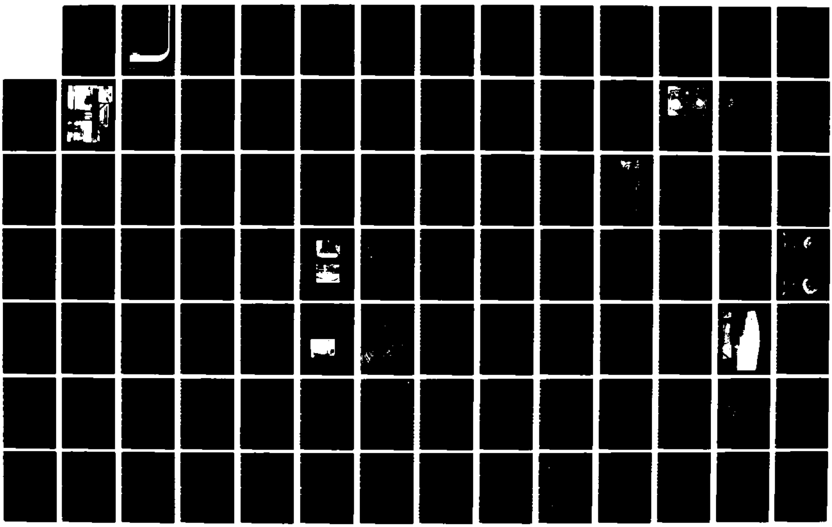
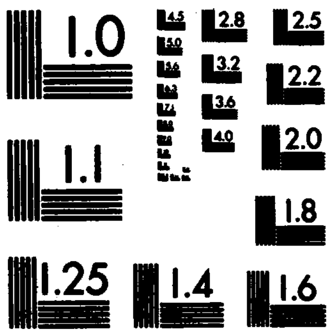
AD-A133 804 LACV-30 INCREASED PAYLOAD STUDY(U) BELL AEROSPACE TEXTRON WHEATFIELD NY AUG 83 7467-928028 DAAK70-82-C-0196 1/2

UNCLASSIFIED F/G 1/3 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

12

AD-A133804

LACV-30

INCREASED PAYLOAD STUDY

CONTRACT #DAAK70-82-C-0196

REPORT NO. 7467-928028

AUGUST 1983

DTIC

OCT 19 1983

Bell Aerospace TEXTRON
Division of Textron Inc

83 09 01 003

Bell Aerospace TEXTRON

Niagara Frontier Operations
Bell Aerospace Textron
Division of Textron Inc.

Post Office Box One
Buffalo, New York 14240
716/297-1000

LACV-30

INCREASED PAYLOAD STUDY

CONTRACT #DAAK70-82-C-0196

REPORT NO. 7467-928028

AUGUST 1983

"The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation."

TABLE OF CONTENTS

PREFACE

This study was conducted by Bell Aerospace Textron, Wheatfield, N. Y. for U. S. Army MERADCOM (DRDME), Ft. Belvoir, Va., under Contract #DAAK70-82-C-0196, to evaluate concepts for increasing the payload of the LACV-30 air cushion vehicle, during the period from September 1982 to April 1983.

Technical direction for the U. S. Army was provided by Dr. James Perkins of MERADCOM (DRDME-MR). Principal contributors to the program included John Hughes, Jerome Emerson, Louis O'Brocta and James Bell from Bell Aerospace Textron. Contributions were also made by Fred Merrihew, Joe Lajudice, Michael Quinn, George MacNamara, Roger Nelson and many others.

Bell Aerospace Textron is indebted to many Army and contractor personnel who provided support and cooperation throughout the study. The contents of this report are solely the responsibility of Bell Aerospace Textron.

1. SUMMARY

This report summarizes the results of a six-month study directed at investigating a number of potential improvements to the U. S. Army's LACV-30. The objective of this program has been to examine and evaluate various ways of increasing the LACV-30's payload, without incurring a large increase in cost, or penalizing its performance, either over land or over water, in varying sea state conditions.

In the process of developing and producing the LACV-30, Bell has conducted numerous investigations (Refs. 1-5) exploring the potential for improving the performance of the craft. These have included programs which have investigated the influence of many lift system parameters on performance. Principal studies included modifications in the design of the lift fan, fan inlet and discharge areas, changes in the seal system to improve air distribution routes to reduce leakage of air through the skirt system and drag while operating over water, and the addition of external machinery, including auxiliary deck fans for supplying additional air to the bag and cushion areas.

The work performed on the above programs identified several potential improvements which could be beneficial to the LACV-30, giving it greater load-carrying capacity. These include:

(a) (1) A reduction in the exit area of the stern seal cones.

(b) (2) Reversal of the direction of rotation of the LACV-30's port side lift fan, with a corresponding adjustment of the volutes to direct the flow of the air from the fan to the stern and side bags,

(c) (3) Replacement of the LACV-30 lift fans, with new fans designed to operate at pressures and flow rates better matched with the seal system requirements.

These items served as the starting point for the LACV-30 Increased Payload Study. First, methods of implementing them on the LACV-30 without incurring extensive redesigns, or costly development programs were examined. Second, additional modifications necessary to complete the installations, and to provide additional thrust or reduced drag to compensate for the additional payload to be carried, were identified and evaluated. Principal areas of study included:

(a) A raising of the longitudinal keel to eliminate excess drag caused by dragging in the water.

(b) A redesign of the stern seal to eliminate increased drag from "water-scooping" caused by the increase in stiffness in the stern cones brought about by their reduction of exit area.

(c) An increase in the diameter of the LACV-30 propellers, for additional forward thrust.

(d) Changes in propeller and fan rotational speeds, so that power saved in the lift system can be redirected to the propellers.

(e) Lengthening the LACV-30 hull structure to reduce cushion pressure, and corresponding wave drag.

(f) A redesigned propulsion module incorporating higher power gas turbine engines with matching lift fans and propellers.

When the above work was completed, various combinations of the different modifications were put together (Table 1) to form a series of design options for the LACV-30. Each of the concepts were then analyzed to determine craft performance in terms of gross weight (payload), speed and sea state.

Once these values were obtained, it was then possible to determine each concept's productivity in the LOTS mission. A computer program was derived, depicting each of the steps within the lighterage cycle. Typical container weight distributions were obtained and a loading strategy at the containership devised. Data from the 1977 J-LOTS exercises 3 at Ft. Story, Va., were used to define the individual cycle segment times involved in a standard LOTS lighterage operation. From the above, each concept's throughput was calculated, in units of containers delivered, ship to shore, per hour of operation. For comparison, the throughput of the unmodified LACV-30 was also obtained. The improvement in productivity for each concept was then determined by dividing its productivity by that of the unmodified LACV-30, and listing the result as a percent increase in LACV-30 productivity.

Incremental costs associated with implementing each of the modifications to the LACV-30 were also determined. These included not only non-recurring development and prototyping costs, but also recurring costs involved in retrofitting 26 LACV-30 craft now either operating, or those scheduled for delivery by early 1986. A summary of these costs are presented in Table 2. Life cycle costs were also estimated along with productivity when placed in a typical series of U. S. Army resupply missions. Those combinations which showed superior characteristics in terms of cost over the payload ranges of interest were identified and recommended for further detailed study and possible incorporation into the LACV-30 in future years.

Table 3 summarizes the LACV-30 and the three best of the eight options studied:

Option (2), which involves a new wrap-around skirt and raised keel, offers an almost immediate improvement in LACV-30 payload carrying capability of 4-5 tons. Its development and installation on the LACV-30 can be accomplished for a modest cost, and in about a year's time. Its design concept has been tested and put into practice on the JEFF-B air cushion vehicle. Its productivity to cost improvement ratio in the U. S. Army's resupply mission of 12 to 1 justifies initiating a development program without further delay.

Option (7), new high-performance lift fan, and 9½ ft diameter propeller, offers a 10-ton improvement in the LACV-30's payload without significantly

TABLE 1

LACV-30 OPTIONS

OPTION	DESCRIPTION
(1)	Unmodified LACV-30
(2)	LACV-30 with New, Wrap-Around Stern Seal and Raised Longitudinal Seal
(3)	Option (2) Plus 5-1/2 Ft. Stretch of the Hull
(4)	Option (2) Plus Counter-Rotating Lift Fans
(5)	Option (4) Plus 5-1/2 Ft. Stretch of the Hull
(6)	Option (2) with High Performance, Counter-Rotating Lift Fans
(7)	Option (6) with 9-1/2 Ft. Propellers
(8)	Option (7) Plus 5-1/2 Ft. Stretch of the Hull
(9)	Redesigned Propulsion Modules with Upgraded Gas Turbine Engines, New Lift Fans and 11-1/4 Ft. Propellers

TABLE 2

LACV-30 BUDGETARY PRICES FOR OPTIONS 2-8

OPTIONS	DEVELOPMENT	PROTOTYPE CRAFT	PRODUCTION AND RETROFIT	TOTAL PROG. COSTS-26 CRAFT	COST FOR FUTURE PRODUCTION
(1) LACV-30 As Is					
(2) Rear Seal and Keel Changes	$ 450,000	$ 200,000	$ 55,000 .8%	$ 2,080,000	$ 20,000
(3) Seal/Keel + 5½ Ft. Stretch	785,000	500,000	390,000 5.6	11,425,000	335,000
(4) Seal/Keel + BHC Counter-Rotating Fan	1,715,000	640,000	285,000 4.1	9,765,000	100,000
(5) (4) + 5½ ft. Stretch	2,050,000	890,000	620,000 8.9	19,060,000	335,000
(6) (4) + High	2,345,000	995,000	427,000 6.1	14,442,000	150,000
(7) (6) + 9½ ft. Propellers	2,410,000	1,130,000	517,000 7.4	16,982,000	150,000
(8) (7) + 5½ ft. Stretch	2,745,000	1,380,000	852,000 12.1	26,277,000	485,000

TABLE [illegible]

SUMMARY OF PROPOSED MODIFICATIONS TO THE LACV-30

Option	PAYLOAD (TONS)	CONFIGURATION OPTION	LACV-30 MODIFICATION COSTS (PER CRAFT)	% INCREASE IN LACV-30 PRODUCTIVITY	% INCREASE IN LACV-30 ACQUISITION COST	DEVELOPMINT COSTS & PROTOTYPING	PERFORMANCE
	25-30	LACV-30	0	0	0	0	SS0 : 47 MPH SS2 : 33 MPH
2	30-35	REAR SKIRT & RAISED KEEL	$ 55,000	11%	0.9%	$650,000	SS0 : 46 MPH SS2 : 29 MPH
7	35-40	NEW FANS NEW REAR SKIRT 9-1/2 FT. PROPS	$517,000	21.5%	7.3%	$3,440,000	SS0 : 47 MPH SS2 : 31 MPH
9	40-50	NEW PROPULSION MODULES	$1,750,000	35%	25%	$5,500,000	SS0 : 72 MPH SS2 : 48 MPH

affecting the craft's overwater/overland performance. LACV-30 payload will increase 33% and its productivity in the resupply mission, 22%. Cost of a development program is estimated at about $3.5M, which will extend over a 2-year period.

The performance gains in the lift and propulsion systems of Option 7 are quite significant; nonetheless, it is believed that an additional 20% performance and/or efficiency increment can be obtained with further development effort in this area, specifically fan and plenum design optimization. It is recommended that additional study effort be directed towards optimizing the performance and efficiency of the high performance fan and the plenum/volute configuration.

The LACV-45 option offers a 20-ton improvement in payload, and substantial gains in performance and productivity. The costs of development of a LACV-45 are high, since new power modules will be required, together with new engines, transmissions, and lift fans. The productivity of a craft of this design increases substantially, offsetting the development and retrofitting costs by a factor of 2 to 1.

The LACV-45, if developed, would be a craft far more capable than the LACV-30, not only in speed and payload capacity, but also in its ability to handle a wide variety of payloads, including beach equipment, light and medium weight fighting vehicles and oversized cargo of various types.

The concept of a LACV-45 requires further study, before its performance, costs and development schedules can be fully defined.

Section 1. presents a detailed description and review of the study. Section 2. contains conclusions and recommendations. Appendices A-D present specific study area details including analyses, data, and intermediate results. Section 4 lists the references.

2. INTRODUCTION

The LACV-30 provides the U. S. Army with the capability of conducting logistics-over-the-shore (LOTS) operations in support of the resupply mission, and for selected cases of rapid-deployment force (RDF) responses in which military cargo and equipment are to be put ashore where conventional ports are not available, or otherwise saturated. As designed, the LACV-30 is capable of carrying payloads of 25-30 tons, in sea states up to three. Although able to carry vehicles, troops, lightweight fighting equipment and palletized cargo, the LACV-30 is designed and equipped to carry principally 20 ft. standard MILVAN containers. It interfaces with either a ship's crane, when available, crane-on-deck (COD) or temporary container discharge facility (TCDF) when being loaded at the containership, and a beachcrane such as shown in Figure 1, when being unloaded ashore. The LACV-30, now being introduced into U. S. Army inventory, is presently in production with a total order of 24 craft. The U. S. Army is planning two Army companies of 12 craft each, operating at Ft. Story, Virginia. Final deliveries are scheduled for early 1986.

Although the LACV-30 represents a major step forward in providing the U. S. Army with a capability for performing LOTS missions, recent advances in the design technology of skirt systems, lift fans and components for air cushion vehicles indicate a potential for increasing the LACV-30's payload, without substantially increasing acquisition or operating costs. This study effort specifically addresses the following tasks:

(a) Establish the physical and operating characteristics and performance of components or subsystems which singly or in combination offer increased payload for the LACV-30.

(b) Synthesize a series of increased payload concepts which range from small changes offering modest payload gains to large changes providing significant payload increases.

(c) Evaluate craft performance of the task 2 concepts in terms of gross weight, speed, sea state, and productivity. Limiting aspects for control, structural, bouyancy, and balance will be identified.

(d) Life cycle costs and cost effectiveness will be estimated including developmental, initial modification, and operating costs.

Potential improvements which were studied on the LACV-30 in the static test rig (Figure 2) included modifying the design of the stern and side bag cones to reduce air loss to ambient, changing the rotation direction of the LACV-30's port lift fan and adjusting the volutes to conform, redesigning the LACV-30 lift fans to obtain greater fan efficiencies, adding auxiliary deck mounted fans to supply an external source of power and air, and exploring various ways of rerouting the air flow within the cushion to increase lift system efficiency. Table 4 summarizes the results obtained from the static tests. Details of the test results are presented in

Bell Aerospace TEXTRON

LOADING ON THE BEACH

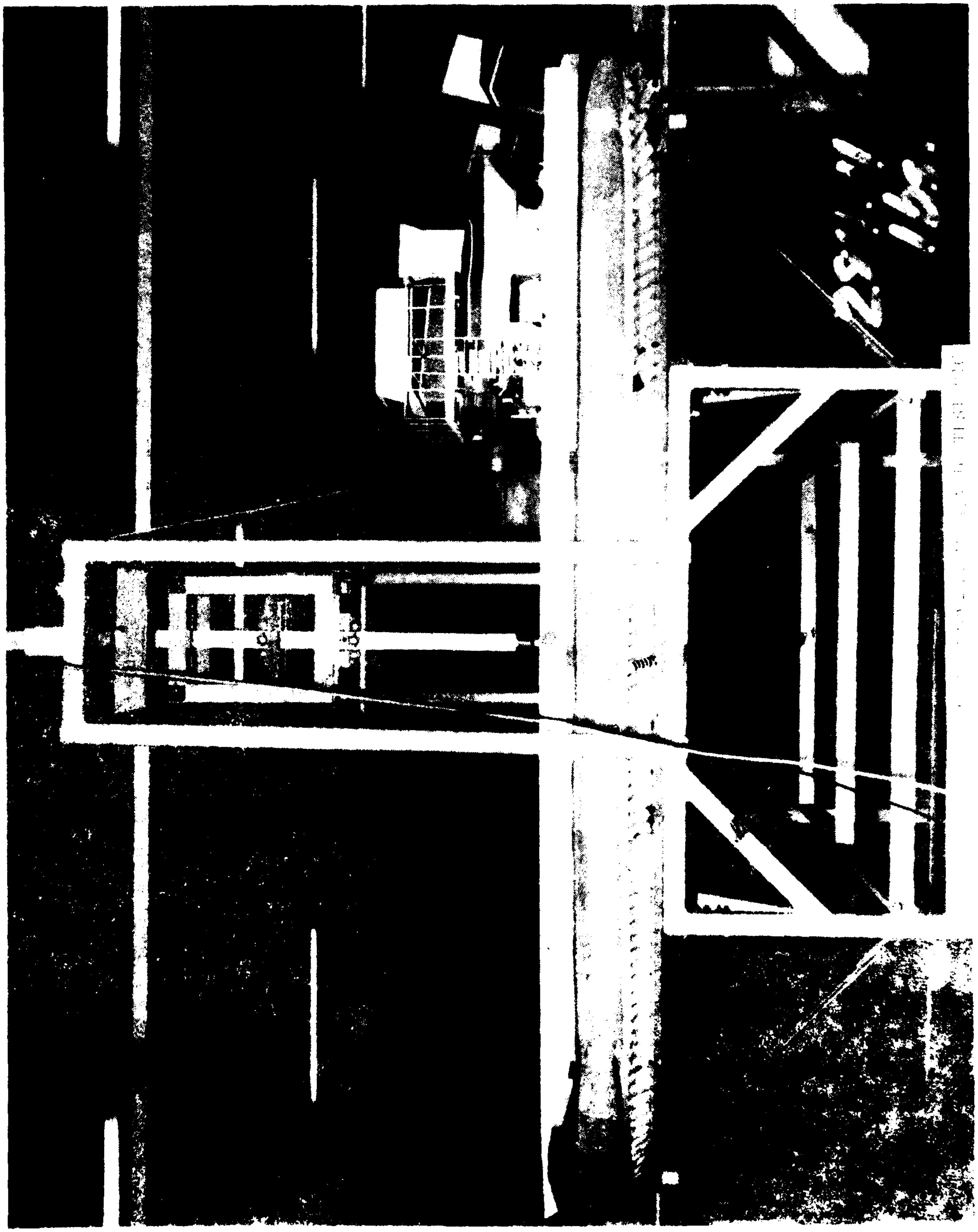


TABLE 4
SUMMARY OF MODEL STATIC TESTS

	Lift System Modification	Heave Ht.	ΔW_{gross}
1)	Close stern and side bag cones	3/4-1 inch	4-5 tons
2)	Connect bow feed from keel	none	none
3)	Counter rotary lift fans	1/4-1 inch	1-4 tons
4)	Offset volutes with counter-rotating fans	1-2 inches	5-7 tons
5)	Stern-bag to cushion feed holes	none	none
6)	Forward keel to cushion feed holes	none	none
7)	Offset volute with LACV-30 synchronous fans	negative	negative
8)	Seven foot, high performance lift fan (Hughes)	2-1/2-3 inches	15-20 tons
9)	Auxiliary deck mounted fans	3/4-1 inch	4-5 tons

Appendix A to this report. As seen, modifications (1), (4) and (8) appeared to offer the greatest potential for increasing the LACV-30 payload.

These three modifications, combined with the aspect of re-engining the LACV-30 formed the basis of the LACV-30 IP study. Results of these four modifications, their impact on LACV-30 design, cost and operational effectiveness are summarized in the sections below.

In addition to the above four modifications, it was found necessary not only to increase the efficiency of the LACV-30's lift system, but also to increase thrust, or reduce drag, as necessary to regain overland/overwater performance lost by the additional weight being added. Therefore, the following additional modifications to the LACV-30 were examined.

(a) Larger diameter propellers, directed at increasing propeller performance, and the overall ability to absorb additional power freed-up by a more efficient lift system.

(b) A raised longitudinal keel to eliminate unnecessary drag caused by greater LACV-30 displacements.

(c) Increased hull length, designed to lower cushion pressure and increase the LACV-30's length to beam ratio.

3. Definition of the LACV-30 IP Options

The above three propulsion modifications, together with the other four lift system modifications provides a total of seven alternatives which could be used in various combinations to improve the LACV-30.

Table 1 presents a listing of a total of 9 options investigated for this study. Of the nine, options (2), (4), (7) and (9) were found to be candidates for further consideration and study. Details of all options are given in the Appendices. Summaries are presented in the paragraphs below.

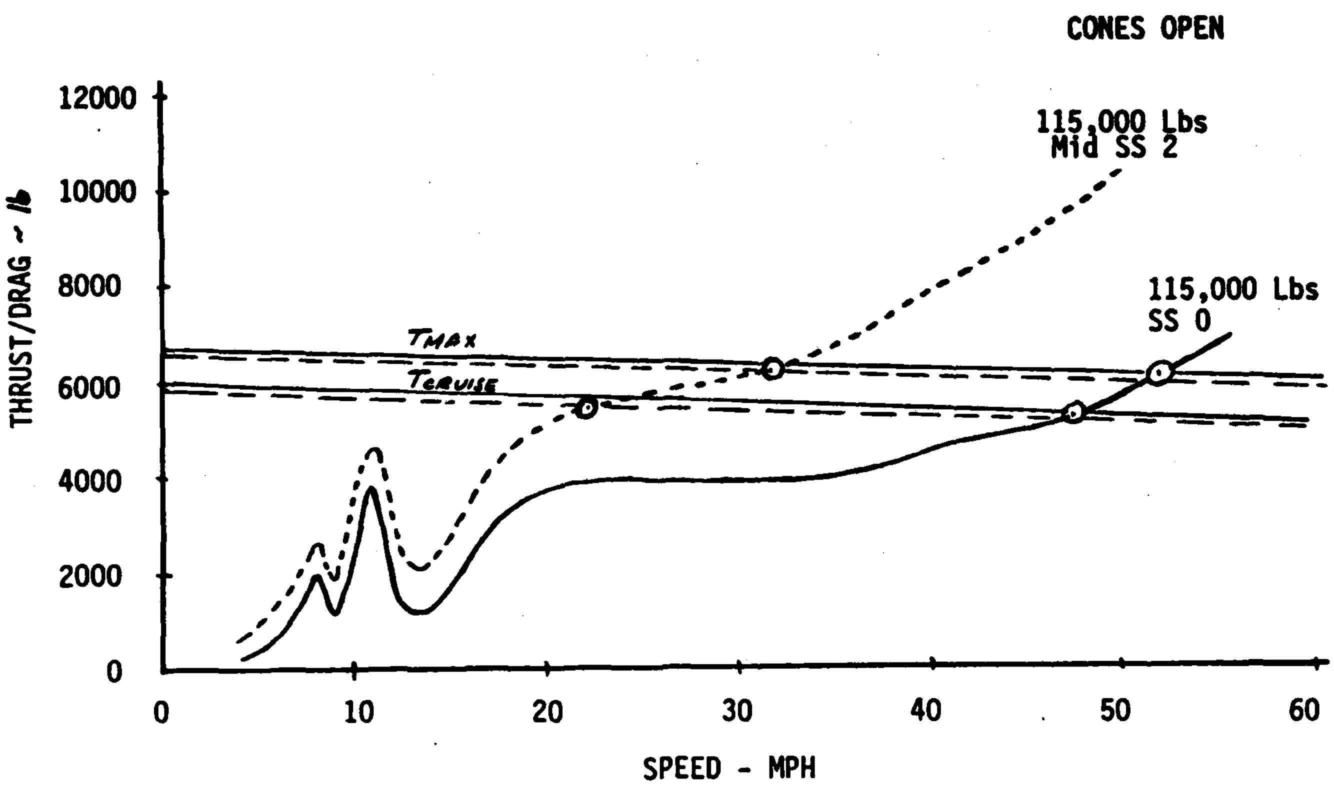
The computer program used for the prediction of LACV-30 lift system performance and overwater speed is the latest of several previous program versions, each of which being an expansion/refinement to suit analysis requirements. Details of the program "ACVPRF" are given in Appendix C. Major subroutines include the LACV-30's lift system, engines, propeller thrust, and drag. Controllable input parameters include sea state conditions (wind, wave heights) propeller size, vehicle dimensions, vehicle gross weight, engine and fan speeds and ambient conditions (temperature, pressure).

Option 1 - Throughout the report, the unmodified LACV-30 has been assigned as Option 1. Where they apply, values of LACV-30 performance, cost and cost-effectiveness are included in the study, and used as comparison with corresponding values obtained for all subsequent options. The LACV-30 was originally designed for operating at a maximum design gross weight of 115,000 pounds. It will achieve a performance typical of that indicated in Figure 3. Appendix C summarizes the LACV-30 performance in a variety of sea-state and gross weights. Presently the LACV-30 is certified to

FIGURE 3

LACV-30 IP PERFORMANCE

OPTION 1 LACV-30 UNMODIFIED



operate at a maximum gross weight of 125,000 pounds. Weights in excess of 125,000 pounds are beyond the design limits of the LACV-30 and are neither reliable nor safe to operate at without some type of upgrading of the LACV-30 structure. Changes and/or improvements to the structure were found to be minimal, up to a gross weight of 153,000 lbs. This is described in Appendix B.

Option 2 - Wrap-around stern seal and raised keel. Previous static testing (Appendix A) on the 1/7.5 scale LACV-30 model had indicated a marked improvement in the lift system was obtained when the open cones of the stern seal were closed off. Results are shown in Figure 4, which indicates that an additional 8-10,000 pounds can be added to the gross weight of the vehicle. In addition, input horsepower to the lift fans for carrying the vehicle can be reduced by 10 to 60 Hp, depending upon gross weight.

The improvements in the lift system can be attributed to a savings of power made possible by blocking the flow of air through the cones which exit to ambient. Pressures within the plenum and peripheral bag increase, and this, combined with the lower flow in the system will reduce lift fan efficiency. However, this effect is more than made up by roughly a 30% savings of horsepower being used to supply air to the stern cones in the first place.

The next step in the process of improving the LACV-30 is to implement the designated change in the stern seal. A closed cone configuration was considered, but rejected because of the combined effects of short life and a tendency to "scoop" water and cause high drag because of high stiffness. On the LACV-30, as well as its predecesser vehicles, the stern cone is configured to be marginally stable, so that it normally holds sufficient pressure to retain shape. When the craft is moving forward, craft motions and waves force the finger to buckle, to relieve load and preclude scooping.

A similar design had been originally used on the JEFF-B stern seal. Because of leakage problems, studies and tank tests were conducted, and these lead to a new-type stern finger-cone design shown in Figure 5. The underside edge of the cone has a flap across its bottom which, in normal forward motion holds the cone closed. Contact with a wave will force air out, causing the cone to flex to the contour of the wave. Water scooping is eliminated. Figure 6 shows how the LACV-30 would look with a wrap-around stern seal, attached to the LACV-30 side bags at the rear corners of the craft.

In addition to the newly designed stern seal, evidence from previous studies (Ref. 5), show that the longitudinal keel of the LACV-30 has a tendency to drag in the water, as it is now configured. The effect becomes more pronounced as the gross weight of the LACV-30 is increased, and the craft displaces greater amounts of water. For this application, therefore, a shortening of the keel (heightwise) by six inches is recommended. Tow tank tests are recommended to determine what ultimate desirable height will be necessary, however, this modification is considered as necessary if the LACV-30 is to operate efficiently at the elevated gross weights.

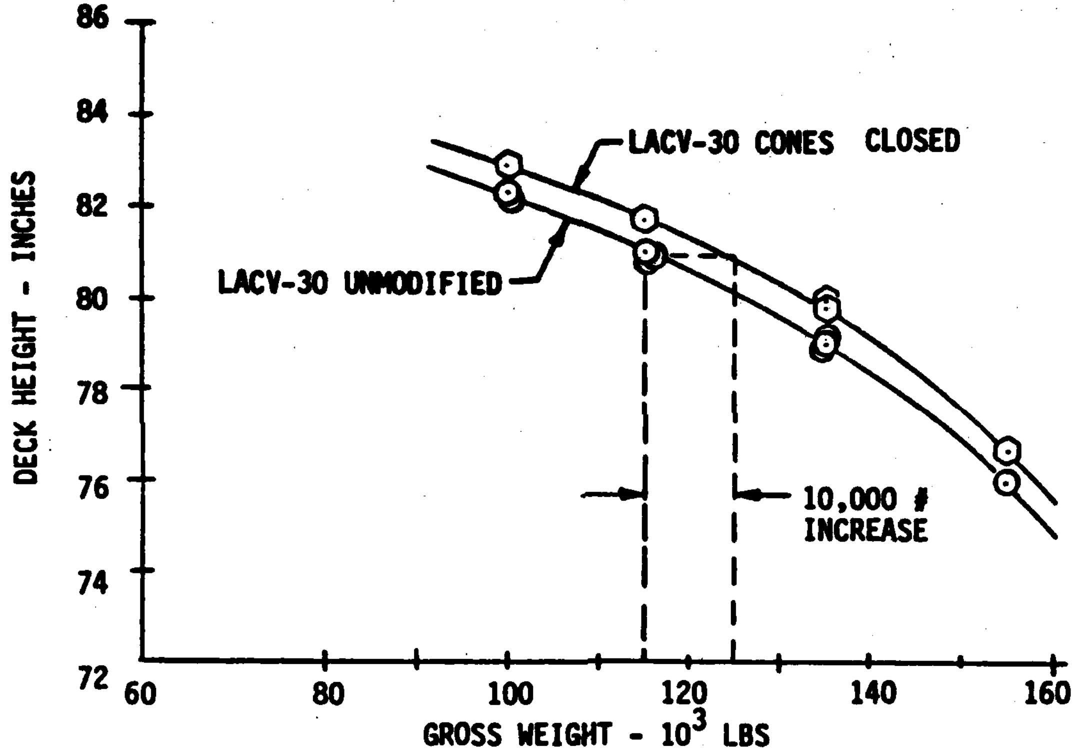


FIGURE 4. LACV-30 OPTION 2 LIFT PERFORMANCE

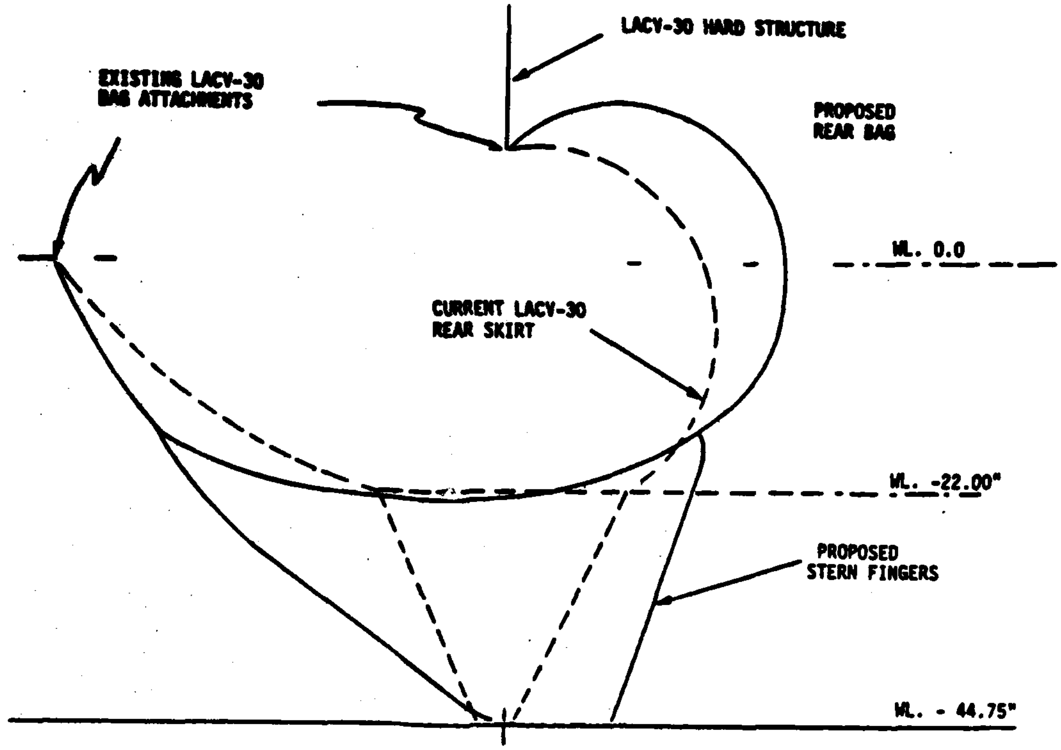


FIGURE 5

VERTICAL PROFILE - PROPOSED LACV -30 REAR SKIRT

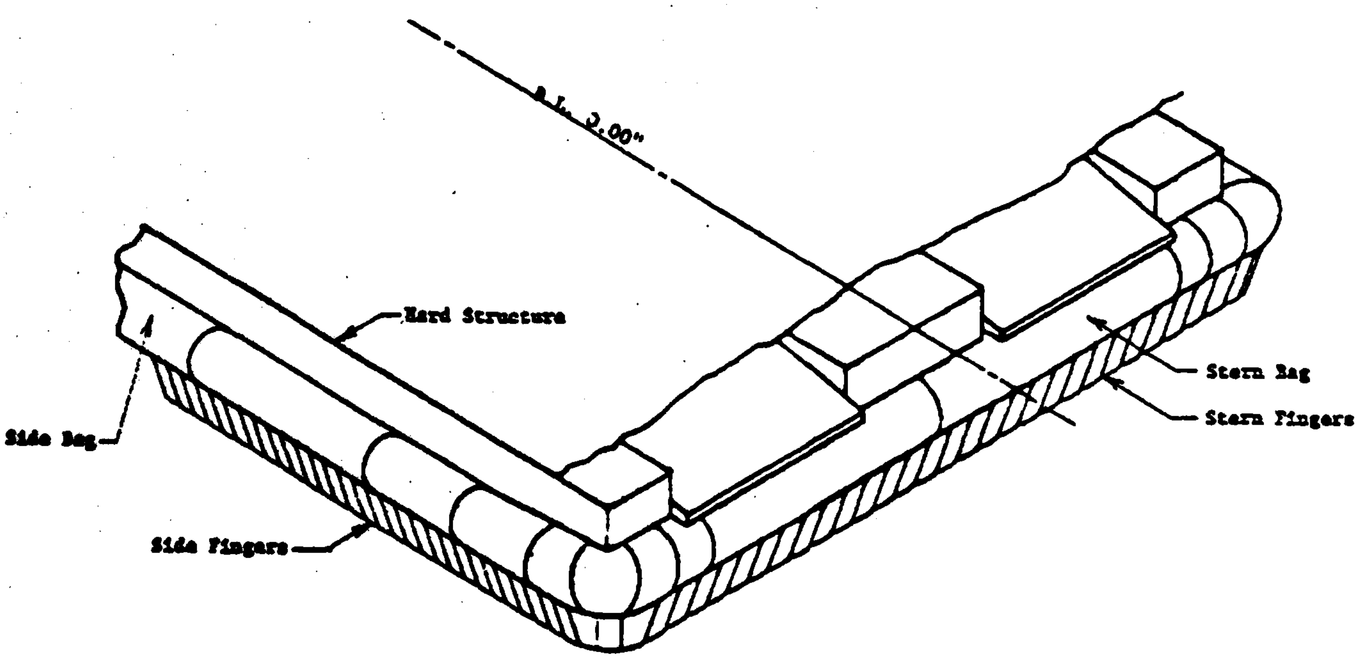


FIGURE 6

PROPOSED LACV-30 STERN SEAL WITH SWEPTBACK OPEN CONE FINGERS

Figure 7 gives the projection for the performance of the LACV-30 Option 2 in two sea-state conditions. Comparison with the unmodified LACV-30 performance (Figure 3) shows a slight speed reduction. To overcome this, Option 3 was studied.

Option 3 - Wrap-around stern seal/raised keel and a 5½ ft. hull stretch

Option 3 is identical to Option 2, except that the effects of stretching the LACV-30 hull to lower cushion pressures and reduce wave drag. The effects of a 5½ and 11 ft. hull stretch are shown in Figure 8. As seen, each successive stretch is worth about 2 mph in the 20 mph speed range.

Option 4 - Counter-rotating LACV-30 lift fans

Discrepancies in port and starboard pressures in the LACV-30 stern and side bags have been noted for some time. These have been attributed to the lack of symmetry in the plenum, due to both fans operating in the same direction. The differences between the right and left sides within the plenum area for the 1/7.5 scale LACV-30 model is shown in Figure 9. Pressures differ by as much as 25% in the stern and side bags. Disemination of the air around the periphery of the LACV-30 also appears to be affected.

Static tests of the LACV-30 model were performed to determine whether the performance of the lift system would improve if the LACV-30 fans were made counter-rotating, and the volutes adjusted to obtain maximum flow efficiency. As can be seen in Figure 10, the increase in lift made possible by this change in configuration can add an additional 10-12,000 pounds to the LACV-30 gross weight. A comparison with the original LACV-30, with open stern cones shows that the two effects are additive, thus producing a total increase in vehicle payload of 20,000 pounds.

In order to implement the counter-rotating fans, several changes to the LACV-30 will be required. These include,

(a) A reversing of the rotational direction of the left side drive shaft from the SPECO transmission to the fan.

(b) A re-arrangement of the volutes in the plenum.

(c) A replacement of the left lift fan with one designed to operate in a reversed rotational direction.

Two different approaches were used to accomplish the reversing of the fan drive shaft. The first approach was to add a differential type gearbox to the bottom of the present gearbox, attaching it to the lower bearing housing. The differential gearbox would consist of a sun gear attached in place of the fan shaft output coupling. This would drive three pinions in turn driving three other pinions, which drive the output sun gear. Figure 11 shows the arrangement of the reversal drive gears. Details are given in Appendix B.

FIGURE 7
LACV-30 PERFORMANCE
OPTION 2 - MODIFIED STERN SEAL

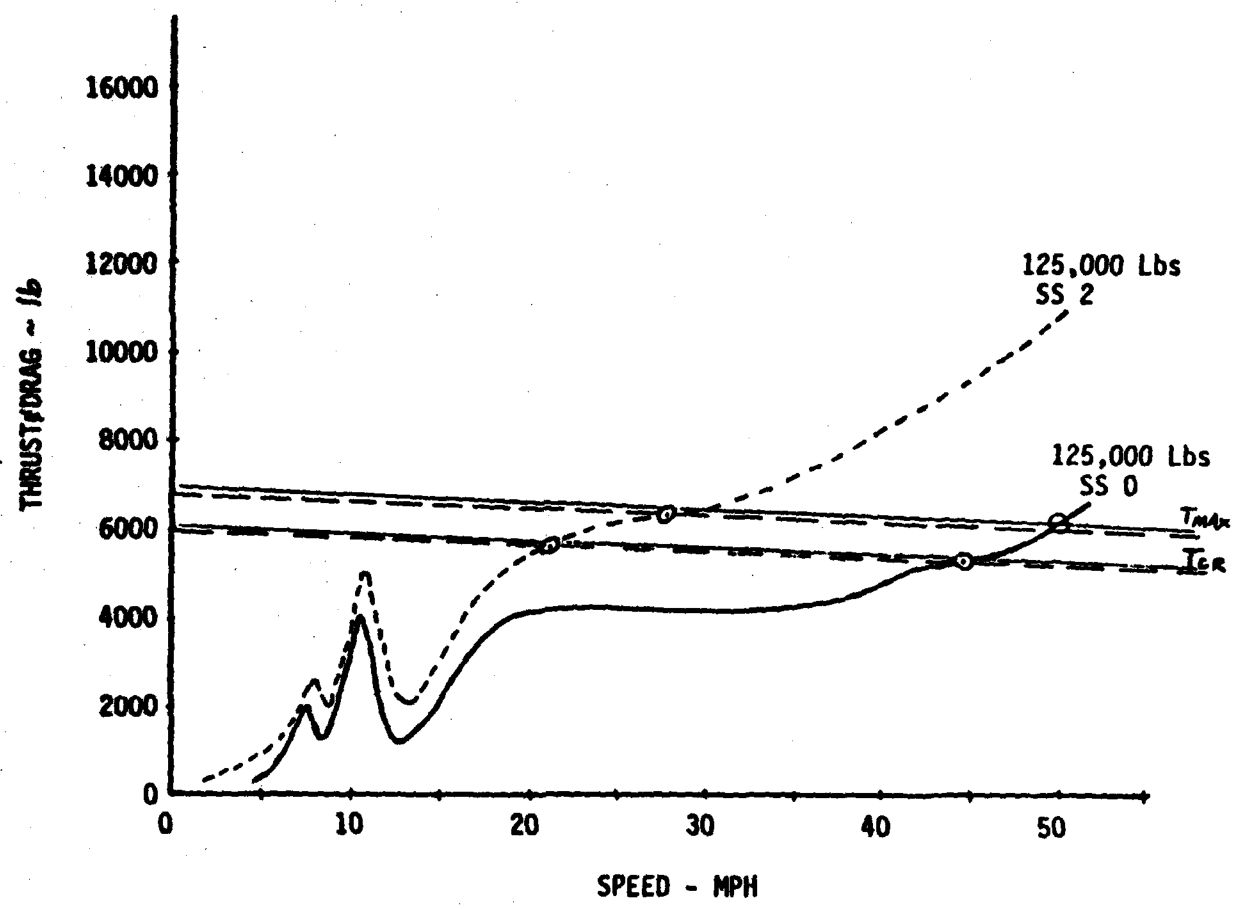
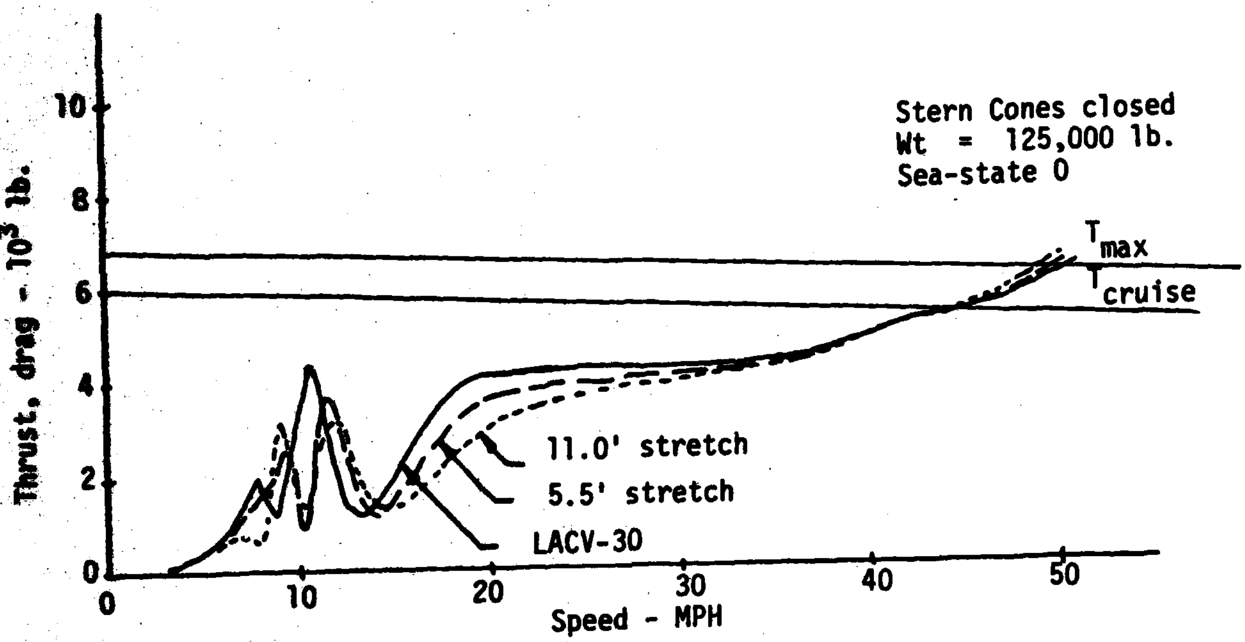
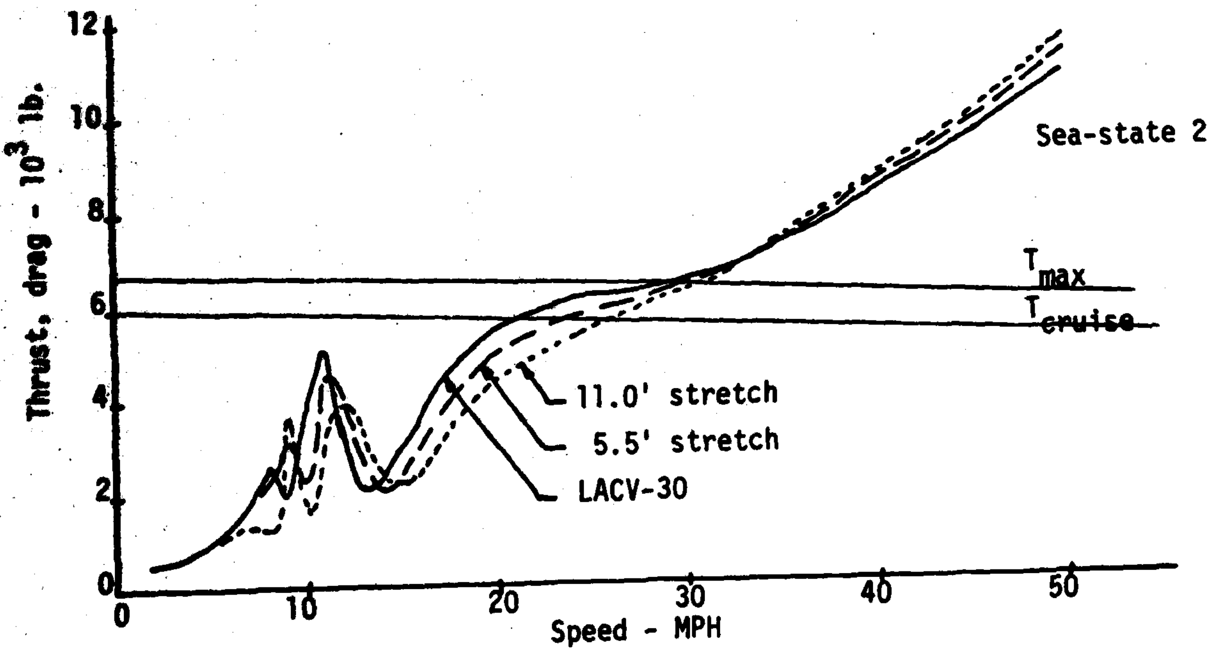


FIGURE 8

LACV-30 IP PERFORMANCE

OPTION 3 - MODIFIED STERN SEAL
STRUCTURAL STRETCH





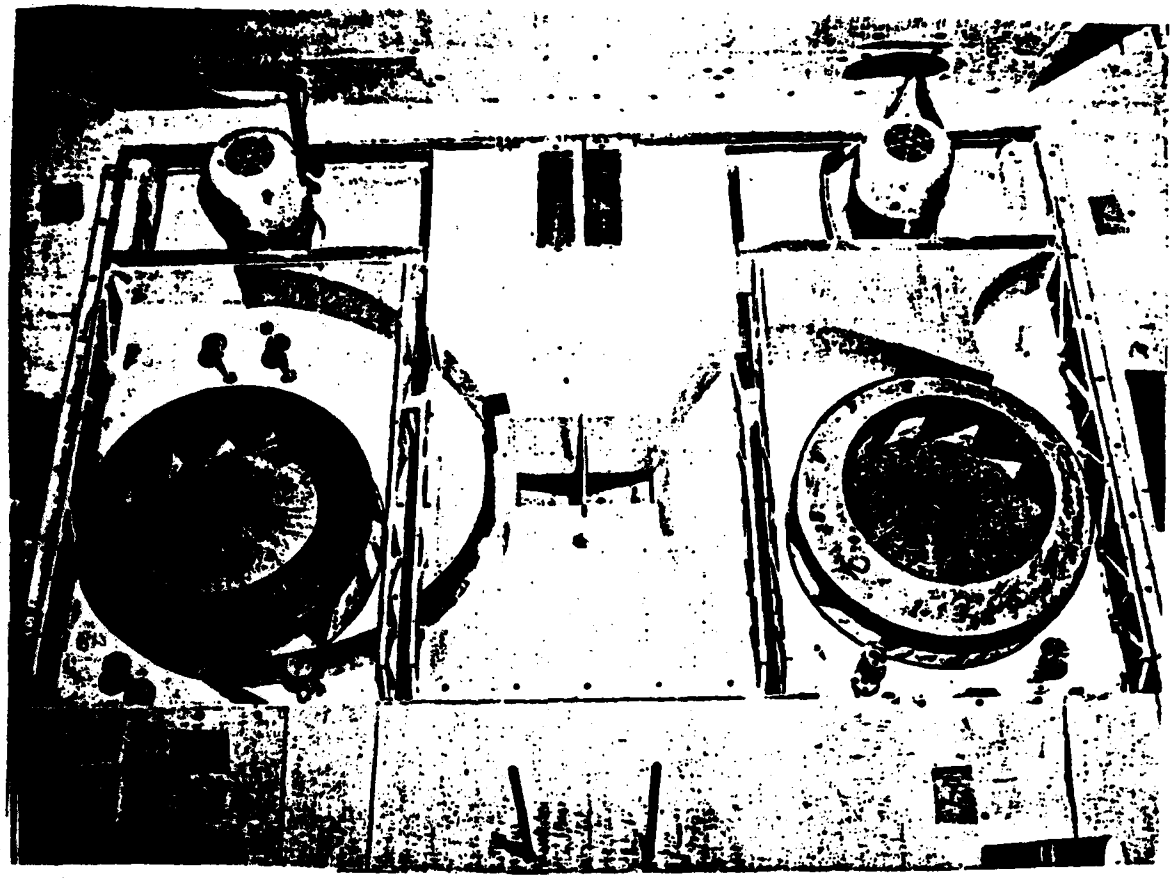


Figure 9. LACV-30 Model Plenum Area

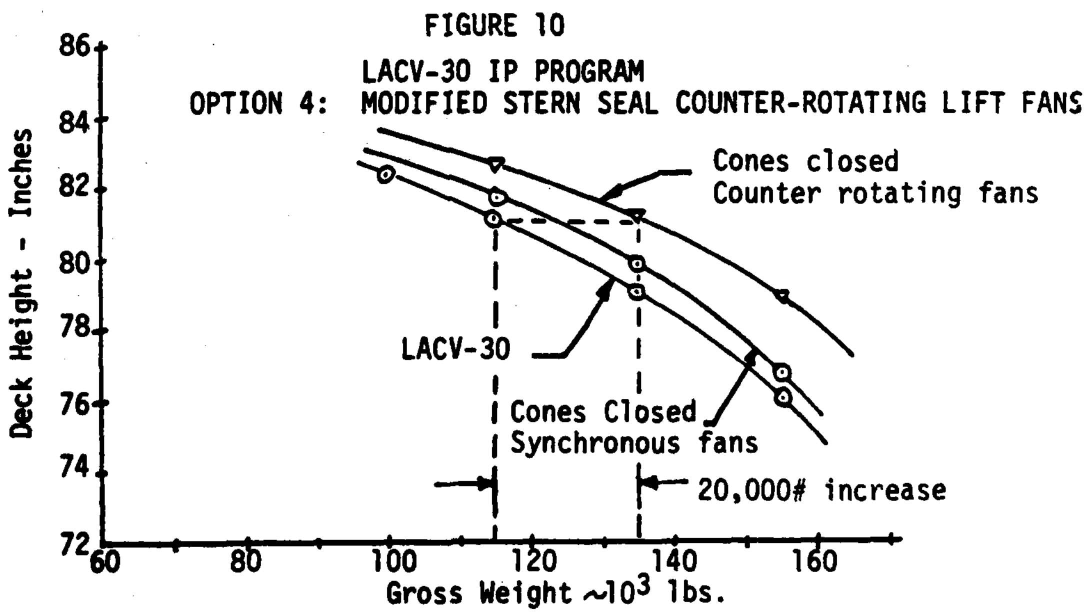


Figure 10. Lift System Performance with Counter-Rotating Fans

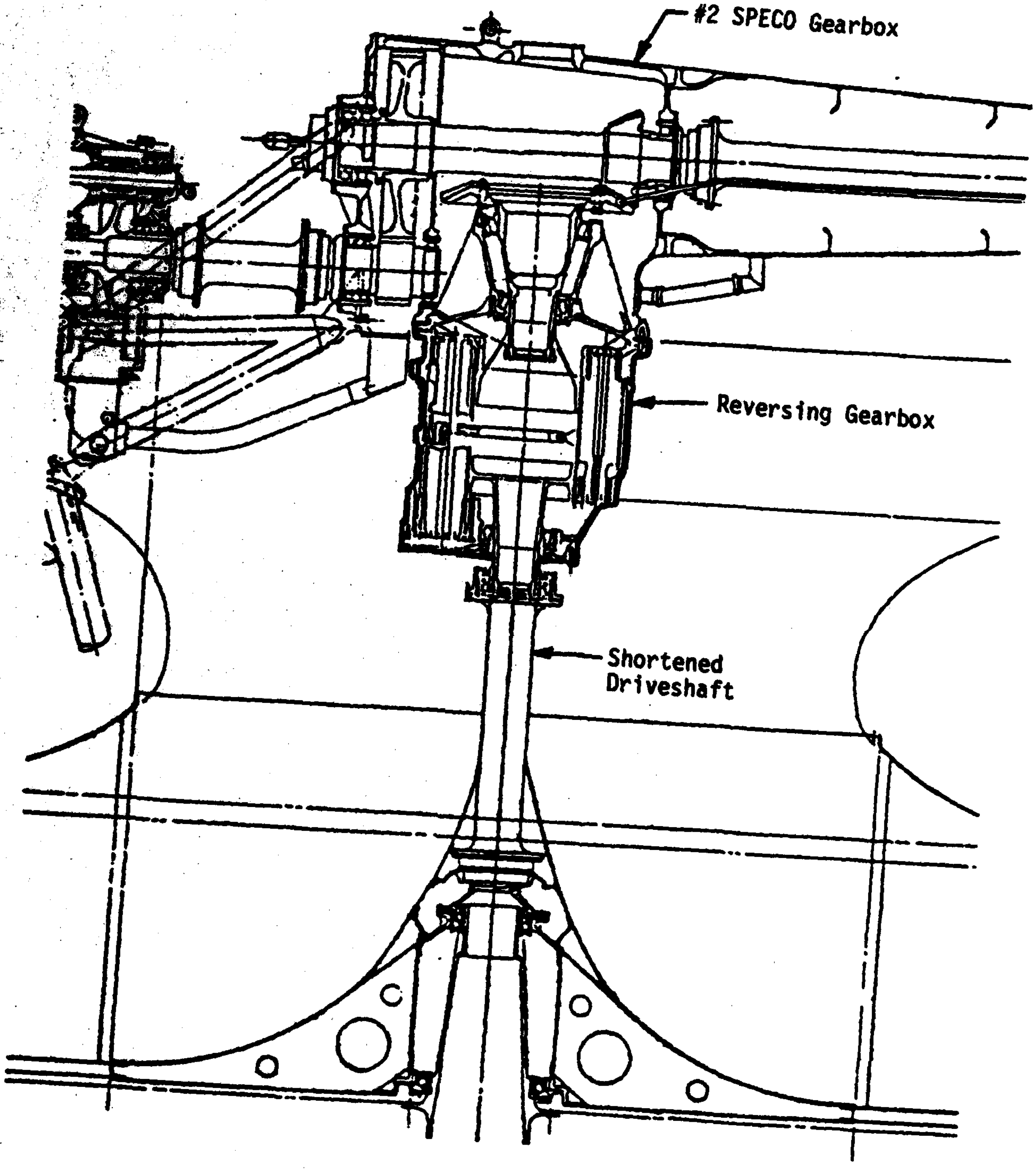


Figure 11.   Lift Fan Reversing Gearbox

The second method of reversing the far output is to move the bevel pinion gear in the transmission box (Figure 12), to the opposite end of the propeller shaft. This requires reversing the spiral angle of the bevel gear set to maintain an axial separating force on the pinion. The helix angle and web in the helical gear set must be reversed to counteract the bevel gear reduction. This makes the port helical and spiral bevel gear sets different. When the spiral bevel pinion is moved, the tapered roller bearing must move with it, and the main housing must be changed accordingly. The cover housing must also be strengthened to carry the tapered roller bearing and its loads. The accessory drive gear and accessory pads must be relocated to clear the bearing assembly.

