S E C T I O N III

DIRECTIONS FOR CONTINUING DEVELOPMENT

A PERSONAL REVIEW OF AIR CUSHION TECHNOLOGY IN CANADA

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Ladies and Gentlemen:

When reviewing the very brief abstract I submitted to the Canadian Aeronautics and Space Institute (CASI), I was somewhat horrified to think that I may have left the impression that having sat in a comfortable pew in Ottawa for the past ten years, I was about to tell my friends and acquaintances in the ACV industry, what they should have done in the past and how to conduct their business in the future. Certainly this was furthest from my mind, for I can assure you I fully appreciate the tremendous effort that the industry has made and that it could be terribly galling to be lectured by a man from Ottawa.

Please forgive me if I should, from time to time, appear critical, any comments I hope will be taken in the spirit of objectivity. The other point I would like to make is that these are purely John Doherty's views and are not intended to represent the opinions of the Coast Guard or any other part of the government. Because of this, I have not sought the approval of my lords and masters for the content of this paper.

The first piece of advice I would like to give is how to become an ACV expert. On joining the Ministry of Transport ten years ago next week, I was given those essential tools of a bureaucrat; a desk, a telephone, a pad of paper, a role of red tape, a wastepaper basket, in and out trays, and the essential pending basket; for a brief moment the pending basket was empty. I had been in the office about ten minutes when my reverie was disturbed by the phone ringing and the voice said: "This is Judy Lamarsh's Executive Assistant, are you the Department of Transport's hovercraft expert?" What could I do but reply - "Yes, Ma'm". Anyway the years following this have never been dull and at times most exciting. I don't think I will ever forget being stranded in an SR.N6 fifty miles north of Churchill at 50^{o} below with willows up our skirt and being rescued by my old naval colleague Bert Mead in a helicopter. The technical challenges have been most fascinating for in my wildest dreams I never thought that icebreaking was to be part of the role of an ACV expert.

Monday evening my boss Bill O'Neil made reference to the tinge of disappointment he had with respect to the establishment in Canada of commercial ACV services. He mentioned the need for the industry to objectively analyze the reasons that these services failed to get going or if they did get going, were unable to sustain an effort. I would like to make some more specific observations in this area. Over the past ten

years, I have been appraised of proposed services by many potential operators but alas only an extremely small number of these have been progressed beyond the planning stage. Some of these have been most imaginative such as using an SR.N4 from Montreal to the Saguenay with a cardeck turned into a casino. Truly a floating crap game!! I wondered at times if I would have to write regulations for hovering croupiers. However, joking apart, some of the other proposals I have seen had a lot of merit and I too have had many regrets they did not seem to progress. On a number of occasions I have had a feeling that the proposer was under a lot of misconceptions as to just what an ACV was capable of doing, also many of those with good ideas had not the faintest notion of the effort which was necessary to carry out a sound feasibility study. For the industry to sort the wheat from the chaff must be most difficult.

I have seen some experienced commercial air service and ship operators attempt to run ACV services and the results have been, to say the least, pretty unsuccessful. One of the prime reasons was that they failed dismally to recognize that an ACV is a tender peice of equipment which, if skillfully operated and well maintained, plus a high level of manufacturer's support, will do an excellent job. If one fails to provide these essential ingredients then the operation is doomed, even if the financial position is sound and if there is sufficient density of traffic to justify this type of surface operation. Any suggestion that an ACV can be treated like a truck spells disaster from the start.

In MOT we have recognized the peculiarities of the ACV and are treating it accordingly. We have fully supported international efforts to provide the ACV and other dynamically supported marine vehicles special regulations. I fully subscribe to the theory that an equivalent level of safety to that provided in a ship can be provided for an ACV by closely controlling its construction, operation and maintenance. However, the manufacturer and operator must be most conscientious in applying the special considerations being given to ACVs. If they do not, then it is inevitable that many of those marine regulations which are rightly applied to ships such as sixty minute Bulkheads, banning of aviation type fuels and large factors of safety will be applied to ACVs. The industry should not forget that almost throughout the world the ACV regulating authorities are part of the marine organization.

A problem which has concerned me over the past ten years is that when the financial going gets tough, there appears to be a tendency to reduce construction, operational and maintenance standards. This snowballs very rapidly and inevitably results in poor craft availability, a drop in reliability and what is even much more serious, unnecessary accidents.

As a retired naval type, I have been somewhat disappointed in the Canadian Forces reaction over the past ten years to air cushion vehicles. The consideration that is being given to the purchase of a small ACV is a good omen and I hope that this is just the beginning. I would also hope that other government departments will identify roles for the ACVs.

Certainly we get many enquiries and I know industry does and yet, for some reason or other, the applications don't seem to develop.

Perhaps this is a good time to mention that I believe there is a most useful role for the ACV in oil pollution control, containment and clean-up. Our very limited trials clearly indicate that the ACV can very successfully spray detergents, lay containment booms, and carry essential equipment to the polluted areas. I also believe that lick-slickers could be used from an ACV. The big advantages are the quick reaction time, all weather capability and the ability to operate in shallow waters and beaches, gives the ACV a head start over any other vehicle. Certainly I am sure this role must be considered when organizations are selecting craft for multi tasks.

I would now like to direct a few words to those less glamorous ACV roles. As many of you know, the original air cushion cable ferry trials were carried out by the Dept. of Transport on the Mackenzie River using the Arctic Systems ACT-100. It is interesting to know that the trials were conducted north of the Arctic Circle. These trials conclusively proved the concept which was later used so successfully in Alaska during the building of the Alaska Pipeline. I am convinced that there are many applications in Canada and other areas. Recently I discussed with a Port expert the problems of many Carribean harbours and I was left with little doubt that a modified application of the air cushion cable ferry may solve many of their problems.

Tomorrow one of my MOT colleagues will talk to you about the potential of icebreaking and I would not like to encroach on what I believe will be a most interesting paper. I will say, however, that having been very near this aspect of the technology for the past seven years I believe we are just scratching the surface of its use in icebreaking. Certainly now that we are all aware that one of the major holdups to winter shipping can be attacked in a new way, it is inevitable that this technology will be exploited. One of the problems is that although it all looks delightfully simple there are many pitfalls and the possibility clearly exists that a failure of an expensive project at this time could set back the development of its use. I would sincerely say to those who are closely connected with ACV icebreaking, be very careful not to over sell the concept. Also I believe that we must work within the state of the art of air cushion technology. For until our position in the field is more firmly established it would not be wise to introduce uproven aspects of the technology. If we follow the conservative course I am sure that the icebreaking role will become a sound cornerstone for a Canadian industry.

I am not sure if there are many attending this Symposium who have a particular interest in the smaller ACVs. I think these can be divided into two categories. Those aimed at the commercial market with about a ½ dozen passengers or ½ ton of freight, and those directed to the pleasure vehicle market. I recollect two or three years ago listening to a very interesting paper which Howard Fowler presented on the ½ ton

ACV. Before and since then my office has had continued enquiries on the availability of that type of ACV. We have directed these to any source which happened to be active at the time. But, alas, there has not been significant development in the field. The reason seems to be one of cost and reliability. I have a tremendous admiration for those tenacious people who have for years been struggling to develop the ½ ton ACV. To these I would say I believe there is a market for a rugged, reliable and capable craft. However, any potential operator must be spoon fed all the way.

The future of the small pleasure craft is, in my mind, somewhat more uncertain. Over the past ten years we have seen a lot of small craft produced in Canada. At least two companies have managed to build and sell about 200 of their particular model; they could not, however, sustain the market. Many of those that have been built are attractive to the eye and they have a reasonable performance over water but over land their performance leaves a great deal to be desired.

I have seen craft that operate very nicely in the water but come to a grinding halt in a slightly ploughed field. Others are maintenance nightmares; two or three engines which are constantly operating at about 90% of their rated power. Would you believe that on one occasion I saw a craft in which had been invested nearly ½ a million dollars and the only way to replace a defective starter was to take the fan guards off, remove the lift fan and finally take the engine out. I believe this sort of maintainability would drive even the greatest enthusiast away. Others, of course, have noise levels which would awaken the dead. To state the requirements for success is, of course, very easy; to meet these is extremely difficult. For the benefit of those who wish to continue or enter the market, I would say that you should aim at a minimum of one foot hard surface clearance, stability in waves up to two feet, controllability equal to a snowmobile on land or an outboard motor boat in water, noise levels similar to those being demanded and achieved for snowmobiles; and to these must be added reliability, maintainability and reasonable cost. I am sure that this cannot be met without a great deal of financial expenditure; in fact I believe that to get such a craft into quantity production an investment of many millions of dollars is required. I wonder if the history of Mr. Bombardier does not provide a very sound lesson in that he started with a vehicle to meet a specific transport job and only when it was well established did he turn to the pleasure market to make his fortune.

Please forgive me if I have ignored any particular segment of the industry such as heavy lift, forestry application and load relief and the multi other uses to which air cushion technology can and will be put. One reason is that I believe I am not particularly competent to comment in these areas. Another reason is that I see a reasonable market developing fairly rapidly for air cushion platforms with cable ferries and icebreaking bows leading the way. The other low-speed activities will, I believe, be slower in reaching the production as some may require significant R&D. Those which do not will use the technology developed for the other two.

Like the Commissioner of the Coast Guard, I too am not a marketing man. However, I have from time to time wondered if because of the peculiar difficulties of selling a new technology that an extra link should be added to the normal marketing procedure. Does it not seem possible that one has to go to a particular area with a full knowledge and the capability and limitations of the whole technology and identify areas in which the technology could be used? A typical example of this might be a review of the icebreaking requirements in the Baltic and how this could be helped by our technology. Many questions come to mind which can only be answered on the spot, for instance, should we attempt to sell the high-speed method or the low-speed method? Another example would be port and harbour operations in the Carribean. Perhaps the industry should get together with DOITC to see if some overall survey could be carried out to identify uses for Canadian air cushion products and follow this up with a more positive marketing drive for a specific type of equipment. Having opened my mouth in an area in which I hardly feel qualified to comment, I am going to quickly cut my losses and say nothing more about marketing.

In closing I would like to say I have very fond memories of the ten CASI Symposiums in which I have participated. I have enjoyed my ten years in the ACV world and would like to express my sincere appreciation to so many in the industry who have helped me with my job and assisted me to, I hope, contribute a little to the future of air cushion technology in Canada. The past ten years have been tough for the industry. The fact that you have survived these leaves me with little doubt that the future will be a good one. I wish you all happy hovering.

ARCTIC ROLLER TRANSPORT

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INTRODUCTION

The Air Cushion Vehicle in its present form has been with us for nearly twenty years. As we look back and recall our early projections of its development and use, we cannot help but feel some disappointment in our lack of success in capturing a segment of the transportation market. There are, no doubt, very good reasons for this state of affairs. A major factor, no doubt, has been lack of development funding to support expansion of the industry. Another has been the relatively little progress that has been made in design innovation and improvement to make the ACV more competitive with existing forms of transportation. A third reason for our general lack of success has been our tendency to place the ACV in competition with other forms of transport in areas where they are already established and over routes which do not take full advantage of the capabilities of the machine.

In regard to the potential users, we believe there is considerable confusion brought about by not clearly explaining to the user the advantages of the ACV to his specific problems along with the potential limitations. A few demonstration operations, of limited success, in Alaska have led to further doubts by the users.

