:

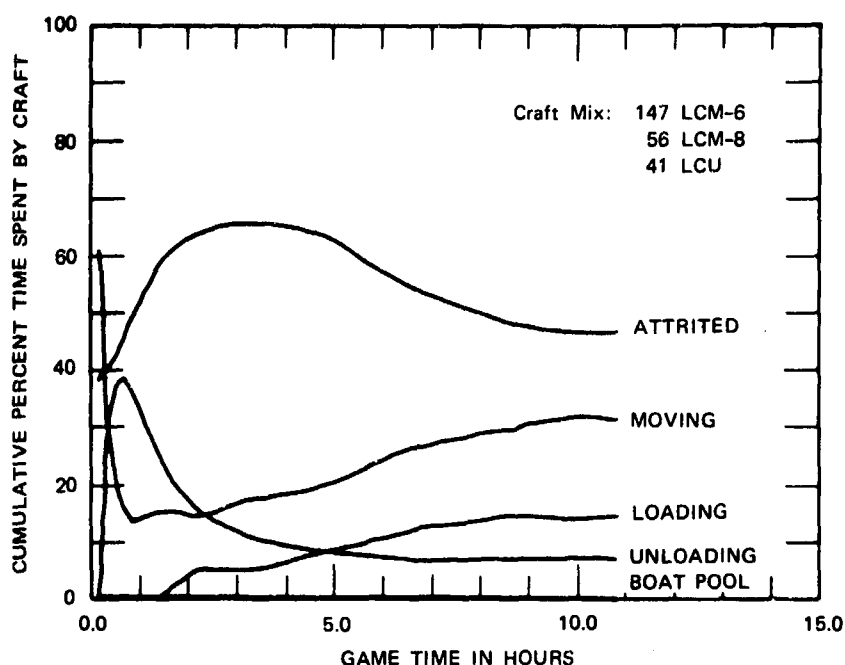


FIGURE 12 DISTRIBUTION OF CRAFT TIME — LCU, RUN 14, 5 nmi STANDOFF DISTANCE

Moving	30%	Boat pool	0%
Loading	15	Attrited	48
Unloading	7		

Boat pool activity is negligible.

LCA Craft. Run 15 was designed to test the performance of the new LCA craft in close-in assaults. The LCA was teamed with the 150ACV and 320P in hopes of achieving very high performance with two different craft types capable of crossing the beach line. The result was disappointing. As indicated in Figure 13, the performance of this mix was ranked low among the advanced craft mixes. The 100 LCAs comprise 65 percent of the craft mix but contribute only 22 percent of the force-time effectiveness and 27 percent of the vehicles delivered ashore. The 100 LCAs contributed less in terms of force-time effectiveness than the 15 320Ps, and the LCAs delivered less cargo ashore up to time H+6 hours than the 320Ps. The key to this disappointing performance is the LCA's low water speed. Figure 13 shows LCA activity. Thirty-six percent of the craft were deck-loaded on LKAs with the balance in well-type ships preloaded with cargo. Attrition rates were high due to low water speed (long exposure) with up to 66 percent of the time spent attrited at H+3 hours. Moving time heavily dominated the active parts of the craft cycle. At H+7 hours the cumulative distribution of craft time was, in percent:

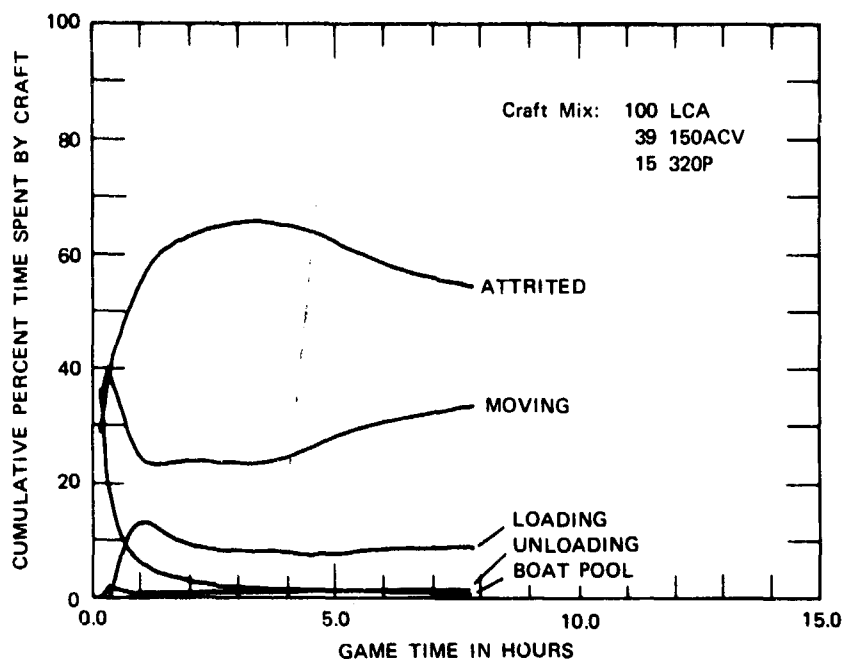


FIGURE 13 DISTRIBUTION OF CRAFT TIME — LCA, RUN 15, 5 nmi STANDOFF DISTANCE

Moving	32%	Boat pool	1%
Loading	9	Attrited	56
Unloading	2		

Unloading time was particularly short because of the LCA's great versatility on the beach.

LARC-15 Craft. Run 16 was designed to test the LARC-15 in the same manner that the LCA was tested in Run 15. The same advanced craft--150ACV and 320P--were combined with the LARC-15 in slightly different numbers due to the different relative geometry among the craft of each mix. LARC-15 performance was substantially less attractive than LCA performance. The 114 LARC-15s comprising almost 65 percent of the craft mix contributed only 9 percent of the force-time effectiveness and delivered only 12 percent of the vehicles ashore. At H+7 hours, the combined force-time effectiveness of 114 LARC-15s was less than half that of 18 320Ps. Similar to that of H+7 hours, the 114 LARC-15s delivered less than half as much cargo ashore and 18 320Ps. In addition, the performance of Run 16 is distinctly inferior to all other advanced craft mixes. As illustrated in Figure 11, the LARC-15's poor performance results from heavy attrition and slow water speed. In addition, it carries a small load for its size (i.e., space occupied aboard ship). At H+7 hours, the cumulative time distribution for the LARC-15s is in percent:

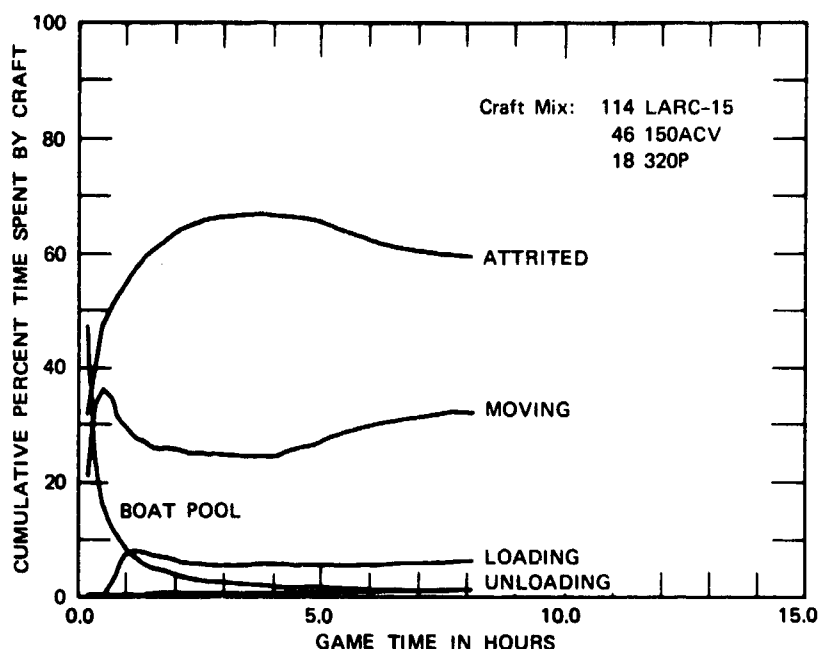


FIGURE 14 DISTRIBUTION OF CRAFT TIME — LARC-15, RUN 16, 5 nmi STANDOFF DISTANCE

Moving	15%	Boat pool	1%
Loading	6	Attrited	60
Unloading	2		

Craft Attrition

Both advanced and present day craft spent the largest single fraction of craft time attrited--either permanently or temporarily out of action because of enemy action, mechanical failure, broaching (for planing hull craft), or personnel error. These attrition results reflect a moderate level of defensive action that declines in two steps during the assault phase as the friendly perimeter is enlarged. The work on craft vulnerability was performed by A. R. Grant, and is reported elsewhere;* the work on mechanical reliability was performed by NSRDL; and the work on personnel error was performed by the NPRDL. This work represents the best current knowledge on these subjects; however, it was necessary to make many assumptions about materials, vulnerability of critical components, mean times before failure, and operability that are not supported by the data available to date. Because of the critical role that attrition plays in craft performance, it is essential that accurate data on craft vulnerability, reliability, and operability be developed during each design and test phase of the advanced amphibious landing craft program.

* See Grant, A. R., op. cit.

Force-Time Effectiveness

Force-time effectiveness measures the cumulative time ashore of all vehicular components of the Marine force up to a specific time. It is the area under the curve of cumulative square feet of vehicles delivered ashore shown in Figure 15. This curve is similar to the curves of Figures 3 and 4 except that entries are made as vehicles are delivered ashore, not as they are off-loaded from the ships. Viewing the area under the curves of Figures 3 and 4 as representations of force-time effectiveness, some interesting observations can be made. First, consider the importance of preboated serials. Craft mixes with large areas of preboated serials gain an almost immediate advantage in force-time effectiveness. It takes a considerable period of time for a craft mix with small preboat area and high delivery rate to overtake a mix with large preboat area and a low delivery rate. For example, the baseline system (Run 14) is superior to Run 16 (LARC-15, 150ACV, 320P) in force-time effectiveness (see Figure 3) up to H+5 hours.

For comparative purposes, force-time effectiveness was measured at H+7 hours. At this time all craft mixes were still delivering vehicles ashore at maximum rate, as few, if any, craft in the boat pool indicated. The force-time effectiveness for the Set One runs at H+7 hours is listed in Table 11. Despite the relative advantage enjoyed by the baseline system as a result of its large preboat area, all but one of the advanced craft mixes (Run 11: 10P, 30ACV, 150ACV) are superior to it in force-time effectiveness by H+7 hours. Run 17 (125P, 150ACV, 320P), the run with the highest force-time effectiveness, is 42 percent better than the baseline system, and Run 11 is 15 percent inferior to the baseline system. Of the mixes containing some present-day craft (Runs 4, 6, 15, and 16), two (6: 30ACV, LCM-8, 150ACV) and (16: LARC-15, 150ACV, 320P) are slightly less attractive than the baseline system, one (4: LCM-6, 150ACV, LCU) is only marginally better, and one (15: LCA, 150ACV, 320P) is 15 percent better.

Time to Deliver 200,000 Square Feet of Vehicles Ashore

The time to deliver 200,000 square feet of vehicles ashore is a measure of the relative time to complete the assault phase, however, unlike force-time effectiveness it does not reflect the variation in the rates at which vehicles were landed. The value of 200,000 square feet was selected to ensure that a quantitative measure could be determined for all runs while the effect of preboated serials was minimized.

Values of time to deliver 200,000 square feet of vehicles ashore are listed in Table 11 for the different runs. All runs are superior to the baseline system with respect to this measure. Run 17 (125P,

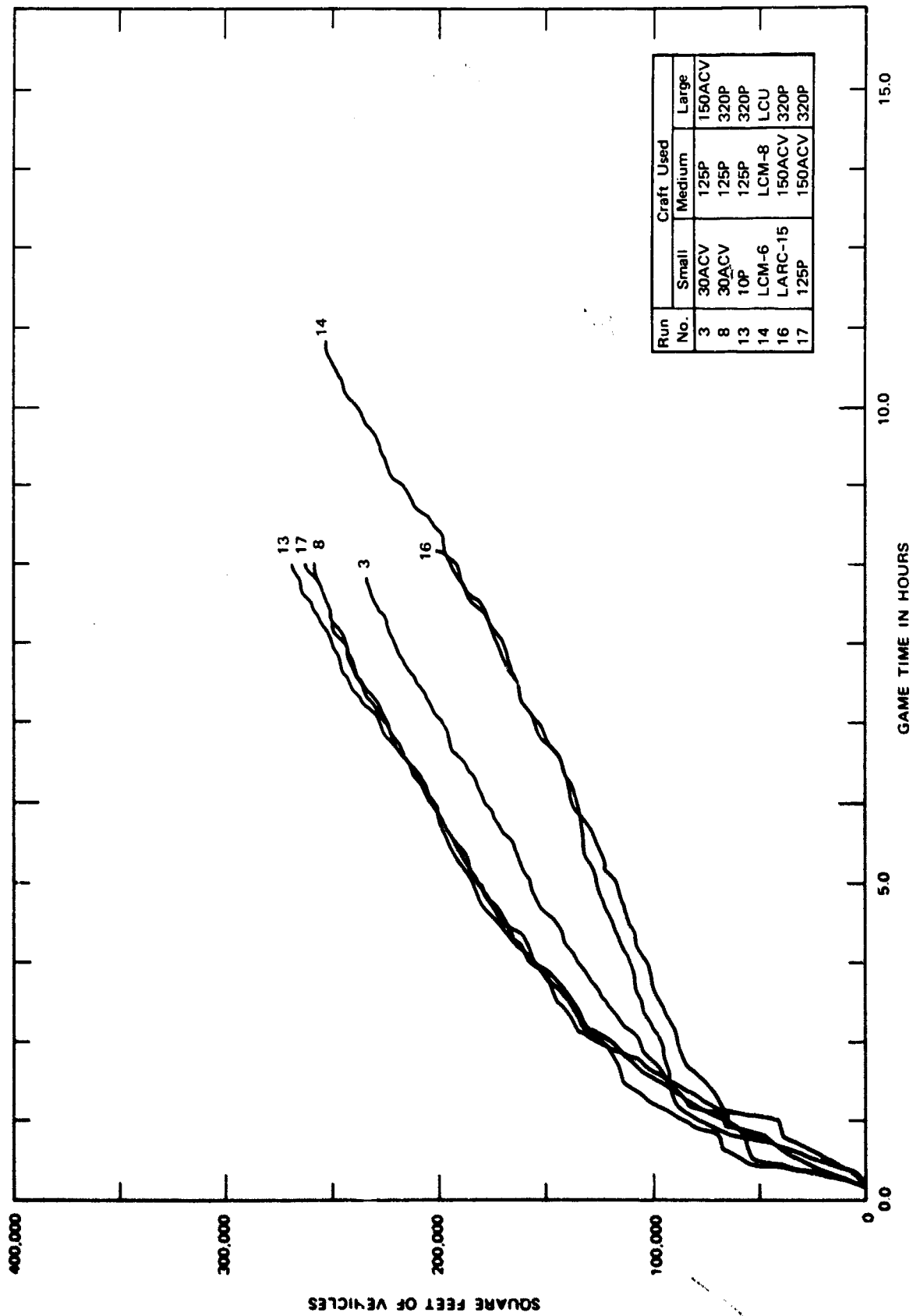


FIGURE 15 CUMULATIVE VEHICLES DELIVERED TO BEACH, 5 nmi STANDOFF DISTANCE

Table 11

MEASURES OF EFFECTIVENESS FOR SET ONE RUNS*
(At H+7 Hours)

Run Number	Craft Mix	Force-Time Effectiveness	Time to Deliver 200,000 sq ft of Vehicles Ashore (hours)	Lost Cargo (sq ft)	Mean Response Time (minutes)
1	30ACV, 150ACV, 320P	825	7.3	1,443	--
3	30ACV, 125P, 150ACV	910	6.1	5,769	31
4	LCM-6, 150ACV, LCU	795	8.2	3,181	41
6	30ACV, LCM-8, 150 ACV	774	7.5	5,623	36
7	10P, 30ACV, 125P	976	5.4	5,913	43
8	30ACV, 125P, 320P	1,074	4.9	10,788	--
9	125P, 150ACV, 320P	890	6.7	4,545	34
10	10P, 125P, 150ACV	902	6.5	6,944	31
11	10P, 30ACV, 150ACV	666	N.A.	5,085	29
12	10P, 30ACV, 320P	855	7.2	4,540	43
13	10P, 125P, 320P	1,074	4.9	10,458	36
14	LCM-6, LCM-8, LCU	780	8.4	5,590	--
15	LCA, 150ACV, 320P	900	7.8	4,871	31
16	LARC-15, 150ACV, 320P	753	N.A.	3,343	36
17	125P, 150ACV, 320P	1,109	4.8	7,467	32
18	30ACV, 125P, 150ACV	965	6.3	12,586	25

* For 5-nmi nominal standoff distance.

N.A. = not available. The simulation terminated before 200,000 square feet of vehicles were delivered ashore.

50ACV, 320P) required only 57 percent as long as the baseline system; four runs (7: 10P, 30ACV, 125P, 8: 30ACV, 125P, 320P, 13: 10P, 125P, 320P, and 17) require less than 65 percent as long as the baseline system.

Marine Forces or Cargo Lost

Lost cargo is measured by the square feet of vehicles that are lost to the assault because of craft sunk enroute to the beach. It is influenced by the amount of preboated cargo carried and the rate of delivery ashore. Craft mixes with high performance in these areas have greater exposure to enemy action than do low performance craft. Lost cargo is also influenced by the vulnerability of the craft in each particular mix. Experience with the GAMUT model (Chapter V) indicates that attrition losses are subject to wider variation than the other effectiveness measures.

Values for square feet of lost cargo are listed in Table 11. By far the smallest amount of cargo is lost in Run 1 (30ACV, 150ACV, 320P) and the largest in Run 18 (30ACV, 125P, 150ACV). Runs 8 and 13 also suffer heavy losses. Losses for the balance of the runs fall into a relatively narrow band. Because attrition due to enemy action was reduced according to a fixed time table for all runs, the low performance mixes gain an advantage by reduced exposure. Thus, if some equitable means could be devised to tie the intensity of enemy action to the delivery of material ashore, the lost cargo for Runs 4 (LCM-6, 150ACV, LCU), 11 (10P, 30ACV, 150ACV), 14 (LCM-6, LCM-8, LCU), and 16 (LARC-15, 150ACV, 320P) might be substantially higher.

Response Time

The response time of interest is the elapsed time from a call for a nonpreboated serial until the complete serial has been delivered to the beach and unloaded from all craft. This time gives a measure of the flexibility with which the tactical commanders can bring Marine elements to bear in a sequence other than the one planned.

Mean response times are listed in Table 11. No results were obtained for the baseline system, because all on-call serials could be preboated. Results for other runs vary from 25 to 43 minutes, with Run 18 (30ACV, 120P, 150ACV) showing the shortest response time and Runs 7 (10P, 30ACV, 125P) and 12 (10P, 30ACV, 320P) the longest. The craft mixes with large numbers of air cushion craft are particularly productive in terms of response time.

Mean Productivity per Craft Type

Mean productivity per craft type measures the return realized per square foot of amphibious ship well allocated to a particular craft type. Mean productivity is calculated by first computing the mean square feet of vehicles delivered ashore per craft up to a specified reference time (H+7 hours) by each craft of a particular type. This value is divided by the rectangular area in square feet that a craft would occupy in the well of an LSD, LPD, or LHA. The means and variances of the productivity factors are listed below for each of the advanced craft. The variance represents variations observed among the different craft mixes in which a particular craft appears. Only mean values are given for the present-day craft that were tested in only one or two runs.

<u>Craft Type</u>	<u>Mean Productivity</u>		<u>Number of Runs</u>
	<u>Sample Mean</u>	<u>Sample Variance</u>	
10P	1.69	.0357	5
30ACV	2.32	.043	7
125P	2.97	.0429	6
150ACV	2.21	.0907	7
320P	2.80	.1826	5
LCM-6	1.88		2
LCM-8	2.11		2
LCU	2.48		2
LCA	1.85		1
LARC-15	1.06		1

The significance of differences between craft productivity means for the advanced craft was tested for all pairs of advanced craft using standard "Student's t" tests. All differences were found to be significant beyond the 95-percent level except for two pairs, the 30ACV and 150ACV and the 125P and 320P. In general, the planing hulls with large ratios of cargo-well area to total area have higher mean productivities than other craft. Further tests revealed that the performance of the present-day craft lay significantly outside the samples collected for the advanced craft.

The tabulation indicates that the LARC-15 is distinctly inferior to all other craft types tested. The 10P is by far the least productive of the advanced craft and is less productive than any of the present craft except the LARC-15. The poor mean performance of the 10P is due in part to its greater inactivity (as measured by time in the boat pool,, because it cannot find suitable loads in many serials. Also, many of the loads that it carries are inefficient.

Consensus Ranking

The essential elements in a consensus ranking of the craft mixes tested in Set One are (1) a measure of distance to be applied to the differences in performance between runs and (2) a set of weighting factors to be applied to the different measures of effectiveness. The two elements need to be applied in such a way that no single difference in one measure of effectiveness is allowed to dominate the final ranking.

For ease of presentation all measures of effectiveness were related to the baseline system so that baseline system effectiveness is 1.0, and mixes performing better than the baseline system have effectiveness greater than 1.0. To avoid dominance, effectiveness values were limited to the interval from 0.5 to 2.0. This suppression mechanism was needed only for lost cargo.

The distance measure of force-time effectiveness is calculated by dividing all force-time effectiveness numbers by that of the baseline system. The distance measure of time to deliver 200,000 square feet of Marine cargo ashore is calculated by dividing the baseline system time by that of the different runs. Runs 11 and 16 were arbitrarily assigned times of 10.0 hours because these simulations were terminated before 200,000 square feet of cargo was delivered ashore. Distance measures for lost cargo were suppressed by using the equation

$$M_R = 0.348 M_u + 0.652$$

where M_R is the lost cargo distance measure and M_u is the baseline system lost cargo divided by the observed lost cargo. To calculate the distance measures for mean response time, the maximum value of 43 minutes was assigned to the baseline system because no suitable measure was available for this run. Thereafter, individual distance measures were taken as the ratio between 43 and the simulated response time. Values of 1.0 were also assigned to Runs 1 and 8 because no simulated values were obtained. The calculated distances for all the measures of effectiveness and all the runs are listed on Table 12.

Table 12

DISTANCE VALUES FOR CONSENSUS RANKING: SET ONE RUNS
(5 nmi Nominal Standoff Distance)

Run Number	Craft Mix	Force-Time Effectiveness	Time to Deliver 200,000 sq ft of Cargo (hours)	Lost Cargo	Mean Response Time (minutes)
1	30ACV, 150ACV, 320P	1.06	1.15	2.00	1.00
3	30ACV, 125P, 150ACV	1.21	1.38	0.99	1.39
4	LCM-6, 150ACV, LCU	1.02	1.02	1.26	1.05
6	30ACV, LCM-8, 150ACV	0.99	1.12	1.02	1.19
7	10P, 30ACV, 125P	1.25	1.56	0.98	1.00
8	30ACV, 125P, 320P	1.38	1.71	0.83	1.00
9	125P, 150ACV, 320P	1.11	1.25	1.08	1.26
10	10P, 125P, 150ACV	1.16	1.29	0.93	1.39
11	10P, 30ACV, 150ACV	0.86	0.84	1.04	1.18
12	10P, 30ACV, 320P	1.10	1.17	1.08	1.00
13	10P, 125P, 320P	1.38	1.71	0.81	1.19
14	LCM-6, LCM-8, LCU	1.00	1.00	1.00	1.00
15	LCA, 150ACV, 320P	1.15	1.08	1.05	1.39
16	LARC-15, 150ACV, 320P	0.95	0.81	1.23	1.19
17	125P, 150ACV, 320P	1.12	1.75	0.91	1.31
18	30ACV, 125P, 150ACV	1.21	1.33	0.81	1.72
Weighting Factor		0.139	0.277	0.171	0.110

The measures of effectiveness were ordered to reflect their relative importance as estimated by the project team. This order is:

Force-time effectiveness

Time to deliver 200,000 square feet of cargo

Lost cargo

Response time

Response time was placed last because of the poor quality of the data. Weightings for the different measures of effectiveness were assigned, and a ratio of 1.6 to 1.0 between successive pairs of measures was maintained. The weightings were calculated by the equation

$$W_i = \frac{N^{N-1} (N^{N-1} - 1)}{N^{N-1} - 1}$$

where W_i equals weight of the i th item (small i least importance) and N is the number of measures of effectiveness. The numerical values of the weightings are shown on Table 10. Table 13 shows the summation of the distance measures multiplied by the appropriate weighting factors.