Although moving the bevel pinion requires a longer lead time (18 vs 9 months), in the long run it will be cheaper and lighter, since it does not require additional parts, but only modifications of those already in use.

Changes within the plenum to account for the opposite rotating fan will be fairly simple, and will be able to be accomplished at the depot level. The inside volute on the starboard side must be shifted forward. Those on the left side will be removed, and the right side copies for use in the left side (with a reversed image).

The BHC-made lift fan design will be retained, but made as a reversed image of the one presently used.

Figure 13 presents the results of the LACV-30 performance for Option 4. Comparison is made with the LACV-30 unmodified case (Option 1). As seen, the drags of Option 4 are considerably higher throughout the entire speed range. The corresponding lower speeds may have an impact on productivity in the resupply mission, as discussed below.

Option 5 - Counter-rotating LACV-30 lift fans - 5½ ft. hull stretch

Option 5 is the same as Option 4, but with a 5½ ft. hull stretch to attempt to compensate for the lower speeds of Option 4, caused by the additional weight. Results were similar to the Option 3 stretch, in that roughly 2 mph additional speed was added to the 20 mph speed range.

Option 6 - High performance counter-rotating lift fans

This option incorporates the high performance lift fan, discussed in Section B.2.7.2 of Appendix B into the LACV-30. Later Options (7 and 8) include slower fan speeds and a larger diameter propeller, but Option 6 retains the 945 rpm lift fan rotational speed, and the 1980 rpm propeller speed.

Air cushion vehicle lift system performance combines the two effects of the basic output of the fan impeller and the method of disemination of flow throughout the lift system. Low fan efficiencies, coupled with high flow losses inherent in the flow distribution system lead to overall low lift system efficiency. This case addresses the increases obtained by

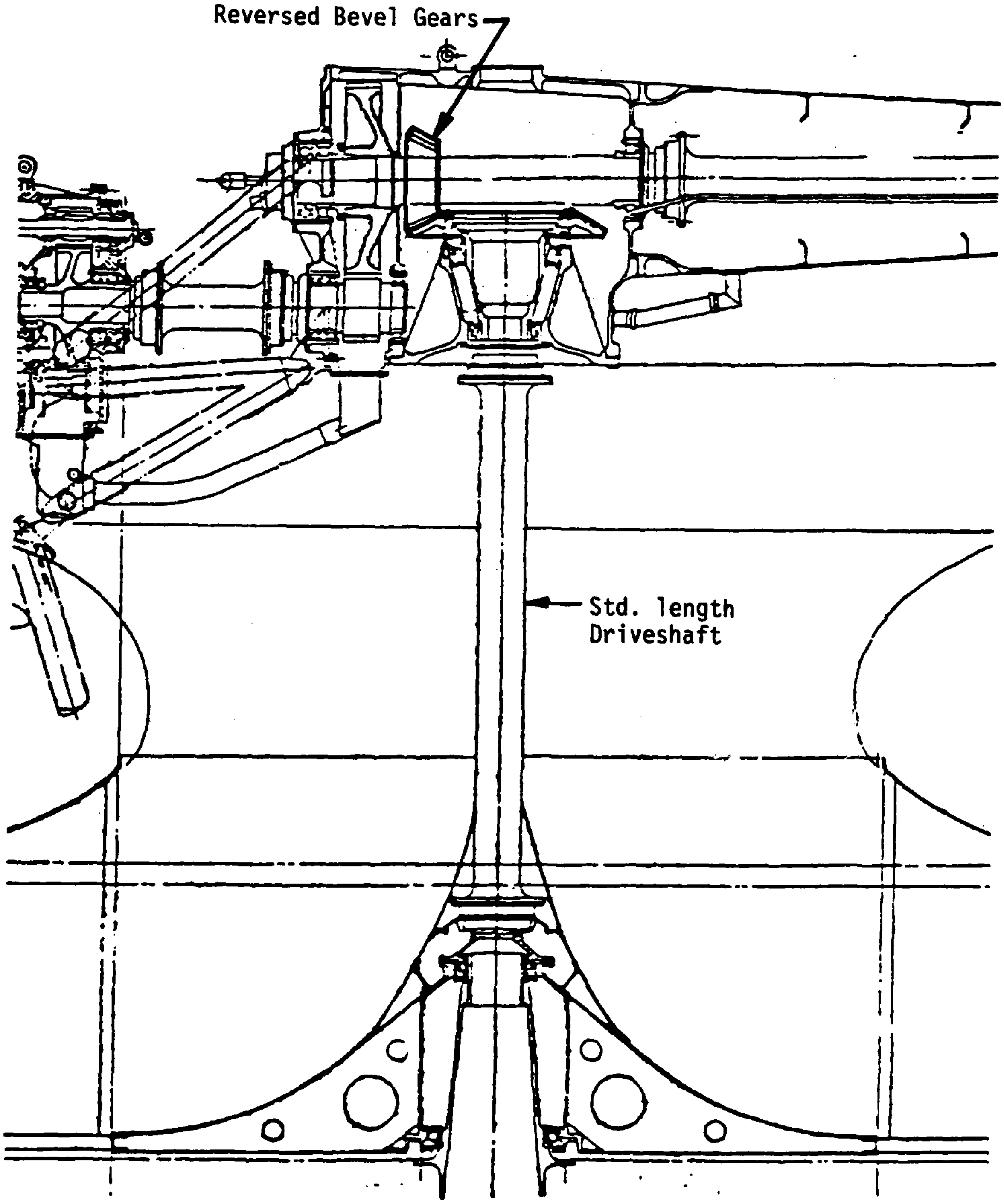


Figure 12. Lift Fan Reversal by Changing Bevel Gear Set

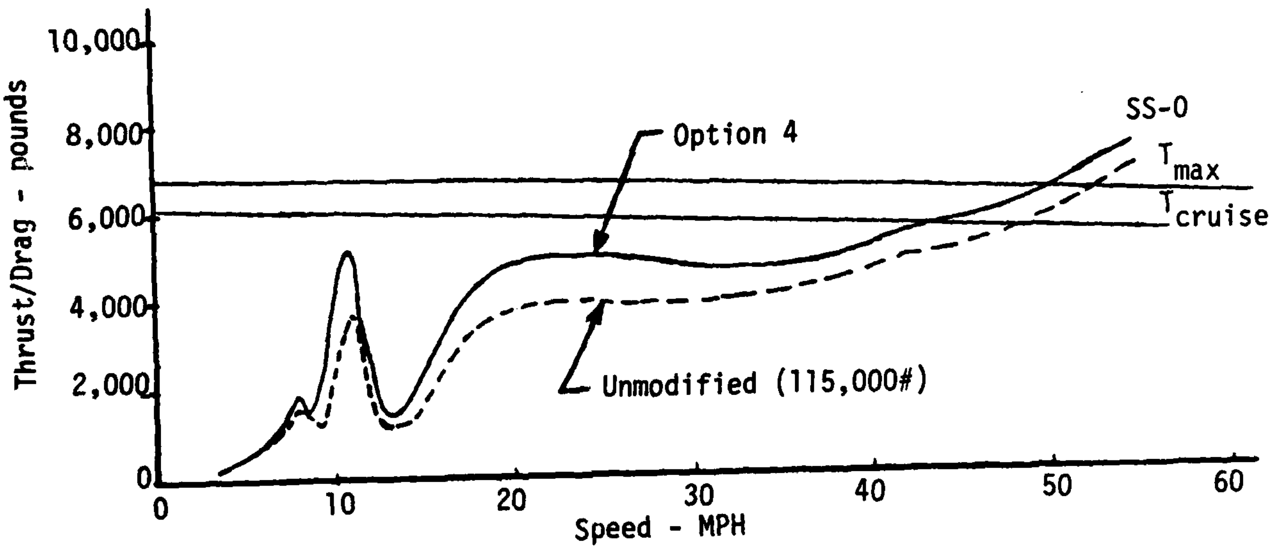
Figure 13

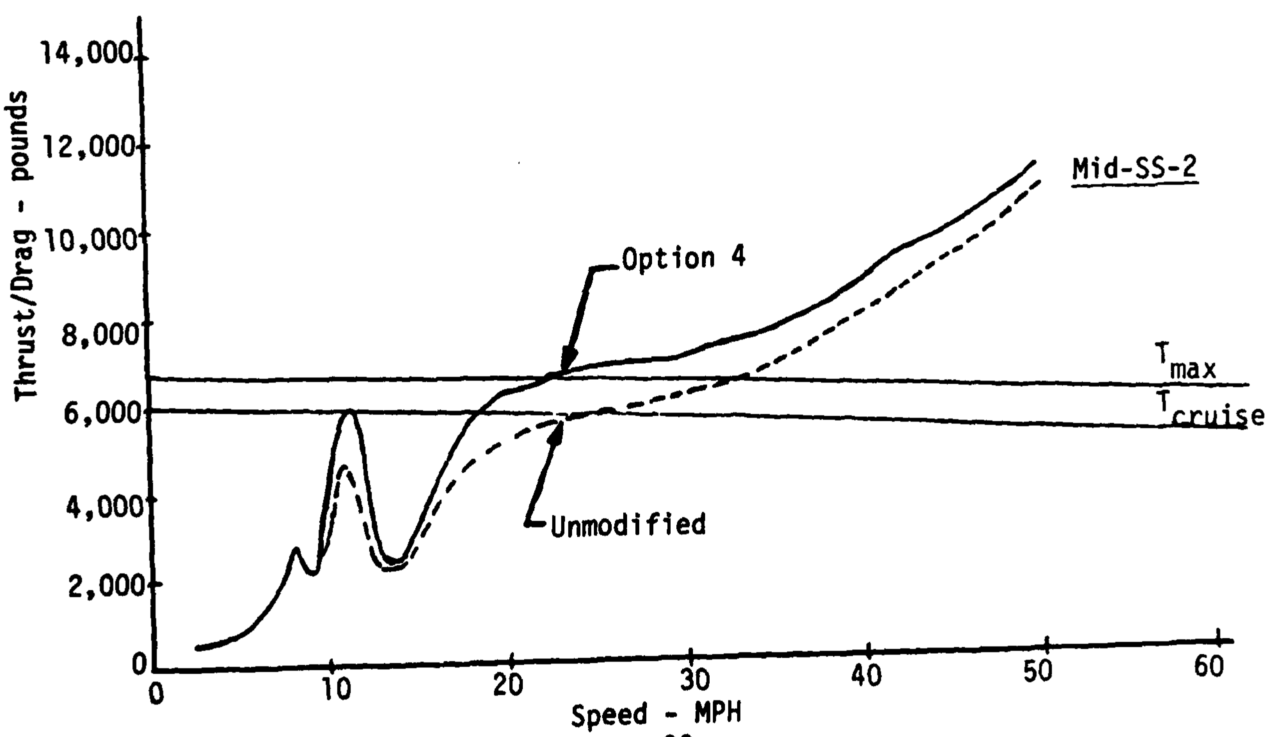
LACV-30 OPTION 4 PERFORMANCE

AND COMPARISON WITH THE

UNMODIFIED LACV-30 CRAFT

OPTION 4: MODIFIED STERN SEAL COUNTER-ROTATING LIFT FANS





redesigning the LACV-30 lift fan, and coupling the benefits obtained by an improved flow system studied earlier, i.e., Option 4 where it was shown that improved flow is obtained by reversing the direction of the LACV-30 port fan, and Option 2, which replaces the relatively inefficient stern seal with an efficient one.

In review, the current BHC lift fan design was taken directly from the SRN.5/SK-5 ACV's. It was used in the Voyageur (Ref. 6) and later, the LACV-30. The "cost-effectiveness" of adapting an existing fan to succeeding derivative ACV's outweighed the inefficiencies of operating the fan farther and farther away from its optimum operating point. The rationale for the high performance lift fan considered in this study is simply to introduce a new design whose optimum operating point more closely matches the requirements of the LACV-30 lift system.

The BHC fan operates at about 2/3 of the flow for maximum efficiency for the LACV-30 in a lightweight condition, 75,000 lbs gross weight. As weight increases, the fan operating condition moves farther away from the maximum efficiency point. Also, at the nominal 945 rpm operating condition for the fan, there is only about a 3% stall pressure margin. In the process of redesigning the fan to operate in the flow regime for maximum efficiency, this stall margin can also be increased.

Using a centrifugal fan performance analysis computer program developed at Bell in 1982 ("CFDAP"), a new fan design was accomplished. The new fan was constrained to have the same outside diameter and rpm values as the BHC fan. Scale models were built and tested. The calculated and measured fan curves are shown in Figure A.13 of Appendix A.

If placed in the LACV-30, the newly designed fans are calculated to have a lift performance as indicated in Figure 14. As shown, the LACV-30 could have, at least theoretically, a lifting capacity of about 150,000 lbs. Performance of the LACV-30 operating at this weight is shown in Figure 15. With the LACV-30 in the Option 6 configuration, the craft cannot develop sufficient thrust to maintain reliable speeds in the 20-30 mph speed regime. Unloading the LACV-30 to 135,000 lbs gross weight did not significantly improve conditions. Therefore, the option of high performance fans, by themselves, is not considered fully viable.

Option 7

Option 7 combines the high performance fan of Option 6, with additional features in an attempt to regain the loss in performance caused by increased vehicle gross weight. These include a slower fan and propeller speed coupled with a 9½ ft. diameter propeller. This allows the propeller to operate at the same tip speed as it now operates at, while simultaneously slowing lift fan speed a corresponding amount (approx. 5%). This effect is discussed in Section B.2.7.2 of Appendix B. Performance is shown below, and is discussed in detail in Appendix C.

When the above modifications are implemented, and the fans are slowed to 889 rpm, 260 Hp in the fans are saved. With the 9½ ft. diameter

FIGURE 14

MODEL TEST DATA - LACV-30 IP PROGRAM

OPTION 6: MODIFIED STERN SEAL, HIGH PERFORMANCE, COUNTER-ROTATING LIFT FANS

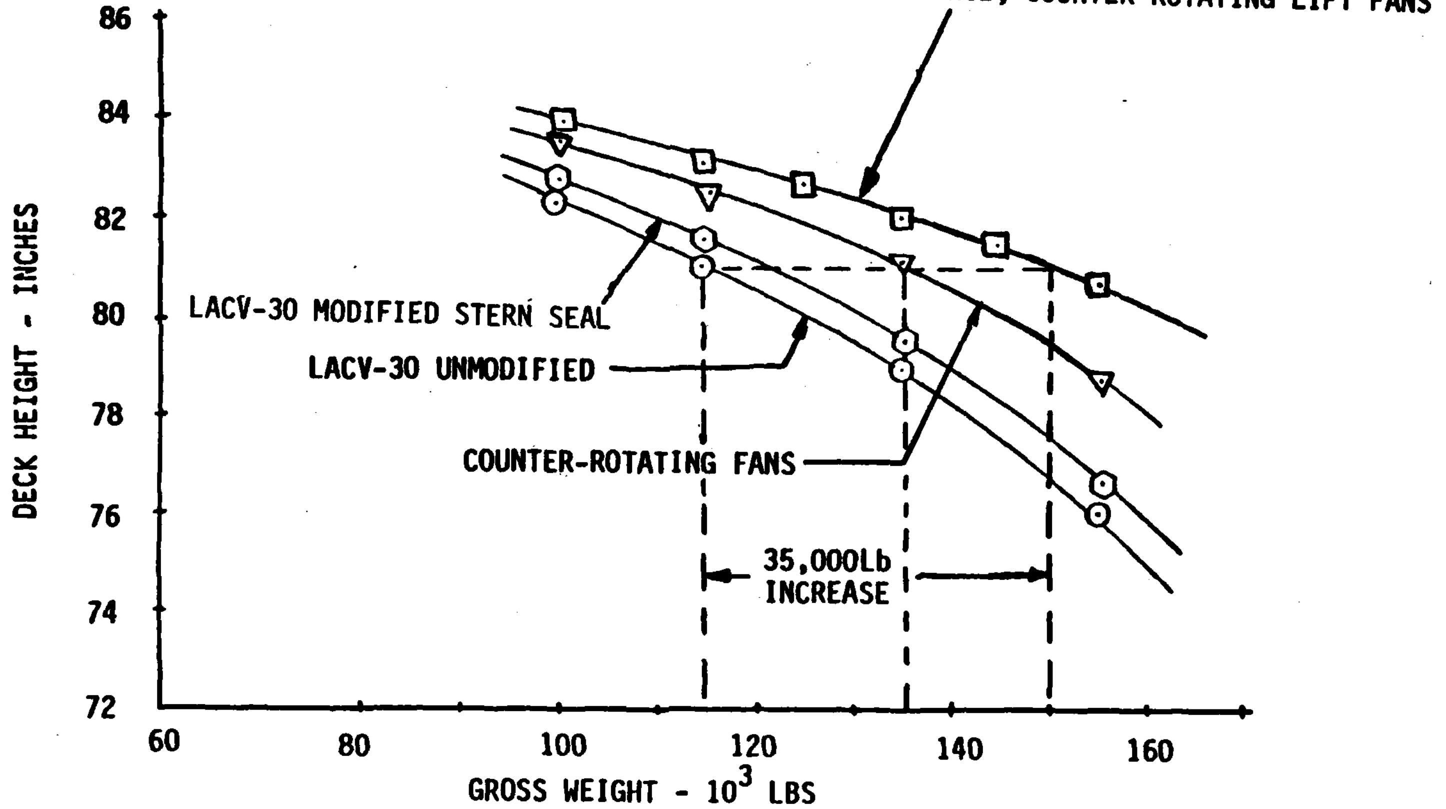
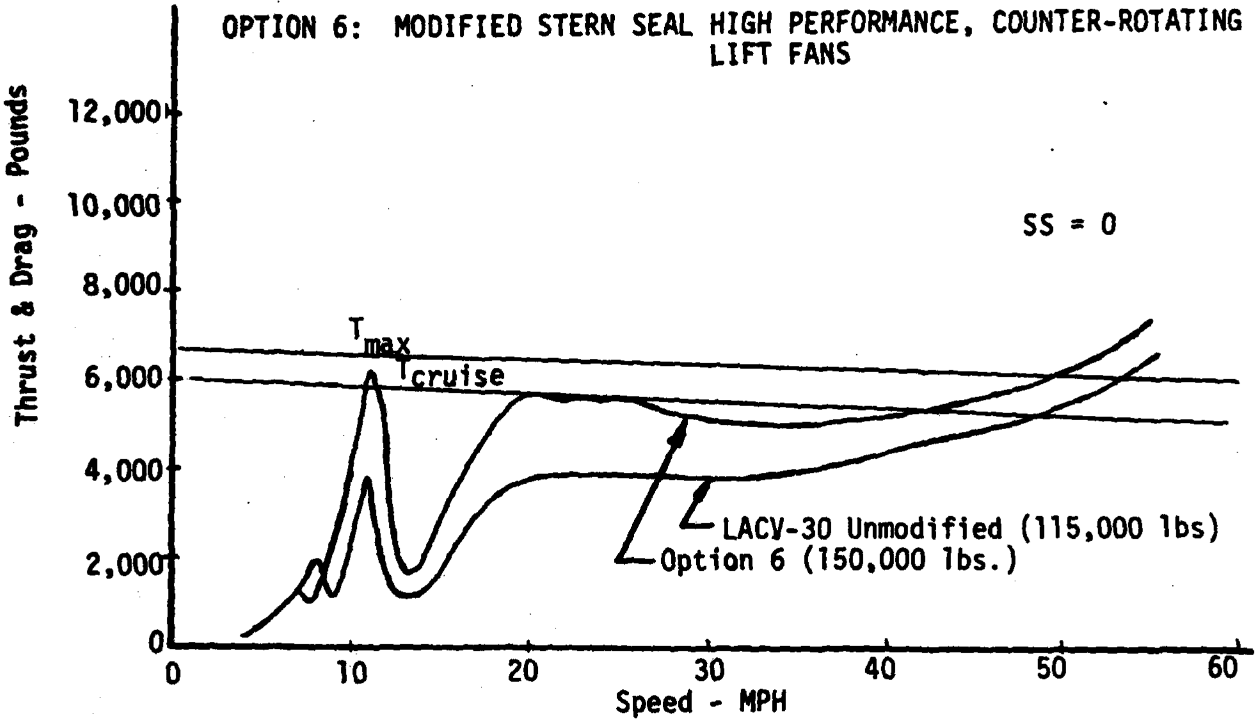
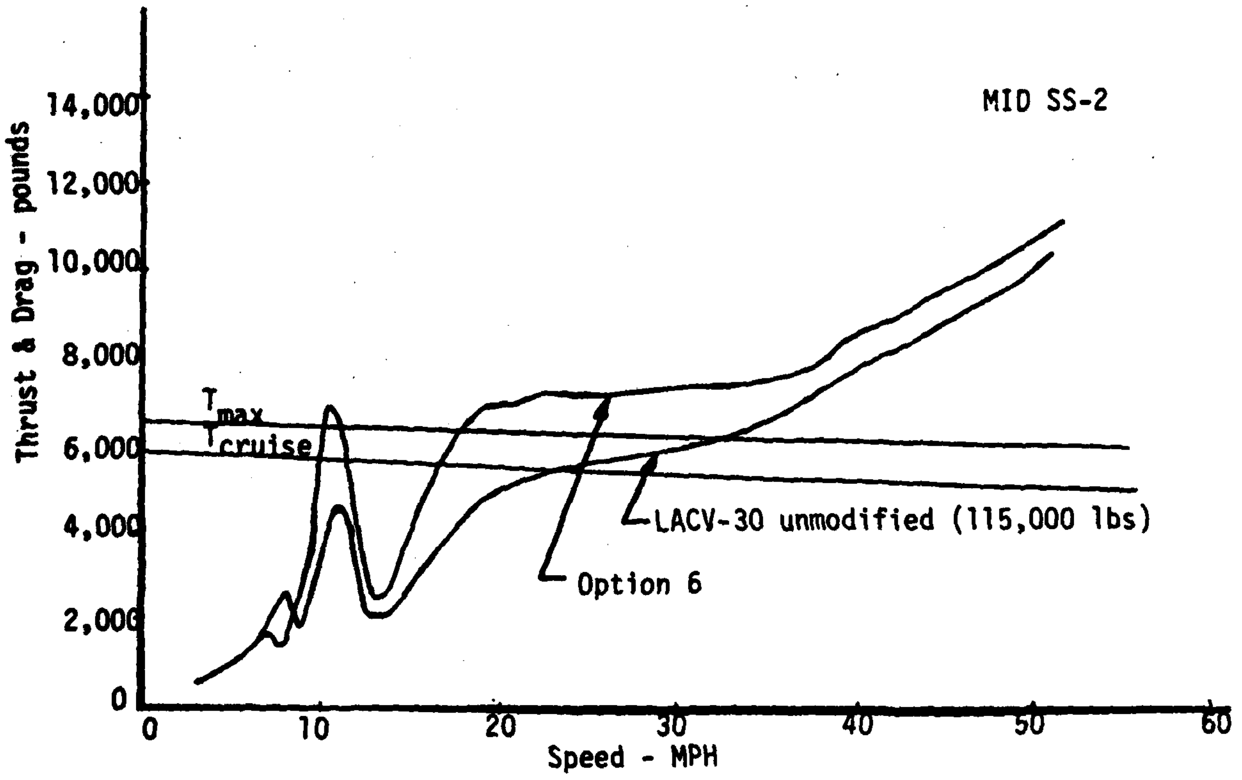


FIGURE 15

LACV-30 IP PERFORMANCE





propeller, this results in an overall increase in thrust of about 700 lbs - a 10% increase. Results, performance-wise are shown in Figure 16. Compared with the LACV-30, Option 7 appears to have regained most of the performance loss due to the additional 20,000 lbs weight.

Once the design parameters and performance of a new lift fan for the LACV-30 were determined and proven effective in the LACV-30, the next step was implementation. A review of commercially available fans was made. Detailed discussions with Buffalo Forge Co., Buffalo ,NY, revealed that fan performance could be easily obtained, but fan construction using commercial techniques would lead to a fan which was 75 to 100% heavier than the BHC fan, i.e., 550-700 lbs versus the present 360 lbs. It would be possible to adapt to the existing LACV-30 pintle and bearings, but the extra weight would require reinforcement of the power module structure. In addition, an increase of as much as 1000 lbs to the aft end of the LACV-30 would lead to c.g. balance problems, and in general, unacceptable operating conditions. A brief cross-check of other companies, and the present program for the development of the LCAC Amphibious Assault Craft, confirmed the weight problem.

As an alternative, the possibility of building the new lift fans at Bell Aerospace Textron, using construction techniques similar to the present BHC fans was examined. It was found possible to make a suitable fan using extruded aluminum airfoil shaped blades. With the proper mix of Bell Aerospace Textron in-house fabrication techniques, and vendor made parts, a suitable fan could be obtained. The recurring and non-recurring costs of a development program were estimated, and are discussed in Appendix C.

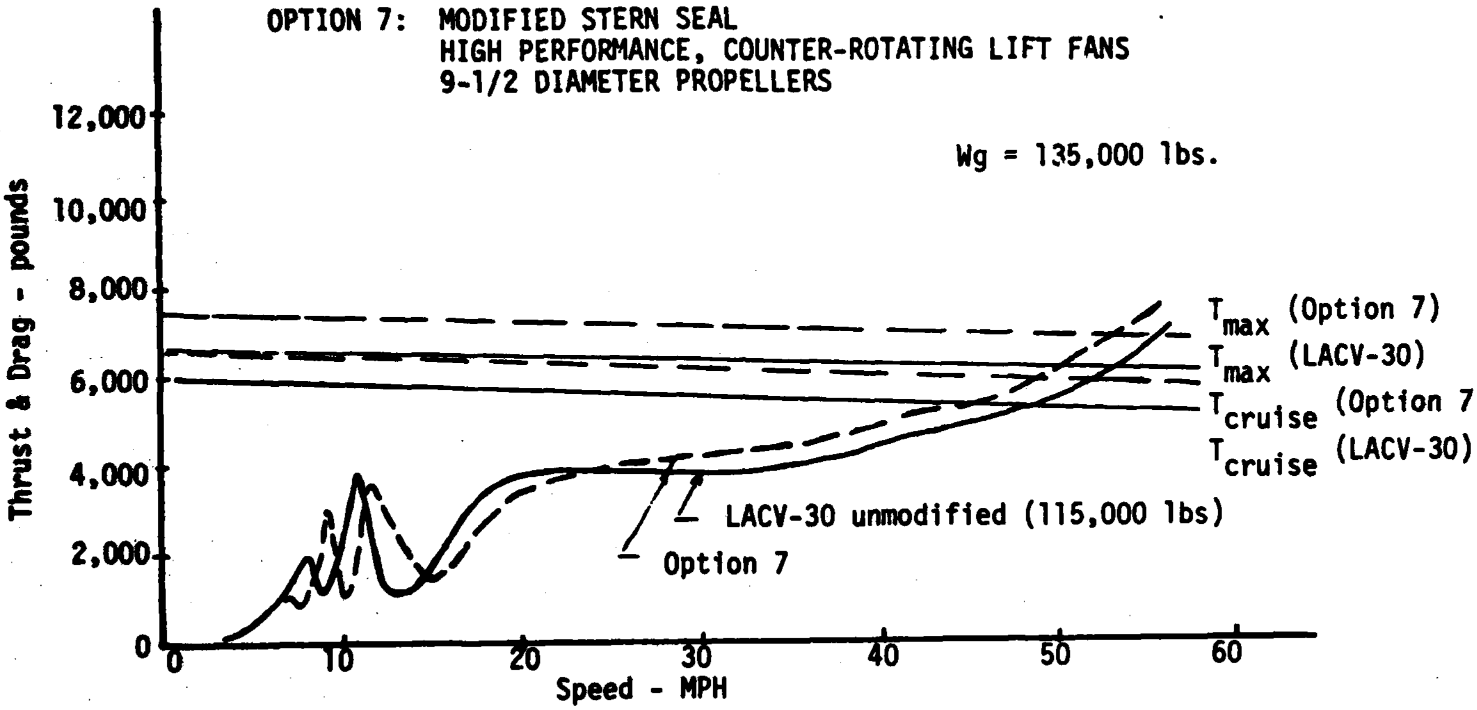
Presently, the LACV-30 is equipped with Hamilton-Standard Model 7005-31 propeller blades mounted on 43D50 hubs. The propellers, originally designed as a 12 ft. diameter system, are cropped to 9 ft. and operated at a maximum of 1980 rpm, giving a maximum tip speed of 933 ft/sec. Noise output at this speed is considered the maximum allowable. Comparisons of the 7005 blade were made with blades of higher and lower activity factors, where it was concluded that the present design represents the best trade-off between forward and reverse thrust. Therefore, a new blade development is not recommended. Rather, 9½ ft. diameter propellers can be obtained simply by cropping to this dimension, rather than 9 ft.

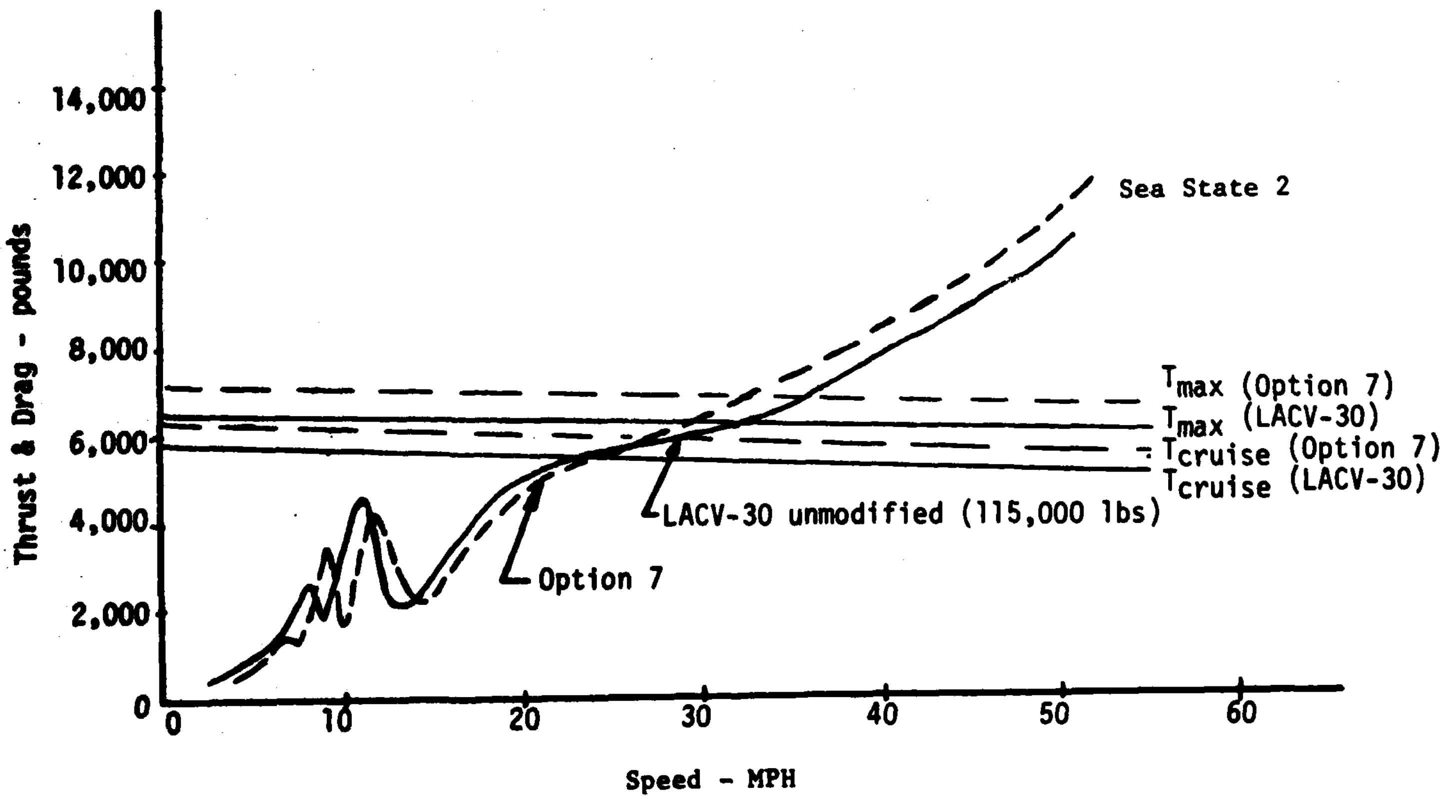
In order to allow for the larger propeller, a 3-inch deepening of the structural section below the propellers will be required. The work will involve a redesign of the structure, replacement of the existing structure by means of splice plates as illustrated in Figure 17, and some reroutings of the fuel line. All retrofit work can be accomplished at the depot level.

Finally, the system will require an overall 5% speed reduction. This appears to be easily accomplished by revising the size and number of teeth on the helical gearsets within the transmission. Only the gears are affected. Changeouts can be made by direct interchange of the old and new gears.

FIGURE 16

LACV-30 IP PERFORMANCE





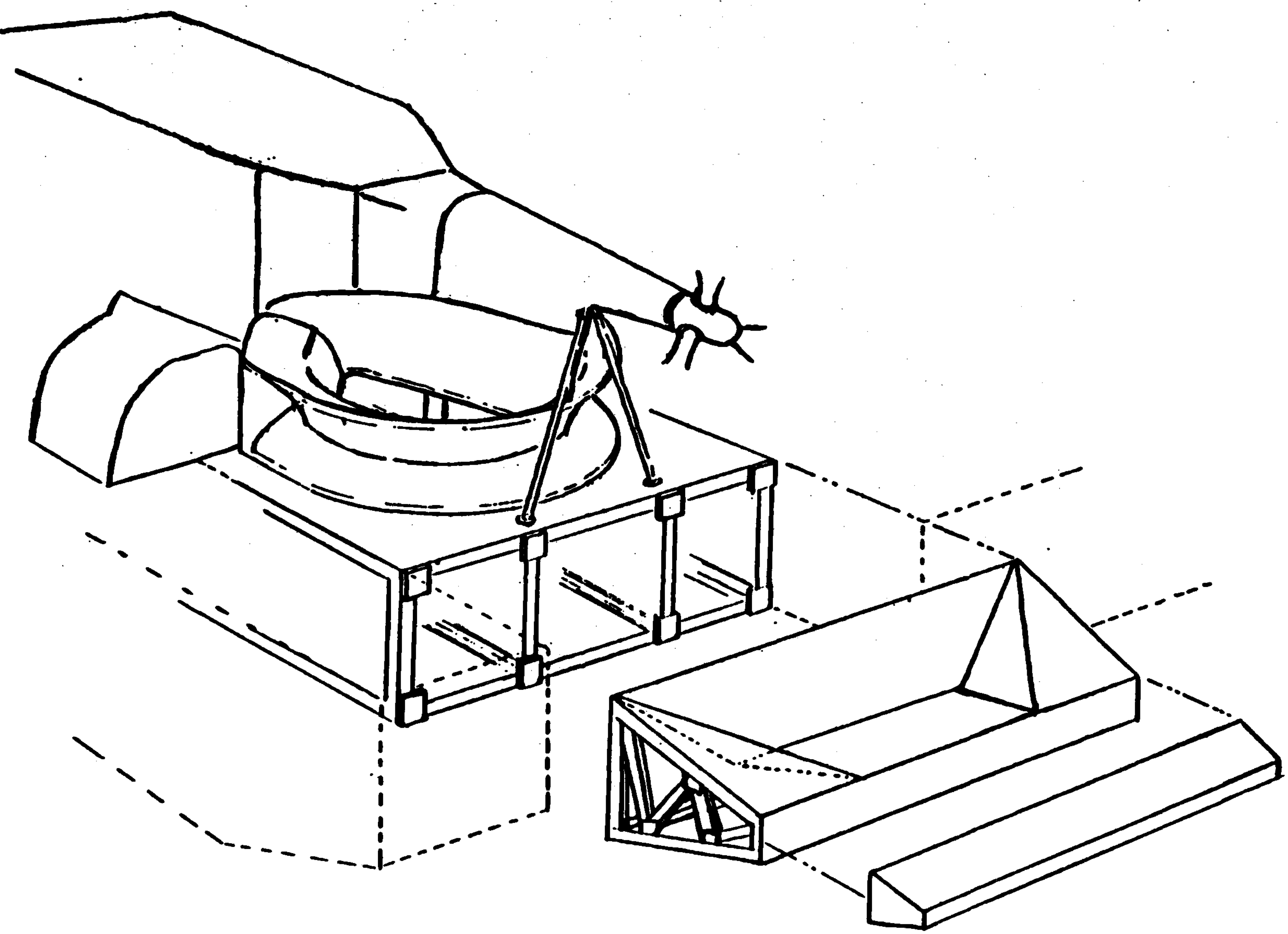


FIGURE 17. AFT STRUCTURAL APRON

Option 8 - Option 7 plus 5½ ft. hull stretch

Option 8 is the same as Option 7, except that an additional hull stretch of 5½ ft. has been added in an attempt to improve performance. As in the previous cases, the hull stretch did increase LACV-30 speeds in the 20 to 25 mile/hr speed range. (See Figure 18). The merits of this additional feature are evaluated along with all the other options in the cost-effectiveness section below.

4. Costs

Budgetary costs for modifying the LACV-30 were estimated for each of the prospective modifications and include non-recurring costs for development, tooling, and prototyping for testing, and recurring costs for accomplishing a retrofit of the 26 LACV-30 craft which will be operating in the 1986+ time frame. Prices are quoted in 1983 dollars and are considered to be within ±25%. Life cycle costs were also estimated on the basis of increments to the annual operating costs, added crew and support training costs, and basing.

Table 3 presents a summary of the prices for the 8 options (2-9) projected for the LACV-30. The column at the far right estimates the differential costs of the future LACV-30 production run, assuming the listed modifications are incorporated into the LACV-30 production line at the factory. It should be noted that, except for the 5½ ft. stretch of the hull section, the incremental costs are insignificant compared to the estimated acquisition cost of the unmodified LACV-30.

A review of additional costs which can be attributed to operating, maintenance and support, etc., making up total life cycle costs showed only small changes to the costs of incorporating the options into the retrofit.

To determine LACV-30 productivity, a computer program was devised ("PROD") depicting each of the steps within the lighterage cycle. Container weight distributions were obtained from reference 9 and then modified to reflect peacetime usage, resupply and a mixture of predominantly heavy containers, such as ammunition and fuel. A loading strategy at the container ship was developed and data from the 1977 J-LOTS exercises at Fort Story, VA, were used to define the individual cycle segment times involved in a standard lighterage (LOTS) operation. Details of the program and input data are described in Appendix D.

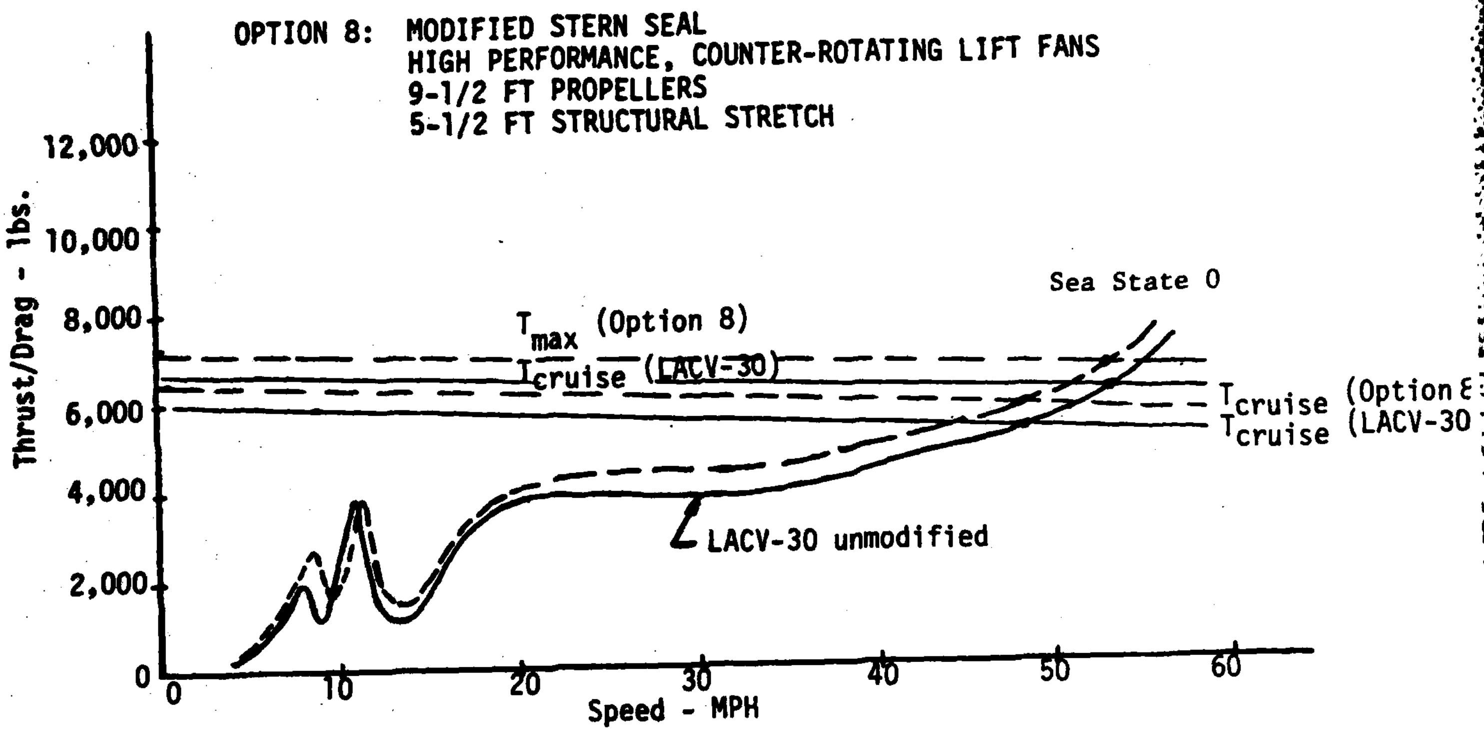
Results of some typical cases for the 9 options are given in Figure 19.

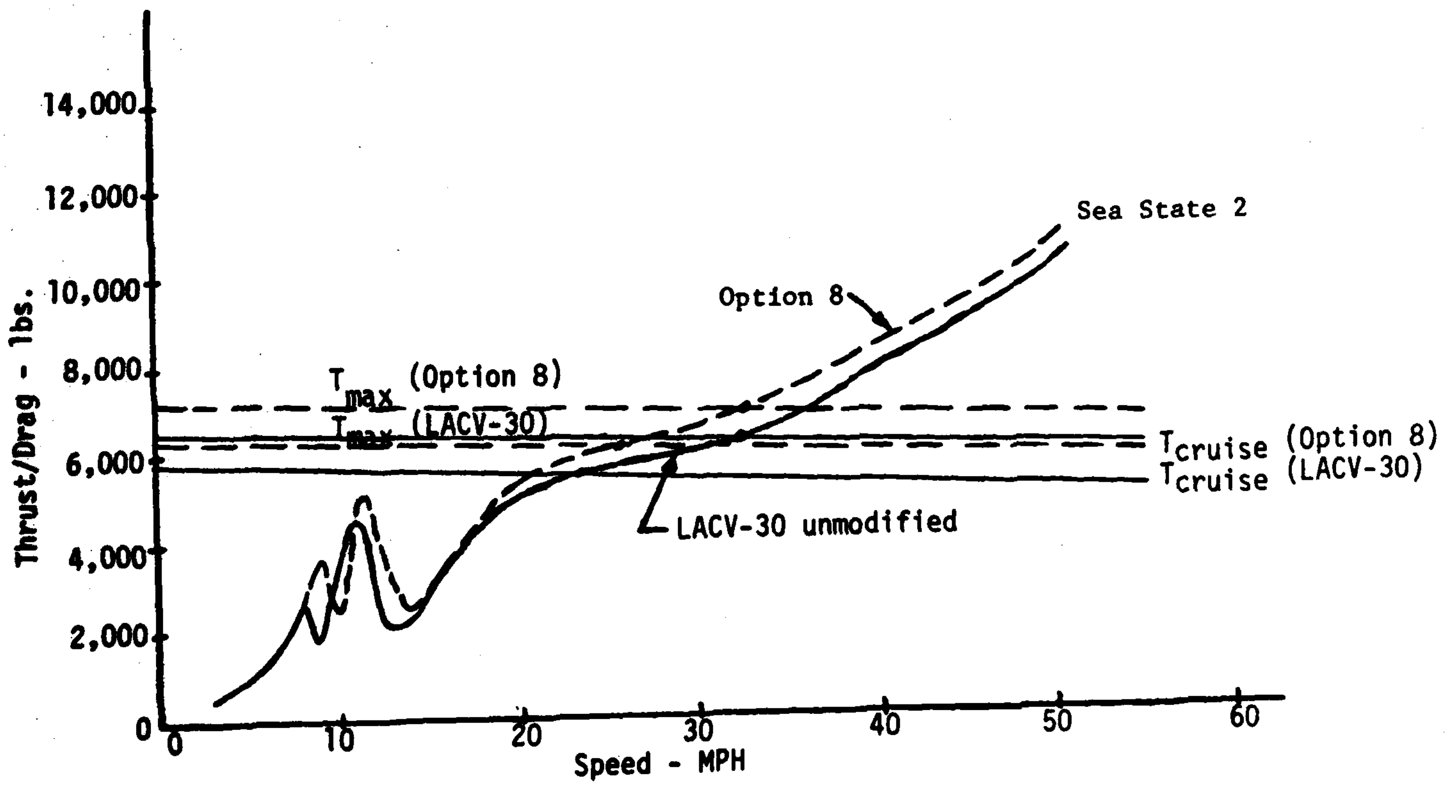
5. Discussion

An examination of the results of the study show clearly that the single most cost-effective option is the new wrap-around stern seal with raised keel. This will allow an immediate payload increase of 4 to 5 tons without a major revision or modification to any of the LACV-30's hardware. As shown in Appendix D and summarized above, the development costs of the new skirt system are estimated to be about $650,000. This should be sufficient

FIGURE 18

LACV-30 PERFORMANCE





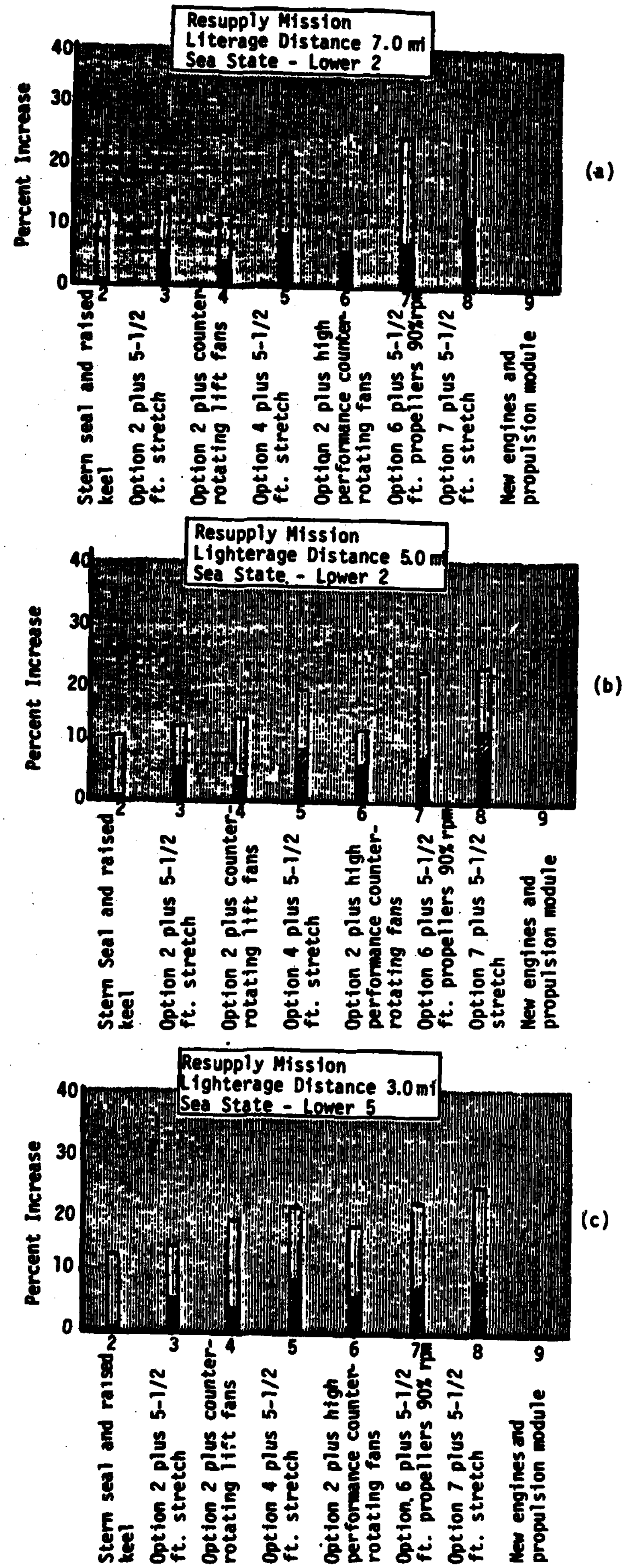


FIGURE 19. LACV-30 IP COST & PRODUCTIVITY INCREASES

to develop the new design, fabricate a test article and proof-test it on a Voyageur or prototype LACV-30 craft. Unit production costs are estimated at $55,000 which apply as retrofit costs. If incorporated into the LACV-30 skirt design and manufactured for new LACV-30's, or as spares, the differential cost is about $20,000. Thus, for a nominal lighterage condition of 3.0 miles offshore, and operating in a typical lower SS-2 condition, productivity of the LACV-30 will increase 11%. The additional cost of the skirt is less than 1%, giving a productivity/cost ratio of 12 to 1. None of the other options came close to this leverage, although others appear desirable.

