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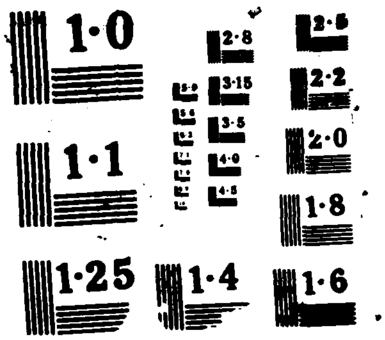
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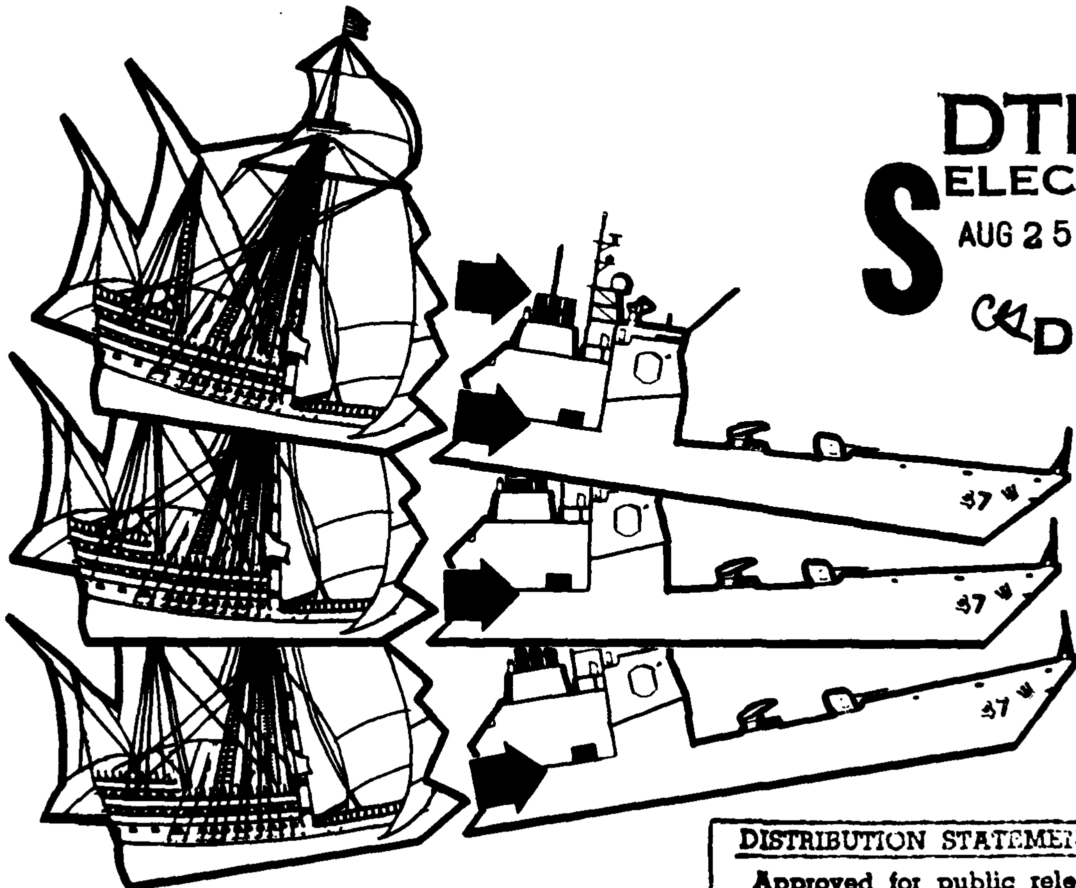

AIR CUSHION VEHICLES FOR ARCTIC OPERATION

by: Jeffrey Koleser, and David R. Lavis

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AIR CUSHION VEHICLES FOR ARCTIC OPERATION

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Abstract

The paper presents the results of the NAVSEA FY85 Surface Ship CONFORM Design Study for an IOC* year-2000 Air Cushion Vehicle (ACV) suitable for logistics and for general search and rescue duties in the Arctic. The study is one of several design studies produced each year by the CONFORM program to provide OPNAV with alternative feasible ship concepts for varying IOC dates and to provide R&D planners with feedback regarding R&D alternatives. Two complete feasibility designs were developed. The first design was developed with the aid of an ACV Design Synthesis Math Model. The second design evolved as a derivative of an existing U.S production craft and, as such, offered a lower risk approach. The results of performance and cost trade-off studies are presented from which it is concluded that gas turbines are the preferred choice of power plants and aluminum alloy is the preferred choice of hull structural material. The most suitable skirt height was found to be approximately 12 ft.

Introduction

In 1985, the U.S. Navy's Sea Systems Command (NAVSEA) initiated a feasibility design study of Arctic ACVs (AACVs) as part of their Continuing Surface Ship Concept Formulation (CONFORM) Program. The objective of the study was to identify new concepts which could provide a surface logistics capability, as well as enhanced mobility and flexibility to support military and civilian search and rescue (SAR) in the Arctic. For both missions, the ACVs would be expected to be capable of reaching large portions of the polar region while operating from coastal bases within the Arctic that are accessible by air or by deep-water ships.

Arctic experience with ACVs is not new. ACVs have been operating in the cold regions of North America for more than 20 years. Most of this experience has been devoted to gathering design data or demonstrating the suitability of ACVs to perform specific transportation tasks. Operations have been conducted with a variety of different craft including: the British SRN.5 & 6, the Bell SK5, Voyager & LACV-30s, the Global Marine ACT-100, the Britten Norman CC-7, the two Mackace Yukon Princesses, the Hoverlift HL-104, Hover System's D-FAAC and many other smaller craft which are still being produced in fairly large numbers by several Alaskan-based manufacturers. In 1984, the AALC JEFF(A), on lease to RMI from the U.S. Navy, completed a successful 8-month winter service in the Beaufort Sea in support of a SOHIO oil-exploration project, Figure 1. Currently, the Wartsila PUC-22 Larus is undergoing trials in the Canadian Northwest. In Northern Europe, experience has included extensive cold-weather operations of the British SR.N5, SR.N6, BH-7, the AP.188 in Sweden and the Wartsila Larus, TAV-40 and Vector-4 in Finland. In 1981, the USSR placed an order for nine Wartsila TAV-40 Arctic transporters and have operated many of their own ACVs in the Soviet far North. The Japanese National Polar Research Institute have been operating two Mitsui MV-PP05As in the Antarctic since 1981.

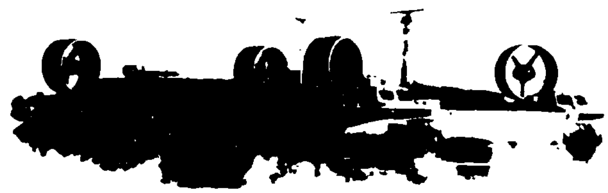

Figure 1. JEFF(A) at Prudhoe Bay.

From this collective experience, the technical feasibility of operating ACVs in cold regions has been amply demonstrated. Almost all of the ACVs used were capable of operating in temperatures of -40 degrees F and below, although few were originally designed for Arctic-type weather. In the United States valuable experience under controlled laboratory conditions was gained from testing the U.S. Army's LACV-30 (1977) and U.S. Navy's AALC JEFF(B) (1983) in the climatic chamber at Eglin Air Force Base, Florida, Figure 2.

Figure 2. JEFF(B) in the Climatic Chamber at Eglin Air Force Base, Florida.