It is fortunate for us that both the U.S. and Canada have large Arctic areas with widely varying terrains during seasonal changes. In these areas, the amphibious feature permits year-round operation not possible with conventional vehicles at reasonable costs. The true potential of the ACV is in those special applications where marginal terrain must be traversed and the construction of roads, airports and extensive docking facilities are economically unfeasible or impossible. It appears that here we have both human needs, as well as industrial needs, that can be served by our industry in these areas.

Maritime Dynamics, Inc., spent approximately two years talking to various aircraft, truck and barge operators in Alaska and determined a desire for a 100-ton payload vehicle. Discussions of costs of such a large vehicle and lack of off-the-shelf hardware led to the preliminary design of a 40-ton payload vehicle which will be discussed in detail. Marketing studies were aggravated by lack of historical freight and passenger movement data and frequency requirements. Continuing discussions then led to an apparent and more urgent need for smaller vehicles for school buses and the "pickup truck" concept. Each of these vehicles are discussed in order of design information preparation and represent a continuing refinement of understanding by the users and our-

selves of the realities of the situation.

Most of us, I'm sure, are quite aware of the poor propulsive efficiency of air-propellers at low speed and certainly of the noise. In our environmental and fuel conservation world of today, these are vital factors. We should point out at least one favourable result of Arctic Operations, and that is the icebreaking feature of ACVs, but we don't know if credit to the industry can be claimed for this more or less accidental discovery. The Arctic Roller Transport seeks to eliminate some of the greater deficiencies of the standard ACV and these deficiencies will become apparent in the vehicle descriptions.

THE ARCTIC ROLLER TRANSPORT - 100 (ART-100)

As stated in the Introduction, the initial market survey led to a vehicle of 100 tons of payload based upon stated user requirements. An artist's concept of such a vehicle is shown in Figure 1 and it was designated the ART-100. Figure 2 shows the craft dimensions. The preliminary design led to the removal of the lift fan intakes to the pilothouse region to give a clear deck space of 50 by 80 feet.

This study work was carried out in 1974 and cane to the conclusion that lack of developed marinized engines of sufficient power precluded a low risk undertaking. Today, engines are available such as the AVCO/Lycoming TF-40 at 3350 hp, the Allison 501KF at 4330 hp, as well as several marinized versions of Rolls Royce engines. By 1978, the Garrett 990 engine will be available in a marinized version at 5000 hp.

Operators are showing a continued interest in the vehicle as ship-to-shore lighters at the ports of Nome and Kotzebue and for overland, tundra and river operation as freighters. One company has also shown interest in this vehicle as a high-concentrate ore carrier.

Detailed performance and operational cost figures were not made on this craft, but it may be expected that with the same power-to-weight ratios, the performance will be near that of the ART-40, a 40-ton payload vehicle, a description of which follows directly. Costs per ton-mile will, however, improve with size.

ARCTIC ROLLER TRANSPORT - 40 (ART-40)

The 40-ton payload version of the ART was the result of a compromise between marinized engines available and the operators' desire for a 100-ton payload. The TF-25 gas turbine has been used in a number of military planing hull gunboats and is widely available in Alaska in helicopter operations. Four candidate test routes based at Bethel are shown in Figure 3 which were selected as a basis of evaluating the economics of the vehicle.

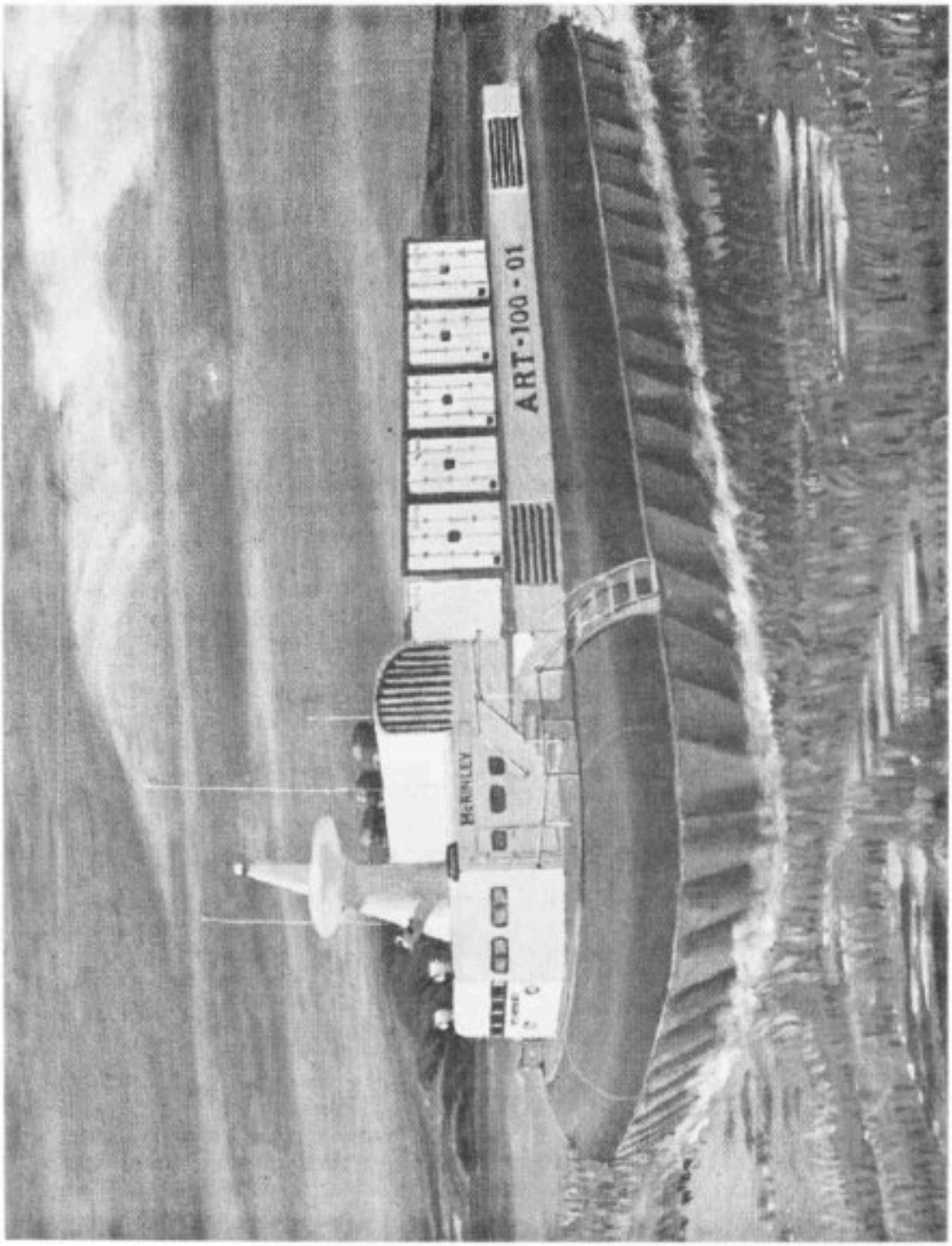
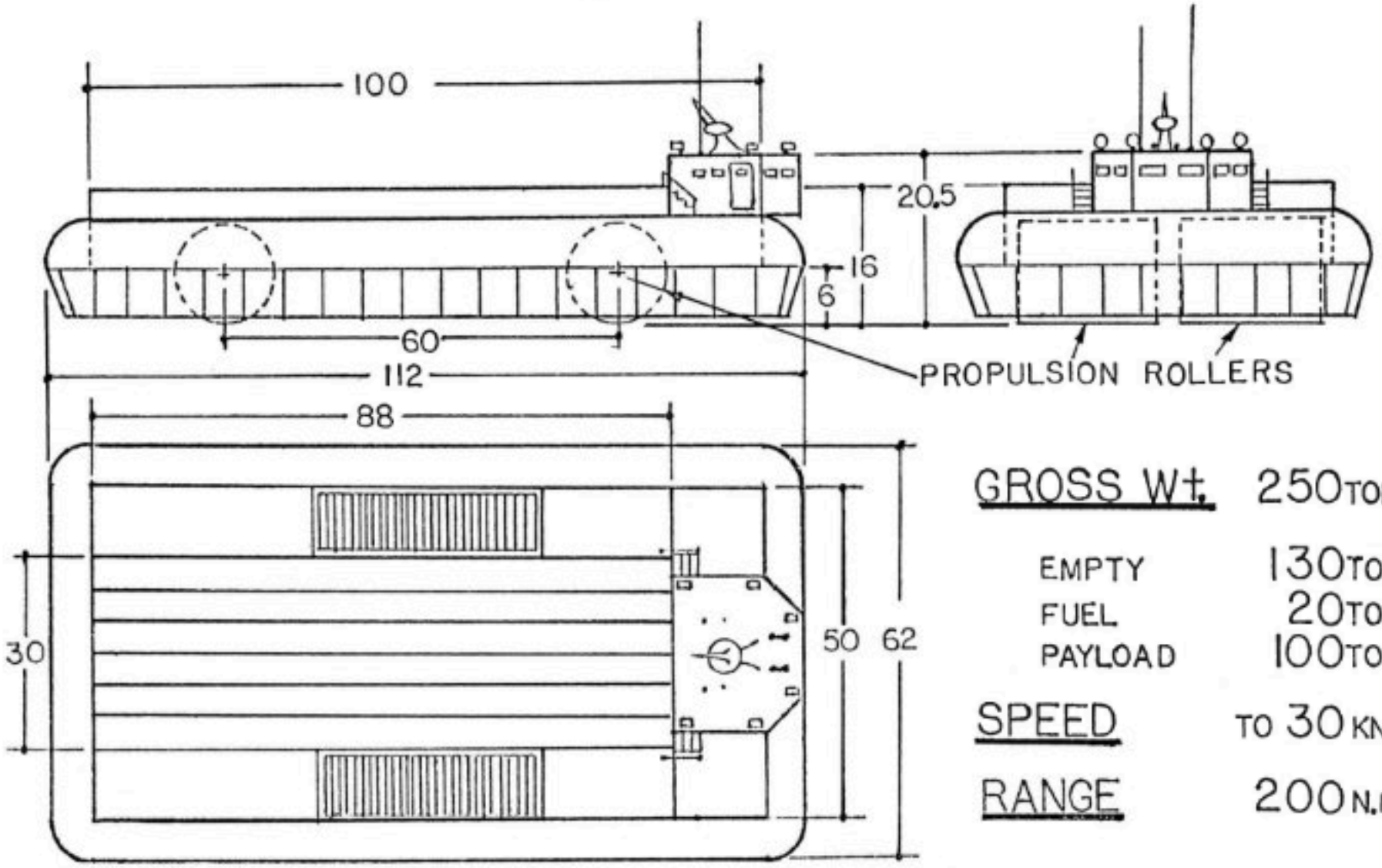


FIGURE 1 - ART-100 (Artist's Rendition)

ART-100



GROSS Wt.	250 TONS
EMPTY	130 TONS
FUEL	20 TONS
PAYLOAD	100 TONS
SPEED	TO 30 KNOTS
RANGE	200 N.MI.

