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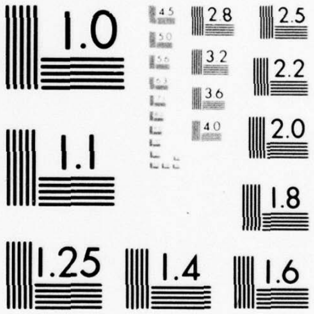

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LEVEL II

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A STUDY OF REQUIREMENTS, MODEL CONFIGURATIONS, AND TEST PLANS FOR AIR CUSHION SYSTEM COMPARISON TESTS

Contract N00014-78-C-0588

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The Navy plans to test several models of air cushion vehicles with different cushion systems. A set of model design requirements suitable for all the modles was developed by the Navy with the assistance of Bell Aerospace Textron and other contractors. The proposed DTNSRDC Model Test Program was reviewed. Minor changes and additions were suggested.

A preliminary model configuration using Bell cushion philosophy was proposed. Ranges of bag and cushion pressures and airflows were established for the

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20. Abstract (Cont)

model. Two existing model fans from an existing model of the AALC JEFF(B) could provide the required nominal flow and pressure. Bell recommends installing four of these existing fans to permit testing over a wide range of flows.

Cost and schedule estimates for the model detail design and construction were prepared. The schedule is shown in this report; cost estimates were provided under separate cover.

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LIST OF ILLUSTRATIONS

1. INTRODUCTION

The U.S. Navy has plans for comprehensive tests to facilitate comparisons between several of the major hovercraft air cushion skirt systems which have been developed and used by different contractors. Under contract N00014-78-C-0588, Bell Aerospace Textron, New Orleans Operations, has:

a. Reviewed U.S. Navy requirements for the models and has established essential criteria for the model (ie, scale dimensions, cushion length, scaling of lift and air supply arrangements, etc)

b. Reviewed the proposed David Taylor Naval Ship Research and Development Center (DTNSRDC) Model Test Program

c. Proposed a preliminary model configuration using Bell cushion philosophy

d. Prepared cost and schedule estimates for the model detail design and construction.

2. REVIEW OF NAVY REQUIREMENTS FOR THE MODEL

2.1 General

Bell's review of the U.S. Navy requirements, together with reviews by other contractors and Navy personnel, has resulted in a set of model design criteria for cushion systems comparison tests (reference 1). This set of criteria, which appears in appendix A of this report, is acceptable to Bell and will be the basic criteria for design and fabrication of a model for cushion system comparison tests.

2.2 Principal Craft Characteristics

2.2.1 Geometry

The full-scale craft dimensions specified in section 1 of appendix A are very close to those of the JEFF(A) and JEFF(B). They are also representative of LCAC preliminary designs. The cushion comparison model tests will therefore provide data which should be useful to the LCAC program. The overall full-scale craft length (96 ft) is about 10 percent greater than that of the JEFF(B) (87.6 ft), but the model data should also permit at least qualitative comparisons with both JEFF(A) and JEFF(B) full-scale craft.

2.2.2 Weights, Inertias, and Centers of Gravity (cg)

The full-scale design weights listed in the Navy criteria for the models are comparable to preliminary LCAC design data and JEFF(A) and JEFF(B) characteristics. However, the minimum specified model weight is higher than typical craft lightweight conditions (see figure 1). It is recommended that 220,000 lb (full scale) be established as a minimum weight goal to permit tests over a wider range of weights and cushion pressures. Efforts to achieve this reduced minimum weight should be limited to what can be achieved without a significant cost increment for model design and construction.

The Navy criteria specifies that ballast weights shall be provided to achieve a specified cg for the design condition and cg changes equal to ±3 percent of overall length and beam on cushion. Ballast weights and locations should be such that moment of inertia changes resulting from weight and cg changes are similar to those for full-scale craft (see figure 1).

Figure 1 (based on references 2 and 3) shows that inertias specified for the models are representative of JEFF(A) inertias, but are considerably higher than JEFF(B) inertias. This is believed to be primarily because of different power plant arrangements. Changes of cargo distributions can change inertia-versus-weight trends shown in this figure.

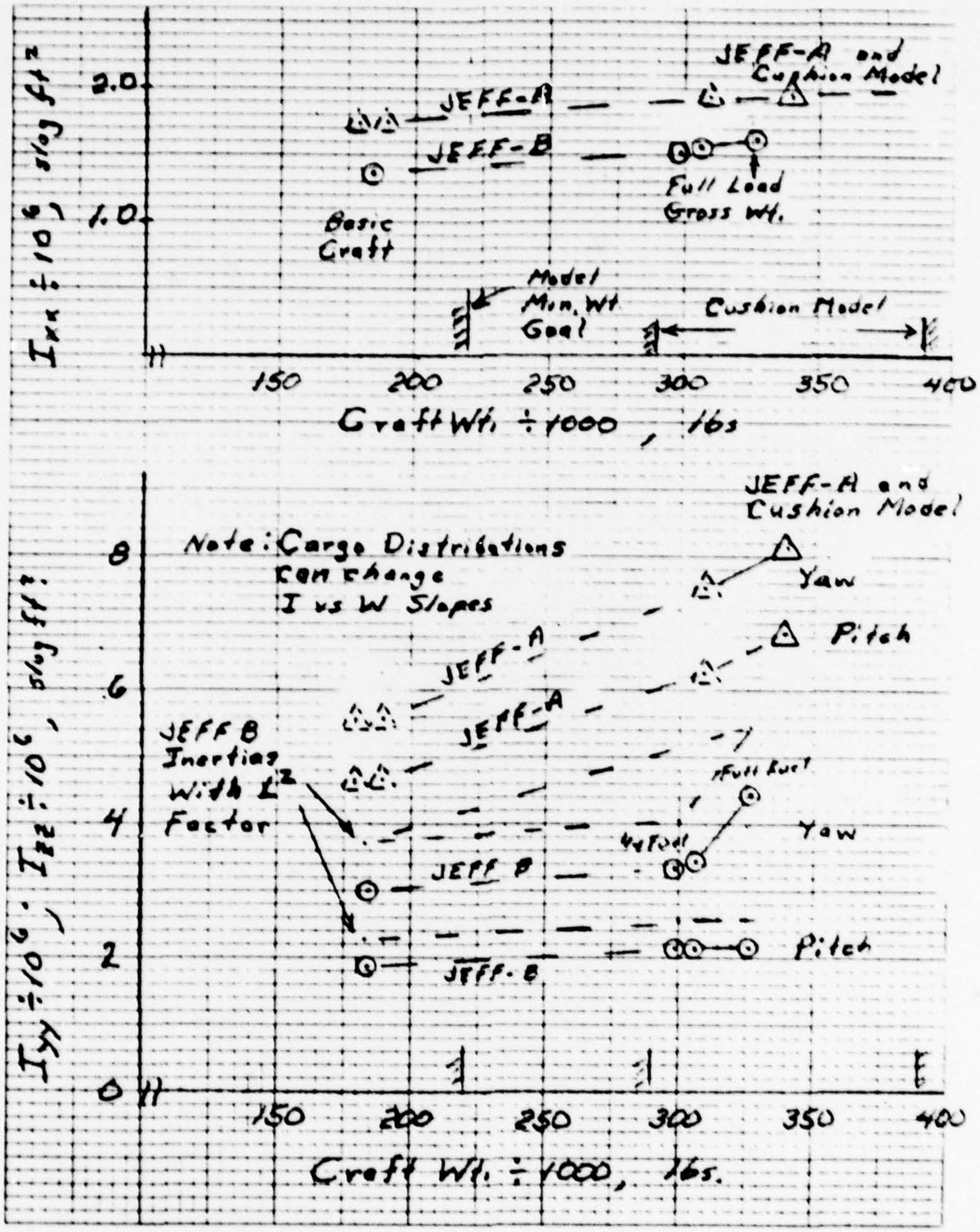

Figure 1 FULL-SCALE INERTIAS VERSUS WEIGHT

When comparative tests of different cushion concepts are made, the ballast weights of the models should be adjusted so there are comparable changes of inertias for all models when weights and cg are changed.

2.3 Model Scale

2.3.1 Geometry

It has been mutually agreed that the model shall be 1/12-scale of the full-scale craft defined by the Navy criteria (appendix A). The model will then be representative of JEFF(A), JEFF(B), and LCAC classes of craft.

2.3.2 Froude Scaling

Froude scaling will be used to establish representative model weights, inertias, airflows, pressures, etc.

2.3.3 Reynolds Number

Reynolds number effects on drag and moments should be comparable for all models and should not introduce significant bias in comparisons of the different concepts.

2.4 Lift System Scaling and Arrangement

2.4.1 Skirt System

Weight and stiffness of model seal material and additional stiffness introduced by seams generally causes some deviation from full-scale behavior of seals. The dominant effects of seal material are on the stability and buckling of fingers. These factors can significantly affect leakage (and hence drag), as well as craft stability.

The model criteria specifies use of the same model seal material by all contractors. This will reduce the effects of slight scaling imperfections with seal materials. However, such effects may be more significant for some concepts than for others. Therefore, if significant differences are found between different seal concepts, efforts should be made to determine if these are due to seal material characteristics. This can be accomplished by noting (and photographing) seal behavior, comparing with analytical investigations (not part of the presently planned program), and perhaps ultimately by retesting one or two configurations with a seal or a portion of a seal made of different material.

This is not intended to imply that model seal characteristics are expected to deviate greatly from full-scale behavior. However, the ability to scale seal characteristics has been the subject of much debate and controversy. Therefore, in a program intended to compare different cushion concepts, efforts should be made to establish that model seal material characteristics are not a major factor in differences of test results between different seal concepts. Qualitative comparisons between model data and full-scale experience with the JEFF craft may also contribute to an understanding of the significance of model-versus-full-scale characteristics of seals.

2.4.2 Lift Fans and Air Distribution System

Scaling of and numbers of fans, ducts, orifices, etc, could be the subject of a test program in itself. However, Bell's experience indicates that overall model behavior is not strongly influenced by these factors, provided that the total air supply system pressure versus flow characteristics, with the model in static equilibrium, are Froude scaled. The slope of the system pressure-versus-flow curve and the selected operating points on the curve will, of course, have some effect on dynamic characteristics of the models.