Activities geared to designing ACVs specifically for the Arctic were first initiated in the United States in the early 1970s. Under the sponsorship of the Advanced Research Project Agency (ARPA) the Navy's David Taylor Naval Ship Research and Development Center (DTNSRDC) conducted a 5-year $18.6M program involving industry, government and several academic insitutions. This program generated significant data on ACV technology and the Arctic environment[1]. Many design studies, technology development efforts and model test programs were conducted as well as several full-scale demonstrations

* IOC: Initial Operational Capability

in the Arctic. This program, therefore, provided a firm basis for future work on Arctic ACVs and contributed significantly to the study described in this paper.

Arctic ACV Missions

The presence of AACVs in the Arctic would provide a reserve capability in that area ready for a selection of military and civilian duties. The Arctic operational area encompasses 3.9 million square miles of land, tundra, open water, ice and marginal ice, all of which are natural operating environments for ACVs. Potential missions are listed below:

a. Naval Forces

Sensor and Navigational Aid Deployment
AACVs could be directed to specific locations to implant transponders or other devices for navigation or detection. AACVs could preposition the devices and retrieve them after the assignment.

Ice Camp Support
The United States has experience with ice camps varying in size from three to almost 100 individuals[2]. Ice camps can operate at the same location for short intervals of just several hours or for extended periods of a year or more. Ice camps are typically set up by airlifting people and equipment by helicopter or fixed-wing aircraft. Requirements for landing strip preparation, ice thickness, surface conditions, and environmental constraints on flight operations (light, visibility, wind, icing, etc.) can severely restrict camp deployment, resupply, disassembly, and backhaul. Since 2/3 to 3/4 of the 4000 pounds per person typically deployed to a scientific ice camp is backhauled, the availability of a full-time logistics ACV would significantly increase the flexibility and efficiency of these activities.

Surveying
AACVs could be used to survey ice characteristics. The endurance of ACVs coupled with their low footprint pressure, high maneuverability, and ability to loiter and/or set down (to take measurements or samples) makes them ideally suitable for this role.

Mine Countermeasures.
The AACV could operate as a mine countermeasures craft based on deployment and operation of a remotely controlled hunter submersible. A submersible capable of searching a large area while being operated from a single point on the ice would be required. After cutting a hole, the submersible would be launched using the AACV's crane and controlled by a communications system designed for underwater use.

Submarine Rescue.
The current operational method for achieving a rescue operation for a submarine under the ice cap is for a second submarine to be used for transporting a Deep Submergence Recovery Vehicle (DSRV) to the location and to conduct all operations under water. Since the DSRV is designed to be air transportable (C141), a combination of air transportation to the AACV base nearest the casualty, and onward deployment by the AACV should prove to be faster than delivery by submarine. The system requires development efforts in five principal areas:

- AACV hull structure
- Transshipment between C141 and AACV
- Handling system onboard AACV
- Ice cutting system
- DSRV supporting facilities.

b. Land Forces

A number of missions dealing with land forces may attract the interest of the U.S. Army. These are:

- Combat vehicle carrier
- Helicopter forward base
- Recovery vehicle
- Armored reconnaissance and scout vehicle
- Armored personnel carrier
- Artillery platform/free rocket launcher
- Tactical transporter
- Assault amphibian
- Support amphibian
- Antiaircraft platform.

c. Air Forces

Missions relating to the U.S. Air Force could include:

- Tactical electronic warfare platform
- Air control center
- Search and Rescue.

d. Miscellaneous Additional Missions

A variety of other missions could be considered:

- Weather monitoring
- Ballistic missile test monitoring
- Electromagnetic emissions monitoring
- Command center and troop shelter
- Security patrol vehicle
- Mobile maintenance shop
- Marine environmental protection
- Icebreaker.

AACV Platform Functional Requirements

For the purpose of the study, AACVs were to have the following functional requirements:

- AACVs will be deployed from one or more bases on the north coast or on northern islands of Alaska, Canada or Greenland.
- Craft will provide a design full-load range of 600 nm radius over ice from any base, after allowing for avoidance maneuvers and detours necessary to transit Arctic ice.
- Containerized cargo shall be carried having a total weight of 36.27 long tons.
- Arctic compatible accommodations for at least 20 persons are to be available for transferring to, or from, the craft during a resupply mission.
- Provisions will be carried for the AACV crew for missions of up to seven days duration. An additional seven days of emergency provisions and consumables will be carried. Normal and emergency provisions and consumables will be carried for the same periods of time for passengers.
- The cargo deck will be open to provide access for loading and unloading cargo, shelters, special mission equipment and other cargo by craft's crane and cranes at the bases.
- The craft shall be capable of operating and maneuvering safely in all weather conditions down to -40°F.
- AACVs will communicate directly or indirectly with a designated base, with aircraft and other elements of the military and civilian complex.

AACV Design Requirements

Design requirements for the AACV were identified as follows:

- Mission Radius = 600 nm
- Rough Off-shore Ice Distance = 20 nm
- Mission Payload + Margin = 42.44 l.tons
- Margin on Payload Weight = 17%
- Margin on Light Ship Weight = 17%
- Average Speed Over Ice = 40 Knots
- Minimum Speed Over Water = 10 knots
- Propulsion by Twin-Ducted Airscrews
- Bow Thrusters and Rudders for Maneuvering
- Fuel Management for Trim Control
- Bag-Finger Skirt with Height = 20% of Beam
- Minimum Overland Slope = 5%
- Number of Craft in Fleet = 6
- Operating Hours per Year per Craft = 1008
- Hours on Secondary Missions = 50% of Hours on Major Mission
- Crew Size = 10
- Life Support for 14 Days
- IOC Date = 2000; AFP Date = 1992*

CONFORM Study Approach

To provide the required capability, two design approaches were adopted. The first approach relied on the use of an ACV design synthesis computer model to explore parametric trends[3]. This CONFORM design was designated as Arctic Air Cushion Vehicle, AACV-1.

The second approach concentrated on defining a suitable craft which could be evolved from an existing U.S. production ACV. This second CONFORM design was designated as AACV-2. Two U.S. military ACVs are currently in quantity production; the U.S. Army LACV-30, which has a full payload of 27.3 long tons and the U.S. Navy LCAC, which has a full payload of 53.57 long tons. The largest low-risk skirt which could be developed for the LACV-30 would have a skirt height of a little over 8 feet as compared to 10.5 feet for the largest skirt which could be fitted to a derivative of the LCAC. For a skirt height of 8 feet, the safe ice-ridge-crossing threshold, at a 40-knot approach speed, would be less than 6.5 feet; a height which will be shown to be far less than ideal for Arctic operations. Thus, the LCAC derivative was assumed to be the smallest production ACV which could perform the required Arctic mission.

The way in which mission range was determined was common to both designs. The method differed from normal practice in ship design as explained below. This had a large impact on the designs derived by the study.

It is well known that the Arctic topography presents a formidable surface for any vehicle traveling at high speed. The primary obstacles to the movement of amphibious vehicles, such as an ACV, are pressure ridges which reach heights as great as 20 ft, and often are several miles long. A typical example of a ground view of a pressure ridge, about 7 to 8 ft high, is shown in Figure 3. The lower the skirt height, the more frequently the craft must alter course to seek a safe passage between ice ridges which cannot be crossed. The ratio of D_T, the total distance traveled to accomplish this, to D_{SL}, the distance actually made good, is referred to as the trafficability ratio γ. This is expressed in Figure 4 as a function of obstacle clearance height for various areas within the Arctic[4] as illustrated in Figure 5 from Reference 4. Here, obstacle clearance height is taken as 80% of the skirt height in each case.

Figure 3. Ground View of First-Year Pressure Ridge in the Beaufort Sea, 1971[4].