The most effective craft mixes examined are Runs 17, 13, and 8, with the following craft combinations:

<u>Run Number</u>	<u>Craft Mix</u>	<u>Weighted Effectiveness</u>
17	125P, 150ACV, 320P	1.413
13	10P, 125P, 320P	1.356
8	30ACV, 125P, 320P	1.333

These mixes contain all the advanced craft, with each of the three mixes containing both the 125P and the 320P. Examination of the P10's performance reveals that this type contributed less than 10 percent of the ship-to-shore movement, and P10 craft were frequently unable to handle available loads. Because of these factors, together with the P10's distinctly inferior mean productivity, it is recommended that the P10 be dropped

Table 13

EFFECTIVENESS-COST RATIOS: SET ONE RUNS
(5 nmi Standoff Distance)

<u>Run Number</u>	<u>Craft Mix</u>	<u>$\sum X_i W_i$</u>	<u>Cost Factors</u>	<u>Effectiveness Cost Ratio</u>
1	30ACV, 150ACV, 320P	1.242	1.14	1.09
3	30ACV, 125P, 150ACV	1.238	1.15	1.08
4	LCM-6, 150ACV, LCU	1.064	1.04	1.02
6	30ACV, LCM-8, 150ACV	1.053	1.11	0.95
7	10P, 30ACV, 125P	1.261	1.19	1.06
8	30ACV, 125P, 320P	1.333	1.19	1.12
9	125P, 150ACV, 320P	1.173	1.13	1.04
10	10P, 125P, 150ACV	1.181	1.14	1.04
11	10P, 30ACV, 150ACV	0.954	1.12	0.85
12	10P, 125P, 320P	1.105	1.18	0.94
13	10P, 125P, 320P	1.356	1.19	1.14
14	LCM-6, LCM-8, LCU	1.000	1.00	1.00
15	LCA, 150ACV, 320P	1.139	1.15	0.99
16	LARC-15, 150ACV, 320P	0.994	1.12	0.89
17	125P, 150ACV, 320P	1.413	1.13	1.23
18	30ACV, 125P, 150ACV	1.242	1.13	1.10

from further consideration. Both the 150ACV and the 30ACV make substantial contributions to Runs 17 and 8. Furthermore, a relaxation of the analytical bias toward planing craft would likely cause them to be even more productive.

Cost factors were developed using the AACOST model* with the addition of estimated costs for the amphibious ships, helicopters, and other equipment directly associated with the movement of the Marine force ashore and

* See Jorgensen, op. cit.

with the cost of the Marine force itself. No costs were included for fire support ships or other naval units provided to protect the amphibious ships. Cost factors were calculated by dividing the cost for each run by the base system cost. These factors are shown in Table 13.

Effectiveness-cost ratios were calculated by dividing the weighted effectiveness factors by the weighted cost factors. The most attractive runs are again 17, 13, and 8.

Set Two Runs

In the Set Two runs, the nominal standoff distance was increased to 25 nmi, but the other characteristics of the amphibious environment were unchanged. Figure 16 shows the development of the Set Two landings in terms of cumulative square feet of vehicles off-loaded from ships over time. Once more, a large variation in the amount of preboated cargo is observed from 45,000 square feet for Run 26 to 95,000 square feet for Run 22. Runs 20 (30ACV, 150ACV, 320P), 23 (125P, 150ACV, 320P), and 26 (30ACV, 150ACV), have the highest delivery rates. Runs 20 and 26 each have two ACV types, and all three of the high delivery rate runs have less than the mean number of total craft for the Set Two runs. The delivery rate for Run 24 (the baseline system) is much lower than those for advanced craft mixes as are the delivery rates for Runs 25 (30P, 150ACV) and 28 (125P, 150ACV). The horizontal portions of the curves next to the y axis indicate the round-trip travel time to the beach. Advanced craft mixes typically reach the beach in an hour or less, but the present-day craft require six hours to complete a round trip.

The shapes of the advanced craft curves for long standoff distances are similar to the corresponding curves for short standoff distances, except that the fraction of time spent moving is considerably larger (e.g., 32 percent versus 20 percent for the 150ACV). The shapes of the present-day craft curves are very different for the 25-nmi standoff distance than for the 5-nmi standoff distance. At long standoff distance the time is about equally divided between moving and attrition, with only very small fractions of time spent engaged in other activities.

30ACV Craft. Figure 17 illustrates the performance of the 30ACV craft in a mix of craft that also includes 125P and 150ACV craft. Because of their small size, the 68 30ACV craft comprise 39 percent of the craft and account for only 22 percent of the force-time effectiveness and 24 percent of the vehicles delivered ashore at H+8 hours. The difference in the 30ACVs contributions to force-time effectiveness and

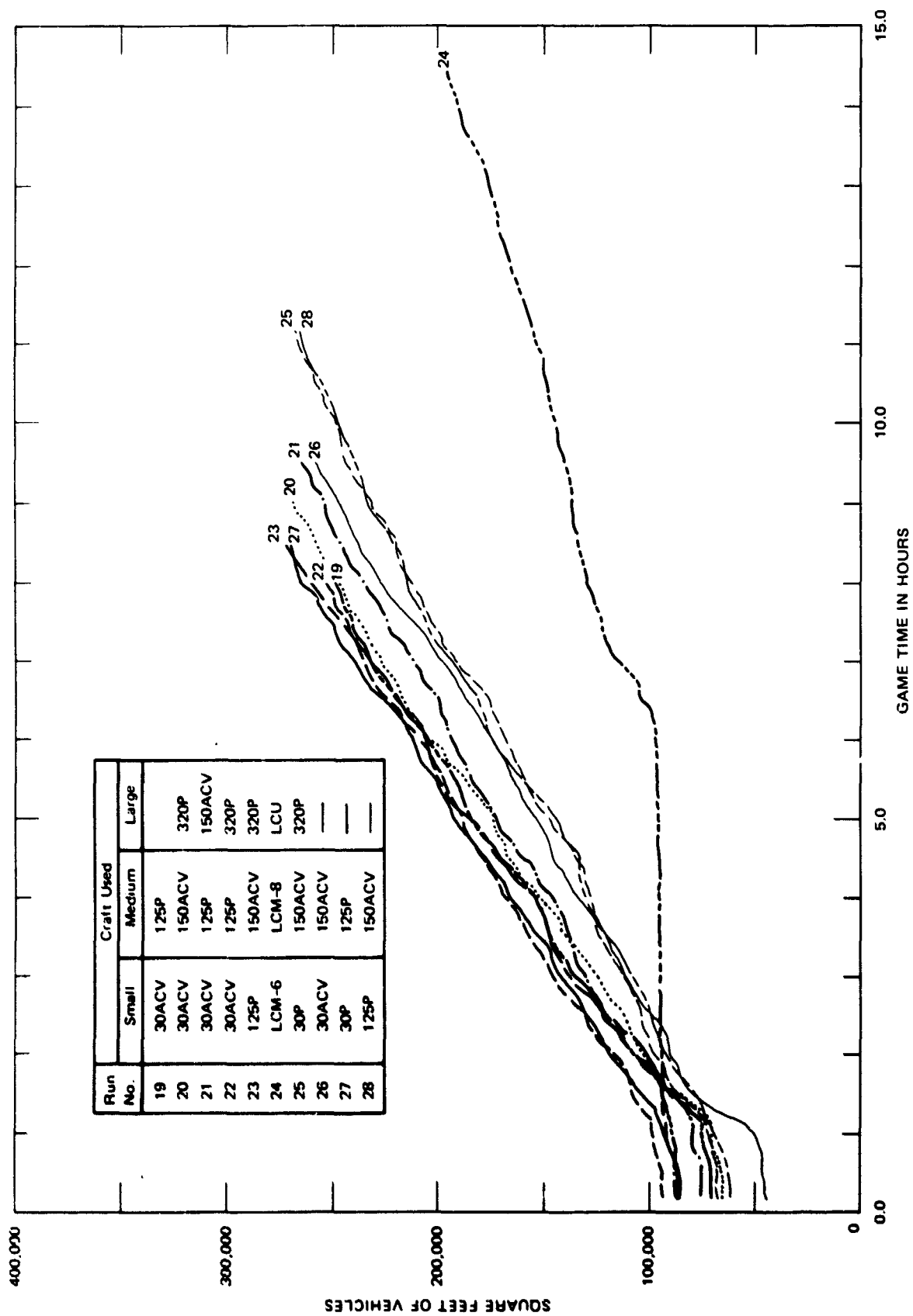


FIGURE 16 VEHICLES OFF-LOADED FROM SHIPS — baseline and advanced runs at 25 nmi standoff distance

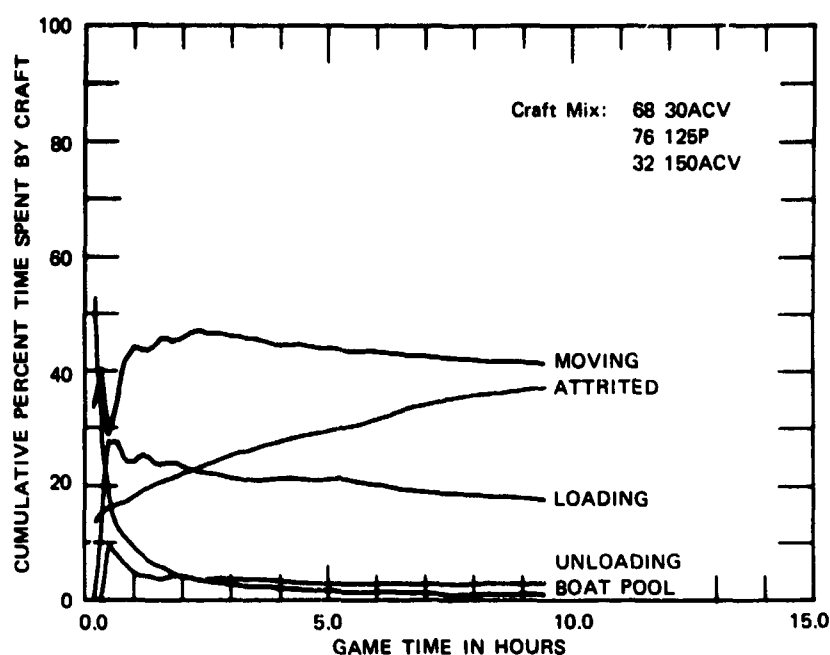


FIGURE 17 DISTRIBUTION OF CRAFT TIME — 30ACV, RUN 21, 25 nmi STANDOFF DISTANCE

vehicles delivered ashore is reflected by the large number (53 percent) carried aboard LKAs that have no initial vehicle loads. The first 30ACV reach the beach at H+25 minutes and begin discharging cargo. At H+35 minutes there are sharp breaks in all the curves except the attrition curve as unloading of the preboated craft is completed and as loading is completed on the first of the nonpreboated craft. In general, the curves of Figure 17 are not unlike those of Figure 6 for the 5 nmi stand-off distance. By H+7 hours, the cumulative distributions of craft activity from Figure 17 and Figure 6 are, in percent:

	<u>Standoff Distance</u>	
	<u>25 nmi</u>	<u>5 nmi</u>
Moving	43%	18%
Loading	19	31
Unloading	3	1.1
Boat pool	1	2
Attrited	3.1	35

The major change occurs in moving time which, is a direct result of the standoff distance. The attrition curves in Figures 6 and 16 reach about the same value by H+7 hours but arrive there by different routes. For 5 nmi standoff distance, the rate of increase of attrition is high during the early stages reaching 35 percent by H+4 hours. This reflects the influence of enemy action. In contrast, for 25 nmi standoff, the attrition fraction increases steadily, reflecting the importance of breakdown and human failure.

30P Craft. Because of the good performance shown by the 30ACV in the Set One runs and because the 10P craft was eliminated from the analysis, a notional 30P craft was postulated by NSRDC. The 30P craft was tested in Runs 25 and 27. Figure 18 illustrates 30P performance in

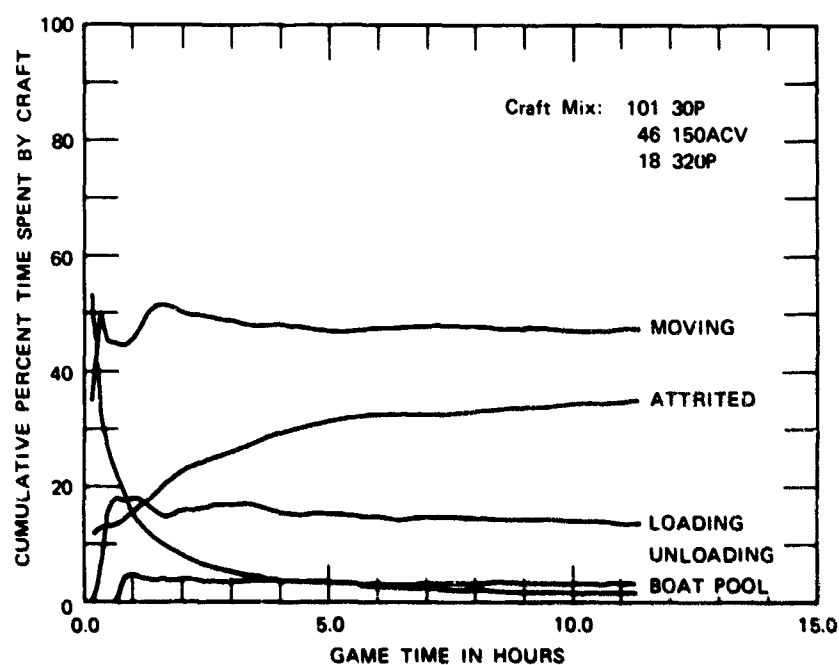


FIGURE 18 DISTRIBUTION OF CRAFT TIME — 30P, RUN 25, 25 nmi STANDOFF DISTANCE

a mix with 150ACV and 320P craft. This run relates directly with Run 20 with the 30P substituted for the 30ACV. The relative numbers and performance of the different craft in the two mixes are:

	<u>Number of Craft</u>	<u>Force-Time Effectiveness at H+7 Hours</u>	<u>Sq Ft Delivered Ashore at H+7 Hours</u>
Run 25			
30P	101	150	38,000
150ACV	46	380	92,000
320P	<u>18</u>	<u>200</u>	<u>42,000</u>
Total	165	730	172,000
Run 20			
30ACV	95	260	75,000
150ACV	37	350	92,000
320P	<u>19</u>	<u>220</u>	<u>61,000</u>
Total	151	830	228,000

This comparison clearly favors the 30ACV over the 30P. Run 20 is 12 percent better in force-time effectiveness and 33 percent better in vehicles delivered ashore than Run 25. The performance difference clearly accrues to the superiority of the 30ACV over the 30P. The 95 30ACV craft have a 75 percent advantage in force-time effectiveness and a 97 percent advantage in vehicles delivered ashore over the 101 30P craft.

Fifty-three percent of the 30P craft were deck-loaded aboard LKAs and reported to the boat pool at H-hour. The balance began moving toward the beach with the first craft reaching the beach at about H+40 minutes. At H+60 minutes, the first LKA-carried craft were loaded and began proceeding toward the beach. Thereafter, craft time for all activities except attrition began to level out. Attrition continued to rise throughout the assault phase, although at successively decreasing rates. By H+7 hours, the distribution of craft time was, in percent:

Moving	48%
Loading	14
Unloading	3
Boat pool	2
Attrited	33

Note that moving time for the 30P is 5 percent higher than moving time for the 30ACV because of the 30P's lower speed. As a result, each craft makes fewer trips, and there is a corresponding reduction in loading time. Unloading time is unchanged because of the difficulty of unloading in the surf.

125P Craft. Figure 19 illustrates the performance of the 125P craft in a mix that also included 30ACV and 150ACV. Because of their intermediate size, the 125P craft carry an amphibious burden almost proportionate to their numbers. They accounted for 43 percent of the craft mix and contributed 36 percent of the force-time effectiveness and 36 percent of the vehicles delivered ashore at H+7 hours.

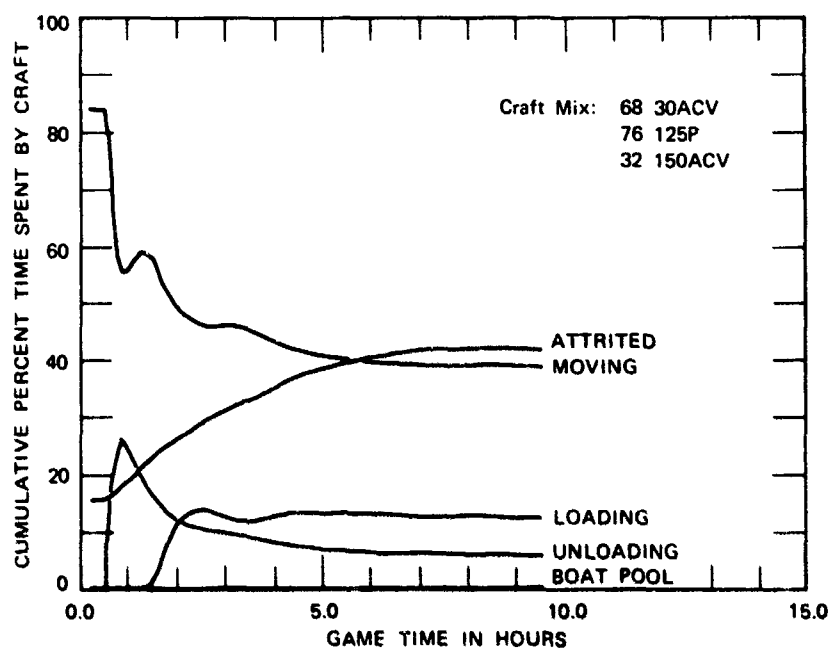


FIGURE 19 DISTRIBUTION OF CRAFT TIME — 125P, RUN 21, 25 nmi STANDOFF DISTANCE

All 125P craft were preboated and proceeded toward the beach immediately after the scheduled waves. Sixteen percent of the craft were attrited before reaching the beach. The successful craft reached the beach and began unloading at H+30 minutes. By H+45 minutes, the first craft were unloaded and retracting from the beach. These early craft began reloading at the ships at H+80 minutes, although substantial loading operations did not get underway until H+2 hours. By H+7 hours, the cumulative time spent in the different activities had leveled out. The time distribution, together with that for the 5 nmi standoff distance, is listed below:

	<u>Standoff Distance</u>	
	<u>25 nmi</u>	<u>5 nmi</u>
Moving	39%	22%
Loading	13	32
Unloading	6	9
Boat pool	0	3
Attrited	42	34

Although the nominal standoff distance is increased by a factor of five, moving time increases only 75 percent, reflecting the smaller number of loads carried. The large reduction in loading time sharply points out reduced productivity. The change in unloading time is moderated by the influence of the preboated loads.

150ACV Craft. Figure 20 illustrates the performance of the 150ACV in the same run as that used to illustrate the 30ACV and the 125P. The 150ACV is tremendously more productive on a per craft basis than either of the smaller craft despite the fact that it carries only 20 percent more payload than the 125P. The 32 150ACV craft represent only 18 percent

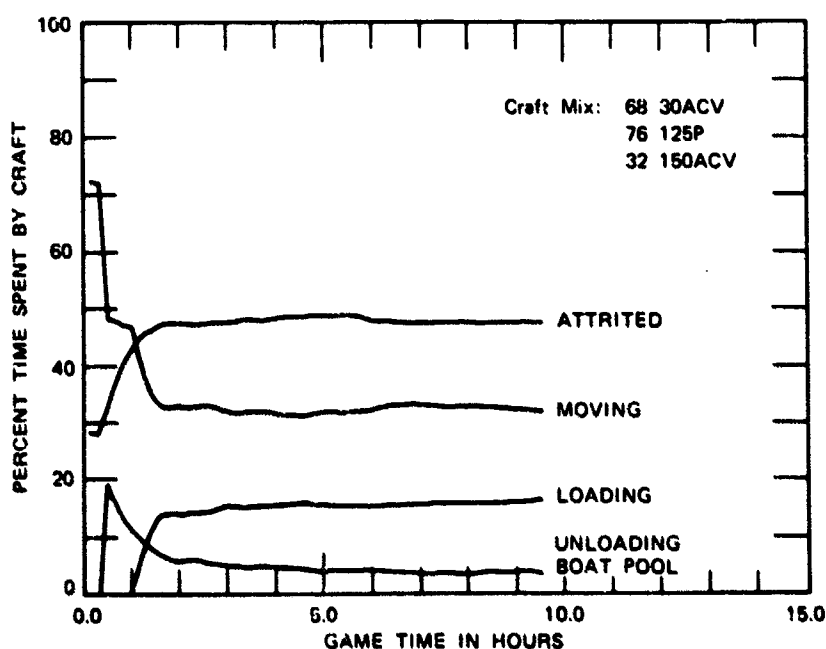


FIGURE 20 DISTRIBUTION OF CRAFT TIME — 150ACV, RUN 21, 25 nmi STANDOFF DISTANCE

of the craft mix; yet these craft account for 42 percent of the force-time effectiveness and 40 percent of the vehicles delivered ashore. Even when one adjusts for the larger size of the 150ACV, it remains the most productive craft in the mix for this run.

The 150ACVs also suffer heavier attrition than the 125Ps during their first run to the beach (28 versus 16 percent). This is almost entirely because of their larger size. The first 150ACV craft reach the beach at H+20 minutes and immediately begin unloading. By H+1 hour, the first of these craft have returned to the ships for second loads. The distribution of time quickly stabilizes. At H+7 hours, time distribution for the short and long standoff distances compares as follows, in percent:

	<u>Standoff Distance</u>	
	<u>25 nmi</u>	<u>5 nmi</u>
Moving	33%	18%
Loading	16	25
Unloading	4	6
Boat pool	0	2
Attrited	47	49

For this craft, there is a slight reduction in attrition time at the long standoff distance where its vulnerability is more effectively reduced by its high speed, thereby balancing the increase in exposure time per run. Moving time almost doubled, and unloading time declined one-third, reflecting fewer trips in seven hours. There was no time spent in the boat pool, because at this distance, there were always loading stations available for returning craft.

320P Craft. Figure 21 illustrates 320P performance in combination with 125P and 150ACV craft. Because of their large load carrying capabilities, the 320Ps were reasonably productive. While they represented only 18 percent of the craft mix, they contributed 32 percent of the force-time effectiveness and 24 percent of the vehicles delivered ashore. The lower productivity for vehicles delivered ashore resulted almost directly from the long loading time required for the second and subsequent trip. When account is taken of craft outside dimensions, the 320P craft performance in this run was slightly less effective in terms of force-time effectiveness than the 150ACV craft in this mix and considerably less effective than the 150ACV in terms of vehicles delivered ashore.