FIGURE 2 - ART-100 Craft Dimensions

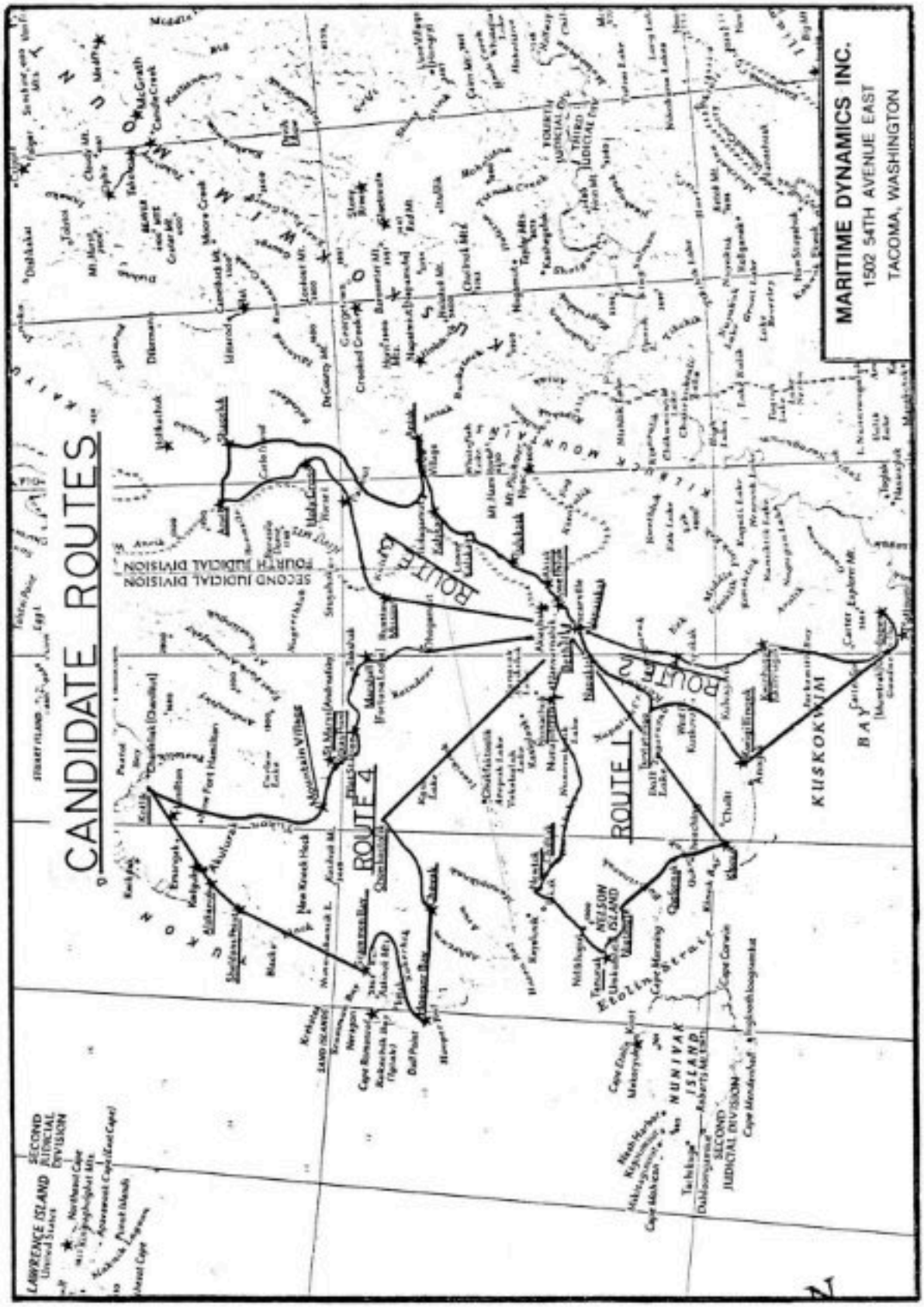


FIGURE 3 - Candidate Routes

It will be well to stop here for a moment and characterize the nature of the ART vehicles. It has been felt for some time that the air propeller was not the ideal method of propulsion for ACVs because of the low propulsive efficiency at low speeds and the noise level (especially from the environmentalists' point of view). Experiments were run in early 1973 to determine if an inflatable roller could be driven with a small diameter axle which would then allow reasonable obstacle clearance. Results showed that an axle diameter 1/6 of that of the roller would be adequate, as long as the internal pressure was held above a certain level for each torque requirement. Calculations then indicated that partial support of the vehicle and its related roller pressure were adequate for known conditions for propulsion on the tundra. In the case where steep grades are encountered, which is most likely to be soil or gravel and not tundra, the grade climbing capability is limited only by the weight one wishes to sacrifice in a small diameter axle. Grades of 30% are easily achievable with no significant weight sacrifice.

Two additional fall-out advantages occur with this concept. First, the addition of blades to the roller provide overwater propulsion, and second, the rollers provide stability over both land and water. Figure 4 shows a cutaway view of the concept. The fore and aft rollers are divided into two parts to provide steering by differential braking of fore and aft pairs of rollers. One TF-25 engine is provided for the rollers' propulsion and two TF-25 engines for the lift fan system. Depending upon one's preferences, the skirts could be of either the pericell type or the simpler finger design. The figure indicates conventional automotive differentials between the rollers; alternatively, hydraulic drive systems could be used but with the complications of power losses and hydraulic fluid cooling.

Figure 5 depicts the characteristics of the ART-40. As shown, it has a clean deck as a result of eliminating the common external air propulsors used on conventional air cushion vehicles. A roll-on, roll-off loading capability is provided. The propulsion rollers are hidden from view because of the surrounding skirt system. The pilothouse is located on the bow for good visibility and is large enough for crew living accommodations and support.

The lift and propulsion systems are both critical to the payload capacity and, aside from the hull, are the most expensive sub-systems. A survey of lift fans and gas turbines indicates that the ART-40 can be constructed using available production or off-the-shelf hardware. Since the vehicle dimensions and physical structure may be capable of carrying larger payloads, possibly 50 to 60 tons, a growth capability exists by retrofitting with lift fans and gas turbines more recently available or currently under development.

The hull is constructed of welded aluminum, and the vehicle is powered by three 2250 hp AVCO/Lycoming TF-25 gas turbines, two of which are used to drive the lift system producing a cushion pressure up to 75 psf, which is within today's state-of-the-art of air cushion vehicles. Since

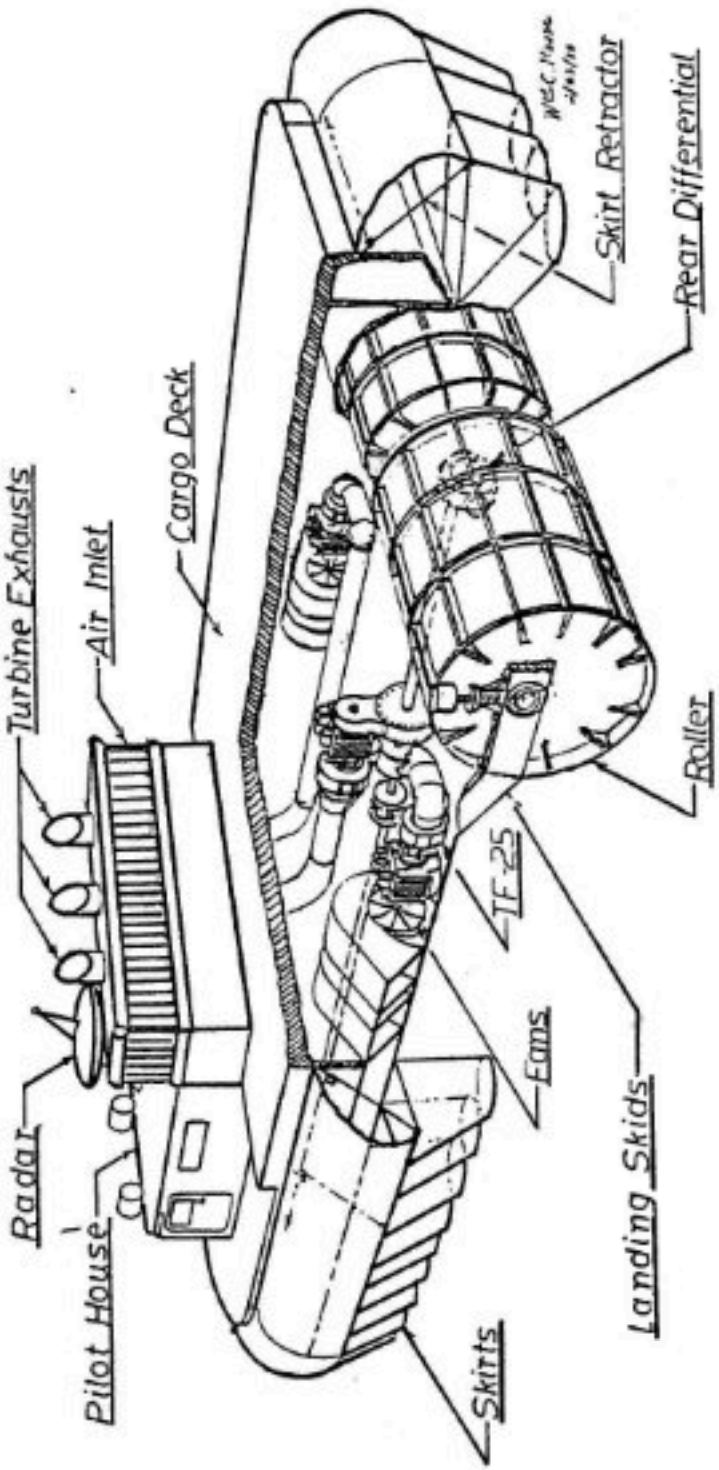


FIGURE 4 - ART-40 Cutaway

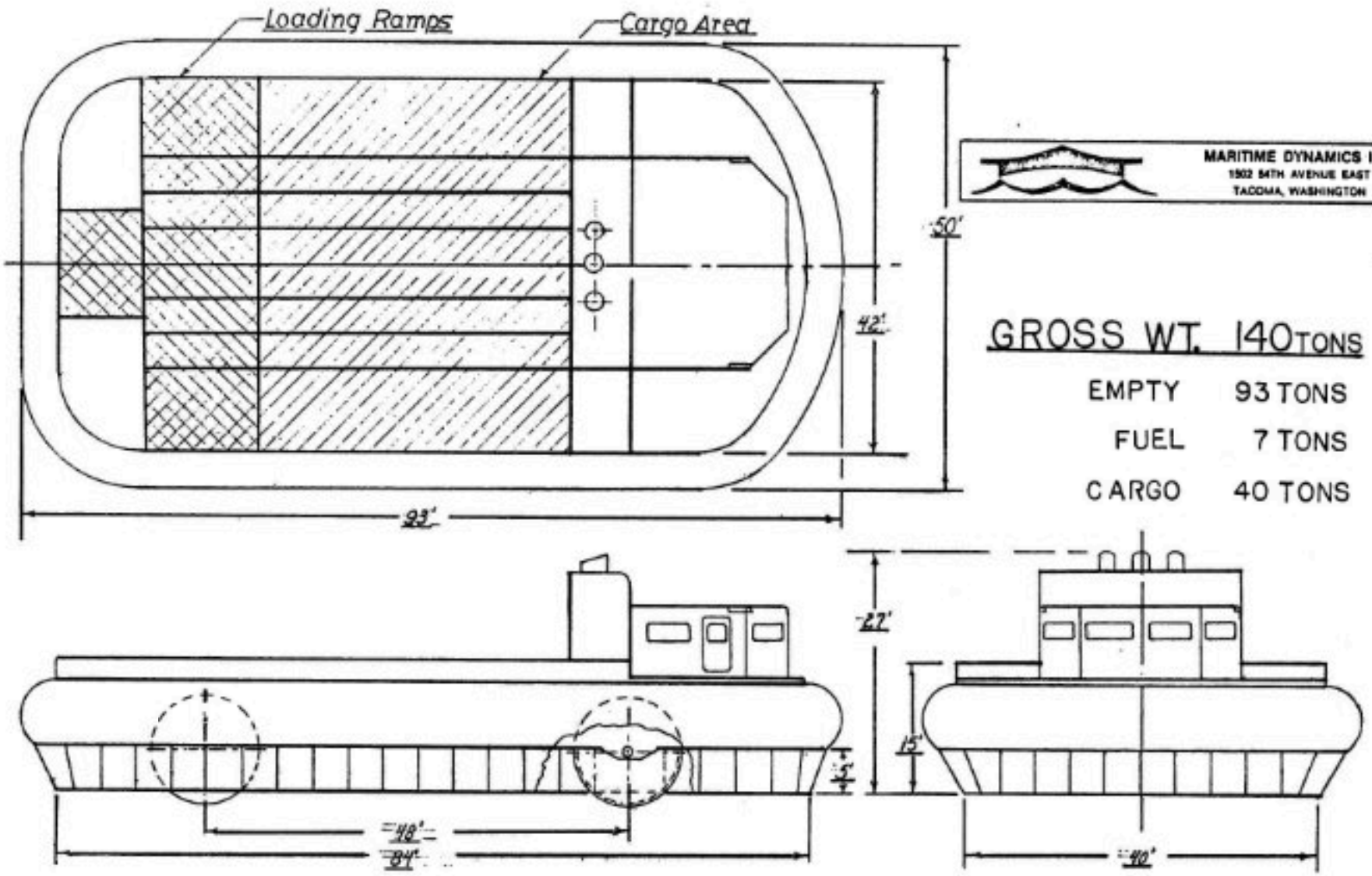


FIGURE 5 - ART-40 Characteristics

the cushion pressure determines the vehicle structure size, the cargo deck area is larger than need be for 40 tons of payload, particularly with containerized cargo as shown in Figure 6.