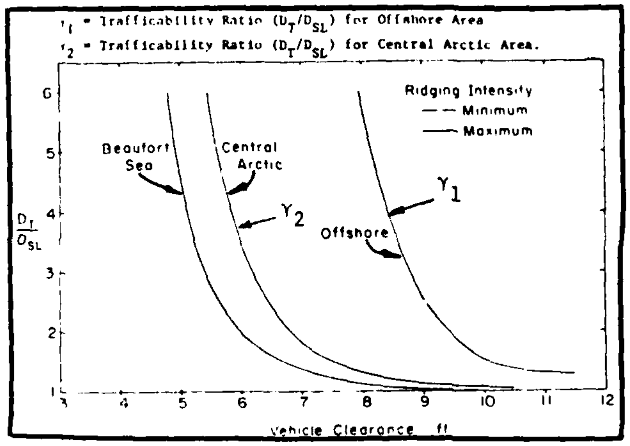

Figure 4. Trafficability Ratio, D_T/D_{SL}[4].

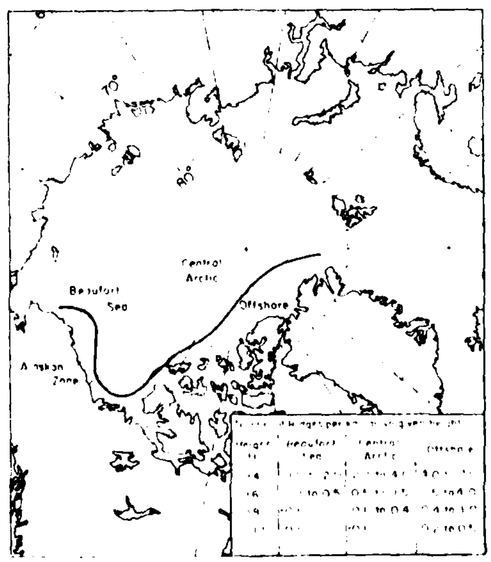

Figure 5. Regional Variation of Ridging in the Arctic Basin[4].

* AFP Date: Date when Approved for Full Production.

The implications for craft design are that reliable equipment to detect ridges must be available to the operator, a good maneuvering capability must be inherent so that the craft can avoid ridges too high for the skirt, and the need for detouring round such ridges must be minimized by providing a high enough skirt.

Parametric Analysis of AACV-1

For the selection of planform size and shape, the following attributes were considered important:

- Full-load gross weight
- Installed total power
- Lightship weight
- In-transit time to reach rendezvous point
- Acquisition cost per craft
- Total fleet cost per year.

Craft sensitivity to changes in several input choices were explored. These included:

- Gas-turbine versus diesel engines
- Aluminum-alloy hull versus steel hull
- Variation in mission radius requirement
- Variation in mission payload requirement
- Variation in the distance of rough off-shore ice.

Initially it was assumed that each craft would be powered by gas-turbine engines and the hulls would be constructed of 5456 aluminum alloy. The subsequent sensitivity analysis clearly showed these to be the preferred choices for AACV-1.

Figure 6 shows, in carpet-plot form, the effect on both full-load weight and total required power of changing craft length and length-to-beam ratio.

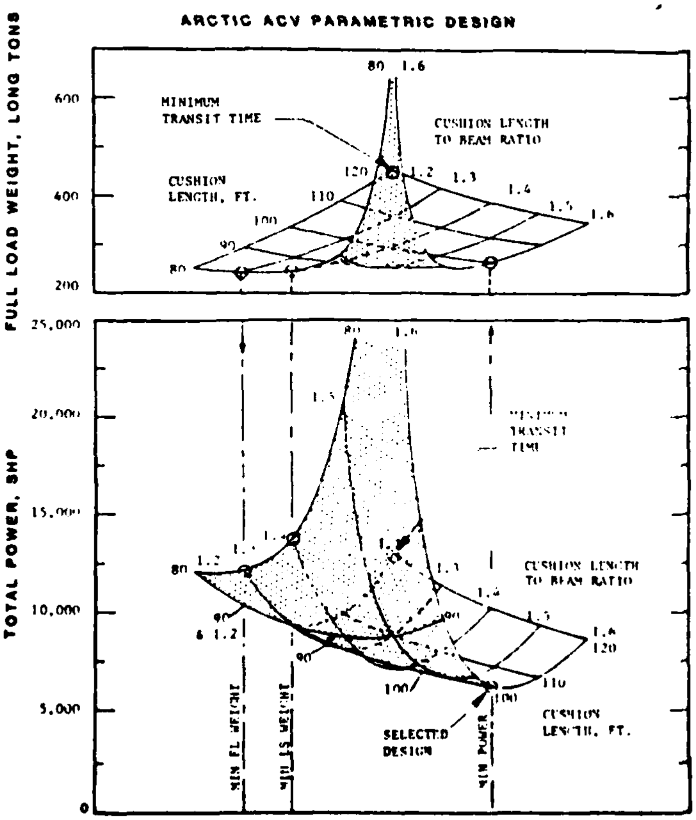

Figure 6. Full-Load Weight and Power vs. Length and L/B.

Similarly, the effect on lightship weight is shown in Figure 7 and the effect on the time required to transit a mission radius of 600 nm, is shown in Figure 8.

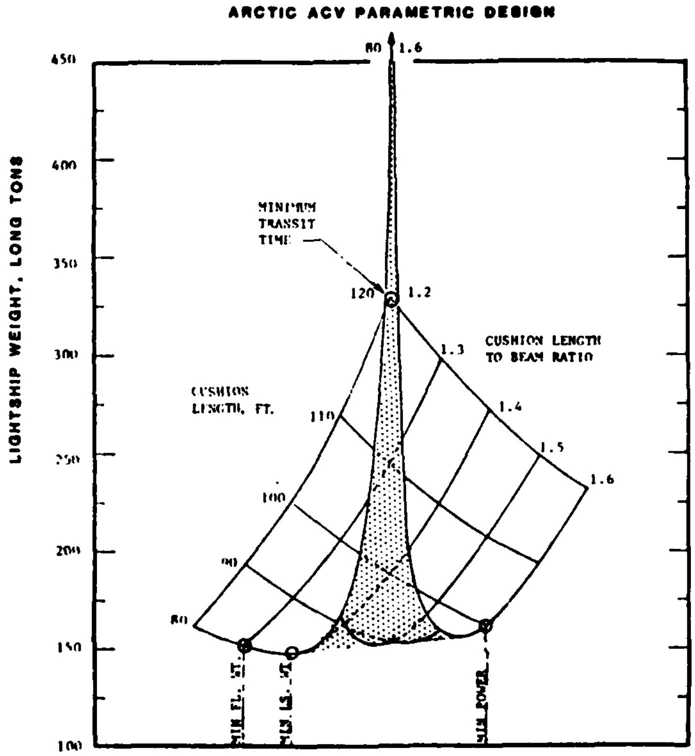

Figure 7. Lightship Weight vs. Length and L/B.