The new skirt/keel system will be easily installed on the LACV-30 to existing attachment points. Once available, retrofits to the existing LACV-30's can be made as the existing skirts wear out. It is estimated that development and prototype testing can be accomplished in about a year's time. Therefore, a changeout to the new skirt system can be incorporated into the production of the second company buy at about its mid-point.

The second most desirable option of the study is Option 7, which incorporates a new high performance lift fan, together with 9½ ft. propellers for added thrust. In this case, the modified LACV-30 will be able to carry 10 additional tons of payload with virtually no degradation in performance. Productivity under these conditions will increase about 22% with a corresponding increase in cost of 7½%. This results in a productivity/cost ratio of 3 to 1 for the nominal resupply mission. It is interesting to note that this option will maintain most of its advantage in productivity, both in heavier sea-states and at the longer lighterage distances. Therefore, the improvement should be relatively independent of the theater operational conditions. As expected, the productivity/cost ratio falls off when the container weights get less, i.e., typically 1.75 for peacetime cargo. Conversely, when heavier containers are to be taken ashore, such as ammunition and fuel containers, Option 7 will have a 3.75 to 1 productivity to cost ratio.

Several features within Option 7 appear to drive the costs up and extend development time. These include the design, development and testing of both the new fan and fan reversal drive. These two items comprise approximately 75% of the total development costs of about $3.5M, and 67% of the total retrofit costs of $517,000. Even so, when these costs are compared to the LACV-30's acquisition and life cycle costs, they represent 7.7 and 6.0% of the total, respectively. When compared to a 33% increase in payload, and a 22% increase in productivity, Option 7 appears desirable. Development time through prototype testing can be accomplished in an estimated 24 months; therefore, if Option 7 is to be incorporated into the LACV-30, the earliest retrofitting that can occur will be mid to late 1985.

The third option which appears practical is Option 9, which is essentially the LACV-45. Much less time was spent examining this option, since this represented a major change to the LACV-30 configuration, and substantial costs to implement. Even so, productivity increased to the extent that a productivity-to-cost ratio of around 2 was obtained. In addition, productivity was limited, perhaps unfavorably, since the loading strategy used did not allow the occasional carrying of three containers, which the craft is quite capable of doing. This option would require additional rigging to accept the third container and the development of loading procedures which can account quickly and easily for recognizing container weights in advance and for loading the craft while respecting its c.g. operating limits.

The concept of the LACV-45 has merits, however, depending upon future Army plans and requirements. The craft will be far more capable than the LACV-30, not only in payload, but also in speed and sea state. The larger capability will allow for a wider variety of payloads, including much of the heavier beach equipment needed for beach set-up and operations, light and medium weight fighting vehicles, and cargo of various types. The LACV-45 also will provide a positive step in growth to more capable Army lighters. Falling short of LAMP-H requirements, the LACV-45 will consist of new propulsion modules with a lift and propulsive capability for expanded designs. Combined with the modular concept of the LACV-30, a variety of LACV's of various sizes and capabilities are possible without major new vehicle development programs. These concepts require further study, however, before new concepts and their performance, costs and development schedules can be defined.

6. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations resulting from the study effort are offered:

(a) New Wrap-around Skirt and Raised Keel Design

This design option offers an almost immediate improvement in LACV-30 payload carrying capability of 4-5 tons. Its development and installation on the LACV-30 can be accomplished for a modest cost, and in about a year's time. Its design concept has been tested and put into practice on the JEFF-B air cushion vehicle. Its productivity to cost improvement ratio in the U. S. Army's resupply mission of 12 to 1 justifies initiating a development program without further delay.

(b) New High-Performance Lift Fan, and 9½ Ft. Diameter Propeller

This design option offers a 10-ton improvement in the LACV-30's payload without significantly affecting the craft's overwater/overland performance. LACV-30 payload will increase 33% and its productivity in the resupply mission, 22%. Cost of a development program is estimated at about $3.5M, which will extend over a 2-year period.

The performance gains in the lift and propulsion systems of Option 7 are quite significant, but it should be noted that no refinement or optimization was done on either the fan design or the air-handling in the plenum.

The performance increment due to the redesigned fans used in this study was judged insufficient to compensate for the volute inefficiencies involved in not using counter-rotating fans. It is believed that an additional 20% performance and/or efficiency increment can be obtained with further development effort in the area of fan and plenum design optimization. It is recommended that additional study effort be directed towards optimizing the performance and efficiency of the high performance fan and the plenum/volute configuration.

The extra fan performance increments possible from optimization brings out the possibility of not using counter-rotating fans. Some of the extra fan performance would be lost to plenum inefficiencies, but the payoff is that now only one fan and gearbox design are required as in the current LACV-30, thus eliminating the large costs for reversed gearbox development and the extra tooling for the reversed fan.

(c) New Engines/Transmission/Lift Fan/Structure (LACV-45)

The LACV-45 option offers a 20-ton improvement in payload, and substantial gains in performance and productivity. The costs of development of a LACV-45 are high, since new power modules will be required, together with new engines, transmissions, and lift fans. The productivity of a craft of this design increases substantially, offsetting the development and retrofitting costs by a factor of 2 to 1.

The LACV-45, if developed, would be a craft far more capable than the LACV-30, not only in speed and payload capacity, but also in its ability to handle a wide variety of payloads, including beach equipment, light and medium weight fighting vehicles and oversized cargo of various types.

The concept of a LACV-45 requires further study, before its performance, costs and development schedules can be fully defined.

7. REFERENCES

1) Bell Aerospace Textron 1974 IR&D Report, "Stretched Voyageur Model Testing," Report 7467-927011, 31 December 1974.

2) Bell Aerospace Textron 1975 IR&D Report, "Stretched Voyageur Model Testing," Report 7467-927011, 31 December 1975.

3) Bell Aerospace Textron Report #7467-927010, F. D. Bond and R. J. Szpakowski, "ACV Lift System Development", December 8, 1975.

4) Bell Aerospace Textron 1976 IR&D Report, "Static Tests of the Stretched Voyageur Model with Fan Plenum Feed Holes for Air Management System Supply," Report 7467-927021, 31 December 1976.

5) Bell Aerospace Textron IR&D Report 7484-950001, R. F. Speth, "Analysis, Design, and Scale Model Tests of an Improved Deep Seal for Air Cushion Vehicles", May 5, 1976.

6) Bell Aerospace Textron Report #7467-950001, "U.S. Army Logistic Voyageur Hardening Analysis", November 1973.

7) BAT Report #D7467-953037, Sept. 12, 1980, "Proposal for Upgrading the LACV-30 to 45 Tons Payload".

8) BAG Internal Memorandum, "Structural Studies - Next Generation Army Lighter" W. Meholick, et al, Aug. 27, 1980.

9) Bell Aerospace Textron Report #7467-927023, "Comparison of the Productivity and Cost of the LACV-30 with Other Vehicles in the LOTS Mission", J. Emerson and R. Nelson, January 1977.

APPENDIX A

PREVIOUS STUDIES AND TESTS

A considerable amount of analytical and design studies preceded the development and fielding of the LACV-30. References A1 through A4 summarize several Bell and Army-sponsored studies which apply to the present effort. Since 1980, additional IR&D studies have been accomplished, which are summarized in References A5 and A6. This Appendix reviews material and results from these earlier studies which have been used as inputs to the LACV-30IP study described in this report.

A.1 Bell Aerospace Textron's Internal Research & Development Studies

The major contributing source for the LACV-30IP studies was derived from References A5 and A6, which summarize 1981-83 results of a continuing IR&D study at Bell Aerospace Textron, directed at the design of high technology ACV's. The long-range objective of this project is to develop the technology necessary to increase the payload of the LACV-30 type vehicle, and thereby increase its productivity in the LOTS role, and expand its cargo versatility in the RDJTF role. This must be done without compromising the craft's deployability as deck cargo in the cargo/container ships deploying to the theater of operation. Also, the craft must retain satisfactory performance characteristics, such as speed, maneuverability, gradient capability and sea worthiness.

The overall performance of the vehicle is related to weight and lift system characteristics, drag and propulsion system characteristics, and general seaworthiness. In increasing payload therefore, we seek to improve lift system efficiency and to increase weight in general, without impairing general performance. For the continuing IR&D studies, therefore, we set as goals to:

(a) Increase current 25-30 ton payload to a minimum of 35 tons, and strive for 45 tons.

(b) Reduce overwater drag by 10-20%.

(c) Reduce structural weight by 5-10% or at least maintain the current unladen weight with improvements above.

In the period 1980-82, lift and power requirements analyses for increased weight LACV's were conducted, vehicle test models were upgraded to LACV-30 status, fan and lift system analysis capabilities were improved, and preliminary lift system modifications were installed and tested at model scale.

In the 1983 period, the prime objective was to complete analyses and model tests aimed at isolating the most effective changes in the overall lift system and structural practices that promise to achieve the overall project targets.

Specific items included in our 1983 work were:

(a) Improved lift fan analyses and model testing
(b) Improved seal system model testing (1/7.5 model)
(c) Structural joint strength tests (holdover from 1982)

From the performance point of view, other aspects which were pursued were:

(d) Keel drag
(e) Propeller diameter
(f) Length to beam ratio

While the payload could be increased by the simple application of more power, this is a very expensive approach. The development of interacting subsystems, the efficiencies of which ultimately determine net payload and performance, is the cost-effective alternative.

The overall approach leaned heavily on scale model testing and full scale verification with progressive improvement of analytical methods and applications gradually replacing dependence on expensive testing. Correlation of model tests and analysis with full-scale tests also lead to increasing confidence in extrapolation of previous experience to more advanced systems.

Our long-term project approach may therefore be summarized as:

(a) Development, verification and application of computational methods, particularly for fans and air distributions;

(b) Continue refinement and use of test models of seal systems, air distribution systems and fans;

(c) Continued testing of complete vehicle models in hover and forward ("table", tow and powered) modes;

(d) Full-scale test verifications;

(e) Continued system trade studies to ensure that effort is concentrated where the reward is greatest.

Computer programs were developed in 1982 for fan performance and air management. These addressed in particular:

(a) Fan installation and volute efficiencies;
(b) Fan design characteristics;
(c) Air management losses within the plenum.

For 1983, the approach to intended tasks has been largely unchanged.

(a) The computer programs developed in 1982 were evaluated and applied to fan design installation and volute efficiencies.

(b) Model tests continued to dominate seal system approaches, in particular, reduction of stern cone leakage and keel drag.

(c) Structural design developments carried over from 1982 will be largely analytical in scope with component test verification.

A.1.1 1/7.5 Scale LACV-30 Model

Figure A-1 shows the 1/7.5 scale model of the LACV-30 mounted in the cushion flow rig in the Bell ACV Laboratory. This model was originally fabricated and used as a test article for Voyageur. When Voyageur was stretched and upgraded to make the LACV-30, the model was modified to conform as well. It has served as a scale model for the hardening studies reported in Reference 6 , and the IR&D studies of References 1-5.

The model contains pressure taps located as shown in Figure A-2 to measure static air pressure in all major components of the air distribution system. As tests proceeded, measurements were made of the model's deck height above ground, the air temperature (dry, wet bulb), air barometric pressure and finger-bag geometry. Watt meters, connected to the starboard lift fan motor, were used to measure input power. Calibration tests on the motors were conducted, so that output power to the model lift fans could be determined as a function of input power.

A.2 Model Test Procedure

Early in the program, it was determined that because of the large number of potential changes in the lift system to be evaluated, it was necessary to derive a method to gauge the efficiency of the LACV-30 lift system quickly and reliably, without having to resort to lengthy and elaborate pressure ratio/measurements. Past experience had shown that the heave-height of the vehicle was directly proportional to bag pressure and vehicle gross weight. In its design condition, of 115,000 lbs. gross weight, the bag to cushion pressure ratio was approximately 1.46, with the bag and finger configuration looking much like that shown in the sketch shown in (a) of Figure A.3. As the weight of the craft was increased (due to increasing payload), the bag-to-cushion pressure becomes less, as shown in the (b) portion of Figure A.3. As a result, the bag was found to deform as shown, letting the craft down somewhat, with a resulting change in heave height. By increasing bag pressure, (due to a better fan, more efficient plenum or air distribution system, or whatever) the $P_{Bag}/P_{Cushion}$ ratio could be raised, and the Δh loss in heave height would be regained. Figure A-4 illustrates the strong, almost linear correlation of heave-height and bag-to-cushion pressure ratio. Thus, a unique relationship was established. Gross weight of the LACV-30 determines cushion pressure, the fan/plenum air distribution system determines bag pressure, and the ratio $P_{Bag}/P_{Cushion}$, determines heave height. Any change (improvement) in the lift system which increases bag pressure, automatically increases heave height. A corresponding increase in payload which returns the craft to its

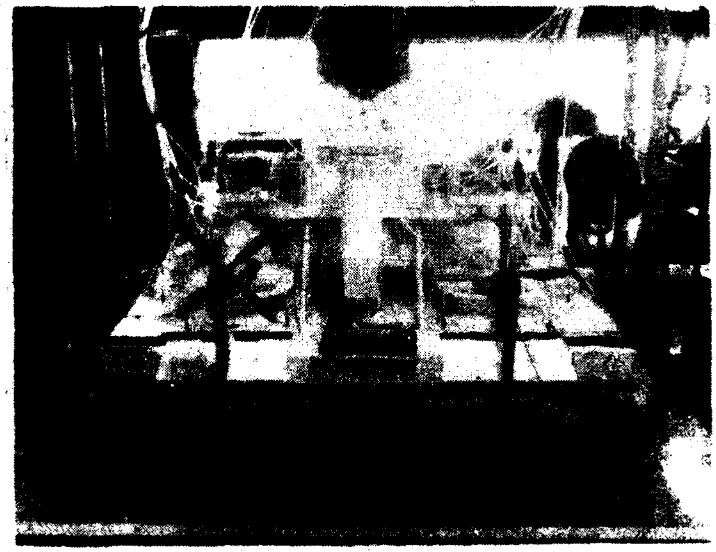


FIGURE A-1 1/7.5 SCALE MODEL OF LACV-30 IN STATIC TEST RIG

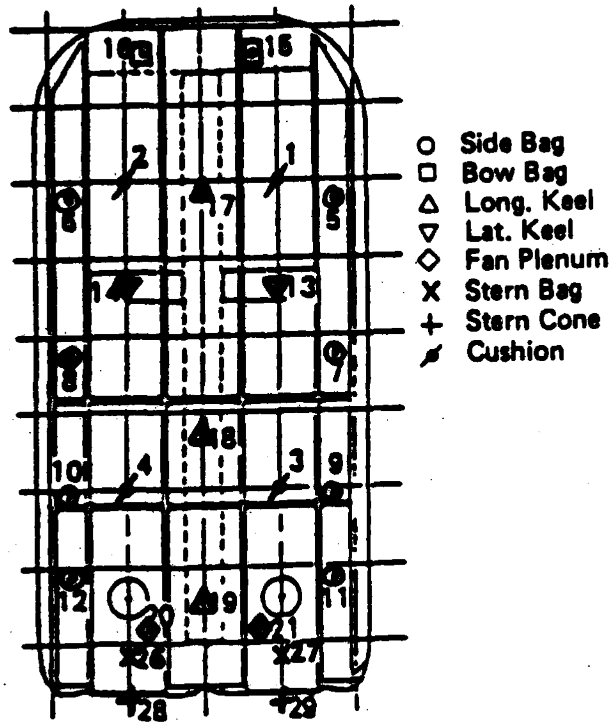


Figure A-2

Pressure Tap Locations

in the 1/7.5 Scale

LACV-30 Model.

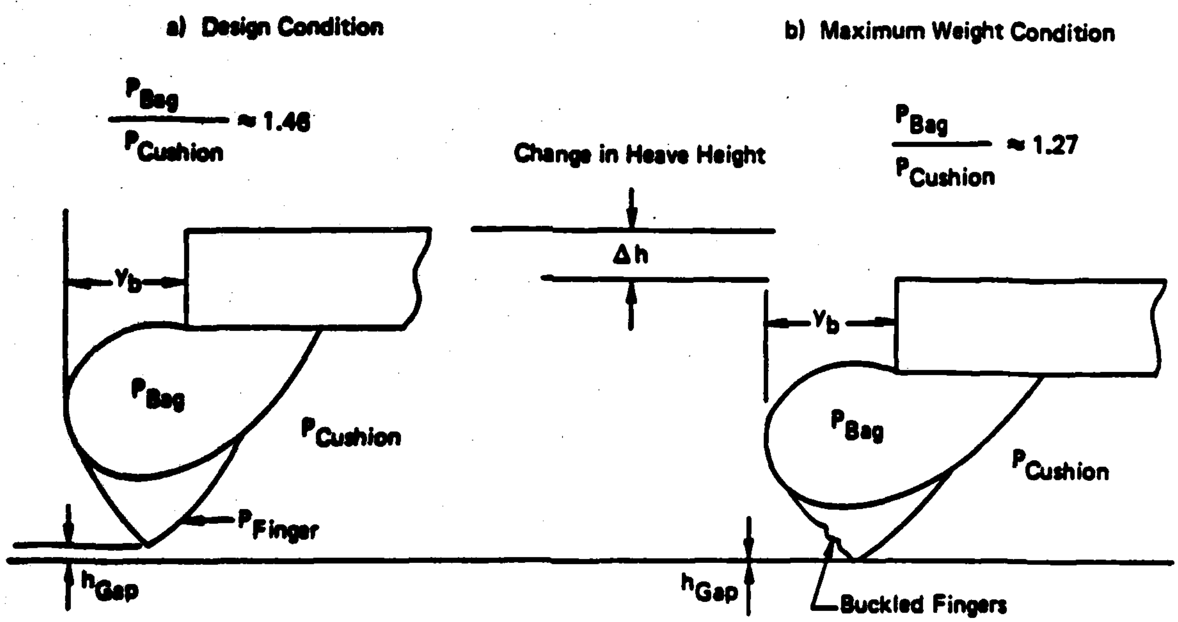


Figure A-3. Effect of $P_{Bag}/P_{cushion}$ Reduction on h_{Gap} & Finger Buckling

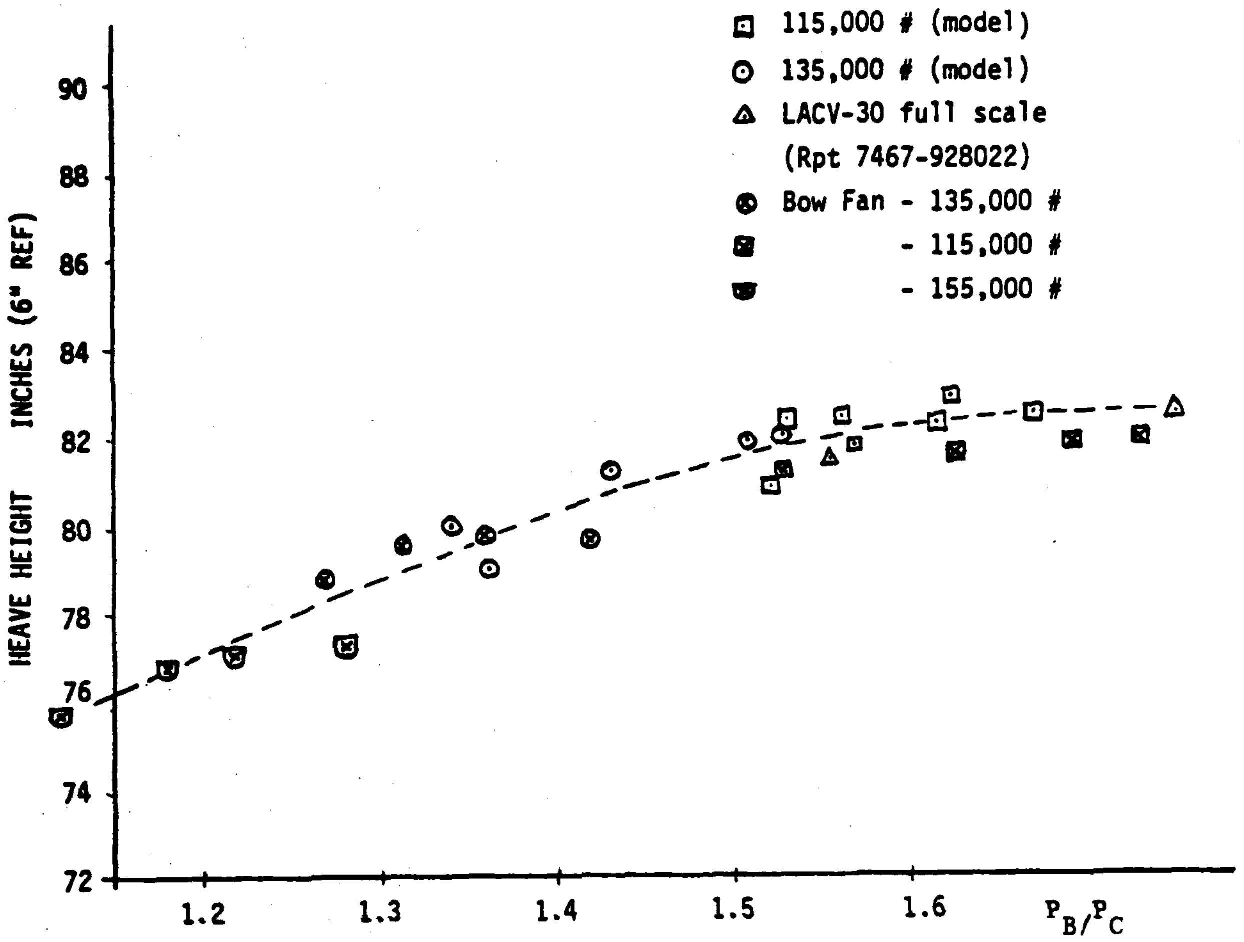


FIGURE 4, CORRELATION OF HEAVE HEIGHT AND PRESSURE RATIO

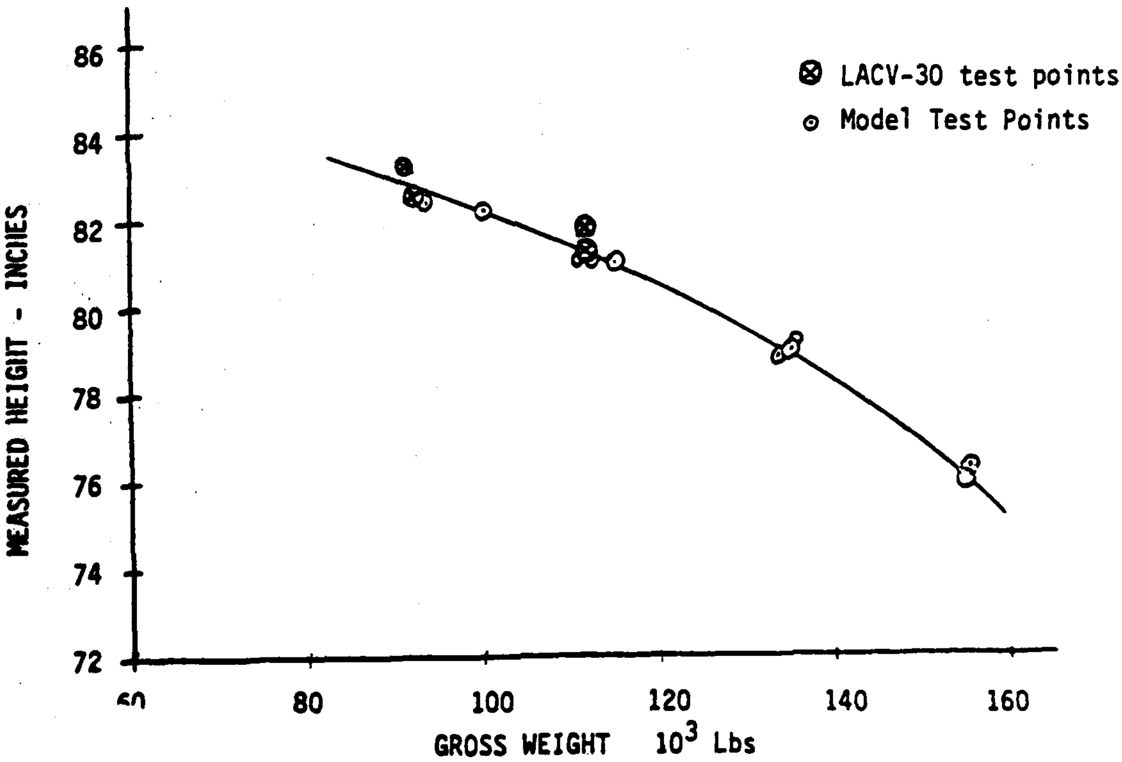


FIGURE A.5 CORRELATION OF HEAVE HEIGHTS AND GROSS WEIGHT original heave height (bag/cushion pressure) can be interpreted as that extra payload which can be supported by the LACV-30, because of the said improvements in the lift system. Correlation of model heave height with LACV-30 full-scale results is shown in Figure A-5.

Table A.1 presents a list of the modifications examined in the lift system, which were originally believed to have potential in increasing payload. As these options were examined, records were made of the power inputs, so that a running assessment of lift power versus payload increase was obtained. Some so-called improvements in the lift system were found to take additional power, thus offsetting an advantage brought about by increased bag pressure. Details of the results of the testing are given in the following sections.

A.3 Test Results

A.3.1 Stern Cone-Finger Exit Area

Previous static testing on the model had indicated a marked improvement in the LACV-30 list system was obtained, when the open cones of the stern seal were closed off. Calculations showed that roughly 30% of the power used to drive the lift fans was being wasted by allowing the air distributed from the plenum to the stern bag to the cones and out the cones to ambient (see Figure A.6). Tests and operations of closed cone designs on other air cushion craft, namely, the JEFF-B showed that considerable savings in lift power could be achieved over the open cone designs of the SRN-5/6's, Voyageur and LACV-30 craft.

In response to the above, deck height and horsepower measurements were made, of the LACV-30 model. Results are shown in Figure A-7. As can be seen, for a constant deck height of 81 inches, weight (payload) increase of 10,000 lbs. can be achieved, and a power savings of approximately 2%. Measured bag pressure for the unmodified and closed stern cones followed heave height for a gross weight of 135,000 lbs. in approximately the same ratio.

A.3.2 Cross Ducting

Two types of cross-ducting were considered; (a) keel to bow feed and (b) stern bags. These two cases are discussed below:

A.3.2.1 Keel to Bow Feed

Keel-bow bag interconnection was expected to reduce plenum outflow losses and to reduce overall losses incurred in pressurizing the bow bag. Although test results of various modifications showed significantly lower keel pressure (20 to 25%) no other significant system effects were observed (see Figure A-8). However, the softer keel bag might be beneficial because of reduced drag; this is discussed in Section C.2 of Appendix C.

TABLE A.1

OPTIONS EXAMINED

LIFT SYSTEM

ITEM	RATIONALE
• CLOSE STERN AND SIDE BAG CONES	CONES EXIT AIR TO AMBIENT
• CONNECT LONGITUDINAL KEEL TO BOW BAG	KEEL PRESENTLY DEAD-ENDED INCREASE BOW BAG PRESSURE MULTIPLE FLOW PATHS REDUCE LOSSES
• CHANGE ROTATION DIRECTION OF PORT LIFT FAN AND ADJUST VOLUTES	INCREASE FLOW EFFICIENCY
• OPEN STERN BAGS TO CUSHION	STERN BAGS DEAD-ENDED WITH CLOSED CONES
• OPEN KEEL BAG TO CUSHION	KEEL OVERPRESSURIZED
• REDESIGN LACV-30 LIFT FAN(S)	INCREASE FAN/LIFT SYSTEM EFFICIENCY
• STRETCH LACV-30 HULL	INCREASE CUSHION AREA

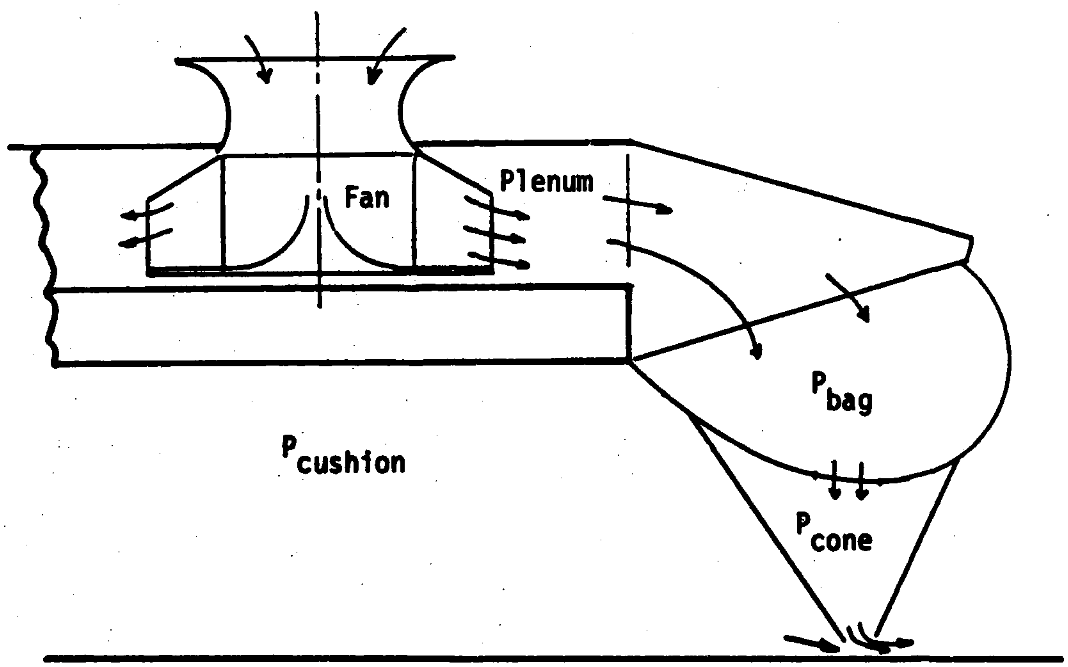
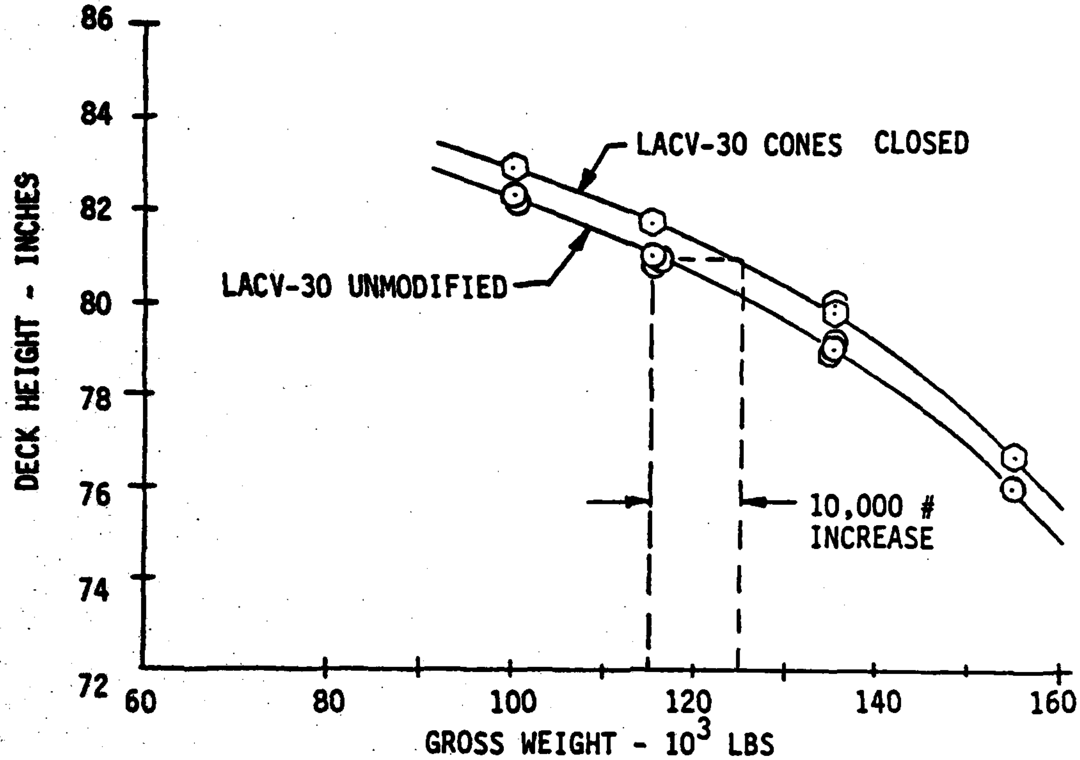


Figure A.6 Air Flow Route through the LACV-30 Stern Seal

MODEL TEST DATA - LACV-30 OPTION 2



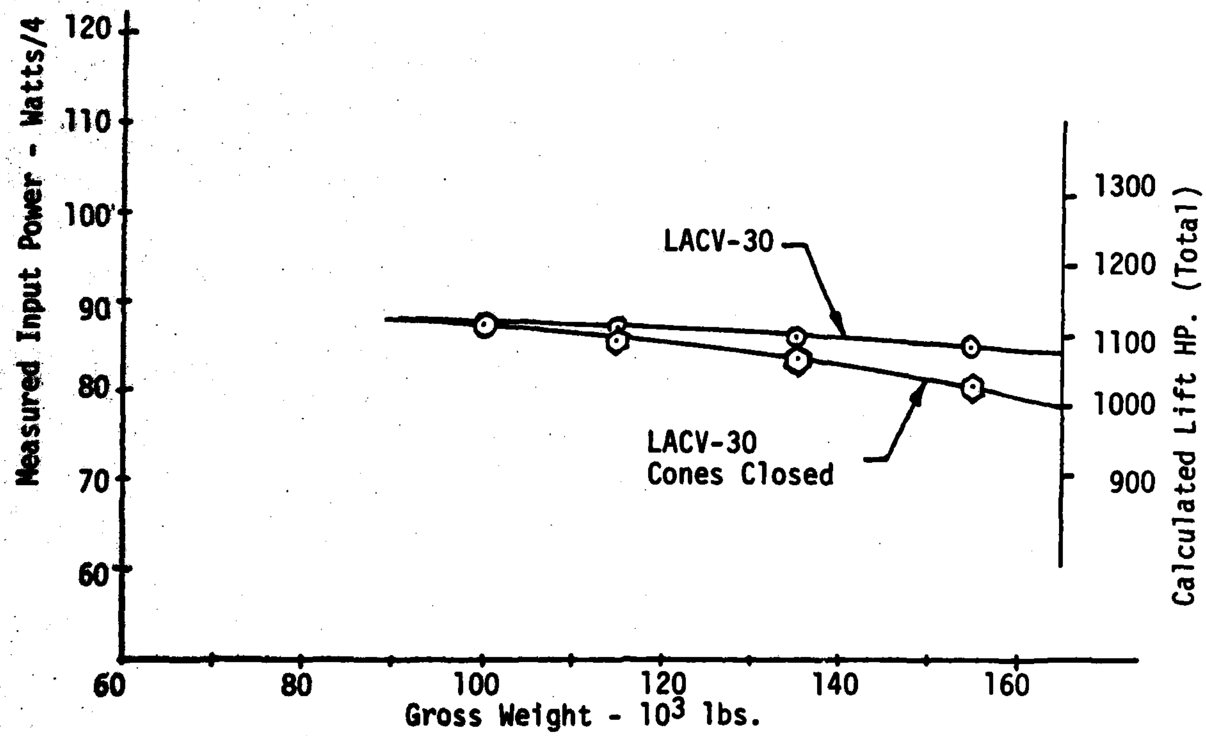
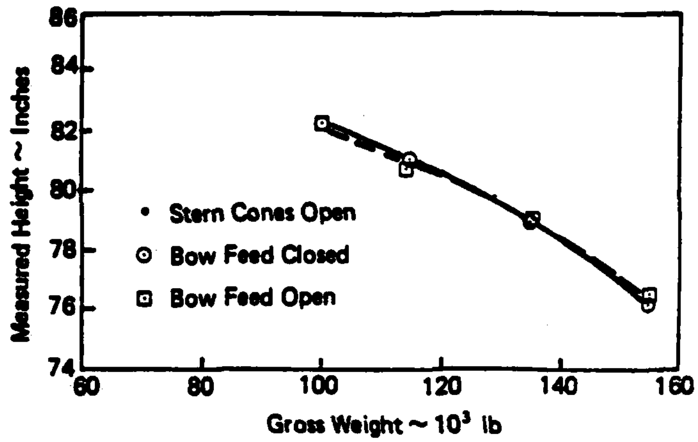


Figure A.7 Lift System Improvement with Stern Cones Closed

Figure A.8 Model Test Data
Bow Feed Open versus Closed



No significant improvements were realized by connecting stern bag to cushion with feed holes.

A.3.2.2 Stern Bags

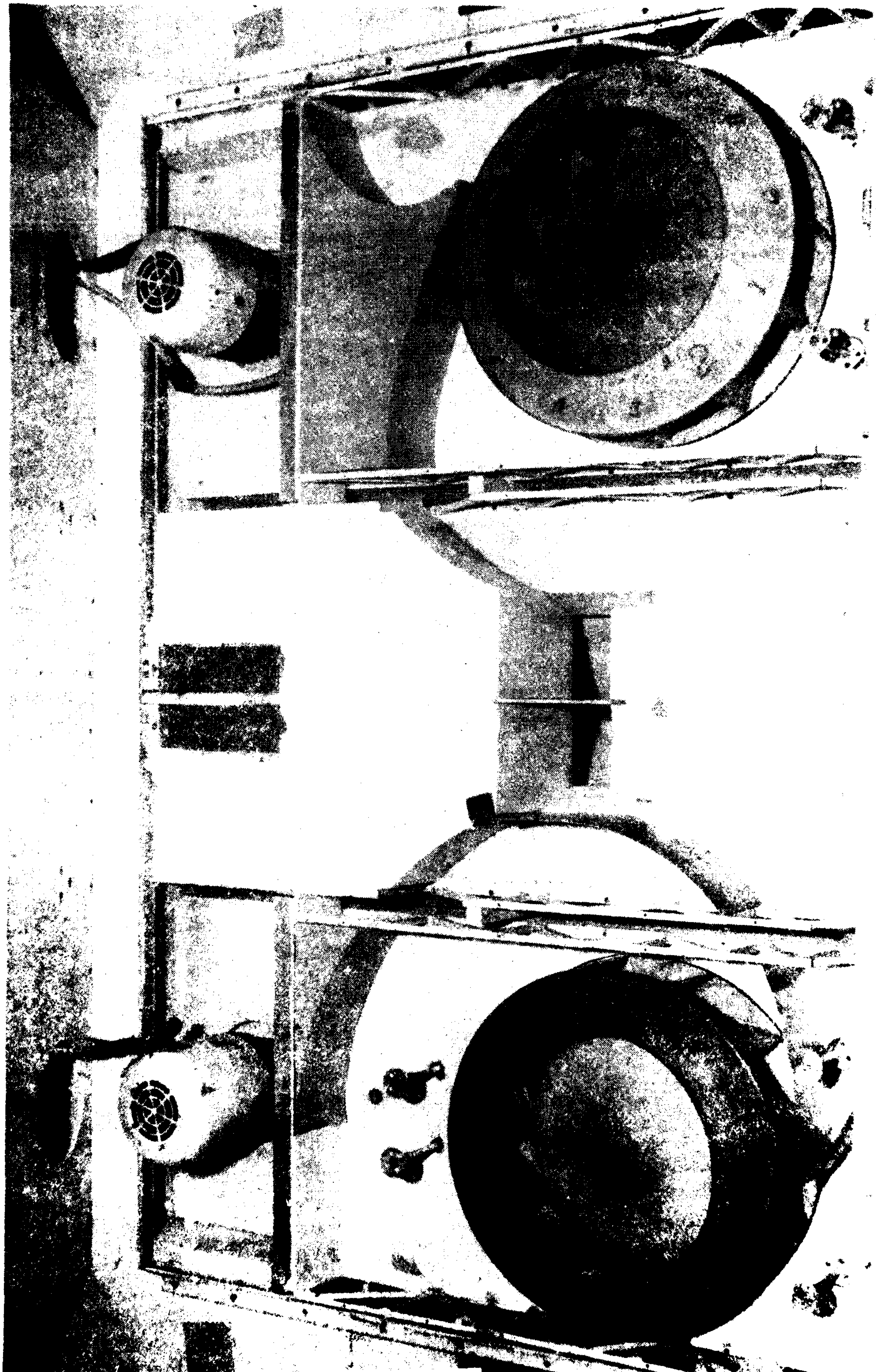
Because of the lack of symmetry in the plenum due to the lift fans both operating in the same direction, with corresponding volutes tailored to account for the exit flow direction of the fan air (see Figure A.9) a large pressure difference results in both the stern bags, and side bags opposite the fans. Pressures differ as much as 25%, which causes imbalances in bag-cushion pressure ratios and subsequent reductions in lift efficiency. Dissemination of the air around the periphery of the LACV-30 may also be affected.

Tests were originally scheduled connecting the rear bags together and connecting the combination to the side bags. Analytical studies indicated that this would result in a better balance of bag pressures around the periphery of the LACV-30, however, the efficiency of the starboard fan in the plenum would not be significantly increased. Therefore, this option was not pursued during the current test phase.

A.3.3 Air-Feed Routes

A.3.3.1 Stern-Bag Cushion

Pressures recorded with the stern cones sealed closed showed the stern bags to be as high a pressure as the plenum. This is to be expected, since the air flow routes through the cones had been blocked. To relieve the back pressure, and perhaps increase the flows, and therefore, efficiencies in air distribution, three 0.8" holes were opened in the forward side of each stern bag. Subsequent testing showed a 5%



reduction in the stern bag pressures, but no change in either heave height or side bag pressures.

A.3.3.2 Keel Bag to Cushion

The addition of six 0.8 inch holes in the forward longitudinal keel bag was made, in an attempt to study the reduction in keel pressure and lift system efficiency. Longitudinal keel pressures were reduced 1 psf (≈10-12%) but no change was detectable in bag pressures or heave height. The dumping of the keel air into the cushion did not affect lift system efficiency.

A.3.4 Counter-Rotating Fans

The discrepancies in pressures in the stern and side bags noted in 3.2.2.2. above suggested that a reversing of the direction of the starboard model lift fan would not only balance the starboard and port pressures, but also the overall efficiency of the total lift system would be increased. Several combinations of fan and volute configurations were tested.

A.3.4.1 Reversed Drive

Although the discrepancies in lift fan performance had been noted in studies and model and full-scale test measurements earlier (Reference A.1), an actual test with counter-rotating fans had never been attempted. Therefore, the LACV-30 model was modified. The plenum area of the starboard fan was configured as a mirror-image of the port side. The counter-clockwise lift fan was replaced with an identical, but reversed-handed fan, designed to operate clockwise. The configuration of the fan/plenum area is shown below.

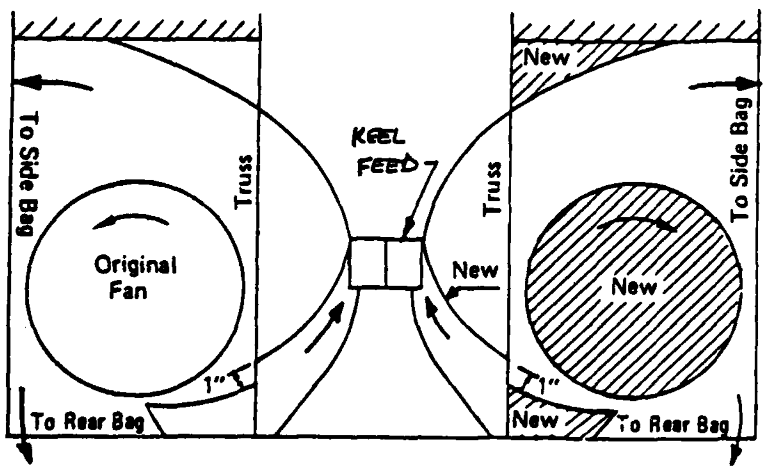


Figure A.10
Volutes for Counter Rotating Fan Test
in the 1/7.5 Scale Model

Static flow tests were conducted for a LACV-30 full-scale gross weights from 80,000 to 155,000 lbs. Results are shown in Figure A.11 below.

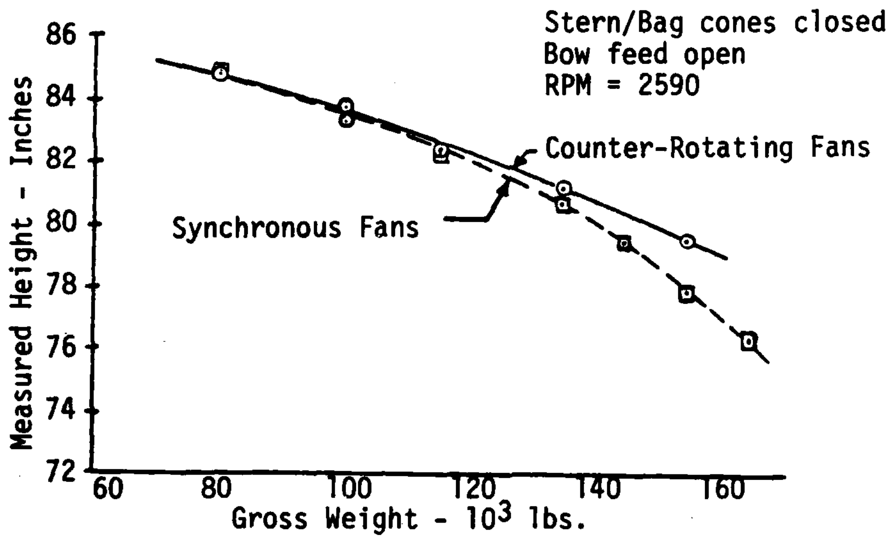


Figure A.11

FAN ROTATION EFFECT ON LIFT SYSTEM

A.3.4.2 Volute Offsets

After examining the results of several test series, it was concluded that the performance of the counter-rotating fans was not as good as twice the performance of the original port fan. Adjustments in the volutes were attempted on a "cut-and-try" basis. The best of the changes resulted in moving the two inside volutes forward an inch (7.5 inches full scale) such that they were off-set a total of two inches (15" full scale) from the stern volutes, rather than the one inch as shown in Figure A.10.

Results with the two-inch offsets were considerably improved, as illustrated in Figure A.12. As can be seen, the increase in lift made possible by this configuration can add an additional 10,000 lbs. to the LACV-30 gross weight. A comparison with the original LACV-30, with open stern cones shows that the two effects are additive, thus producing a total increase in vehicle payload of 20,000 lbs.

A check of fan input powers were made. Results are shown in Figure A.13. As shown, the counter-rotating fan configuration requires additional power, thus taking back the savings that were obtained by closing the cones originally. Performance runs of the LACV-30 in the above counter-rotating fan configuration are given in Appendix C.