The central barge structure has longitudinal and athwartship beams to provide adequate space for machinery. Watertight doors are provided on all compartments below the cargo deck for safety afloat, as well as for maintenance and inspection. Direct access from the pilothouse to the machinery space during vehicle operation is provided. The hull's compartmentization will provide fuel bunker storage capacity of approximately 10,000 U.S. gallons.

The locations of the 12 foot diameter bow and stern rollers are shown. The roller surfaces have five inch high radial and lateral flexible "paddles" to provide surface traction to drive the vehicle on any surface and to prevent side slippage when operating along an inclined surface. The rollers are pressurized from 75 psf for operation over soft snow and tundra to 1200 lb psf for operation on hard gorund, on solid ice or over water. It should be noted here that, unlike the Rolligon which is certified for limited operation over the tundra, the roller pressure will be in the order of 75 to 125 psf - well below the Rolligon's pressure which ranges from 420 to 780 psf.

The third turbine is used to drive the rollers. Power is transmitted to the centers of each set of rollers through shafting connected to the main engine gearbox via a gear shift transmission. Each fore and aft set of rollers can thus be disconnected and power can be transmitted to only one roller, if desired. The speed can be varied up to about 30 knots, and somewhat lower when operating at full load over continuous grades.

The inherent pitch and roll stability of the rollers permits the choice of several ACV skirt systems, including the British developed bag-and-finger system, which is currently used on the Voyageur. The ART-40 is illustrated with the bag-and-pericell system which is an American improvement over the British system and is being used on the large air cushion amphibious assault landing craft currently under construction for the U.S. Marine Corps.

An auxiliary power unit provides electric and pneumatic power for the vehicle, including critical machinery, the pilothouse and the air supply to pressurize the rollers. Landing skids are provided on the underside of the hull to prevent damage when the rollers are deflated during inoperative periods.

The independent lift system and the roller propelled propulsion system of the Arctic Roller Transport allow the operator to tailor the total onboard power to the terrain over which he is operating, thereby optimizing fuel consumption and, hence, minimizing the operating costs. On water, soft snow and tundra, the lift system is tailored to the onboard payload and the rollers will be kept at the low pressure over the operating speed range up to its maximum speed of 30 knots. When on

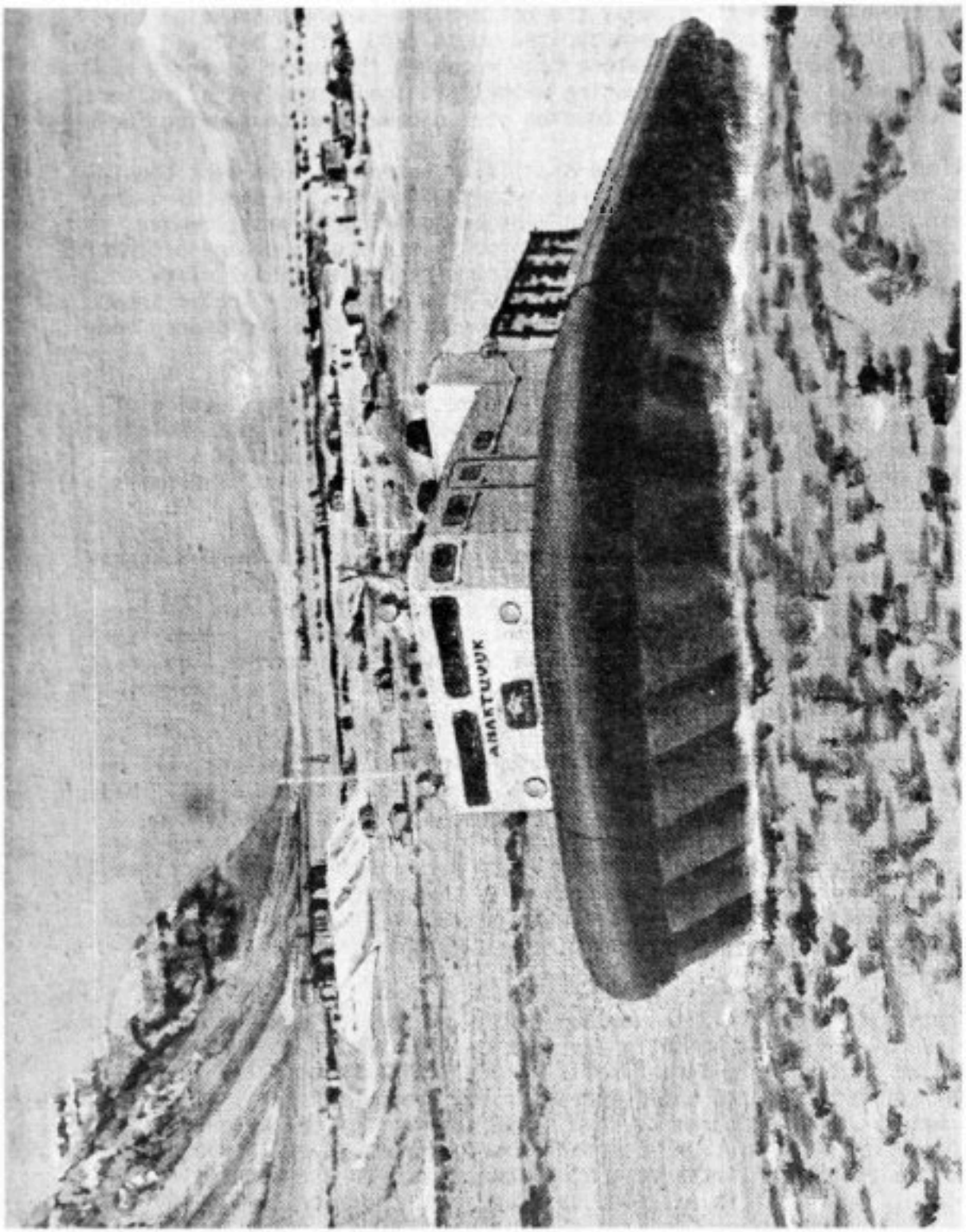


FIGURE 6 - ART-40 (Artist's Rendition)

hard ground or solid ice, only the rollers are used (thus saving the lift system fuel) and are pressurized up to 1200 psf or tailored to the onboard payload. This operating mode requires the least power at any given speed. And, when operating with light loads, one set of rollers can be disengaged - further reducing needed power and conserving fuel.

Roller operation only is a mode that is an extremely important consideration which permits the ART prototype to operate with one-third the power of conventional air cushion vehicles over hard roads, frozen ground, frozen rivers or ice, with a fuel savings of the same order of magnitude. This constitutes 60 to 70 percent of the annual climatic condition in the regions of interest in Alaska and other Arctic areas. In these cases, the skirt system would be retracted to avoid drag and wear.

The load carrying capability of the roller is strictly a function of the internal pressure. At the design gross weight, 1200 psf inflation pressure will carry the full load with about a 7% deflection of the radius and a 4.16 foot long print on the ground. This still permits better than a four-foot obstacle clearance under the axle.

The combination of lift system and roller drive is designed for operation during the Summer months where rivers, ground and tundra have thawed. In certain areas, this will average 30 to 40 percent of the year. The primary purpose of the combination roller-lift system is to allow safe, non-damaging operation on tundra wherein most of the craft weight is on the air cushion with just sufficient weight on the rollers to provide traction for propulsion.

Other conditions where the partial use of cushion and rollers will be desirable are: soft dry sand, mud and swampy areas where a full load on the rollers might dig in, or where full lift on the cushion would blow the soil away. In these cases, partial cushion lift in any proportion would aid in keeping a low footprint area on the surface, as well as lowering total vehicle drag. In the case of grade climbing, we may expect the surface to be reasonably hard such that low cushion pressure and high roller pressure will give the best grade climbing capability.

Operation of the ART-40 in various depths of shallow water have been analyzed. For cases of up to two foot depths, a firm roller contact with the bottom would appear satisfactory. Alternately, low lift power could be used to expel the water out from under the vehicle. For water depths of three to five feet, lift system operation would be desirable with overland approach speeds in excess of 12 knots such that the vehicle will traverse above hump speed on the water's surface. Again, it is expected that the earth surfaces under shallow water may vary from mud to soft sand. The choice of operational mode in these conditions can really only be determined by actual demonstration to establish minimum fuel consumption.

OBSTACLE OPERATIONS

The basic ART-40 is designed to pass over obstacles of the order of four to five feet and it is expected that these would not be full roller width, but some fraction thereof. The rollers are interconnected to the air supply system such that a decrease in volume of one roller will cause the air to enter the other rollers to equalize pressures. Thus, a pressure rise would be cut one-quarter by this plenum effect. Consideration can be given to connecting the roller air feed system to another plenum in an available void space to function as an accumulator, so long as there is no adverse weight penalty. An alternative method of operation would be to lower roller pressure and carry some load on the air cushion. This would greatly reduce the "g" forces when encountering a series of obstacles.

For analysis of roller penetration by sharp obstacles, DuPont's Fluorosilicone coated Dacron was chosen. To obtain a wall strength to safely handle 1800 psf, 1.5 times the maximum planned pressure, ten plies of 0.015 material was selected. This material has a tear strength of 800 lb per inch, which would provide a burst pressure strength of 10,000 pounds per foot or an internal burst pressure of 1818 psf, with a total thickness of the order of 0.15 inch. This neglects the strength of the 0.375 inch of roller rubber surface which provides a means of attaching the rubber paddles, and provides for scuffing and wear. A good rubber has a tensile strength of 5000 psi.

Since there is no significant background of published data related to this specific problem, the "Mullins Burst Pressure" in psi was chosen and, in effect, used in reverse. For the Mullins test, a sample material is laid over a one square inch opening and pressure applied until it bursts. For a single ply of the 0.015 material, the burst pressure would be 150 psi; therefore, allowing for ten plies and assuming additive properties, the burst pressure is 1500 psi. A very brief analysis showed that a one inch square steel rod could indent the roller approximately two feet without rupture.