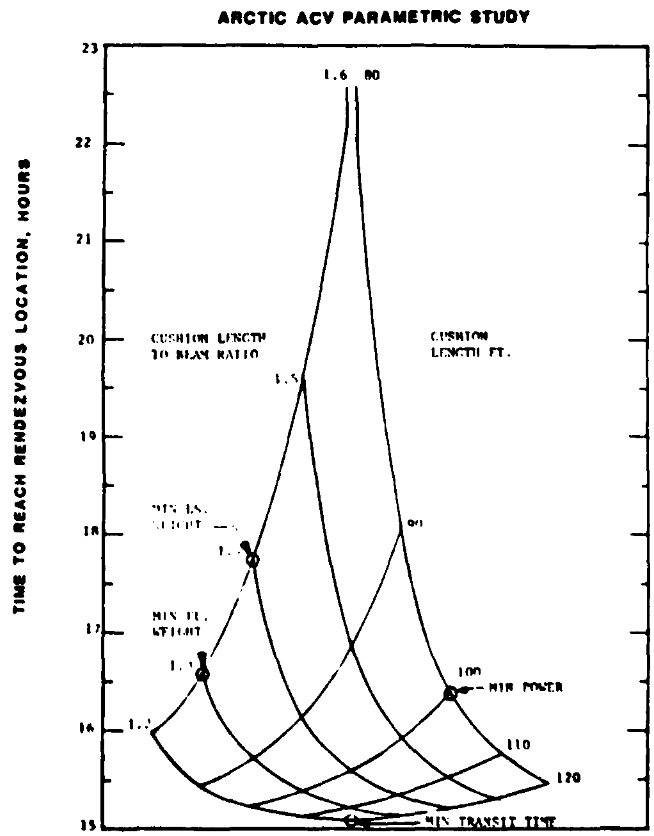

Figure 8. Time In-Transit to Rendezvous.

Figure 9 shows the effect of changing planform shape and size on craft and fleet annual total cost. The selected design was the one which exhibited the least installed power and acquisition cost.

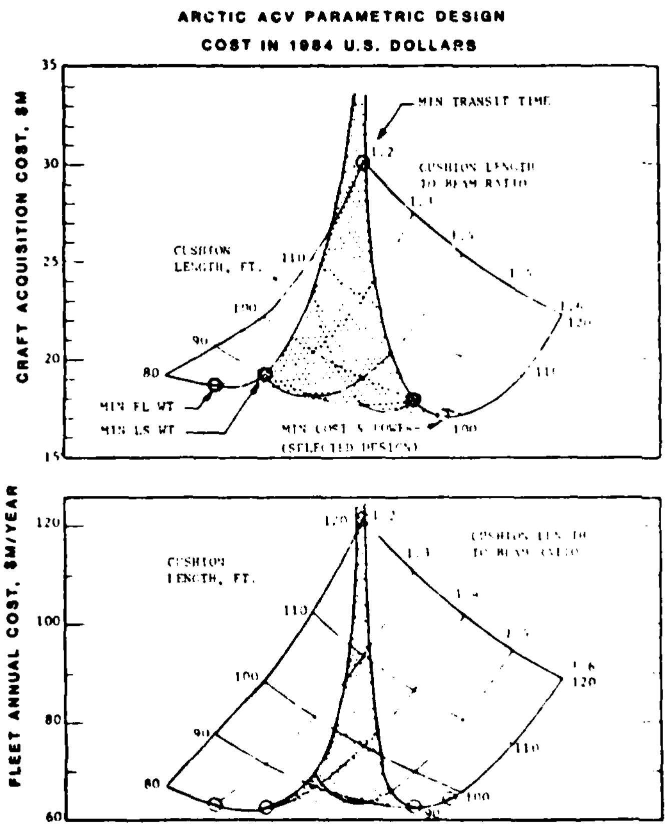

Figure 9. Acquisition Cost and Fleet Annual Cost.

The acquisition cost was determined by scaling and summing the component costs of the LCAC. The direct and indirect operating costs were based on the U.S. Army's experience with its fleet of LACV-30s at Fort Storey, VA. The Arctic ACV fleet annual cost is the sum of all costs including 10% of the acquistion cost per year. Year 1984 dollars were assumed throughout and the total operating hours per craft per year was assumed to be 1,008 hours.

The design parameter which appears to have the greatest influence on the trends exhibited by major design attributes, (a) through (f), is the skirt height. This was illustrated graphically in Figure 4.

As length-to-beam ratio is increased for a given cushion length or as length is reduced for a given length-to-beam ratio, the cushion beam (B_c) is reduced and therefore the maximum allowable skirt height (H_s) is reduced to maintain a maximum allowable value of (H_s/B_c) of 0.2. As skirt height is reduced, less ridges can be safely crossed by the craft and, therefore, the craft must do more detouring and travel further for each mile made good.

This situation becomes very critical for the rough off-shore ice when the skirt height is reduced to a value of about 10 feet, i.e. a vehicle clearance height of 8 ft.

For an 8-ft ridge clearance height, the trafficability ratio ($\gamma_1 = D_T/D_{SL}$) for off-shore ice approaches a value of 6. Thus, for this craft to traverse through the 20 nm of rough off-shore ice, it must travel a total of 120 nm. For the remaining 580 nm of the 600 nm radius, operation is over ice where the high ridges are less frequent. However, for a craft with only an 8-ft obstacle clearance height, even in this less demanding area of the Arctic, the range must be increased by approximately 30%, or 174 nm. Thus, the total distance traveled to achieve a 600 nm radius, with a craft having a 10-ft skirt, is 874 nm, or 1,748 nm for the round trip. The extra fuel required to achieve this additional range increases the craft gross weight, the cruise power required and hence the fuel consumption which further increases the required fuel load. The net result is illustrated in all these cases in Figures 6 to 9 where the cushion length is 80 ft, the L/B is 1.6, the skirt height is (80 x 0.2/1.6) = 10 ft and the gross weight and cost become prohibitively high.

Design of AACV-2

A derivative of the Landing Craft Air Cushion (LCAC) was considered to be the smallest production craft available to meet the AACV mission requirements. The LCAC is similar in size, and in many respects, similar in configuration to the AALC JEFF(B). As part of the Arctic SEV Program, conducted by DTNSRDC in the early 1970's[1], Bell Aerospace Textron (BAT) studied the suitability of modifying the JEFF(B) for Arctic use. For this approach, the two major changes which were considered to be necessary for the JEFF(B) included:

- A change in skirt height from 5 ft to 10.5 ft, accompanied by a change in cushion beam from 40.8 ft to 53 ft.
- A change in the beam of the hard structure of the hull from 43 ft to 55.5 ft to support the larger skirt. This increase in the beam of the structure was achieved using lightweight, tubular-truss side extensions to the craft. These were designed as sacrificial, energy absorbent structures.

Other changes were made, including additional structure for hull-bottom protection, an enclosure for the deck aft, and an Arctic-capable life-support system for the crew.

Similar changes were considered for the LCAC derivative explored in this present study for AACV-2. The skirt height, cushion beam and hard structure beam were increased to exactly the same dimensions that BAT had proven to be satisfactory. The weight allocation for the large skirt, however, was increased substantially over that predicted by BAT to reflect a more realistic projection from the known weight of the LCAC skirt and its more robust attachment system as compared to the JEFF(B). Although an additional weight allowance was made to the hull structure for additional under-hull protection from the occasional ice impact, no structure was considered to be necessary for enclosing any portion of the LCAC payload deck. It was assumed, as with AACV-1, that for AACV-2 all payload elements for any of the possible missions would be shipped onboard the craft within containers having their own life support or environmental control system.

The cushion dimensions of AACV-2 are compared with the JEFF(A) and JEFF(B) dimensions in Table 1.

Table 1. Comparison of Cushion Dimensions.

	JEFF(A)	JEFF(B)	AACV-2
L_c	84.0	76.9	81.0
B_c	42.0	40.8	53.0
A_c	3530.0	3140.0	4293.0
H_s	5.0	5.0	10.5
L_p	242.0	222.8	305.1

Le = Equivalent Cushion Length, Ft
Bc = Cushion Beam, Ft
Ac = Cushion Area, Ft^2
Hs = Skirt Height (to Wet Deck), Ft
Lp = Hemline Peripheral Length, Ft

During the winter of 83/84, the JEFF(A) operated over ice in the Beaufort Sea at a maximum weight of 425,000 lb. This corresponds to a cushion pressure of 120.4 psf and a cushion density (P_c/L_c) of 1.43 lb/ft^3. The JEFF(B) has operated over water at a maximum weight of 366,000 lb with a cushion pressure of 116.6 psf and a cushion density of 1.52 lb/ft^3.