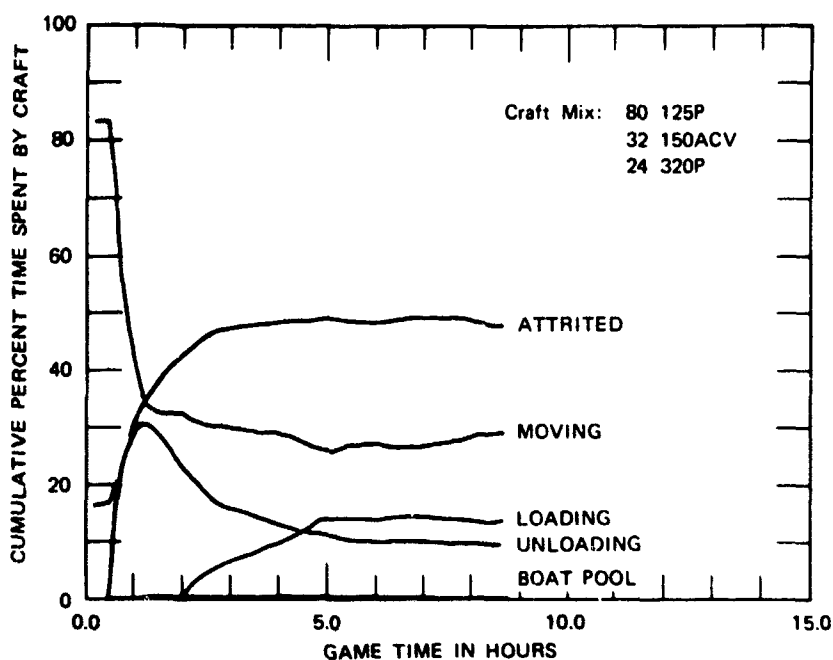


FIGURE 21 DISTRIBUTION OF CRAFT TIME — 320P, RUN 23, 25 nmi STANDOFF DISTANCE

The 320P craft were all preloaded and proceeded to the beach at H-hour with the first craft arriving at H+30 minutes. Sixteen percent of the craft were damaged or sunk enroute to the beach. Although unloading began at H+30 minutes, it was not completed for the initial loads until almost H+2 hours. This resulted in part from congestion at the beach and limited beach unloading positions, but it was also heavily influenced by long unloading times. The first 320P craft commenced re-loading at the ships at H+110 minutes and reached the beach with their second loads at H+3 hours. At H+7 hours some craft had not yet made two trips to the beach. After H+5 hours the division of craft time reached equilibrium. The equilibrium time distributions and the similar distribution for the 5 nmi standoff distance are, in percent:

	Standoff Distance	
	25 nmi	5 nmi
Moving	27%	20%
Loading	14	20
Unloading	10	12
Boat pool	0	0
Attrited	49	48

These figures reflect the influence of standoff distance. Attrition times remained practically constant because of the opposing effects of longer distances and longer exposure.

Present-Day Craft. Run 24 illustrates present-day craft in a long standoff environment for comparative purposes. Time distributions for the three craft types--LCM-6, LCM-8, and LCU--are illustrated in Figures 22, 23, and 24. As illustrated in Figure 16, the performance of this mix was very poor when compared with advanced craft mixes. The first craft did not reach the beach until H+2.5 hours, and loading did not begin for the second trip until H+6 hours. The first craft did not reach the beach with their second loads until after H+9 hours. By H+15 hours, many craft had not completed two trips. Attrition rates were also high:

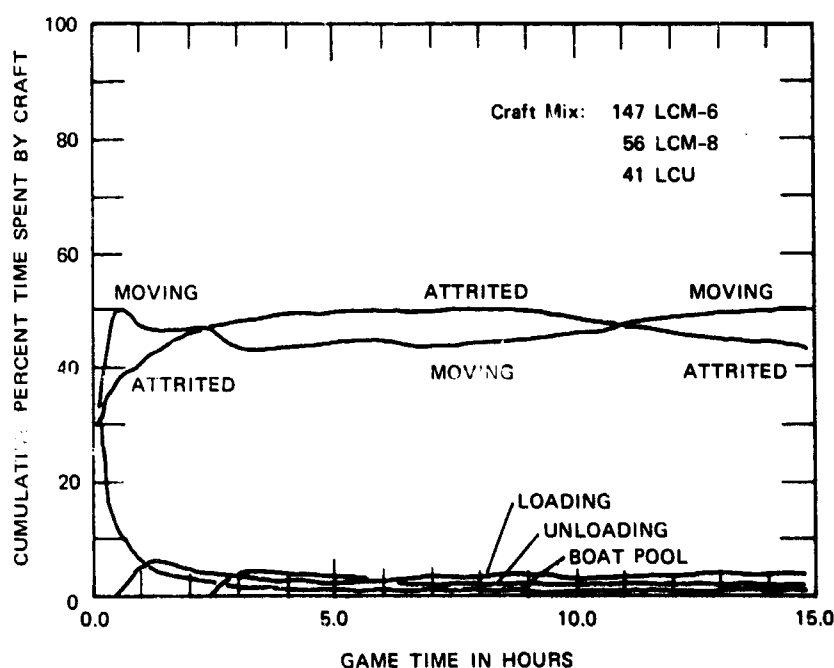


FIGURE 22 DISTRIBUTION OF CRAFT TIME — LCM-6, RUN 24, 25 nmi STANDOFF DISTANCE

about half of the preboated craft were out of action before initially reaching the beach. The contributions of the three craft types to the amphibious operation at time H+10 hours were, in percent:

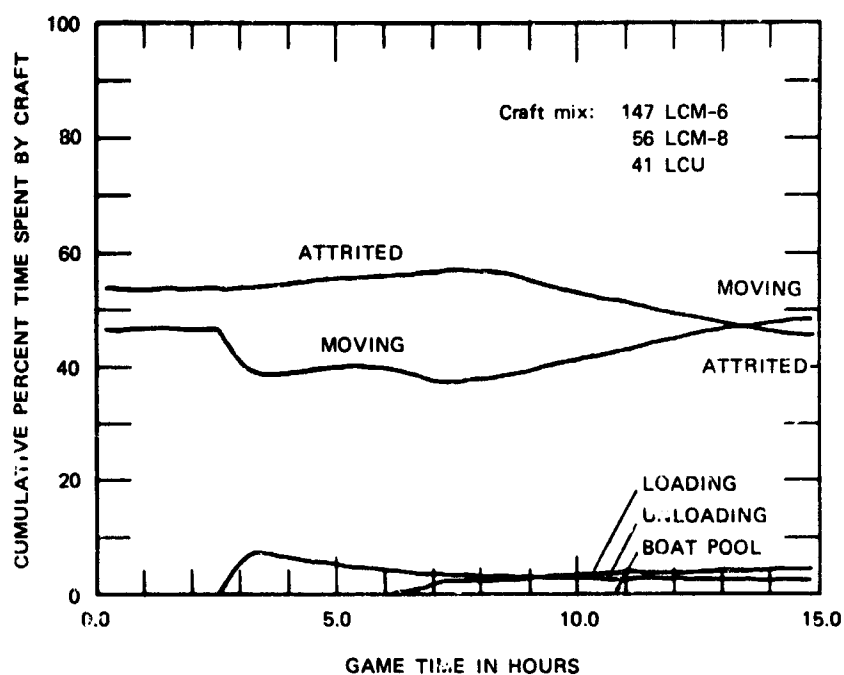


FIGURE 23 DISTRIBUTION OF CRAFT TIME — LCM-8, RUN 24, 25 nmi STANDOFF DISTANCE

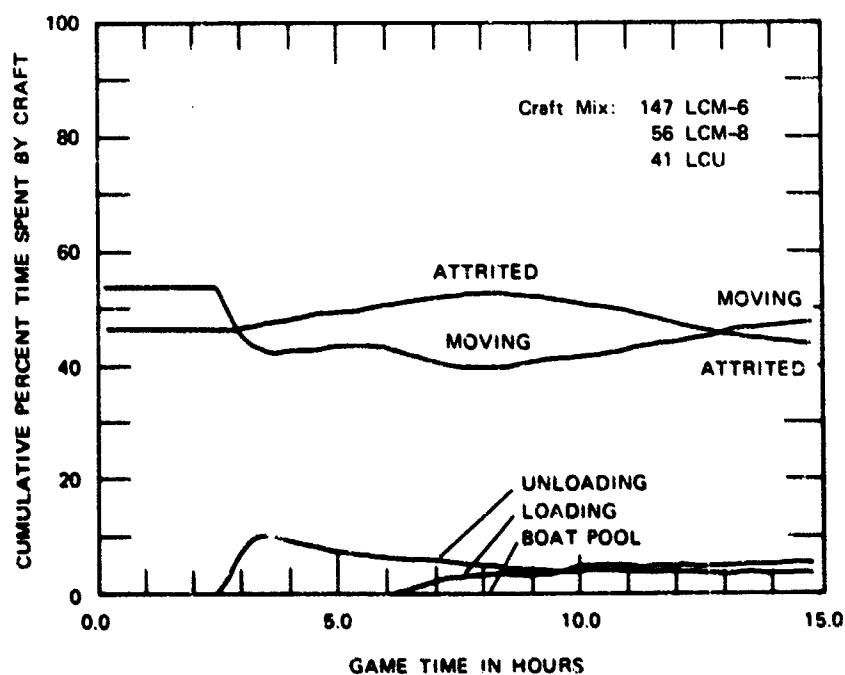


FIGURE 24 DISTRIBUTION OF CRAFT TIME — LCU, RUN 24, 25 nmi STANDOFF DISTANCE

	<u>LCM-6</u>	<u>LCM-8</u>	<u>LCU</u>
Craft	60%	23%	17%
Force-time effectiveness	25	25	50
Vehicles delivered ashore	30	23	47

These results illustrate the relatively high productivity of the large LCU craft among today's available craft. And yet, by H+10 hours no LCUs had reached the beach with its second load while a few LCM-6 and LCM-8 craft had.

The distributions of time in percent for the three craft types at H+10 hours are:

	<u>LCM-6</u>	<u>LCM-8</u>	<u>LCU</u>
Moving	46%	42%	42%
Loading	3	3	3
Unloading	2	2	2
Boat pool	1	0	0
Attrited	48	53	52

The overwhelming dominance of moving and attrition (94 percent of craft time) clearly demonstrate the unsuitability of present-day craft for long standoff service.

Measures of Effectiveness

The preceeding discussions have highlighted craft performance at long standoff and have pointed out some differences between craft operating in the same or similar environments. It is important to note that the comparisons between craft were based on single runs, and, except for one instance, general conclusions should not be drawn. The single exception applies to the 30P versus 30ACV comparison where a direct substitution was made of one craft for another. General conclusions for the Set Two runs are based only on the established measures of effectiveness.

Measures of effectiveness for Set Two runs are listed in Table 1-1. All measures were calculated in the same manner described for the Set One runs. Note that all the advanced runs except 25 (30P, 150ACV, 320P),

Table 14

MEASURES OF EFFECTIVENESS FOR SET TWO RUNS*
(At Time H+7 Hours)

<u>Run Number</u>	<u>Craft Mix</u>	<u>Force-Time Effectiveness</u>	<u>Time to Deliver 200,000 Sq Ft of Vehicles Ashore (hours)</u>	<u>Lost Cargo (sq ft)</u>	<u>Mean Response Time (minutes)</u>
19	30ACV, 125P	854	6.4	6,134	43
20	30ACV, 150ACV, 320P	829	6.7	4,002	34
21	30ACV, 125P, 150ACV	839	7.0	6,768	45
22	30ACV, 125P, 320P	899	6.5	6,126	50
23	125P, 150ACV, 320P	898	6.3	8,656	58
24	LCM-6, LCM-8, LCU	363	†	4,828	186 [‡]
25	30P, 150ACV, 320P	728	8.1	12,250	61
26	30ACV, 150ACV	734	7.7	9,010	32
27	30P, 125P	820	6.5	9,312	N.A.
28	125P, 150ACV	710	8.0	10,564	53

* For 25-nmi standoff distance.

† 160,468 square feet of cargo delivered in 14.8 hours.

‡ Overflow occurred at this value.

N.A. = results not obtained.

26 (30ACV, 150ACV), and 28 (125P, 150ACV) had higher force-time effectiveness from 25 nmi than the baseline system had from 5 nmi. Similarly, all the advanced craft mixes can deliver 200,000 square feet of cargo ashore faster from 25 nmi than the baseline system can from 5 nmi. Square feet of cargo lost are roughly comparable for the two standoff distances, and the mean response time for advanced craft is only slightly longer from 25 nmi than from 5 nmi. Marked degradation in performance for long stand-off distance is evident for the present-day craft only. For the baseline system, force-time effectiveness at 25 nmi drops to 46 percent of its value at 5 nmi; time to deliver 200,000 square feet of cargo would likely double, and the mean response time would likely increase by a factor of five or six.

Mean Productivity per Craft Type

Sample means and variances for the productivity values taken from the different simulation runs are listed below:

<u>Craft Type</u>	<u>Mean Productivity</u>		<u>Number of Runs</u>
	<u>Sample Mean</u>	<u>Sample Variance</u>	
30ACV	2.18	0.021	3
125P	2.08	0.066	3
150ACV	2.21	0.060	3
320P	2.62	0.003	3
LCM-6	0.71		1
LCM-8	1.03		1
LCU	1.13		1

The mean productivity of the advanced craft at 25 nmi was not appreciably different from that at 5 nmi, but the mean productivity of present-day craft dropped to half as distance offshore increased to 25 nmi. The mean productivity of the 150ACV actually increased from 2.21 to 2.31. Because of the small sample sizes, these are not significant differences between most pairs of advanced craft; but all advanced craft are significantly more productive than all present-day craft.

Consensus Ranking

Distance measures for the long standoff runs are listed in Table 15. These were computed in a manner similar to the close-in runs, except that distances were allowed to exceed 2.0 because of the large differences in performance between the advanced and the present-day craft. The force-time effective distance is the ratio of observed force-time effectiveness to that of the baseline system. The distance for time to deliver 200,000 square feet of cargo is 20 hours (estimated time for the baseline system) divided by the observed time. The lost cargo distance is the ratio of observed lost cargo to that of the baseline system. The mean response time measure is 186* divided by the observed time.

The weighted distance values for each run are listed in Table 16. All but two of the craft mixes (Run 25: 30P, 150ACV, 320P, and 28: 125P, 150ACV) are more than twice as effective as the baseline system. It is noteworthy that the most productive runs from the viewpoint of force-time effectiveness (22 and 23) had the largest amount of preboated cargo. Run 20 (30ACV, 150ACV, 320P) was the only one with less lost cargo than the baseline system. This is in part because of the very much smaller amount of cargo handled by the baseline system. The best response times were attained by craft mixes with a preponderance of air cushion craft. The most effective craft mixes were Runs 20, 19, and 22 with the following craft composition:

<u>Run Number</u>	<u>Craft Mix</u>	<u>Weighted Effectiveness</u>
20	30ACV, 150ACV, 320P	2.490
19	30ACV, 125P	2.356
22	30ACV, 125P, 320P	2.336

Except for Run 22 which is the same mix as Run 8, these are not the same mixes that ranked best for a close-in assault. In fact, the mix of Run 20 tied for fifth ranking. However, these mixes do include the four most productive advanced craft of the five analyzed. The 30P is conspicuously absent. In fact, 30P mixes rank among the worst of the Set Two runs.

* This is an approximate value.

Table 15

DISTANCE VALUES FOR CONSENSUS RANKING: SET TWO RUNS
(25 nmi Standoff Distance)

Run Number	Craft Mix	Force-Time Effectiveness	Time to Deliver 200,000 Sq Ft Of Cargo (hours)	Lost Cargo (sq ft)	Mean Response Time (minutes)
19	30ACV, 125P	2.35	3.13	0.79	4.32
20	30ACV, 150ACV, 320P	2.28	2.99	1.21	5.47
21	30ACV, 125P, 150ACV	2.31	2.86	0.71	4.13
22	30ACV, 125P, 320P	2.48	3.08	0.79	3.72
23	125P, 150ACV, 320P	2.48	3.17	0.56	3.21
24	LCM-6, LCM-8, LCU	1.00	1.00	1.00	1.00
25	30P, 150ACV, 320P	2.01	2.47	0.39	3.05
26	30ACV, 150ACV	2.02	2.60	0.54	5.81
27	30P, 125P	2.26	3.08	0.52	3.10*
28	125P, 150ACV	1.96	2.50	0.46	3.51
Weighting Factors			0.277	0.174	0.110

* Estimated.

Table 16 also lists the cost factors and effectiveness-cost ratios for craft mixes. The effectiveness-cost calculations show that the four most attractive advanced craft mixes are about twice as cost-effective as the baseline system. Run 20 stands out as the most cost-effective (of the Set Two runs) from a range of 25 nmi. The preferred mixes from a cost effectiveness viewpoint are:

<u>Run Number</u>	<u>Craft Mix</u>	<u>Effectiveness/ Cost Ratio</u>
20	30ACV, 150ACV, 320P	2.18
19	30ACV, 125P	1.98
26	30ACV, 150ACV	1.97
23	125P, 150ACV, 320P	1.97

Run 22, the fourth in effectiveness, dropped out of the top four in cost-effectiveness because of its high cost. It was replaced by Run 23 (125P, 150ACV, 320P) which ranked fifth in effectiveness but had a lower cost factor than Run 22.

Table 16

EFFECTIVENESS-COST RATIOS: SET TWO RUNS
(25 nmi Standoff Distance)

<u>Run Number</u>	<u>Craft Mix</u>	<u>Effectiveness $\sum X_i W_i$</u>	<u>Cost Factors</u>	<u>Effectiveness/ Cost-Ratio</u>
19	30ACV, 125P	2.356	1.19	1.98
20	30ACV, 150ACV, 320P	2.490	1.14	2.18
21	30ACV, 125P, 150ACV	2.242	1.15	1.95
22	30ACV, 125P, 320P	2.336	1.19	1.96
23	125P, 150ACV, 320P	2.260	1.15	1.97
24	LCM-6, LCM-8, LCU	1.000	1.00	1.00
25	30P, 150ACV, 320P	1.848	1.17	1.58
26	30ACV, 150ACV	2.210	1.12	1.97
27	30P, 125P	2.124	1.27	1.68
28	125P, 150ACV	1.894	1.13	1.68

The two craft mixes do not enjoy the cost advantages that were expected because development costs are not as dominant as was once thought. There is not a significant change in the number of craft purchased when going from a three craft mix to a two craft mix. In fact, Run 27 (30P, 125P) has the highest cost factor because of the large number of craft (324) included in the mix to lift one MAF.

Combined Results

The combined results of the analyses at both short and long stand-off distances show a clear preference for advanced craft. However, the accuracy of present data is sufficient merely to eliminate the small planing craft (10P) and to suggest that unless a vastly superior 30P to the one analyzed can be derived, this size should also be dropped. All the other advanced craft appear sufficiently attractive to warrant further investigation.

V WORK BEYOND COMPARISON OF PRELIMINARY CRAFT DESIGNS

This chapter places the comparison of preliminary advanced landing craft designs in perspective with respect to the balance of the AALC (Amphibious Assault Landing Craft) Program (S14-17). This perspective will take the form of narrating events both past and future that bear on the final selection of advanced landing craft for engineering development.

The analysis was completed in September 1969. Letter reports were issued announcing the principal conclusions presented in Chapter II. Since September 1969, important work has been initiated in the areas of craft design, craft support activities, analytical model building, and analysis with analytical models. The principal work in each of these areas is outlined briefly below.

Craft Design

Acting on the conclusions of the analytical comparisons and of the technological evaluations of preliminary craft designs, the AALC project office has contracted for additional design effort. This effort is directed toward the following five landing craft sizes:

<u>Payload</u> <u>(1,000 lb)</u>	<u>Hull Type</u>
30	Air cushion
30	Planing
125	Planing
150	Air cushion
320	Planing

The design work is divided into two categories: (1) the 150ACV craft and (2) the other craft.

150ACV Design Work

The 150,000-pound payload air cushion craft was singled out for particular emphasis, because this craft among all the recommended sizes pushes current technology the most. As a result, the time necessary to design, build, test, and evaluate this craft is longer than the time needed for the other craft sizes. One might also argue that the 150ACV shows the greatest promise for outstanding performance because it performed well despite deliberate handicaps such as the operating policies described in Appendix B. However, this argument is qualitative and did not enter into the decision to give special emphasis to the 150ACV.

In January 1970, contracts were let to Bell Aerospace Company and Aerojet General Corporation to design, construct, test, and evaluate 150ACV craft, subject to review and approval at the end of each of several phases. The initial design phase was funded. This work was completed in October 1970 and is now under review.

During the initial design phase, the contractors, with project office approval, made many engineering decisions that led to mainstream designs and thereafter to completed initial designs. Of these many decisions, one warrants mention because of its effect on the operating capability of the craft. In June 1970, the design payload of this craft was reduced from 150,000 to 120,000 pounds with provision to carry overloads at reduced performance up to 150,000 pounds. This change in payload is estimated to reduce the craft's effectiveness by less than 4 percent.* The small penalty results because only a small number of craft loads are expected to fall between 120,000 and 150,000 pounds. Furthermore, these loads can be (1) carried at reduced speed, (2) assigned to larger craft, or (3) divided into two or more loads. At 120,000 pound capability, the craft remains able to carry the heaviest equipment items in the Marine Corps inventory. Because there was no reduction in the size of the ACV's cargo well, the 150ACV can continue to carry the large area low density vehicle loads that are so abundant.

The results of the initial design phase suggest that the craft can be appreciably smaller than the 150ACV craft described. It also appears that preliminary operational goals can be substantially met.

* Letter from P. S. Jones to M. W. Brown, May 28, 1970.

Other Craft Designs

Recognizing the importance of providing a complete set of advanced landing craft, the AALC project office also undertook revised preliminary designs of the other four craft types. In the spring of 1970, a contract was let to Gibbs and Cox, Inc. to act as design agent for a second round of preliminary craft designs. Gibbs and Cox let the following design subcontracts:

<u>Craft</u>	<u>Contractor</u>
30ACV	Bell Aerospace Co.
30P	Atlantic Hydrofoils, Inc.
125P	Atlantic Research Corp.
320P	J. E. Bowker Associates, Inc.

Some modifications are under consideration that will provide more effective craft within the many constraining forces. It is inappropriate to announce changes at this time because of their tentative nature. However, it is quite likely that least one craft under study will emerge in a substantially different form. This design effort is scheduled for completion in early 1971.

Craft Support Activities

Several Navy laboratories are engaged in specialized support of the AALC program. The areas of principal activity are (1) craft technology; (2) reliability and maintainability; (3) cargo and craft handling; (4) command, control, communications, and navigation; (5) human factors and personnel; and (6) test and trials. Other naval activities are investigating instrumentation, lift systems, machinery subsystems, structures, power and control. This work is intended to provide timely inputs to design contractors on specialized problems and to review and support contractor activities.

Craft Technology

Work on craft technology is being performed at the NSRDC (Naval Ship Research and Development Center) at Carderock, Maryland. This work includes a broad range of activities concerned with the hydrodynamics of advanced craft operation. Its principal purpose is to

augment contractor activities with the vast wealth of experience available at NSRDC. The craft technology group also plays a major role in design evaluation with emphasis on the credibility of performance estimates.

Reliability and Maintainability

The NSRDL (Naval Ship Research and Development Laboratory) at Annapolis, Maryland, has been investigating the reliability and maintainability of advanced landing craft for several years. It developed the reliability and maintainability components of the attrition rates used in the comparison of preliminary designs of advanced craft. Since the completion of the preliminary design comparisons, it has developed a maintainability model and tested it with LCM-8 data. This model will be used to estimate the reliability of the C150 from the initial design data. It will also be used to estimate reliability from the revised preliminary designs of the other craft types.

Maintainability work concentrates on repair accessibility and estimates of repair times for different craft types. This work is embodied in thorough design reviews and rests on the extensive machinery experience within NSRDL.

Cargo and Craft Handling

NSRDL is the lead activity in developing new craft and cargo handling techniques and equipment. Task assignments have been made to HPNS (Hunters Point Naval Shipyard) for shipboard handling and to the NCEL (Naval Civil Engineering Laboratory) for beach handling. Effort to date has focused on documenting present handling techniques and equipment and on the development of a large logistic pallet capable of lifting four conventional pallets. Simulated shipboard tests have been conducted with the large pallets,* and beach handling tests are scheduled for late autumn 1970.

Preliminary work has been directed toward identifying craft and cargo handling needs.† Considerably more work is programmed for the

* Conducted at Hunters Point Naval Shipyard in December 1969.

† Hunters Point Naval Shipyard and Naval Civil Engineering Laboratory, "Amphibious Assault Landing Craft Program, Craft and Cargo Handling Systems Concept Review," HPNS Technical Report, 11-70, San Francisco, June 1970.

future. Because the general unloading phase of an amphibious assault depends on cargo handling performance, the principal analysis of landing craft performance in a general unloading environment must await further developments in this area.

Communications, Command, Control, and Navigation

Analysis of communications, command, control, and navigation requirements is being performed by the NELC (Naval Electronics Laboratory Center) in San Diego, California. It has prepared electronic equipment requirements for the L50ACV craft from an analysis of several operating scenarios and a set of tactical parameters.* This work is being revised and extended to include other craft sizes.

Human Factors and Personnel

Complementary tasks related to personnel skills, personnel requirements, and human factors are being performed by the NPRDL (Naval Personnel Research and Development Laboratory) in Washington, D.C., and NSRDL. These tasks have been in process since the inception of the AALC Program. Personnel and human factor requirements are especially important because of the dramatic differences between the operating environments of present landing craft and those contemplated for the advanced landing craft.