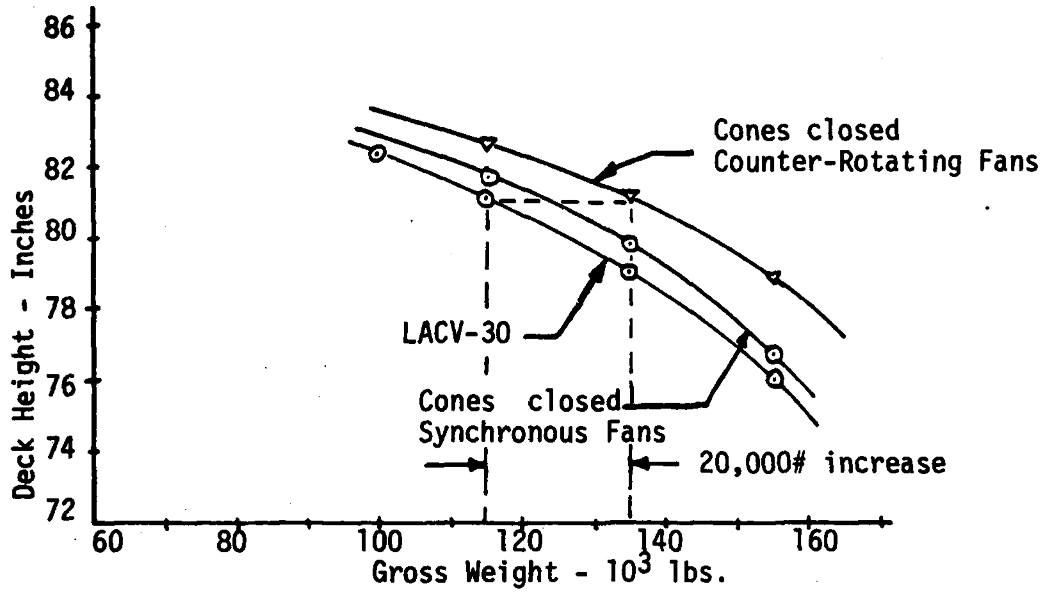


Figure A.12 Lift System Performance with Counter-Rotating Fans

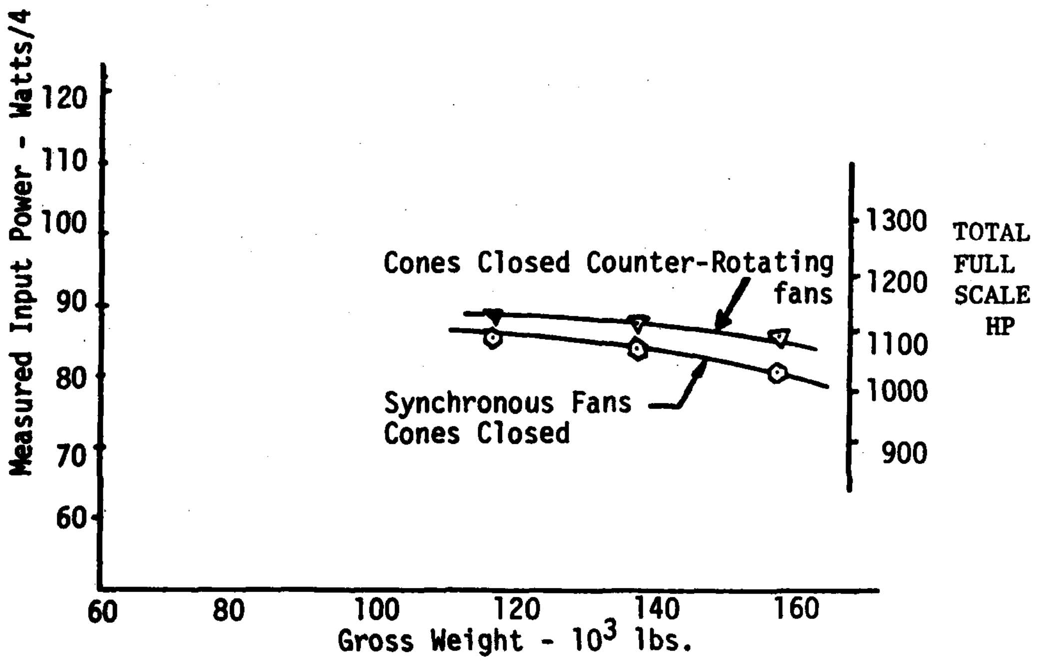


Figure A.13 LACV-30 Performance with Counter Rotating Fans

A.3.5 High Performance Lift Fan Design

In 1982 a computer program for predicting centrifugal fan performance was written, based on standard theoretical centrifugal fan formulae with provision for variable and various loss coefficients. The adjustment of these coefficients was validated by applications to four existing fans of known performance. The effect of given design changes on pressure, flow, and efficiency may now be rapidly evaluated. A new 7-foot diameter fan was designed using the program and a scale model was built and tested. Initial test correlation without an outlet diffuser was poor, actual performance being considerably below the predicted value. With the incorporation of a parallel plate diffuser, the new design showed the predicted 20% higher output pressure for the same input power (Figure A.14) as compared to the current fan.

Tests were not conducted on the model with the high performance lift fans. Calculated values were obtained from the computer model of the LACV-30 lift system. Results are shown in Figure A.15. As seen, the LACV-30 with counter-rotating lift fans, designed specifically for the LACV-30 lift system will provide sufficient lift for the craft to operate at a gross weight of 150,000 lbs. A considerable saving of input horsepower will also be experienced.

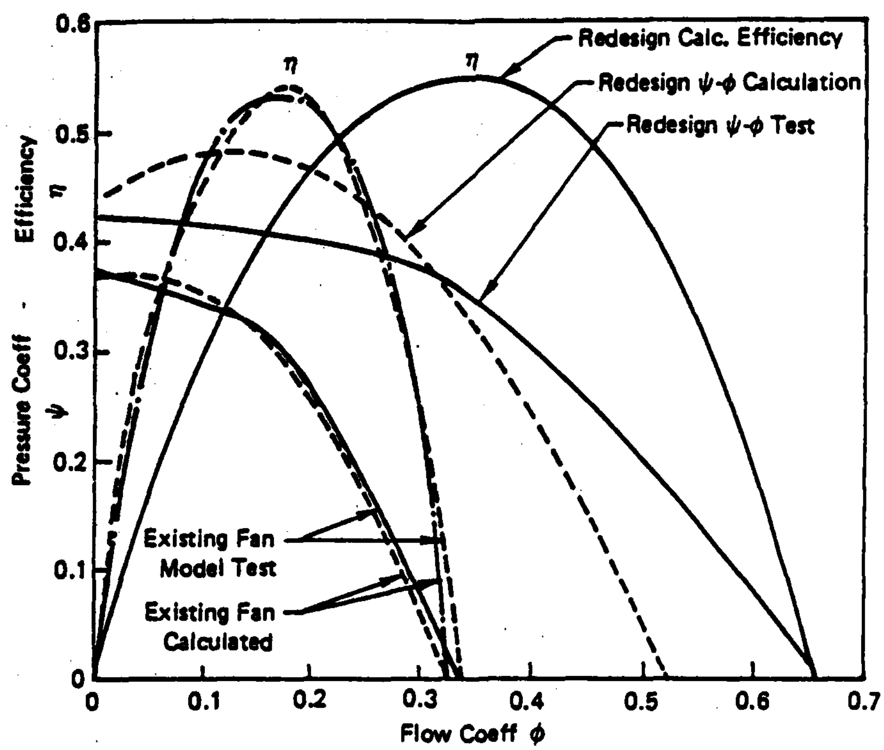
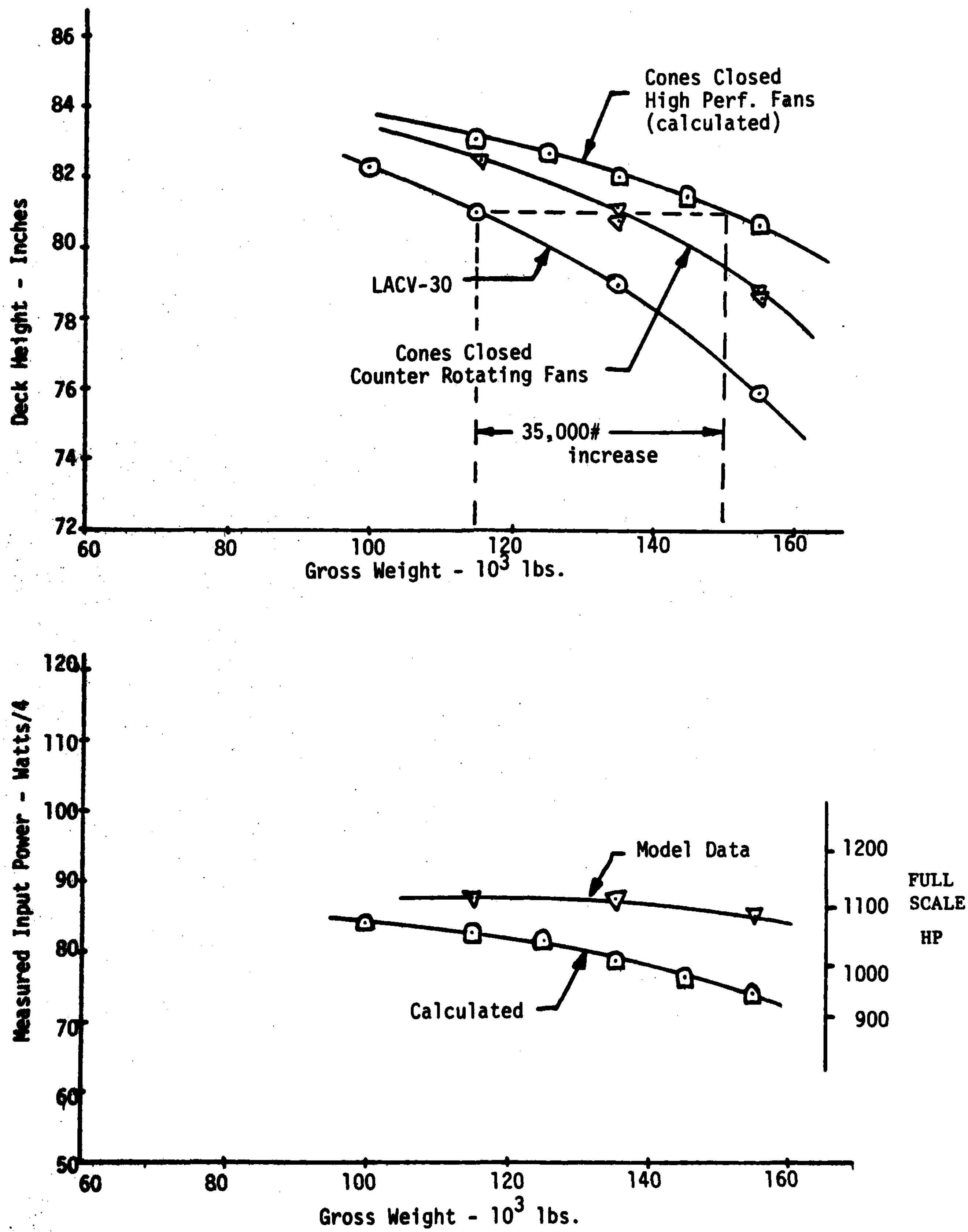


Figure A.14 Performance Curves for LACV-30 Lift Fans (ψ-ϕ-η Diagram)

Figure A.15 Lift Performance of High Performance Fans



A.3.6 Auxiliary Bow Fans

As an alternative to, or in addition to, changes in the existing power module machinery, extra cushion lift can be obtained by adding auxiliary engine/fan units. The auxiliary fan is attractive because as a separate self-contained unit, it could be mounted when needed and removed [illegible] when not used. [illegible] installed horsepower. [illegible] of the deck where the auxiliary fan could be installed and not interfere with cargo.

An existing 8-inch diameter model fan impeller was retrieved from storage and mounted in the volute assembly shown in Figure A.16. On the 1/7.5 model, it was convenient to install this auxiliary fan directly over the keel duct from the longitudinal keel to the bow bag such that its discharge could be directed into the keel, bow bag, or both. On an actual LACV-30 this forward-center position would interfere with cargo loading/unloading, and so two separate units might be located on the forward side decks as shown in the sketch in Figure A.17.

Bow Fan on
1/7.5 Scale Model
LACV-30

Figure A.16

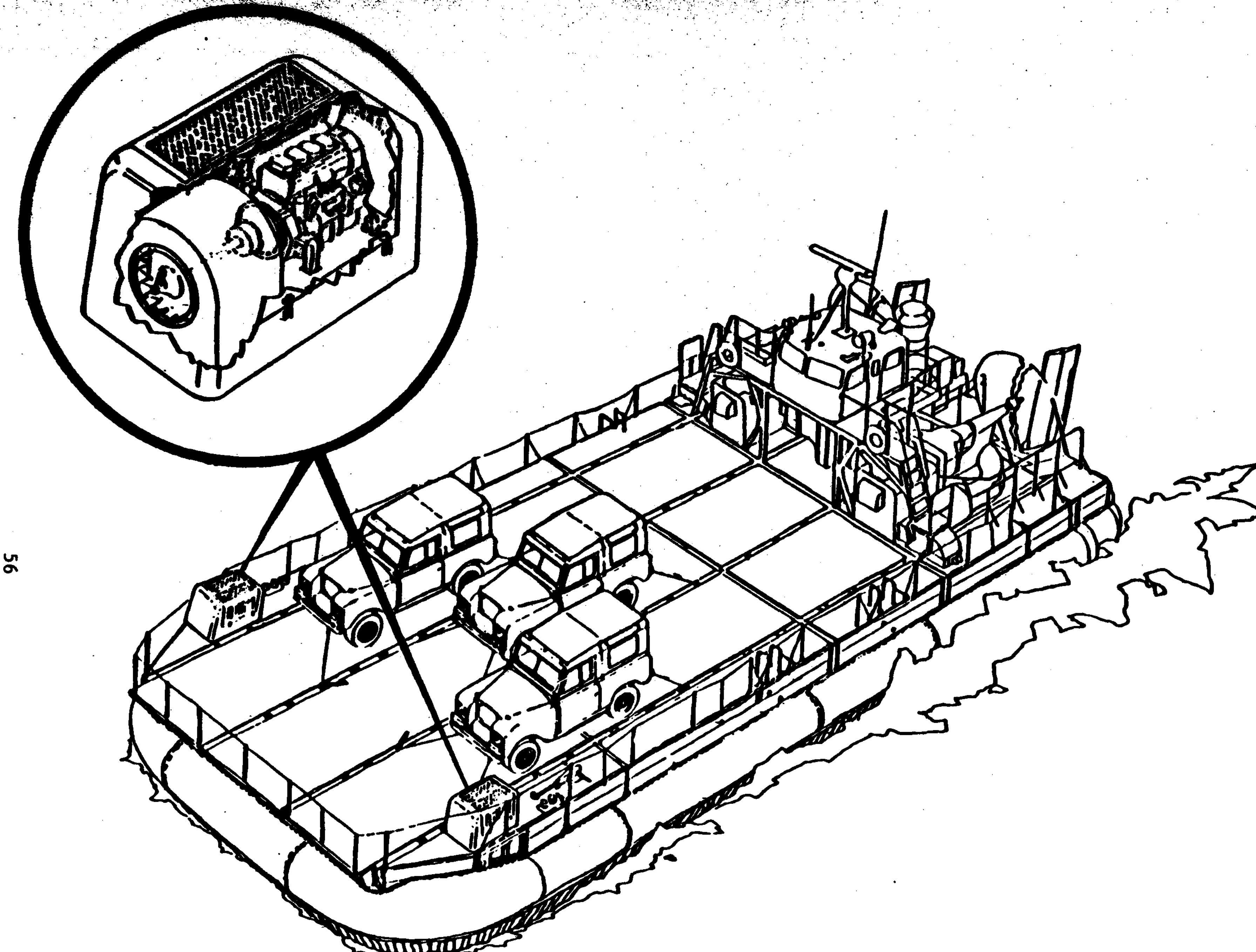


FIGURE A.17 LACV-30 AUXILIARY DECK FAN CONCEPT

The pressure-flow and efficiency curves for the 8-inch model fan were obtained from the fan flow-box rig and are presented in Figure A.18 in nondimensional form.

To determine the extra gross weight (and payload) that the auxiliary fan would allow, the auxiliary fan was run at several RPM's with the model at several gross weights. Other than the bow fan and forward duct, the model was in the standard LACV-30 configuration. The main lift fans were running at their standard 2588 RPM (95% at 1/7.5 model scale). Figure A.19 shows the heave height measured for this matrix of fan speed-weight conditions. The dotted line across the lower portion of the carpet curve represents the auxiliary fan RPM necessary just to maintain pressures and system lift equal to the unmodified LACV-30.

As expected, increasing fan speeds provide increased gross weight capability. Eventually, the added pressure and flow from the bow fan forces the main lift fans to operate at smaller flows such that they become stalled and they become the limiting factor in the lift system.

Figure A.20 shows the amount of improvement which can be expected, if the auxiliary fans were added to the LACV-30 with counter-rotating BHC fans and a "cones-closed" condition.

At this point, the rather meager payload gains possible with the auxiliary fans combined with the anticipated installation complexity resulted in the auxiliary fans being dropped from further consideration.

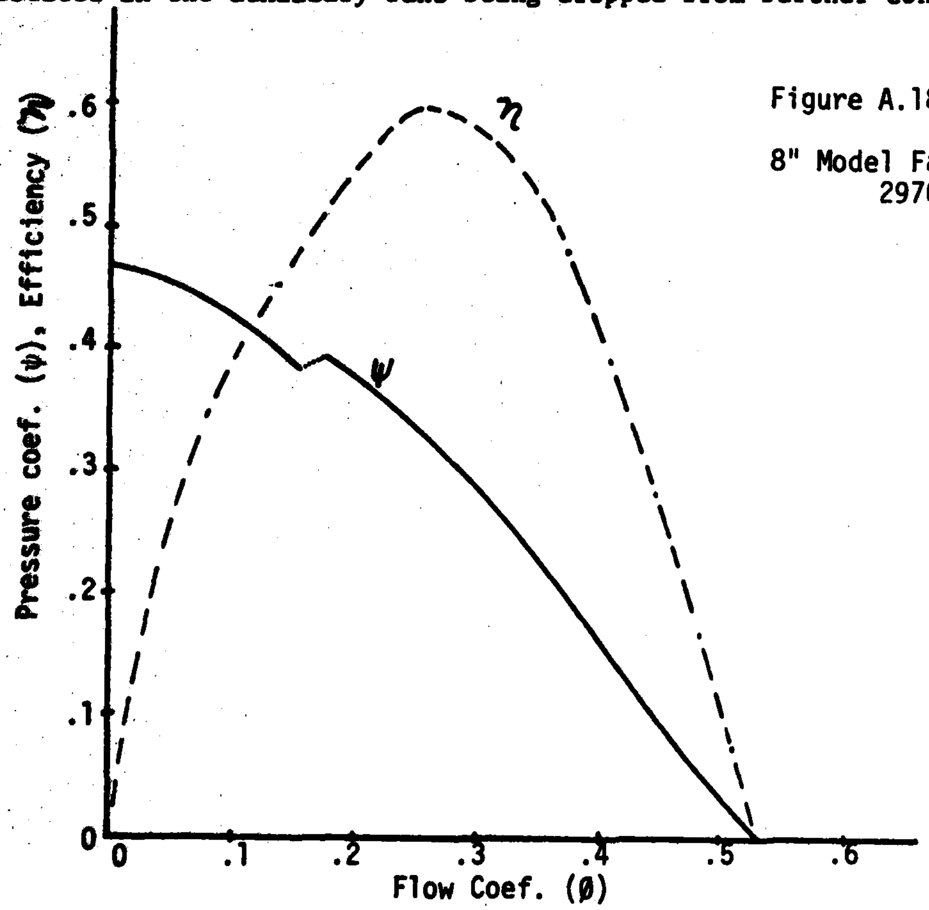


Figure A.18

8" Model Fan in Volute
2970 RPM

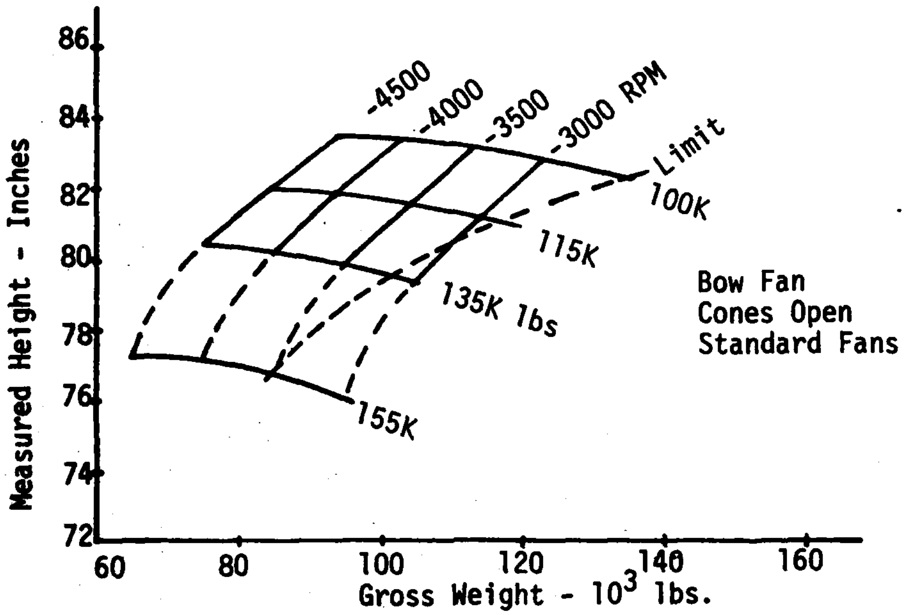


Figure A.19 Effect of Auxiliary Bow Fans

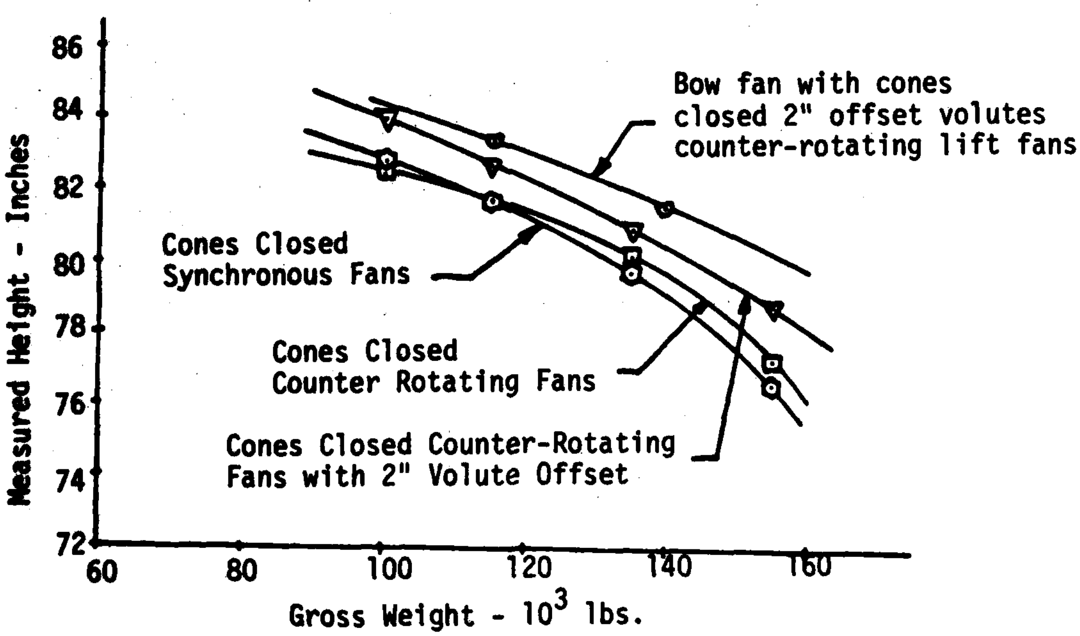


Figure A.20 Lift Performance with Aux. Deck Fans

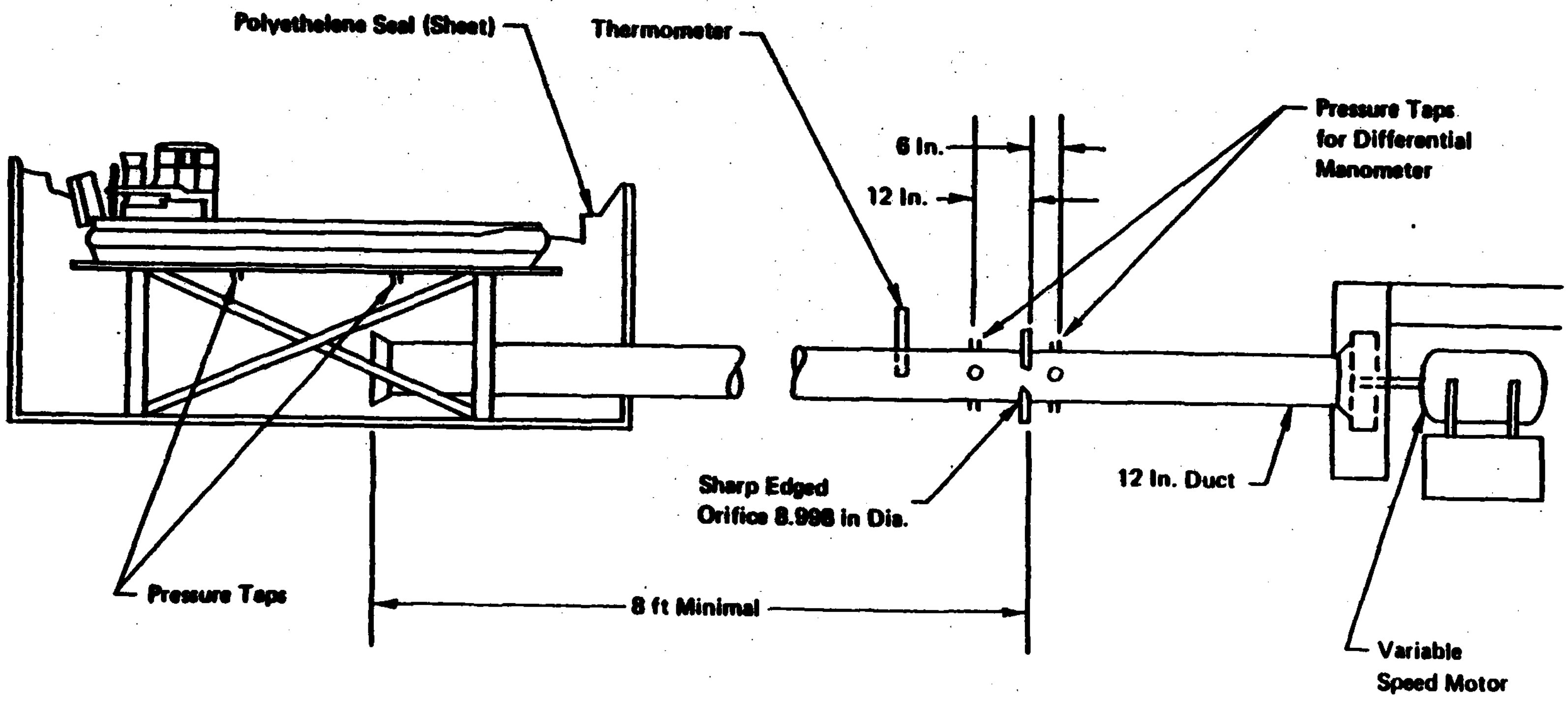


Figure A.21 Cushion Flow Rig

A.4 Lift System Flow Tests

These tests were done to provide data for determining lift system efficiency, defined as cushion pressure times useful cushion flow divided by lift system power input. The unique aspect of these tests is the measurement of cushion air flow. The test setup is shown in Figure A.21. The model LACV-30 is tethered to hover on a plywood platform. A thin plastic sheet is taped all around between the model deck and the upper lip of the outer box such that all air escaping from the cushion is caught in the box. An exhaust fan and flow measuring orifice meter are connected to the box and the exhaust flow is adjusted to keep the thin plastic sheet in a "neutral", zero pressure differential condition. Thus the cushion flow is measured by the exhaust orifice meter. Other measurements during these tests included cushion pressures and lift fan drive motor wattage. For the standard LACV-30 configuration, the flow out of the stern cones was subtracted from the measured flow since the stern cone flow does not contribute to cushion lift. (The percentage of stern cone flow was obtained from the lift system computer program results.) The resulting lift system efficiencies are plotted in Figure A.22. A significant improvement in efficiency is shown.

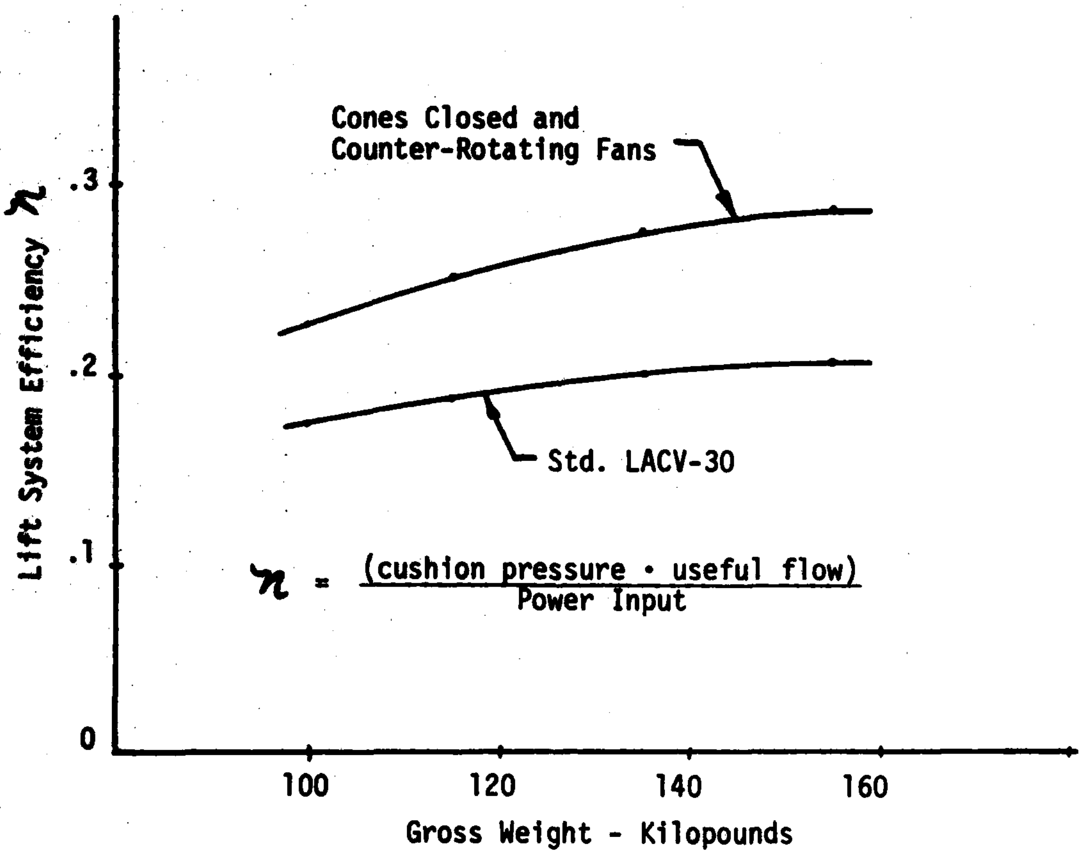


Figure A.22 Lift System Efficiency

APPENDIX B

LACV-30 MODIFICATIONS

B.1 General

The previous studies of the LACV-30 modifications which could lead to increased payload show the following:

(a) Closed stern and side bag cones can add 4 to 5 tons payload. In examining other options, it was shown that such a modification is additive, i.e., closing the cones always seems to add 4 to 5 tons to the payload, regardless of other modifications which also can add (or subtract) from the payload. A saving of 3.4% in input power to the LACV-30 fans is also experienced.

(b) With minor adjustments of the volutes, counter-rotating lift fans can add 5 tons to the LACV-30 payload, at a corresponding increase in input power to the fans equivalent to 4%.

(c) Counter-rotating, high performance lift fans have the potential of adding 30,000 pounds payload to the LACV-30, in addition to that obtained from the closed cone modifications. A 10% savings in input power can also be realized.

Other modifications investigated seemed to have little or no positive effects compared to the three options discussed above. This section, therefore, address the problems of how to incorporate either case (a) or case (a) and (b) or case (a) and (c) above into the LACV-30, and also, what can be done to either increase thrust, or decrease drag such that the performance of the LACV-30 is not compromised in the Army Resupply mission.

B.2 LACV-30 Improved Payload Modifications

B.2.1 Wrap-Around Stern Seal

Although the static tests show that a significant improvement can be achieved by limiting the flow of air through the stern and side bag cones, there still exists the problem of implementing the change. Figure B-1 is a stern view of the LACV-30 showing the typical buckling and leakage of the vertical open stern fingers. On the LACV-30, as well as the Voyageur and BHC predecessor craft which used essentially the same stern cone design, the finger cone is configured to be marginally stable, so that it normally holds sufficient pressure to retain its shape. When the craft is operating, craft motions and waves will allow the water to impact the aft finger face, causing the finger to buckle to relieve the load and precluding "scooping" that would increase vehicle drag considerably, if not tearing off the finger completely. Similar problems had been encountered on the JEFF(B) stern seal

FIGURE B-1 STERN VIEW OF FULL SCALE LACV-30 SKIRT SYSTEM which had a similar design. In that case, however, the stern fingers were somewhat stiffer and they had good inflation stability and cushion sealing. The stiffness produced severe wear and high drag. A subsequent advanced skirt development program, using tow tank and full-scale tests of varying stern seal designs, resulted in a "swept back open cone" finger design concept. As applied to the LACV-30, this design in profile, would look like the cross-sectional B-B and C-C as shown in Figure B.2. The underside edge of the cones have a flap across the bottom of the opening which, in normal forward motion of the craft, would hold the cone closed, and the pressure within the cone at a high level. Contact with a wave will force air out, thus causing the cone to flex to the contour of the wave. The flap also serves to eliminate water scooping, thus reducing the drag of the entire flap-cone system. Model tests have been conducted for the JEFF(B) and LCAC skirts. Full-scale tests of the JEFF(B) stern seal indicate a 300-hour finger life, with good finger action and low drag.

Figures B.3 and B.4 show how the LACV-30 would look with a wrap-around stern seal, attached to the LACV-30 side bags near the rear of the craft.

B.2.2 Propellers

B.2.2.1 Propeller Blade Selection

Presently, the LACV-30 is equipped with Hamilton-Standard Model 7005-31 propeller blades mounted on 43D50 Hubs. The propellers, originally designed as a 12 ft. diameter system, are cropped to 9 ft., and operated at a maximum RPM of 1980, thus giving a maximum tip speed of 933 ft/sec. Operational experience with the system show satisfactory performance for the LACV-30 at 115,000 pounds gross weight. At the 933 ft/sec tip speed, noise output is considered to be the maximum allowable.

A review of the variation of propeller thrust with activity factor AF, lift coefficient, C_L and number of blades, N was made, for both forward and reverse thrust conditions. Results are shown in Figures B.5 and B.6 for a variety of calculated values and for three available blades;

(a) 7105-31 (151 AF, .597 C_L)

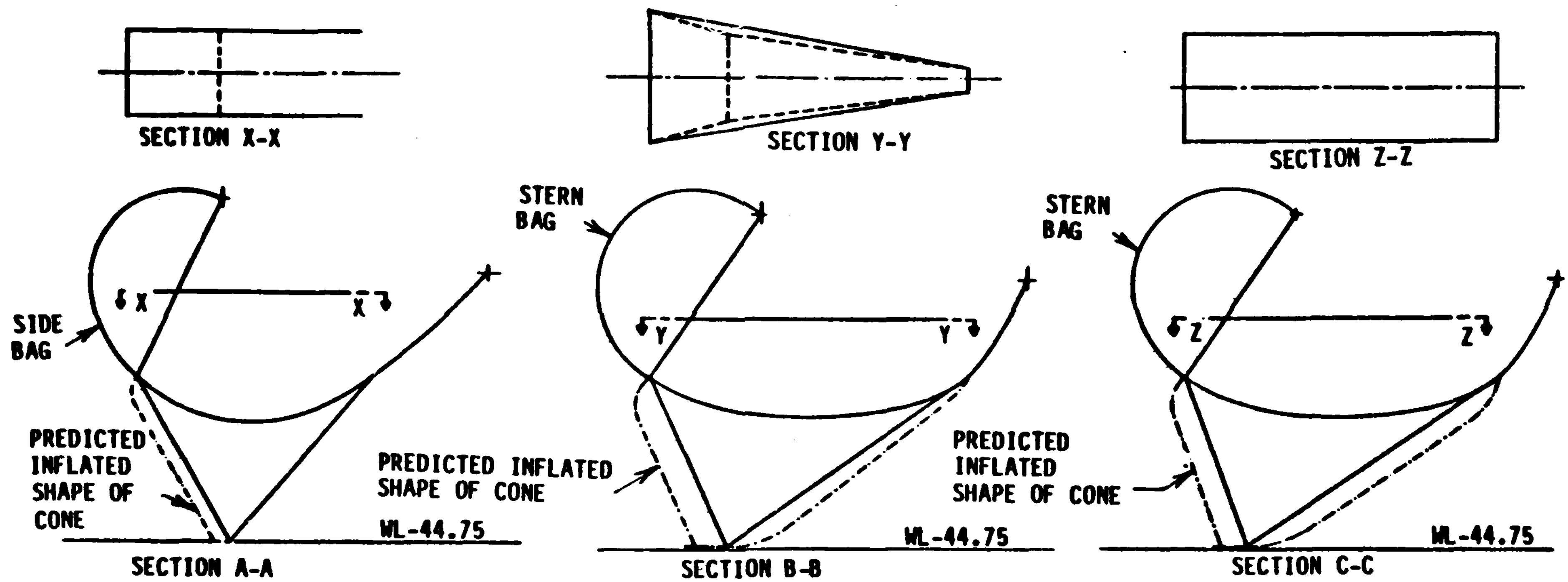
(b) 7005-31 (156 AF, .465 C_L)

(c) 7173-1 (165 AF, .725 C_L)

The 7105 blade represents a design which enhances reverse thrust with a corresponding sacrifice to forward thrust. The 7173 blade, with an activity factor of 165 represents a practical limit for maximum forward thrust, with minimum reverse thrust. Comparing requirements for forward and reverse thrust, the 7005 blade represents about the best trade-off between the two extremes. Therefore, it appears that a new blade development for the LACV-30 is not warranted for the options being considered in this study.

FIGURE B.2

PROFILE VIEWS OF LACV-30 STERN SEAL



EXISTING LACV-30 SIDE FINGERS

OPEN CONE STERN CORNER FINGER

LATERAL OPEN CONE STERN FINGER

FIGURE B.3

PLAN VIEW OF PROPOSED LACV-30 SWEPT-BACK OPEN CONE FINGER STERN SEAL

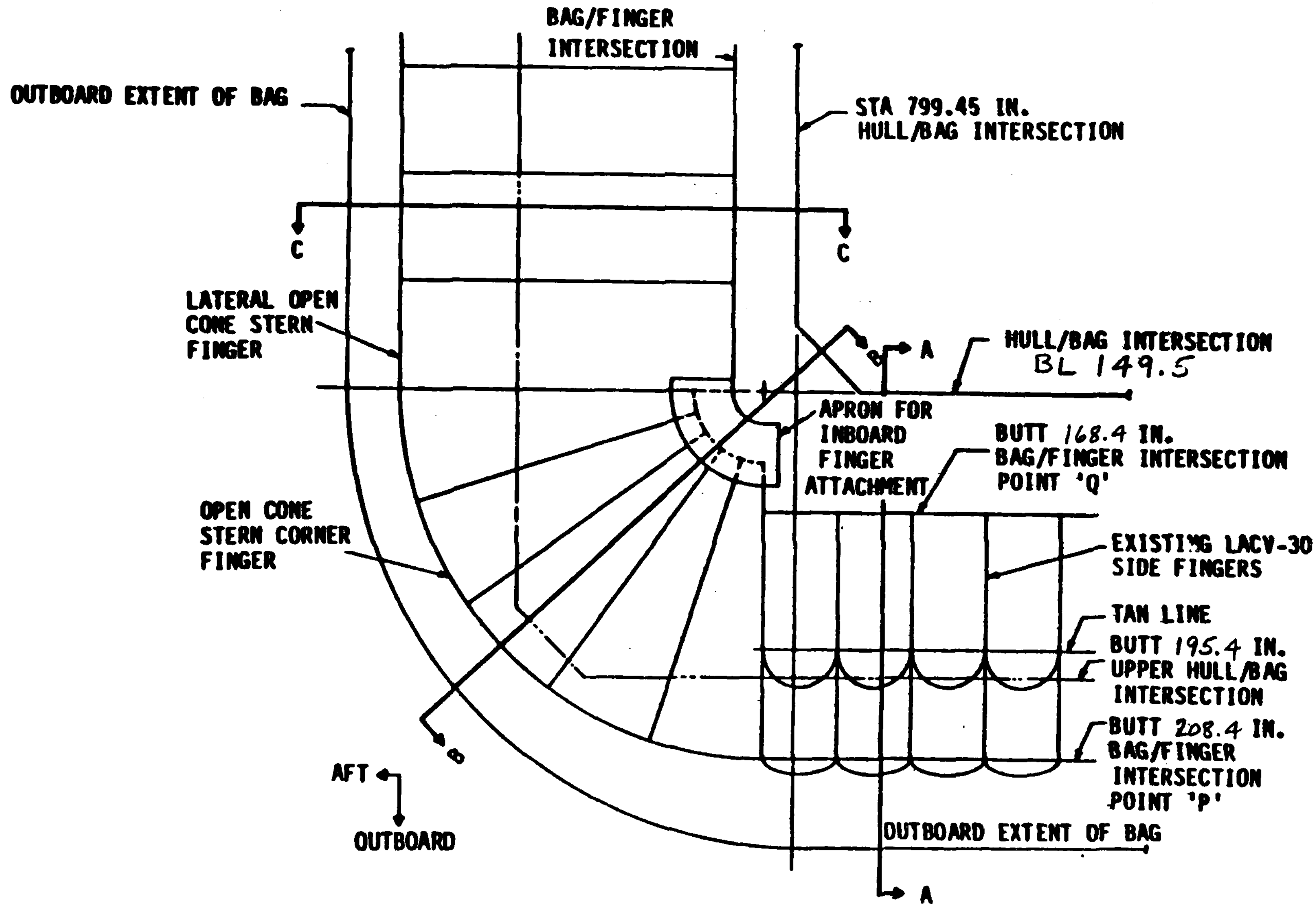
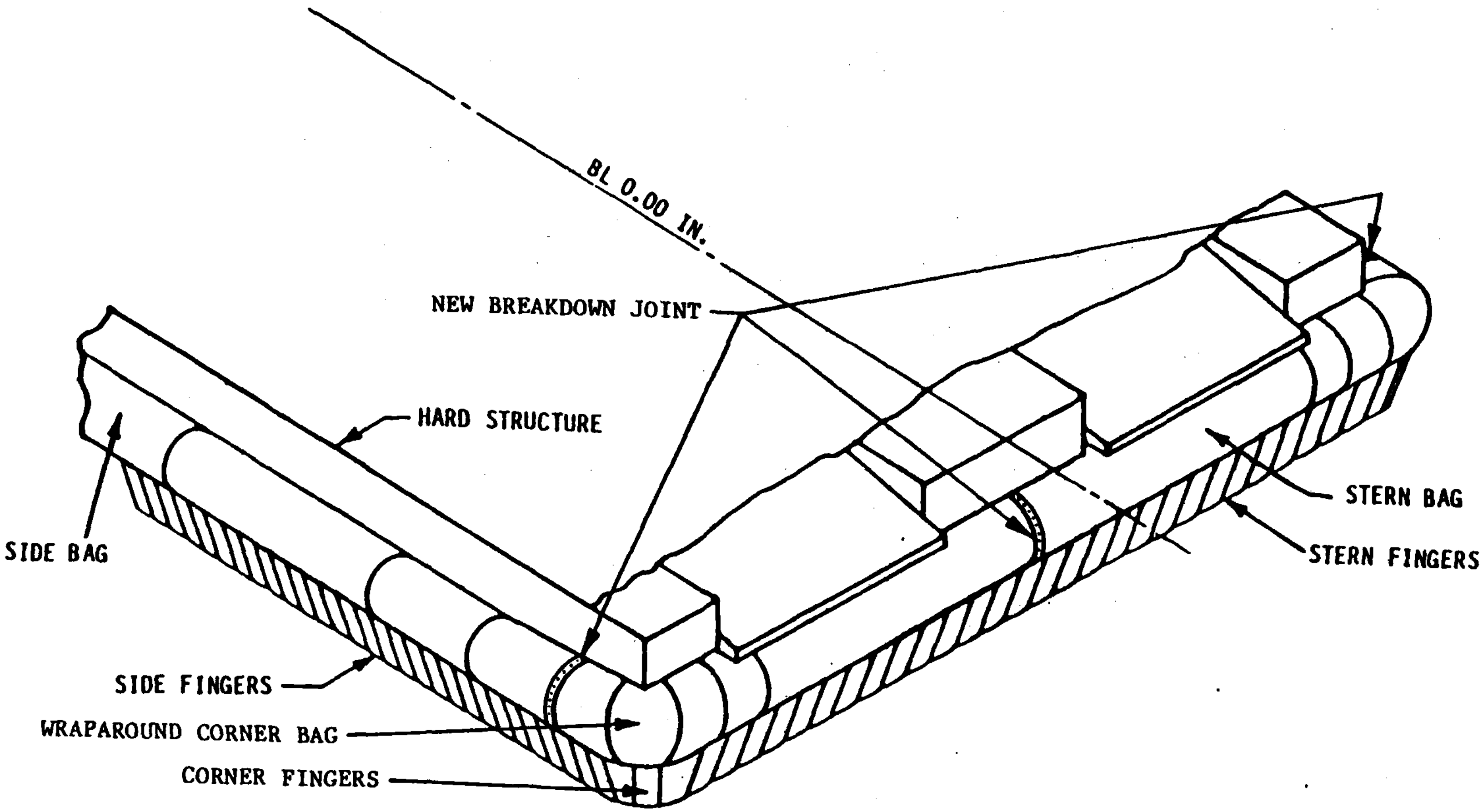


FIGURE B.4

LACV-30 SWEPT-BACK OPEN CONE FINGER STERN SEAL



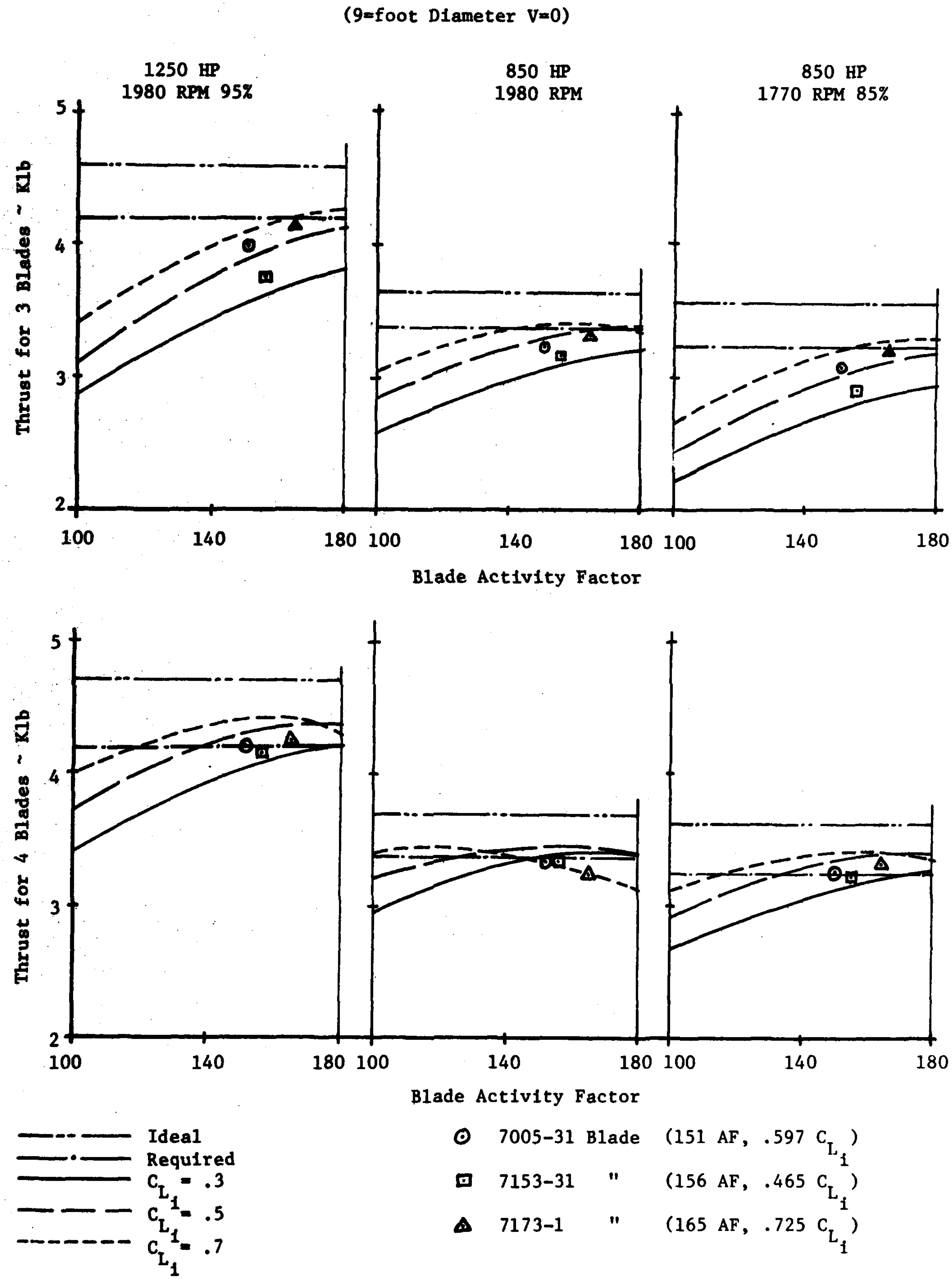


FIGURE B.5 PROPELLER COMPARISON FOR FORWARD THRUST

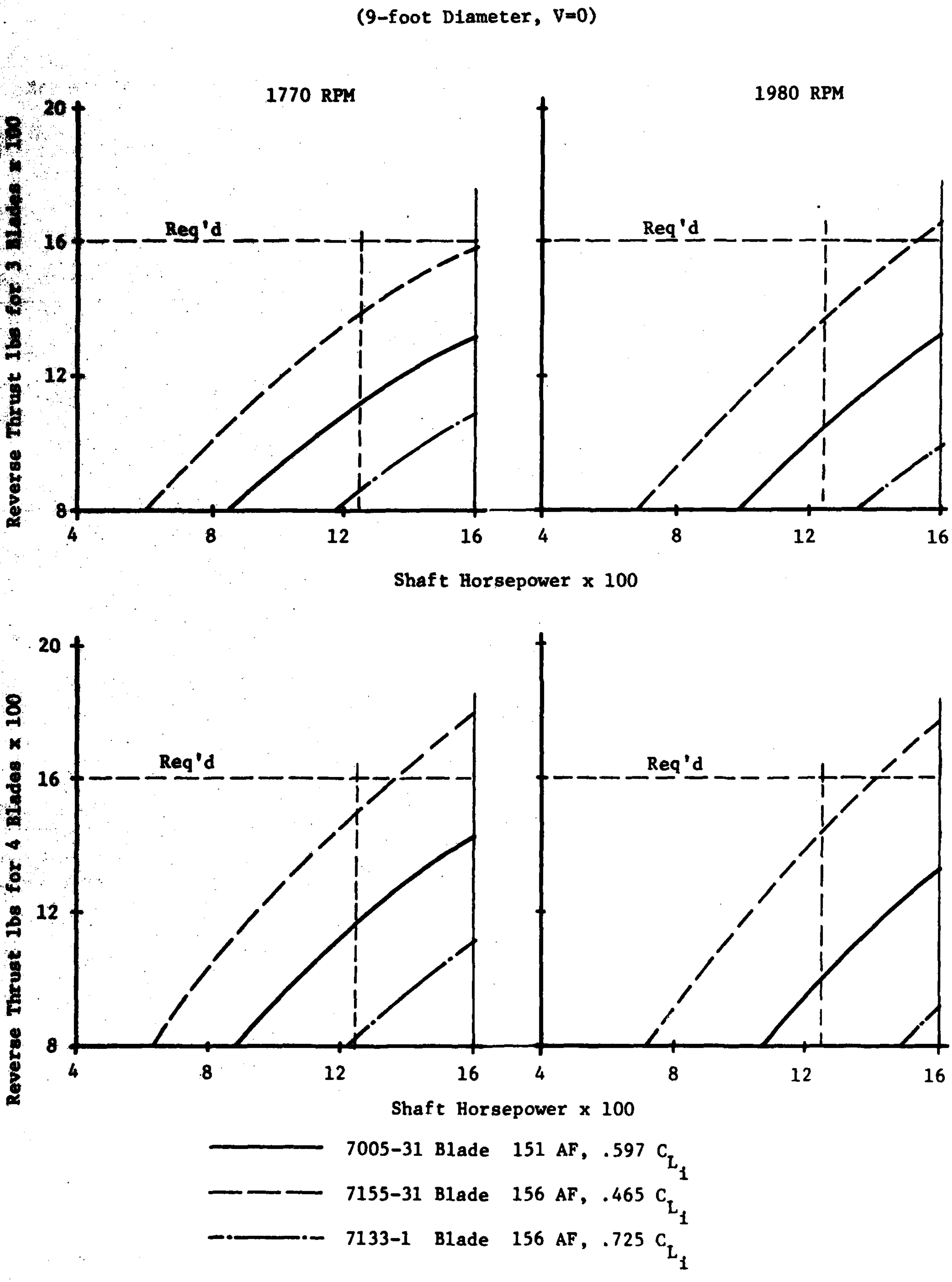


FIGURE B.6 PROPELLER COMPARISON FOR REVERSE THRUST

B.2.2.2 Increase Propeller Size

An increase in propeller size offers both increased forward and reverse thrust, for a given horsepower input. Unfortunately, a simple increase in propeller size is not possible, because of the near sonic tip speed of the present propeller. Figures B.7 and B.8 present uninstalled thrust as a function of both RPM and propeller diameter, for two HP inputs, 850 which corresponds to cruise power, and 1250, which corresponds to maximum power. The dashed lines on the carpet curves, represent maximum tip speeds of 933 ft. and 884 ft/sec, respectively, versus RPM and diameter. Preserving 933 ft/sec as the maximum tolerable tip speed, a 9.5 ft. diameter propeller would have to be reduced from 1980 to 1876 RPM. Thus, thrust with 850 hp input could be increased from 3300 lbs. to 3400 lbs., 100 lbs. per side, or 200 lbs. total increase. For maximum power, thrust could be increased from 4000 lbs. to 4200 lbs. per side, or 400 lbs. total. Another benefit is the increase in propeller efficiency as a function of propeller diameter. Table B.1 gives $\Delta T/\Delta HP$, the increase in thrust per unit increase

HP	Diameter	RPM	$\Delta T/\Delta PH$
1250	9 ft.	1980	.843
	9.5 ft.	1876	1.60
	10.0 ft.	1782	1.56
850	9 ft.	1980	2.04
	9.5 ft.	1876	2.54
	10.0 ft.	1782	3.12

Table B.1 - Thrust to Horsepower Ratios for the LACV-30 7005 Propeller.

in horsepower. As shown an increase from 9 to 9.5 ft. diameter propeller will almost double the ratio at maximum power, and will increase by 40% if at cruise power. Therefore, if horsepower to the propellers is increased, as indicated from the static tests, a 9.5 ft. propeller will increase forward thrust at a rate substantially faster than the 9.0 ft. diameter one.