The design gross weight of the AACV-2 was limited to 454,000 lb. At this weight the cushion pressure is 105.7 psf and the cushion density is 1.30 lb/ft^3, both values of which are less than the maximum values experienced by the JEFF(A) and JEFF(B), and therefore considered to be conservative for over-ice operation.

One of the major differences between LCAC and AACV-2 operation will be the significant increase in fuel load required of AACV-2. This will require additional fuel tanks and additional structure to contain them.

Margins

Performance Margins

A 5% (unused) reserve fuel allowance was assumed for all mission range calculations.

Weight Margins

The weight estimate for AACV-1 includes a combined design, builder's and service-life growth margin equal to 17% of the lightship weight. In addition, at the start of the study, a 17% margin was also assumed for cargo weight for both craft. This was allowed to diminish as the study progressed and as the various cargo elements were more precisely defined. At the completion of the study the following margins on cargo weight remained in the total weight estimate.

Table 2. Cargo Weight Margin.

	CARGO WEIGHT MARGIN, LB	% OF DESIGN CARGO WEIGHT
AACV-1	10,545	11.1%
AACV-2	545	0.57%

Accommodation Margin

Crew accommodations were made consistent with NAVSEA practice. A margin of 7 days additional life support including stores was also provided.

Electric Load Margin

Electric load estimates included a 100% margin on ship service load plus a 55% service-life growth.

Weights

Table 3 lists the estimated one-digit level weight components for the AACV-1 and AACV-2. Weights for the AALC JEFF(B) are also provided for comparison.

Cargo component weights for both AACV-1 and AACV-2 include the additional weight of the bow-mounted crane, one snowmobile and one small inflatable boat.

Table 3. Weight Summary (L.Tons).

		AACV-1	AACV-2	JEFF (B)
100	Hull Structure	81.313	55.476	46.25
200	Propulsion Plant	16.300	20.731	16.88
300	Electric Plant	4.788	2.926	1.10
400	Command & Surveillance	3.184	2.109	0.46
500	Auxiliary System	10.927	6.638	7.92
600	Outfit & Furnishings	9.057	5.083	3.30
700	Armament	0.090	0.069	0.0
	Light Ship	125.66	93.032	75.91
	Margin	21.36	1.86	0
	Crew & Effects	1.400	0.697	0.58
	Fuel	55.730	64.724	17.32
	Payload	42.440	42.440	53.57
	Full Load Displacement	246.59	202.753	147.38

Reserve Buoyancy

The intact reserve buoyancy of both configurations at light- and full-load has been estimated to be as follows:

	AACV-1	AACV-2
LIGHT LOAD	225%	260%
FULL LOAD	65%	70%

Flooding due to damage reduces the reserve buoyancy. In the worst case examined, the reserve buoyancy values were reduced to:

	AACV-1	AACV-2
LIGHT LOAD	220%	195%
FULL LOAD	45%	35%

The light-load values are considered to provide adequate margin by normal military ACV standards. The full-load values need further examination.

Damage Stability

The extent of hull damage to be survived is specified by NAVSEA. The locations of longitudinal and transverse watertight bulkheads for both craft were determined by taking a longitudinal outer-skin opening of 10% extending across to the centerline of the craft. The critical damage case is to the starboard side aft with a 60-kt beam wind and a

42.33 l.ton payload located 3 ft aft of the normal c.g. location with forward fuel ballast to counteract the payload to obtain an lcg of 12 inches aft of its normal location. The study indicated that the following approximate values of the vertical center-of-gravity (KG) are critical:

	AACV-1	AACV-2
LIGHT LOAD	15.0 in	14.0 in
FULL LOAD	11.5 in	5.5 in

At full load, in this damage case, the hull draft at the starboard stern is approximately 4.4 ft. This is close to the limiting value of 4.5 ft. Under no conditions of damage investigated did the angle of heel come anywhere close to exceeding the limit of 15 degrees.

Intact Stability

(a) Off-Cushion

For the intact condition, an area ratio (A_1/A_2)* greater than 1.4 is required. This appears to be easily satisfied for either craft in the full-load condition with KG values as follows:

	AACV-1	AACV-2
FULL LOAD	12 in	10 in

When loading, or unloading, cargo from an intact craft over water by using the onboard crane, the maximum heeling arm is 280,000 ft-lb. With an initial intact roll stiffness of approximately 400,000 ft-lb/deg for AACV-2, the maximum static angle of heel will be 0.7 degrees. The corresponding angle of heel for AACV-1 will be less than 0.7 degrees.

(b) On-Cushion

On-cushion stability was assessed based on model test data for a craft geometrically similar to AACV-2. It was shown that, with stability seals, a longitudinal GM of 116 ft and a transverse GM of 36.4 ft could be obtained at full scale.

Based on the same source of data, it was determined that the AACV-1, on-cushion, would have a longitudinal GM of 139.2 ft and a transverse GM of 44 ft. In both cases this level of initial static stability is considered to be adequate for a cushion height to beam ratio of 0.2.

Ride Quality

Figure 10 shows the effect on RMS vertical acceleration of varying the forward speed and displacement of AACV-2. Results are shown for the motions at the craft c.g. and at a bow location 35 ft forward of the c.g.

Figure 11 shows the predicted response of the AACV-2, at three craft locations, in terms of one-third octave band vertical acceleration versus response frequency. Results are shown for operation at full-load displacement at 40 knots over the rough off-shore ice. These results are compared on Figure 11 with the ISO Fatigue Decreased Proficiency (FDP) duration limits for 1 to 6 hours of operation.

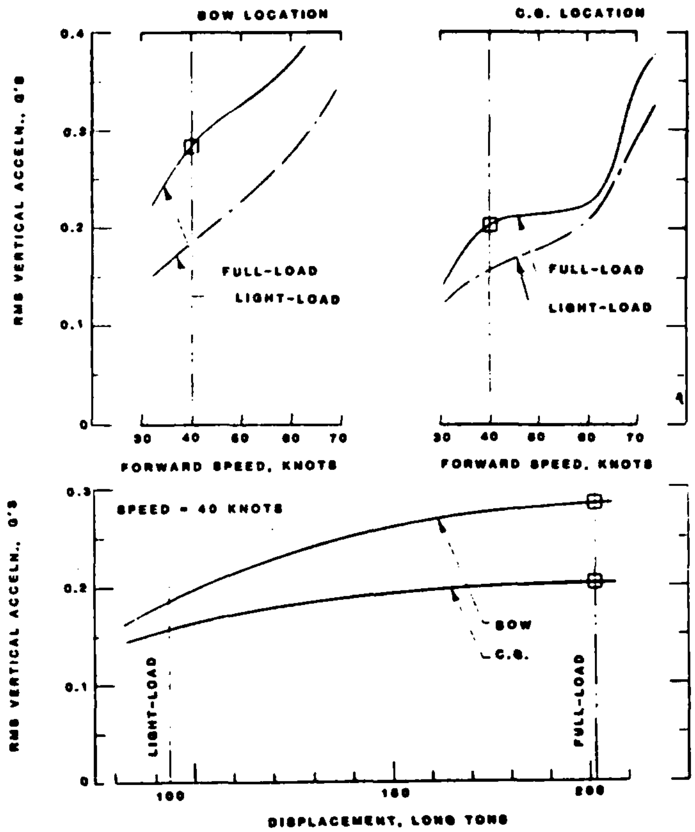

Figure 10. Predicted RMS Vertical Acceleration for AACV-2 Over Off-shore Ice.