The performance analysis for the ART-40 is broken into three parts: (1) hard ground, ice and snow-covered ice or ground (rollers only); (2) summer tundra operations (cushion plus rollers); and (3) water operations (cushion plus rollers). For the purpose of this paper, the data is presented as a sample analysis based upon estimated rolling co-efficient of friction of the rollers on various surfaces in the cases of hard ground, ice or snow-covered ground. More knowledge from the route survey would be needed to establish actual route average propulsion performance. Land gradient knowledge will also be essential.

When traversing hard ground, ice and snow-covered ground, only the rollers are employed. For hard ground and ice, a rolling co-efficient of friction of 0.042 is used, while for soft snow, 12 to 14 inches

deep, a value of 0.099 is utilized. Both aerodynamic drag and rolling friction co-efficient drags are utilized at the vehicle full gross weight of 280,000 pounds. In all cases, 20°F is used as engine air inlet temperature for engine performance characteristics. Figure 7 shows the total power required plotted versus velocity for the hard ground or ice conditions. The solid lines are power versus velocity with wind velocities up to 40 knots as both head winds and tail winds. The dashed lines are for 12-14 inches of soft snow and wind velocities range from 0 to 40 knot headwinds. The corresponding fuel flows in gallons per hour are plotted for reference. The 240 gph power "Reserve Rating" allows 30 minuts at that level, but all lower levels are for continuous operation. The power-required curves indicate a full 30-knot capability on hard ground or ice, but speeds would be limited to about 28 knots in a 10-knot headwind in soft snow.

Another factor exists which could be significant in terms of speeds available over long gradients. Figure 8 shows the increase in power required for 5, 10 and 15% gradients. A 2% gradient over long distances at 30 knots may require an addition of about 520 horsepower. This would not limit the speed over hard ground, but the additional fuel consumption would have to be accounted for. A "low gear" option is available to increase tractive effort at low speed for unusually severe grades or difficult terrain.

Operation over the melted tundra will have many variables such as depth to frozen surface, grass density and soil stability at the roots. Again, these matters are probably variable with location, elevation and time of season. The route survey will help in designating paths for repeated travel with specified limits to minimize potential damage to the tundra. Alternately variable routes could avoid continuous wear. Figure 9 represents power required for propulsion only versus velocity, based upon our current best knowledge of the tundra. (NOTE: The total fuel consumption will be that of the lift power system setting plus propulsion power setting.) The 2650 horsepower "Reserve Rating" is for the AVCO/Lycoming TF-25B at 59°F, which was considered to be a nominal day in unfrozen tundra operations. Gradients from Figure 8 would also affect the maximum speed available. However, it is believed that these data are conservative and should be regarded so until a route survey is completed. Roller pressures would vary from about 98 psf at the lower speeds to 131 psf at the higher speeds.

Figure 10 shows the drag versus speed curves for the ART-40 in different depths of water. The thrust line curve for a blade co-efficient, C_b, of 1.0 is also plotted on the curve and shows a water speed variation of between 25 knots in a 10-knot wind to 27 knots in no headwind. It should be noted that, since the original analysis which is shown here, it has been determined from test data that the blade co-efficient, C_b, will be in excess of 1.2. Shallow water peak drags actually experienced are normally less than the theoretical values shown. However, it may facilitate hump transit to allow the vehicle to accelerate to between 8 and 12 knots on land where practical or in very shallow water before entering a water channel of uncertain depth.