One approach would be to use the same fans and/or total air supply system for all models. The use of the same fans seems desirable, provided that the number and characteristics of the selected fans are acceptable to all contractors. However, identical total air supply systems can probably never be achieved because of requirements for different distributions of flows for different cushion concepts.

Whether or not the same fans are used for all models, it would be desirable to measure dynamic as well as static characteristics of air supplies for each model (eg, magnitude and phasing of bag and cushion pressure response versus frequency of forced heave or pitch motions of the model). However, such response will vary with motion amplitudes, with nominal pressure and flow, and hence with craft weight. A comprehensive dynamic test of each model could be quite expensive and time consuming. It is therefore recommended that only static-pressure-versus-flow characteristics be experimentally determined, for the fans and the total system, unless unusual or unexpected tow test results indicate a need for dynamic tests to explain such results.

2.4.3 Atmosphere Scaling

Another factor that will not be correctly scaled is the result of testing in a real atmosphere rather than a Froude-scaled atmosphere. This theoretically results in dynamically stiffer bags and cushions in models than in full-scale craft. Such effects are generally small for cushions and for air cushion vehicle (ACV) bags, which generally have large volumes. It may be of some significance for surface effect ships (SESs), which have relatively smaller bag volumes (bags only at the bow and stern). If ACV bags have diaphragms to intentionally create small local volumes, the model pressure increases due to wave passage, and slams may be somewhat larger than for full-scale craft.

Experience with a JEFF(B) model (section 3.23.1.1.1 of reference 4) indicates one reason why testing in a non-scaled atmosphere does not generally introduce large errors. In static heave stiffness tests, it was found that heave stiffness was only 25 percent of the stiffness that would be calculated with a fixed bag cross section. In such calculations the stiffness depends on a decrease of gap height and the fan-pressure-versus-flow curve. The change of bag shape with pressures greatly reduced the heave stiffness. This is analogous to two springs in series, where the soft spring dominates the total stiffness. If a non-scaled atmosphere results in too great a stiffness, the total error can still be small if the atmosphere spring is in series with a much softer spring created by seal geometry.

The effects of non-scaled atmosphere are insignificant for calm-water tests. However, care should be taken when interpreting dynamic data from high sea state tests that non-scaled atmospheres are not biasing comparisons between different cushion concepts (eg, the non-scaled effects, though small, may not be of equal importance for all concepts).

2.5 Model Construction

The requirements for model construction specified in section 4 of the Navy criteria (appendix A) are acceptable and adequate.

Although not specifically called out in the requirements, it is expected that all contractors will provide buoyancy, tightness of construction, and waterproofing, so that model weights and cg will not change appreciably due to absorbing or trapping water during tests. This should be verified periodically during the test program.

It is also suggested that the Navy review model designs to ensure that mountings for ballast weights are located so that consistent changes of model inertias can be achieved for all models when weights or cg are changed.

2.6 Instrumentation

The requirements for instrumentation specified in section 5 of the Navy criteria (appendix A) are acceptable and adequate.

Discussions with the Navy technical monitor have indicated an interest in the direct measurement of cushion flow on the model. Several approaches have been investigated to accomplish this objective, but all are considered either impractical or too expensive for this program. The two principal methods considered were:

a. A Pitot-static rake in the volute exit. While this approach is feasible in principle, and would lead to accurate results, the size of the volutes in the model, together with the large number of rake elements required (>25) make it prohibitively expensive. If an attempt is made to use a much smaller array of probes, perhaps as few as one, and precalibrate the model, then errors will be introduced by the inevitable changes in velocity distribution in the volute duct under operating conditions. Also, if the system were operated over water, the probes will tend to get blocked with water droplets, again introducing measurement errors.

b. Static tappings in the inlet bellmouth. This approach is considerably simpler to incorporate in the model, but has been found to be subject to unacceptable errors in the past. Primarily, these errors result from the fact that static pressure changes dramatically with location on the bellmouth, and with detailed bellmouth shaping. In fact, it is so sensitive that structural distortion of the bellmouth due to internal pressure and model loading conditions can invalidate the data. Any wind over the deck will introduce distortion in the inlet flow which will also impair the accuracy of this type of measurement. Bell believes that, while the method can give acceptable results in a laboratory test with heavy-duty machined metal inlets, it is not advisable on a dynamic model.

It is recommended that the model be calibrated in a lift flow measurement rig, and that flow be related to bag pressure and fan rpm. This calibration can then be used to establish fan operating conditions for all towing tank tests. It is believed that this approach will result in adequate accuracy, and will be much less expensive than any more exotic flow instrumentation built into the model.

2.7 Model Propulsor

Section 6 of the Navy criteria (appendix A) specifies that only one propulsor will be built, and it will be adequate to propel each of the cushion system comparison models. The criteria states that the propulsor will be used to provide adequate thrust for self-propulsion tests in waves. It is understood that these will be free-to-surge tests with the model loosely attached to a tow tank carriage rather than completely free (eg, radio-controlled model) tests.

It is expected that the propulsor will consist of one (possibly two) fixed-pitch propeller. A variable-speed electric motor will permit thrust variation to approximately match model average drag.

Figure 2 is an estimate of JEFF(B) drag and propulsion thrust requirements. The 1/12-scale equivalents of these craft requirements (scale at right side of figure) indicate that a thrust of at least 17 lb will be required to balance the cushion comparison model drag in simulated high sea states. To provide a margin, and to cover high weight conditions, a thrust of about 20 lb should be provided. An electric motor rated at approximately 3 hp will be required for propulsion of the model.

2.8 Model Spare Parts and Materials

Bell agrees that the spare parts listed in section 7 of the Navy criteria (appendix A) should be provided to avoid delays in the test program.

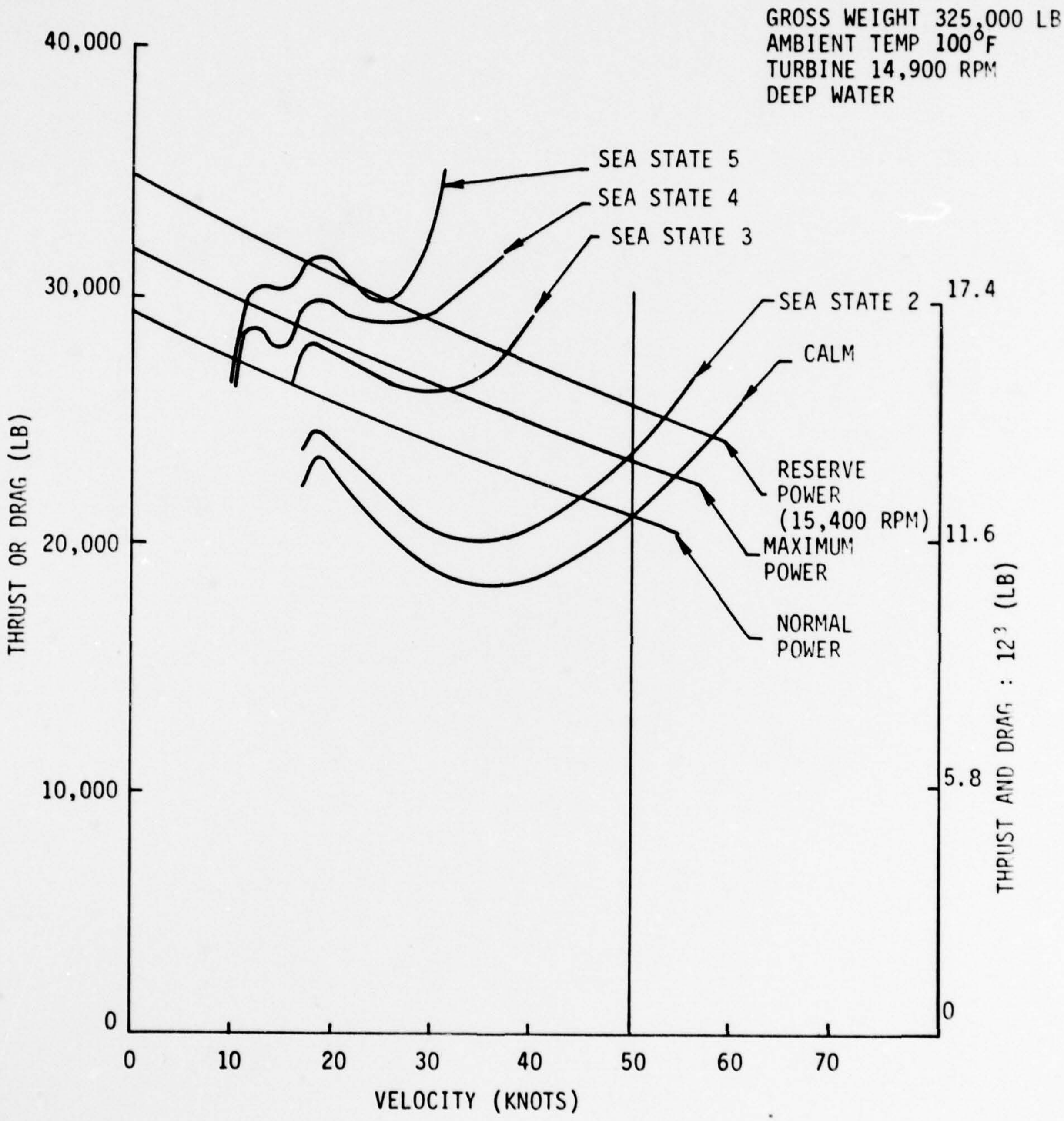

Figure 2 JEFF(B) DRAG VERSUS SPEED FOR VARIOUS SEA STATES (25-KNOT HEAD WIND)

3. REVIEW OF DTNSRDC TEST PROGRAM

3.1 General

Section 4 of reference 5 is a brief outline of a DTNSRDC-proposed test program. That outline lists tests to determine:

a. Model fan performance (p, η, and rpm versus Q)

b. Model lift system performance (p, η, and rpm at different points versus Q)

c. Model resistance as a function of speed, wave height, frequency, all-up weight, trim, heel, and Q

d. Model stability (moment to trim and heel)

e. Dynamic characteristics (natural periods and damping in pitch, roll, and heave)

f. Plow-in characteristics (speed, Q, wave height, and frequency)

g. Craft response to regular waves of varying length and height

h. Craft response to irregular waves in sea states 2, 3, and 4.