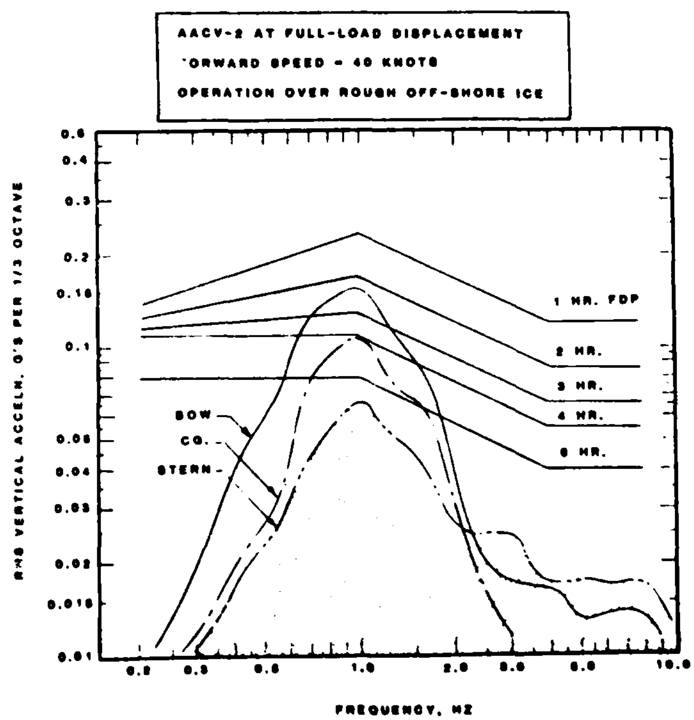

Figure 11. Predicted 1/3rd Octave Band RMS Vertical Acceleration Relative to ISO Fatigue Decreased Proficiency (FDP) Duration Limits for AACV-2 Over Rough Off-shore Ice at 40 Knots.

* Ratio of the stabilizing to destabilizing area beneath the righting arm versus heel angle characteristic curve.

The least habitable location on the craft is seen to be at the bow location. At the control cabin location, 17 ft aft of the bow, crew members would be limited to approximately 2.9 hours of duty. At 40 knots a distance of 116 nm would be covered during this time. This would appear to be sufficient time in which to find a passage through the rough off-shore ice to the less rough Arctic ice cap. The ride quality onboard the larger AACV-1 would be expected to be somewh: ; less severe than onboard the AACV-2 at equal speeds and surface conditions.

Unfortunately, the assessment of acceptable ride quality is not an exact science. Work will be required to examine this further during the next phase of design.

Speed Performance

The forward speed performance of AACV-1 and AACV-2 when operating over ice and over water is shown in Figures 13 through 16. For both craft, the drag over ice was determined using data derived from recent tests of the full-scale JEFF(A) in the Arctic. The average height of ice ridges encountered by both craft was assumed to be 2.98 ft at an average separation distance of 137 ft. These values were derived by examining the character of the rough off-shore ice[4]. Over-water drag was determined using the same procedure which is currently being used to predict the performance of the LCAC.

Figure 12 shows the predicted over-ice drag of AACV-1 for the full-load condition. The total power required, including (2%) power for engine driven accessories, to achieve a speed of 40 knots over rough ice, is 8,387 shp. Of this, only 971 shp is consumed by the propellers and 7,252 shp is consumed by the fans which provide air to the bow thrusters and cushion. The performance of AACV-1 in calm water is shown in Figure 13. Similar plots for over-ice and over-water operation are shown in Figures 14 and 15 for AACV-2. At full-load displacement, AACV-1 cannot achieve speeds above hump speed in calm water but can achieve the required minimum speed of 10 knots. AACV-2 can easily achieve post-hump speed, as shown in Figure 16.

Maneuvering and Control

No maneuvering and control analyses were conducted for this design study. Both AACV-1 and AACV-2 were configured with twin swivelling bow-thrusters and twin controllable/reversible-pitch air propellers aft housed within fixed shrouds each with slipstream rudders. This arrangement would be adequate for Arctic operations for forward speeds well in excess of the maximum speed required of this present study.[1]

Design Descriptions

The configurations selected for AACV-1 and AACV-2 are illustrated in Figures 17 and 18. Both craft are designed with an open payload deck. The purpose of this is to permit the maximum versatility in mission capability for the craft. Mission packages that might include accommodation shelters, instrumentation shelters or weapons modules can be loaded on the deck by crane or by way of the stern ramp.

Both craft economize on development and design costs by incorporating large portions of the LCAC hardware. These include the engine modules, the lift system modules and the control cabin modules. The AACV-1 has room for two additional modules for crew bunking accommodations built in as part of each sidestructure. AACV-2 requires the loading of a portable bunk module on the cargo deck.

CONSTANTS FOR FIGURES 12 AND 13	
GROSS WEIGHT	= 552,362 LB
CUSHION AREA	= 6260 FT
CUSHION BEAM	= 82.6 FT
CUSHION HEIGHT	= 12.5 FT
HEMLINE PERIPHERAL LENGTH	= 305.4 FT
CUSHION AIR FLOW RATE	= 10,678 CFS
AIR TEMPERATURE	= 32°F
NO WIND	

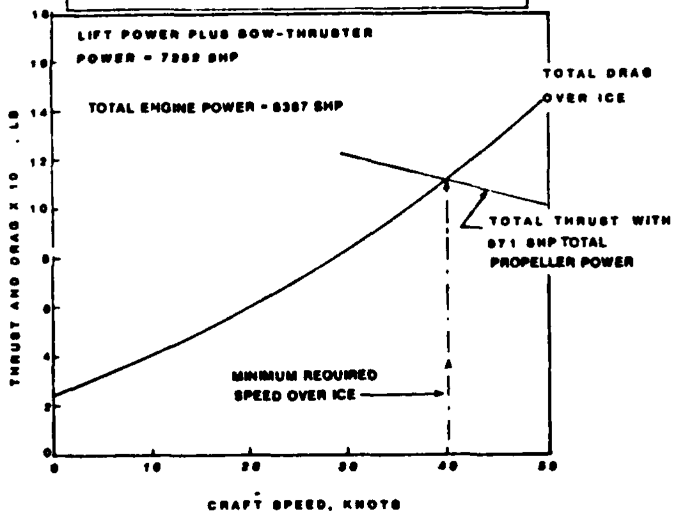

Figure 12. Thrust and Drag of the AACV-1 Operating *Over Ice at Full-Load Weight.*

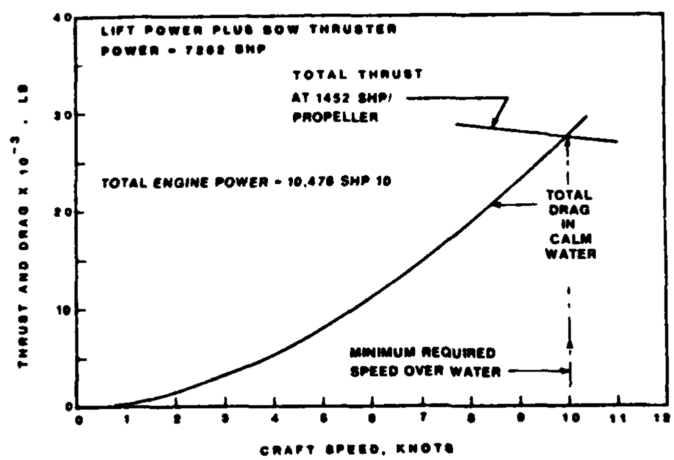

Figure 13. Thrust and Drag of the AACV-1 Operating Over Calm Water at Full-Load Weight.