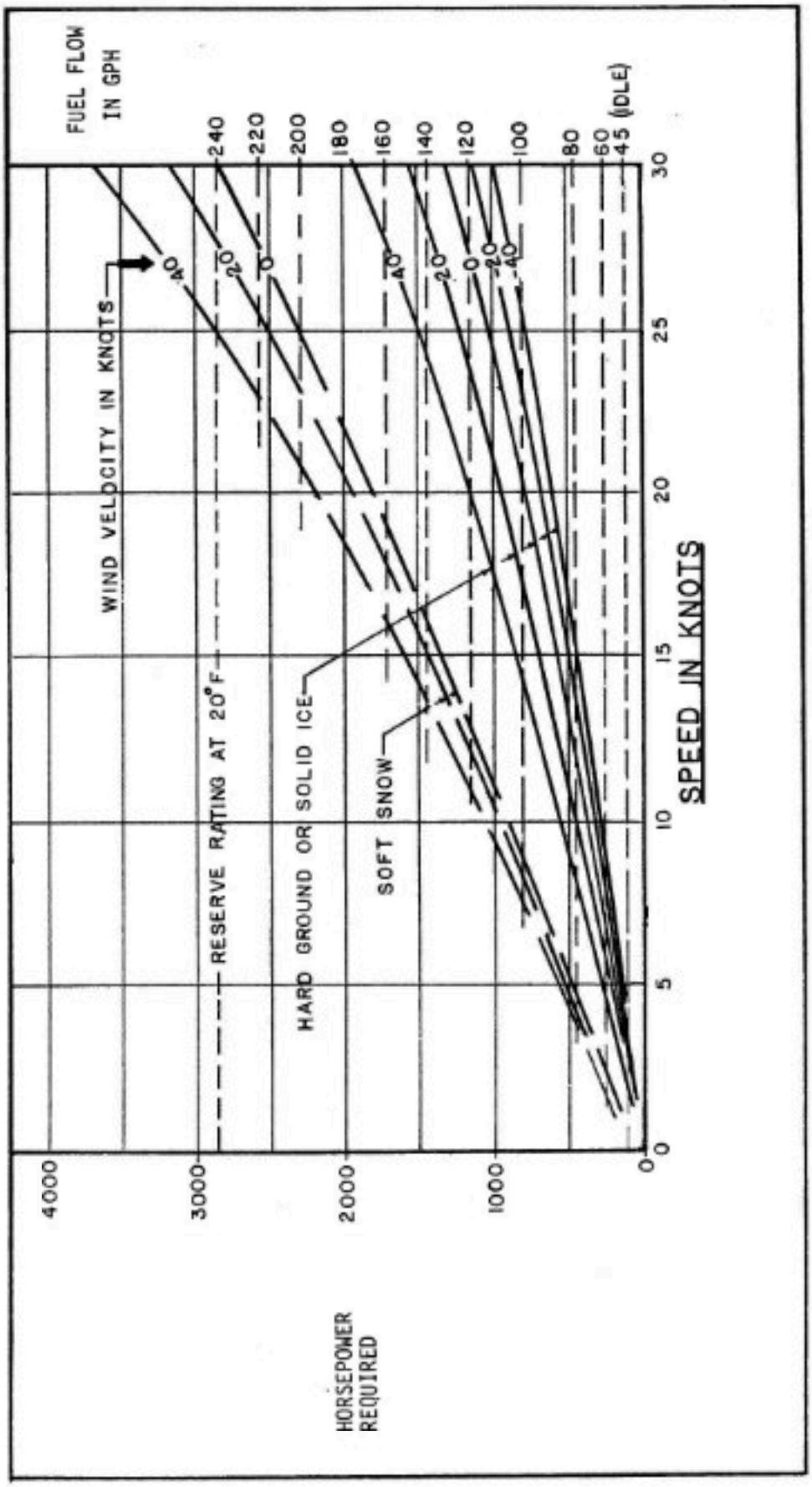


FIGURE 7 - ART-40 HP & Fuel Flow Vs. Velocity

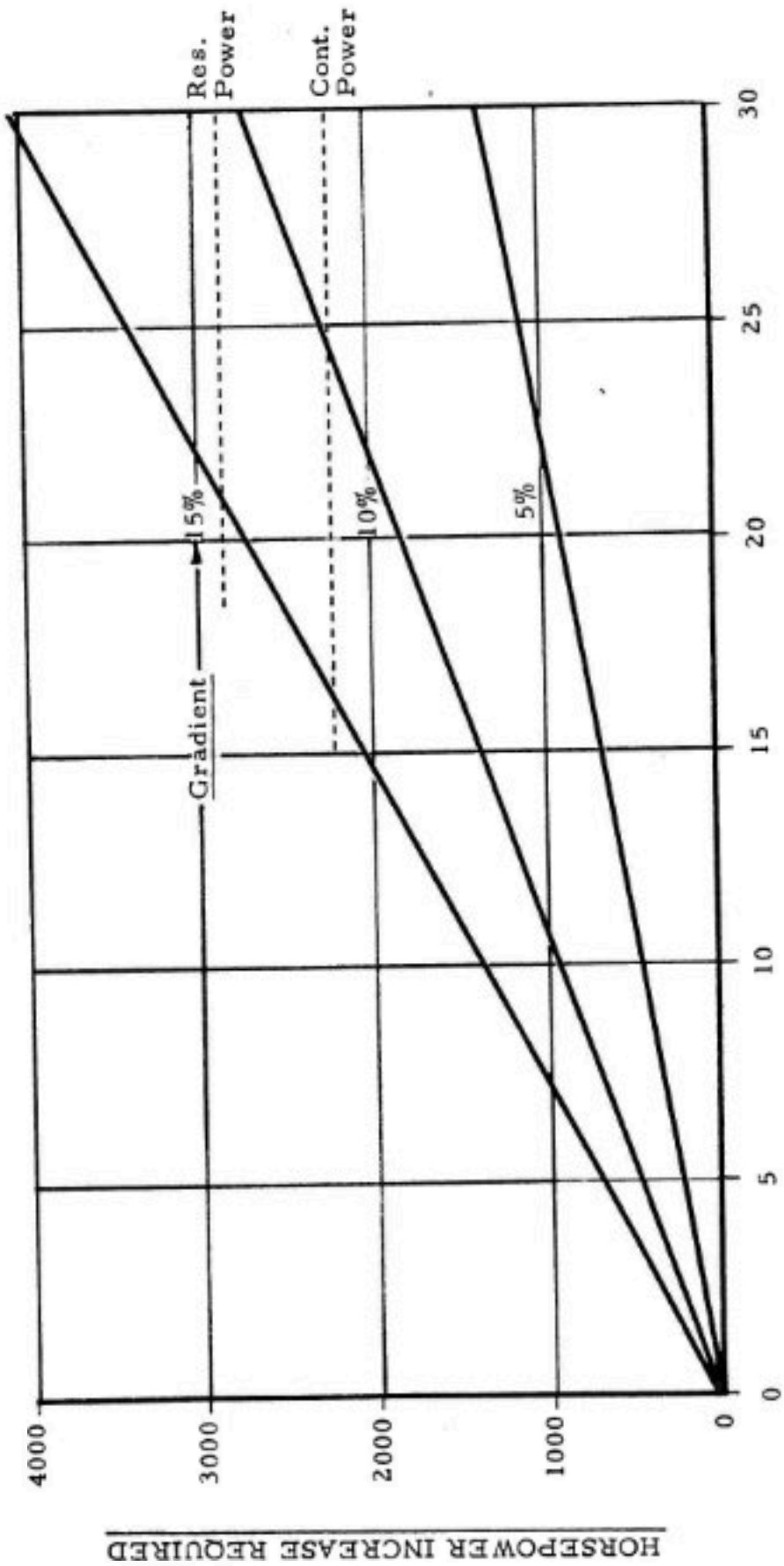


FIGURE 8 - ART-40 HP Increase Required Vs. Speed and Gradient

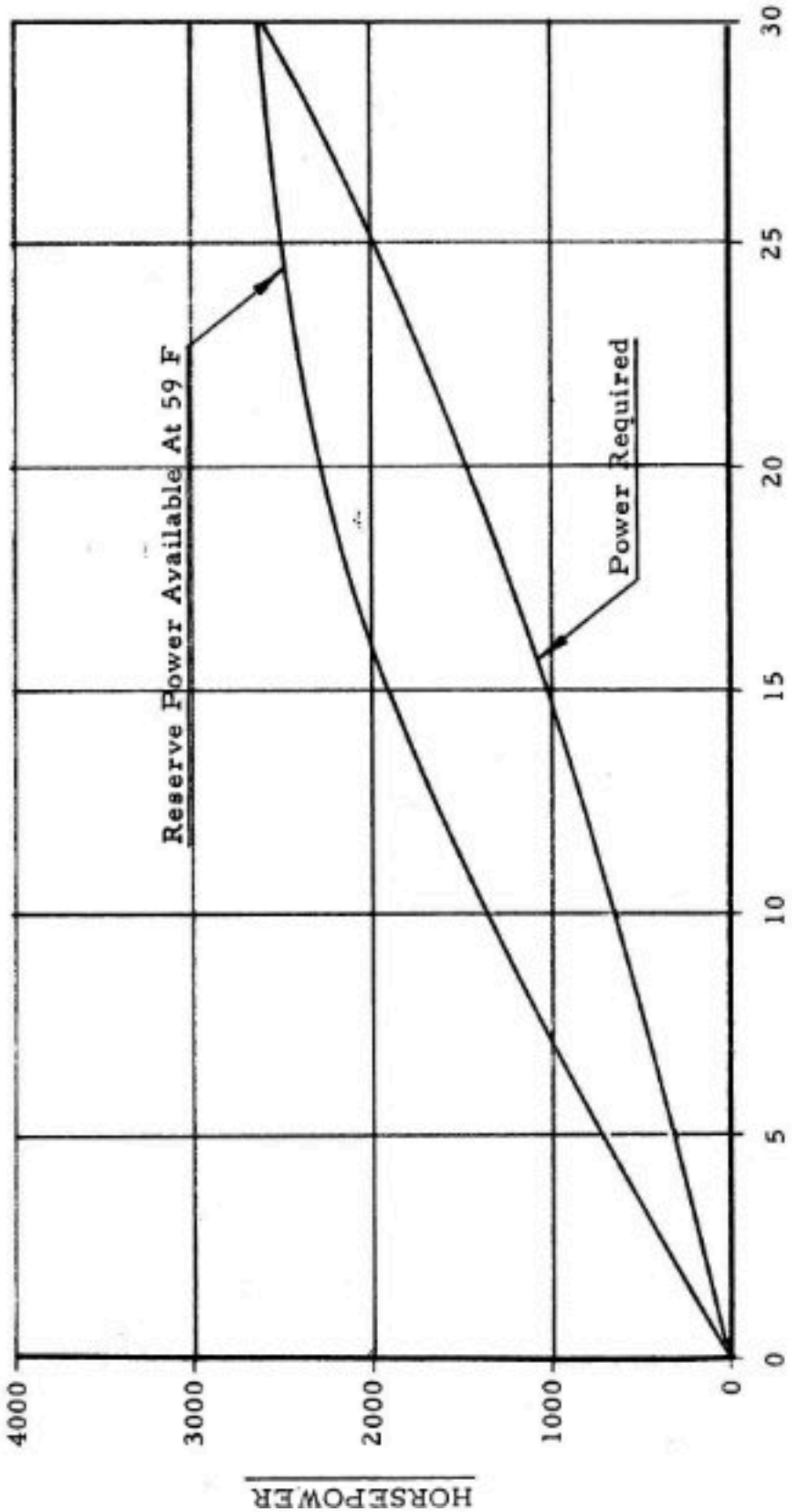


FIGURE 9 - ART-40 Horsepower Required Vs. Velocity on Tundra

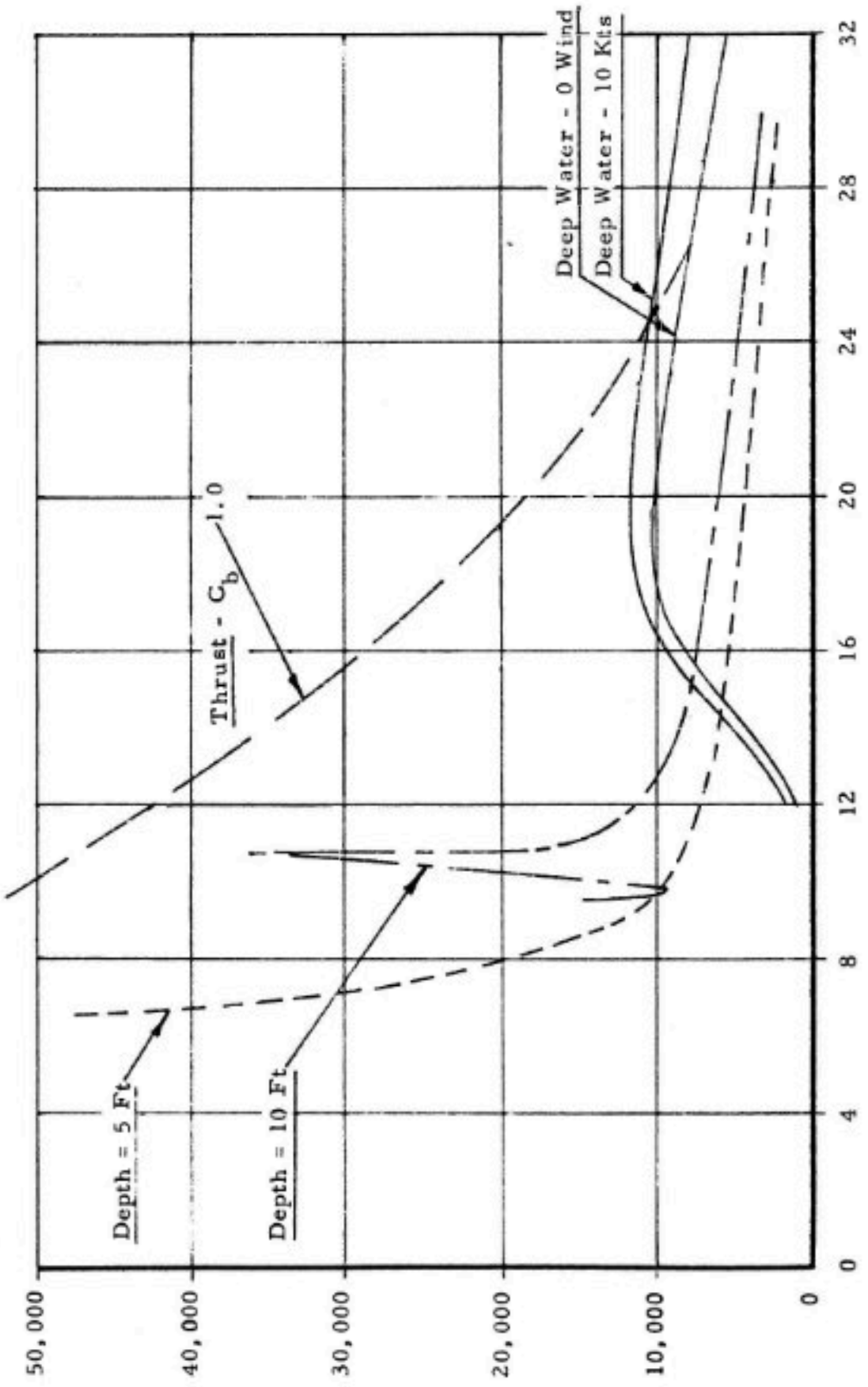


FIGURE 10 - Wave Resistance of ART-40
as Affected by Water Depth Based on Computations of
Newman & Poole, DTMB Report 1619

ARCTIC ROLLER TRANSPORT - 10 (ART-10)

Again, as indicated in the Introduction, continuing discussions with Alaska State personnel revealed a need for school bussing operations in Southwestern Alaska. A further need was indicated for passenger and freight operations during off-school hours. Because of the weight sensitive nature of air cushion vehicles, gas turbine engines were retained in the design because of their light weight and the resulting better net payload capabilities. The United Air Craft of Canada, Ltd., ST6-70 engine was chosen as the smallest marinized engine available, and a preliminary design was developed around it for the school bus and freighter applications. In addition, we placed upon the craft the requirement that it be modularized for air transport in the C-130 aircraft. Obviously, it should also be comprised of as many developed components as possible. The design resulted in a 10-ton payload capability, or as we call it, the ART-10.

The ART-10 was considered for possible use as a freighter as well as a school bus. This was essential since the school bus operation alone could not afford the amortization costs of this size of craft as a single purpose vehicle. It was, therefore, proposed that a special removable school bus module be designed to fit the truck bed space of the ART-10. Figure 11 shows the general concept. The module would have the dimensions of 20 by 20 feet square and would allow seating of 90 to 100 students. Assuming that the freight portion of the ART-10 application would meet, together with the school bus role, an annual utilization of 3600 hours per year, then the cost per seat-mile as a school bus would be of the order of eight cents for a 100% load factor. An operation having to depend on only a 50% load factor, would, of course, double these costs.

It may, at first glance, appear doubtful that such a high vehicle utilization can be achieved in a year's time. However, when the operation is looked at from the combined point of view, the operator now has a much greater assurance that his total operating times will be met.

ART-10 LEADING PARTICULARS

Hard Structure:	Length	40 ft.
	Beam	20 ft.
	Height (incl. gearbox)	8.5 ft.
Air Cushion Duct and Skirt:	Length	46 ft.
	Beam	26 ft.
	Height (on rollers or skirt)	12 ft.
Load Area:	20 ft. by 20 ft.	