It is understood that prior to the above tests DTNSRDC will conduct tests to measure and adjust model weight, cg, and inertias. Periodic checks during the tow test program are recommended to verify that weight and cg do not change appreciably due to the model shipping or absorbing water. It should be possible to perform these checks without removing the model from the tow carriage.

It is strongly recommended that the time for testing each model in the tow tank should include a period of at least three days, and preferably a week, for exploratory runs and adjustments or minor changes of the seal system. Experience has shown that observations of seal behavior and preliminary data analyses often indicate a need for small changes which can result in large improvements in seal system performance. The need for such adjustments can be a result of difficulties of precisely predicting bag and finger inflated geometry and of fabricating the small seals of very flexible model material. Adjustments could include minor local changes to bag loop lengths, finger attachment lines, vent areas, etc. The effects of minor adjustment could be as great as the differences between different cushion systems.

Bell generally concurs with the DTNSRDC test program outline. The degree to which data can be obtained for combinations of test parameters, such as weight, trim, heel, Q, etc, may be limited by funds or time available. The following priorities are suggested:

PRIORITY	TASK
1	Fan performance
2	Lift system performance
3	Adjust ballasts to achieve design weights, cg, and inertias
4	Static stability tests on land - moment to trim and heel and heave stiffness. Effect of bag-to-cushion-pressure ratio and flow on these characteristics
5	Dynamic characteristics on land - natural periods and damping (pitch, roll, heave). Effect of P_b/P_c and Q on these characteristics.
6	Repeat selected points from test 4 on water.
7	Repeat selected points from test 5 on water.
8	Model resistance and moments versus speed with model fixed attitude in calm water (first priority - trim, second priority - Q; third priority - yaw, fourth priority - weight, fifth priority - heel).
9	Plow-in characteristics in calm water with model free to pitch (safety snubbers required).
10	Response to regular waves with model free to pitch. Select model speeds and wave lengths to emphasize encounter frequencies near model pitch and heave natural frequencies. Present results as transfer functions and as power spectral densities (PSDs) of model motions, pressures, and accelerations for consistency with later data from irregular waves. Also obtain conventional tank data statistics (largest value, average of 1/3-highest, etc). Tests with at least two (preferably three) wave heights are desirable. Wave heights of 1/3-, 1/2-, and 2/3-cushion height are suggested.
11	Response to simulated sea states 2, 3, and 4 with model free to pitch.

PRIORITY	TASK
12	Tests in oblique waves with model free to pitch and roll.
13	Repeat selected tests for maximum and/or minimum weights with appropriate inertias.

It is believed that, in general, it will be most efficient to proceed through the entire test sequence with one model weight, cg, and inertia combination before varying these parameters individually or in combination. Changes from this approach may be influenced by tank and manpower availability and assessments of overall program efficiency.

There are also questions as to whether tests 9 through 13 should be conducted with the model fixed in surge or free to surge. The latter is certainly more realistic and is preferred if the added complexity of testing does not become prohibitive in test time or cost. It has been Bell's experience that free-to-surge results are generally not significantly different from fixed-in-surge results. The one exception is plow-in tests, where free-to-surge tests are desirable.

Self-propulsion can be used for free-to-surge tests to reduce the nominal load on the surge mechanisms of the tow carriage. The decision whether or not to use a propulsion unit will depend more on characteristics of and experience with the DTNSRDC surge mechanisms than on any basic technical need for a propulsion module.

Test 12 has been added because tests in a tow tank with head seas do not assess dynamic roll and yaw characteristics of the models. Some roll information can be obtained by testing with the model yawed (fixed in yaw, free to roll), but this is still not a good measure of craft lateral characteristics.

4. PRELIMINARY MODEL CONFIGURATION

4.1 Model Geometry and Construction

Bell advanced design drawing SK-1, Cushion Systems Comparison Test Model, shows the general size and geometry of Bell's proposed model (figure 3).

The proposed method of construction uses a wooden egg-crate frame with plywood outer skins. A lightweight, closed-cell foam will be used throughout most of the basic raft to minimize entry of water. Wooden inserts will be incorporated at required hard points (motor mounts, propulsion mounts, tow fittings, ballast weight attachments, skirt attachment lines, etc).

The superstructure will also have a foam core. Outer skin will be lightweight plywood or fiberglass. Removable sections, with fans and volutes, will be incorporated for ease of access to fan assemblies. It is presently planned that these sections will be fabricated from aluminum.

All exposed surfaces will be sealed and painted with marine finishes to minimize water absorption.

This method of construction has been used for other models, resulting in high strength and stiffness, light weight, and high flotation with little water absorption.

4.2 Skirt System

4.2.1 General

The skirt will be fabricated from Government-furnished Belflex 40. The skirt configuration will be very similar to the bag and finger system used on the JEFF(B). Transverse and longitudinal stability seals will be included. Parameters such as finger angles, finger height to cushion height, finger width to finger height, and bag cross section will be similar to those of the JEFF(B). However, as a result of JEFF(B) experience, Bell is now reviewing that skirt design to determine if detailed changes are desirable.

The skirt will be attached to the hull by screws and batten strips. Bell experience has shown that this is preferable to Velcro attachments. The latter method of attachment facilitates removal of seals for modifications, but introduces risk of undetected local detachment which can invalidate tests and/or damage seals.

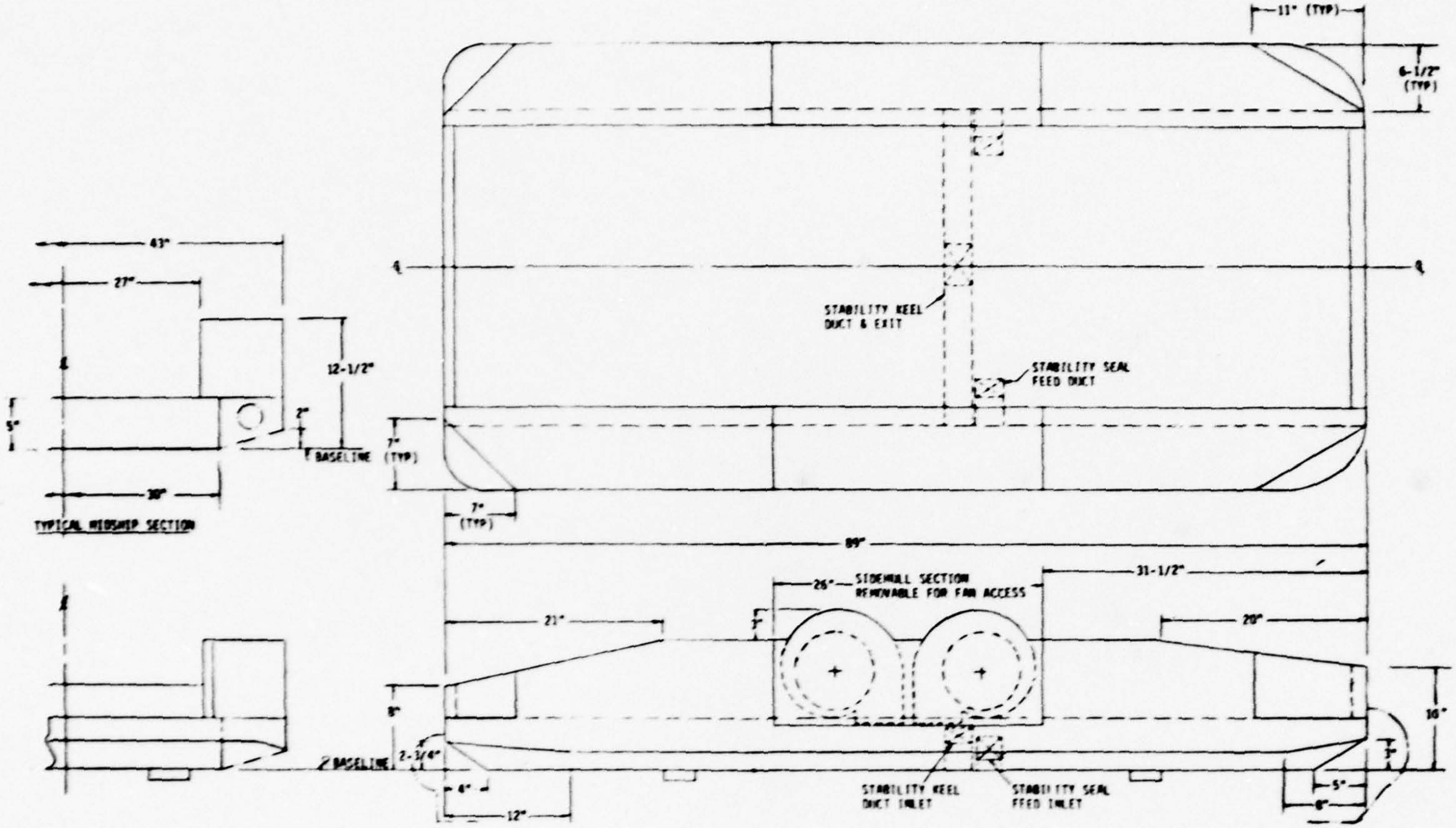

Figure 3 SK-1 CUSHION SYSTEMS COMPARISON TEST MODEL

4.2.2 Skirt Geometry and Bag-to-Cushion-Pressure Ratio

The Navy criteria for the model fixes the full-scale skirt height at 5 feet at the design all-up weight. Additional constraints are imposed by the specified hard structure beam, overall beam, and overall length. Among the design parameters to be selected are:

a. Bag-to-cushion-pressure ratio

b. Finger-height-to-cushion-height ratio

c. Finger-width-to-finger-height ratio

d. Finger external angle to the horizontal

e. Bow, side, and stern cross sections

f. Longitudinal and transverse stability seal cross sections and depths.

It is planned to deviate from the JEFF(B) skirt design only where JEFF(B) experience has shown that improvements are desirable.

The JEFF(B) skirt is shown on Bell drawing JEFF(B)-806-4566903. Reference 4 describes the JEFF(B) skirt system and its design history. Major elements of the final seal configuration are shown in figure 4. Changes will be guided by reference 6, supplemented by analyses being made specifically for the JEFF(B). Reference 6 is a study of skirt concepts for large ACVs (3000 tons). However, trends shown by that study will generally also apply to smaller craft.