B.2.2.4 Implementation of a Larger Diameter Propeller (Aft Structural Apron)

The proposed modification to the LACV-30 of 9-1/2 ft. propellers in place of the present 9 ft. ones, requires a 3 inch deepening of the cutout in the structural section below the propellers. The work will involve:

(a) A redesign of the structure

(b) Replacement of existing structure to the LACV-30 by means of splice plates, as illustrated in Figure B.9

Figure B-7

Propeller Thrust vs Size and Rotational Speed
7005 Hamilton Standard Propeller

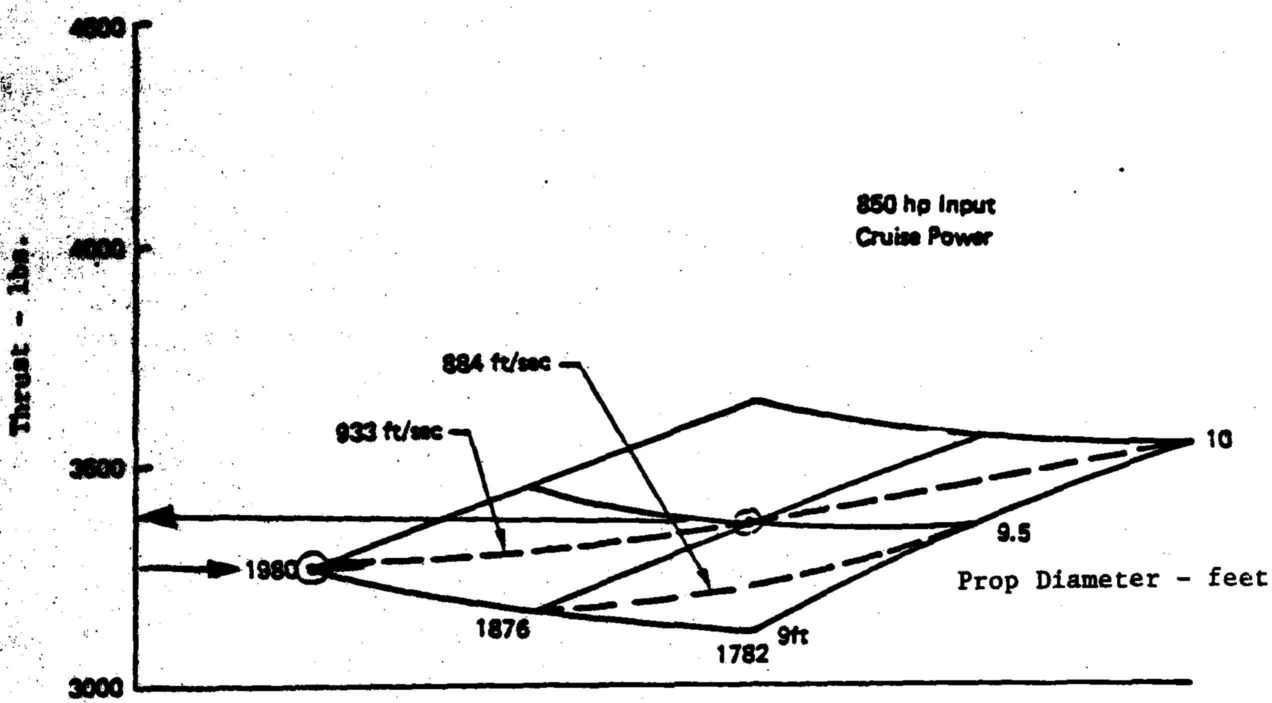
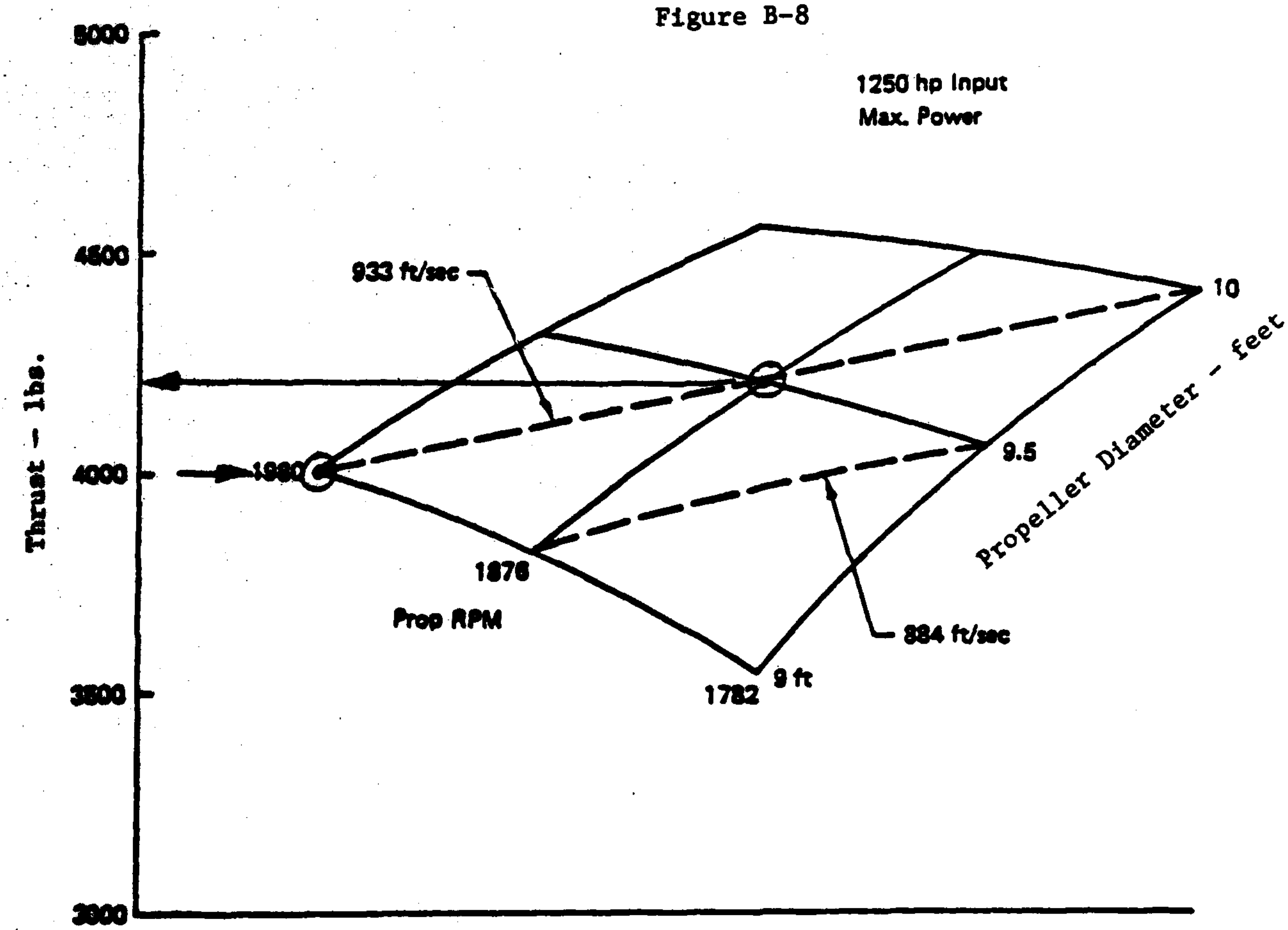


Figure B-8



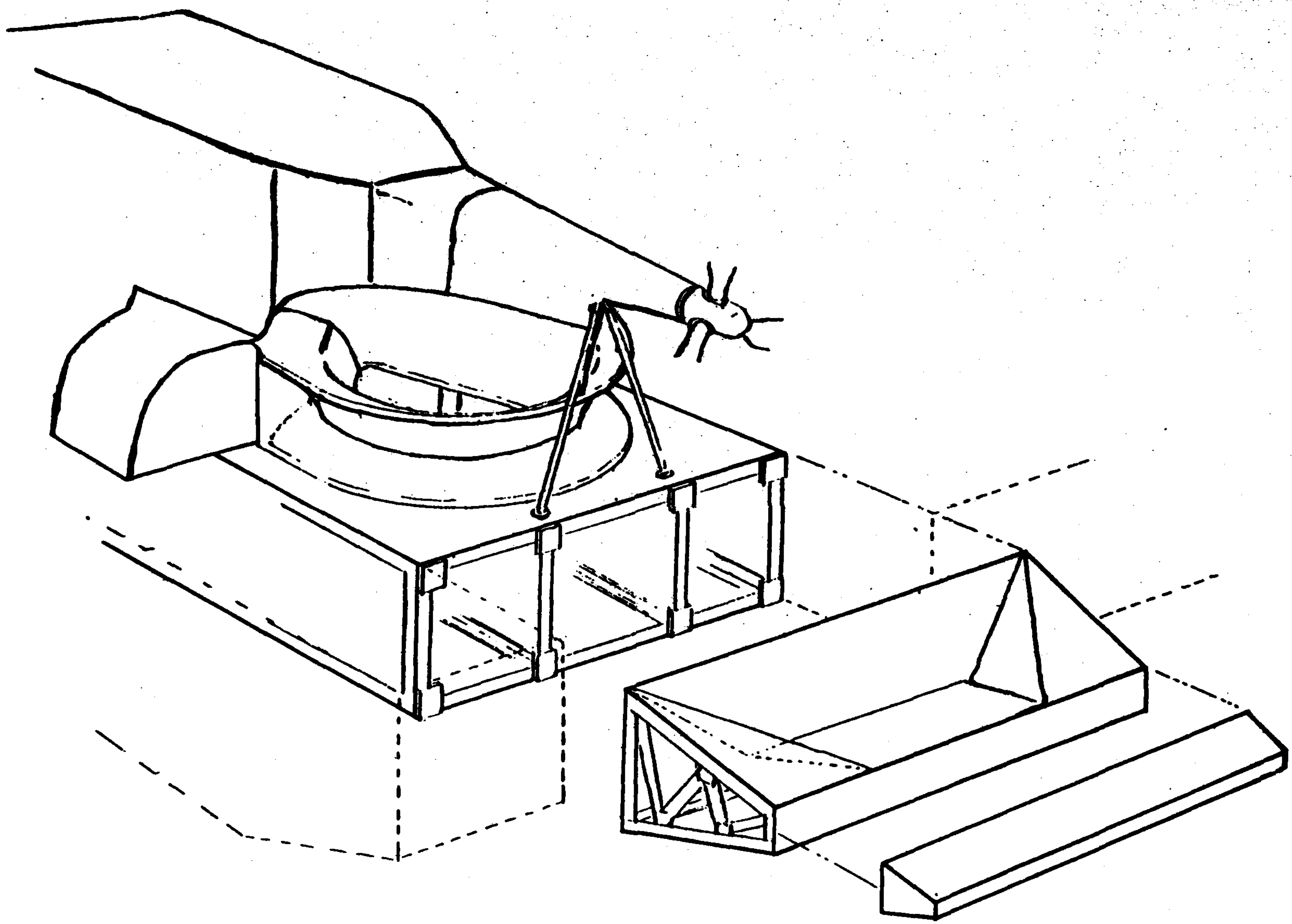


Figure B-9 Assembly of Aft Structural Apron for 9½ Foot LACV-30 Propeller

(c) Rerouting of the fuel line

The sloping sections of deck plating have been moved forward and outward to each side to maintain the same tip clearance as is allowed around the 9 ft. propeller now.

Budgetary costs have been estimated based on removal of the existing structure and replacement with a new assembly. An alternate method would be to remove and replace only the minimum number of panels and fittings, but depends on sufficient cutting and welding accessibility.

This area is subjected to high acoustic loading from the propeller blade tips. The clearance modification for the increased propeller diameter provide the opportunity to also upgrade the fatigue resistance of this area of interim operating experience so indicates.

B.2.3 Reduced Keel Depth

Previous LACV-30 model tank testing, together with observations from full-scale LACV-30 operation indicates that, at the heavier gross weights, the longitudinal keel seems to drag in the water, slowing the LACV-30 at speeds in excess of hump.

Reducing seal drag can improve the overall performance of the craft since it frees up propulsive power which can then be used to attain higher speeds at the same weight and/or carry more payload at the same speed. The entire LACV-30 peripheral seal, except for the stern portion, is of the bag and open finger design. Tests have shown that this type of design results in a "soft" seal with low drag; therefore, not much improvement is expected in this area. The longitudinal keel, on the other hand, is of the closed bag design with a knife edge type keel. Bell tests on this type of seal on other ACV programs have shown that it has a relatively high drag and that drag is a function of bag pressure. This was partly verified in the model test studies of the 1975 and 1976 IR&D programs, References 2 and 5, where raising the longitudinal keel one foot (full-scale) was found to reduce drag in calm water by about 14% (Figure B.10). A similar trend was found when the depth of the peripheral seal was increased by one foot to five feet while keeping the keel depth the same. Model tests were also conducted to determine the influence of the increased keel gap on roll stiffness. It was found that there is a significant reduction and that it could limit the amount that the keel could be raised and/or the peripheral seal deepened.

Figure B.11 shows the profound influence keel immersion has on drag; especially at post hump speeds. Comparison of drag estimates made for two otherwise identical vehicles at a gross weight of 135,000 lbs. shows that raising the keel by approximately 12 in. can eliminate nearly half the drag at 45 mph and substantially reduce the drag at hump speed. While raising the keel by itself does not make a 135,000 lb. vehicle feasible (negative thrust margin at hump and lower speeds), it is a change that is mandatory for any increase in payload. Further testing and analysis need to be done in this area to determine if this potential in drag reduction

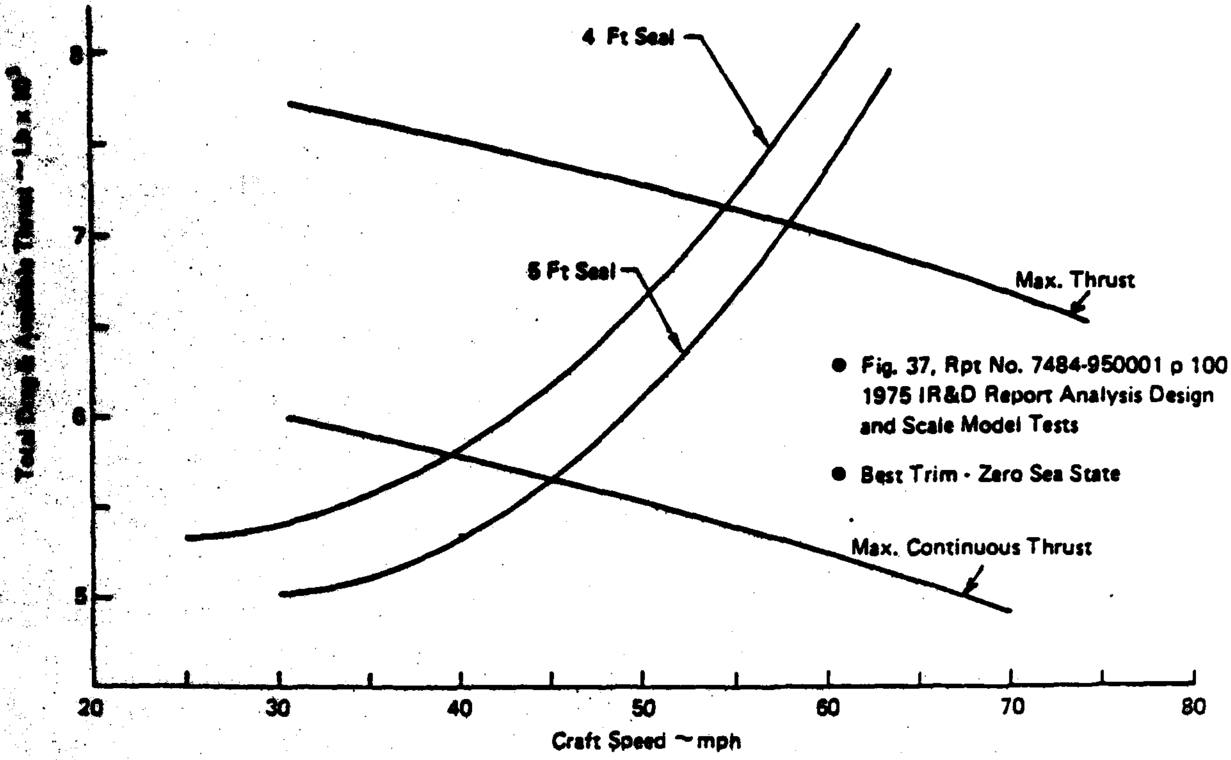


Figure B-10 LACV-30 Product Improvement Program Model Test Data

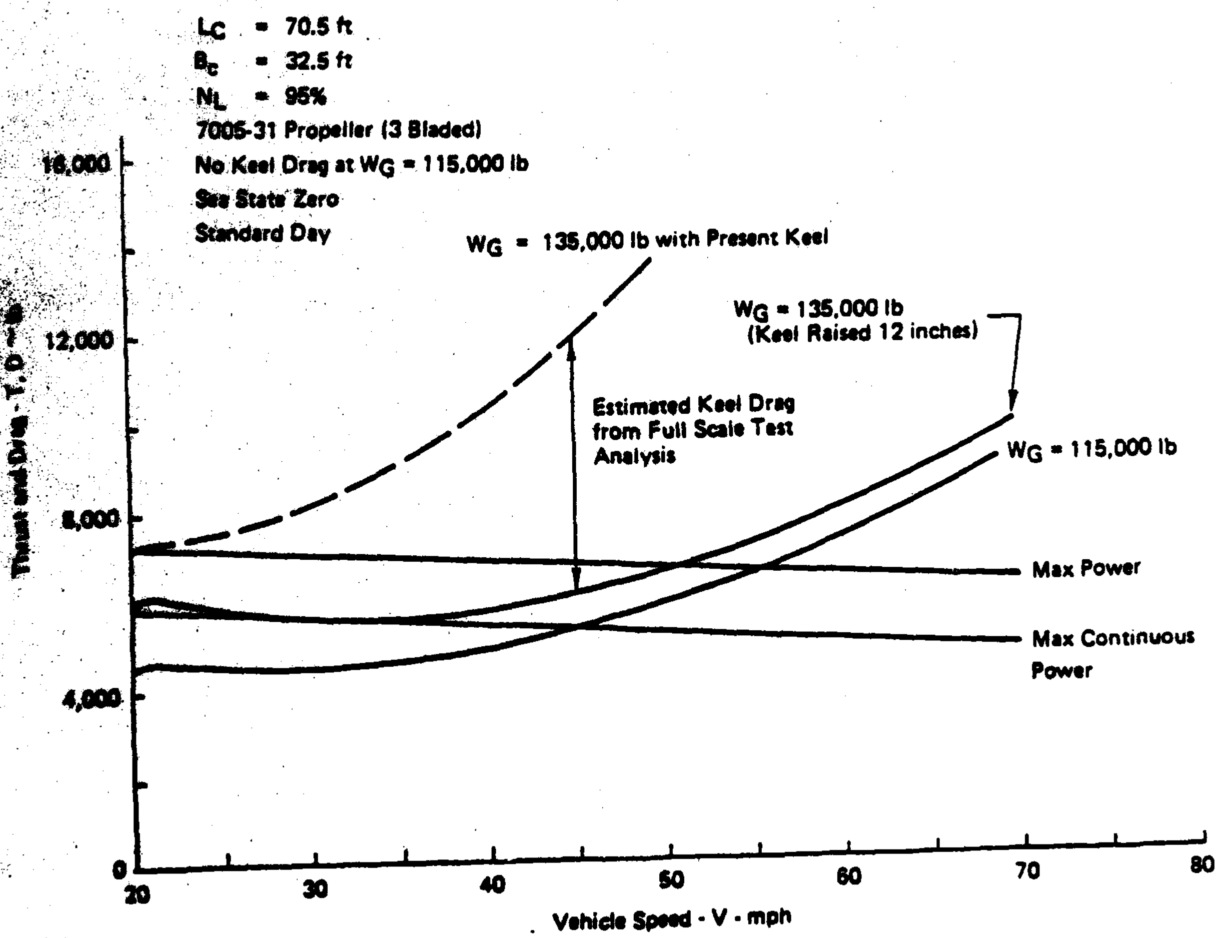


Figure B-11 Effect of Keel Drag on LACV-30 Overwater Performance can be realized. Investigation also needs to be made to determine if lowering the keel bag pressure will reduce drag without adversely affecting roll stability.

Keel clearance can be increased by:

(a) Raising the keel bags

(b) Lowering the peripheral seal

Of the two options, the first appears to be the more promising, since the shallower keels can be designed to attach to the existing hull attachment points. Keel replacement can be made in the field at any regularly scheduled maintenance interval.

B.2.4 Structure - Hull Stretch and Reinforcements for Increased Gross Weight

B.2.4.1 Summary

The structural studies addressed the problem of determining the capacity of the LACV-30 at gross weights substantially increased from the present design weight of 115,000 lbs. Table B.2 identifies the critical hull components when gross weight of 153,000 pounds is approached. Recommended methods of reinforcement which minimize the extent of rework in the critical areas are given. Overall, the structural upgrading of the LACV-30 to a 153,000 lb. gross weight is relatively minor. Those areas which are affected are readily accessible.

Presently, 153,000 lbs. appears to have adequate margins of safety to operate. Limitations are based on the strength of the bottom plating in tension. If the LACV-30 is lengthened 5.5 ft., then the maximum allowable gross weight is 140,000 lbs. As indicated in Table B.2 to achieve these gross weights requires additional bolts at the vehicle's transverse splices.

The landing pads support structure is adequate, but new landing pads will be required for gross weights in excess of 121,000 lbs.

An examination of the effects of stretching the LACV-30, as shown in Figure B.12, was made, where it was concluded that maximum allowable gross weight will be a function of the length of stretch. For example, if the craft is stretched 5.5 ft. in length maximum allowable gross weight is reduced to the 135,000-140,000 lb. range. Figure B.13 summarizes the trade-off between hull stretch and gross weight.

B.2.4.2 LACV-30 Structural Analysis

The LACV-30 is a stretched version of the Voyageur and with structural modifications to provide strength for an operational gross weight of 115,000 lbs.

TABLE B-2
SUMMARY OF STRUCTURAL STUDIES FOR LACV-45 AT 160,000 LB GROSS WEIGHT

Structural Elements of the Hull	Critical Feature	Limitation Reached at Gross Weight of	Proposed Solution
1.1 Basic Hollowcore	Weld strength over a bulkhead		
Top plating	– axial compression	185,600	Adequate for LACV-45
Bottom plating	– axial tension	153,120	Increase splice plate length in critical landing region
1.2 Station 480-486 Splice	– Bolt bearing strength in splice	145,000	Increase number of bolts ~20%
1.3 Station 618-624 Splice	– Bolt bearing strength in splice – Finger doubler weld strength in 6063-T6 power module deck hollowcore extrusion	154,900 150,700	Increase number of bolts ~10%
1.4 BL 150 Longitudinal Beam	– Basic tube and end connection strength	<150,000	Redesign tube and end connection
1.5 Landing pads	– Effective compressive area	121,330	Pads redesigned and retrofitted to LACV-30 are adequate
Landing pad support structure	– Strength margin on internal hull support elements	182,000	Adequate for LACV-45
1.6 Skirt hinges	– Corner hinge weld to the craft	<150,000	Redesign hinge and attachment to craft
	– Side hinge bending	<150,000	Redesign hinge and attachment to craft

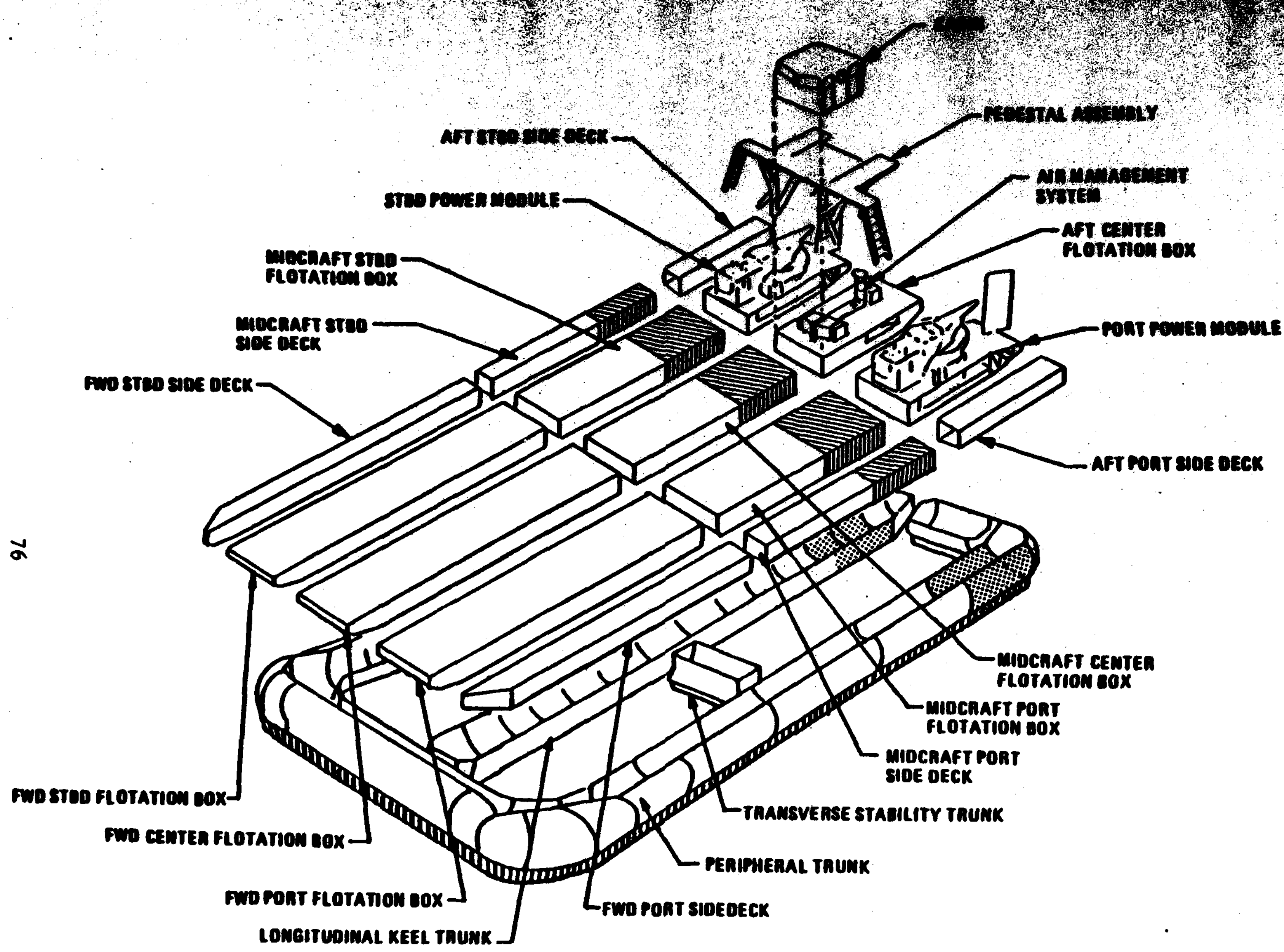


Figure B-12 Exploded View of LACV-30 Modules

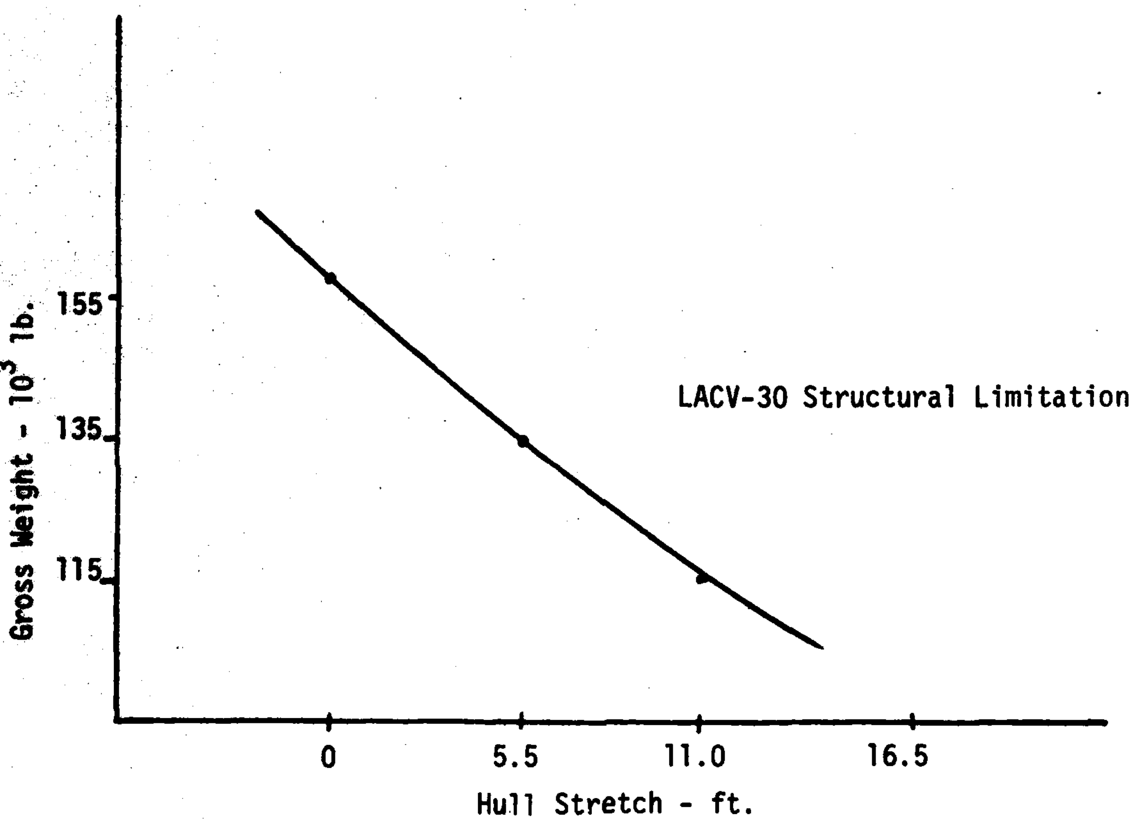


Figure B.13   LACV-30 Hull Stretch Limits

The structural analysis of the Voyageur LACV-30 was reviewed to determine the critical hull components. The components are the basic hollowcore deck in compression, the box transverse splices at stations 480 to 486, and 618 to 624, truss tubes in the BL 150 longitudinal beam, the landing pads and support structure, and the skirt hinges. Critical bending moments and torsions were obtained from Voyageur analysis as a linear function of gross weight.

The basic hollowcore provides sufficient strength in overall bending of the hull provided the cargo pressures from the load spreading pallets remain the same. The strength is based on the mechanical properties of Table B.3 and the section properties for the hull structure hollowcore extrusions summarized in Table B.4. Bending moment diagrams for various configurations are shown in Figure B.14. The bending moment curve for the Army LACV-30 at a G.W. = 124,409 lbs. was used to determine the permissible G.W. The top plating at the peak bending moment over a bulkhead was analyzed and found to limit the gross weight to 185,602 lbs. The bottom plating at the peak bending moment over a bulkhead was found to limit gross weight to 153,120 lbs.

Station 480 to 486 splices - Existing AN-5 bolts bearing in the splice extrusion limits the Gross Weight growth to 145,000 lbs. A 20 percent increase in the total number of bolts concentrated where the load peaks will be required to provide a positive margin of safety. The splice joint is shown in the sketch below.

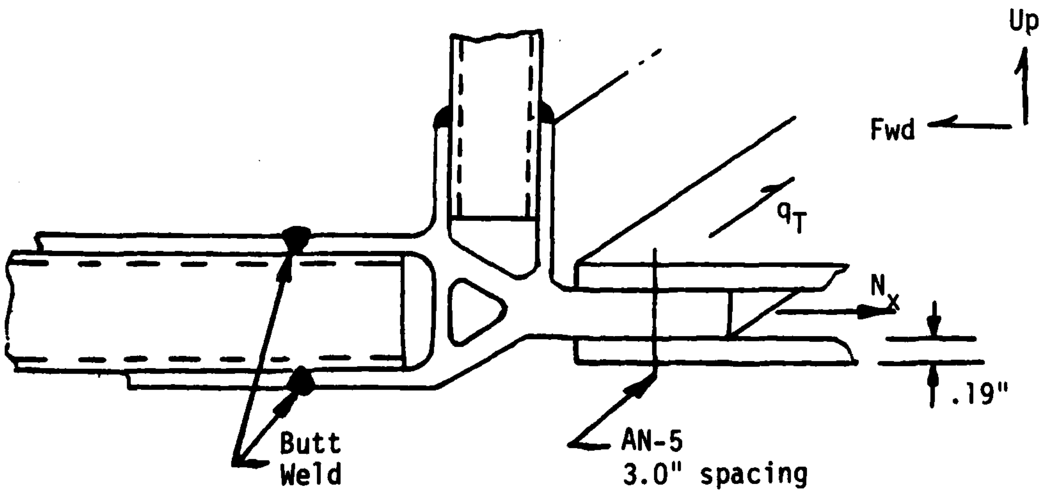
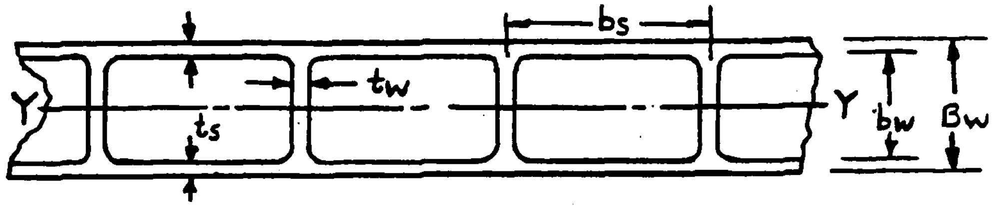


TABLE B.3 SUMMARY OF MECHANICAL PROPERTIES FOR MATERIALS USED ON VOYAGEUR

			PARENT METAL, KSI				WELD ZONE, KSI		
	Material	Type	F_{tu}	F_{ty}	F_{su}	F_{bru}	F_{tu}	F_{ty}	F_{su}
ALUMINUM ALLOY	6061-T6	Sheet & Plate	42	35	27	88	24	20	14.4
	6061-T6	Extrusion	38	35	27	80	24	20	14.4
	6105-T6*	Extrusion	38 (42)	35 (39)	27 -	80 -	24 (26)	20 -	14.4 -
	7075-T73	Plate & Forgings	66	56	39	125	-	-	-
	6063-T6	Extrusion	30	25	19	63	17	11	11

* The 6105-T6 aluminum alloy (Revere designation) exhibits slightly higher mechanical properties than 6061-T6. For design of the LACV-30 structure, however, where 6105-T6 is employed the properties of 6061-T6 are used.

TABLE B.4 HULL STRUCTURE HOLLOWCORE EXTRUSIONS - SECTION PROPERTIES



	Extrusion Type	1.5 in. Deep DOW XM-18	.888 in. Deep Bell 150003	.675 in. Deep Revere F13430S
	Material	6061-T6	6105-T6	6105-T6
	Usage	Fwd. Flotation Boxes-Decking LACV-30 Surf Fence	All bottom plating, aft center flotation box-decking, and top surface of the fwd side decks.	Top surface of the aft side decks all transverse bulkheads and longit. beams & power module top decking.
Geometry	Extruded Width	24.75"	9.4	11.0
	b_s	1.775	1.35	.932
	B_w	1.500	.888	.675
	b_w	1.415	.818	.620
	t_s	.085	.070	.055
	t_w	.108	.065	.055
	$\bar{t}$	.256	.176	.146
Section Prop. for 1.0 in. Wide Strip	Area, A in^2	.256	.176	.146
	Moment of Inertia, I_Y in^4	.0994	.0250	.0117
	Section Modulus, Z in^3	.1326	.0563	.0347
	Radius of Gyration, ρ in	.623	.377	.283
	Weight lbs/ft^2	4.58	2.48	2.03

NOTE: Panel weights include the effects of heavier sections which exist at the edges of the basic extrusion.

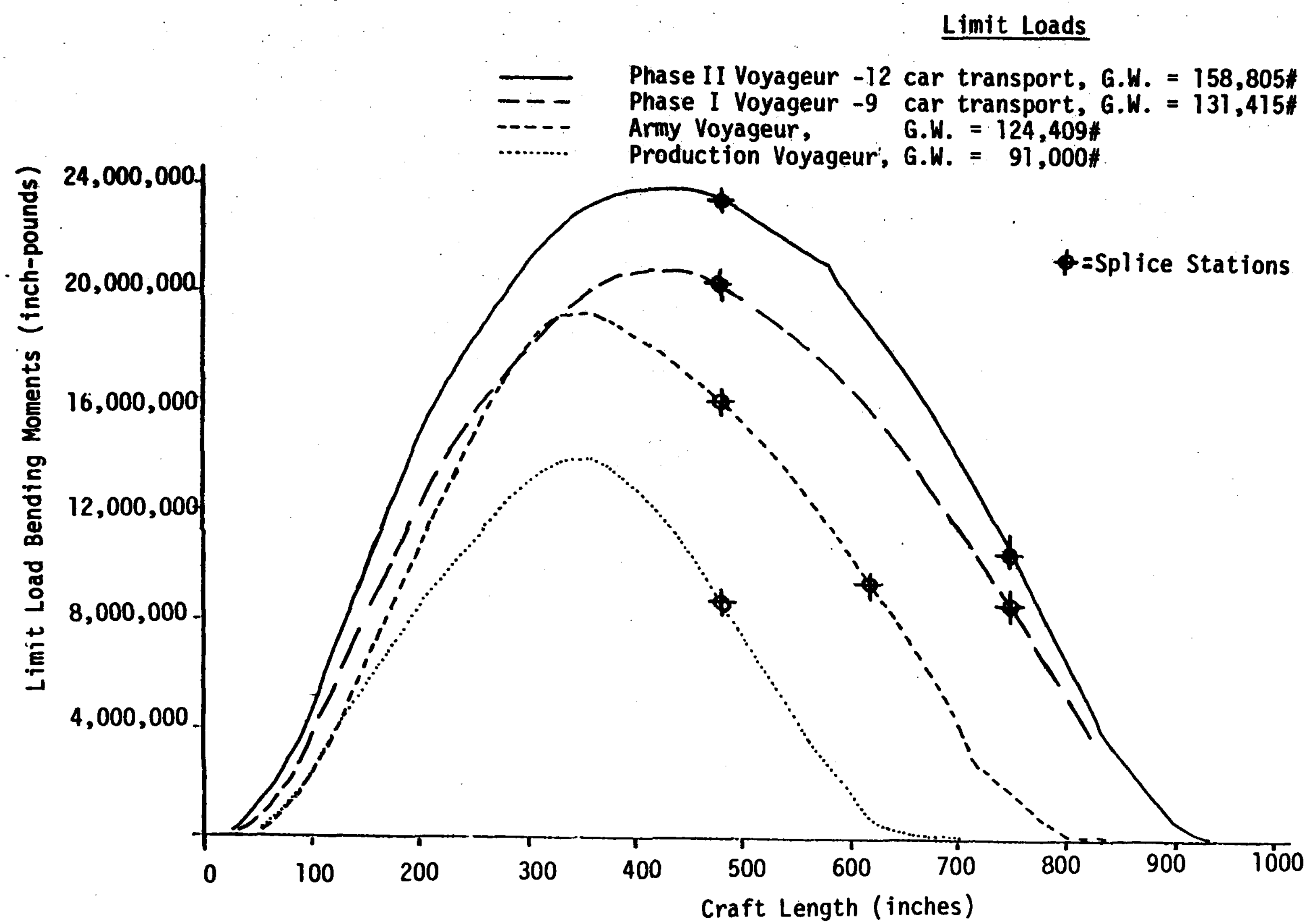


Figure B.14 Bending Moment Diagram for Various Voyageur Configurations
Design Condition Hull-Borne/Sagging (1g Bow/.5g Stern Impact)

Station 618 to 624 splices - Existing AN-5 bolts bearing in the splice extrusion allows the Gross Weight to grow to 154,000 lbs. The finger doubler welded to the future 6063-T6 extrusion is marginal and a static test of the splice is recommended.

The LACV-30 stretch section is 138 inches; therefore, this is the same splice analyzed in the Voyageur stress analysis with details on Figure 9.2 of that report at a G.W. = 91,000 lbs. The critical condition is Unsymmetrical Sagging. (1.0 g Bow Impact/0.5 g Stern Impact.) This analysis determines that the bearing load of the AN-5 (.312 inch diamter) produces the lowest allowable load. The welds on the finger doublers are higher in strength. The lug thickness is 0.25 inches; therefore, the bolt bearing allowable equals 80,000 (.25) (.312) = 6240 lbs.

- Top and bottom splices are the same.
- Bolt spacing = 3.0 inches
- Top splice resultant loading = 1553 lb/in is greater than the bottom splice as shown on page 9.07 of Bell Report 7380-941001 (Reference).
- Total bolt load = 1553 x 3 - 4660 lbs. ultimate
- Margin of safety = 6240/4660 - 1 = +.34. The bending moment at this margin of safety is 8,800,000 in-lbs.
- Consequently, the bending moment capability is 1.34 x 8,800,000 = 11,792,000 in-lbs.
- Applied bending moment at Station 618 to 620 is 9,500,000 in-lbs. Reference Figure B.14.
- G.W. capability, therefore, increases toll .792/9.5 x 124,409 = 154,409 lbs. for the 6105-T6 aluminum alloy.

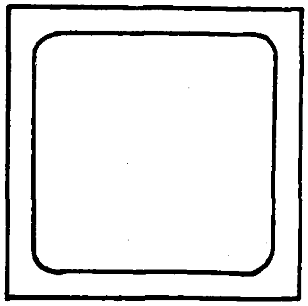
For future craft, 6063-T6 aluminum extrusion material is being planned for the .675 inch deep hollowcore extrusion on the power module decks, bulkheads, etc. This material has substantially lower mechanical properties than 6061-T6 or 6105-T6 material.

The finger doubler shear strength running load capability is 3300 lb/in. as shown on Page 9.08 of Report 7380-941001. This results in a bending moment capability of 3300/1553 times 8,800,000 in-lbs. or 18,700,000 in-lbs. for the 6105-T6 material.

- Therefore, the G.W. capability = 18.7/11.792 (124,409) = <u>197,290 lbs</u>.
- For 6063-T6, G.W. capability = 11/14.4 (197,290) = <u>150,708 lbs</u>.
- Since the weld shear strength of the 6063-T6 extrusion has not been well established on a good data base, a static test of this splice is recommended to verify the strength prediction.

Two truss tubes which are in question are on the BL 150 longitudinal beam between stations 653 and 682 on the LACV-30. The section is shown below. Eight CR 2563-8 (1/4 inch dia.) cherry lok fasteners are used at the end connections.

(Full Size)



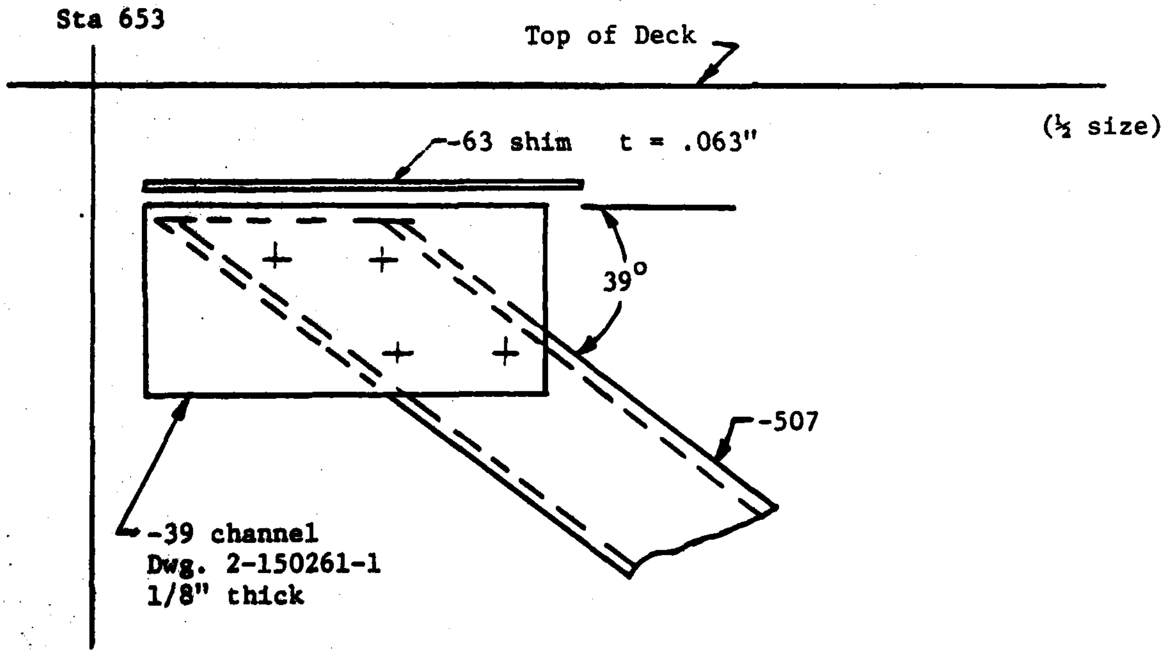
1.5 x 1.5 x .125
A = .688 in^2
I = .218 in^4
P = .563 in
L = 30 in
End Fixity assumed C=2.0
L = 37.7

Column allowable stress
= 31000 psi

Column allowable load
= 21328 lbs

The compressive limit load for the 91,000 lbs. Voyageur is 13,222 lbs. (19,833 lbs ultimate) for Unsymmetrical Sagging as shown in Reference Varying the load in this tube linearly with the G.W., the LACV-30 load in this tube at a G.W. of 150,000 equals 32,692 lbs. A larger size tube is required with a cross sectional area of .934 in^2, assuming the tube is stable as a column and the compressive yield stress is 35,000 psi.

The details of the end connections are shown as follows:



The -39 channel is machined from a larger extrusion and provides capability for two additional fasteners along the tube. The horizontal component of the load shearing into the deck equals 32,692 cos 37^{o} = 26,109 lbs.

- Weld shear strength = 2 .707(.125) thick bead (14,400) (4.5" length) = 11,453 lbs.

- Eight 1/4" dia. bolts bearing in .125" extrusion equals 8(80,000)(.125).25 = 20,000 lbs.

Based on inadequate strength of the tube, weld shear strength into the deck and the bearing strength of the fasteners, a replacement is required to obtain the G.W. = 150,000 lbs. capability for the craft.

B.2.4.3 Landing Pads

Analysis of the landing pads and landing pad support structure is presented in a BAT IR&D stress analysis report (Reference 8). Each landing pad consists of a polyester-based urethane cushion 10 inches high, set in a steel frame which is secured to a reinforced section of the hull. The critical condition is taken for a two-point landing. Landing pad reactions are based on a craft sink speed of 3 ft/sec., with cushion lift equal to 1g. These reactions are ultimate and the landing pad energy absorbing characteristics shall be such as to limit the applied pad load to 2/3g. The pad is also designed to withstand a horizontal load, longitudinally or laterally, equal to one-half of the vertical load magnitude. The longitudinal or lateral loads are to be applied separately or in combination with the vertical load.

The LACV-30 craft is comparable to the British Hovercraft BH7; therefore, the landing pad design criteria as reported in Reference report was reviewed. The variation of landing pad weights and ultimate design loads of the SR.N2 through SR.N6 and the BH7 were compared with Bell's JEFF(B) and Voyageur. Operational experiences of the British Hovercraft have shown that an ultimate vertical landing pad design load of .75 W is satisfactory.

A 50 percent margin of safety exists in the landing pad support structure for the ultimate Voyageur design load of 1.0 W or 91,000 lbs. Coupling this with a .75 W design load, the GW capability becomes (1.50 x 91,000/.75 or 182,000 lbs. The landing pad itself, however permits a GW capability of 91,000/0.75 = 121,330 lbs; consequently, a 24 percent increase in area is required to bring it up to the 150,000 lbs. capability.

B.2.4.4 Skirt Hinges

The skirt hinges attach the longitudinal, corner and side seals to the hull. The hinges are designed for two ultimate load conditions, i.e., 3 x (operating pressure) x 1.5 and 1.5 x (seal full of sea water). For the hinges (limit x 1.5) equals ultimate while for the fabric

TABLE B.5 CRITICAL SEAL HINGE ELEMENTS - 3P CONDITION

Seal	Hinge	Critical Loading	Allowable Loading lb./in.	Allowable Loading lb./ft.	Applied Loading at 115,000 Lb. lb./ft.	Applied Loading at 115,000 Lb. lb./in.
Bow	Aft	Rivet Bearing in Fabric	284	3,400	T_1 = 650	54.1
		Hinge Fitting Weld to Craft	121	1,450		
Corner	Inbd.	Rivet Bearing in Fabric	284	3,400	$2T_1$ = 1300	108.2
		Hinge Fitting Weld to Craft	86	$\boxed{1,030}$		
Side	Outbd.	Rivet Bearing in Fabric	113	1,355	T_2 = 390	32.5
		Hinge Rivet Tension	92	1,102		
		Bending in Hinge	335	$\boxed{401}$		
	Inbd.	Rivet Bearing in Fabric	113	1,355	T_1 = 650	54.1
		Hinge Rivet Tension	254	3,050		
		Bending in Hull Extrusion Tab	109	1,310		
Stern	Fwd.	Rivet Bearing in Fabric	142	1,700	T_1 = 650	54.1
All	Either	Hinge Pin	410	4,910	$2T_1$ = 1300	108.2

(limit x 3.0) equals ultimate. These factors are based on the criteria originally developed by the United Kingdom.