Hull Structure

The hull structure of each AACV is similar to that of the LCAC. The purpose of this is to avoid engineering costs by building on existing technology. The use of this hull dictates much of the rest of the craft's design. In particular, for AACV-2 all major components of the side structures and machinery are taken from the LCAC.

The hull structure of each AACV, like that of the LCAC, is built primarily of the strain hardended aluminum alloy 5456 H343. A review of materials

CONSTANTS FOR FIGURE 14	
WEIGHT	= 454,000 LB
CUSHION AREA	= 4293 FT
CUSHION BEAM	= 63 FT
EQUIVILENT CUSHION LENGTH	= 81 FT
CUSHION HEIGHT	= 10.5 FT
HEMLINE PERIPHERAL LENGTH	= 263.3 FT
AIR TEMPERATURE	= 32°F
NO WIND	
N2	= 92.61%
CUSHION AIR FLOW RATE	= 7000 CFS

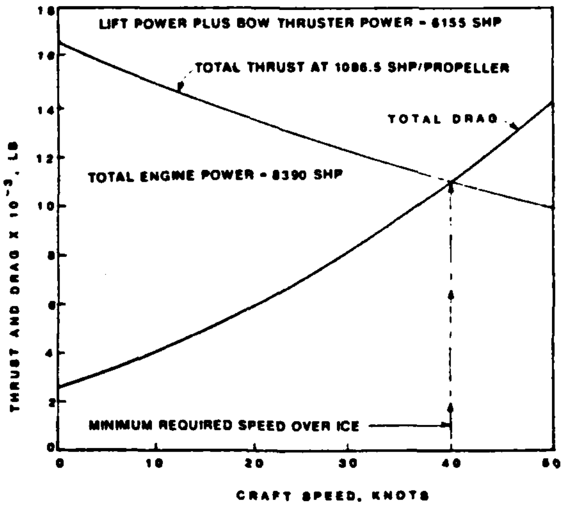

Figure 14. Thrust and Drag of the AACV-2 Operating Over Ice at Full Load.

CONSTANTS FOR FIGURES 15 AND 16	
GROSS WEIGHT	= 454,000 LB
CUSHION AREA	= 4293 FT
CUSHION BEAM	= 63 FT
CUSHION HEIGHT	= 10.5 FT
EQUIVILENT CUSHION LENGTH	= 81 FT
HEMLINE PERIPHERAL LENGTH	= 263.3 FT
CUSHION AIR FLOW RATE	= 8462 CFS
N2	= 95.38%
AIR TEMPERATURE	= 32°F
NO WIND	
CALM WATER	

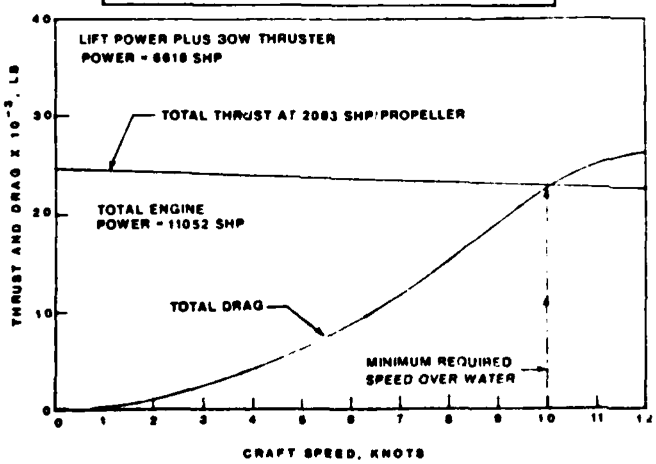

Figure 15. Low Speed Thrust and Drag of AACV-2 Operating Over Calm Water at Full Load Weight.

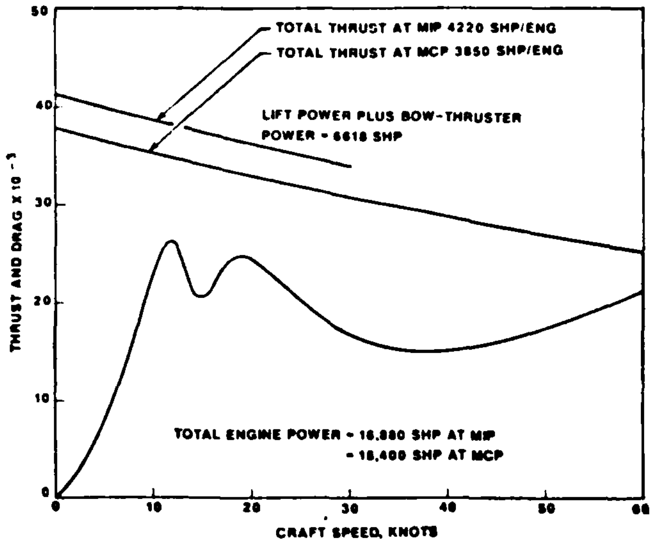

Figure 16. Thrust and Drag of AACV-2 Operating Over Calm Water at Full Load.

suitable for Arctic-weather ACV applications appears in Reference 1. 5456 is included in the list of suitable materials and in the H343 condition it has been certified by the Navy as a marine alloy.

A principal departure from the LCAC design lies in its skirt, and the structure includes adaptors to accommodate the new design. Each of the AACV skirts are much bigger than the LCAC skirt, so that the craft can operate more effectively over ice ridges and maximize over-ice range.

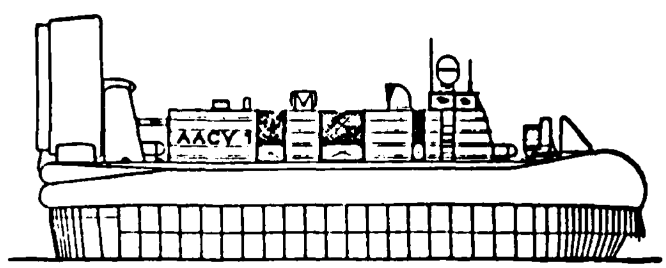

Figure 17. AACV-1 Configuration.

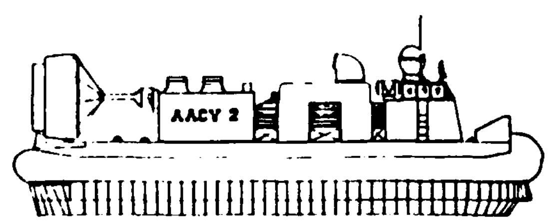

Figure 18. AACV-2 Configuration.

For AACV-2, minimum engineering and assembly cost is achieved by adding lightweight structural members along each side of the LCAC hull, providing an increase in hard-structure beam of approximately 11 feet. These structural additions are attached to the hull at the ends of the frames using welded lugs and removable pins. The added structure is divided into a number of individual modules so that assembly is easy, and so that low tolerances can be used in fabrication. Air seals are provided at deck level, and the added structure modules provide additional cross section for bag air flow along each side of the craft. The added structural modules, and their attachment technique are designed to protect the main hull from damage in the event of collision with ice, while providing easy replacement after damage has been sustained.

The LCAC hinged bow ramp is removed and lightweight structural modules are added in the bow area of AACV-2 to provide:

- Support for an inflatable fender located within the bow bag
- Support for a deployable anti-radar signature screen shielding the cargo crane and cargo
- Frangible, easily replaced, protection for the main structure in the event of collision with ice
- A means to bring the center of lift of the cushion slightly forward of its location in LCAC, in partial compensation for the crane weight and moment
- A forward working deck area. The area is made available by swinging sections of the anti-radar screen either down or forward.