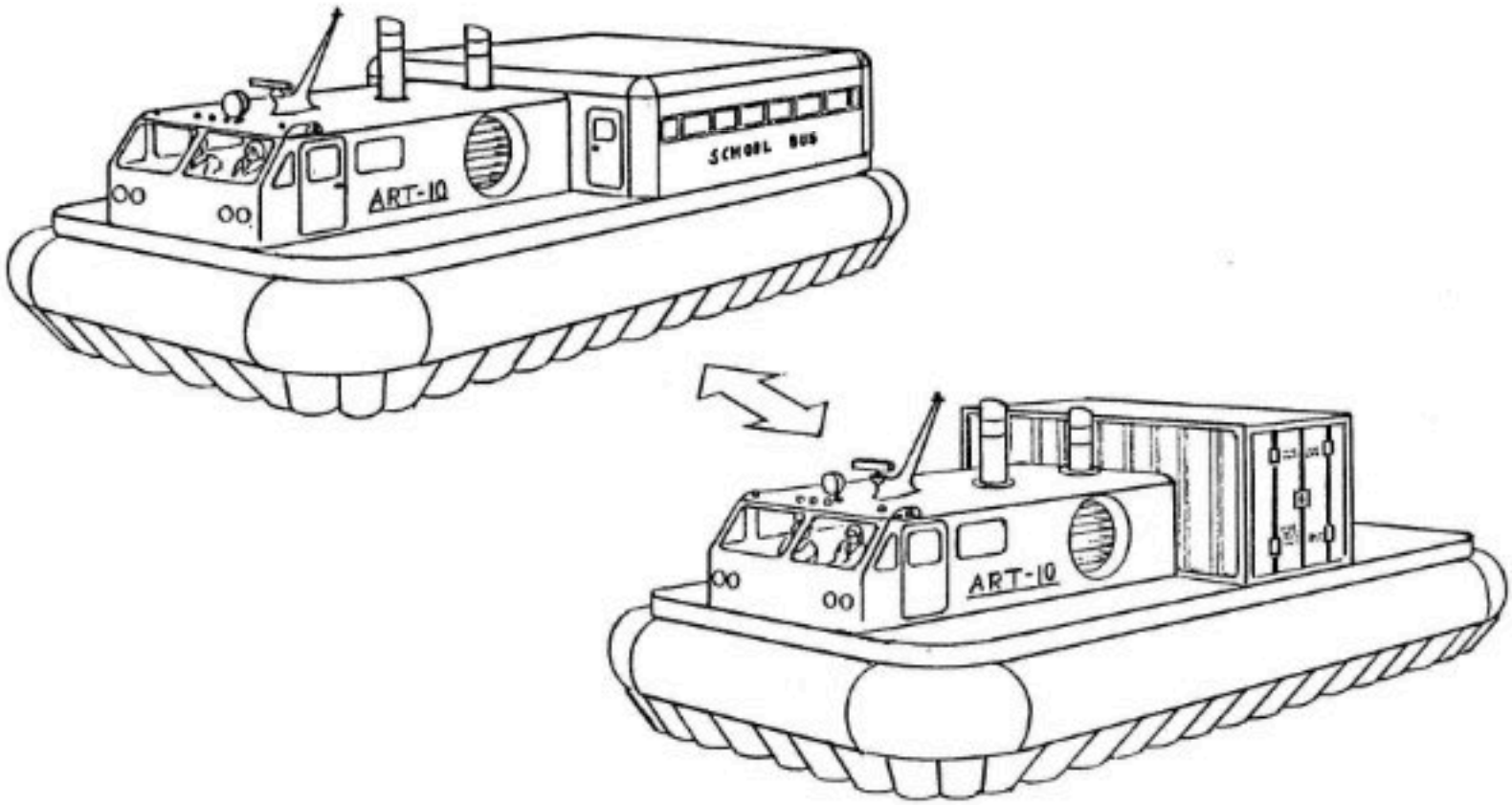


FIGURE 11 - ART-10 General Concept

Weights:	Gross Weight	45,000 lbs.
	Payload	20,000 lbs.
	Fuel (300 U.S. gallons)	2,000 lbs.
	Empty Weight	23,000 lbs.
Performance:	Overland range at 40 knots into 20 knot wind	290 n.mi.
	Overwater range (calm) at 37 knots	120 n.mi.
	Overwater range (rough) at 32 knots	90 n.mi.

HULL STRUCTURE

Since the ART-10 is expected to traverse both fresh and sea water in the Arctic, the structure consists of welded marine aluminum alloys. This provides a strong lightweight structure capable of traversing deep water and resistant to salt water corrosion. The 5000 series aluminum alloys selected for this application have been successfully used in many other seagoing applications.

Figure 12 shows a sectional view of the ART-10. In this particular view, the design has been modified to locate the lift system at the aft end of the vehicle in order to ease the problem of minimizing center of gravity movement with widely varying loads.

The structural arrangement provides two compartmented side hulls joined together by a center deck which is of compartmented box-beam construction, housing the propulsion engine and gearbox as well as the air ducts from the lift fans. The flotation provided by the hulls and center deck is sufficient to support the weight of the fully loaded vehicle off-cushion in deep water.

The crew compartment structure and lift system housings are of conventional aluminum construction. The school bus passenger module and cargo containers are held in place on the deck with conventional cargo hold-down fittings.

PROPULSION SYSTEM

Propulsion is provided by four large diameter low pressure rollers (tires) mounted on standard truck tandem differentials with shortened axles. The driveline will be driven through a reduction gearbox by an ST6 gas turbine engine. When operating on-cushion, the engine will operate at increased inlet air pressure provided by one lift fan. This size of craft could accommodate six foot diameter rollers and thus would be capable of clearing up to three foot obstacles.

The ST6 gas turbine engines are proven engines in full production at United Aircraft of Canada, Ltd. These engines with a normal rating of

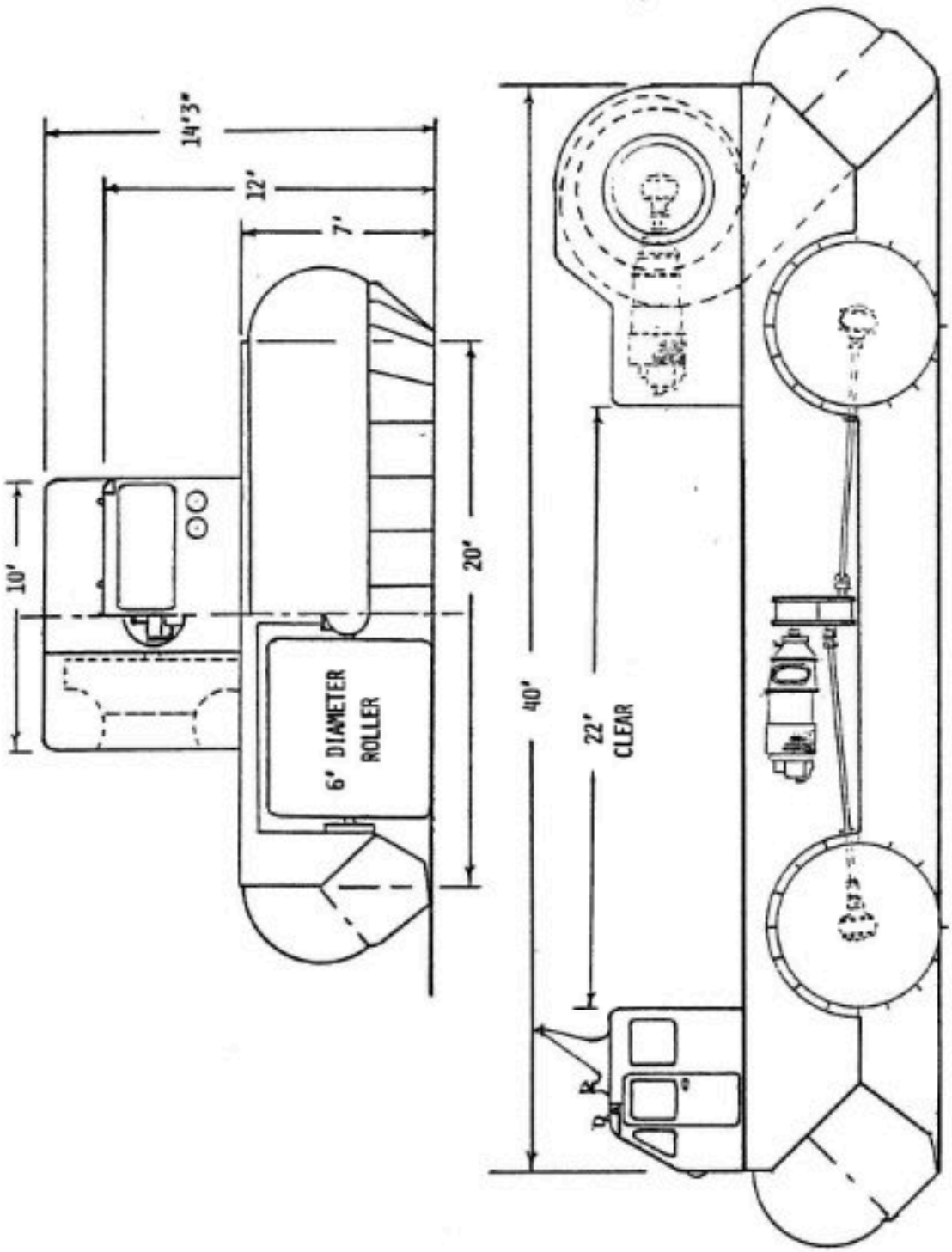


FIGURE 12 - ART-10 Sectional View

over 500 horsepower have seen service in several aircraft applications, as well as in the Voyageur Air Cushion Vehicle and the Bras D'Or Hydrofoil.

The transmission of power from the propulsion engines to the rollers will be accomplished through standard transmission gearboxes, shafts and axles currently in use on highway transport trucks. Depending upon the dimensional constraints, it may be necessary to modify the axles to a shorter-than-standard length.

The reduction gearbox from the engine to the propulsor shafts will use available gear ratios.

The rollers are the means of support on hard ground or ice and are the propulsors of the vehicle under all conditions. The manufacture of the rollers is similar to that of low pressure tires (like the Rolligon-type) except that, like the ART-40, the tire pressures used are much lower (about half).

On hard ground and in water, the tire pressure is increased to provide support of the vehicle weight on hard ground and to provide stiffer tire and tread paddles for water propulsion.

LIFT SYSTEM

The lift system consists of two centrifugal fans driven through a right-angle bevel gearbox by an ST6 gas turbine engine. The lift fans shown are those entering use on the JEFF(A) AALC (Amphibious Assault Landing Craft). These have been shown in the design presented. Other fans which would be suitable for this application are those in use in the SES-100B and a Rotafoil five foot diameter fan, available from England.

The skirts consists of a loop (the upper semi-circular duct) and peripheral cells. The air exhausting from the lift fans is fed into the loop which distributes air around the periphery of the vehicle. Air then passes through holes in the loop down into the cells and fills the air cushion space, lifting the vehicle.

The loop and cells are fabricated from rubber coated fabric material similar to that used in all air cushion vehicles.

ELECTRICAL SYSTEM

The electrical power for starting the main engines and providing for other electrical needs will be provided by an alternator driven by the auxiliary power unit (APU). The APU will be started from storage batteries.

COMMAND AND SURVEILLANCE

The controls, instruments, radio and radar (if needed) will be drawn from conventional sources.

AUXILIARY SYSTEMS

Deck machinery or winches if required will be electrically driven utilizing power from the APU.

Hydraulic power for operation of vent system, brakes or the like will be powered from a hydraulic pump mounted on the APU.

Firefighting in the engine compartments will be provided by a bottled gas system. Portable extinguishers will be provided in the crew compartment.

OUTFIT AND FURNISHINGS

The ART-10 will carry a crew of two, an operator, and an observer, who will alternate in their duties. The crew cab will be a modified transport truck cab with rudimentary bunking, toilet and messing facilities.

MODULAR CONSTRUCTION

In order to fit into the cargo hold of a C-130 Hercules aircraft, the ART-10 hull has been divided into three major sections. The centre section containing the crew cab and all machinery is ten feet wide, 8-1/2 feet high (including the propulsion gearbox) and 40 feet long. The two side sections are five feet wide, two feet deep and 40 feet long. The skirts would remain attached to the side sections during transport. It is important to note that the alignment of all engines, fans and gearboxes is not disturbed. Rollers and drivelines will be disassembled for shipment. With careful design of the modules and crating, it should be possible to move the craft to a remote site with two aircraft loads.

CARGO CAPACITY

The clear deck area is 20 feet by 20 feet. Any combination of bulk loading is feasible so long as the load is properly spread. A payload weight of 20,000 pounds was designed for when sizing powerplants for overwater operation. A heavier load may be carried overland, but certain restrictions with regard to load bearing capability of the ground surface must be observed. Note that a 20 by 8 by 8 foot container can easily be accommodated.

PERFORMANCE OVER ICE OR HARD GROUND

Over ice or hard ground, the ART-10 is fully supported on the rollers, the lift fan system is not operating, and the skirts are retracted. As the vehicle moves at velocity over level ground, the propulsion system must overcome rolling friction and aerodynamic drag of the vehicle. As the vehicle climbs a grade, the propulsion system must also overcome the component of vehicle weight acting parallel to the grade.