Tests and Trials

Test and trials planning began early in 1970 under the guidance of the Acting Test and Trials Director appointed at NSRDC. A test and trials program was developed, and test and trials requirements were established for the L50ACV craft. To avoid delays and to make maximum use of facilities and personnel, present plans call for complete rehearsal of test and trial procedures with present craft before builders' tests of advanced craft are complete. A test and trials committee has been formed that includes members from all the major disciplines represented in the AALC program.

* J. Martin, et al., "Communication, Navigation and Command Control System Configuration Definition for Amphibious Assault Landing Craft (U)," Naval Electronics Laboratory Center, June 30, 1970.

Analytical Model Building

For over a year, a clear need has existed for a model to supplement the computer models listed in Table 4. To meet this need a family of models called GAMUT has been developed, programmed, tested, and exercised. The models have been designed to perform types of investigations that are excessively costly, time consuming, or infeasible to perform with the detailed models. These include:

- (1) Investigations that require very large numbers of simulation runs
- (2) Investigations that for one reason or another cannot be performed adequately with the present detailed models
- (3) Investigations that require logic changes.

Two specific investigations fall into the first category--cargo handling and tactical parameters; one falls into the second category--the investigation of the complementary roles of helicopters and landing craft; and the third category is illustrated by variations in LVT delivery. Each of these investigations is described later. The purpose in the paragraphs below is to briefly describe the GAMUT models.*

GAMUT models are ship-to-shore simulations written in GPSS/360 (General Purpose Simulation System) and run on an IBM 360/67 computer. The input to the model consists of modified results from the EMBARK model, craft characteristics, operational characteristics, and environmental conditions. EMBARK results are modified primarily to reduce the level of descriptive detail about the Marine force. The force is described in terms of square feet of vehicles, number of personnel, and number of pallets of general unloading cargo. Up to eight different classes of general cargo can be treated.

To simplify the handling of 90 or more different pallet types used in a MAF, an SRI-developed clustering analysis[†] was used to group, or cluster, the pallets into a smaller number of types according to their essential characteristics. For the detailed consideration of pallets,

* A detailed description of the models will be included in a forthcoming report.

[†] See D. J. Hall et al., PROMENADE, An Improved Interaction-Graphics Man/Machine System for Pattern Recognition, developed by Stanford Research Institute for Rome Air Development Center, 1969.

eight separate pallet types were used. For other considerations, as in the consolidated GAMUT model, the eight types were further consolidated into three types as indicated by the clustering analysis. These breakdowns are considered adequate for the analysis of craft and helicopter activity.

The GAMUT models consist of one consolidated program and a number of subsets that can be run separately if desired. These include:

- (1) A craft operation section. This is the main part of the model.
- (2) A landing ship operations section, which is called GAMUT-S when run separately.
- (3) A helicopter operations section, which is called GAMUT-H when run separately.

There is also a version of the craft operations section, called GUSIM, that treats only the unloading of pallets during general unloading and does so in somewhat greater detail than the consolidated program. It includes eight separate pallet types of differing characteristics and allows for considerable flexibility in craft and pallet priorities.

The craft operations section simulates craft activities in considerable detail. Computations of vehicle loading and unloading times are somewhat less detailed than in STS-2, since vehicles are not considered individually but on a square foot basis. Load size is computed using experience data gained from the STS-2 model. The craft section has several features that are not available in the STS-2 model. These are:

- The ballast condition of well-type ships is taken into account. Planing craft are assigned to well-type ships that are ballasted down. If no planing craft are available, a delay occurs while the ship ballasts up to a dry well and then ACV craft are assigned. Similarly, a ship with a dry well seeks ACV craft. If none are available, the ship ballasts down and then accepts planing craft.
- Landing craft can be assembled into waves for movement to and from the assault beach, both for the scheduled waves and for subsequent operations. Wave sizes and wave wait times can be adjusted. Separate waves are provided for ACVs and planing hulls.

- Craft attrition rates due to enemy action decrease exponentially with time. By using a continuous density function rather than a step function to represent reduced vulnerability as friendly forces move forward, the impact of sudden reductions is eliminated.
- Craft repair times have a negative exponential density function rather than a linear density function. This is more consistent with available data.
- Interaction among craft and helicopters is included, i.e., some of the force can go ashore by either means, the mode of delivery being determined dynamically within the program through consideration of the current (simulated) state of the operation. This is more flexible than a priori segmentation of the force into parts by mode of delivery.
- Pallet types may be mixed aboard a craft during the general unloading phase.
- Delivery of LVTs in a number of ways by craft or ship is provided for. For long standoff distances, the LVT delivery mode has a critical effect on force effectiveness.
- The distance offshore and the size of the ship formation can be adjusted readily, and the procedures can be adapted to formations of ships that are under way.
- Assignment of craft to ships and cargo to craft is based on priorities specified in the inputs.
- ACVs can discharge their cargo either behind the shoreline or at a specified point inland (e.g., the LSA).
- Delay is allowed for at the start of the problem for the offloading of deckloaded craft from the LKAs and for the delivery of LVTs before vehicle delivery is started.
- A running inventory is maintained for LVTs, other vehicles, personnel, and pallets (by type) at the beach.
- A procedure is included to account for attrition of cargo and personnel at the beach, as well as for the flow of non-attrited vehicles, personnel, and pallets out of the beach area

and to the rear. Delivery of pallets to the LSA by all means is monitored.

- Speed of craft and helicopters varies with payload.

The landing ship operations section simulates LST operations, keeps track of vehicles, personnel, and pallets delivered by LSTs, and segregates this from cargo delivered by other means for the purposes of statistical reporting. The number of causeways and their installation time can be varied.

The helicopter section simulates the operation of up to three types of helicopters. The helicopters perform their assault missions as at present. After the assault units are delivered to their objective areas, all or some of the helicopters are made available to assist with the continued delivery of vehicles and cargo ashore. In general, helicopters are given loading preference at LHA- and LPD-type ships that can offload simultaneously by helicopter and landing craft; however, this is an input and can be varied. Helicopter loads are limited to vehicle and cargo types that they can lift. Helicopter delivery of vehicles and cargo can be made either to the LSA or to a separate operations area, as well as to the beach. This facilitates comparison with ACV craft delivering cargo inland and PLH craft deliveries at the beach. Statistical data on helicopter delivery are maintained separately from those delivered by other means.

The GAMUT models are much more economical to use than the detailed model set. A full scale simulation of a MAF sized force, using all three sections and including both assault and general unloading phases, requires less than 6 minutes of computer time. This compares very favorably with the 630 minutes of computer time (480 on the IBM 7030 STRETCH and 150 on the B-5500) required to simulate craft operations only for the assault and general unloading phases. Thus, the greatest advantage of the GAMUT model is the ability to investigate many more situations at reduced cost. However, this reduced cost has a condition--sufficient STS-2 experience must be available to allow for accurate representation of craft loads.

Analysis with the GAMUT Model

To date, the GAMUT model has been used to investigate a variety of different tactical parameters. Some of this work has supported NELC in the definition of communications, command, control, and navigation requirements. Other work has been directed toward posing important

questions to professional tacticians in hope of better defining the future roles of advanced landing craft. Because most of this work is in process, no effort is made to develop it in detail; instead, selected tasks are summarized.

The tactical parameters of interest are tactical decisions that influence the performance or management of landing craft in amphibious operations. Some tactical parameters, like the choice among alternative means for delivering LVTs to their launching area, have a profound effect on the conduct of the operation but may not affect craft design appreciably. Others, like the decision always to operate craft in formations, have an impact on craft design and cost, and also introduce potential delays in amphibious operations. Still others, like the division of ship-to-shore chores between landing craft and helicopters, may profoundly affect the Navy's future ship building program. The GAMUT analysis is intended to explore these questions and rank alternative answers in terms of amphibious operation effectiveness and cost. The final answers must come from professional tacticians.

LVT Delivery Techniques

The prospect of launching amphibious assaults from fleets standing 25 nmi or further off assault beaches poses grave problems for the operation of LVTs. Slow water speed and limited seaworthiness assure that they will not be launched from 25 nmi offshore and be expected to make their way to the beach. Thus, means need to be provided for delivering LVTs to a point from which they can form waves and move to the beach. As a result of the development of procedures for under way launching of LVTs from LPD-, LSD-, and LST-type ships, four alternative means are postulated for delivering LVTs to amphibious objective areas.

- (1) LVTs can be carried aboard LPDs that leave the fleet formation standing far offshore and launch the scheduled LVT waves under way, close enough to the beach for the LVTs to make their own way ashore.
- (2) LVTs can be carried aboard the LSDs that follow the maneuver described above for under way launch near the shore. However, because of the absence of troop accommodations, all the troops to land by LVT must be transferred to the LSDs before H-hour.
- (3) LVTs can be carried aboard LSTs and launched under way near the shore.

- (4) LVTs can be carried to, or close to, the assault beaches by landing craft.

Analysis of the above alternatives with the aid of the GAMUT model confirms that none is particularly attractive. All profoundly and adversely affect the conduct of the assault following the scheduled waves.

The first three alternatives require large ships to make close approaches (a few miles offshore) to assault beaches before assault waves are launched. This tactic would tend to nullify many advantages of long standoff distances. It may also greatly increase the risk of operational failure by singling out the small number of ships that carry the critical assault waves and bringing them close to shore where they can be subjected to concentrated attack. If LPDs carry the LVTs in upper vehicle storage spaces, their capability to carry heavy vehicular serials would be severely limited. When LSDs carry the LVTs, a large amount of craft-carrying space would be sacrificed. Finally, if LSTs carry the LVTs, heavy vehicles normally delivered directly to causeways by these ships would have to be brought ashore by other means.

If LVTs are delivered by craft instead of by ship, i.e., the last alternative is adopted, LVTs would constitute the bulk of the cargo preboated in landing craft. Most of the landing craft would be engaged in delivering scheduled waves ashore. As a result, the bulk of the first assault serials (scheduled or on-call) could not be delivered ashore until the craft that carried LVTs could return and be reloaded. This would require 1 to 2 hours. A delay of this magnitude may well be fatal to an amphibious operation against a prepared enemy.

The results of this analysis point to a need for new concepts of delivering LVTs ashore. Such concepts are being actively sought through discussions with operational commands and panels of professional military tacticians.

Helicopter/Landing Craft Interface

As discussed in the Introduction, separate versions of the STS-2 model are used to investigate landing craft and helicopter ship-to-shore operations. Because of the complementary roles of helicopters and landing craft, it was judged important to investigate the extent to which landing craft and helicopters can complement one another and the extent to which they interfere with one another. For this purpose, the

GAMUT model was designed to include both helicopter and landing craft operations. Investigations are under way that seek to identify the most attractive working relationships between the two. In all these investigations, helicopters assign first priority to delivering assault troops and vehicles to their objective areas. Only after these missions are complete are some or all of the helicopters available to help offload first serialized vehicles and then cargo from the ships of the amphibious fleet. At this time, helicopters compete directly with the available landing craft for certain of the loads. The relative numbers of helicopters and landing craft are modified by changing the composition of the amphibious fleet. The fleet always carries the maximum number of helicopters and landing craft that it can accommodate. Since the results of this analysis are now being developed, no conclusions can be drawn at this time.

Craft Formations

To aid NELC in preparing requirements for communications, command, control, and navigation equipment, a series of GAMUT runs explored the sensitivity of amphibious operation effectiveness to changes in craft operational mode. Two operational modes were explored: (1) independent craft operation after scheduled waves had been landed and (2) operation of craft in waves throughout the assault phase of the amphibious operation. The latter mode would restrict the most complex electronic gear to designated wave guide craft and make nonwave guide craft dependent on wave guides for communications and navigational functions. Maximum wave sizes of five and ten craft were explored. The results of the analysis indicated that the adoption of waves of five craft would reduce assault effectiveness by 1 to 4 percent and the adoption of waves of ten craft would reduce effectiveness by 4 to 11 percent.

Number of Beach Unloading Positions

Beach requirements and requirements for navigational equipment accuracy were explored by changing the number of landing (beaching) areas available to ACV and planing craft. Analyses were made with the GAMUT model using 32, 24, and 16 beach unloading positions for standoff distances of 30 and 50 nmi. Reducing beach unloading positions from 32 to 24 caused only marginal reduction in assault effectiveness. However, the change from 24 to 16 was marked. With only 16 unloading positions available, significant numbers of craft were held outside the line of departure awaiting unloading space. The overall assault effectiveness was reduced by 20 to 25 percent from 30 nmi standoff distance and 15 to

20 percent from 50 nmi standoff. These results suggest that a minimum of 24 unloading positions are required to assure that an MAF-sized assault is not delayed. Subject to modifications for specific beach areas, this suggests that craft lanes can be as wide as 50 to 100 yards. Thus, navigation equipment need not be more accurate than dictated by this lane width if it is more limiting than obstacle clearance requirements.

Fleet Standoff Distance

Standoff distance has a marked influence on amphibious operation effectiveness. Clearly, it is desirable to bring the amphibious fleet as close to the assault beaches as is tactically feasible. However, where long standoff distances are needed, the GAMUT model can be used to measure effectiveness lost for the sake of the longer standoff distance. Comparative force-time effectiveness measures for standoff distances from 5 to 50 nmi are plotted in Figure 25.

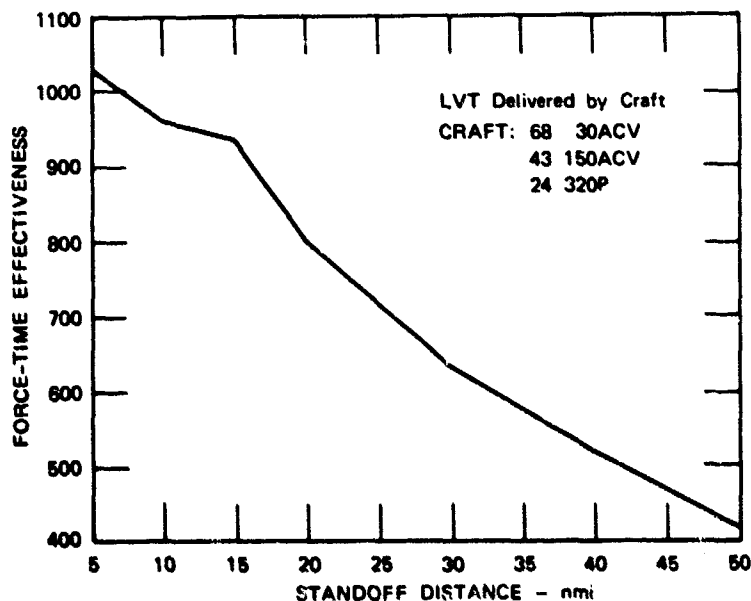


FIGURE 25 FORCE-TIME EFFECTIVENESS AT 10 HOURS VERSUS STANDOFF DISTANCE

Amphibious Ship Movements

In the comparisons of preliminary advanced landing craft designs described in preceding chapters, the issue of sea echelon formations was avoided. However, the question of what formations should be adopted by amphibious fleets launching assaults from long standoff distances cannot be lightly set aside. Although the question of future formations is left appropriately to military tacticians, some insights into the results of different assumptions can be gained by exercising the GAMUT model. The investigations to date have been limited to explorations of the effect of increased ship separation on the effectiveness of amphibious operations. Figure 26 illustrates the changes

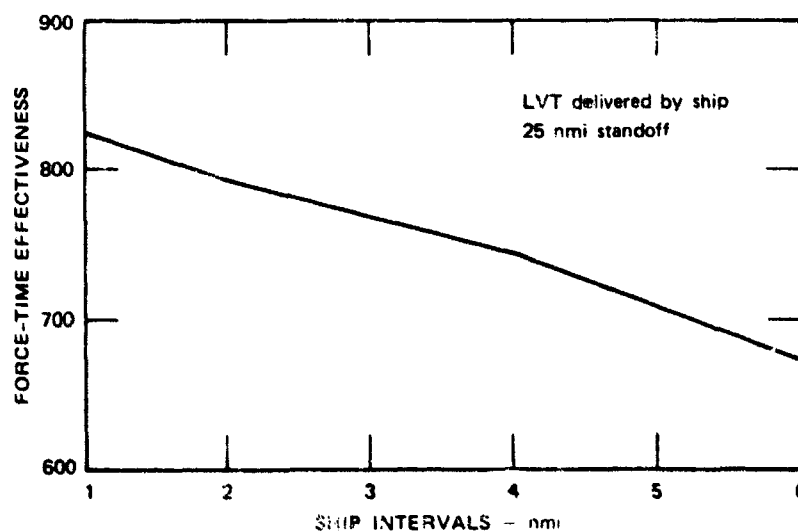


FIGURE 26 FORCE-TIME EFFECTIVENESS AT 10 HOURS FOR VARIOUS SHIP INTERVALS

in force-time effectiveness as mean ship separation changes from 1 to 6 nmi. The former represents a compact formation like the one used in comparing preliminary craft designs. The latter separation provides each with 36 square miles of maneuvering room, sufficient to allow it to operate independently. Note that force-time effectiveness decreased only 18 percent as ship separation increased from 1 to 6 nmi, the decrease being accounted for by the greater travel time in the ship area.

ACV Operations Beyond the Beach

Much discussion has centered about the potential capability of ACV to move across the beach and carry Marine cargo directly to inland destinations. This concept has some obvious shortcomings, including: (1) access and egress paths would need to be provided,* (2) the ACV would be subjected to greater potential enemy damage, and (3) craft control would be more complex because of the need to deal with multiple destinations. Nonetheless, we explored the impact on force-time effectiveness of directing ACV craft to inland destinations as far as 10 miles beyond the beach line. The generalized results of this work are plotted in Figure 27. It is not surprising that force-time effectiveness drops as inland distance increases. However, an amphibious

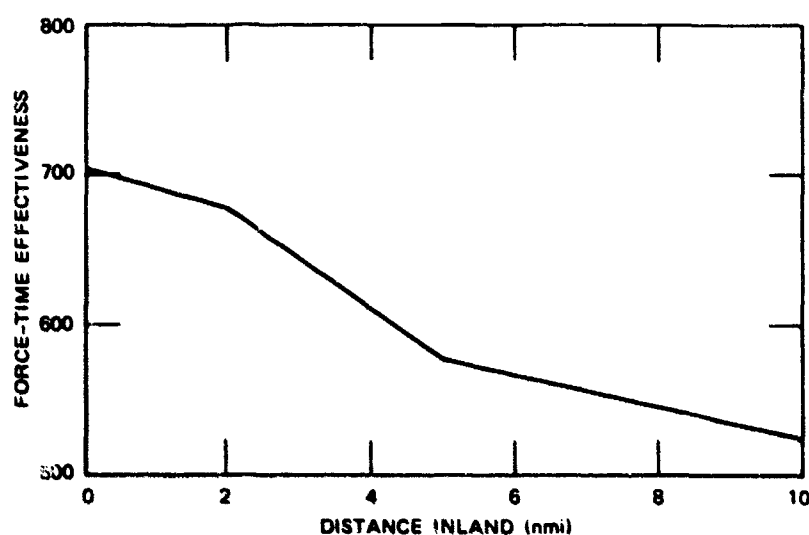


FIGURE 27 FORCE-TIME EFFECTIVENESS AT 10 HOURS VERSUS DISTANCE TO INLAND DELIVERY POINT

commander would need to decide whether the delays in delivering vehicles ashore are overcome by the more strategic placement of serialized units. In the general unloading phase, craft time that is normally surplus can be used to deliver cargo to logistic support areas inland and thereby reduce or eliminate cargo handling on the beach and motor shuttle operations between the beach and LSA.

* Both the 30ACV and 150ACV would likely be too wide to use conventional military roads.

Variations in the Number of Craft

Based on a limited number of runs, it was found that minor variations in the numbers of craft had little effect on force effectiveness. More critical was the extent to which the craft filled up available well space. Some combinations of craft do not do this efficiently because of size and shape restrictions, with the result that fewer craft are available and mission effectiveness suffers.

Craft Operations during General Unloading

Previous analyses* suggested that the available landing craft are not fully used during the general unloading phase of an amphibious assault. This results from long craft loading and unloading times for nonvehicular cargo.

Investigation with the GAMUT model revealed that only about half the number of the available craft are productively useful during the general unloading phase. Furthermore, high craft speeds are relatively unimportant, because performance is largely governed by the long craft loading and unloading times. When craft operating speeds are reduced to 10 knots while retaining a 25 nmi standoff distance, throughput declines only about 5 percent.

The above results clearly point to the need for improved cargo handling as the principal means for improving general unloading performance. They also suggest that some advanced craft might be diverted to other duties after the assault phase is complete without affecting the general unloading performance.

Assistance with Craft Design Parameters

During the preparation of initial designs for the L50ACV craft and the revision of the preliminary designs of the other craft types, questions about craft size, load capacity, and other major design parameters have arisen.† Analyses using the GAMUT and CRAFT models were of material benefit in answering these questions. The steps listed below generally outline the procedure followed in investigating new cargo well dimensions and load capacities:

* See Jones, et al., op. cit.

† Load capacity for the L50ACV craft has already been discussed.

- (1) Select candidate craft parameters for investigation. This might include a set of alternative cargo well sizes and load capacities.
- (2) Select the craft type or types to round out the craft mix for each alternative. Each mix is made up of one of the alternatives identified in (1) above and one or two augmenting craft types. Use the same augmenting craft types for all mixes.
- (3) Fit the entire Marine force into the selected craft mixes using CRAFT. Rank the alternative mixes in terms of gross square feet of craft well area needed to lift the force.
- (4) Rank the alternatives in terms of gross outside craft* area needed to lift the entire force, and the number of the craft alternative under study selected to lift the force. A craft mix may be efficient in terms of craft cargo well area and craft outside area, but, if only a small number of the craft alternative under study are selected, that size is probably not efficient. In this case the high efficiency would reflect only on the craft selected in (2).
- (5) Determine load distributions for the craft alternatives under study. If capacities are inconsistent with cargo well area revise one or both and return to (3).
- (6) Compute mean well area utilization for each alternative size and capacity of the craft under study.
- (7) Rank the alternative craft in terms of:
 - Gross craft cargo well area
 - Gross craft outside area
 - Number selected of the craft alternative under study
 - Mean area utilization for the craft alternative under study
- (8) Combine the rankings by means of a consensus ranking scheme.

* Rectangular outside area = overall length x maximum beam.

- (9) Select the two or three highest ranking craft mixes and for each fit a craft mix aboard the amphibious ships whose proportions approximate those resulting from the CRAFT program.
- (10) Simulate the highest ranking mixes with the GAMUT model.
- (11) Compare the Craft mixes in terms of the measures of amphibious assault effectiveness.
- (12) Select the most effective craft alternative.

The above procedure requires a few weeks' time, depending on the number of alternatives to be examined. It provides studied answers to questions that relate to a craft's operational effectiveness. If appropriate, questions of cost can also be addressed through analyses not unlike the one described above.

Future Work

In addition to continuing the support described above, the project team is preparing to initiate two important new tasks that will depend heavily on the use of versions of the GAMUT model. The first task is concerned with identifying limiting beach constraints and relating constraining values with amphibious assault effectiveness. The second task is a parametric investigation of cargo handling to help guide the developers of new cargo handling equipment and to evaluate new concepts as they are developed.

Beach Analysis

An amphibious commander is concerned with assaulting a particular beach or beaches. He would like to know what performance he can expect from landing craft in the particular environment that confronts him. He would be well served if his judgment is not clouded by performance claims that do not relate to his tactical environment. Since there is no way to single out the relatively few beaches that might see future amphibious assaults from among the vast number that might not, techniques for relating craft performance to beach characteristics are suggested.

A beach classification scheme has been prepared. This scheme is being used as a basis for identifying assault performance degradation due to beach characteristics. The assault beach used in the comparison

of preliminary craft designs is nonrestrictive. In this sense, no beach characteristic limits assault performance. There are adequate craft lanes and ACV discharge areas. Beach exits are adequate to provide timely egress for arriving vehicles. No offshore obstacles hamper planing craft operations, and the beach gradient does not hinder either planing or ACV craft. In fact, it is the best of all beaches. Real life is not this good. As reported above, we have explored the effects of restricting the number of beach unloading positions. We have also looked into the problems of moving ACV craft long distances inland that could represent traversing marsh land as well as moving to an LSA. Work is now under way to identify the level at which the different beach characteristics begin to be restrictive and the nature and magnitude of the changes in effectiveness that accompany increased restrictions.