The nominal bag-to-cushion-pressure ratio for the JEFF(B) is 1.4 (see section 3.20.2.2 of reference 4). This ratio was selected early in the design and was not changed throughout the program. A lower bag pressure is desirable to reduce lift fan horsepower. However, lower bag pressures may require larger bags to prevent tuck-under of the bow bag and fingers, with subsequent decrease of pitch stability and a potential plow-in condition at high speeds. Similar trends exist for craft lateral stability, but roll is generally less critical.

Larger bags, with constraints on hard structure and overall craft dimensions, generally result in shorter fingers. This can result in reduced capability of fingers to resist drag without pullback, but it will also result in improved lateral stability of fingers of a given width. Provided the fingers are designed so that lateral buckling does not cause excessive cushion leakage, the larger bags required with low bag-to-cushion-pressure ratios with shorter fingers will generally increase seal drag in waves.

The bow bag section, away from the centerline, could be increased, relative to the JEFF(B) configuration, by raising the upper attachment line. Finger height can still be constant. Although this complicates the transition to the smaller side bag, it is being considered for the cushion model. This will improve bow bag resistance to drag from corner and side fingers.

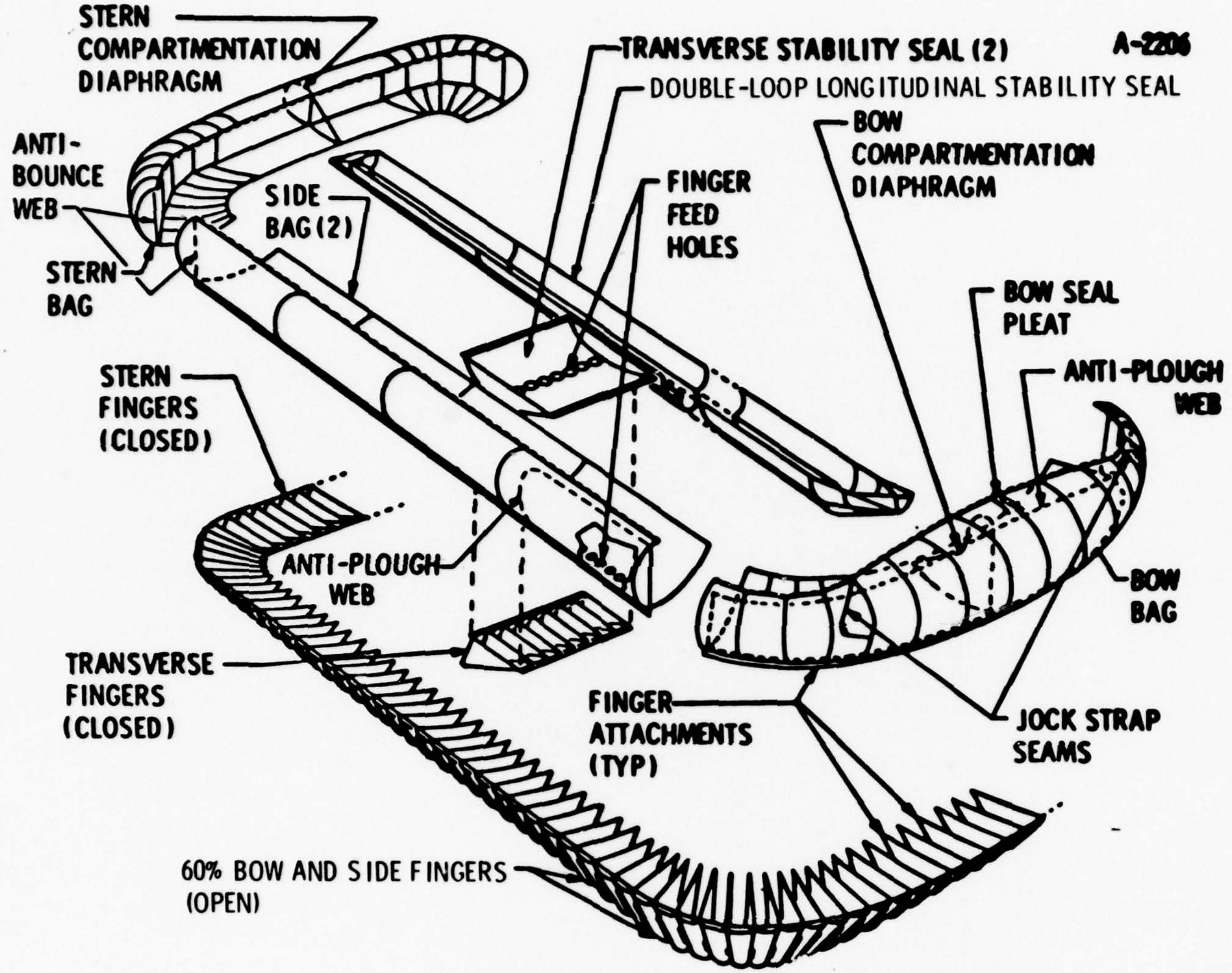

Figure 4 JEFF(B) SEAL CONFIGURATION

The plow-in resistance of the B-17 model of the JEFF(B), shown in figure 5, and the good pitch and roll stability of the JEFF(B) models indicate that the bag-to-cushion-pressure ratio of the cushion comparison model could be reduced below 1.4 However, full-scale craft experience, discussed later, indicates that the full-scale craft has less pitch stability than the model. A nominal value of 1.25 has been tentatively selected for the cushion comparison model. This is the value which the Navy has specified for the LCAC.

No specific requirements for changing bag-to-cushion pressure are specified in the Navy criteria for the model. However, a capability will exist for varying P_b/P_c from at least 1.1 to 1.4, with flow fixed, by blocking (or opening) bag-to-cushion vents in the bag and chaning fan rpm. At least exploratory runs to determine effects of P_b/P_c on model pitch stability and plow-in are very desirable. However, if this is done, care should be used in assessing overall air supply system efficiencies and power requirements for off-nominal P_b/P_c ratios. For an actual craft, the fan design would be modified to place the point of maximum air supply efficiency near the operating point(s) for the finally selected seal pressure ratio. In the model tests, important effects of P_b/P_c can be assessed even though the air supply is not optimized for each seal pressure ratio.

JEFF(B) experience has indicated some characteristics which might be improved by seal design changes. These include a pitch-click/tuck-under susceptibility at high speeds, and wear and subsequent leakage of closed stern fingers and closed fingers on the transverse stability seals. The pitch-click/tuck-under/plow-in characteristic was not detected within the JEFF(B) operating envelope by model tests (figure 5). To date, the cause of this pitch-click/tuck-under tendency on the actual craft has not been positively identified. Possibilities being considered to improve pitch characteristics include wider fingers at bow corners to improve lateral finger stability, reduce leakage, and improve pitch stability; improvements of transverse and/or lateral stability seals; and higher bag pressure (rather than the lower nominal pressure tentatively selected for the cushion comparison model).

It is believed that wider bow corner fingers may be the only change required to achieve acceptable pitch characteristics. This will be investigated on the craft in the near future.

Although it is not being considered for the JEFF(B), as discussed earlier, a raised hinge line for the bow bag away from the centerline is also being considered for the cushion model to improve bag resistance to drag, and hence improve pitch stability.

The finger wear problem cannot be directly assessed with the cushion comparison models. However, because of difficulties of access for repair or replacement of stability seals, the elimination of stability seals would greatly reduce

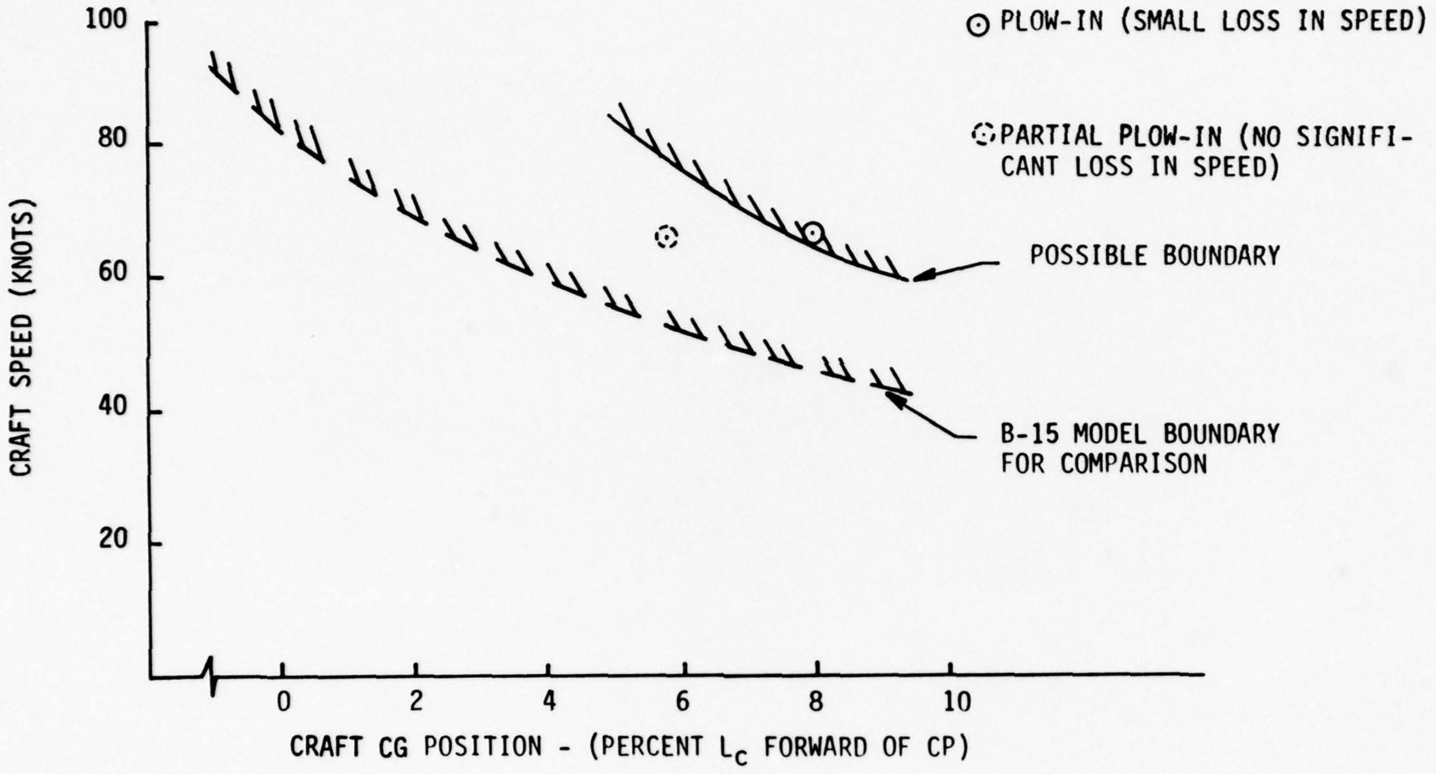

Figure 5 PLOW-IN BOUNDARY SCALED FROM B-17 MODEL OF JEFF(B)

consequences of finger wear. Figure 6 suggests that roll stability provided by a longitudinal stability seal is a strong function of the depth of the stability seal relative to the depth of side seals. It also shows that roll stability comparable to present stability with the longitudinal seal could be obtained without the stability seal if the external angle between the finger and the horizontal is decreased. The degree that this can be achieved in an actual craft is limited by constraints on hard structure and overall craft width. Similar trends, but different magnitudes, would exist for pitch stability.