The crane is supported on a secondary structure that fits the fixed portion of the bow ramp. The structure acts as a bed plate that distributes crane loads and moments into the LCAC bow structure. Structural attachments are intended to be removable so that the craft can be restored to its assault role at any time.

Further changes include the provision of additional fuel tanks in the hull, and replaceable panels to protect the wet deck from ice damage. These, and other, changes will require design effort and review during the technology development phase up to 1992.

The hull structure of the AACV-1, while it has different dimensions to that of the AACV-2, is built using the same technology. The bow ramp, (fixed and hinged portions) is deleted, and a permanent crane foundation is constructed forward. The side machinery and accommodation structures, like those of the AACV-2, are LCAC modules. Changes in height of mounting are used to gain more room in the control cabin module and accommodations modules aft of the fan modules.

Propulsion Plant

The larger of the two craft, the AACV-1, obtains a relatively high propulsive efficiency through the use of a pair of large 21.67 ft diameter airscrews mounted within 26 ft diameter shrouds. The smaller craft, the AACV-2, retains the same propulsors as the LCAC and trades off range capability for a lower first cost with respect to propulsors. The support of the propellers in AACV-1 is an inverted Vee structure incorporating the Zee transmission, in some ways similar to the propeller support system of the Soviet AIST Air Cushion Vehicle.

The lift-fan systems for both craft are derived from the LCAC. The prime movers for AACV-1 consist of two LM-500 gas turbine engines. The prime movers for AACV-2 consist of four TF40B gas turbine engines. This latter choice for AACV-2 was made since redesign, or replacement of the LCAC system with smaller units must be weighed against the life-cycle benefits. Retaining the higher power capability has benefits for over-water operation at sprint speeds and for emergency operation at high speed over ice.

The power transmission for AACV-1, while otherwise identical to the LCAC transmission, has been rearranged to accommodate the larger propellers. Two arrangements of propeller transmission were considered, one the same in principal to that of the LCAC, with 8 ft center-to-center transfer gearbox and a second arrangement using a Z-drive. The reduction ratio of 10.7 required is determined from the propeller rpm of 655, and speed of the output from the engine gearboxes of 7,000 rpm. This ratio is easily accommodated by either arrangement.

In the transfer box arrangement, the offset between the input and the output shaft is approximately 10 feet which would require many meshes as well as the 10.7 to 1 reduction. The advantage of a single gearbox for this part of the transmission was considered lost if it had to be 8 feet long. The centerline of the output shaft from the engine module came close to intersecting an inverted vee of 72^{o} included angle that could be aligned with the struts of the shroud supported by five struts. The transfer shaft of the Z-drive could be housed in the inboard leg of the inverted vee.

Electrical Plant

The electrical plant for both craft is the same as that of the LCAC, but with modifications to reflect recommendations arising out of the JEFF(B) cold environment testing at Eglin AFB, and subsequent operation of ACVs in the Arctic, particularly JEFF(A). The electrical system will be required to supply power to heat the APU start fuel, propeller lubrication oil and blow-in door seals. NiCad batteries are recommended in place of the lead acid type. The plant was designed for a 55% growth margin on the original LCAC electrical load.

Command and Control

The command and control system for both craft is that of the LCAC, but with the addition of an obstacle avoidance radar and CRT. Certain modifications to the LCAC appear to be relevant to the AACV-1 and AACV-2. These include leaving extra room in between crew's seats and control panels to allow for bulky Arctic clothing, and arranging for both the operator and navigator to have CRT obstacle avoidance displays. A selection of the type of radar should be left to 1992.

Auxiliary Systems

The auxiliary systems for each craft include LCAC systems and also a number of additions and changes:

- The bow ramp and associated hydraulic equipment is deleted.
- A cargo handling crane is included. The HIAB 360 Sea Crane was chosen as an example exhibiting features such as lift, reach and profile in its stowed position that permitted a reasonable coordination of the craft's general arrangement.
- An auxiliary winch, or set of auxiliary winches, is proposed. The winch(es) will serve to assist

recovery from "grounding" on ice obstructions and also will be part of a cargo handling system when used in conjunction with sliding pads and removable cheek blocks on the cargo deck.

Outfit & Furnishings

Outfit and furnishings are installed in each craft generally consistent with those provided on the LCAC. Exceptions include provisions for avoiding frozen pockets of water, review of hatch closures, valves and other exterior components to ensure they can be operated without removing gloves, provision of grounding chains, antistatic paint, antistatic tufts and grounding straps to avoid electrostatic problems, ladders to access ground without bow ramp (in emergency), provisions for operating craft in control cabin with protective clothing on.

Armament

No armor or armament was specified in the requirements for the AACV mission. However, a weight allocation for small arms and munitions has been provided for each design. Also, since the LCAC carries armor protection, a small weight allocation (4,680 lb) for armor was provided in the design of AACV-2.

Conclusions

Both designs developed during the study are considered to be feasible from an engineering and naval architectural standpoint. Both would be capable of performing all the functions specified by the requirements with the exception of the less-than-desirable mission range of the smaller craft. Several conclusions of significance to future Arctic ACV design can be drawn from the study:

(i) An ACV can be built with an operational range providing coverage of a large proportion of the Arctic Ocean using shore bases in Alaska and Canada. The craft can be built with essentially the same technology as that used for the Navy's LCAC. Using an open-deck design and modular mission packages, the craft can be reconfigured rapidly for a wide variety of alternative missions.

(ii) The minimum acceptable skirt height is approximately 12 feet for an Arctic ACV capable of long ranges or large operational radii. This translates to a minimum cushion beam of 60 ft and an overall inflated beam of close to 70 ft. Craft with skirt heights much less than 12 ft are severely penalized by the significantly greater distances which must be covered to find a safe circuitous path to the Arctic ice cap through the rough off-shore ice, as well as some limitations thereafter. ACVs which are smaller and have less skirt height than the smaller of the two craft presented in the paper are still expected to possess a reasonably good capability in Arctic Regions but not for long-range operations.

(iii) The smallest craft capable of meeting all of the study requirements has a light-ship weight close to 150 L.tons. There are 39 ships available to the U.S. Navy which can transport a craft of this weight to deep water ports within the Arctic. In addition, there are heavy-lift barges available which transport cargo to Prudhoe on an average of over 35 times a year. One of these transported the AALC JEFF(A) to Prudhoe Bay in 1983.

(iv) Gas turbine engines, as opposed to diesel engines, are the preferred choice to meet the study requirements. The lower specific fuel consumption of current and near-term diesel engines does not compensate for their much larger installed weight compared to gas turbine engines for the total power and mission range required.

(v) Similarly, a very severe reduction in range capability is incurred if steel is used instead of aluminum alloy for the hull structure.

It was concluded that careful consideration should be given to the following items during the next phase of design:

(i) The design of energy absorbing structural side and bow extensions which support the skirt.

(ii) The design and arrangement of fuel tanks to accommodate the very large quantities of fuel to be carried.

(iii) The definition of an acceptable minimum reserve buoyancy.

(iv) The careful monitoring of KG during design.

(v) An improvement in the prediction of drag over rough ice.

(vi) An assessment of the mission range implication of extended operation over water as may be necessary when operating from some Arctic bases during the summer months.

(vii) An improvement in the ability to predict maneuvering capabilities and the associated threshold of safe ridge crossing performance.

(viii) A more precise assessment of the acquisition and life-cycle cost.

(ix) Development of a reliable obstacle detection and navigation system.

(x) Planning for adequate ACV ILS in Arctic regions.

(xi) Development of acceptable Ride-Quality Criteria.

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