It is hoped that this work will provide a sound basis for evaluating craft in terms of their potential beach requirements. We also hope to provide a planning tool that can be used to evaluate alternative beaches or to provide quantitative estimates of the degradation of effectiveness that will accompany an assault on a difficult beach.

Analysis of Materials Handling

In the general unloading phase of an amphibious assault, the relative merits of advanced craft depend heavily on the materials handling techniques and equipment that are used for craft loading and unloading. Without improved materials handling techniques, the full capability of advanced craft cannot be realized. Results to date indicate that only half the available advanced craft can be used effectively during the general unloading phase.

The materials handling analysis will be concerned with handling nonwheeled supplies and equipment on board amphibious ships, loading them into landing craft, unloading them at or beyond the beach, managing temporary dumps on the beach, and loading the supplies and equipment into trucks for delivery to logistic support areas or other inland destinations. The materials to be handled include palletized ammunition, provisions and supplies, oversized (banded or unitized) cargo, special skid-mounted equipment, and other items that cannot be driven or towed.

The materials handling analysis will consider the manner in which improved equipment being developed by NavSec, NSRDL, HPNS, and NCEL will perform in complex amphibious environments. The study team will

also develop performance guidelines for specific items of equipment and will compare and evaluate equipment alternatives as they are developed.

The materials handling work includes three tasks: (1) parametric analysis of cargo handling equipment, (2) analysis of shipboard materials handling, and (3) analysis of beach handling.

In the parametric analysis, the GUSIM portion of GAMUT will be used to critically examine current materials handling practices and to identify present and potential bottlenecks.

The GAMUT model treats materials handling productivity and the relationship of different materials handling systems, such as LPD systems and beach-unloading systems. It does not treat specific differences in equipment such as improved fork truck cycle times in the hold of an LPD. Problems of this sort will be resolved by construction of simple, manually manipulated models of shipboard and by beach-handling procedures, as outlined in the two tasks described below.

Shipboard Materials Handling. The objectives of the shipboard materials handling task are to devise and compare alternative systems for moving nonmobile supplies and equipment rapidly from storerooms and magazines to and aboard landing craft. The ships of interest include all principal cargo carrying types LPD, LPH, LHA, LST, and LKA.

A computer simulation model of LPD materials handling has been completed. This model, written in GPSS, simulates the movement of palletized cargo from four storerooms through the materials handling devices--fork trucks, pallet elevators, and monorail cranes--to landing craft and helicopters. The model accurately represents present equipment and techniques, accounts for the limitations of equipment interfaces and for the size and arrangement of intermediate storage areas, and measures the reaction to changes in requirements. The model can be modified to represent new equipment and techniques. It will be used for an analysis of materials handling aboard well-type ships, evaluating and comparing (1) monorail cranes and bridge cranes for operation in well decks, (2) the relative merits of pallet conveyors and elevators of different sizes, (3) the handling of large logistic pallets aboard ship, and (4) other potential modifications.

LHA materials handling will be examined with an adaptation of the LPD model. The SRI transfer model,* with modifications, will be used for LKA-type ships. Separate models will not be needed for LPH and LST types.

Model development is only a small part of the shipboard materials handling task. Data collection for use in the models is under way and will require considerable effort. The models will be extensively used in comparing new equipment, developing equipment requirements and guidelines, and estimating system costs. This work will require continuous interaction with the different equipment design teams and will undoubtedly include the investigation of many items of equipment that prove unattractive. It is important that alternative solutions be explored methodically until the levels of productivity identified by the GUSIM model can be achieved.

Beach Handling Analysis. The objectives of the beach handling analysis are to compare and evaluate equipment and techniques for (1) unloading cargo from landing craft on or near an assault beach and (2) loading cargo aboard trucks or other vehicles for delivery to inland destinations.

We plan to use the GAMUT model to analyze the interfaces between complementary equipments. Manual analyses will be used to explore directly means for rapidly unloading landing craft on or behind the beach. Particular attention will be given equipment that offers the operational flexibility needed in an amphibious assault. These analyses will consider the influences of water, surf, soft sand, and hard soil.

The beach analyses will be directed toward testing, comparing, and evaluating new equipment, equipment ideas, and techniques that are developed and suggested by NCEL, NavSec, NSRDL, HPNS, and others. Performance guidelines will be established, and system cost-effectiveness will be estimated.

* See McFadden, Fred R., Replenishment at Sea: Description of Transfer Model, NWRC/LSR RM-26, Stanford Research Institute, Menlo Park; 1964.

Appendix A

REPRESENTATIVE GRAPHICAL OUTPUT

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Appendix A

REPRESENTATIVE GRAPHICAL OUTPUT

Two examples of the standard graphical output produced by the PLOT program are presented for each of the runs simulated using the detailed set of programs. These curves provide graphical representations of the assault, the roles played by different craft types, and the activities of the different craft types. They are very helpful in understanding simulation results. All the craft performance curves presented in Chapter IV are taken from the standard graphical output.

Seven graphs are prepared for a simulation that uses three craft types. The first set of graphs are for Run 17 (Figs. A-1 through A-7). The craft mix for Run 17 comprises:

80 125P
32 150ACV
24 320P

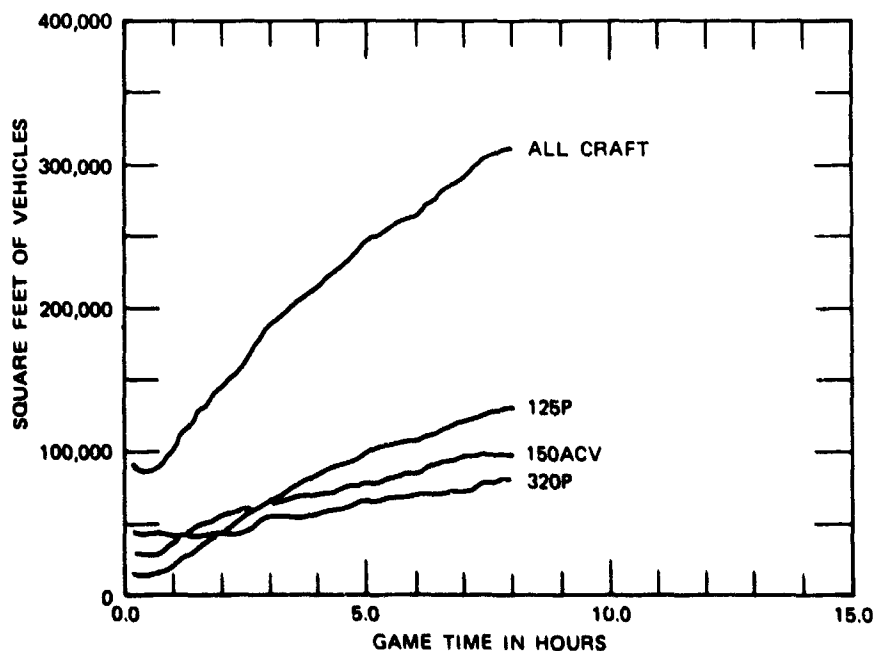


FIGURE A-1 VEHICLES OFF-LOADED FROM SHIPS — ADVANCED RUN 17,
5 nmi STANDOFF DISTANCE

The assault was launched from a nominal standoff distance of 5 nmi. This craft mix demonstrated the best overall effectiveness-cost performance for all of the Set One runs.

Figure A-1 shows the square feet of vehicles offloaded from ships plotted against game time (time after the last scheduled wave crosses the beach). Separate curves are given for each craft type and for the mix as a whole. The y-axis intercepts of these curves show the vehicular area preboated in each craft type and in the mix. The curves of Figures 3, 4, and 15 are taken from these graphs.

The second graph (Figure A-2) shows square feet of vehicles delivered to the beach plotted against game time. Separate curves are given for each craft type and for the mix as a whole. These curves have x-axis intercepts giving the time that the first vehicles are unloaded ashore.

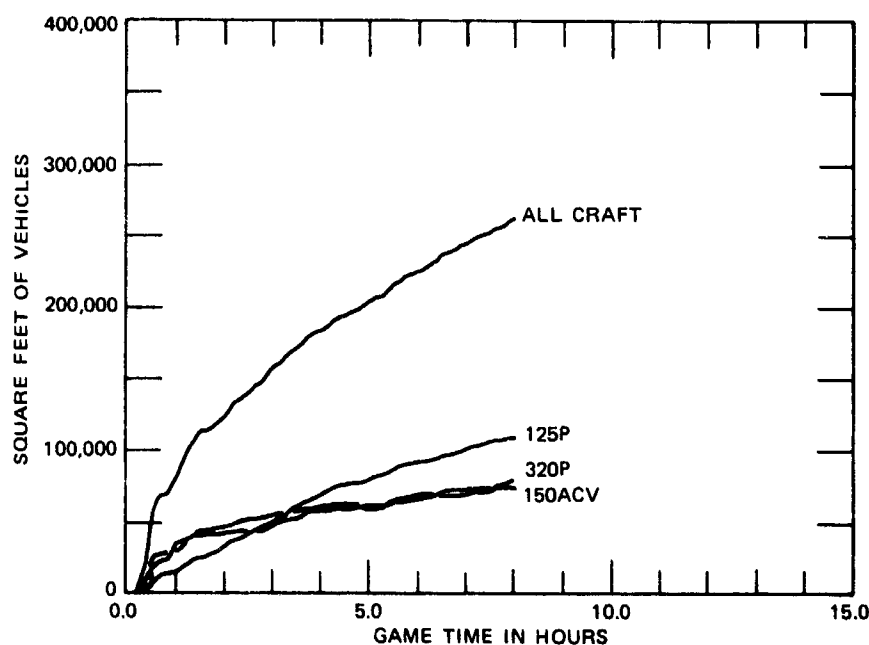


FIGURE A-2 VEHICLES DELIVERED TO BEACH — ADVANCED RUN 17, 5 nmi STANDOFF DISTANCE

The third graph (Figure A-3) shows force-time effectiveness for vehicles offloaded from ships plotted against game time. Separate curves are given for each craft type and for the craft mix as a whole. These curves are the areas under the corresponding curves of Figure A-1.

The fourth graph (Figure A-4) shows force-time effectiveness for vehicles delivered to the beach plotted against game time. As with Figure A-3, separate curves are plotted for each craft type and for the mix

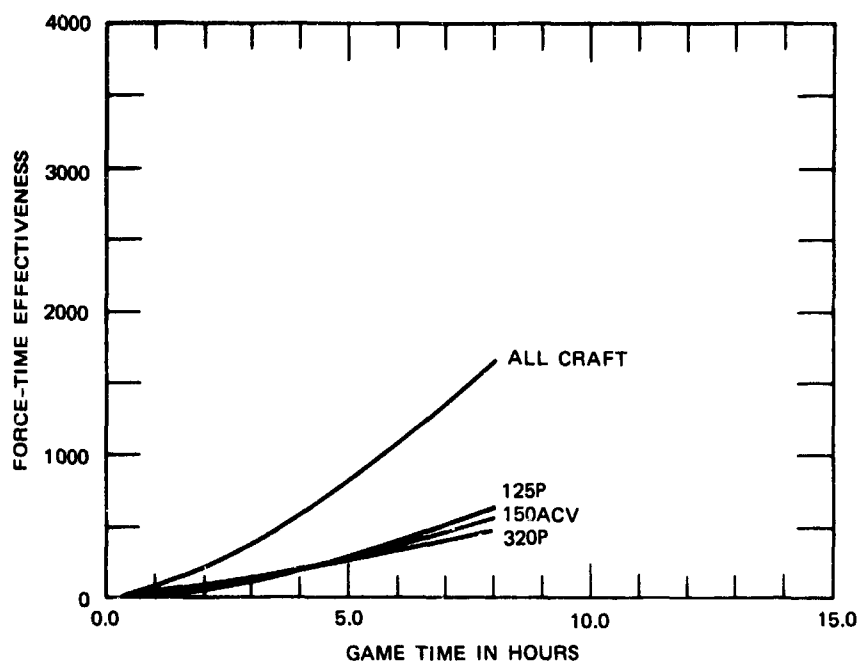


FIGURE A-3 FORCE-TIME EFFECTIVENESS OF VEHICLES OFF-LOADED FROM SHIPS — ADVANCED RUN 17, 5 nmi STANDOFF DISTANCE

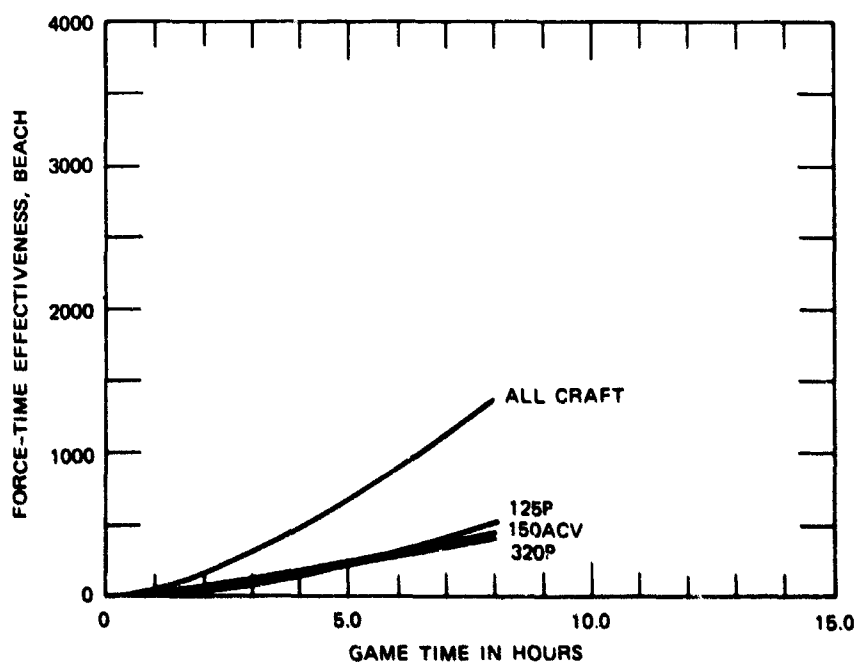


FIGURE A-4 FORCE-TIME EFFECTIVENESS OF VEHICLES DELIVERED TO BEACH — ADVANCED RUN 17, 5 nmi STANDOFF DISTANCE

as a whole. These curves are the areas under the corresponding curves of Figure A-2.

The last three graphs (Figures A-5 through A-7) show the cumulative distribution of craft activity versus game time. These curves have been extensively discussed in Chapter IV and need no further elaboration.

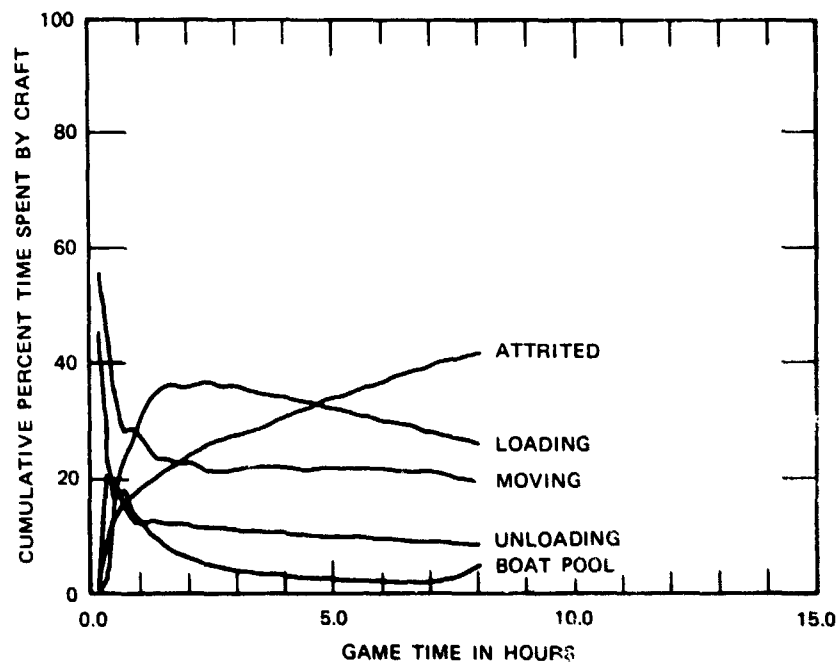


FIGURE A-5 ADVANCED RUN 17 — 125P ACTIVITY CURVES,
5 nmi STANDOFF DISTANCE

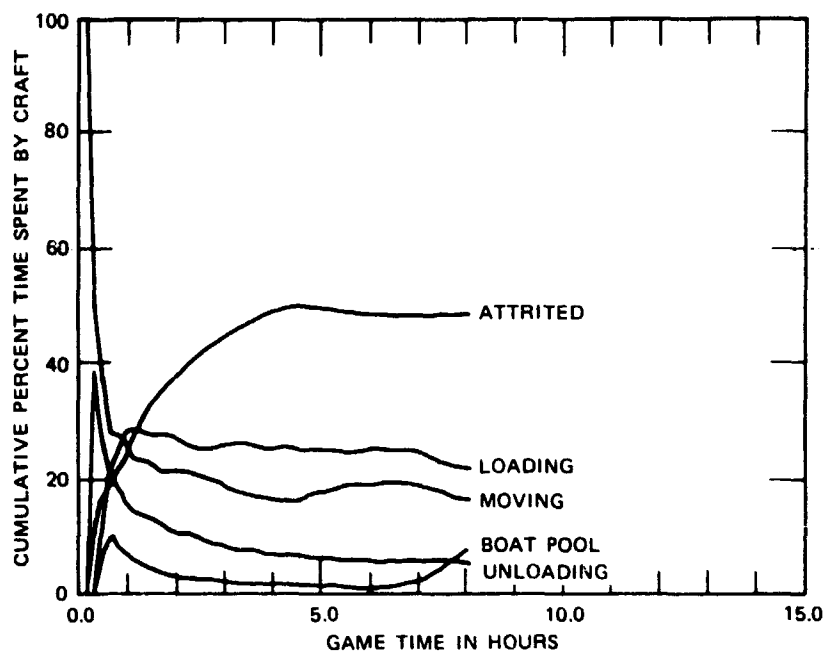


FIGURE A-6 ADVANCED RUN 17 — 150ACV ACTIVITY CURVES, 5 nmi STANDOFF DISTANCE

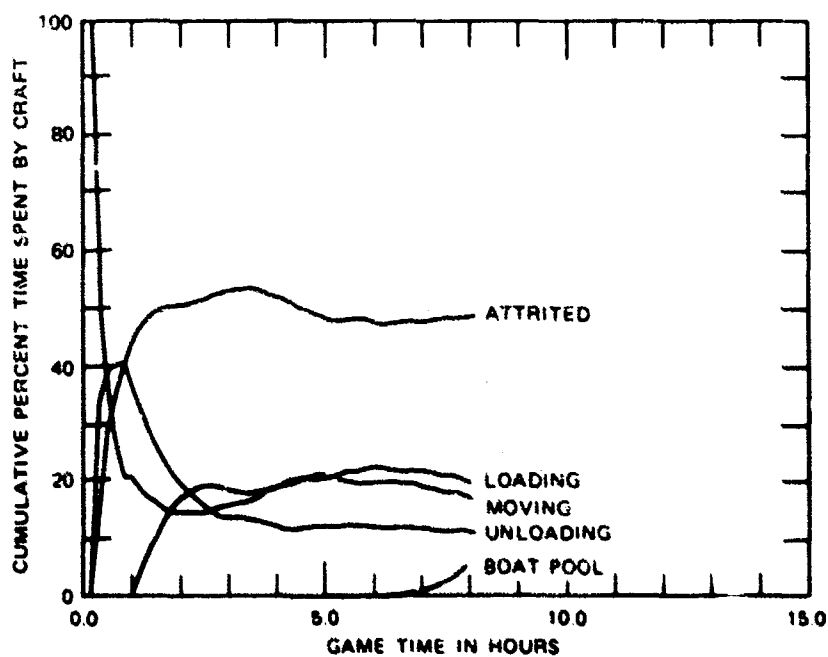


FIGURE A-7 ADVANCED RUN 17 — 320P ACTIVITY CURVES, 5 nmi STANDOFF DISTANCE

The second set of graphs are for Run 20, Figures A-8 through A-14.
The craft mix for Run 20 comprises:

95 30ACV
37 150ACV
19 320P

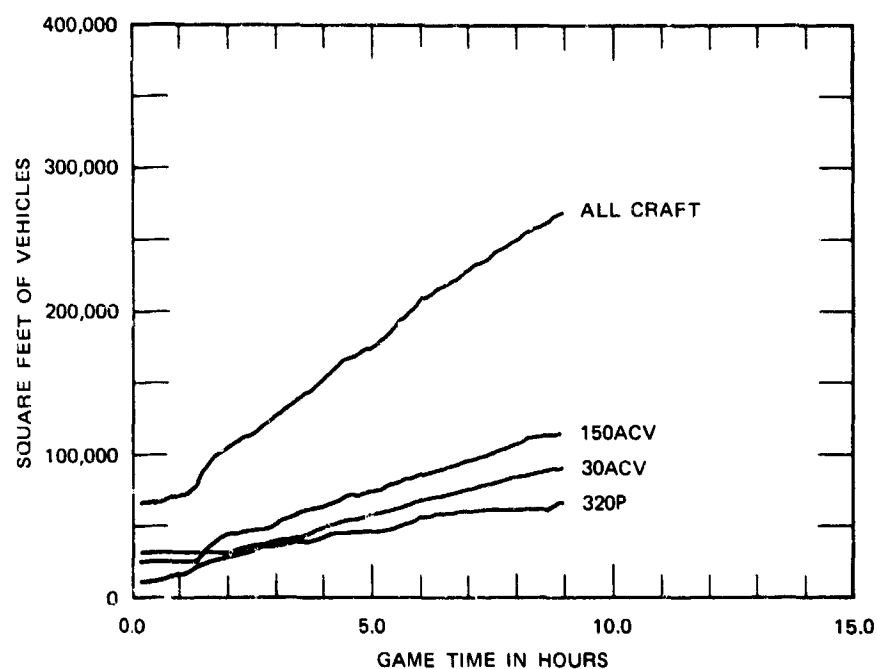


FIGURE A-8 VEHICLES OFF-LOADED FROM SHIPS -- ADVANCED RUN 20,
25 nmi STANDOFF DISTANCE

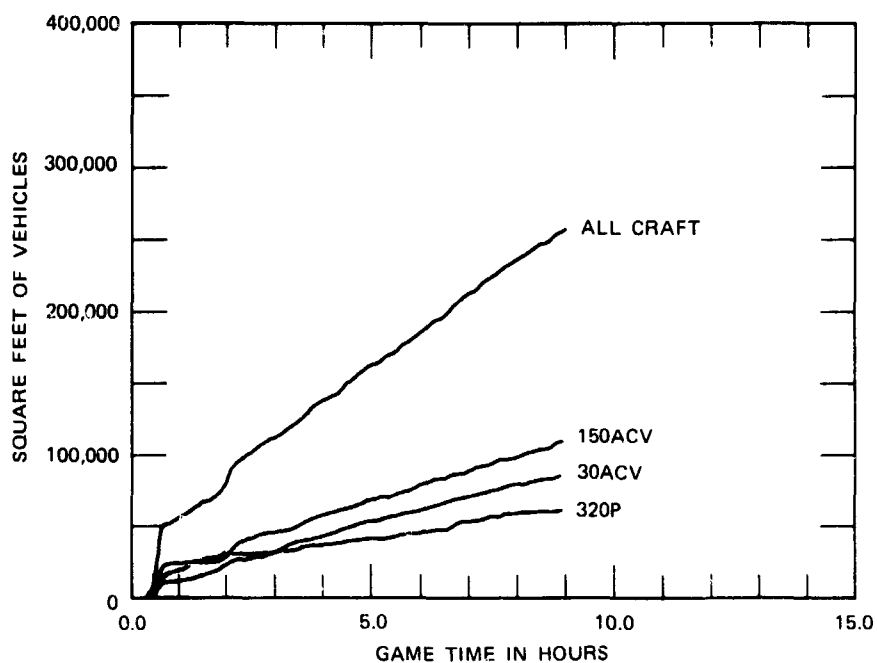


FIGURE A-9 VEHICLES DELIVERED TO BEACH — ADVANCED RUN 20, 25 nmi STANDOFF DISTANCE

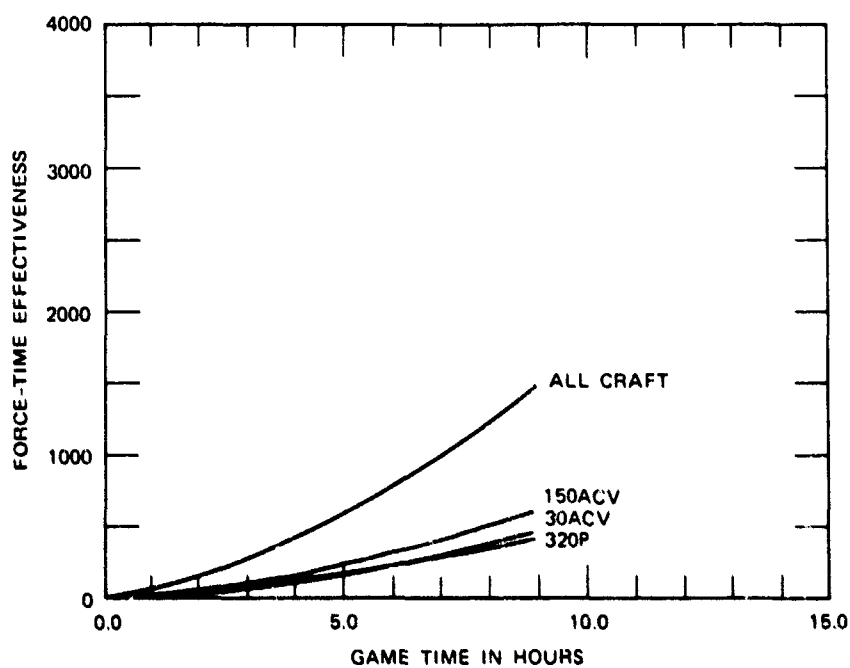


FIGURE A-10 FORCE-TIME EFFECTIVENESS OF VEHICLES OFF-LOADED FROM SHIPS — ADVANCED RUN 20, 25 nmi STANDOFF DISTANCE

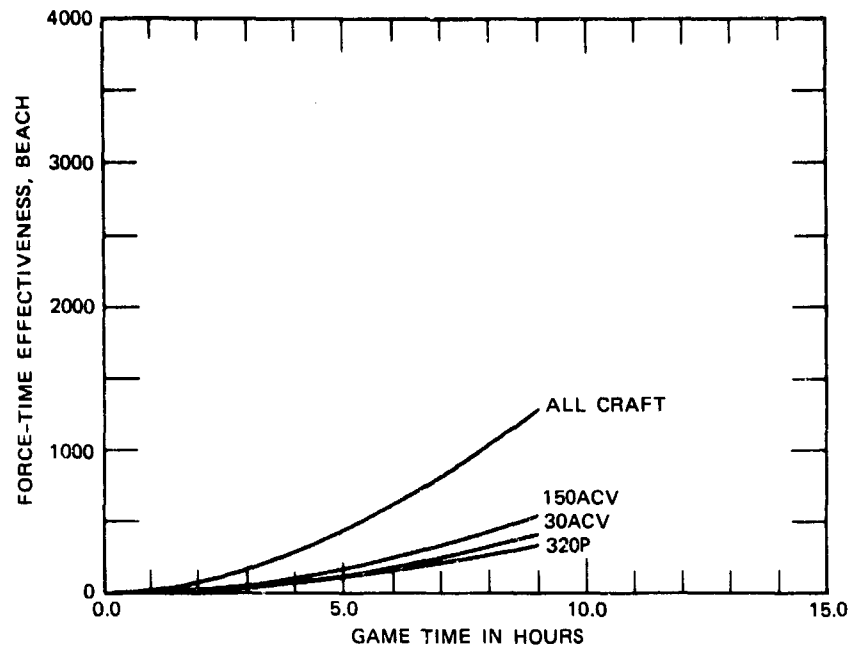


FIGURE A-11 FORCE-TIME EFFECTIVENESS OF VEHICLES DELIVERED TO BEACH — 25 nmi STANDOFF DISTANCE

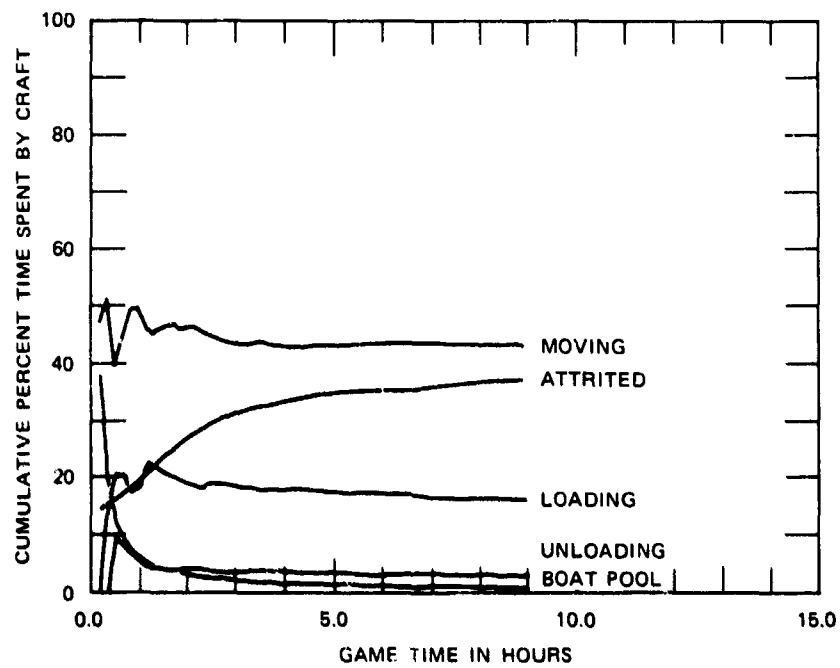


FIGURE A-12 ADVANCE RUN 20 — 30ACV ACTIVITY CURVES, 25 nmi STANDOFF DISTANCE

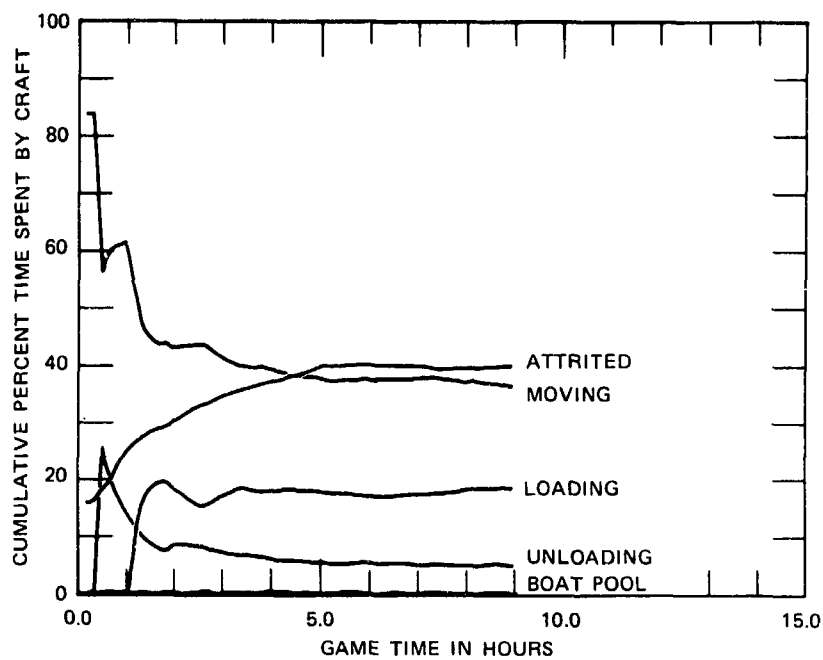


FIGURE A-13 ADVANCED RUN 20 — 150ACV ACTIVITY CURVES, 25 nmi STANDOFF DISTANCE

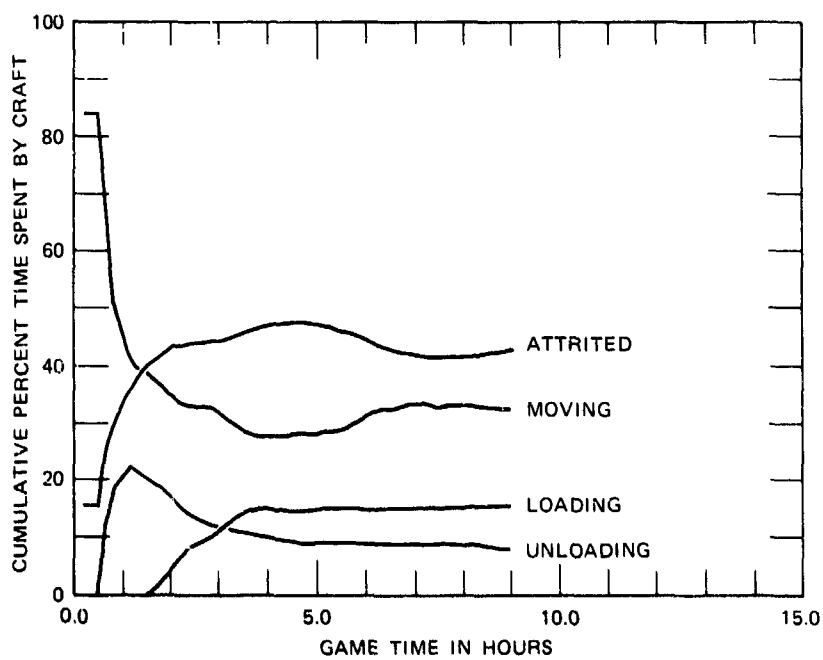


FIGURE A-14 ADVANCED RUN 20 — 320P ACTIVITY CURVES, 25 nmi STANDOFF DISTANCE

The assault was launched from a nominal standoff distance of 25 nmi. This craft mix demonstrated the best overall effectiveness-cost performance for all of the Set Two runs.

Appendix B

OPERATING CONVENTIONS USED AS A BASIS FOR
THE COMPARISON OF PRELIMINARY ADVANCED CRAFT DESIGNS

Appendix B

OPERATING CONVENTIONS USED AS A BASIS FOR THE COMPARISON OF PRELIMINARY ADVANCED CRAFT DESIGNS

This appendix presents data that were developed to define craft operating cycles between the different ships of the amphibious fleet and the assault beach. These data do not represent best potential operating practices, but rather they are compromises prepared for use in the STS-2 set of models. Some of the results have also been used in the GAMUT model. The ships of interest include those used in the amphibious environments in which advanced craft mixes were compared--LSD, LPD, LHA and LKA types. Although LPH and LST types are not discussed in this appendix because they did not participate significantly in craft activities, their contributions were recognized in the broad analysis of assault effectiveness. The assault beach was the notional one described briefly in the introduction.

Operating Assumptions

The analysis of operating cycles was based on a number of critical operating assumptions. Several of these are controversial and perhaps do not reflect the manner in which advanced craft may actually be used in future amphibious assaults. Of the controversial assumptions, some were dictated by the limitations of the computer models. Others were deliberately picked to bridge gaps in present doctrine or to avoid assumptions that would tie the analysis to specific scenarios.

As a general practice, we deliberately overestimated operating times for air cushion craft. This position was taken for the following reasons:

- (1) Because of the scanty available data on ACV operations, operating times are highly speculative. What appears to be feasible may actually not be.
- (2) The proposed ACV craft are so different from existing ACVs that a direct transferral of operating data may not be appropriate.

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- (3) There is very strong emotional support for ACV craft in Navy and Marine Corps circles. We were reluctant to feed this enthusiasm with optimistic performance estimates.

The result is an analysis that is slightly biased against ACV craft. Nonetheless, ACV craft performed so well that they clearly merit further development effort.

All Craft Must Have Drive-Through Capability

The requirement for drive-through capability is discussed in the Introduction. This appendix touches briefly on the implications of drive-through capability to landing craft operations. Because PLH (planing hull craft) must discharge vehicles and cargo over their bow ramps at the beach, they must be backed into the wells of well-type ships to take advantage of drive-through capability. This procedure, which was assumed for the analysis, introduces a number of problems. For proper beaching, planing craft are designed with deeper draft aft than forward (the 320P draws about 7 feet aft when fully loaded). Thus, when backing into a well, they can be expected to ground out before they reach the forward part of the well. In the case of LPDs it will be impossible to back a 320P far enough into the well for the craft's bow to enter the well. As a result, vehicles might normally be expected to drive into the ship's well through deep water before they can enter the craft. A further difficulty is that none of the planing craft have stern ramps, only access gates. These two problems were overcome together by assuming that all well-type ships carry portable ramps capable of bridging the deepest water to the stern gates of craft. When not in use, a ramp would be hoisted to the overhead in a position that would not interfere with craft operations.

ACV craft have no difficulties with drive-through capability. Because of their beach crossing capability, they can enter the well in a forward aspect. Vehicles are driven aboard and then driven off over the stern ramp when the craft has reached its unloading area.

Craft Can Be Assigned to Any Ship

A principal feature of the computer models is the ability to have craft compete for cargo irrespective of which ship brought the cargo to the objective area. By this device craft utility is maximized. To achieve this end, good communications are required between ships, craft control points, and craft. This good communication was assumed. We also

assumed that the combat cargo officer of each ship had the capability of selecting craft as effectively as the craft selection program (SELECT), and loading them as efficiently as the craft loading program (FIT).*

All Craft Entered Ship Wells in the Displacement Mode

This assumption is controversial and is based on a heterogeneous craft mix. If ACV craft are the only ones being used in an assault, this assumption does not apply.† In future operations it is expected that ACV craft will be loaded on board well-type ships that have dry wells. The ability to enter a dry well is a major advantage of ACV craft. It completely eliminates problems of ballasting depth, wave action in the well, ACV spray, grounding craft, and the other operational handicaps associated with the operation of well-type ships. Nonetheless, this utopia of the dry well is not without its problems. If the craft mix contains both ACV and planing craft, it must be decided which ships are to be ballasted down and which retain dry wells. To maximize craft utility, ships need to anticipate the type of craft that they will receive far enough in advance to be ballasted so that the craft would not have to be idle during ballasting. The ACV utopia would also require that a single serial (unloaded from a single ship) be loaded entirely on ACV craft or entirely on planing craft.

The problem of segregating craft into planing and ACV classes was not addressed in the preliminary analysis. The STS-2 simulation in its present configuration does not differentiate between craft types and therefore does not assure that a succession of ACV craft are loaded in the dry well of a ship.‡

All Craft Are Towed Into Wells

All well-type ships were assumed to be equipped with special types of towing equipment so that all craft could be towed into and out of wells. Towing gear eliminated problems associated with backing planing craft into wells. It is also possible that more advanced versions of

* See Stidham, op. cit. for a description of these procedures.

† In the GAMUT models, the procedure is more flexible.

‡ The STS-2 does assure that if more than one craft enters the well at a time, then all craft entering simultaneously are either planing craft or ACV craft.

the towing equipment might be capable of moving the craft further into the well than their draft would normally permit.* Towing devices in wells also allow ACV-type craft to secure their air propulsers before entering the well. This eliminates a potential hazard to line handling personnel and personnel stationed on catwalks and other locations near the air screws. Securing the air propulsers will also eliminate a wind tunnel effect that may be hazardous to personnel or equipment.

Preliminary estimates of towing equipment performance and cost were prepared by NSRDL. Operating times for entering and leaving wells were based on these estimates.

Ships Were Anchored or Lying to During Loading

Operating procedures for the close-in assault are based on conventional present day practice in which all ships except LPHs are anchored in the objective area.† Thus, other ships were relatively stationary so that landing craft could enter wells or come alongside and tie up in a conventional manner to receive cargo. For long standoff distances (e.g., 25 nmi), it is almost certain that water will be too deep for anchoring. Therefore, in all probability the amphibious ships would be under way, at low speed, in some sea echelon mode for purposes of station keeping and to reduce ship vulnerability to enemy action. Low speed operation likely would pose serious problems for both well-type and LKA ships. Some forms of towing or docking gear would be needed to preserve relative craft position while entering wells or during loading. The design of this gear would likely influence the number of available LKA loading stations and the time that craft require to come alongside and move clear. To avoid wild speculation about the nature and performance of the required towing or docking gear, it was assumed that all ships were lying to while loading craft so that conventional methods would apply. Clearly, this question requires considerable attention and a solution rather than the unlikely assumption adopted for this analysis.

* For example, LHAs will be equipped with landing craft conveyors that will carry LCM-8 (or equivalent) craft out of the well onto the ramp to increase craft carrying capacity.

† See Jones, et al., op cit., for a sample landing plan.

Craft Attempt to Deliver Serials Simultaneously

Each Marine Corps serial is composed of men, vehicles, equipment and supplies that have a common purpose ashore. Even though effectiveness was measured in terms of square feet of vehicles delivered ashore, vehicle square is useful only as it is delivered ashore in serial quantities. To facilitate simultaneous delivery of a complete serial ashore, craft carrying parts of the same serial formed into a group outside the LOD and attempted to move ashore together. To avoid long craft delays, a limit was placed on the time that a craft could wait for other craft carrying the balance of its serial. In the preliminary comparison, this limit was 15 minutes. However, other values could be adopted for future analysis.

Completion of Craft Unloading Can Be Anticipated

In this analysis mixes of advanced craft were compared under conditions of maximum efficiency--conditions that are not likely to be experienced in real life. This approach was justified, because the study team was comparing craft mixes, not trying to reproduce real life situations. In the comparisons, craft performance was deliberately stressed. Serials were scheduled ashore in a manner that assured a continuous backlog of work for landing craft. Similarly, the beach was managed in a manner that yielded maximum use of available unloading positions. To accomplish this end, craft waited outside the LOD until an unloading position was open. However, the computer programs anticipated when the unloading position would be open so as to minimize idle time between craft.

As standoff distance is increased, the LOD may move out to sea, making anticipation more difficult. Where anticipation is needed, it will depend on the urgency of delivering the Marine forces ashore. A primary objective of the advanced landing craft program is to provide sufficient flexibility so that events, not craft capability, dictate the rate of buildup ashore.

No Offshore Obstacles

In the analysis, it was assumed that there were no offshore obstacles that impeded the movement of planing craft to the assault beach. This assumption favored planing craft over ACVs because underwater obstacles are not uncommon. However, the assumption did make the assault

operations independent of tidal conditions, and it avoided having to consider restrictions in craft passage that obstacles might pose.

Hard Soil Is Available for ACV Unloading

The one concession to ACV operations was the assumption that there was an area of firm soil adjacent to the beach where ACV craft could be unloaded to best advantage. By this assumption, it was possible to use unloading data based on tests conducted by the Fifth Marine Division.*

Hard soil does not always occur immediately adjacent to a beach. However, in many instances, hard soil can be reached by crossing the beach and some marginal terrain that either can be crossed by ACVs or made crossable. Thus, this assumption was not unrealistic.

Craft Operations at Amphibious Ships

Craft operations in and about amphibious ships include all activities that begin when the craft throttles down on approaching the ship and end when the craft begins to accelerate to full speed when it leaves the ship with a full load of Marine cargo. The specific activities entailed depend on the type of ship and the type of craft. The following discussions cover the four types of ships in the amphibious fleet that engage in craft operations and the two types of craft under study--ACVs and planing hulls.

Landing Ship Dock (LSD)

The LSD-type ships that were used in the comparisons of preliminary craft designs were of the LSD-28 (Thomaston) class. A profile and plan of this class is shown in Figure B-1. Some of the characteristics of this class that were useful to the analysis are:

* See Nielsen, op cit.

LSD - Thomaston Class

<u>Overall Dimensions (ft)</u>		<u>Well Deck Dimensions* (ft)</u>	
Length	510	Length	396
Max beam	84	Width	48.5
Draft	19 (loaded)	Height	26
<u>Ballasted Conditions†</u>		<u>Draft at Sill</u>	
Up rate	3.9 min/ft	Max. (loaded)	10
Down rate	4.3 min/ft	Normal	8

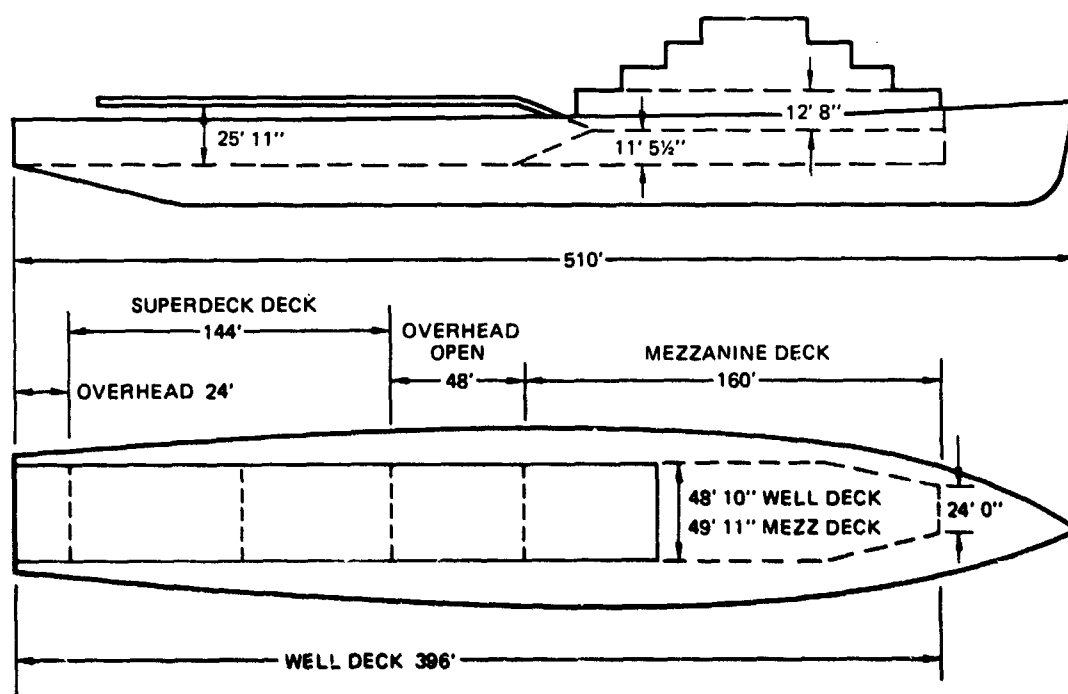


FIGURE B-1 PROFILE AND PLAN OF LSD-28

* Maximum usable dimension.

† Computed average for the LSD-28 Class.

The LSDs used in the analysis were assumed to have their temporary mezzanine deck, the associated vehicle ramps, and their water barrier removed. Three significant modifications to these ships were assumed to accommodate the advanced assault landing craft.

First, a towing device was installed, possibly on the bulkheads along each side of the well deck. This device could tow a craft into, and out of, the well at a rate of one knot, 100 feet per minute.

Second, a ramp was installed that permitted vehicles to drive from the super deck to the well deck. This ramp could be stowed against the overhead of the well deck when not in use. Alternatively, vehicles could be prestaged into the well by means of the ship's rotating cranes.

Third, a movable ramp was available on the well deck level that was vertically and horizontally adjustable to the stern gates of the planing craft that were backed into the well.

The LSD cargo consisted of preboated serials on the craft that were embarked in the well deck, and some vehicular cargo stowed on the super-deck. No general palletized cargo was off-loaded from the LSDs.

Typical ACV Operations. To accommodate all the types of craft, the LSD was ballasted down to some nominal water depth in the well that approximated the average draft of the craft mix, 5 feet at the sill. The well deck has a 2 percent slope. When an ACV approached the sill of the LSD, it stopped and lowered to the displacement mode. It proceeded forward to the sill and received towing and handling lines. After these lines had been attached, the air propulsers were stopped; the ACV was passively towed into the well. It proceeded into the well about 150 to 200 feet to a point where the hull made contact with the well deck. The towing device stopped and ballasting up of the LSD began. When the craft had become securely positioned on the well deck,* the bow ramp was lowered and the ballasting operation ceased.

* After the hull of a craft has made initial contact with the well deck, a one foot decrease in the well deck water level caused by the ship's ballasting up is considered adequate to "securely position" the craft on the well deck.

The prestaged vehicles from the bow end of the well deck were driven forward into the craft. After the last vehicle of the serial had entered the craft, the ballasting down of the LSD began; and the craft's ramp was closed.