In the future, it is expected that trends will be toward elimination of stability seals. This will not only reduce seal maintenance/repair costs, but will significantly reduce seal complexity and initial costs. Further analyses, beyond the scope of this program, and development model tests would be required before Bell would be committed to a design without stability seals. Therefore, the cushion comparison model will have stability seals similar to those on the JEFF(B). These are briefly described below.

The present JEFF(B) longitudinal and lateral seals (figure 4) are designed to inflate to a depth 6 inches above the peripheral seals under normal loading conditions (ie, stability seals are 4 ft., 6 inches deep). The transverse seal consists of a flat or shallow bag plus the same closed acute fingers as the stern seal.

The longitudinal stability seal is double-bubble configuration formed by single horizontal diaphragm running the length of the seal. This replaced a V-shaped cross section of early design studies, which required numerous diaphragms to provide the V cross section. Section 3.22.4.2 of reference 4 notes that the B-17A model had the earlier V-section keel, rather than the double-bubble configuration. The latter is believed to result in slightly higher drag in waves, a price that was paid for reduced complexity.

The 3-foot-high JEFF(B) fingers are 60 percent of cushion height (5 feet). The same finger height is used all around the skirt. The pitch or width of all fingers is 2 feet, for a height-to-width ratio of 1.5. This was a change from the configuration of the B-17A model, which had a finger height equal to 50 percent of cushion height or a height-to-pitch ratio of 2. (B-17A represented 2.5-feet-high fingers, 1.25 feet wide.) The change was made to reduce drag in waves, improve finger lateral stability, and to reduce the number of fingers. JEFF(B) experience indicates that it may be desirable to further increase the width of bow corner fingers to improve their lateral stability and reduce leakage at bow-down attitudes.

The angles between the external faces of bow and side fingers and the horizontal are 50 degrees. A decrease of this angle would improve pitch and roll stability, if it could be achieved without decreasing cushion dimensions

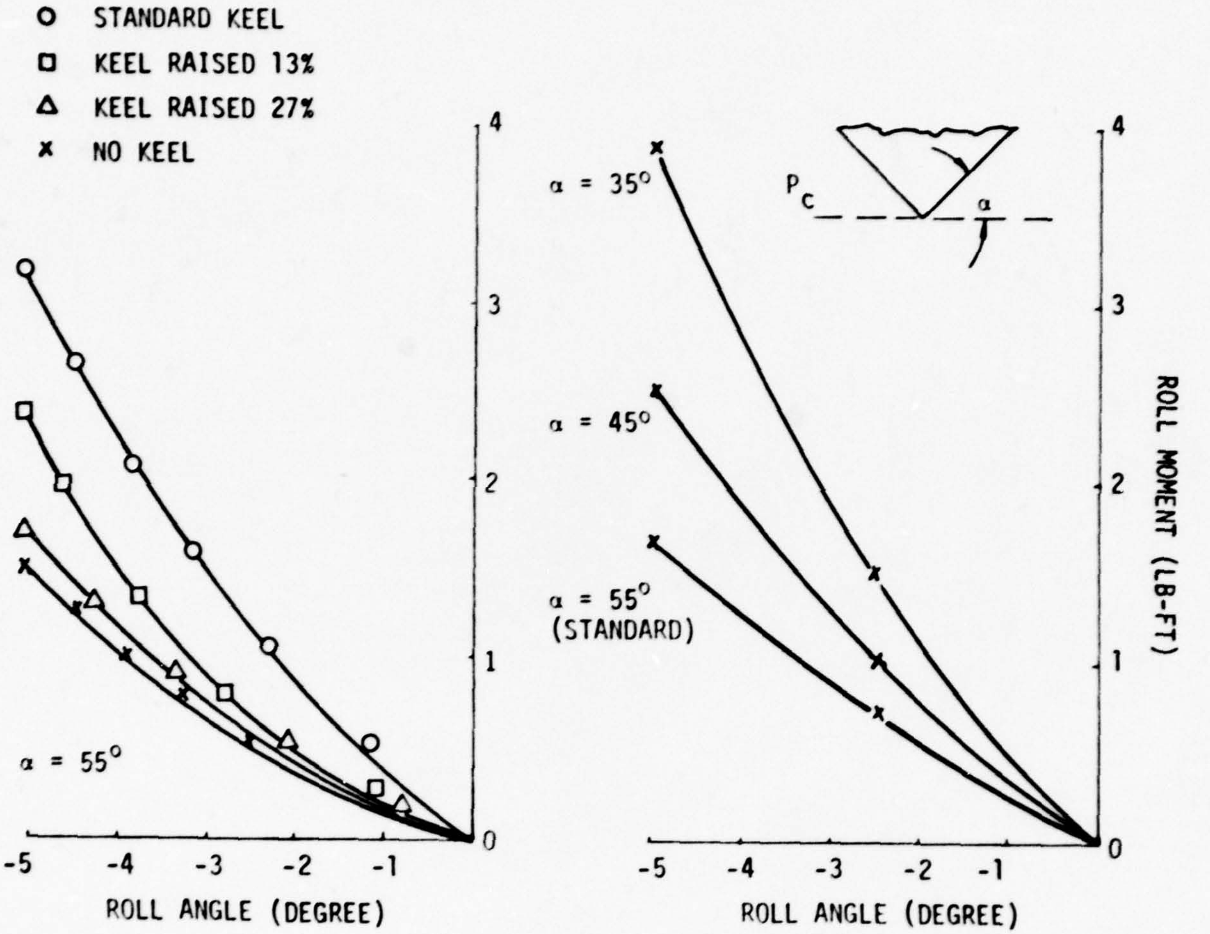

Figure 6 COMPARISON OF JEFF(B) KEEL HEIGHT AND FINGER ANGLE EFFECT ON ROLL STIFFNESS

(figure 4). Such changes are being considered for the cushion comparison model. However, with hard structure and overall constraints imposed by model criteria, such changes must be small. A decrease to 45 degrees, or perhaps even 40 degrees, may be feasible at the bow. However, a difference of more than a few degrees between the angle of bow fingers and side fingers complicates the design and fabrication of transition fingers and will probably make a decrease of more than 5 degrees at the bow undesirable.

Figure 7 (based on equation (5) of reference 6) shows that reasonable changes of finger leading edge angle have very little effect on bow finger resistance to buckling aft or tuck-under. Finger depth has a much greater effect on buckling of bow fingers. For a given immersion (water level relative to bottom of the finger), doubling finger depth, d, decreases Z/d by 50 percent. Figure 7 indicates that this results in a large increase of the craft speed at which bow finger buckling occurs. When this critical velocity is reached, the finger leading-edge angle with the horizontal will decrease, and/or a leading-edge radius will develop until drag forces are balanced by pressure forces and tensions in the finger material. Therefore, the fingers will not collapse, but pitch stability will be reduced. Craft speed is theoretically independent of finger width. However, if finger depth is increased without also increasing finger width, fingers may buckle laterally with detrimental effects on stability and drag. An increase of finger depth, with a corresponding increase of width, can increase pitch stability and plow-in resistance. However, only small increases of JEFF(B) finger depth are practical with the craft geometric constraints specified for cushion comparison models. Therefore, it is planned to retain JEFF(B) finger depth for the model.

The JEFF(B) closed, acute-angle stern fingers and side-to-stern transition fingers have performed well, except for greater wear than desired. Options include the addition of abrasion strips and a proposed minor configuration change to reduce local low spots which wear most rapidly. It is planned that the model stern fingers will represent the present configuration of JEFF(B) fingers. The proposed minor changes to craft stern fingers are not believed to be significant except for reduced wear. The new design would be more expensive to model with little or no benefit to the model program.

The JEFF(B) bow seal (figure 4) includes an anti-plow web which extends around the corners and partially down the side bags. There is also a bow compartmentation diaphragm at the bow seal centerline. The anti-plow web and compartmentization diaphragm will be represented in the model seal. The stern seal has an anti-bounce diaphragm that will be modeled.

JEFF(B) bow and stern seals also have jock-strap seams which are required for lowering of the ramps through the bags. These do not influence seal characteristics and, for simplicity, will not be included in the model.