The membrane tension loading applied to the skirt on the side seal versus GW of the craft was taken from Reference 5. In this report the critical seal hinge elements were determined and are summarized in Table B-5 for the 3P load condition. The 401 and 1030 lb/foot allowables in the corner and side of the craft exceed the applied loading.

The corner hinge is critical where the hinge fitting welds to the craft and the side hinge is critical in bending of the hinge itself at the 115,000 pounds LACV-30 Gross Weight. For a Gross Weight increase to 150,000 pounds, modification and reinforcement of these hinges will be required.

B.2.5 Transmission Modifications

B.2.5.1 General Remarks

Modifications will be required of the transmission in two respects:

(a) A reduction in gearbox output shaft speed to account for longer propellers (5 to 10%) and,

(b) Reverse direction of the fan drive shaft, to account for counter-rotating lift fans.

The LACV-30 transmission, shown schematically in Figure B-15 is built by SPECO, Division of Kelsey-Hayes Company. Modification to it, to accomplish the above two objectives are discussed below.

B.2.5.2 Speed Reduction

To accomplish typically a 10% overall speed reduction of (a) above, the helical gearset's number of teeth are revised from 25 and 79 to 23 and 81. This results in the need for a new helical gearset but no other changes to the gearbox since they are directly interchangeable with the old set. By revising the number of teeth as stated, as overall increase in gear reduction of 10.27%. This gives a propeller output speed of 1796 rpm and a fan output speed of 855 rpm for a 6325 rpm input.

B.2.5.3 Fan Drive Reversal

Two different approaches were used to accomplish the reversing of the fan drive of item 2 above. The first method and the one with shorter lead time is to add a differential type gearbox to the bottom of the present gearbox by attaching to the bearing housing. The only change to the gearbox would be to add a pilot diameter to the bearing housing which only requires an additional machining operation. The differential gearbox would consist of a sun gear attached in place of the fan shaft output coupling. This would drive three pinions in turn driving three other pinions which drive the output sun gear. All gears would be spur gears resulting in

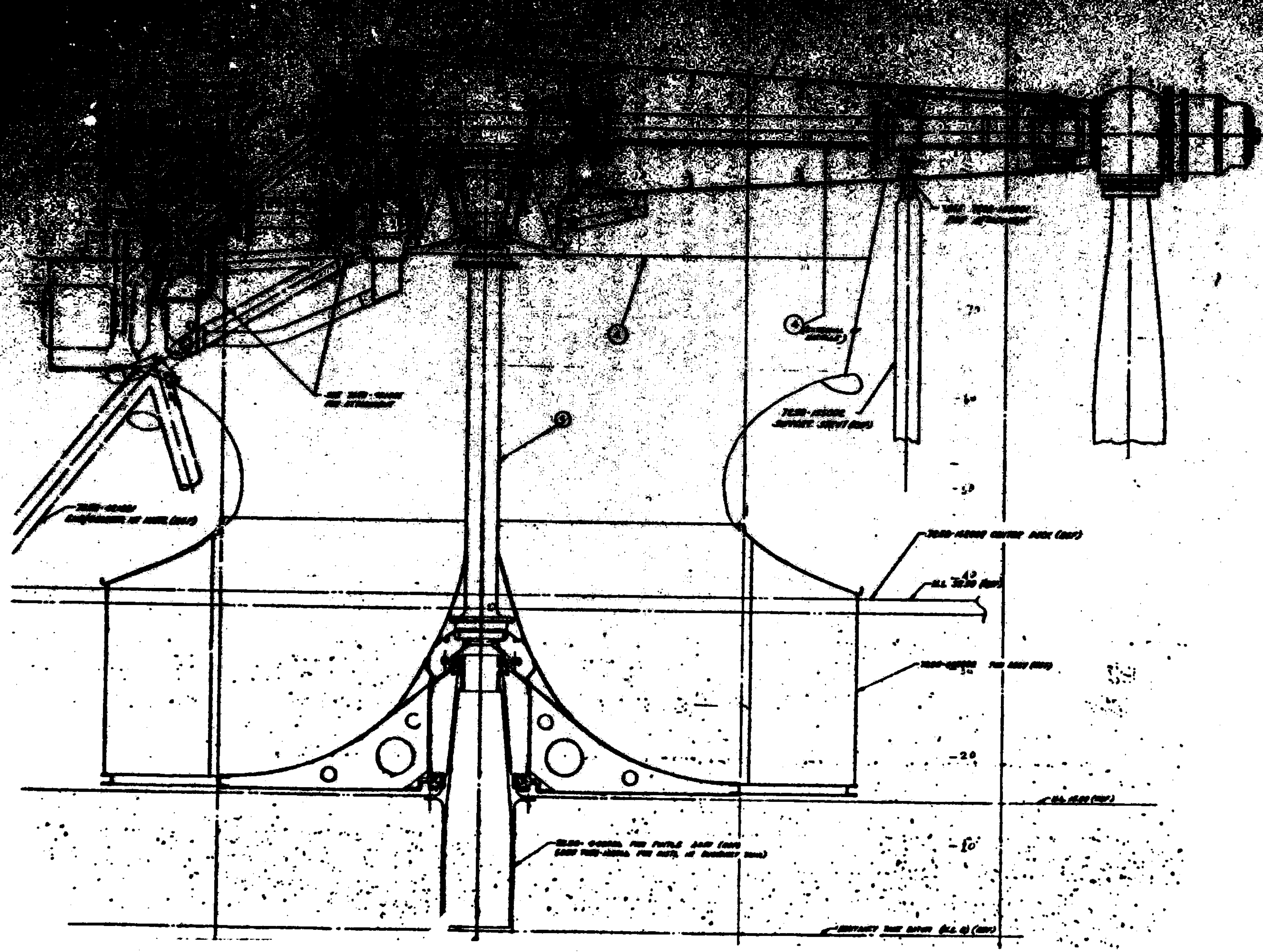


Figure B.15 Schematic of Transmission

minimum development time. The spur gear design and bearing selection is well developed, and there would be little risk of unsuspected problems showing up. This means development time can be quoted with a high degree of accuracy and confidence.

The individual bearings are sized for their respective loads and have a calculated B-10 life of 4500 hours. All bearings and gear meshes are pressure lubricated by oil supplied from the craft to an input at the front of the gearbox. The oil slinger on the output shaft acts as a centrifugal pump to raise the oil to a level equal to the main gearbox drain.

Due to the construction of the reversing drive, it must be built up on the bottom of the gearbox as opposed to being assembled and bolted on. This means that there would be a port and a starboard gearbox built and shipped by SPECO for each craft.

The second method of reversing the fan output is to move the bevel pinion to the opposite end of its shaft. Although on the surface this appears to be the simpler solution, it becomes complicated due to the gear reactions and bearing loads.

The spiral angle of the bevel gear set must be reversed due to the reverse rotation to maintain an axial separating force on the pinion. Then the helix angle and web on the helical gear set must be reversed to counteract the bevel gear reactions. This makes the port helical and spiral bevel gear sets different from the starboard sets. Spiral bevel gear sets have a very long development time since it is a cut and try procedure.

When the spiral bevel pinion is moved, the tapered roller bearing must be moved along with it. This changes some parts where the bearing was and all parts at the other end. The main housing must be changed to accommodate an oil jet to lubricate the spiral bevel mesh. The cover housing must be completely changed and strengthened to carry the tapered roller bearing and its loads. The accessory drive gear and the accessory pads must move out as shown to clear the bearing assembly. The accessory pads are located on a separate cover that mounts to the cover housing.

Although moving the bevel pinion requires a longer lead time, in the long run it will be cheaper and lighter since it does not require additional parts but only modifications of those that are already in use.

Moving the spiral bevel pinion is higher risk than the spur gearbox due to the development of the spiral bevel mesh especially since SPECO does not have a full load/speed test stand.

Conceptually, a surplus power module could be modified, anchored, and instrumented for use as a gearbox test stand. It might also double as a test bed for other power module changes discussed elsewhere.

B.2.6 Engines

Previously, an engine survey was made to investigate power plants of up to 10,000 horsepower (Reference 7). A limited exploration of 200 to 400 horsepower engines was conducted for use in auxiliary power units providing air in the bow portion of the peripheral bag. This survey covered 19 engines in all, some of which were still in development, many were in use, and some were "quite mature", and out of production. It was fairly obvious from the previous engine survey that there should be a modest choice of available engines at whatever future time a commitment to re-engine the LACV-30 might be made.

A tentative selection in the previous study was the AVCO Lycoming TF-25 engine rated at 2500 HP continuous. The A-L TF series are all marinized and use the same mounting attachment pattern, such that a choice of engine model would only depend on power required and price/availability status.

B.2.7 Lift Fans

B.2.7.1 Counter-Rotating Lift Fans

The reverse rotation of the port lift fan is conceptually simple but implementation requires further consideration. The machinery changes for the fan reversal involve repositioning the bevel pinion gear in the #2 gearbox, a (new) fan impeller with mirror-image blades, and mirror image volutes in the plenum. Also the volute section in the center aft buoyancy box was repositioned slightly providing another significant gain in lift system performance. The aerodynamic design of the reversed BHC fan is to be retained with only the blades being made in a mirror image. The main disk and the upper shroud should not require any changes. The reversed blades and all their attachments to the disk and shroud will require new tooling and a new assembly fixture. The reversed fan should not require any structural or performance development testing or any other form of certification.

The associated changes in the gearbox are discussed in Section B.2.5.

The installation of the reversed fan into the port power module will require new volutes. The removal of the existing volutes can be accomplished either by cutting the sheetmetal and leaving the attachment flanges in place thus preserving the watertightness of the flotation boxes, or by drilling out the flange fasteners and removing the entire volutes and attachment flanges which will leave the plenum cleaner aerodynamically but will require plugging and sealing the holes in the buoyancy box. The installation of the new volute section will require wet-fastener type of assembly to maintain buoyancy box watertightness. The repositioning of the volute section in the center module will be accomplished in a manner similar to the plenum volute.

The propellers will still rotate in the same direction as before. Smoke visualization flow studies of air entering the fan inlet showed no visible swirl such that no change in propeller installed performance is expected. Fan gyroscopic reactions onto the hull due to hull motions will now cancel each other.

B.2.7.2 High Performance Lift Fans

This modification of the LACV-30 is of major significance in terms of performance improvement but the physical machinery changes are only slightly more complicated than the reversed rotation of the existing port fan. The major emphasis here is, of course, the new impeller design. Some plenum changes will also be required in the volutes and the depth of the plenum. It is possible to install the high performance fan(s) with or without the reversed rotation fan drive on the port side. Some lift performance loss would occur for synchronous rotation, but it is estimated that synchronized high-performance fans would still provide more lift than counter-rotating BHC fans.

Several important aspects of the new fan are its aerodynamic performance, mechanical design and methods of construction, and the manufacturing technology to build it.

Aerodynamic performance analysis methods have advanced to a sophisticated state via the application of finite difference/finite element techniques. Most of these analysis results need to be tempered with experimental data to be useful for fan design. Once a given design has been tested, classical analysis methods are usually sufficient to predict the effects on performance of small perturbations to the original design. This latter method has been used for the LACV-30 fan, as discussed below.

The analysis of fan pressure-flow performance is depicted in Figure B.16 where the various pressure (head) rise and loss components are defined and plotted as a function of flow. Outside diameter and RPM determine the ideal maximum pressure. Blade angle and exit area determine the slope of the "Euler line". The various other losses are functions of the blade passage proportions, shroud gap, and blade leading edge angle. Constraints were set down for RPM (hold constant at 945), diameter (7 ft. max., smaller if possible), rated flow (bring fan closer to peak efficiency), and rated pressure (20% higher pressure to support increased gross weight).

A small computer program was developed to iterate on the fan design parameters. Increasing the number and trailing-edge angle of the blades increases the pressure. The width of the fan outlet (height of blades) and the blade leading edge angle influence the flow rate at peak efficiency. A photo of the current BHC fan and the high performance fan are shown in model form in Figure B.17.

Correlating the computer program predictions with the test results of several existing fans generally similar to the LACV-30 fan, has indicated that it is possible to obtain this improved performance. The construction features of a high performance fan will be good aircraft practice in order to keep weight down within the current 350 lbs. per fan. Weights higher than this may require strengthening of the pintle and pintle support structure as well as upgrading the fan impeller bearings. The main disk and upper shroud will be built-up sheetmetal construction, and machined

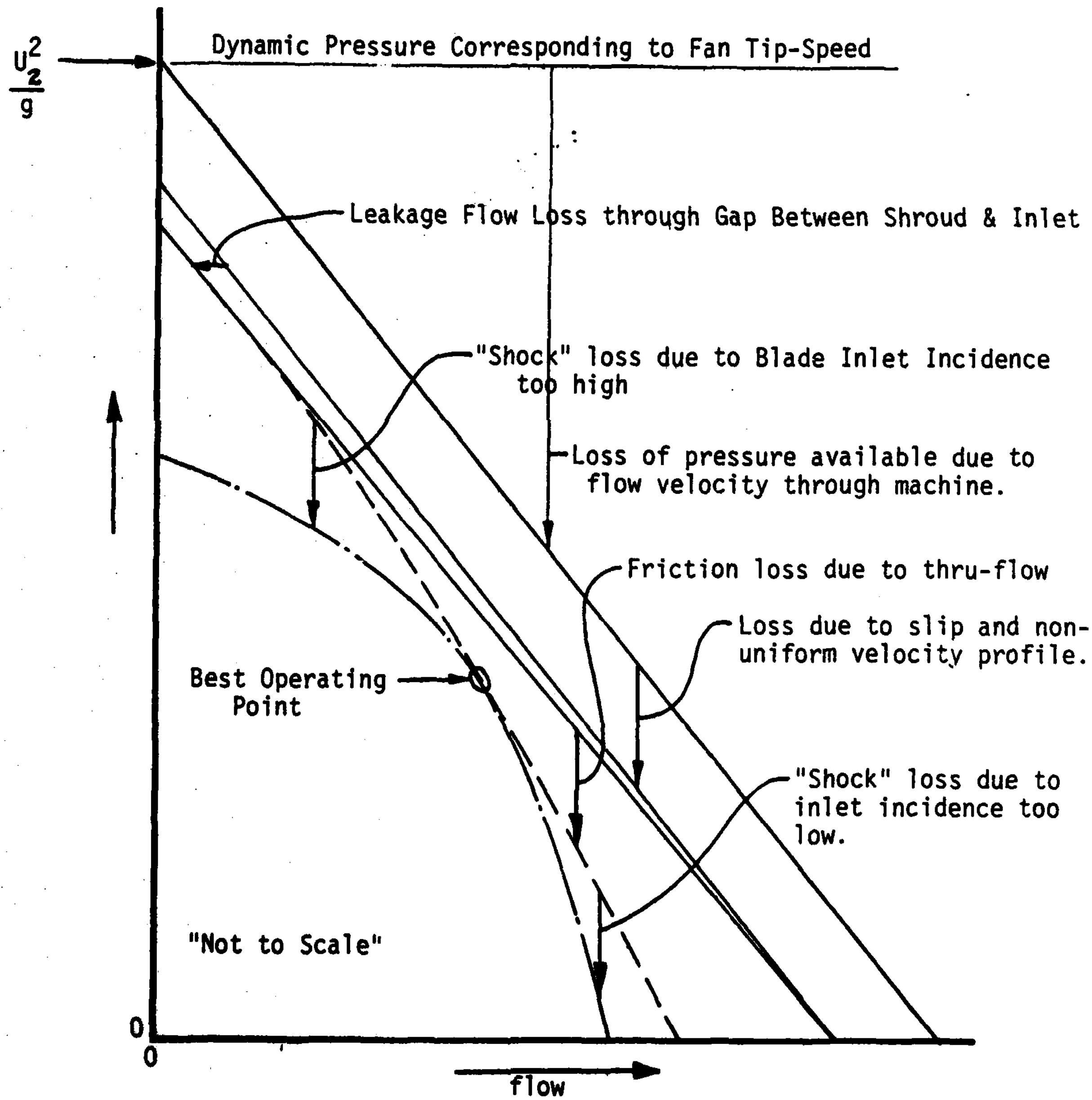
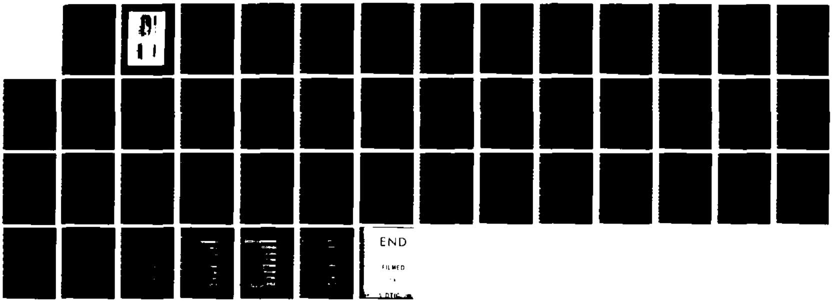
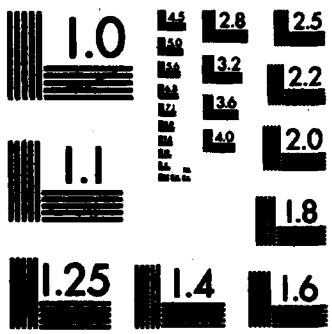


FIGURE B.16 FAN PERFORMANCE PARAMETERS

AD-A133 804 LACV-30 INCREASED PAYLOAD STUDY(U) BELL AEROSPACE TEXTRON WHEATFIELD NY AUG 83 7467-928028 DAAK70-82-C-0196 2/2

UNCLASSIFIED F/G 1/3 NL




1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

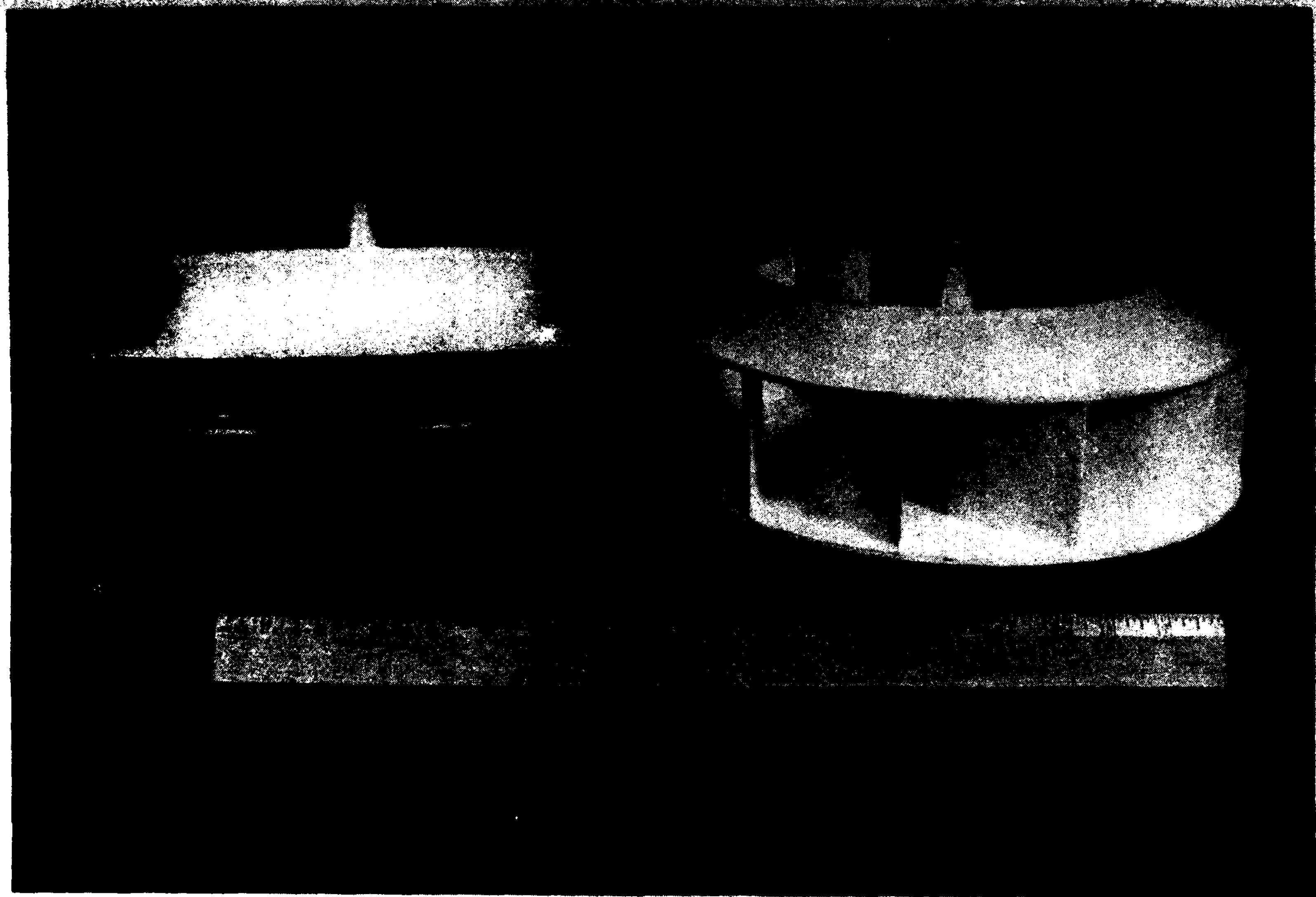


FIGURE B.17 BELL HIGH PERFORMANCE (LEFT) AND BHC PRODUCTION LIFT FANS
(NEG. #340180-7)

parts will be used for the bearing supports and drive coupling connection. The blades will be either extruded or built-up airfoil section. Protective coatings will be applied to the fan blades similar to current practices.

Although not as involved as fan design, efficient diffusion of the air as it leaves the fan is quite important. The trusses in the power module encroach on the diffusion process of the current fan. Any reduction in fan diameter, while still meeting the pressure-flow requirements, will aid the diffusion in the plenum because the extra space between fan tips and the trusses will reduce the interference. Since a high performance fan will have significantly shortened blades, raising the plenum floor to the back plate of the fan will maintain smooth air flow through the plenum. Reshaping the volutes should also be beneficial because of the different flow angle out of the new fans. The false plenum floor can be fabricated out of sections of hollowcore plate with suitable spacers attached to the existing plenum and the new plate. New volutes will use existing type construction.

All of the above remarks also apply to a new fan for upgrading to a LACV-45.

B.2.7.3 LACV-45 Lift Fan

The previous discussion included the constraint that fan speed was fixed at 945 RPM ±5% nominal. To be practical, a 45-ton payload LACV requires new machinery including fans, engine, propeller and gearbox. Since the gearbox is new (because of increased power, different propeller gearing, etc.), advantage can be taken of the opportunity to redesign the lift fan without the RPM constraint. Previous preliminary studies have indicated that a 5 ft. diameter fan rotating at about 1600 RPM to be the optimum design which meets the LACV-45 pressure and flow requirements. A final iteration on the design of lift fan would naturally be included in any future LACV-45 design efforts.

B.3 Weight, Balance and Buoyancy

The Weight and Balance of the LACV-30 has to be kept within prescribed limits for safe and efficient operation. The changes in the center of gravity location due to the redesigned components presented in this report are expected to be insignificant.

The new rear seal should weigh the same or slightly less than the current seal. Reversal of the port lift fan should leave the fan and gearbox weighing the same as before; the volute for the reversed fan should weigh less than the current volute because it is smaller. The high performance lift fans are not expected to weigh significantly more than the current fans but depend on the manufacturing technology used (fans significantly heavier than the current fans will require reinforcement of the pintle and upgrading the fan bearings). Proper diffusers for the high performance lift fans could add up to several hundred pounds in each power module. The larger diameter propeller will add only a few pounds due to the longer blades; the gear ratio change and reshaping the aft apron under the prop will be about the same as current weights for these pieces.

In all, whichever options are used, the net c.g. changes due to component replacement to the LACV-30 will be quite small and trim control should remain the same as before.

One area which may require additional study and/or analysis is the positioning on deck of the heavier containers and other cargo, allowed by the new higher payload capability. No problems are anticipated, since the LACV-30 has a built-in fuel trim system which will be able to account for any c.g. shifts caused by the additional payload.

Marine vehicles are required to have a buoyancy reserve of 100% of their all-up design weight. In the case of the LACV-30, buoyancy is provided by air spaces, subdivided by watertight bulkheads. Requirements stipulate that damage to any one subdivision or rupture will not exceed 20% of the total buoyancy provided.

The intact LACV-30 has a maximum design buoyancy of 311,500 lbs. in salt water, 303,700 lbs. in fresh water. At a maximum gross weight of 135,000 lbs., this results in reserve buoyancies of 130% and 124%, respectively. (Maximum gross weight that meets the 100% reserve requirement is 155,000 lbs.)

In a damaged condition, the loss of buoyancy allowed in the criteria is 20%, or 62,300 lbs. in salt water, 60,740 lbs. in fresh water. In the most extreme damaged condition, losses will not exceed 37,791 and 36,845 lbs. respectively. Both values are well below the criteria.

APPENDIX C

SYSTEM SYNTHESIS

C.1 Approach

Appendix B has been devoted to defining the various LACV-30 hardware modifications necessary to improve the lift and propulsion system as necessary to increase payload without compromising performance. This section covers the portion of the study in which the modifications were assembled into a series of design options to the LACV-30 and analyzed for performance. Options which were selected included payloads progressively raised from the 25-30 ton range up to a minimum of 45 tons. Each of the candidate options were then analyzed, by means of a computer performance program which predicted LACV-30 speeds for varying gross weight and sea-state conditions.

C.1.1 Air Cushion Vehicle Performance Computer Program

The evaluation of the various increased payload configurations in terms of overwater speed and lift system performance has been done using the Bell Aerospace Textron computer program "ACVPRF". This program is the latest of several previous program versions, each of which was an expansion and/or refinement to suit analysis requirements. Figure C.1 is a block diagram showing the two main sections for the lift system and the speed analysis. Also indicated are the modular data files for vehicle and machinery component definition.

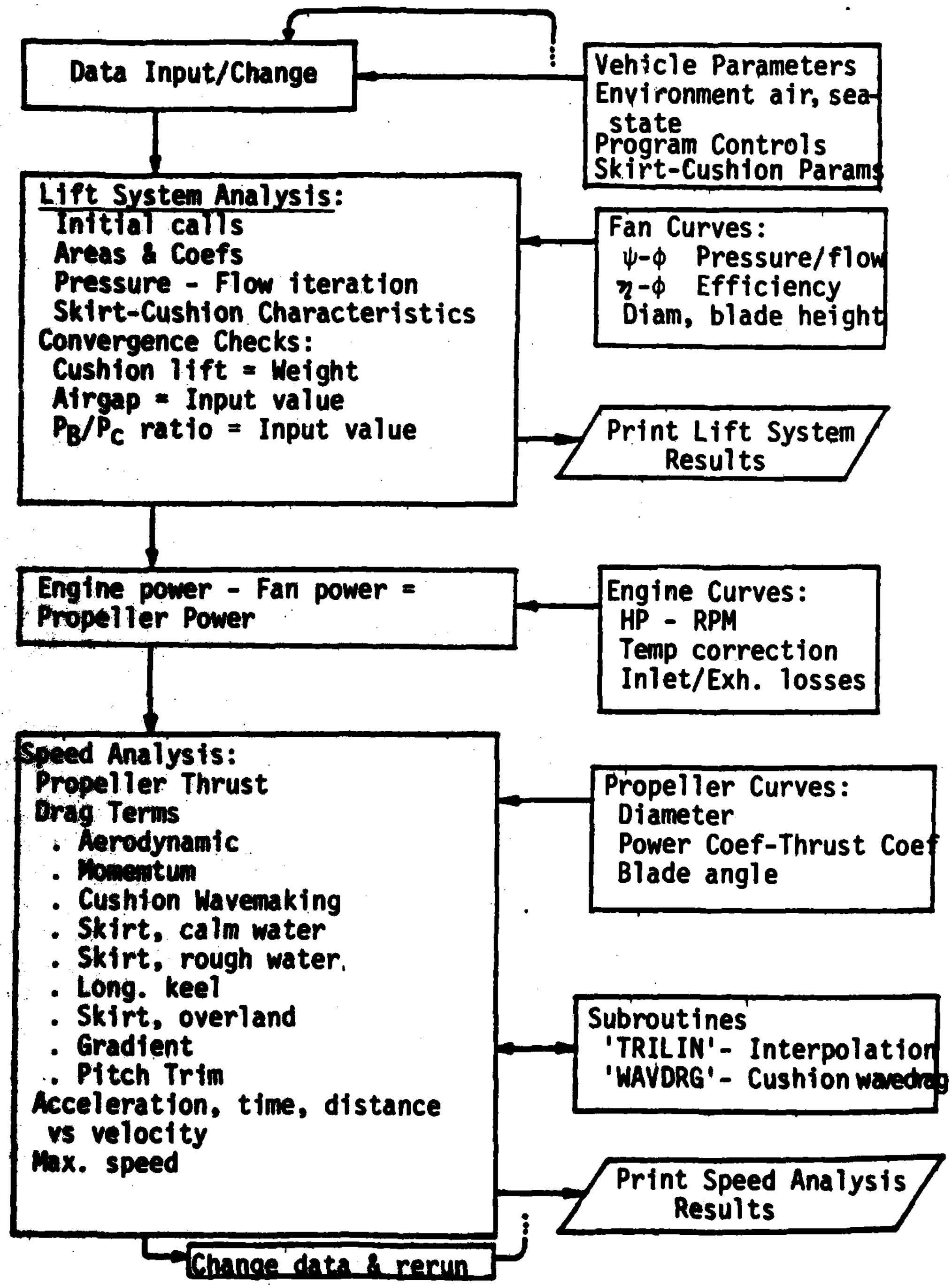
Figure C.2 presents a schematic of the LACV-30 lift system for analysis of pressures, flows, fan operation, etc. Figure C.3 shows the degree of correlation achieved with the lift system math model. Actually only one side of the LACV-30 is modelled due to symmetry. Because of the nonsymmetry of the fan plenum volutes, twice the average fan flows and power are used. The input data files are defined in Reference C.1 for the vehicle data, engine, fan, and propeller, respectively.

Maximum craft speed overwater at continuous engine power has been calculated for ranges of gross weight and sea-state of the various configurations.

Correlation of computed and experimental top speeds is shown in Figure C.4, where the dotted line indicates a 3-4 mph over prediction of top speed.

Reference C.1 - ACV Performance Program - Input Data Files for the LACV-30 IP Program. Bell Aerospace Textron Report No. J. Hughes, April 1983.

Figure C.1 ACV Performance Analysis Computer Program



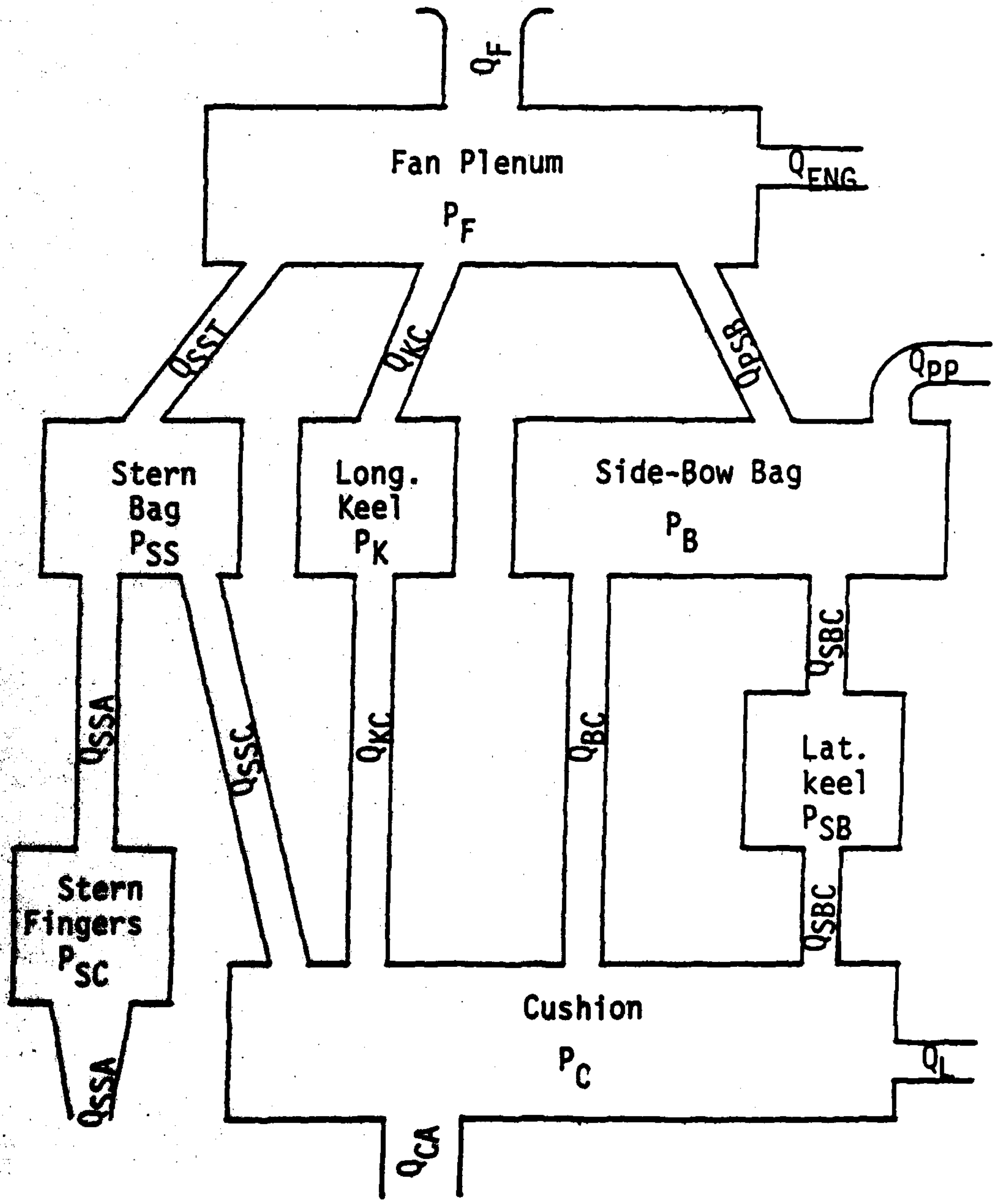


Figure C.2 Schematic of LACV-30 Lift System

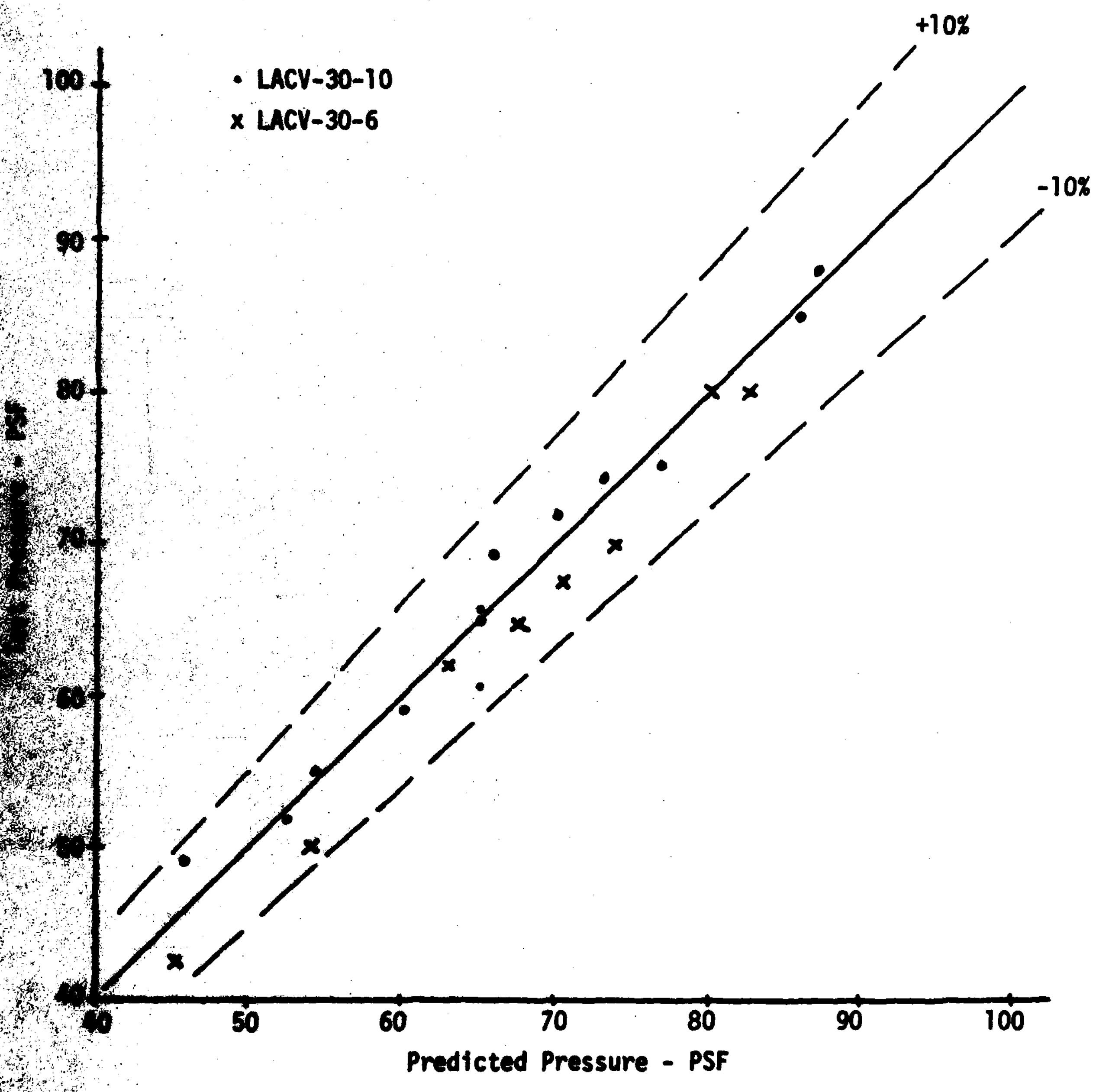


Figure C.3 Comparison of Test and Predicted LACV-30 Lift System Pressures

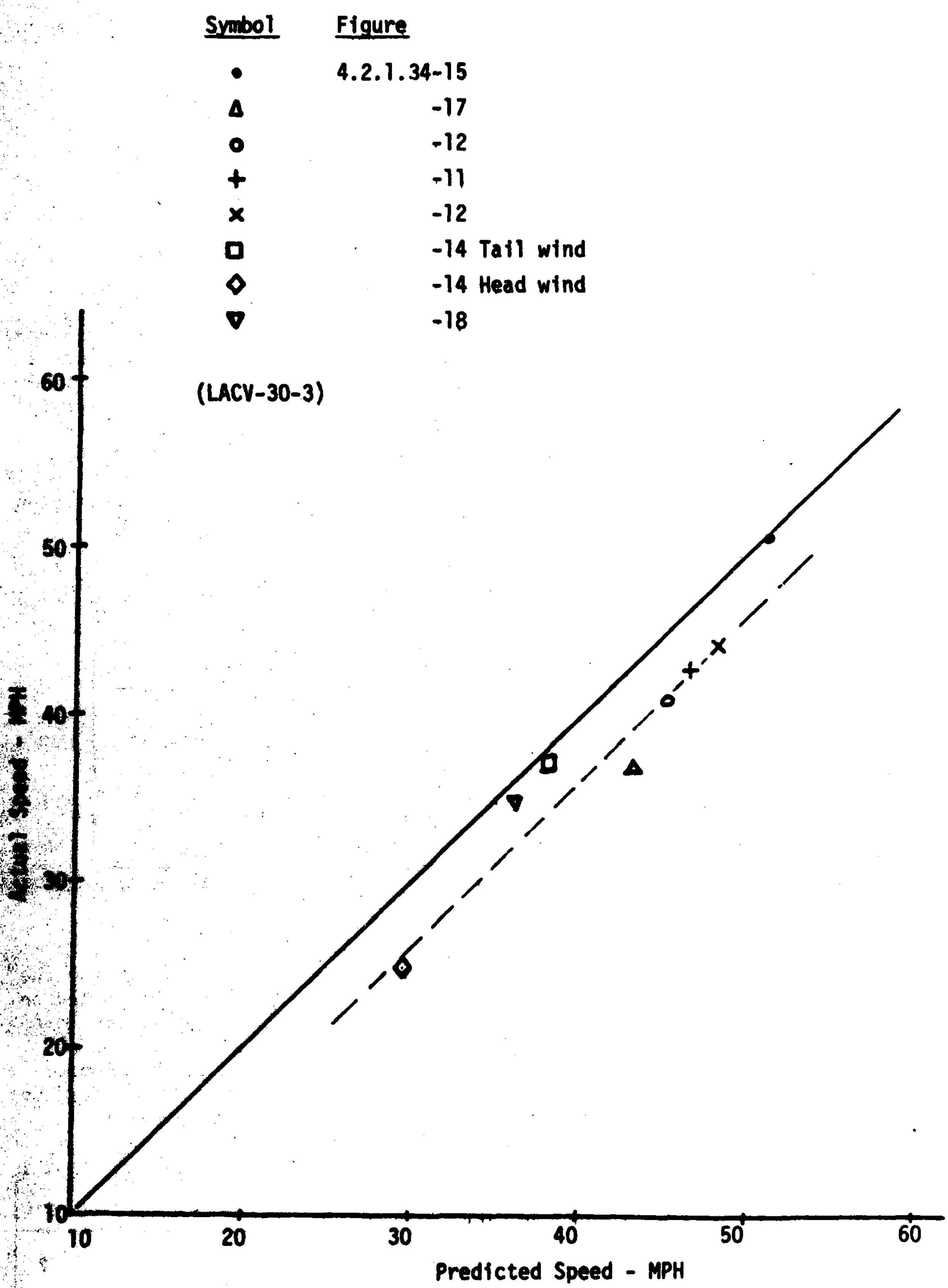


Figure C.4 Comparison of Predicted and Actual Test LACV-30 Speeds

C.2 Definition of the LACV-30 IP Options

Option 1 - Unmodified LACV-30

Throughout the report, the unmodified LACV-30 is referred to as Option 1. Where appropriate, values of LACV-30 performance, cost and cost effectiveness are included in the study, and used as comparison with corresponding values obtained for all subsequent options.

For the record, the LACV-30 is designed for operating at a maximum design gross weight of 115,000 pounds, and will achieve a performance typical of that indicated in Figure C.5. Table C.1 summarizes the LACV-30 performance in a variety of standard sea-states, and gross weights varying up to 155,000 lbs. Presently, the LACV-30 is certified to operate at a maximum gross weight of 125,000 lbs. (overload). Weights in excess of 125,000 lbs. are beyond the design limits of both the structure and the lift system; and without modifications, neither reliable nor safe operation can be expected.

TABLE C.1 - LACV-30 PERFORMANCE

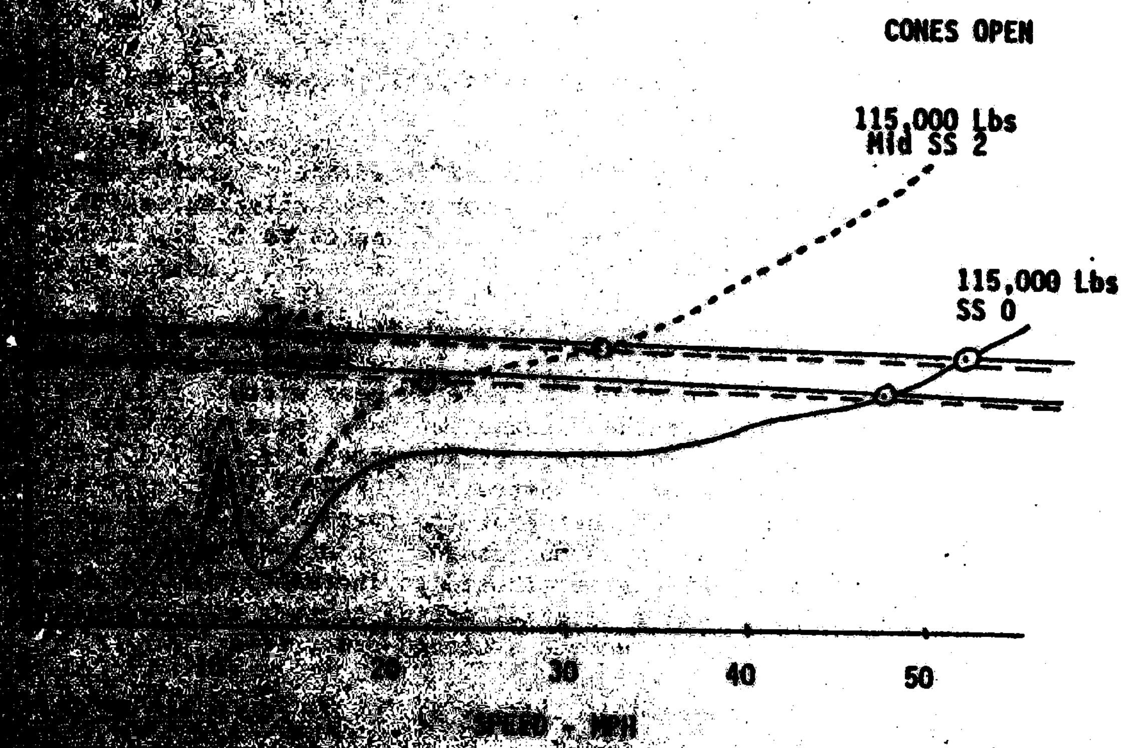
Gross Weight Pounds	Lower SS 0	1	2	3	4
		(MPH)			
75,000	50.4	48.1	38.4	27.7	21.9
95,000	49.1	46.7	36.4	24.2	19.3
115,000	47.5	43.2	33.3	19.8	17.6
135,000	40.0	37.7	20.6	17.5	16.5
155,000	19.0	18.7	17.5	16.5	15.9

Option 2 - Wrap-Around Stern Seal and Raised Keel

A wrap-around, aft sloping open-cone bag-finger design for the stern seal has been selected as Option 2 for the LACV-30. When modeled on [illegible], a performance as shown in Figure C.6 is obtained. The modifications include the new stern seal as described in Appendix B, and a raised longitudinal keel to overcome excessive water drag at the heavier weights. A discussion of keel drag is presented in Appendix B. Performance as a function of gross weight and sea state is given in Table C.2.

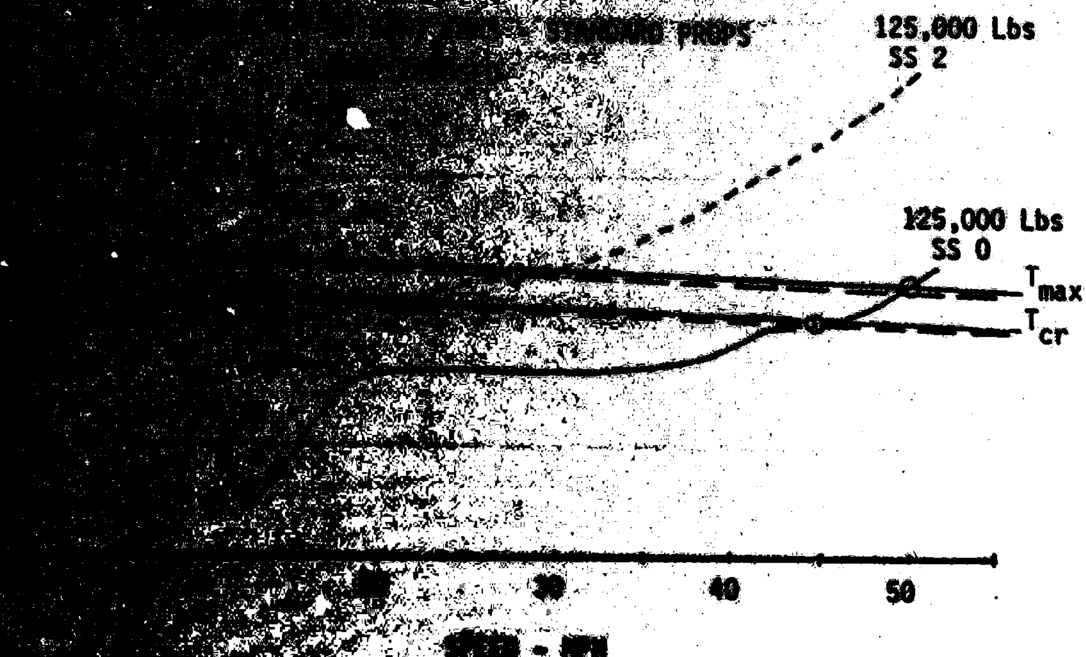
TABLE C.2 - PERFORMANCE OF LACV-30 OPTION 2

Gross Weight (Pounds)	Sea State - Lower 0	1	2	3	4
	(MPH)				
75,000	52.2	49.9	40.3	29.4	23.2
95,000	50.5	48.5	38.2	26.2	20.4
115,000	49.2	46.8	35.8	21.4	18.1
135,000	42.4	31.6	22.4	17.9	16.8
155,000	21.8	19.9	18.0	16.8	16.2



PERFORMANCE

STANDARD PROPS



PERFORMANCE

Option 3 - Wrap-Around Stern Seal, Raised Keel and 5-1/2 Ft. Hull Stretch

Option 3 includes all the modifications of Option 2, plus the additional feature of a 5-1/2 ft. stretch of the hull, increasing the on cushion length of the LACV-30 from 75 ft. 5 inches to 80 ft. 11 inches. The [illegible] of the LACV-30 is unaffected.

The purpose of the hull stretch is to decrease wave drag through the region of hump speed. By stretching the craft, cushion pressure is lowered, without a corresponding increase in beam width. This, in effect, reduces wave drag, which reaches maximum at hump speed at around 19 mph. Figure C.7 presents drag and thrust, versus speed for the 5-1/2 ft. hull stretch. The performance of the unstretched LACV-30 (Option 2) is presented for comparison. As can be seen, the speed of the craft is improved by several mph through the 15-25 mph range. At higher speeds, the Option 3 craft is not as fast. This is attributed to increased surface drag due to the increased amount of skirt material making contact with the water. Wave drag at these higher speeds becomes a second-order effect.

Table C.3 contains a listing of the Option 3 speeds as a function of gross weight and sea-state.