When ballasting was adequate to float the loaded craft,* the towing device was activated and towed the craft from the well. The transition of the ACV from inside the well to the open sea was continuous. The ACV crossed the sill, the lines were cast off, the cushion inflated, and the air screws engaged. The ACV maneuvered backward, away and clear of the LSD, turned and accelerated toward the beach.

Typical Planing Hull Operations. The PLHs operated with the LSDs. To accommodate the heterogeneous craft mix, the LSD was ballasted down to the conditions cited in the typical ACV operation. The PLH to be loaded was standing by waiting to enter the well, about 500 feet to the stern of the LSD. When the order was given to come aboard, the LSD began to ballast down further so that it could receive the craft stern first. The craft proceeded slowly to the stern gate and received handling lines from the LSD. It pivoted about so that the stern of the craft was facing into the well. The coxswain applied reverse thrust on the propulsers; the towing device took in the slack lines; and the craft moved into the well, constrained and guided. The craft proceeded approximately 150 feet into the well where initial hull contact with the deck was established. The towing device stopped, ballasting down ceased, and ballasting up of the LSD began. When the PLH had become securely positioned on the well deck, the ship's ramp was moved into position at the stern of the craft, and the stern gate was opened. The vehicles that were prestaged in the bow end of the well deck moved forward up the stern ramp, and into position in the craft's cargo box. As the last vehicle of the serial moved into the craft, the LSD began to ballast down, the craft stern gate was closed, and the ship's ramp was moved clear of the craft. When the LSD had ballasted down adequately to float the loaded craft, the craft was moved out of the well by the towing device. As the craft approached the sill, the lines were cast off and retrieved by the ship. The PLH continued over the sill and stern gate, established its bearing to the shore, and accelerated to normal cruise speed. The LSD then ballasted up to the nominal depth of water over the sill.

* A two-foot increase from the "securely positioned" water level was assumed "adequate to float the loaded craft" in the well.

Summary of LSD Operations. The elements of the operating cycles discussed above were assigned operating times to determine the relative performance of the preliminary craft designs as shown in Table B-1. A large number of factors influence the cycle times of these operations. All these factors cannot be specifically delineated; consequently, the values presented below should not be accepted as absolute.

Table B-1

OPERATING TIMES FOR LSD OPERATIONS
(Minutes)

Element	ACV		PLH		
	30ACV	150ACV	30P	125P	320P
Maneuver to sill (500 ft) and receive lines	2.0	5.0	3.0	4.0	7.0
Proceed into well*	1.7	1.7	1.7	1.7	1.7
Ballast up ship (1 ft)†	3.9	3.9	3.9	3.9	3.9
Load time multiplier	1X	1X	1X	1X	1X
Ballast down ship (2 ft)†	8.6	8.6	8.6	8.6	8.6
Proceed out of well and cast off lines*	1.7	1.7	1.7	1.7	1.7
Maneuver clear of ship	2.0	2.0	1.0	1.0	1.0

* Travel distance 150-200 ft.

† Computed from average ballasting rates for LSD-28 class ships.

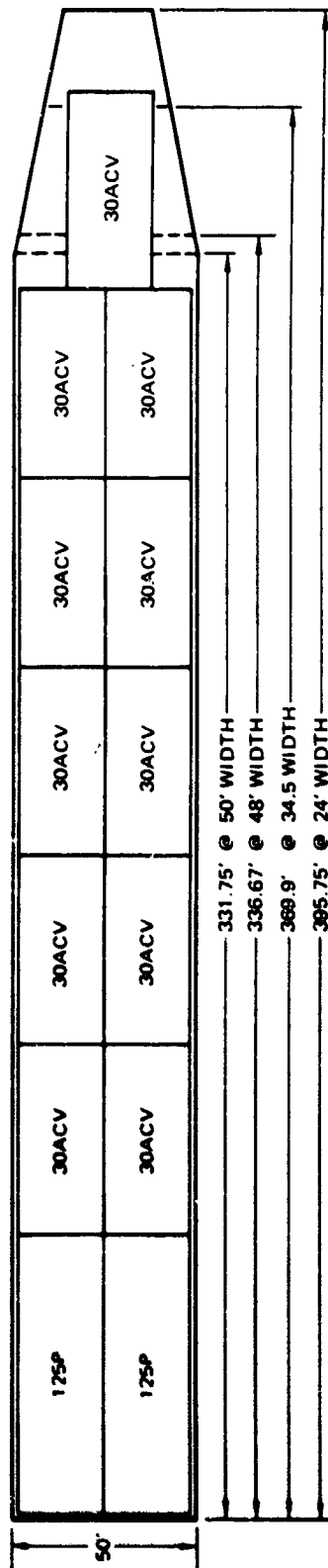
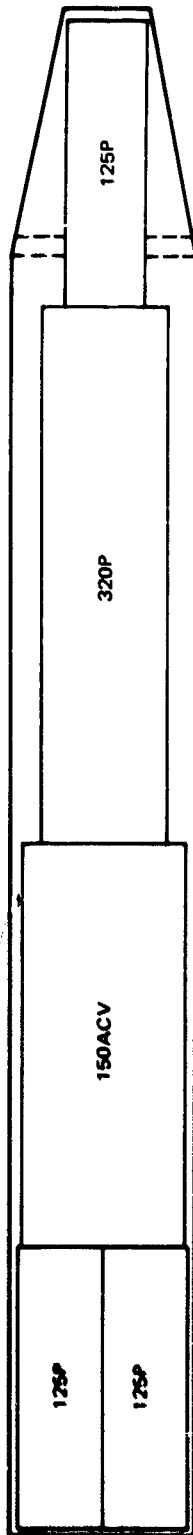
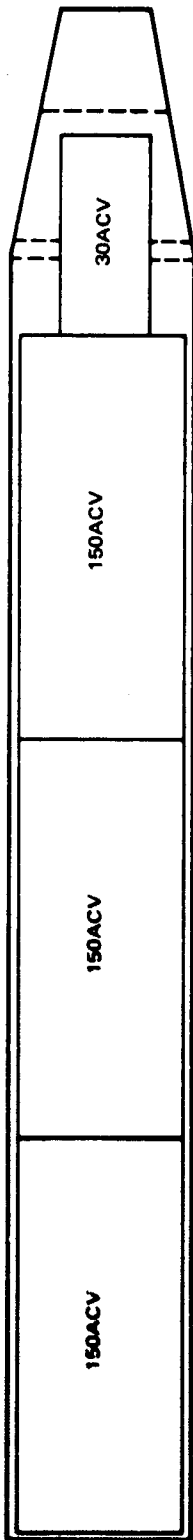


FIGURE 8-2 TYPICAL LSD CRAFT LOADING PLANS

It is quite probable that the vehicles prestaged in the well deck would be subject to partial immersion in sea water because of the ballasting requirements. This was judged acceptable for the sake of efficient loading. The load time multiplier is a ship-related factor that modifies vehicle loading time. The value of one presumed that vehicles could be prestaged from the superdeck fast enough to avoid delaying craft. It also presumed drive-on loading.

Figure B-2 shows several typical craft loading plans for the LSDs. These plans make efficient use of the available well space.

Amphibious Transport, Dock (LPD)

The LPD-type ships used in the assault craft operating cycles were of the LPD-4 (Austin) class shown in Figure B-3. This class represents the newer ships being built and is typical of the ships of this type. Some of the characteristics of the LPD that were useful to the analysis are as follows.

LPD - Austin Class

<u>Overall Dimension (ft)</u>		<u>Well Deck Dimensions* (ft)</u>	
Length	569	Length	164
Max beam	105	Width	48.5
Draft	25 (loaded)	Height	27.5
<u>Ballasted Condition†</u>		<u>Draft of Sill</u>	
Up rate	2.8 min/ft	Maximum	10
Down rate	1.8 min/ft	Normal	8

* Maximum usable dimension.

† Computed average for the class.

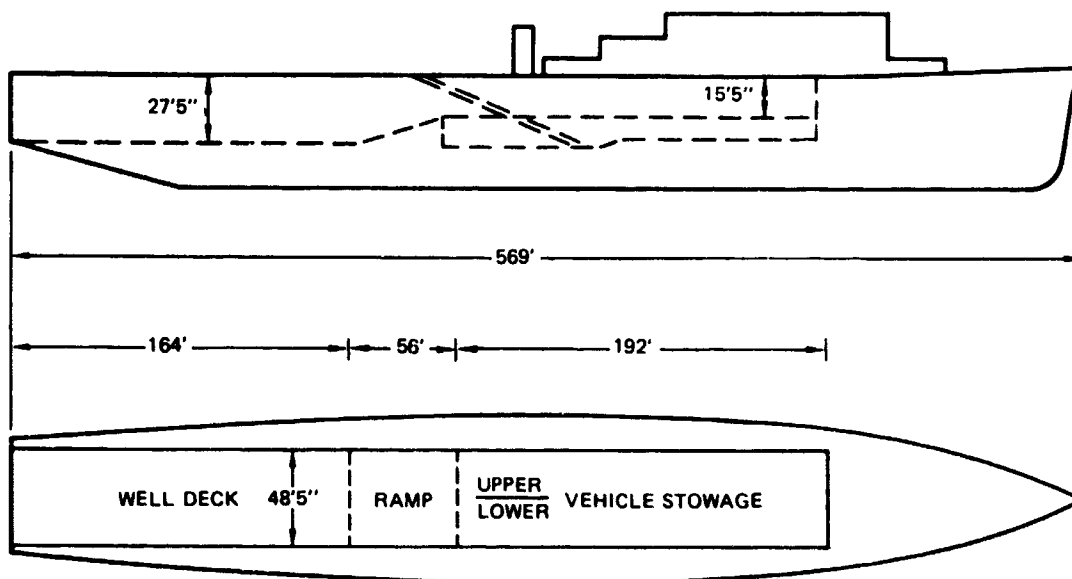


FIGURE B-3 PROFILE AND PLAN OF LPD-4

Amphibious assault craft operate from the LPD and transport a variety of cargo to the beach. However, for the preliminary comparisons of advanced landing craft, only the personnel and vehicular cargo constituting the assault phase were considered.

There were two significant modifications assumed for craft handling in the well of the LPD to accommodate the advanced assault craft. First, a towing device was assumed to be installed. Its function and installation were similar to those assumed for the LSD well. The device was capable of towing craft in and out of the well at a rate of one knot, 100 feet per minute. Next, a stern ramp was provided for the planing craft.

The two proposed modifications to the LPD for craft handling in the well are considered feasible and were included in the operating cycle.

Typical ACV Operation. Air cushion craft were operated with the LPDs. Most of the assumptions concerning the physical characteristics of the ACV made for LSD operations applied to LPD operations as well. Briefly, these assumptions were:

- The ACV operated with a heterogeneous craft mix.
- The LPD was ballasted down to some nominal water depth in the well that approximated the average draft of the craft mix.

An ACV operating with an LPD began at an arbitrary position 500 feet astern the ship. The ACV was either circling or standing by in position awaiting an order to come aboard. When the order was given, the ACV moved slowly to the sill of the ship. The handling and towing lines were passed to the ACV crewmen, who secured them to the craft. When the lines had been secured, the ACV stopped the air propulsers and settled to a displacement mode. The towing device was activated and towed the craft into the well to the point where the bow rested at the base of the boat ramp. The towing device stopped, and the LPD ballasted up enough to securely position the craft on the deck.* The craft lowered its bow ramp, and the loading operations began. Vehicles had been pre-staged on the upper vehicle stowage deck and were driven forward from the upper vehicle stowage, over the bow ramp of the craft, and into the cargo box.

When the loading operation was completed, the ship began to ballast down and continued until the loaded craft was afloat.† The craft bow ramp was closed and the towing device pulled the craft to the sill of the LPD. The handling lines were cast off, the cushion was inflated, and the air propellers were engaged. Transition from the well to the open sea was continuous. The ACV backed away until its bow was clear of the stern of the LPD. The ACV turned, selected the appropriate heading to the beach, and accelerated to its cruising speed.

Typical Planing Hull Operations. The PIH operations with the LPD were similar to those described for the LSD. The craft began the cycle at a position about 500 feet astern of the LPD. It approached the LPD; lines were passed from the LPD to the craft; and the craft pivoted about so that the stern faced the opening into the well. The slack of the lines was taken in, and the towing device was activated. The coxswain of the PIH reversed the thrust of the propulsers and the craft entered the well of the LPD, controlled by the towing device. The craft proceeded stern first into the well to a position where the movable ramp

* The one-foot change in water level described for LSD operations applied to the LPD.

† The two-foot change in water level described for LSD operations applied to the LPD.

would mate with the stern gate of the craft. At this point, about 165 feet into the well, the towing device stopped and ballasting up of the ship began. The craft was held in place by the handling lines until the ship had ballasted enough to securely position the craft on the well deck. The ramp was mated to the stern of the craft, and the prestaged vehicles were driven over the ramp into the cargo well of the craft. When the last vehicle of the load had driven into the craft, the ship began ballasting down; the boat ramp and stern gate were disconnected; and the stern gate was closed. The towing device was activated after the LPD ballasted down enough to float the loaded craft. The craft moved into the sill, the lines were cast-off, and the PLH continued out to the well. Once clear of the ship's stern gate, the craft selected the proper bearing to the beach and accelerated to cruising speed.

Summary of LPD Operations. The elements of the operating cycles discussed above were assigned the same operating times used for LSD-type ships with the exception of ballast and deballast times which were derived from the characteristics of the LPD-4 class. These times are summarized in Table B-2. Typical craft loads in LPD wells are illustrated in Figure B-4. These loads presume that craft can move forward in the well until the hard structure of the craft meets the ship's vehicle loading ramp. The amount of added craft area depends on the characteristics of the craft in the forward most positions.

Table B-2

OPERATING TIMES FOR LPD OPERATIONS
(Minutes)

Element	ACV		PLH		
	30ACV	150ACV	30P	125P	320P
Maneuver to sill (500 ft) and receive lines	2.0	5.0	3.0	4.0	7.0
Proceed into well*	1.7	1.7	1.7	1.7	1.7
Ballast up ship (1 ft)	2.8	2.8	2.8	2.8	2.8
Loading time multiplier	1X	1X	1X	1X	1X
Ballast down ship (2 ft)	3.6	3.6	3.6	3.6	3.6
Proceed out of well and cast off lines*	1.7	1.7	1.7	1.7	1.7
Maneuver clear of ship	2.0	2.0	1.0	1.0	1.0

* Travel distance about 165 ft.

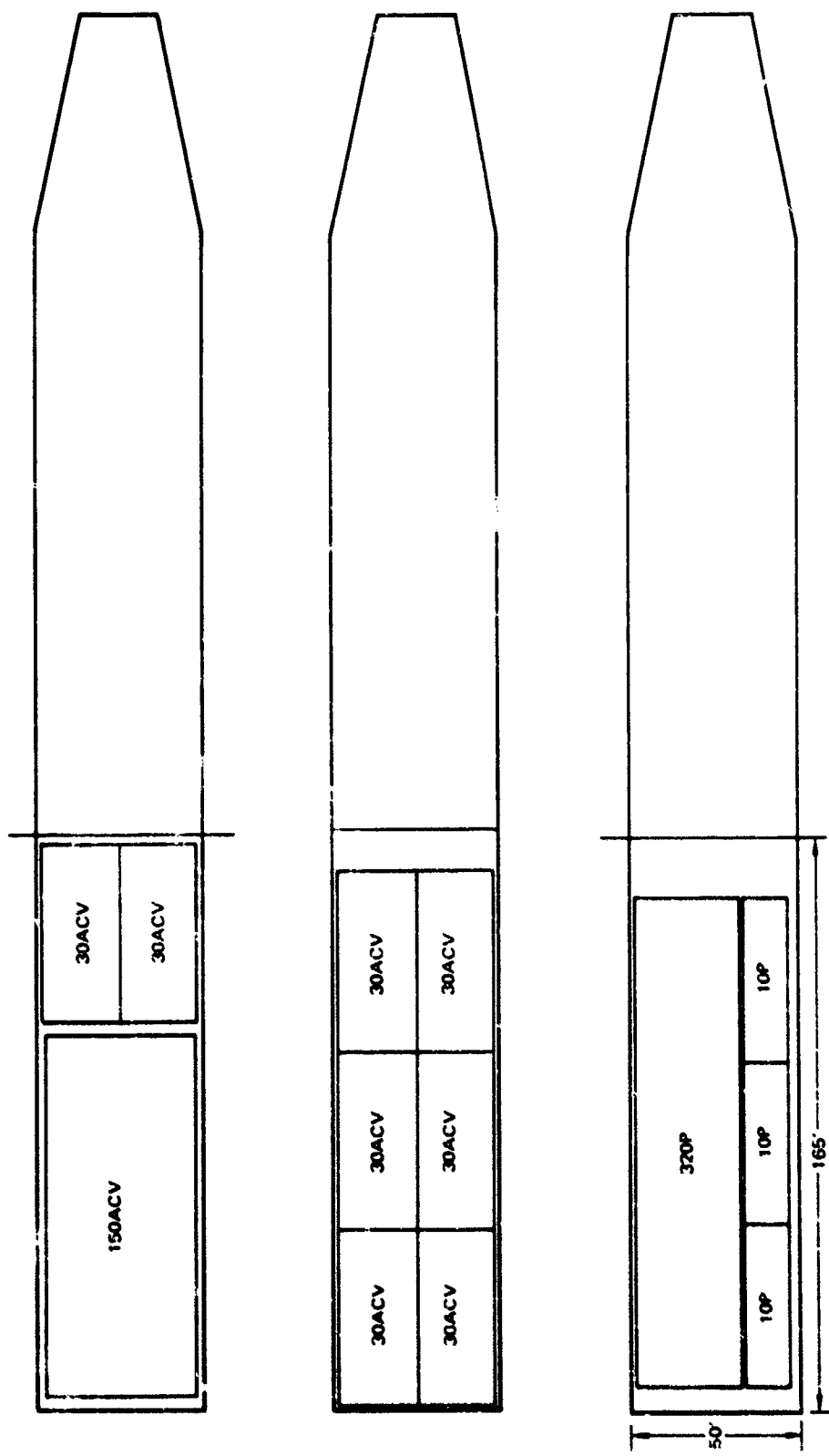


FIGURE B-4 TYPICAL LPD CRAFT LOADING PLANS

LHA

The proposed LHA represents the newest concept in amphibious assault ship design. Figure B-5 shows the profile and plan of an LHA. In addition to having the mission capabilities of the LPD, it has modest helicopter capabilities. LHA characteristics are still subject to revision as the design and construction proceed. The characteristics reported below are those used in the comparison of preliminary advanced craft designs and do not necessarily represent up-to-date designed characteristics.

Only one modification was assumed to facilitate operations with advanced landing craft. A stern ramp was provided for access to the stern gates of planing hull craft. This modification could be accomplished without major changes in the present design.

Overall Dimensions (ft)

Length	820
Maximum beam	128-152
Draft	28

Well Deck Dimensions (ft)

Length	112-282
Width	78
Width, Sidewells	30.8
Height	28

Hangar Deck Dimensions (ft)

Length	264
Width	80
Height	23.5

Ballasting Condition

Up rate	2.8 min/ft (est.)
Down rate	1.8 min/ft (est.)

Draft at Sill (ft)

Maximum	10
Normal	8

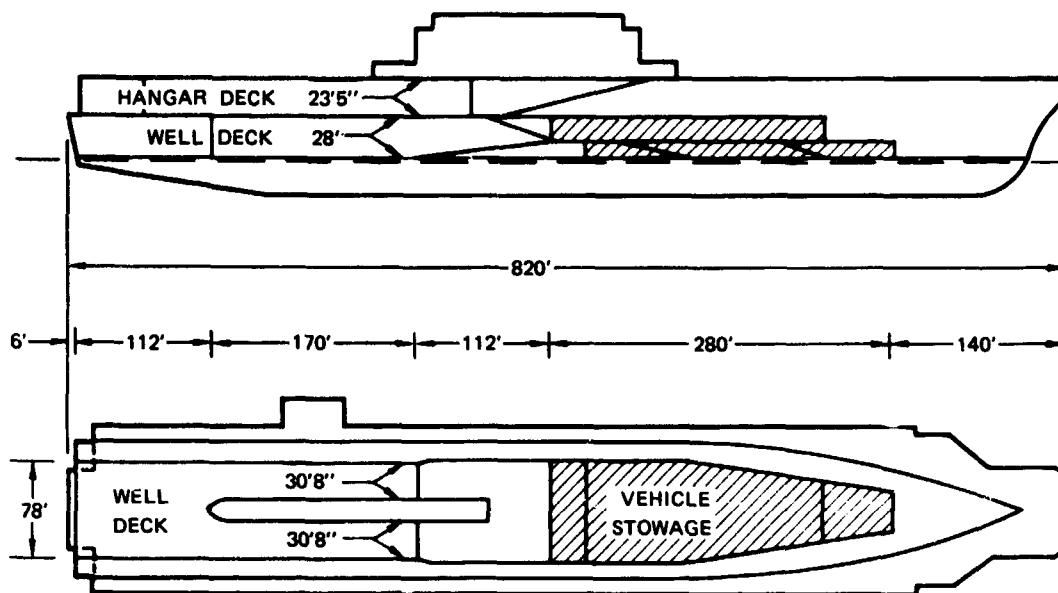


FIGURE B-5 PROFILE AND PLAN OF LHA

Typical ACV Operations. Both sizes of ACV craft operated with the LHA but their modes of operation were different. The 30ACV operated in the manner already described for LSD- and LPD-type ships. One of the craft could move forward on either side of the well deck divider and be grounded out near the vehicle ramp. The 150ACV is too wide to move forward of the well deck divider and was grounded out aft of the break. This required that the vehicles to be loaded be driven down the length of the well before driving aboard the craft.

Typical Planing Hull Operations. Planing hull operations were exactly as described for the LSD- and LPD-type ships.

Summary of LHA Operations. The operating cycle elements assigned to LHA type ships are shown in Table B-3. Note that proceed times are longer than those for the LPD because of the larger well. Ballasting times are the same as those for the LPD. Figure B-6 shows some typical craft loads in LHA wells. Note the effect of assuming that 320P craft are narrow enough to fit into the forward parts of the well. Otherwise, only the 30P, 30ACV, and 125P craft would fit forward of the divider and none of these craft would fill the area very efficiently.

Table B-3

OPERATING TIMES FOR LHA OPERATIONS

	ACV		PLH		
	30ACV	150ACV	30P	125P	320P
Maneuver to sill (500 ft) and receive lines	2.0	5.0	3.0	4.0	7.0
Proceed into well*	3.0	1.0	3.0	3.0	3.0
Ballast up ship (1 ft)	2.8	11.2†	2.8	2.8	2.8
Loading time multiplier	1X	1X	1X	1X	1X
Ballast down ship (2 ft)	3.6	3.6	3.6	3.6	3.6
Proceed out of well and cast off lines*	3.0	1.0	3.0	3.0	3.0
Maneuver clear of ship	2.0	2.0	1.0	1.0	1.0

* Travel distance about 300 ft except for 150ACV, 100 ft.

† Ballast up 4 feet.