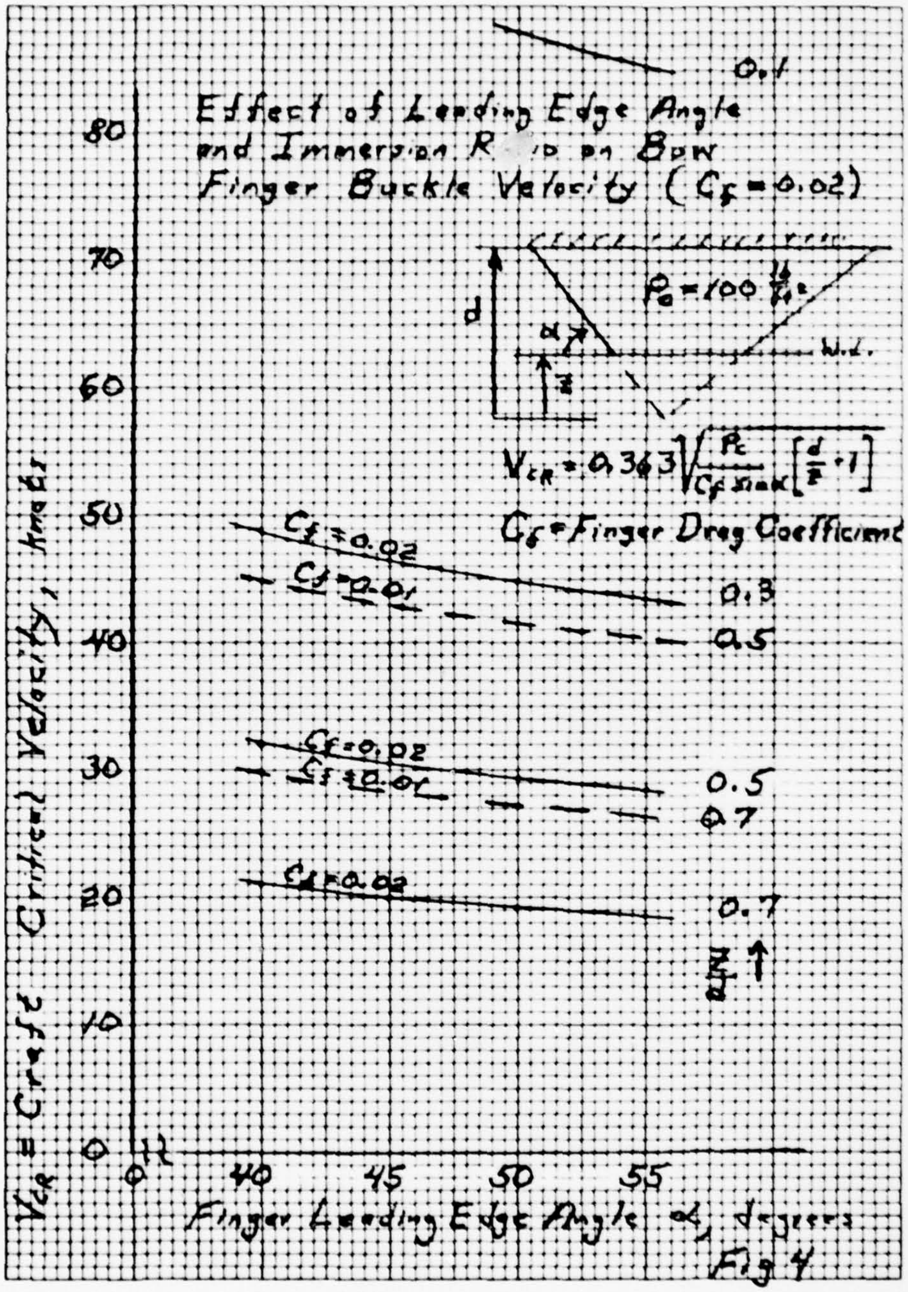

Figure 7 EFFECT OF LEADING-EDGE ANGLE AND IMMERSION RATIO ON BOW FINGER BUCKLE VELOCITY ($C_f = 0.02$)

4.3 Air Supply System

4.3.1 Airflow

The model airflow will be based on JEFF(A) and JEFF(B) flows. The JEFF(B) has a total nominal fan flow of 19,400 cfs at a design weight of 325,000 lb. However, normally only 10,400 cfs is allotted to the cushion with the remainder for bow thrusters. The JEFF(A) nominal cushion flow is approximately 13,200 cfs at a craft weight of 340,000 lb.

If the JEFF(B) cushion flow is increased to account for the longer cushion, greater cushion perimeter, and increased weight, a full-scale flow requirement of 10,800 cfs is obtained for the cushion comparison model. This is essentially the JEFF(A) flow. Froude-scaling gives $10{,}800/12^{2.5} = 21.6$ cfs for the model at a weight equivalent to a full-scale weight of 340,000 lb.

Figure 8 shows that this flow, as well as an allowance for leakage, can be provided with two existing fan impellers from the B-17A model with new volutes. It is proposed to install four B-17A model fans so that full-scale cushion flows up to approximately 24,000 cfs can be simulated.

4.3.2 Bag and Cushion Pressures

Figure 9 shows preliminary ranges of required bag and cushion pressures for the cushion comparison model. A nominal bag-to-cushion-pressure ratio of 1.25 has been tentatively selected. However, by adjusting bag-to-cushion vent areas, it should be possible to test at ratios from approximately 1.1 to 1.4.

4.3.3 Lift Fans

A review of the fans now in the B-17 model has shown that they are suitable for the cushion comparison model. It is presently anticipated that all four fans will be installed in the model in order to provide a large range of available flow. Preliminary calculations show that the design point lift conditions can be realized with only two of the four fans operating. Two fans will be incorporated in each side structure. New volutes (one per fan) will be incorporated in the removable sections of the superstructure. It is not proposed to use the Siamese-twin volute configuration of the JEFF(B).

Air from the lift fans will be discharged entirely to the side bags. Provision will be made to direct some of the air from the peripheral bags to the keel and lateral stability seals.

Pairs of fans on opposite sides of the craft will be interconnected by shafts and flexible couplings. Each of the two shafts will be driven by an electric motor via toothed timing belts and pulleys to ensure a positive gearing down from motor speed to fan speed.