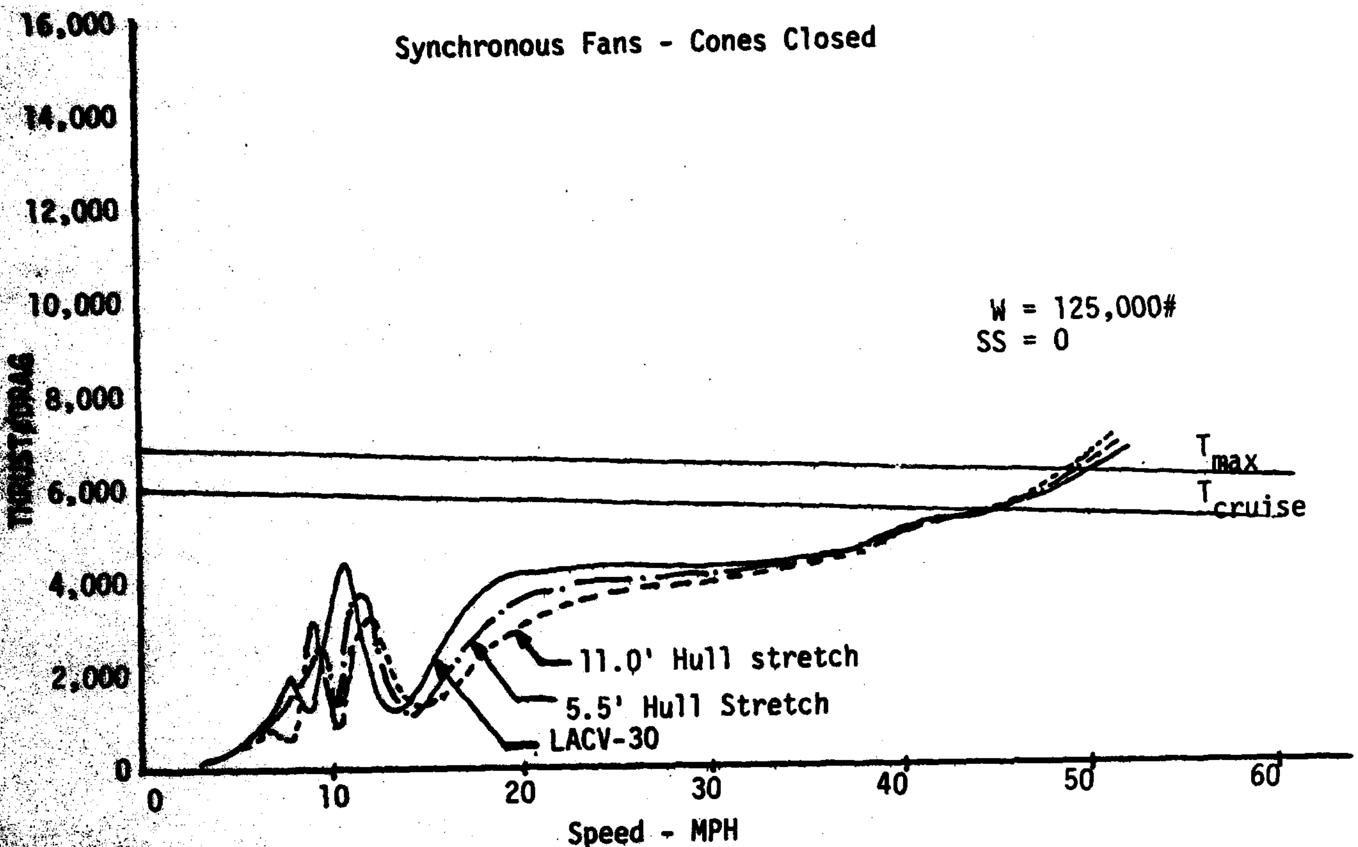
TABLE C.3

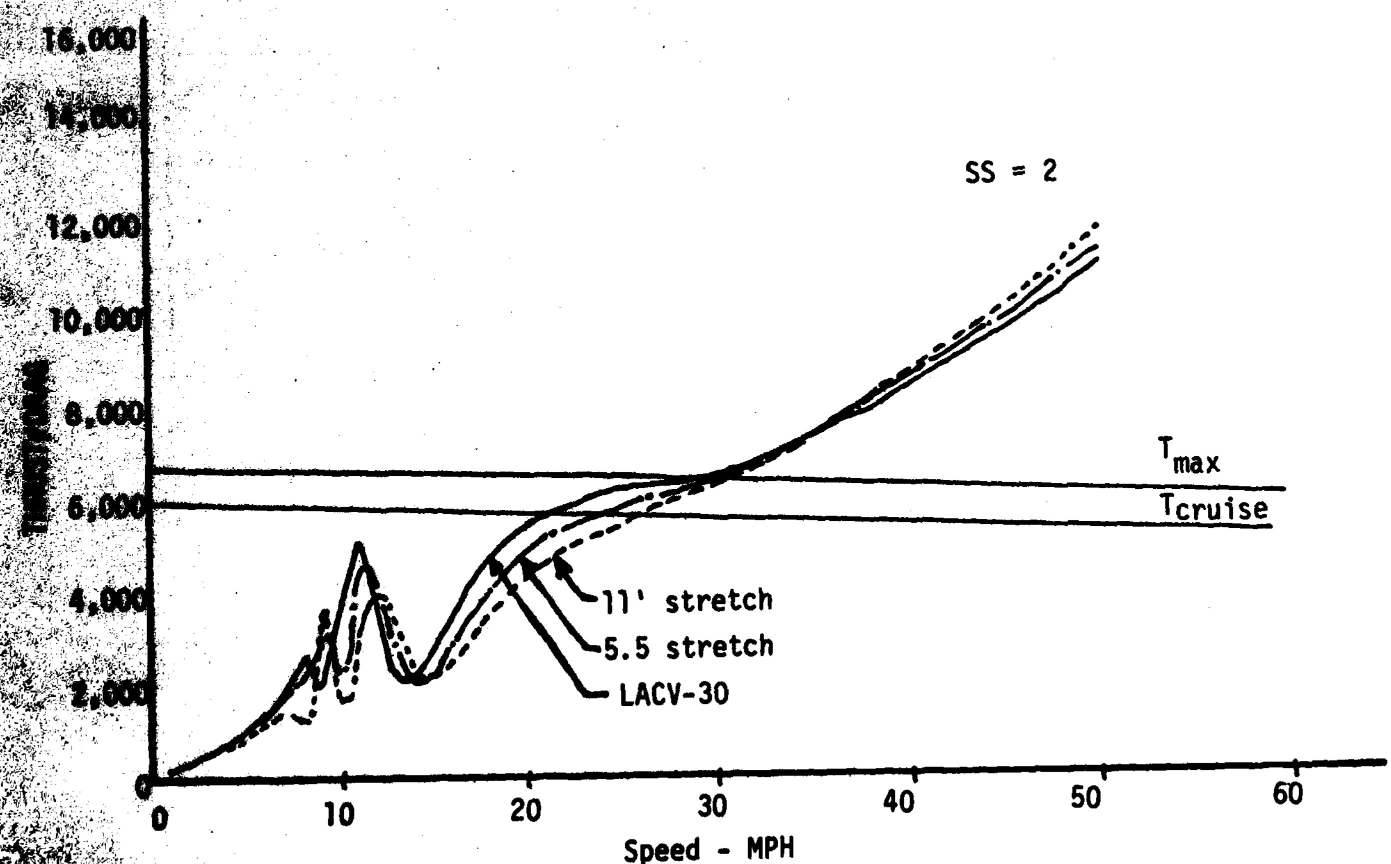
[illegible]	Sea-State-Lower (mph) 0	1	2	3	4
[illegible],000	51.6	49.4	39.9	29.1	23.3
[illegible],000	50.1	47.9	37.9	26.7	21.2
[illegible],000	48.6	45.9	35.6	22.8	19.2
[illegible],000	42.6	39.9	29.0	19.7	17.9
[illegible],000	13.1	35.5	20.8	18.1	17.0

Figure C.7

LACV-30 Performance

Synchronous Fans - Cones Closed





Option 4 - Counter-Rotating LACV-30 Lift Fans with Wrap-Around Stern Seal and Raised Keel

As described in Appendix B, an increase of another 5 tons (payload can be obtained when the lift fans of the LACV-30 are in the counter-rotating configuration shown in Appendix A. The objective of this section is to evaluate the LACV-30's performance when the above modifications are incorporated into the design.

Figure C.8 presents the drag/thrust versus speed curves for this option. Comparison is made with the LACV-30 unmodified case. As can be seen, the drags of Option 4 are considerably higher, for both the SS-0 and mod SS-2 cases. In the former, a few miles per hour are lost in the 40-50 mph region, which can ordinarily be tolerated. For the latter case, 4 mph are lost at 18-22 mph. This will have a substantial reduction in the crafts productivity, as discussed in Appendix D.

Table C.4 presents a listing of speeds (mph) versus gross weight and sea state, for Option 4.

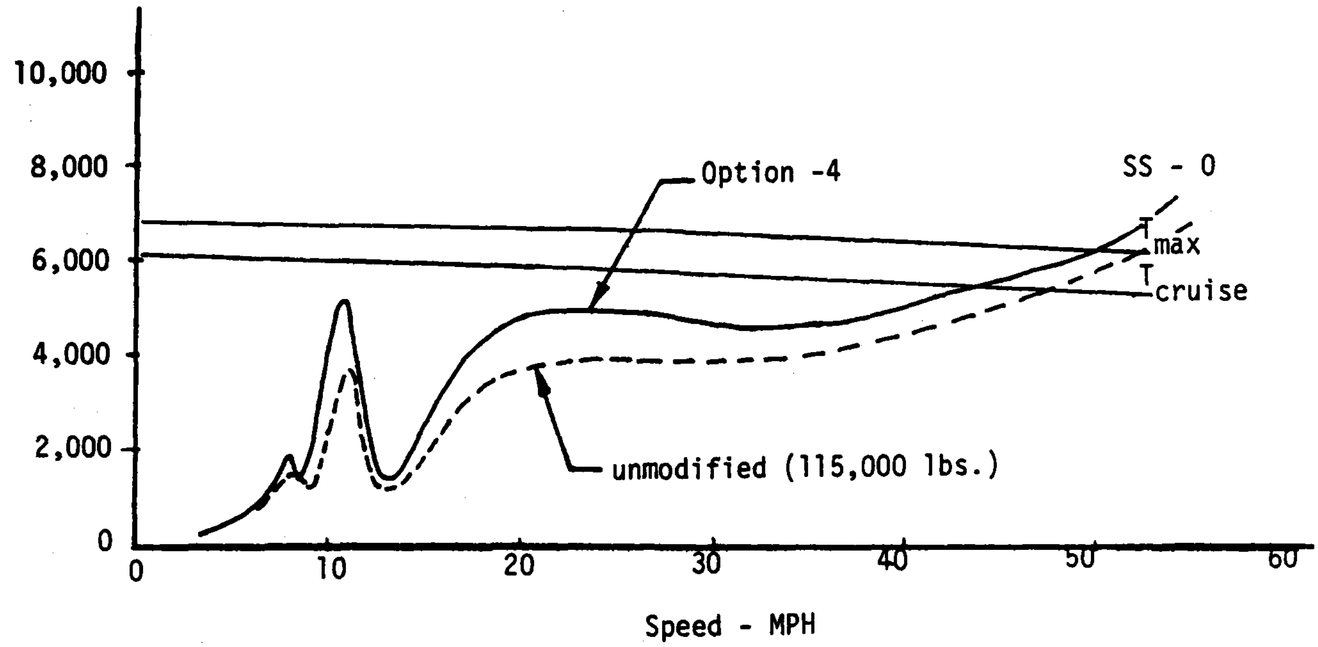
TABLE C.4 SEA-STATE LOWER

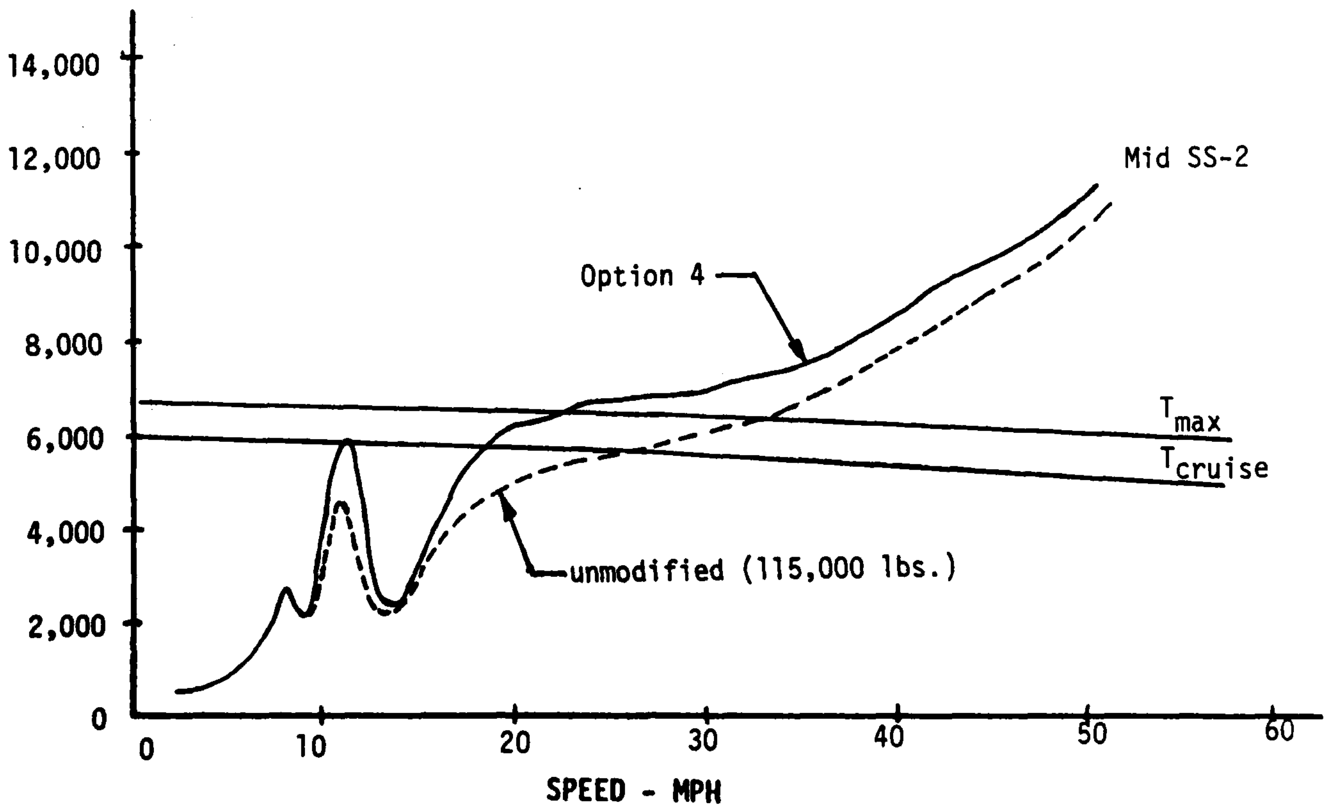
Gross Weight pounds	0	1	2	3	4
75,000	52.2	49.7	40.2	29.2	23.0
95,000	50.4	48.3	37.9	25.8	20.1
115,000	49.0	46.5	35.4	20.9	17.9
135,000	42.1	39.5	21.9	17.8	16.7
155,000	21.2	19.0	17.8	16.7	16.1

FIGURE C.8

LACV-30 OPTION 4 PERFORMANCE AND COMPARISON

WITH THE UNMODIFIED LACV-30 CRAFT





Option 5 - Counter-Rotating LACV-30 Lift Fans with Wrap-Around Stern Seal, Raised Keel and 5-1/2 Ft. Hull Stretch

Option 3 addresses the effects of a hull stretch for the purpose of recovering some of the speed lost on the LACV-30 due to increased gross weight. Option 5 studies the same effects, when a hull stretch of 5-1/2 ft. is applied to Option 4.

Figure C.9 presents Option 5's performance for the two sea-states, and makes the comparison with Option 4 and the unmodified LACV-30. As seen, the 5-1/2 ft. stretch regains 2 of the 4 mph lost by Option 4 for the mid SS-2 conditions, but loses speed at the higher speed ranges.

Table C.5 presents the listing of Option 5 speeds.

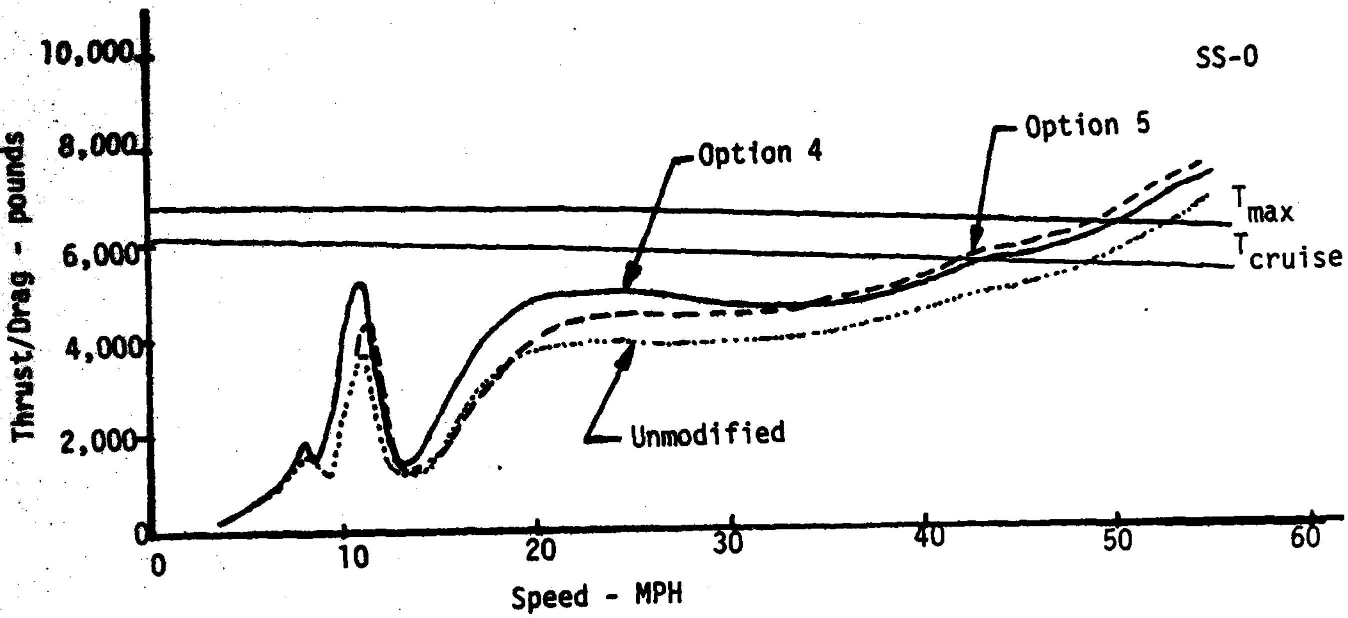
TABLE C.5

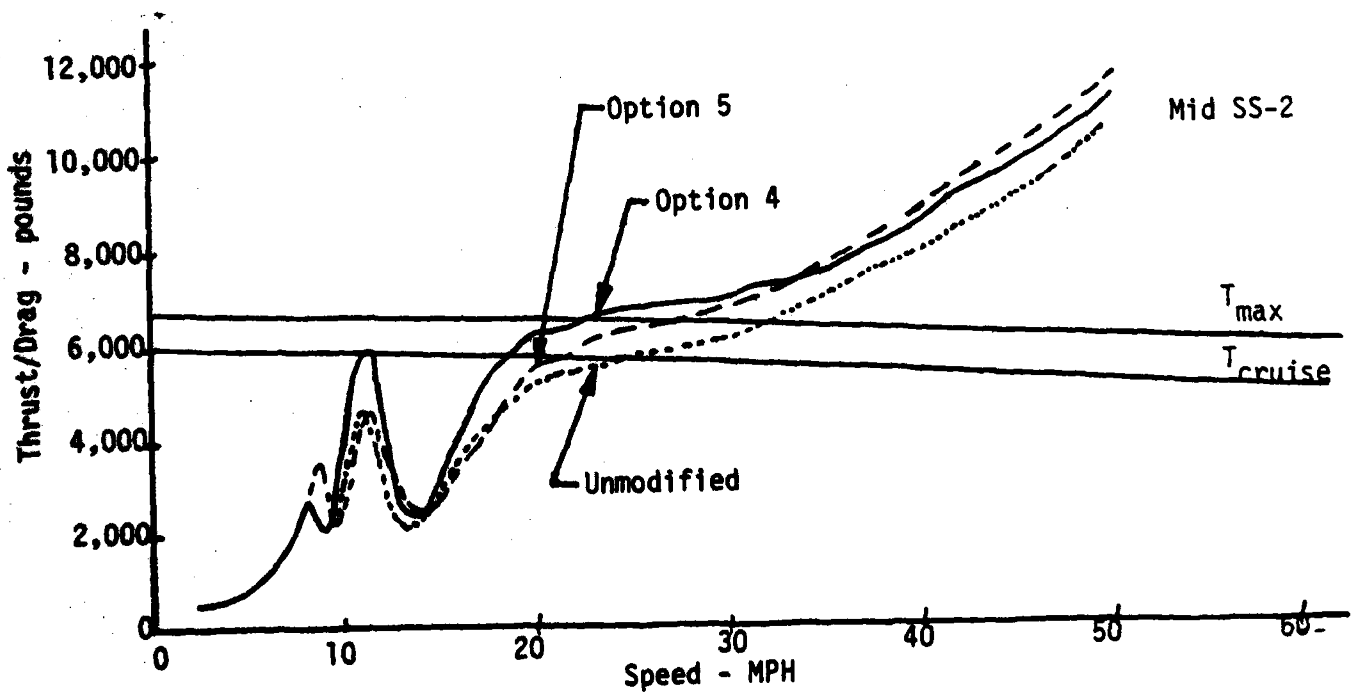
Gross Weight pounds	Sea State - Lower				
	0	1	2	3	4
75,000	51.7	49.3	39.8	29.0	23.1
95,000	50.0	47.8	37.7	26.4	21.0
115,000	48.6	45.8	35.4	22.6	19.0
135,000	42.2	39.7	28.4	19.4	17.7
155,000	38.0	35.0	20.5	18.0	16.9

Figure C.9

LACV-30 OPTION 5 PERFORMANCE AND COMPARISON

WITH THE UNMODIFIED LACV-30 CRAFT





<u>Option 6</u> - High Performance Counter-Rotating Lift Fans with Wrap-Around Stern Seal and Raised Keel

This option incorporates the high performance lift fan design discussed in Appendix B into the LACV-30. Later options will include slower fan speeds and larger diameter propellers, but Option 6 retains the 940 rpm lift fan speeds connected with the 1980 rpm propeller speed. The corresponding performance curves for lift are given in Figure A.15 of Appendix A. As seen, the increase in lift performance appears to be sufficient to allow the LACV-30 to operate up to 150,000 lbs. gross weight. The computer program results shown on Figure C.10 indicate that at these weights, the craft would have difficulty operating above 11 mph in mid SS-2. A stretching of the hull would reduce drag, however, this would require a redesigned structure to withstand the loads (See Section of Appendix B).

An analysis of Option 6 operating at 135,000 lbs. gross weight was studied. Performance results, predicted from the computer program ACVPRF are given in Figures C.11. In this case, some decrease in drag is obtained, however, the conditions are still tenuous for operating in the mid and high SS-2 conditions.

Table C-6 presents the speeds predicted for Option 6, operating at the 135,000 lbs. gross weight condition.

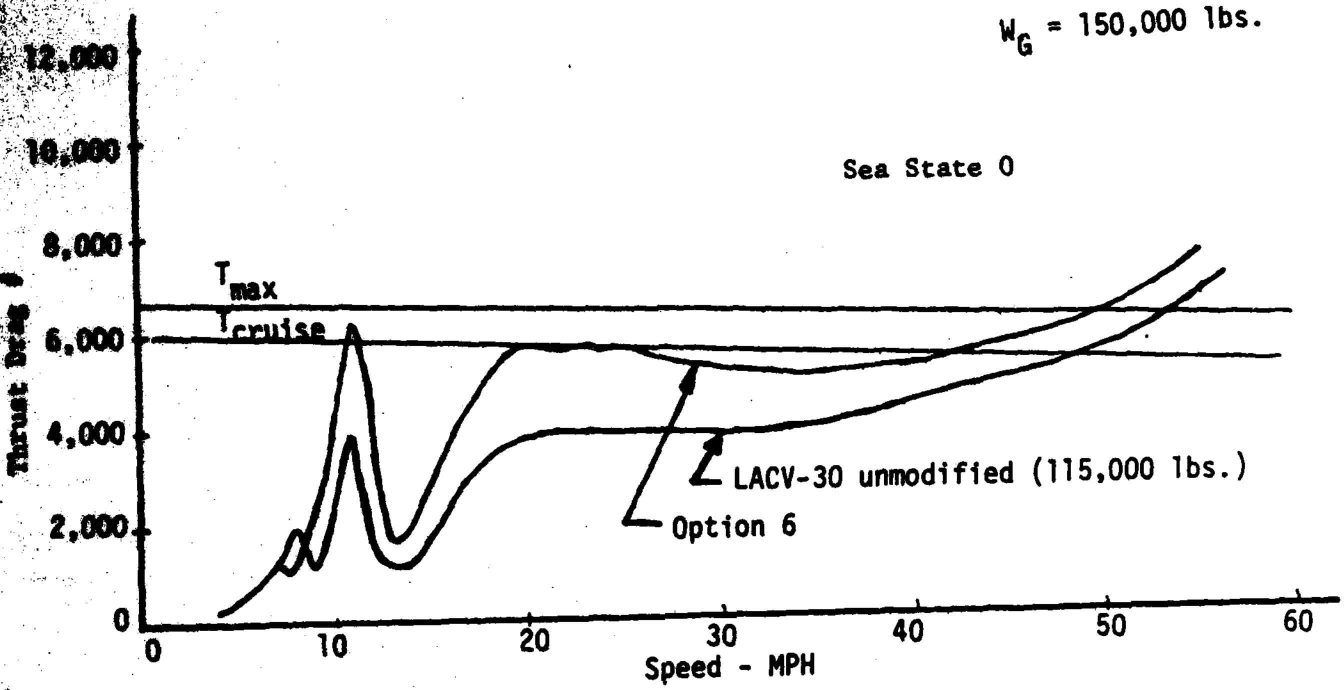
TABLE C-6

Sea State - Lower

Gross Weight Pounds	0	1	2	3	4
75,000	51.9	49.5	49.8	28.8	22.7
95,000	50.2	48.0	37.2	25.0	19.4
115,000	48.9	46.3	34.8	19.9	17.6
135,000	41.5	39.0	20.3	17.4	16.5
155,000	18.9	18.6	17.4	16.5	15.9

Figure C.10

LACV-30 PERFORMANCE



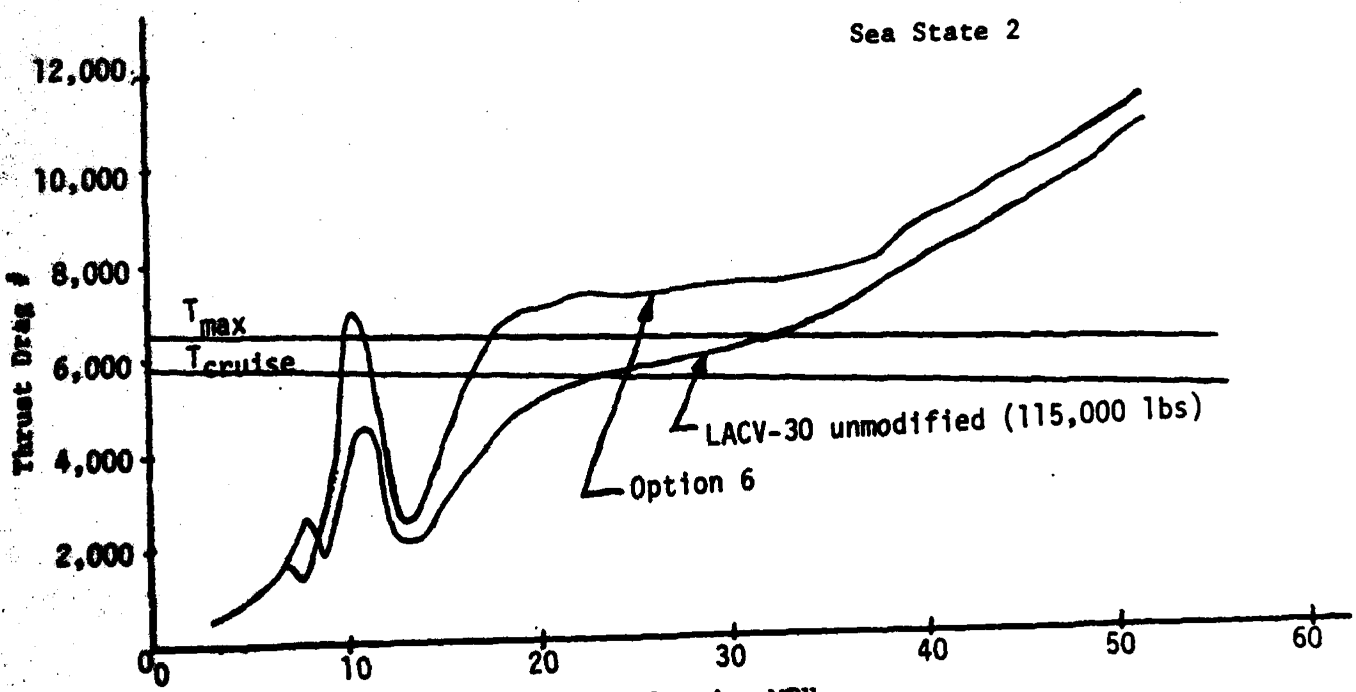
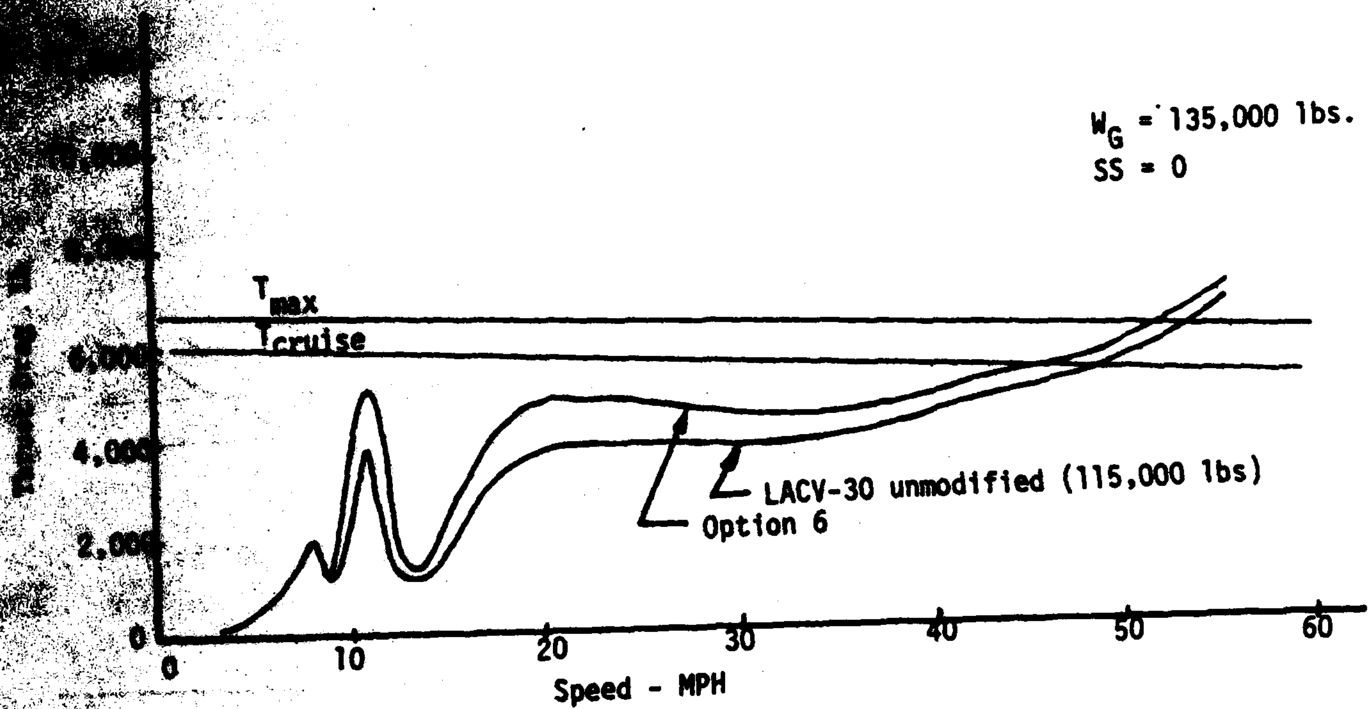
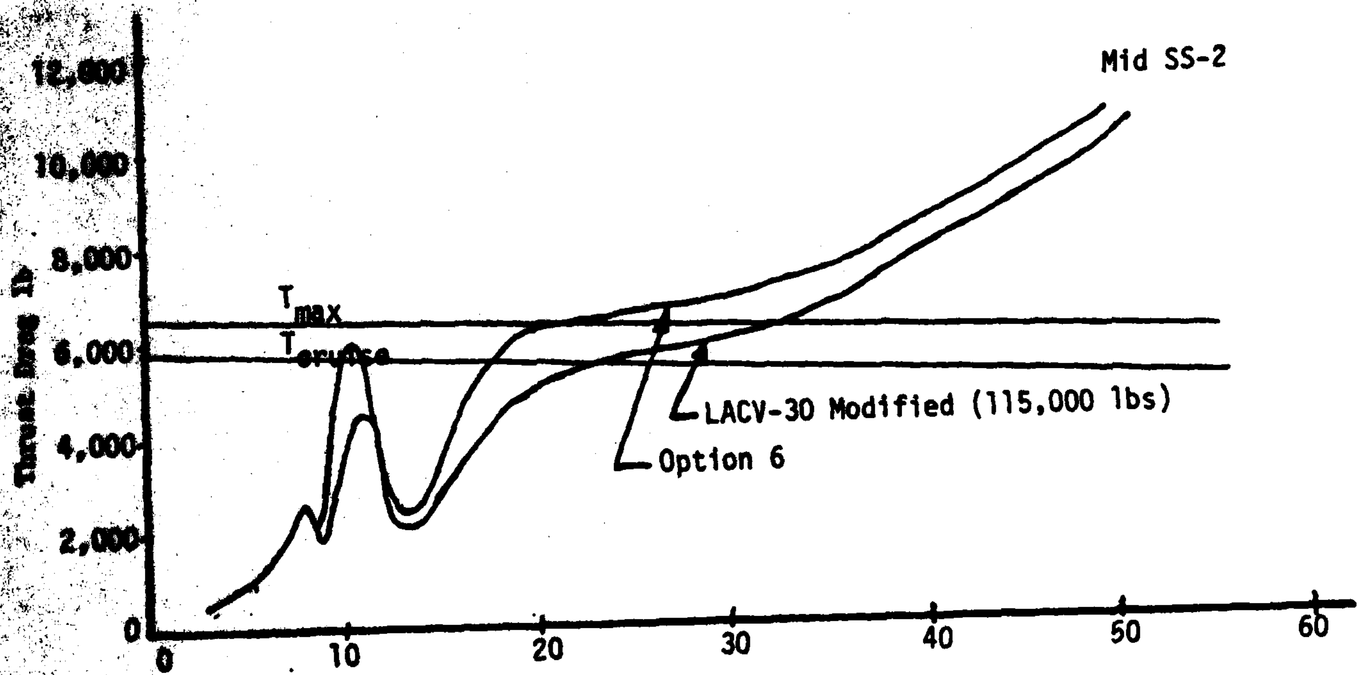


Figure C.11

LACV-30 PERFORMANCE





Speed - MPH

Option 7 - High Performance, Counter-Rotating Lift Fans with Wrap-Around Stern Seal/Raised Keel, 9-1/2 Ft. Diameter Propellers at 90% RPM

Option 6 incorporated the high performance lift fans, but, as seen in the performance runs, it was not possible to develop sufficient thrust to operate reliably in the 20-30 mph speed regime in mid and upper SS-2. Option 7 includes the 9-1/2 ft. diameter propellers, coupled with a reduction in the gear ratios in the transmissions. This allows the propellers to operate at the same tip speeds as they now operate at, while simultaneously slowing lift fan speeds (approximately 5%), thus making available additional horse-power for increased forward thrust. This effect is discussed in Appendix B; this section quantifies the performance.

Figure C.12 presents the performance of Option 7 for the two sea-state conditions: SS=0 and SS= mid two level. The T_{max} and T_{cruise} values of thrust have been increased about 700 lbs., and as shown, the Option 7 performance is roughly equivalent to the unmodified LACV-30 operating at 115,000 lbs. gross weight.

Table C.7 presents the matrix of Option 7 speeds at varying gross weights and sea state.

TABLE C.7

Sea State - Lower

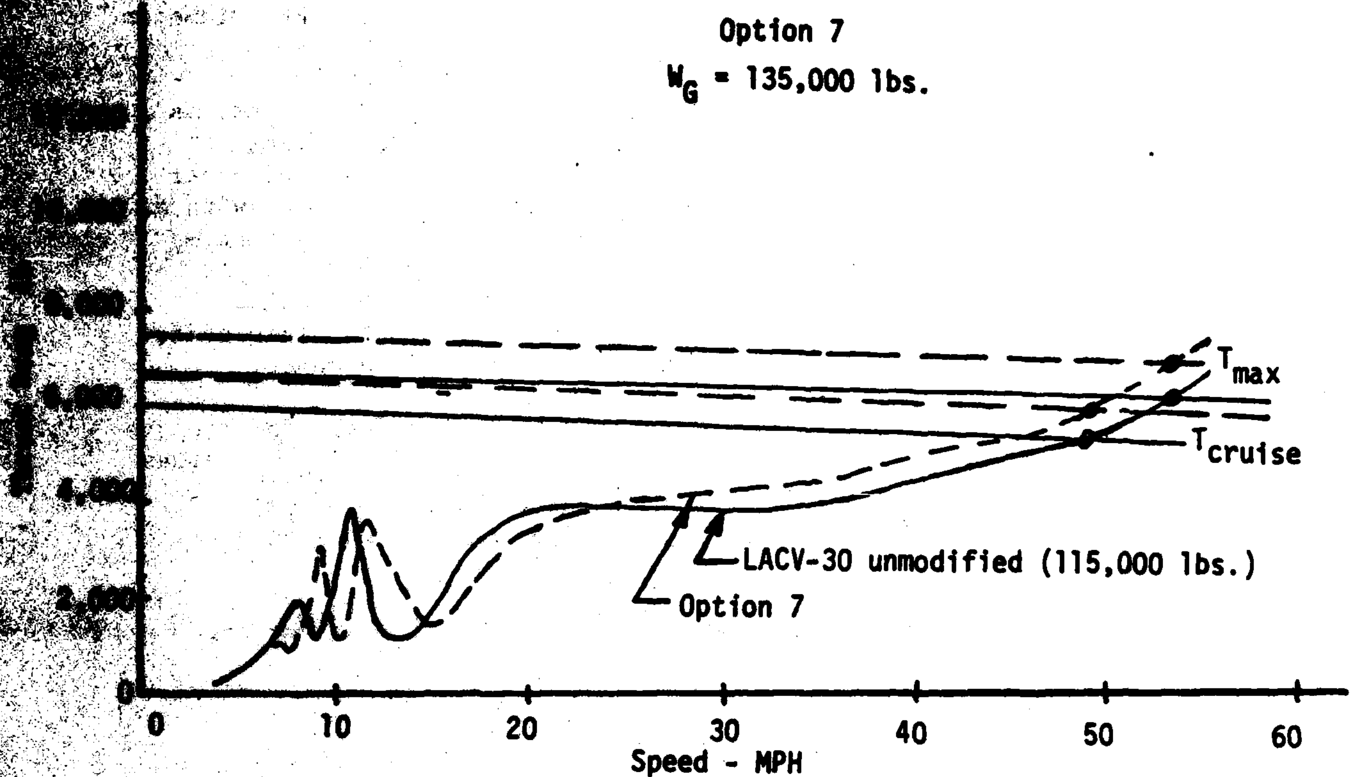
Gross Weight Pounds	0	1	2	3	4
75,000	54.7	52.0	42.8	31.3	24.9
95,000	52.7	50.4	40.5	28.7	22.1
115,000	51.0	49.0	38.1	23.7	18.9
135,000	47.6	42.5	30.9	18.6	17.2
155,000	40.3	38.0	18.6	17.1	16.5

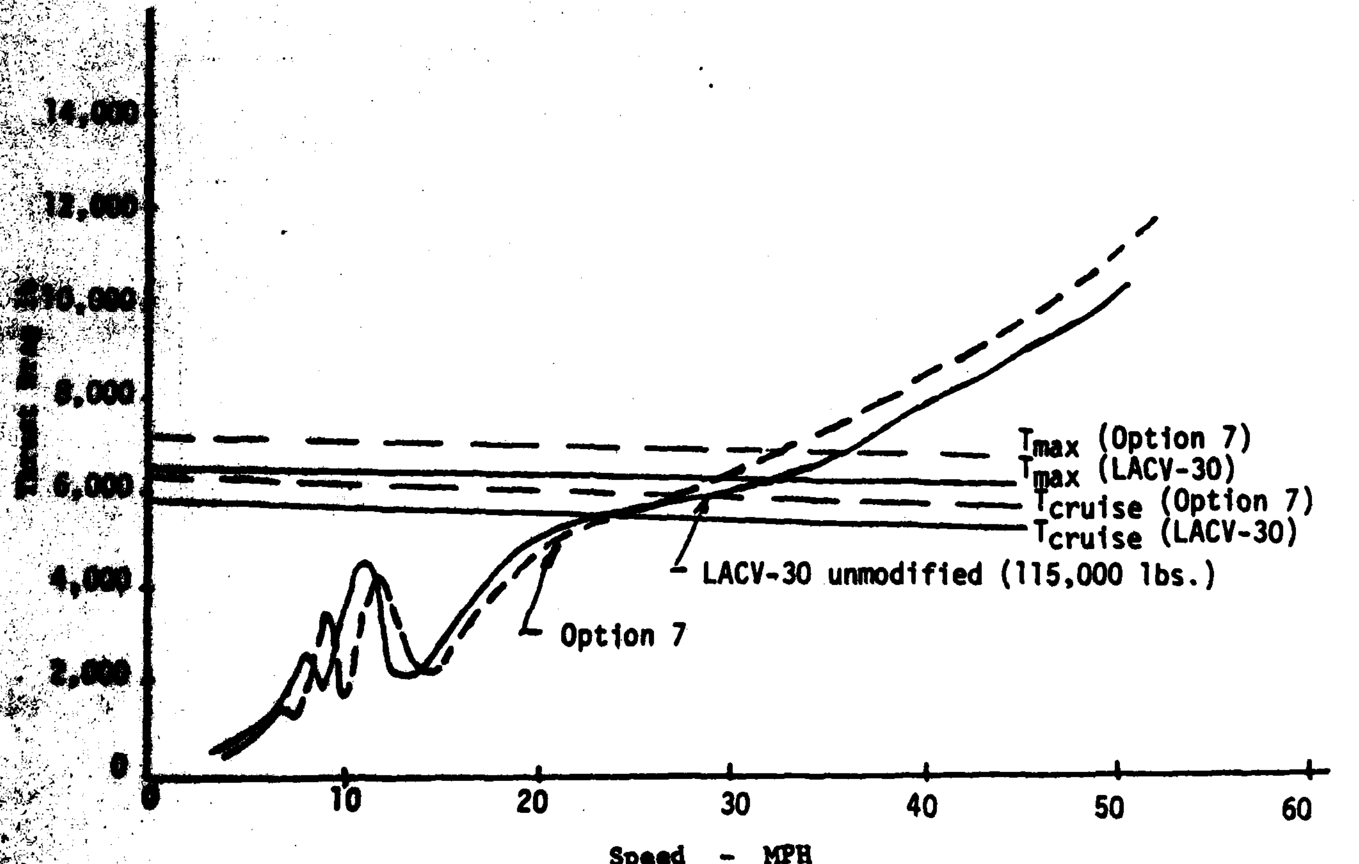
Figure C.12

LACV-30 PERFORMANCE

Option 7

W_G = 135,000 lbs.





Option 8 - High Performance, Counter-Rotating Lift Fans with Wrap-Around Stern Seal/Raised Keel 9-1/2 Ft. Diameter Propellers at 90% RPM 5-1/2 Ft. Hull Stretch

Option 8 presents all of the best options considered to this point, rolled into one configuration. Figure C.13 presents the performance, and Table C.8 the listing of speeds as a function of gross weight and sea-state.

As seen, the performance of Option 8 is roughly the same as Option 7, except that 2-3 mph extra speed is realized through the 19-24 mph "hump speed" region.

TABLE C.8

Gross Weight Pounds	Sea State - Lower 0	1	2	3	4
75,000	54.1	51.4	42.3	30.9	24.8
95,000	52.2	49.9	40.1	28.7	22.5
115,000	50.5	48.4	37.9	25.1	20.4
135,000	47.1	42.6	33.3	21.0	18.5
155,000	40.8	38.7	22.4	18.7	17.5

Option 9 - Typical LACV-45

To put the previous increased payload options into perspective, a typical LACV-45 configuration at 160,000 lbs. was analyzed with the performance computer program. The various components used were AVCO Lycoming TF-40 engines, a 5 ft. diameter lift fan, 11.25 ft. diameter propellers, and the current hull and skirt dimensions.

Figure C.14 shows overwater performance for 3 sea-states and a power setting corresponding to 3000 Hp per engine. Obviously this massive infusion of power provides all the speed performance one could possibly use for LOTS missions.

Figure C.13

LACV-30 Performance

Option 8

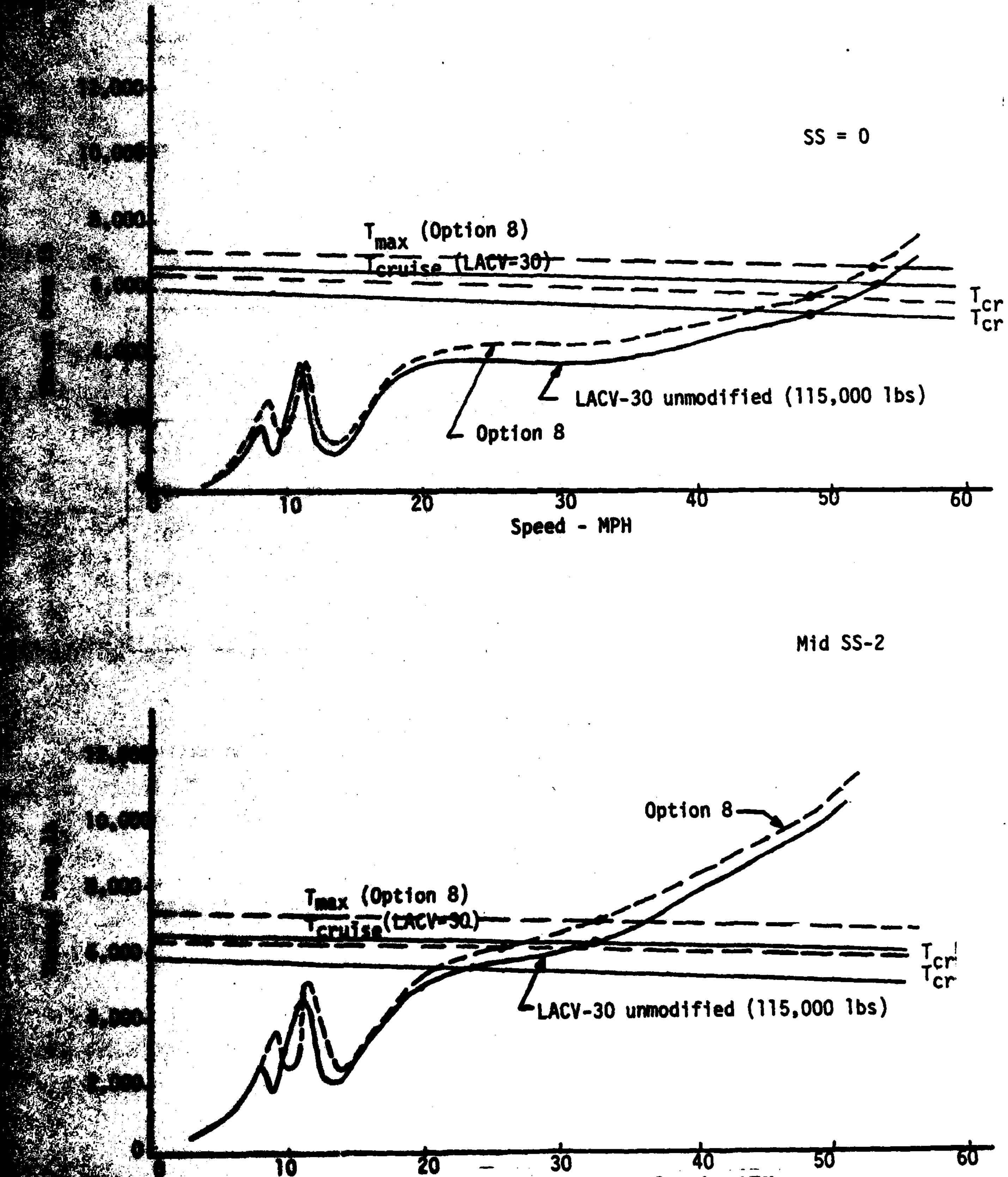
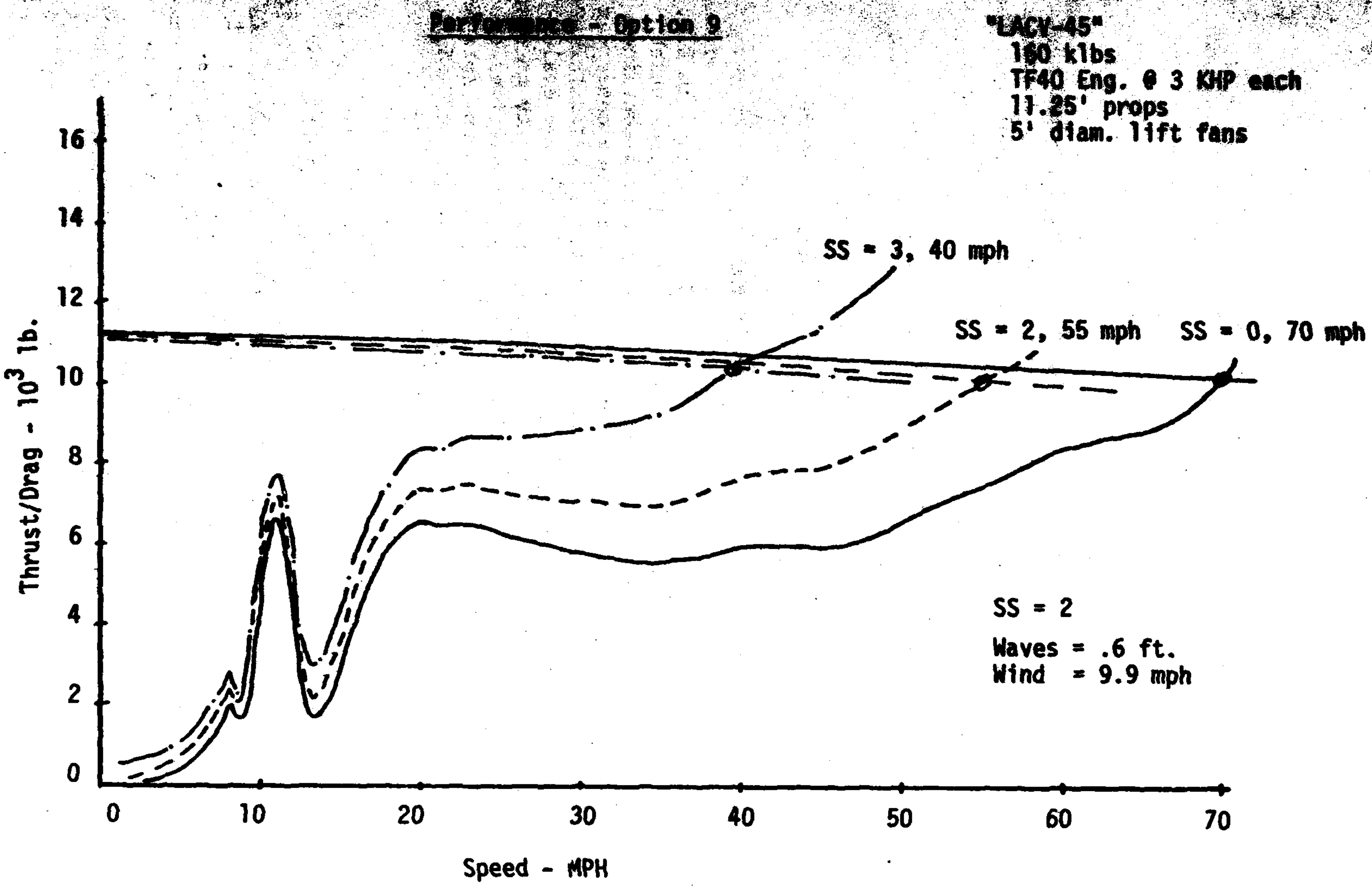


Figure C.14

Performance - Option 9



APPENDIX D

SYSTEM COSTS AND EFFECTIVENESS

D.1 General Remarks

This portion of the study deals with evaluating costs and cost-effectiveness of the candidate LACV-30 IP concepts identified in Appendix C. The life cycle costs were estimated, using the LACV-30 as a baseline. These estimates were constructed from the following:

- LACV-30 initial acquisition costs
- System and component development costs
- Prototype retrofit for qualifying tests
- LACV-30 modification costs, assuming a retrofit of 26 LACV-30 craft in the field
- LACV-30 15-year operating and support costs

The productivity of each of the LACV-30 IP concepts in the U.S. Army LOTS Resupply mission was calculated, using a computer model which simulates LACV-30 container selection procedure, distance from container-ship to shore, sea state and wind conditions, vehicle speed and container loading and unloading times. Results in terms of productivity (containers delivered per hour) were plotted versus vehicle cost. From these evaluations, the most "cost-effective" concepts in terms of productivity to cost ratios were determined versus payload increase. Table D.1 summarizes the best concepts in terms of LACV-30 payload, ranging from 25-30 tons (present LACV-30) in steps of 5-ton increments to what was formerly the LACV-45, a vehicle capable of carrying 40-50 tons payload.