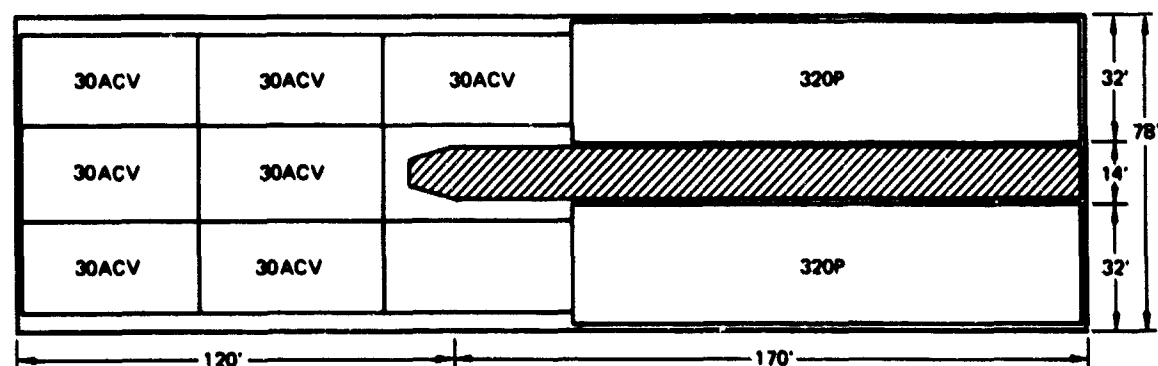
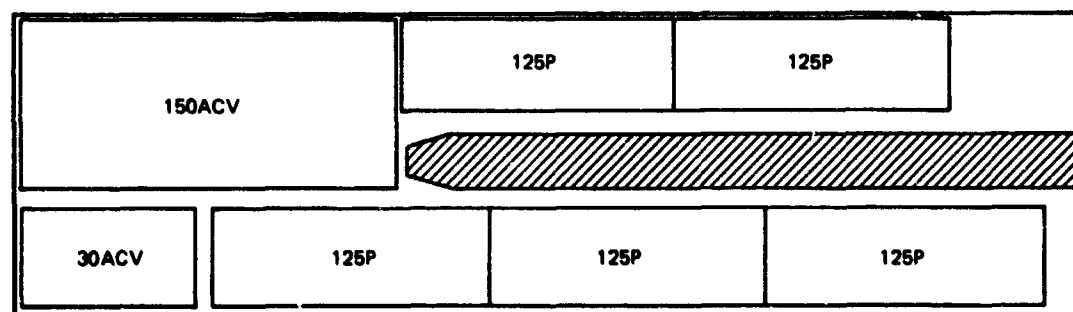
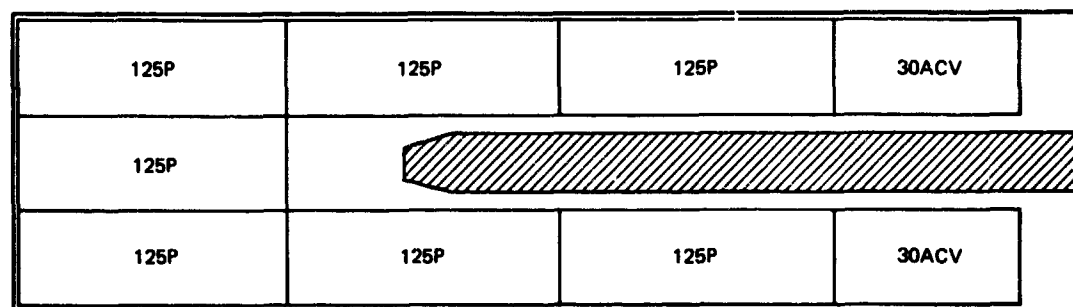
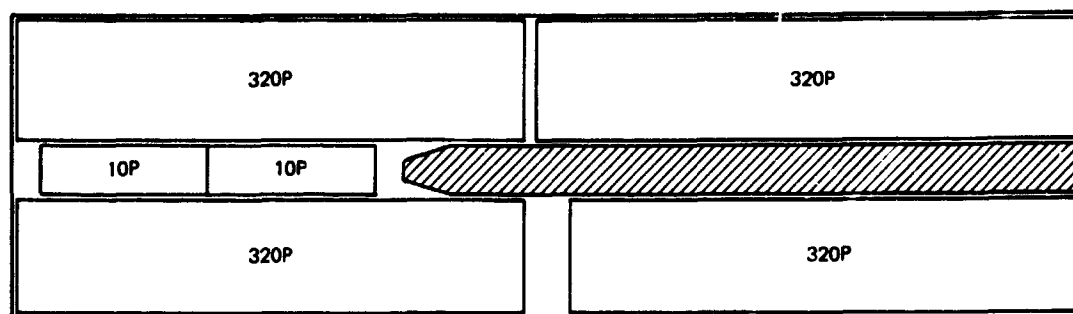


FIGURE B-6 TYPICAL LHA CRAFT LOADING PLANS

LKA

The 113 class LKA was used as the prototype for the LKAs of the amphibious fleet. However, because of the limited number of LKA 113 class ships planned, it is sometimes necessary to add older ships to the fleet. These ships are smaller and have less boom and winch capability than the 113 class.

The LKAs carry vehicles and a wide range of cargo. They are the only amphibious ships capable of carrying bundles of SATS matting and other items of outsized cargo. The LPD and LHA ships can carry only cargo palletized on standard 40 x 48 inch pallets.

Before LKAs can operate effectively with the 150ACV and 320P craft, it is necessary to extend the outreach of their cargo booms or make other modifications. For this analysis, boom extensions were assumed with no reduction in boom capacity. In practice, it may not be possible to have both reach and lift. However, both have been assumed for the present analysis.

Typical ACV Operations. A typical ACV loading operation was assumed to proceed as follows. When a loading station became available and an ACV was assigned to it, the craft maneuvered alongside the ship under its own power. When lines could be passed, the air propulsers were secured and the craft was pulled close aboard and moored by the ship's crew. The craft dropped to the displacement mode for loading. Vehicles and trailers were hoisted aboard the craft with the ship's gear, with care being taken not to exceed the load unbalance limitations of the craft. When loading was complete, the air screws were engaged, lines were cast off, and the ACV maneuvered clear of the ship. The best method for ACV operations is yet to be devised.

For purpose of loading station assignment an LKA 113 can accommodate four craft at one time.

Subsequent to the comparisons of preliminary designs, the study team proposed an end on docking technique, and it is now being investigated.

Typical Planing Hull Operations. Loading operations for the planing hull craft proceeded as described for ACVs, except that PLH maneuvered in the displacement mode. An LKA 113 can accommodate four craft at one time.

Summary of LKA Operations. The operating cycle elements assigned to LKAs are shown in Table B-4. Note that loading time multipliers apply to both vehicles and trailers since the prime mover and trailer must be handled separately.

Table B-4

OPERATING TIMES FOR LKA OPERATIONS
(Minutes)

Element	ACV		PLH		
	30ACV	150ACV	30P	125P	320P
Maneuver alongside and receive lines	2	5	2	3	5
Prepare for loading	1	2	1	2	3
Loading time multiplier	1x	1x	1x	1x	1x
Cast off lines and clear ship	2	3	2	2	2

Craft Operations at the Beach

Beach facilities are generally a constraint to the conduct of an amphibious operation. Thus, beach planning begins with a thorough analysis of the available beach. Such an analysis is inappropriate to this study, which has sought to avoid the limitations of specific scenarios. Therefore, the approach has been to provide the minimum beach facilities necessary to support the amphibious assault without constraining it.

Even though the general unloading phase has not been considered in the comparisons of advanced craft mixes, it has been necessary to consider the need for beach dumps in the overall planning for the use of beach resources. Therefore, provisions need to be made for planing craft unloading positions, ACV unloading positions, beachmaster equipment and facilities, vehicle staging, and beach dumps for the different classes of supply. The beach organization was much as it is today.

The beachmaster unit and the shore party unit retained primary responsibility for management and supervision of the beach. They controlled traffic, directed beaching and retracting, supervised causeway installations, and supervised bulk fuel transfer and other operations.

Concern of the study team was with the movement of vehicles and cargo across the beach to inland points of use. Of major interest were the possible material flow routes that were the most feasible. Three different cases, dictated by the mix of landing craft, were of interest: (1) all planing hull craft, (2) all ACV craft, and (3) mixed planing hull and ACV craft. Each imposed different constraints on the use of limited beach resources. The ACV, being an amphibian, left the surf zone and moved to some point inland to off-load vehicles and cargo; whereas, the PLH had to off-load in the surf zone. These differences produced three alternative operations.

The All Planing Hull Operations

In the case of an all planing hull craft mix, the operating procedures were very similar to those that are experienced today in amphibious operations (see Figure B-7).

A planing hull craft crossed the LOD at operating speed, 35 knots. It proceeded toward its designated beach slot at this speed until the coxswain determined the need to decelerate, about 200 yards offshore. The coxswain then stood by in this position, adjusting and maneuvering his craft until signaled by the beach master to land at the designated beach slot. After adjusting his speed and position relative to the wave action, the coxswain grounded his craft in the surf zone and lowered the bow ramp.

In Figure B-7, a typical beach is shown as it might have been organized to satisfy the requirements imposed by planing hull assault landing craft. Mobile loaded vehicles were driven off the craft to staging areas in or behind the motor pool. Once the entire serial had reached the staging area it moved out to perform its assigned mission.

Beach slots were segregated between tracked and wheeled vehicles. Tracked vehicles could be driven over unprepared beach but were not allowed over beach matting or other stabilizing agent that could be damaged by tracks. Wheeled vehicles, on the contrary, generally required beach preparation to avoid getting stuck in soft sand.

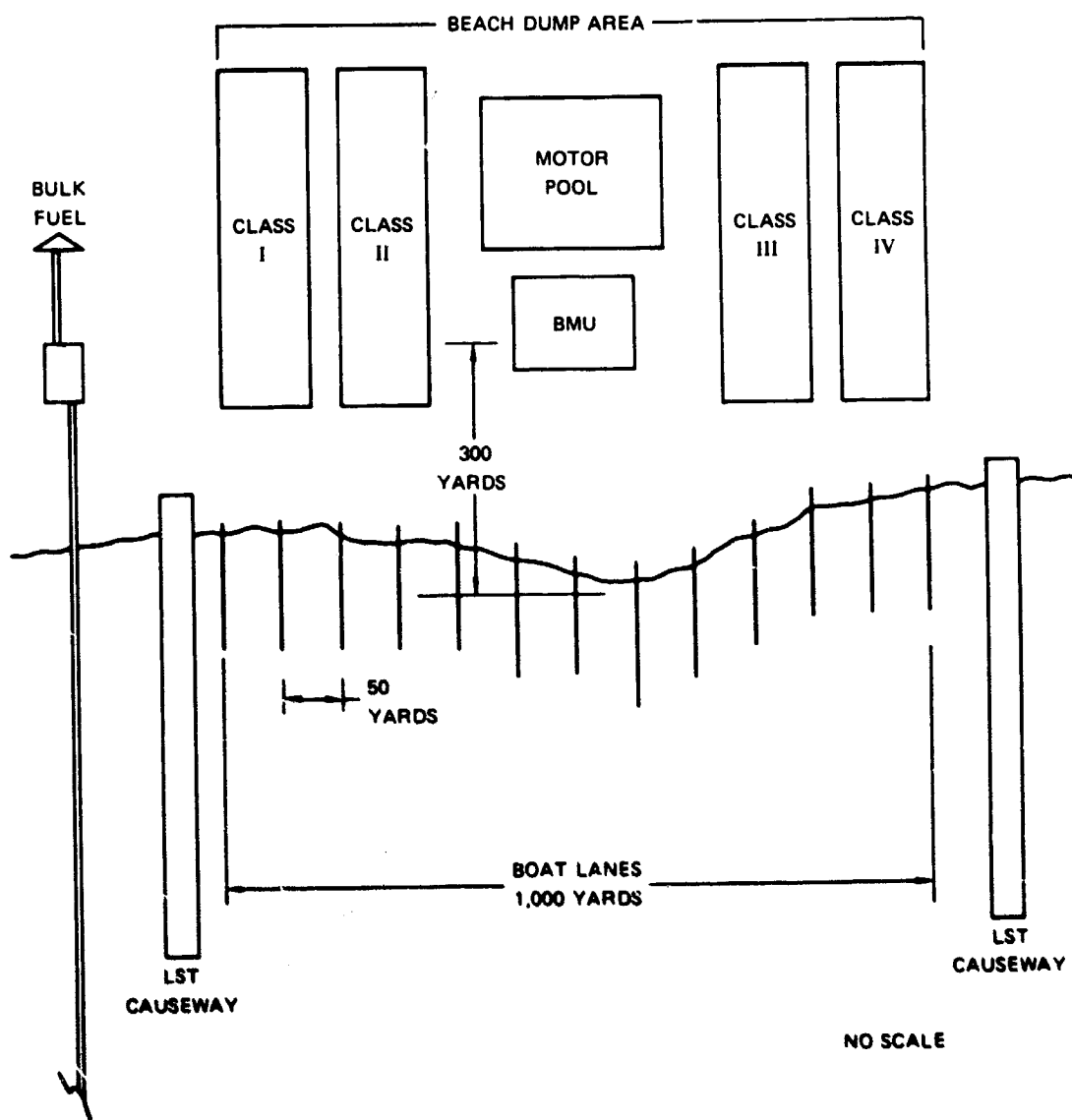


FIGURE B-7 TYPICAL BEACH LAYOUT

As the amphibious assault progresses to the general off-loading phase, the cargo was largely palletized and was handled by beach master equipment. Pallets were segregated by class and transported to temporary storage areas as indicated in Figure B-7 or they were loaded immediately onto waiting vehicles and transported to the logistic support area inland.

After the planing hull craft was completely empty, the beach master ordered it off the beach. The coxswain backed off the sand and through the surf zone. When he had cleared the breakers, he turned the craft 180° and accelerated toward the next ship to be off-loaded.

The unloading time estimates for the above were based on average observed times during amphibious operation exercises. These are by no means precise and should be viewed as best estimates under present data sources. They are shown below.

Craft	Vehicles Off-loading Time			Pallet Off-loading Time*
	Small	Medium	Large	
30P	2.5 min	2.5 min	2.5 min	20 min
125P	4.4 min	4.4 min	4.4 min	1 hr 23 min
320P	17.0 min	17.0 min	17.0 min	3 hr 43 min

The All Air Cushion Vehicle Operation

The introduction of the amphibious ACV allowed the material flow pattern to be altered somewhat from present day practices. It was inappropriate to force the ACV to operate at the beach similar to the planing hull craft when it could cross the beach and proceed to firm ground.

The ACV craft are large and are likely to be difficult to control. This suggests that low overland speeds will be necessary and that special routes need to be provided. Figure B-8 illustrates a proposed beach organization for an all ACV mix of landing craft.

* Estimates are based on one pallet/minute/fork truck. One fork truck is assumed available in all cases.

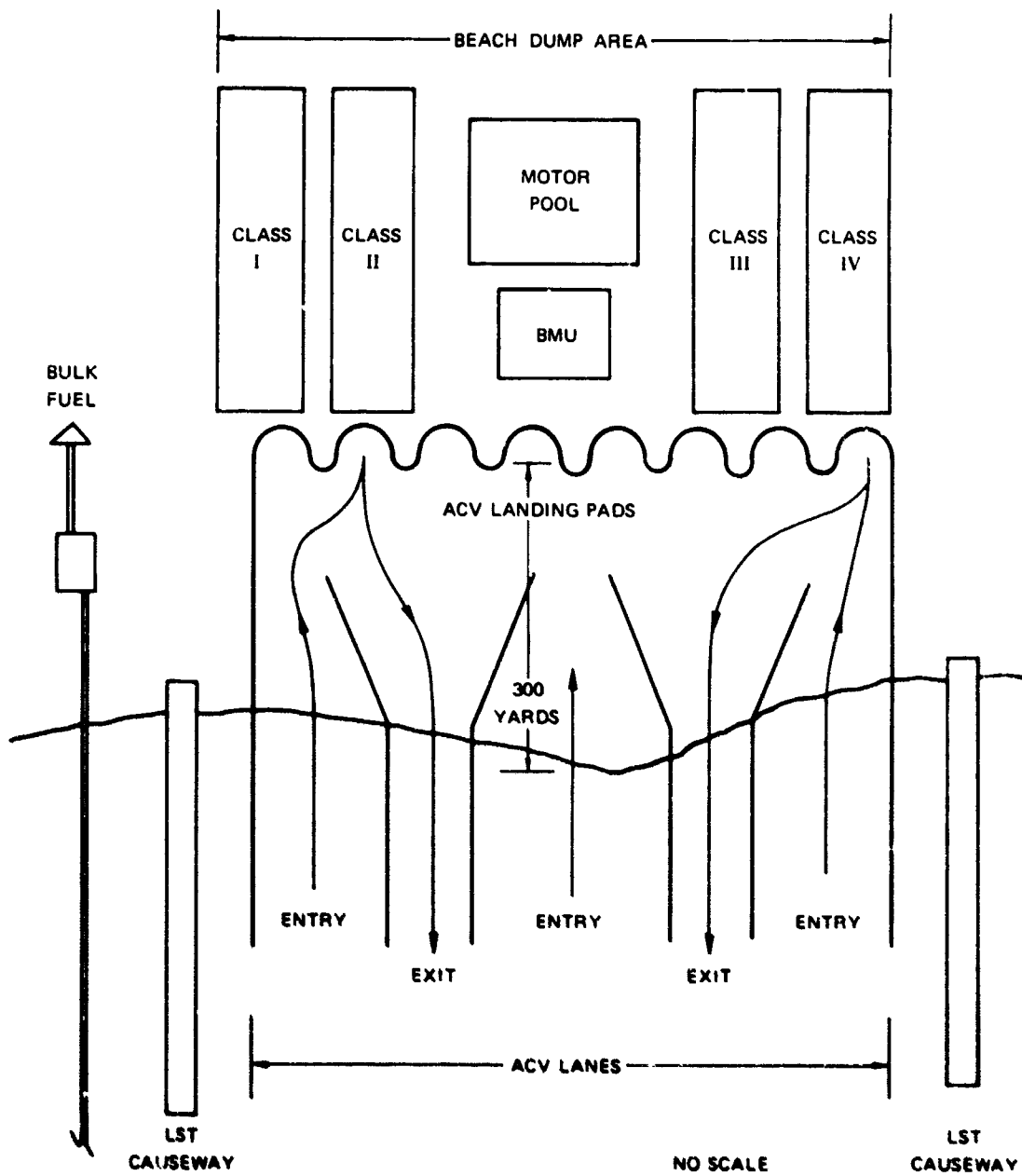


FIGURE B-8 PROPOSED BEACH LAYOUT-ALL ACV

As an ACV craft approached the surf at operating speed (50 knots) via the appropriate entry route, the coxswain or pilot reduced speed to a forward speed of 5 to 10 knots. The craft proceeded at this speed over a right-of-way prepared early in the assault operations by the engineers.* The distance to the landing pad was about 300 yards inland from the surf line. As the ACV approached the pad, it slowed even more and maneuvered to off-loading position. When precisely positioned, the ACV settled off of its cushion and lowered its stern ramp. Vehicles drove off the craft and headed for their assigned staging areas. Both bow and stern ramps were used during general unloading to facilitate access by rough terrain fork trucks. Estimated unloading times for vehicles and cargo from ACV craft are shown below.

Craft	Vehicle Off-loading Time			Pallet
	Small	Medium	Large	Off-loading Time†
30ACV	1.0 min	1.0 min	1.0 min	10 min
150ACV	2.0 min	2.0 min	2.0 min	35 min

After the ACV had completed off-loading its vehicles or cargo, it rose on its cushion, turned, and proceeded along the one-way route to the surf line. Once clear of the beach, it accelerated to the next ship to be off-loaded.

The Combination of Planing Hulls and ACV Operations

From a beach management point of view, a mixture of planing and air cushion craft is the least desirable, because the two dissimilar craft types conflict with one another at the surf line and on the beach. This conflict is evident in the fact that planing hull craft operate in a conventional mode; they will beach in the surf line and off-load onto the surf line. The ACV craft have the capability of moving overland, and will unload at inland positions. Thus, if the two craft types are to use the same beach, there is a strong likelihood of

* The route is prepared with beach matting or some stabilizing method to reduce flying sand and debris. Excessive grades, ditches, and protruding obstacles such as trees have been removed.

† Assume two fork-lift trucks.

traffic interference between the vehicles brought ashore by the planing craft and the air cushion craft. New concepts of beach management and craft maneuvering are required to circumvent these potential difficulties. Rules need to be set to establish right-of-way and to enforce this right-of-way.

A possible solution to the dissimilar craft problem is to establish two distinct beaches, i.e., one to handle planing hull craft only and a second to handle ACV craft only. This approach would relieve the beach access problem but would cause added complications to the command and control problems. Separate supply dumps would be required; however, this would create no great problem, since both are temporary.

An alternative approach to the problem would be to accommodate the two craft types, planing hulls and ACVs, at the same beach by combining the previous operating features. The establishment of two off-loading sites, one 300 yards inland and the other at the high water level, should enhance the materiel flow rates. This is further supported by the fact that the depth of the beach is not restricted to the surf line capabilities of planing craft. Some of the craft by their amphibious capability can service points inland. This feature increases the usable depth of the beach. The need for linear displacement along the beach is reduced, providing a greater force concentration of troops and materiel.

Figure B-9 shows how a combined beach might be organized for both types of craft hulls operating together. Unloading rates for this beach would be the same as those presented for the separate beaches. It is particularly important in this suggested beach configuration to establish the rules of right-of-way. If this is not accomplished, it is certain that an uncontrollable, chaotic traffic pattern will result that can offset any advantages in the use of the advanced landing craft.

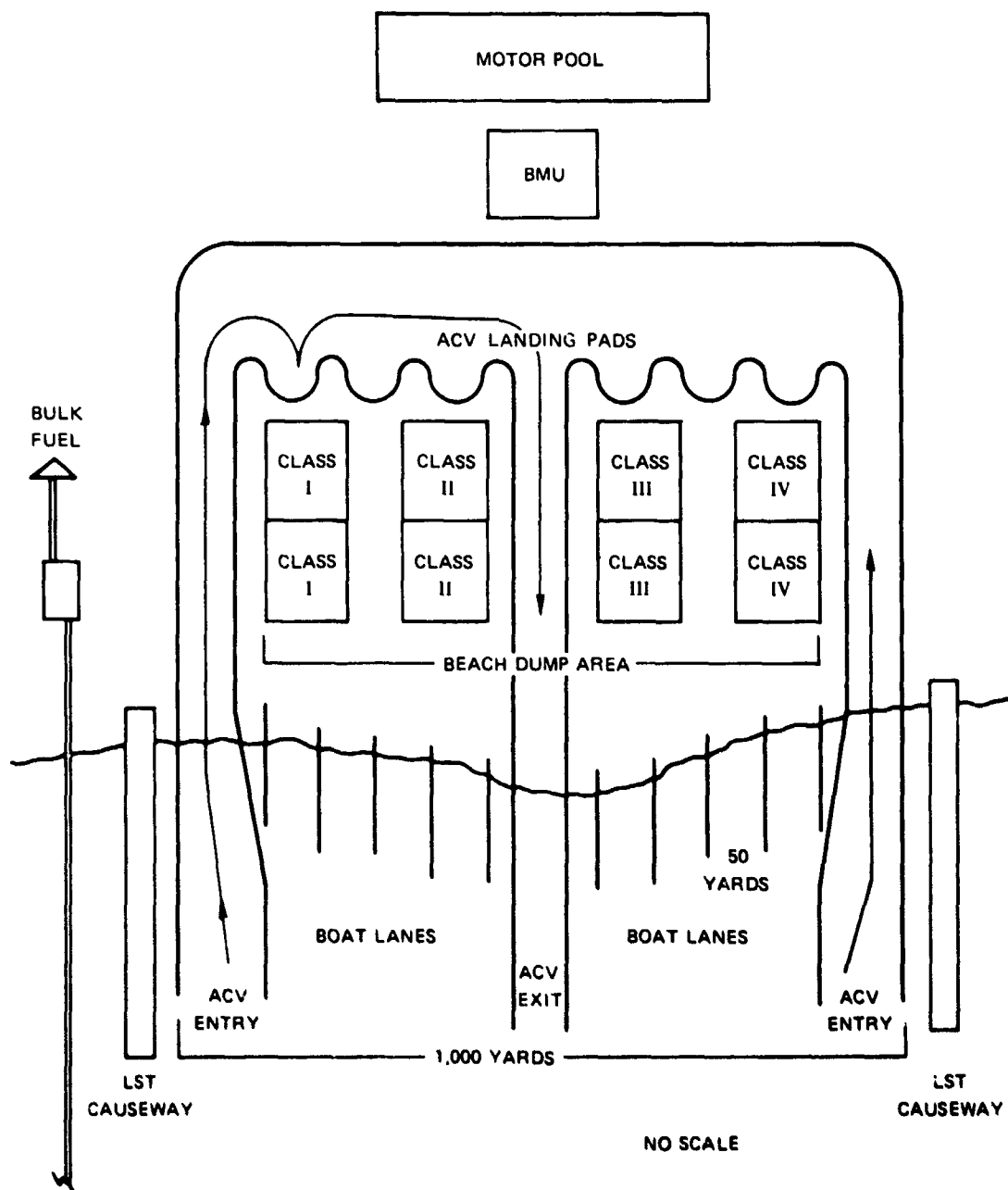


FIGURE B-9 PROPOSED BEACH LAYOUT-ACV AND PLANING HULL

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