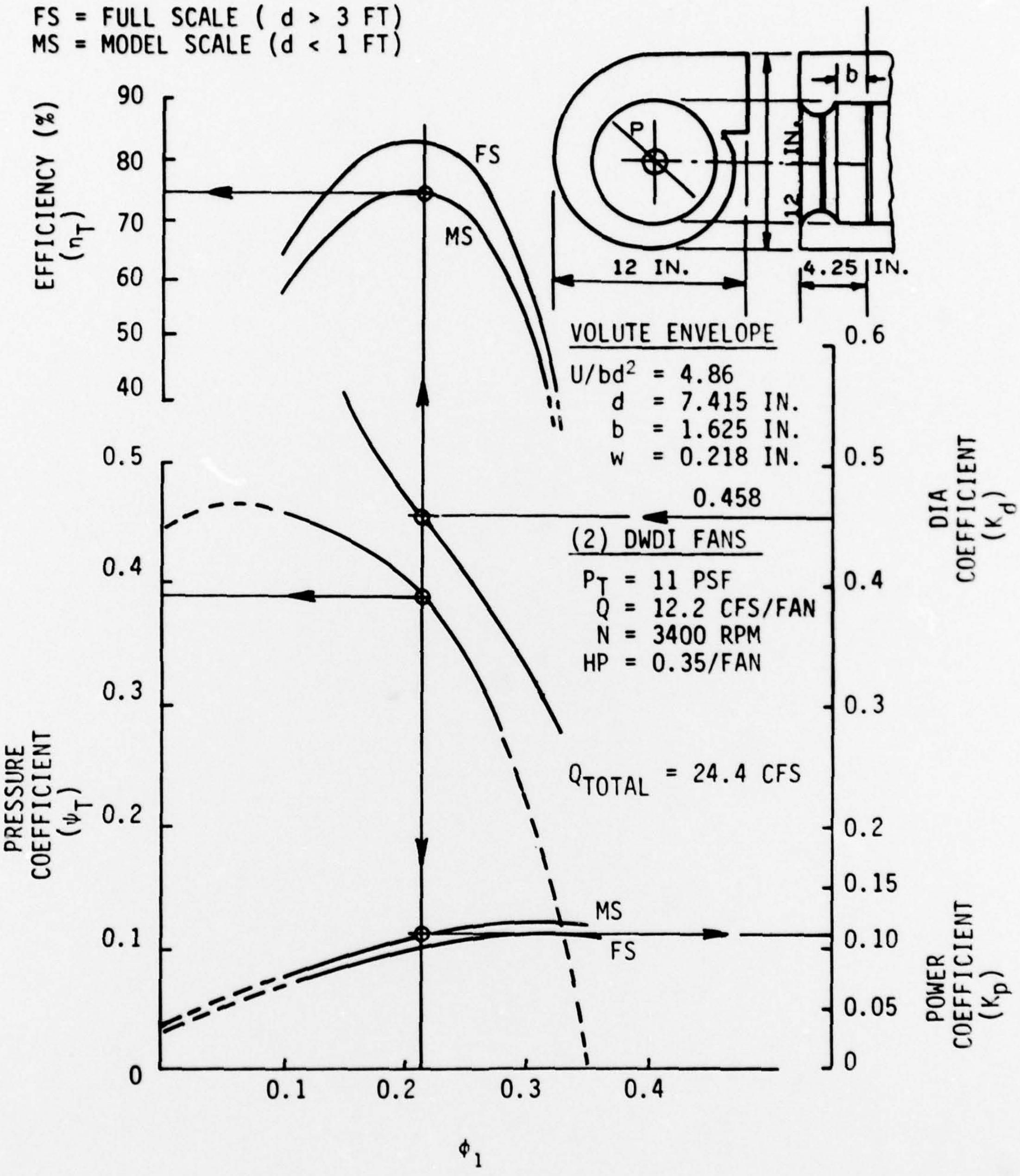

Figure 8 CHARACTERISTICS OF 7.5-INCH-DIAMETER LIFT FAN FOR CUSHION COMPARISON MODEL

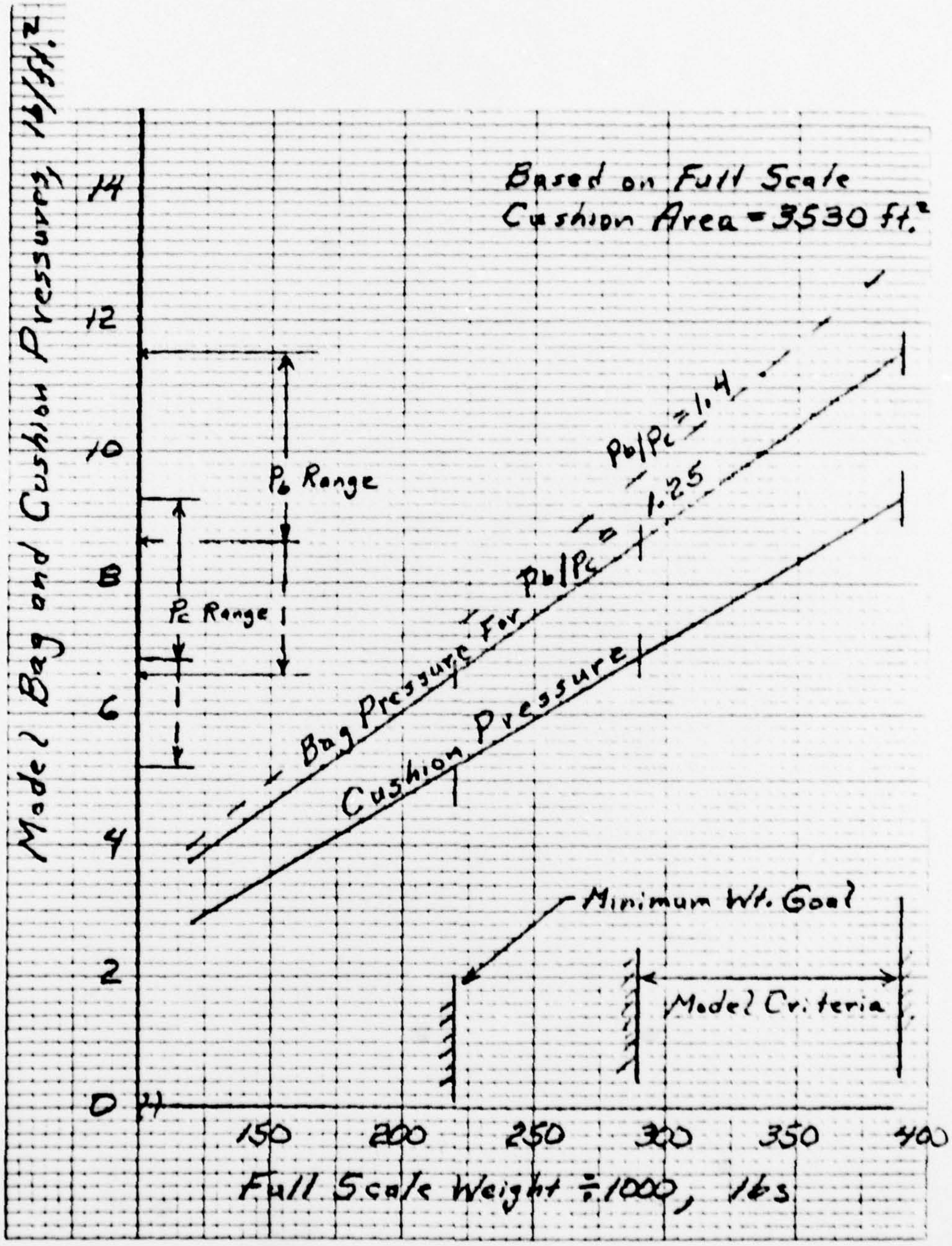

Figure 9 CUSHION COMPARISON MODEL BAG AND CUSHION PRESSURES VERSUS SIMULATED CRAFT WEIGHT

Each fan will provide a nominal flow of 12.2 cfs when bag pressure is approximately 11 psf. Nominal bag-to-cushion-pressure ratio will be 1.25:1. The air supply system will be capable of at least ±25 percent changes of airflow by changing motor rpm.

It is presently planned that tests with off-nominal flow will be conducted with the bag-to-cushion-pressure ratio changes which result from rpm changes, weight changes, sea state changes, etc. However, if it is desired to make a series of runs with a higher nominal pressure ratio, this can be done by adding internal flaps over selected bag-to-cushion vents. Bell will make recommendations on how to make such changes if they are desired. It is not considered practical to maintain a precisely constant bag-to-cushion-pressure ratio as other test parameters are varied.

Figure 8 shows an estimated bag pressure versus flow curve for a single fan. It is expected that the Navy will measure the actual pressure flow characteristics of the fans and of the complete installed system prior to tow tests.

The volute and inlet slightly exceed the craft superstructure envelope specified by the Navy criteria. It is proposed that small bulges above the basic superstructure be allowed so these fans and volutes can be installed as shown on figure 3. An alternative would be to design entirely new fans, at considerable cost. Another possibility would be use of smaller volutes. This would result in fan characteristics which are less representative of full-scale fans. The small local deviations from the specified craft envelope seem preferable to either of these alternatives.

4.4 Instrumentation

The model will be provided with pressure taps to measure bag and cushion and fan exit pressures, as specified in the Navy critieria for the model. Metal tubes will be brought from these measuring points to the deck. As specified in the Navy criteria, all required transducers will be provided by the Navy.

4.5 Model Weight and Inertias

The Navy criteria specifies a model minimum test weight equivalent to 290,000 lb and a maximum weight of 390,000 lb. A minimum of 220,000 lb is desirable if it can be achieved without appreciable increase of model cost. An allowance of 10 lb is to be made for towing gear and instrumentation that will be added by the Navy.

The minimum weight of the models provided by the contractors shall therefore be no more than 158 lb, with a minimum weight goal of 117 lb. The corresponding maximum weight is 216 lb.

Engineers' notebooks from JEFF(B) B-17A model tests list the following weights:

Basic Model (includes carriage gimbal)	120.5 lb
Lead	64.5 lb
Tow Mast	2.25 lb
Cables, etc	0.75 lb
Initial Test Weight	188.00 lb

The 120.5-lb basic weight of the B-17A model is well below the criteria minimum weight for the cushion comparison model. It is slightly greater than the unspecified, but desirable, goal of 117 lb. The cushion comparison model will be approximately 10-percent longer than the B-17A model. Because of relatively fixed weights for fans, motors, etc, a basic weight of a cushion comparison model similar to the B-17A model would be less than 1.1 × 120.5 = 133 lb.

It is planned to fill the basic structure of the cushion comparison model with Styrofoam, or the equivalent, to improve flotation in the event of structural leaks and to minimize weight increase due to water that might otherwise be taken aboard. The volute of the basic craft will be less than 96 by 48 by 5 inches = 23,040 in^3 = 13.3 ft^3. If a density of 0.001 lb/in^3 is assumed, the flotation material could add about 23 lb. This would bring the model basic weight to 133 + 23 or 158 lb, which is the criteria minimum weight. By using careful weight control, lower density foam, etc, it should be possible to achieve a weight below the specified 158 lb. However, it will be difficult and expensive, but probably not impossible, to achieve a weight of 117 lb. It is expected that a weight of the order of 140 lb can be achieved at a reasonable cost.

The above weight discussions do not account for possible ballast weights to achieve desired model inertias. Model equivalents of inertias specified for the all-up design weight at 36,523; 127,243; and 152,041 lb-in^2 for roll, pitch, and yaw, respectively. If all model weights were uniformly distributed over the planform, roll inertia would be of the order of $1/12\ WB^2$ and pitch and yaw inertias would be of the order of $1/12\ WL^2$. For the model design weight of 196.8 lb, L = 96 inches and B = 48 inches. This approximation gives a model roll inertia of 37,500 lb-in^2, and pitch and yaw inertias of 151,100 lb-in^2. These are near the specified values.

Concentrated weights of fans, motors, etc, will reduce these approximate values, leaving some margin for ballast weights to achieve prescribed inertias and cg for the design weight condition. It is more difficult to achieve realistic inertias for light weight conditions, but with careful attention to minimize weight and to properly locate motors, etc, it will be possible to obtain realistic inertia characteristics throughout the weight range.

5. SCHEDULE

Figure 10 is the proposed schedule for model design, fabrication, checkout of the seal system, and checks of weight, balance, and inertias. The latter will be of sufficient accuracy to demonstrate that Navy criteria have been met.

The overall time from go-ahead to delivery is 26 weeks. No allowance has been made for year-end holidays. If go-ahead is after mid-May 1979, an extension of 2 to 3 weeks may be desirable to compensate for Bell scheduled holidays without increasing costs. However, Bell will make every effort to arrive at a schedule which is consistent with both the Navy's test schedules and the desire to keep costs low.

6. DOCUMENTATION

Drawings will be those required to define the model hull, seal, and installations for fabrication and assembly in a model shop with close liaison between engineering and the fabricators. Design analyses will be limited to those which Bell experience has shown to be essential to model design.

Copies of drawings and pertinent results of analyses will be provided to the Navy, if requested. Such documentation will be provided as informal enclosures to letters of transmittal rather than as formal reports.

7. COSTS

Estimated costs of model detailed design and construction were transmitted by reference 7. It also transmitted reference 8, which contained a preliminary description of the model.

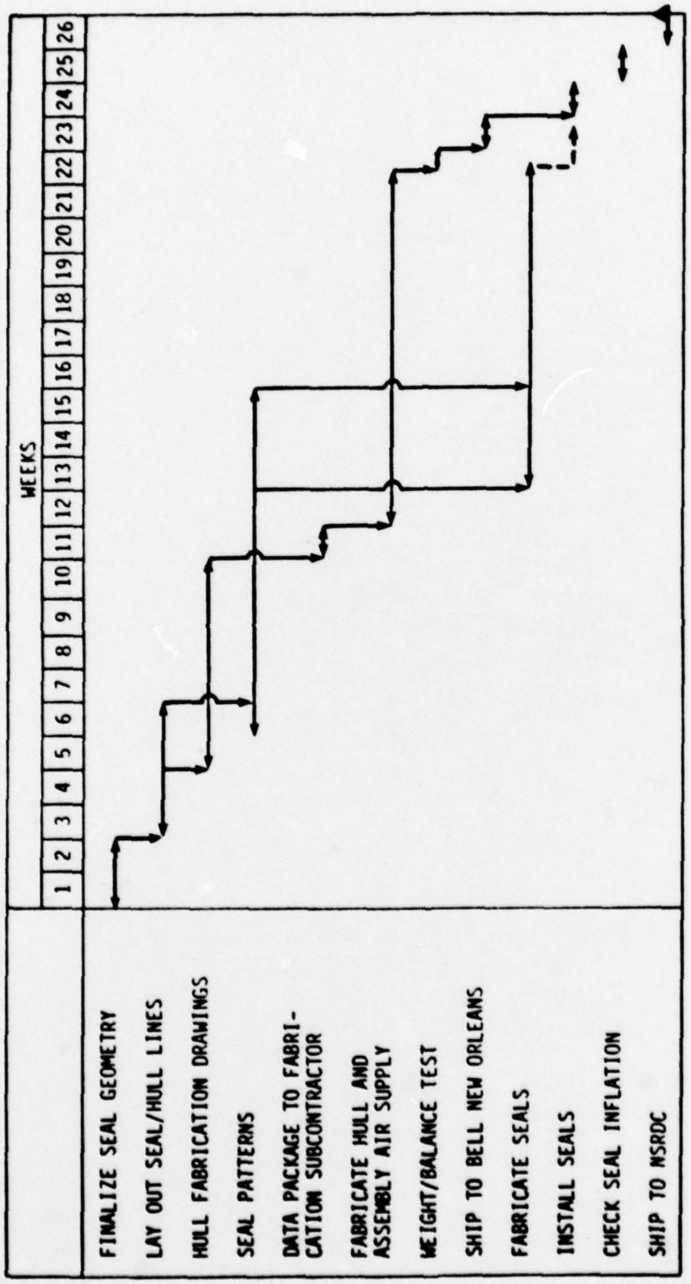

Figure 10 CUSHION COMPARISON MODEL SCHEDULE

REFERENCES

1. Letter, DTNSRDC Letter 9070:1182:ZWG, January 26, 1979, Enclosure (1), Subject: Navy Model Criteria.

2. *JEFF(A) Summary Detail Design and Construction Report* (Aerojet Liquid Rocket Company Operations Report AGC-T-603, March 25, 1977).