D.2 Costs

Budgetary costs for modifying the LACV-30 were estimated, for each of the modifications necessary for accomplishing a retrofit of the 26 LACV-30 craft which will be operating in the 1986+ time frame. Prices in this report are quoted in 1983 dollars and are considered to be within ±25%. Since the details of the individual development programs have not been defined, the prices quoted in this report are approximate. They were generated for planning purposes only, and although they are believed to be within the targeted limits, they are not to be construed as a commitment or proposal in any way for accomplishing the described programs.

D.2.1 Summary Costs of Individual Tasks

Table D.2 presents a summary of the individual tasks necessary for accomplishing the options discussed in Appendix C. Not all tasks apply to all options, however, Task 2, Gear Box reversal drive is a necessary prerequisite for having counter-rotating fans, (Tasks 3 or 4). Likewise

Table D.1 Summary of Proposed Modifications to the LACV-30

Payload (tons)	Configuration Option	LACV-30 Modification Costs (per Craft)	% Increase in Productivity	% Increase in Acquisition Cost	Development Costs & Prototyping	Performance
25 - 30	LACV-30	0	0	0	0	SS 0 : 47 mph SS 2 : 33 mph
30 - 35	Rear Skirt & Raised Keel	$55,000	11%	0.9%	650,000	SS 0 : 46 mph SS 2 : 29 mph
35 - 40	New fans New Rear Skirt 9-1/2 ft. props.	$517,000	21.5%	7.3%	$3,440,000	SS 0 : 47 mph SS 2 : 31 mph
40 - 50	New Propulsion Modules	$1,750,000	35%	25%	$5,500,000	SS 0 : 72 mph SS 2 : 48 mph

Table D.2 LACV-30 Product Improvement by Task

Budgetary Prices

Item	Development Engrg/Tool/Tests	Retrofit for Prototype Testing	Unit Production Retrofit 26 Craft
Task 1 Rear Seal and Keel Changes	450,000	200,000	35,000
Task 2 Gear Box Reverse Drive	700,000	260,000	130,000
Task 3 Left-Handed Fan & Plenum Change	565,000	180,000	100,000
Task 4 High Perf. Fan & Plenum Change	1,195,000	485,000	217,000
Task 5 Larger Prop & Modified Apron	65,000	135,000	90,000
Task 6 5-1/2 ft. hull stretch	335,000	250,000	335,000
Disass'y & reass'y of craft	-	50,000	25,000

the 9-1/2 ft. diameter propeller requires reducing the RPM of the propeller, which, in turn, reduces the lift fan speed. This options applies only to Task 4, the High Performance lift fan, which has the capability of supporting the craft at the slower fan speeds.

Costs were estimated for three categories:

(a) Development costs including non-recurring engineering, manufacturing (including tooling);

(b) Retrofit of a LACV-30 craft for prototype testing, also non-recurring and

(c) Unit production costs (recurring) for the retrofit of 26 LACV-30 craft, which will be operating in the 1986 and beyond time frame.

Prototype vehicle testing, following retrofit costs, were not estimated, since this is considered a U.S. Army task. All the necessary subsystem, and system model and full scale testing as necessary to bring the modification to the prototyping state are included.

Details of the modification and what must be done to the LACV-30 are given in Appendix B.

·.2.2 Summary Costs of the Individual Options

Once the individual tasks were identified and priced, it was then possible to identify the prices associated with the seven different options described in Appendix C. Table D.3 summarizes the prices, and the cost of the total program of retrofitting 26 craft. The column at the far right estimates the differential cost of a future LACV-30 production run, assuming the listed modifications are incorporated into the LACV-30 production line at the factory. It is interesting to note that except for the 5-1/2 ft. stretch of the hull section, the incremental costs are insignificant compared to the estimated $7.14M acquisition cost of the unmodified LACV-30.

D.2.3 Life Cycle Costs

The life cycle costs of the LACV-30 can be attributed to several major areas, as follows:

(a) LACV-30 acquisition costs, fielding, spares and training

(b) Annual operating costs

(c) Crew, support and training

(d) Basing

These are discussed in the following paragraphs.

TABLE D.3

LACV-30 PRODUCT IMPROVEMENT
BUDGETARY PRICES

OPTIONS	DEVELOPMENT	PROTOTYPE CRAFT	PRODUCTION AND RETROFIT	TOTAL PROG. COSTS - 26 CRAFT	ΔCOST FOR FUTURE PRODUCTION
1) = LACV-30 as is					
2) Rear Seal and Keel Changes	$ 450,000	$ 200,000	$ 55,000	$ 2,080,000	$ 20,000
3) Seal/Keel + 5-1/2 Ft. Stretch	$ 785,000	$ 500,000	$390,000	$11,425,000	$335,000
4) Seal/Keel + BHC Counter-Rotating Fans	$1,715,000	$ 640,000	$285,000	$ 9,765,000	$100,000
5) (4) + 5-1/2 Ft Stretch	$2,050,000	$ 890,000	$620,000	$19,060,000	$335,000
6) (4) + High Perf. Lift Fans	$2,345,000	$ 995,000	$427,000	$14,442,000	$150,000
7) (6) + 9-1/2 Ft. Propellers	$2,410,000	$1,130,000	$517,000	$16,982,000	$150,000
8) (7) + 5-1/2 Ft. Stretch	$2,745,000	$1,380,000	$852,000	$26,277,000	$485,000

(a) LACV-30 Acquisition Costs

Additions to life cycle costs of the LACV-30 caused by the modifications are classified as additions to the acquisition cost. Individual contributions to the retrofit of 26 craft have been addressed in Section D.2.2, summaries of Development, Prototyping and Production including retrofit are given in Table D.3. Assuming the present average acquisition cost of the LACV-30 as $7.41M, and an additional 15% for spares, fielding and training, the total cost per LACV-30 for item (a) becomes $8,521,500. Corresponding increases in price due to the candidate modifications are given in Table D.4 below.

(b) Annual Operating Costs

The annual operating costs of the LACV-30 are assumed as $4.7M, which is based on consumption of consummables of spares, contribution to the overhaul reserve and contractor support. Each of the options have been examined individually as to their increase (or decrease) on life cycle costs.

<u>Option 2</u> - Rear Seal/Keel Changes

Wear of the rear seal is expected to be at the same rate as the present design. Based on the 417 hours that the U.S. Army projects in its peacetime use of the LACV-30, the rear seal finger life is expected to be about one year. Therefore, replacement of stern fingers annually will be required, with a differential cost of approximately $20,000 per craft.

<u>Option 3</u> - Option 2 with 5-1/2 ft. Hull Stretch

The addition of the 5-1/2 ft. hull stretch, will require some additional maintenance, which is estimated at about 40 man-hours for inspection, disassembly and assembly of extra structure whenever the LACV-30 is modularly separated, and miscellaneous costs of painting and miscellaneous repairs. Because of the size of the LACV-30 company, and its present availability of manpower, no additional personnel is expected to be required.

<u>Option 4</u> - Option 2 + Counter-rotating Fans

This option will have the added costs of Option 2, plus any additional costs of the reversed lift fan, and drive. Maintenance and servicing will be the same, however, additional spares will be required. Based on a present reserve of 8 transmissions and 6 spare fans for the present company of LACV-30, a new reserve of 10 transmissions (5 per side) and 8 fans (4 per side) will be required. This raises the cost of the spares by 2 transmissions and 2 fans, or an estimated total of about $400,000 or $33,000 per LACV-30. Over a life of 15 years, this amounts to an annual cost of $2,200/craft.

TABLE D.4

LACV-30 PAYLOAD IMPROVEMENT

OPTIONS	TOTAL DEVELOPMENT & PROTOTYPING	PRODUCTION & RETROFITING PER CRAFT	% INCREASE IN PRODUCTION COST	PRORATED DEV'MT & PROTO PLUS PRODUCTION	% INCREASE IN PRODUCTION
(1) LACV-30 Unmodified = $7.14M each					
(2) Rear Seal/ Keel Changes	$ 650,000	$ 55,000	0.6	$ 80,000	.9
(3) (2) + 5-1/2 Ft. Hull Stretch	$1,285,000	$390,000	4.6	$439,423	5.1
(4) (2) + Counter-Rotating Fans	$2,355,000	$285,000	3.3	$375,579	4.4
(5) (4) + 5-1/2 Ft. Stretch	$2,940,000	$620,000	7.2	$730,077	8.6
(6) (4) + High Performance Fans	$3,340,000	$427,000	5.0	$555,462	6.5
(7) (6) + 9-1/2 Ft. Propellers	$3,540,000	$517,000	6.1	$653,154	7.7
(8) (7) + 5-1/2 Ft. Stretch	$4,125,000	$852,000	10.0	$1,010,653	11.9

Option 5 - Option 4 + 5-1/2 ft. Stretch

Additional costs attributed to this option can be obtained from the previous options, dealing with the same modifications, but in different combinations.

Option 6 - Option 4 + High Performance Fans

Maintenance, and useful operational life of the high performance fans are expected to be the same as the present LACV-30 lift fans, therefore no additions to life cycle costs are expected from these aspects. Spares may be impacted the same way as discussed under Option 4; because of slightly higher procurement costs, the $2,200/craft assessment will increase about 10%, or $2,400/craft.

Option 7 - Option 6 + 9-1/2 Ft. Propellers

The 9-1/2 ft. propellers will be the same (7005-31) as those the LACV-30 now uses. Since they will be running at the same maximum tip speed, no increase in costs is anticipated.

Option 8 - Option 7 + 5-1/2 Ft. Hull Stretch

All modifications have been discussed previously.

Table D.5 summarizes the additional costs by Option, attributed to the proposed modifications to the LACV-30.

TABLE D.5

OPTION	ADDITIONAL ANNUAL OPERATING COSTS	15 YRS ADDITION TO LCC	% INCREASE IN LCC	TOTAL LCC FOR OPERATING
2	20,000	300,000	6.3	4.991M
3	20,000	300,00	6.3	4.991M
4	22,200	333,000	7.1	5.024M
5	22,200	333,000	7.1	5.024M
6	22,400	336,000	7.2	5.027M
7	22,400	336,000	7.2	5.027M
8	22,400	336,000	7.2	5.027M

Modifications associated with the Options are not expected to impact the crew, its training and support (c) or basing (d). Therefore, these contributions to life cycle costs have not been addressed on an individual basis.

Table D.6 presents a summary of all the individual contributions to life cycle costs, and the final increase (in percent of LACV-30 LCC) each of the options cause.

D.3 Cost Effectiveness

D.3.1 General

Cost effectiveness has been assumed as made up of LACV-30 acquisition cost, the cost of modifications to the LACV-30 necessary to arrive at each of the seven options described in Appendix C, and each option's productivity in terms of containers delivered ashore, per hour of routine lighter operations in the resupply mission.

The 1977 J-LOTS exercises were used as a source of data (Reference 9) to define the individual steps involved in the LACV-30 lighterage operation, and to determine cycle times of the individual segments within this operation. A summary of each of the segments and their associated times are given in Table D.7, for one and two container payloads.

A computer program was derived, depicting each of the steps within the lighterage cycle. Container distributions of weights were obtained, using the sample of peacetime defense cargo given in Reference D.2. The initial distribution, divided into 9 segments is shown as Figure D-1 (a). Because the sample is representative of a peacetime defense cargo, its mean container weight is low, i.e. 13 tons. Since that projected for the resupply mission averages about 15 tons, the peacetime distribution was purposely biased upward by 2.5 tons, which resulted in Figure D.1(b). This is considered typical of container distributions for normal U.S. Army resupply. Other cases are expected to exist, however, in which a preponderance of containers will "weigh out" rather than "volume-out". These might consist of a large proportion of ammunition and fuel containers, as well as some mixture of lighter weight containers. To account for this, the distribution was biased a second time by 2.5 tons, resulting in Figure D.1(c). These samples were then put into the computer program.

The container loading procedure assumed for the calculations, is summarized in Table D.8. Normally, the loadmaster at the container discharge facility will have available the ship's manifest and theoretically will be able to select from a number of containers, to obtain an optimum pairing of weights to accommodate each individual LACV-30's payload capacity. In actual operation, it has been assumed that this procedure will not be implemented with this degree of sophistication. The LACV-30's will be in a hurry, que lines must be avoided, and the (lack of) exchange of information and incumberence from using voice commands at the scene of operation will work in a manner to degrade the operation. As a compromise,

TABLE D.6

SUMMARY - LACV-30 LIFE CYCLE COSTS

OPTIONS	TOTAL PROCUREMENT COST (000)	FIELDING, INITIAL SPARES, TRAINING (000) (15%)	DIRECT OPRTG. COSTS - (1000) 15 YRS.	BASING (192 x 21,000/yr. x 15 yrs)(000)	TOTAL	% INCREASE
1) LACV-30 As Is	$7,410	$1,111	$4,690 (625 hrs/yr at $500/hr)	$5,040	$18,251	0
2) Rear Seal and Keel Changes	7,490	1,124	4,991	5,040	18,645	2.2
3) Seal/Keel + 5½ ft. Stretch	7,849	1,177	4,991	5,040	19,057	4.4
4) Seal/Keel + BHC Counter-rotating Fan	7,786	1,168	5,024	5,040	19,018	4.2
5) (4) + 5½ ft. Stretch	8,140	1,221	5,027	5,040	19,428	6.4
6) (4) + High Perf. Lift Fans	7,965	1,195	5,027	5,040	19,227	5.3
7) (6) + 9½ ft. Propellers	8,063	1,209	5,027	5,040	19,339	6.0
8) (7) + 5½ ft. Stretch	8,421	1,263	5,027	5,040	19,751	8.2

TABLE D.7

TYPICAL LACV-30 TIMELINE

	1 CNTR (min)	2 CNTRS (min)
1) Moor at Ship	1.0	1.0
2) Load Containers	4.0	10.0
3) Leave and Accelerate to Speed	2.9	2.9
4) Transit to Shore	$\frac{60\ D_L}{V_L}$	$\frac{60\ D_L}{V_L}$
5) Transit Surf Line	1.0	1.0
6) Position at Crane	2.0	2.0
7) Unload	5.0	6.0
8) Transit Beach and Surf	1.0	1.0
9) Accelerate to Speed	2.0	2.0
10) Travel to Ship	$\frac{60\ D_L}{V_{UL}}$	$\frac{60\ D_L}{V_{UL}}$

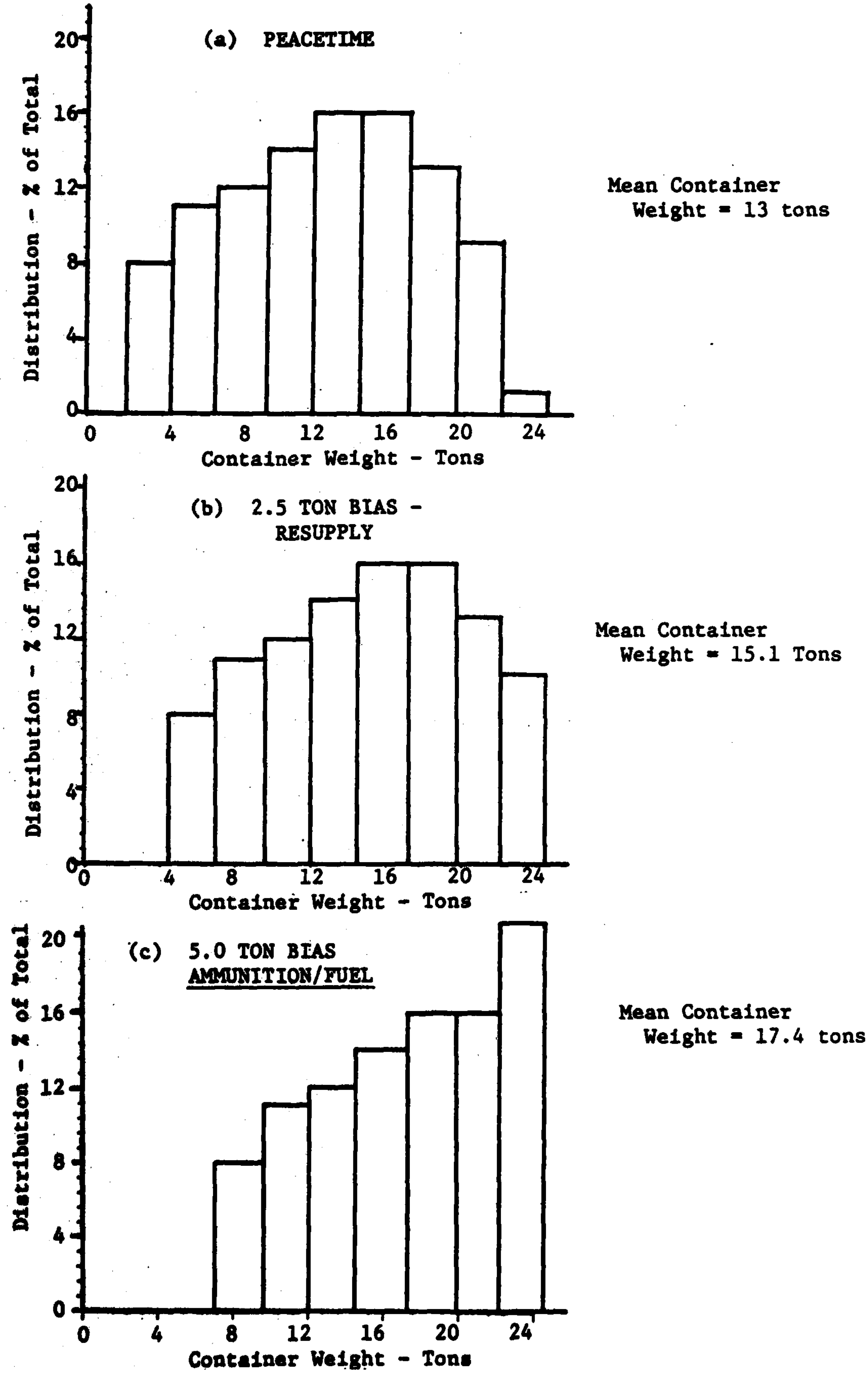
V_L = Ladened Speed

V_{UL} = Unladened Speed

D_L = Distance from Ship to Shore

Figure D.1

CONTAINER DISTRIBUTION WEIGHTS



therefore, a simplified loading procedure was assumed. The first container will have been selected and placed on the hook, as the LACV-30 moves aside the container discharge facility. It is expected that before the container is loaded, the loadmaster will communicate to the LACV-30's operator, its weight, and the weight of the next container in line to be loaded. A decision will be made whether to load one or both, depending upon the LACV-30's payload capacity. In the computer model, the containers were assumed to be selected randomly, just as they might well be in actual operation in the mission.

Table D.9 presents a summary of LACV-30's ladened or unladened speeds.

TABLE D.8

CONTAINER LOADING PROCEDURE

1) MOOR AT CONTAINERSHIP AND LOAD ONE CONTAINER.

2) NOTE CONTAINER #1 WEIGHT W1

3) NOTE CONTAINER #2 WEIGHT W2

4) DECIDE WHETHER W1 + W2 ALLOWABLE

5) IF NOT ALLOWABLE, REJECT CONTAINER #2 BEFORE IT IS LOADED

6) CAST OFF WITH CONTAINER #1 AND TRANSIT TO SHORE

5*) IF CONTAINER #2 IS ALLOWABLE, LOAD IT AND THE DEPART.

D.3.2 Productivity

Tables D.10, 11 and 12 summarize the results of the computer runs for the three container distributions - general cargo, resupply and ammunition and other heavy containers. Figure D.2 through D.6 present plots of productivity versus the eight options.

TABLE 10.9

LACV-30 OVERWATER SPEEDS FOR NINE POTENTIAL OPTIONS

Design Option →	Sea-State	1	2	3	4	5	6	7	8	9
Unladened Speed (W_G = 75,000 lbs.)	0	50.4	52.2	51.6	52.2	51.7	51.9	54.7	54.1	70.0
	2	38.4	40.3	39.9	40.2	39.8	39.8	42.8	42.3	55.0
	3	27.7	29.4	29.1	29.2	29.0	28.8	31.3	30.9	40.0
1-Container Speed	0	49.0	49.0	49.4	49.0	48.6	48.9	51.0	50.5	68.0
	2	35.8	34.7	36.7	35.4	35.4	34.8	38.1	37.9	53.0
	3	23.8	24.5	24.7	20.9	22.6	19.9	23.7	25.1	40.0
2-Container Speed	0	47.5	45.8	45.6	42.1	42.2	41.5	47.6	47.1	60.0
	2	33.3	29.1	32.3	21.9	28.4	20.3	30.9	33.3	50.0
	3	19.8	19.6	21.2	17.8	19.4	17.4	18.6	21.0	40.0
Capacity Payload:	Tons	26.5	31.5	36.5	36.5	36.5	36.5	36.5	36.5	45
Maximum Gross Weight:	Lbs.	115K	125K	125K	135K	135K	k35K	135K	135K	160K
Single Container Weight:	Lbs.	95K	100K	100K	115K	115K	115K	115K	115K	N/A

Table D-10

CALCULATED PRODUCTIVITY OF THE LACV-30 IP

(PEACETIME CARGO)

Distance (mi)	Lower Sea State	(1) Basic LACV-30	(2) New Stern Seal & Raised Keel	(3) Same as (2) with 5½ ft. Stretch	(4) (2) with Counter-Rotating LACV-30 Fans	(5) (4) with 5½ ft. Stretch	(6) (2) with High Performance Lift Fan	(7) (6) + 9½ ft. Props at 90% RPM	(8) (7) + 5½ ft. Stretch	(9) LACV-45 New Power Module
1	0	3.86	4.13	4.13	4.26	4.26	4.26	4.29	4.29	4.42
	2	3.73	3.97	4.00	4.02	4.11	3.99	4.15	4.16	4.35
	3	3.50	3.77	3.79	3.86	3.90	3.85	3.90	3.94	4.24
3	0	3.24	3.49	3.49	3.59	3.59	3.58	3.66	3.66	3.89
	2	2.98	3.17	3.22	3.13	3.28	3.07	3.36	3.39	3.73
	3	2.58	2.81	2.85	2.85	2.91	2.83	2.91	2.99	3.50
5	0	2.79	3.02	3.02	3.11	3.10	3.09	3.20	3.18	3.47
	2	2.48	2.64	2.70	2.56	2.73	2.50	2.82	2.86	3.26
	3	2.04	2.24	2.28	2.26	2.32	2.24	2.32	2.40	2.98
7	0	2.45	2.67	2.66	2.73	2.73	2.72	2.83	2.82	3.13
	2	2.12	2.26	2.32	2.16	2.34	2.10	2.43	2.48	2.90
	3	1.69	1.86	1.90	1.87	1.93	1.85	1.93	2.01	2.59
9	0	2.18	2.38	2.38	2.44	2.44	2.43	2.54	2.53	2.86
	2	1.85	1.98	2.04	1.87	2.05	1.82	2.14	2.18	2.61
	3	1.44	1.59	1.63	1.60	1.65	1.58	1.65	1.73	2.29
11	0	1.97	2.16	2.15	2.21	2.20	2.20	2.31	2.30	2.62
	2	1.65	1.76	1.81	1.65	1.82	1.60	1.91	1.95	2.38
	3	1.25	1.39	1.43	1.39	1.44	1.37	1.45	1.52	2.06

Table D-11

CALCULATED PRODUCTIVITY OF THE LACV-30 IP

(RESUPPLY)

Distance (mi)	Lower Sea State	(1) Basic LACV-30	(2) New Stern Seal & Raised Keel	(3) Same as (2) with 5½ ft. Stretch	(4) (2) with Counter-Rotating LACV-30 Fans	(5) (4) with 5½ ft. Stretch	(6) (2) with High Performance Lift Fan	(7) (6) + 9½ ft. Props at 90% RPM	(8) (7) + 5½ ft. Stretch	(9) LACV-45 New Power Module
1	0	3.48	3.86	3.86	4.12	4.12	4.11	4.15	4.15	4.41
	2	3.36	3.71	3.74	3.90	3.97	3.87	4.01	4.02	4.34
	3	3.16	3.52	3.54	3.73	3.76	3.71	3.77	3.81	4.23
3	0	2.90	3.24	3.24	3.46	3.46	3.45	3.53	3.51	3.88
	2	2.66	2.95	2.99	3.03	3.16	2.98	3.24	3.26	3.72
	3	2.31	2.61	2.64	2.74	2.79	2.72	2.81	2.87	3.49
5	0	2.38	2.79	2.79	2.99	2.98	2.98	3.07	3.05	3.6
	2	2.20	2.45	2.49	2.48	2.63	2.42	2.71	2.74	3.25
	3	1.81	2.07	2.10	2.17	2.22	2.14	2.23	2.30	2.97
7	0	2.16	2.45	2.45	2.62	2.62	2.61	2.72	2.70	3.12
	2	1.87	2.09	2.14	2.09	2.45	2.04	2.34	2.37	2.89
	3	1.49	1.72	1.75	1.79	1.84	1.77	1.86	1.93	2.58
9	0	1.92	2.19	2.18	2.34	2.34	2.33	2.43	2.42	2.85
	2	1.63	1.82	1.87	1.81	1.96	1.76	2.05	2.09	2.60
	3	1.27	1.46	1.49	1.52	1.58	1.50	1.59	1.65	2.29
11	0	1.73	1.97	1.97	2.11	2.11	2.10	2.21	2.19	2.62
	2	1.44	1.62	1.66	1.60	1.74	1.55	1.83	1.86	2.37
	3	1.11	1.28	1.30	1.33	1.38	1.31	1.39	1.45	2.05

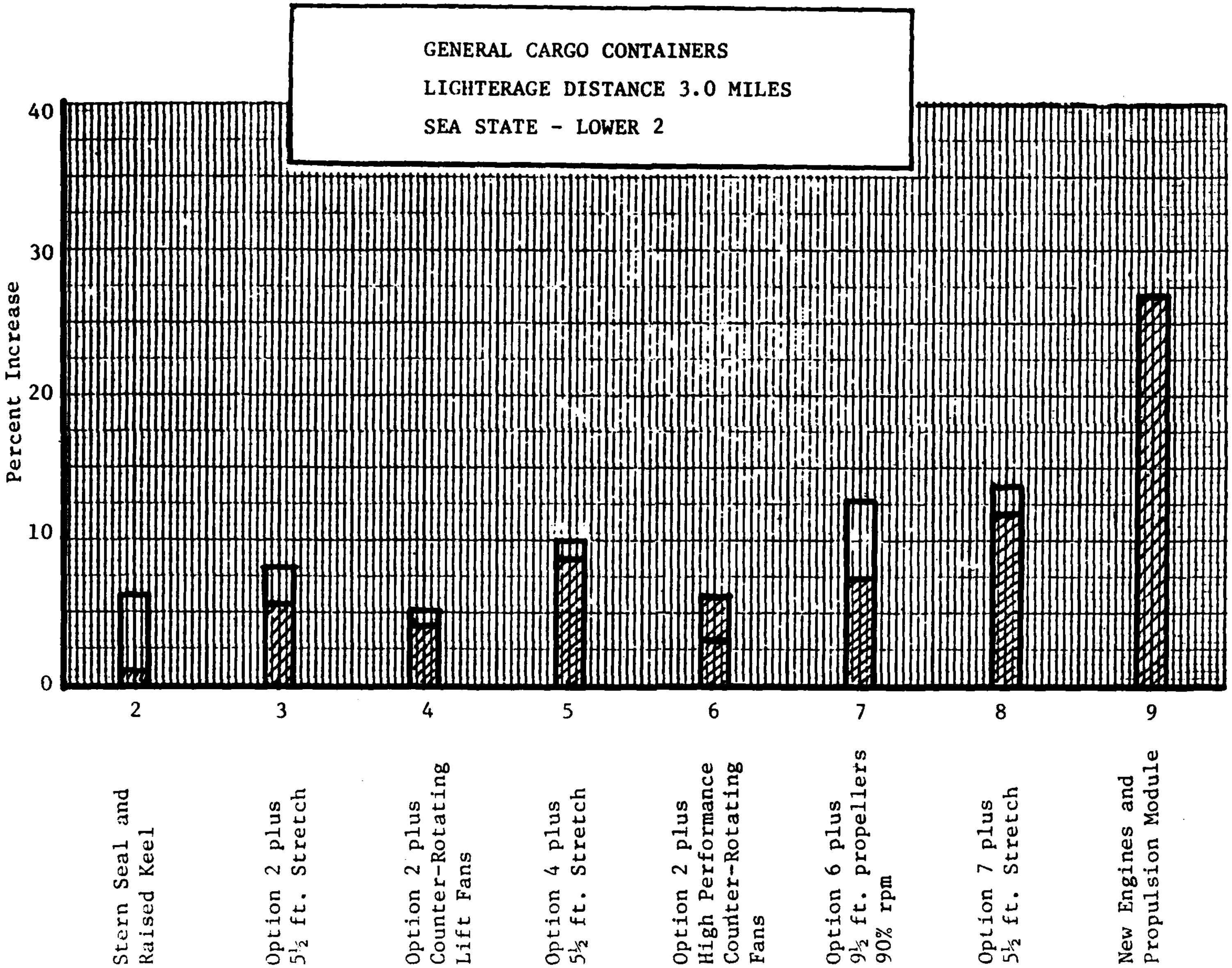
Table D-12

CALCULATED PRODUCTIVITY OF THE LACV-30 IP

(AMMUNITION & OTHER HEAVY CONTAINERS)

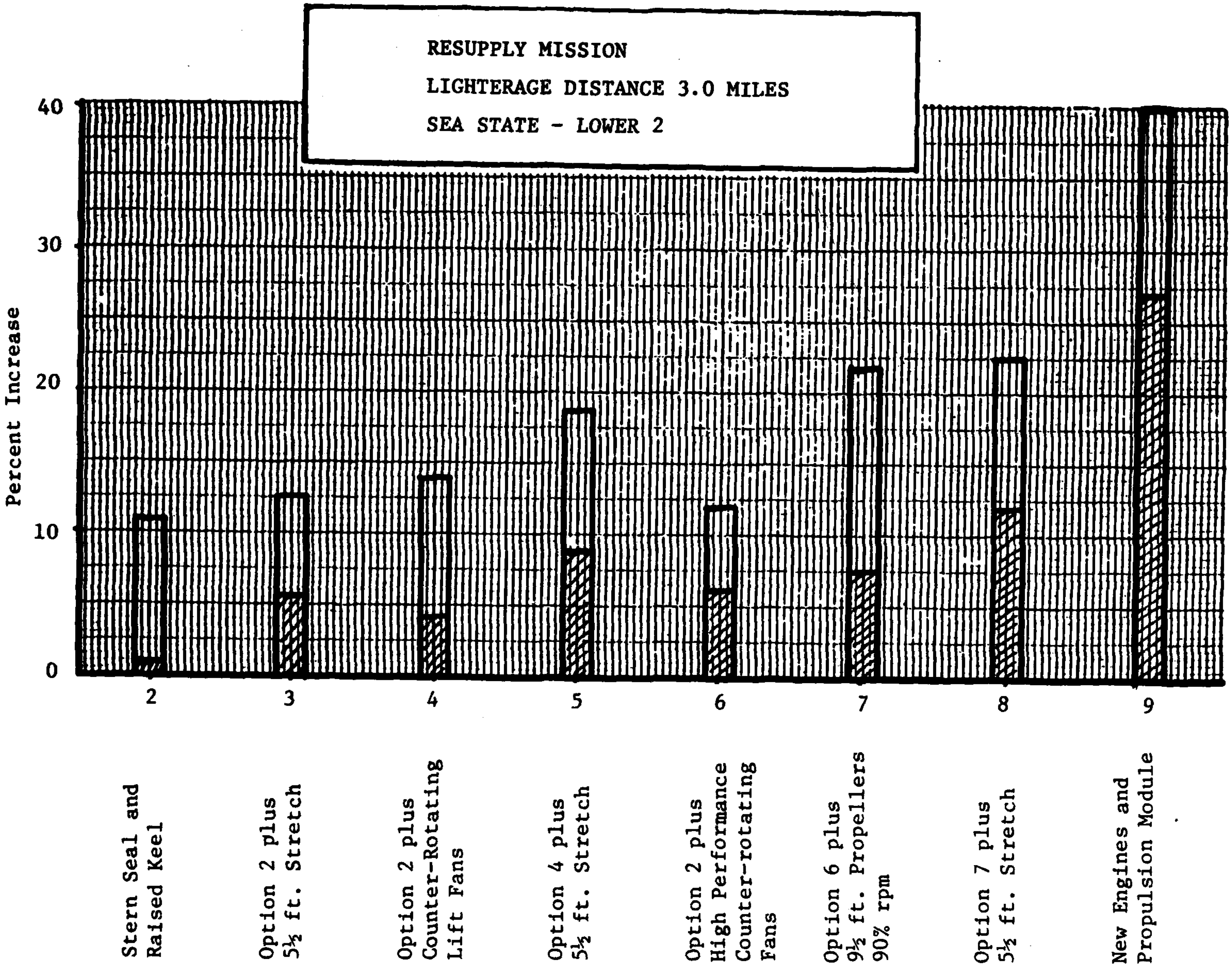
Distance (mi)	Lower Sea State	(1) Basic LACV-30	(2) New Stern Seal & Raised Keel	(3) Same as (2) with 5½ ft. Stretch	(4) (2) with Counter-Rotating LACV-30 Fans	(5) (4) with 5½ ft. Stretch	(6) (2) with High Performance Lift Fan	(7) (6) + 9½ ft. Props at 90% RPM	(8) (7) + 5½ ft. Stretch	(9) LACV-45 New Power Module
1	0	3.14	3.52	3.52	3.88	3.88	3.88	3.91	3.91	4.36
	2	3.03	3.38	3.40	3.69	3.74	3.66	3.78	3.79	4.29
	3	2.84	3.21	3.22	3.51	3.54	3.49	3.55	3.59	4.18
3	0	2.58	2.93	2.92	3.25	3.24	3.34	3.31	3.30	3.83
	2	2.37	2.66	2.70	2.86	2.97	2.82	3.04	3.16	3.67
	3	2.05	2.35	2.37	2.56	2.61	2.53	2.63	2.69	3.44
5	0	2.19	2.51	2.50	2.79	2.79	2.78	2.86	2.85	3.41
	2	1.94	2.20	2.23	2.34	2.46	2.30	2.54	2.56	3.21
	3	1.61	1.86	1.88	2.02	2.07	1.99	2.09	2.15	2.92
7	0	1.91	2.19	2.19	2.45	2.44	2.44	2.52	2.51	3.08
	2	1.65	1.87	1.91	1.98	2.10	1.95	2.18	2.20	2.85
	3	1.32	1.54	1.55	1.66	1.71	1.64	1.73	1.79	2.54
9	0	1.69	1.95	1.94	2.80	2.17	2.17	2.26	2.25	2.81
	2	1.43	1.63	1.66	1.72	1.82	1.67	1.91	1.94	2.56
	3	1.12	1.31	1.33	1.41	1.46	1.39	1.48	1.53	2.25
11	0	1.51	1.75	1.75	1.96	1.96	1.95	2.04	2.03	2.58
	2	1.26	1.44	1.47	1.51	1.62	1.47	1.70	1.72	2.33
	3	0.97	1.14	1.16	1.23	1.27	1.21	1.29	1.34	2.02

Figure D-2



GENERAL CARGO CONTAINERS
LIGHTERAGE DISTANCE 3.0 MILES
SEA STATE - LOWER 2
Percent Increase
0
10
20
30
40
2
3
4
5
6
7
8
9
Stern Seal and Raised Keel
Option 2 plus 5½ ft. Stretch
Option 2 plus Counter-Rotating Lift Fans
Option 4 plus 5½ ft. Stretch
Option 2 plus High Performance Counter-Rotating Fans
Option 6 plus 9½ ft. propellers 90% rpm
Option 7 plus 5½ ft. Stretch
New Engines and Propulsion Module

Figure D-3


RESUPPLY MISSION
LIGHTERAGE DISTANCE 3.0 MILES
SEA STATE - LOWER 2
Percent Increase
0
10
20
30
40
2
3
4
5
6
7
8
9
Stern Seal and Raised Keel
Option 2 plus 5½ ft. Stretch
Option 2 plus Counter-Rotating Lift Fans
Option 4 plus 5½ ft. Stretch
Option 2 plus High Performance Counter-rotating Fans
Option 6 plus 9½ ft. Propellers 90% rpm
Option 7 plus 5½ ft. Stretch
New Engines and Propulsion Module

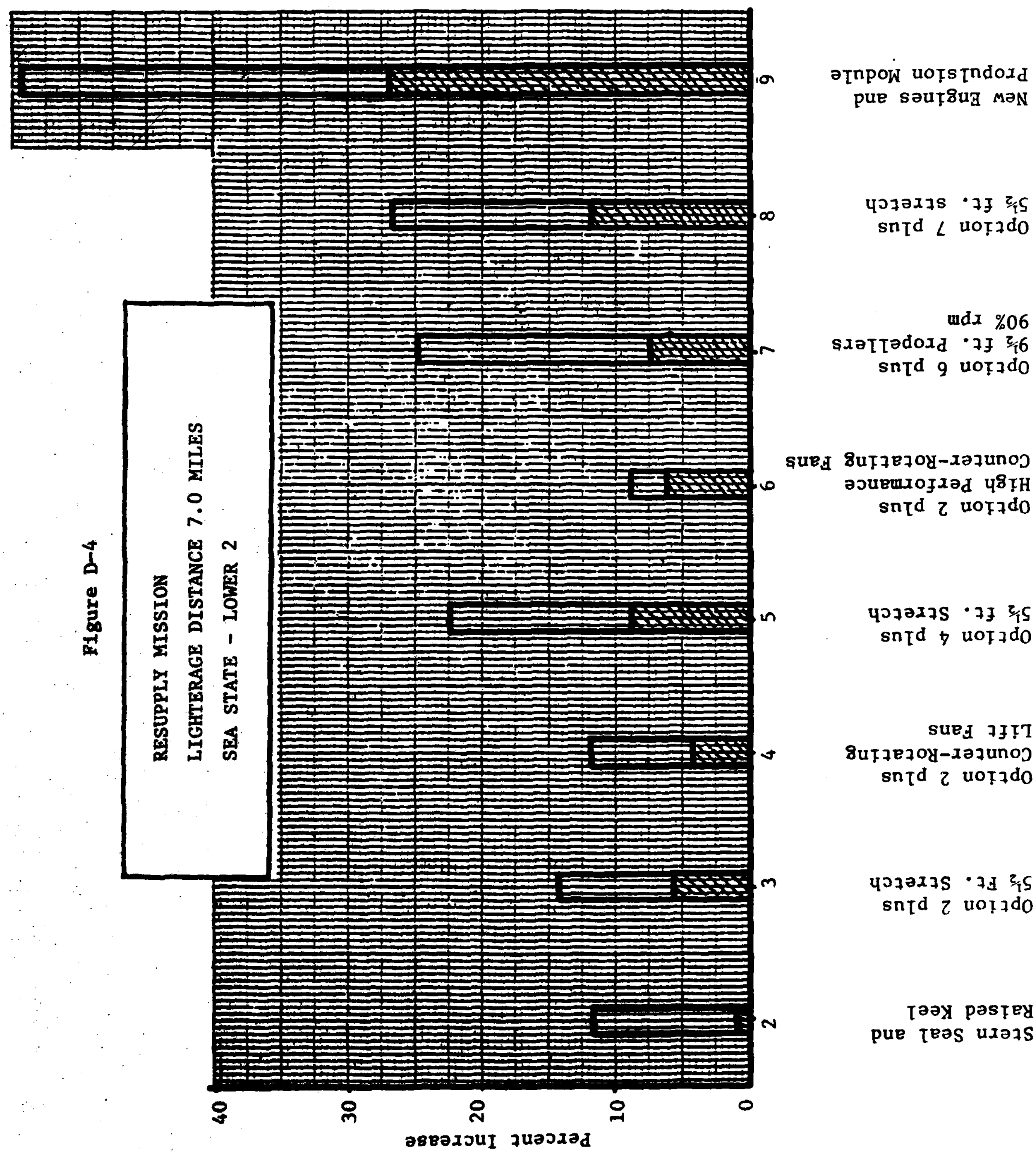

RESUPPLY MISSION
LIGHTERAGE DISTANCE 7.0 MILES
SEA STATE - LOWER 2
Percent Increase
0
10
20
30
40
2
3
4
5
6
7
8
9
Stern Seal and Raised Keel
Option 2 plus 5½ Ft. Stretch
Option 2 plus Counter-Rotating Lift Fans
Option 4 plus 5½ ft. Stretch
Option 2 plus High Performance Counter-Rotating Fans
Option 6 plus 9½ ft. Propellers 90% rpm
Option 7 plus 5½ ft. stretch
New Engines and Propulsion Module

Figure D-4

Figure D-5

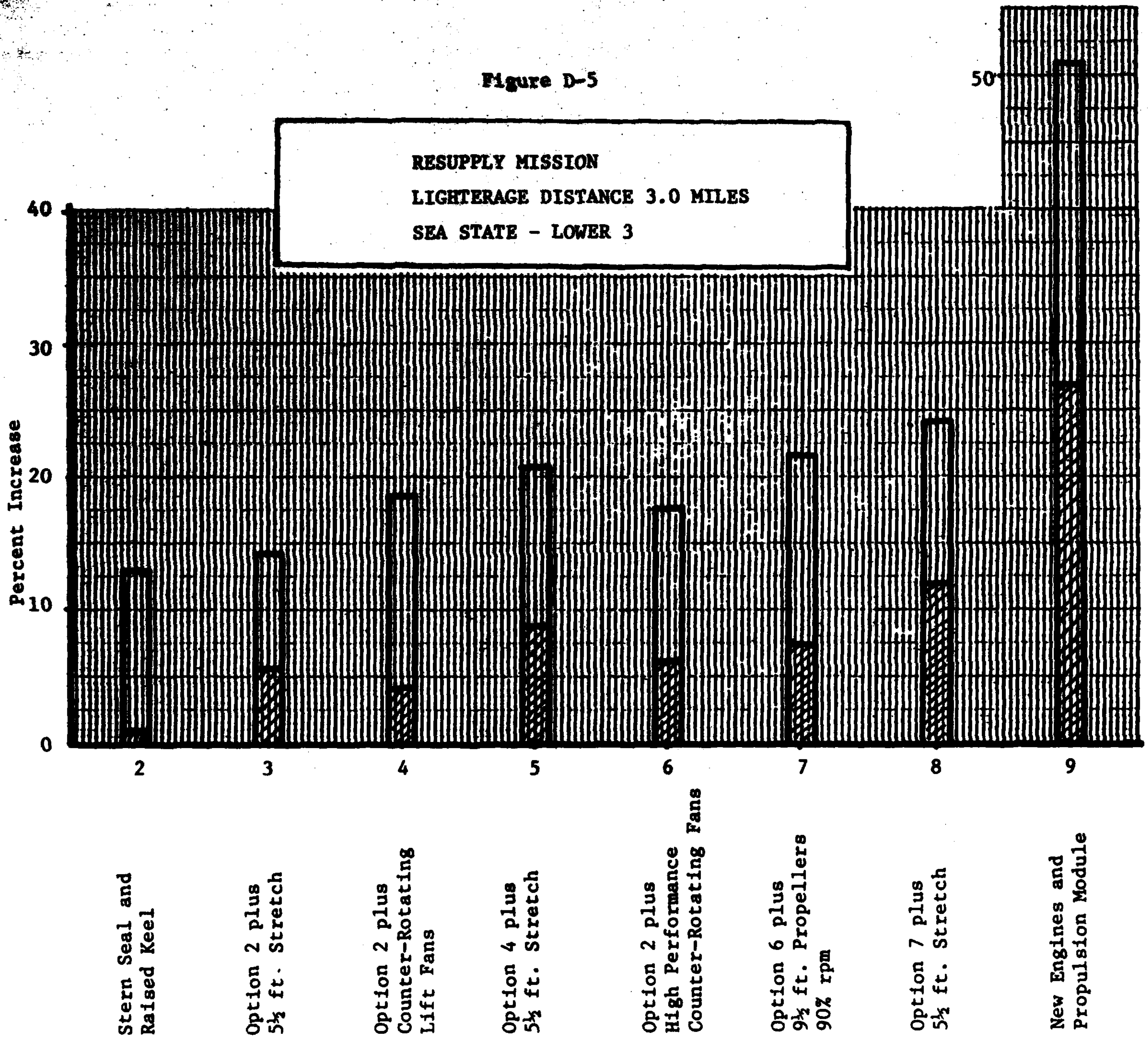
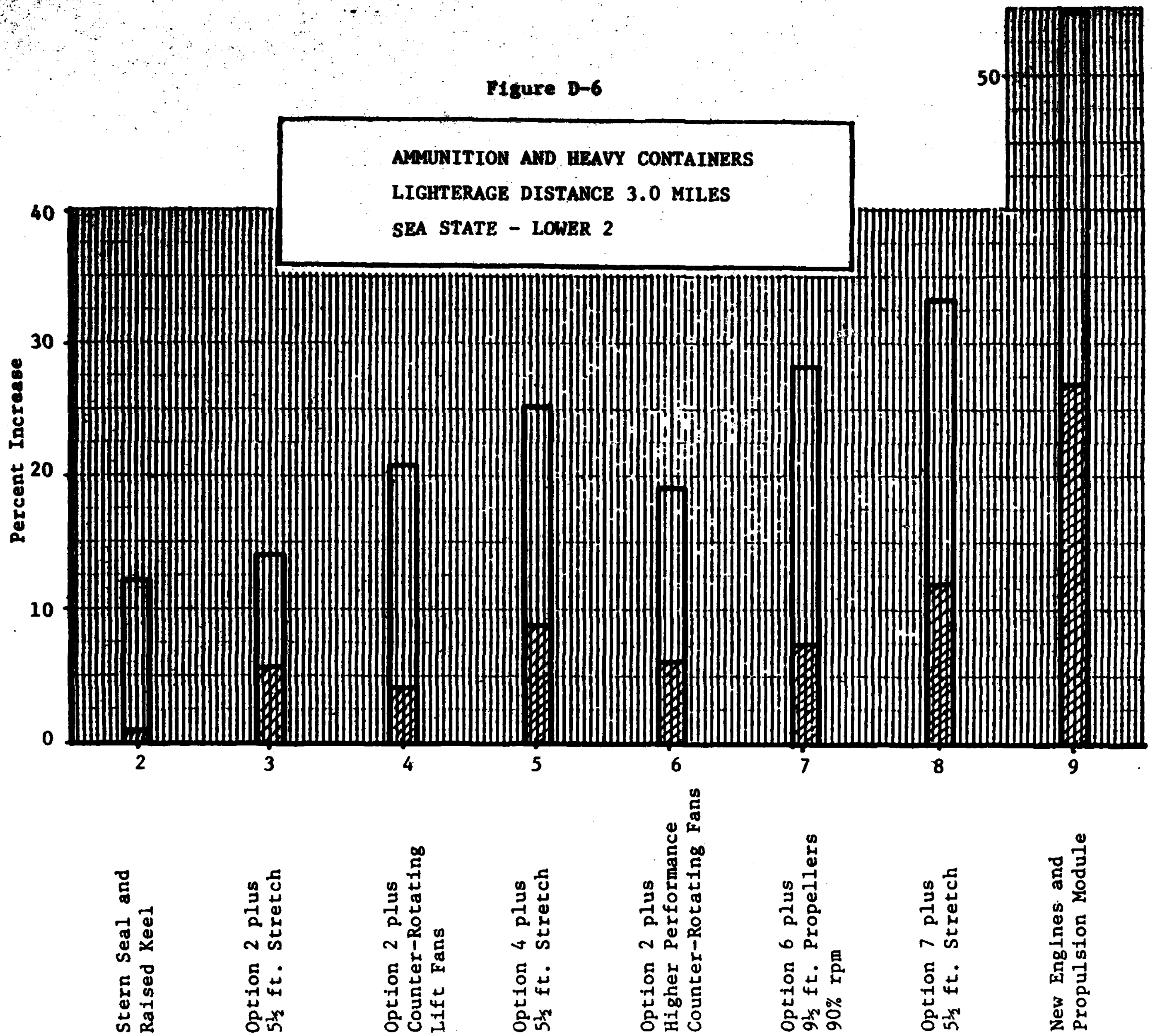

RESUPPLY MISSION
LIGHTERAGE DISTANCE 3.0 MILES
SEA STATE - LOWER 3
Percent Increase
0
10
20
30
40
50
2
3
4
5
6
7
8
9
Stern Seal and Raised Keel
Option 2 plus 5½ ft. Stretch
Option 2 plus Counter-Rotating Lift Fans
Option 4 plus 5½ ft. Stretch
Option 2 plus High Performance Counter-Rotating Fans
Option 6 plus 9½ ft. Propellers 90% rpm
Option 7 plus 5½ ft. Stretch
New Engines and Propulsion Module

Figure D-6


AMMUNITION AND HEAVY CONTAINERS
LIGHTERAGE DISTANCE 3.0 MILES
SEA STATE - LOWER 2
Percent Increase
0
10
20
30
40
50
2
3
4
5
6
7
8
9
Stern Seal and Raised Keel
Option 2 plus 5½ ft. Stretch
Option 2 plus Counter-Rotating Lift Fans
Option 4 plus 5½ ft. Stretch
Option 2 plus Higher Performance Counter-Rotating Fans
Option 6 plus 9½ ft. Propellers 90% rpm
Option 7 plus 5½ ft. Stretch
New Engines and Propulsion Module

END

FILMED

11-83

DTIC