3. *AALC JEFF(B) Moment of Inertia Report* (Bell New Orleans Report No. 7385-942002, March 1, 1979).

4. *AALC JEFF(B) Summary Detail Design and Construction Report* (Bell New Orleans Report No. 7385-950008, December 1977).

5. Letter, DTNSRDC Letter 1182:ZGW, February 2, 1978, Enclosure (1), Subject: DTNSRDC Proposed Test Program.

6. *Study of Large Air Cushion Vehicle Skirt Design Concepts* (Bell New Orleans Report No. 7588-950048, January 31, 1977).

7. Letter, Bell New Orleans Letter B-383, April 12, 1979, Subject: Contract N00014-78-C-0588, Submittal of Cost and Schedule Information for the Construction of an Air Cushion Vehicle (ACV) Model for Cushion System Comparison Tests.

8. *ACV Model for Cushion Comparison Tests* (Bell New Orleans Report No. 7575-953031, April 12, 1979).

APPENDIX A

CUSHION SYSTEMS COMPARISON TESTS MODEL DESIGN CRITERIA

A.1 PRINCIPAL CHARACTERISTICS

Length Overall, On Cushion, L. Ft	96.0
Beam Overall, On Cushion, B. Ft	48.0
Beam, Hard Structure, Maximum, Ft	43.0
Height Overall, On Cushion, Including Propulsor, Ft	24.0
Skirt Height, Mean at Design All-Up Weight from Bottom of Skirt to Baseline, Ft	5.0
Cargo Deck Width, Minimum, Ft	26.0
Cargo Deck Height, Above Baseline, Ft	5.0
Ramp Height Above Baseline, Ft	
Forward	10.0
Aft	8.0
Sidewall Height Above Baseline, Ft	
Maximum	12.5
Minimum	10.0
Landing Pad Depth, Below Baseline, Ft	1.0
All-Up Weight, Design, Lb	340,000.0
Maximum, Test	390,000.0
Minimum, Test	290,000.0
Mass Moment of Inertias, at Design All-Up Weight, Slug-Ft^2	
Roll	1.96×10^6
Pitch	6.83×10^6
Yaw	8.16×10^6
Transverse Center of Gravity, from Centerline, Ft	0.0
Vertical Center of Gravity, Above Baseline, Ft	6.1

A.2 MODEL SCALE

The general configuration of the model should be similar to the prototype it represents for the purposes of aerodynamic and hydrodynamic tests as outlined in Model Test Program with the exception of the lift system fan (see section A.3). The model scale shall be 1:12.00.

A.3 LIFT SYSTEM SCALING AND ARRANGEMENT

The lift system modeling shall be dynamically similar to the prototype it represents for the purpose of providing data for the comparison of the different cushion systems.

A.3.1 Skirt System

It is recognized that proper representation of all structural characteristics in the skirt system is not possible within the context of Froude scaling. However, the model skirt system shall represent the significant design features of the full-scale skirt including geometry of all component panels and joints, points of attachment and general material type. For convenience a common material, Belflex 40, shall be used. The material shall be procured by one contractor for the use of all. Color preference is yellow or orange to give maximum visibility in the presence of water and spray.

A.3.2 Lift Fans

The fan inlets, rotors and volute housings shall be geometrically similar to that required for the full-scale craft. Scaling imperfections of the small fan model may be compensated by using a larger, geometrically similar fan and/or increasing rotor rpm. The size of the model fans is constrained by the model sidewalls within which they must be housed.

The lift fans must provide appropriate pressure, sufficient flow, and proper ratio of pressure-to-flow rate for optimum operation of the model under all conditions. Contractor recommended optimum flow should be indicated and the fan should be able to deliver ±25 percent of that flow.

The lift fans shall be powered by 3-phase, nominal 400 Hz, variable frequency motors. For convenience and economy the motors may be mounted outside the sidewalls within the cargo deck area. The same type of electric motors will be used in all models and will be procured by one contractor. Provisions shall be made to measure fan shaft rpm with a digital magnetic pickup.

A.3.3 Air Distribution System

The air distribution system should be geometrically similar to that of full scale craft and should be confined below cargo deck level (5.0 ft WL).

A.4 MODEL CONSTRUCTION

The model shall be built to resemble the JEFF craft general configuration and should have freeboard all around. The freeboard on the model shall be governed by the following: on the model sides by the height of the sidewalls; at the bow by the height of the bow ramp; and at the stern by the height of the stern ramp.

The model shall be capable of representing a range of full-scale all-up weight conditions considering model towing gear and model instrumentation weight, cg location, and moment of inertias. The range of all-up weight conditions for the full-scale vehicle is: design 340,000 lb, maximum 390,000 lb, and minimum 290,000 lb.

The weight allowance for the model towing gear and instrumentation is 10 lb each. The model shall be capable of representing the craft design center of gravity, and craft off-design conditions corresponding to ±3 percent of the length overall on cushion (L) and beam overall on cushion (B). The model shall be capable of representing craft moment of inertias at the design all-up weight as specified in A.1, Principal Craft Characteristics.

Hard points shall be provided in the model for the purpose of lifting the model, and attaching towing apparatus, instrumentation and other equipment required for the tests. Hard points should be fabricated from 1/4-inch aluminum or 3/4-inch mahogany plate. Horizontal dimensions of the plates the their locations are specified in figure A-1. These plates shall be securely mounted to the model by means of through-bolts in the major longitudinal members. They shall be removable and replaceable for convenience in making changes and drilling and tapping holes to suit particular fittings.

The model shall be built to the following tolerances:

Model weight	±1 percent
Model hard structure dimensions	±1/8 inch
Model principal dimensions, on cushion	±1/4 inch
Model mass moment of inertia	±5 percent
Model center-of-gravity position	±0.1 inch
Model cushion depth	±1/4 inch.

A.5 MODEL INSTRUMENTATION

The contractor shall provide piezometer openings to measure fan exit, bag and cushion static pressures. Metal tubes not smaller than 1/4-inch ID, suitably mounted, should be brought from these measuring points to the deck. Four probes should be mounted at each fan exit, twelve in the bag and four to measure cushion pressure.

Provisions should be made to measure fan rpm. Transducer rpm and instrumentation to measure model speed, motions, accelerations, and pressures will be provided by the Navy.

A.6 MODEL PROPULSOR

Independent of the model, air propulsor is required that provides adequate thrust for the self propulsion tests in waves. The propulsor thrust line should simulate that of the full-scale craft. The propulsor electric motor should be of a 400-Hz variable frequency type similar to the lift system motor in section A.3. One propulsor only will be built, adequate to propel each model.

A.7 MODEL SPARE PARTS AND MATERIALS

The following spare parts shall be provided:

Spare bearings for the complete model lift fan system	1 set
Spare bearings for the model propulsor (applies only to the contractor procuring the propulsor unit)	2 sets
Skirt material, per model (applies only to the contractor procuring the material)	5 yd
Transmission belts	1 set.

NOTES:

1. Tow points ① are for seakeeping tests, one being an alternate.
2. Tow points ② are for rotating arm tests.
3. Material should be 1/4-inch aluminum plate or 3/4-inch mahogany plate.
4. Install tops of plates flush with deck and make them removable for easy drilling and/or tapping as necessary.
5. Center of gravity is represented by ⊕ .
6. If suggested locations cannot be used, changes may be suggested.

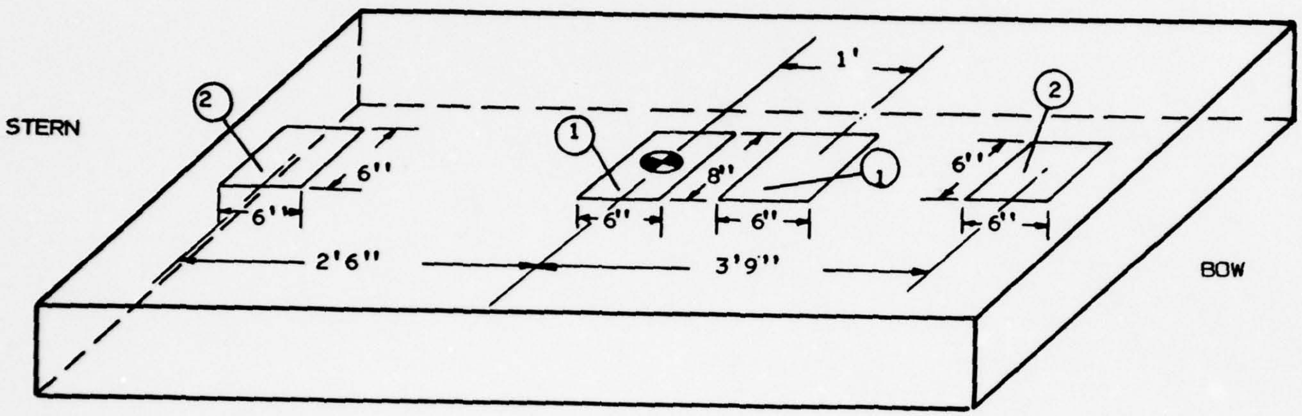

Figure A-1 SKETCH OF TOW POINTS