On level ground with no wind, the ART-10 can achieve about 42 knots at 200 hp, or 50 knots at 300 hp, as shown by the lowest curve on the chart. As wind and slope conditions are added, the drag increases and horsepower requirements go up.

The force required for the rollers to break away on ice is shown for the vehicle at 45,000 pounds gross weight. It can been seen that application of greater than 200 hp will cause the rollers to break away and slip on ice. However, even on a 5% slope into a 20-knot wind, a speed of greater than 15 knots can be maintained. The combined performance numbers are shown in Figure 13.

PERFORMANCE OVER WATER

The drag of the ART-10 while operating over water has been plotted for both calm water operation and when a 14-knot wind is blowing causing two foot waves. This is shown in Figure 14. The thrust provided by the rollers at various rpm's is also shown and the intersection of the thrust and drag curves indicates the speed which can be achieved. Thus, at a roller speed of 250 rpm, the ART-10 can achieve 23 knots in waves and 28 knots in calm water. The propulsion engine horsepower requirements are also shown on the plot. The ST6 engine is capable of a steady output of 500 horsepower, if required.

ARCTIC ROLLER TRANSPORT - 1 (ART-1)

Studies continued to find a less expensive vehicle to meet the school bus requirement for Western and Southwestern Alaska. Initial plans call for bussing operations from as few as eight pupils for eight miles to fifty pupils for forty miles, and a maximum of sixty-one students for twenty-two miles. The route conditions include operation on rivers, over open water, sand bars, lakes and swamp or tundra. The ART-1 is our response to the Alaska Dept. of Education requirements to meet their average pupil flow requirement.

The ART-1, like its forerunner designs, is an off-road vehicle designed to meet load carrying requirements on marginal terrain as well as solid ground. It is an air cushion supported truck using low pressure rollers (tires) for propulsion. When the bearing strength of the surface is not sufficient to support the footprint pressure of the rollers

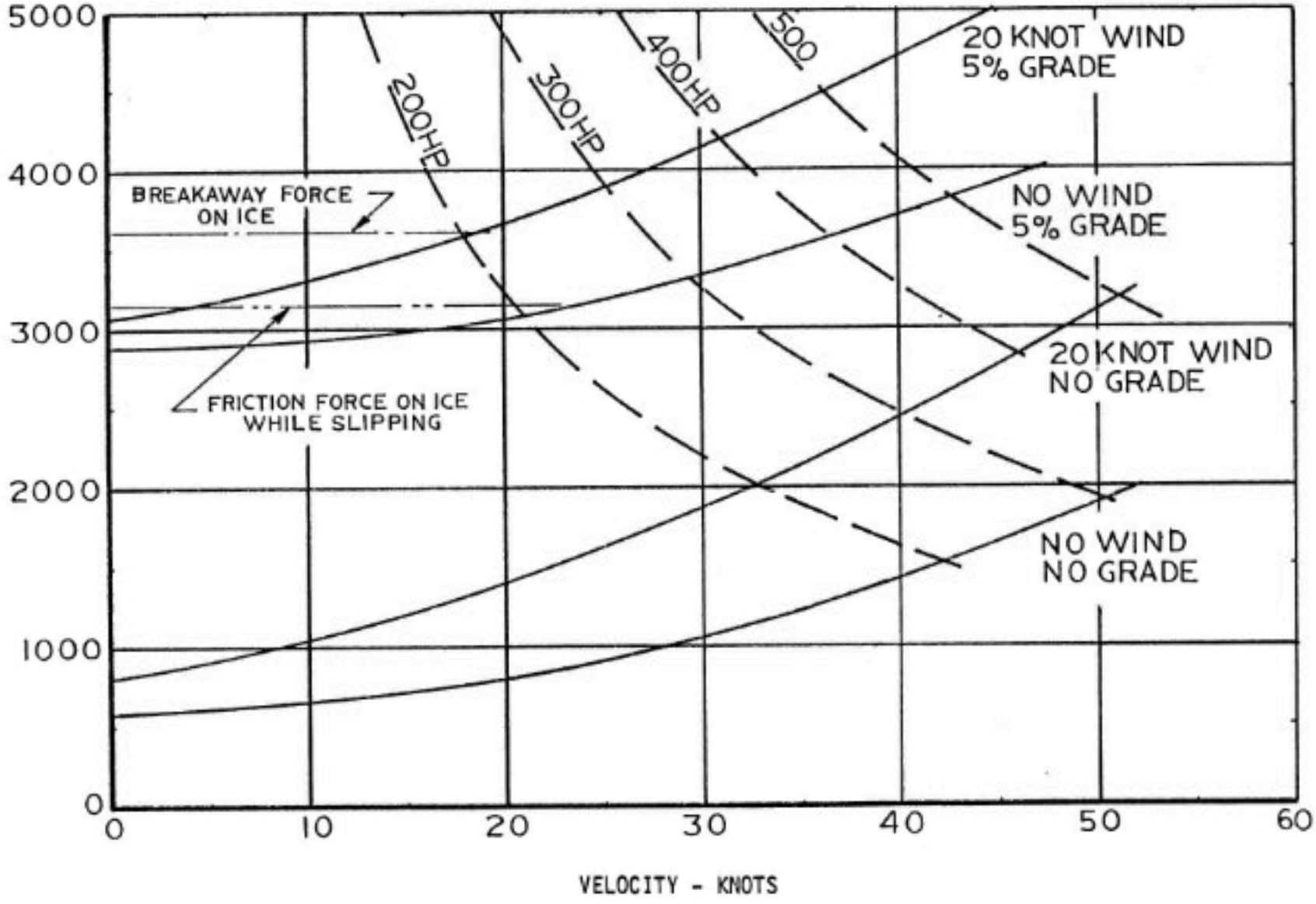


FIGURE 13 - ART-10 Performance over Ice or Hard Ground

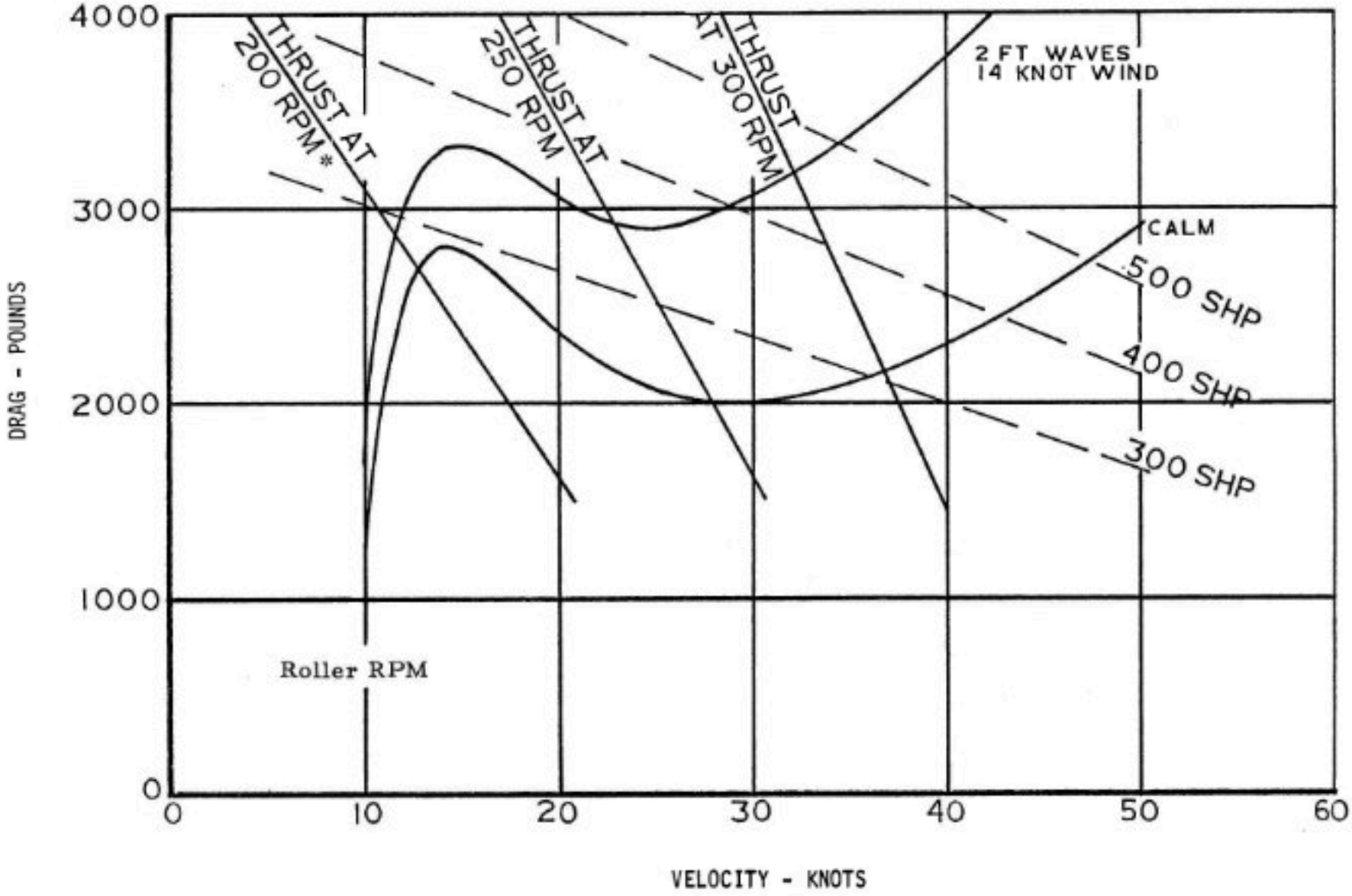


FIGURE 14 - ART-10 Performance over Water

or for operation over water, the skirts are dropped and air cushion assist is used. Propulsion is again provided by the rollers. If desired, a small propulsive force can also be provided by selective venting of cushion air.

As noted before, the advantages of the roller transport concept over air propelled air cushion vehicles are the reduction in noise and the improved propulsive efficiency, plus inherent stability. In addition, when the air cushion support is not required, fuel consumption is significantly reduced. Since the rollers are in constant contact with the surface, directional control of the craft is good and the need to slew the craft to counteract winds or side gradients should be greatly reduced or eliminated.

The basic design requirements for the ART-1 were that it should be easily modularized for air transport; that it should make use of as many developed components as possible; and that it should be capable of carrying a useful load of one short ton.

The study conducted resulted in a 17-student school bus configuration, shown in Figure 15. By removal of the seats as needed, the craft could do off-hour duties as a truck. In an expanded configuration, the basic vehicle could be used to tow a second 25-passenger ART-1 trailer on reasonably level ground, as shown in Figure 16. The trailer would, of course, have a lift engine and fans for air support but not a propulsion engine.

A cross-sectional view of the basic tractor is shown in Figure 17 with the detail of the school bus body deleted for clarity. Similarly, a cross-sectional view of the trailer is shown in Figure 18. A three-view of the vehicle which would be essentially identical for the tractor and trailer is shown in Figure 19. The dimensions and capability of the ART-1 design are given below.

ART-1 LEADING PARTICULARS

Hard Structure:	Beam	10 feet
	Length	20 feet
	Height	6 feet, 4 ins.
Air Cushion Duct (Rubberized Fabric)	Beam	16 feet
	Length	26 feet
	Height (on-cushion)	9.5 feet
Load Area:	10 feet by 9 feet	
Obstacle Clearance:	2 feet	
Weights (Tractor):	Gross Weight	8,425 lbs.
	Payload	2,000 lbs.
	Fuel	625 lbs. (90 gals.)
	Vehicle (Empty)	5,800 lbs.

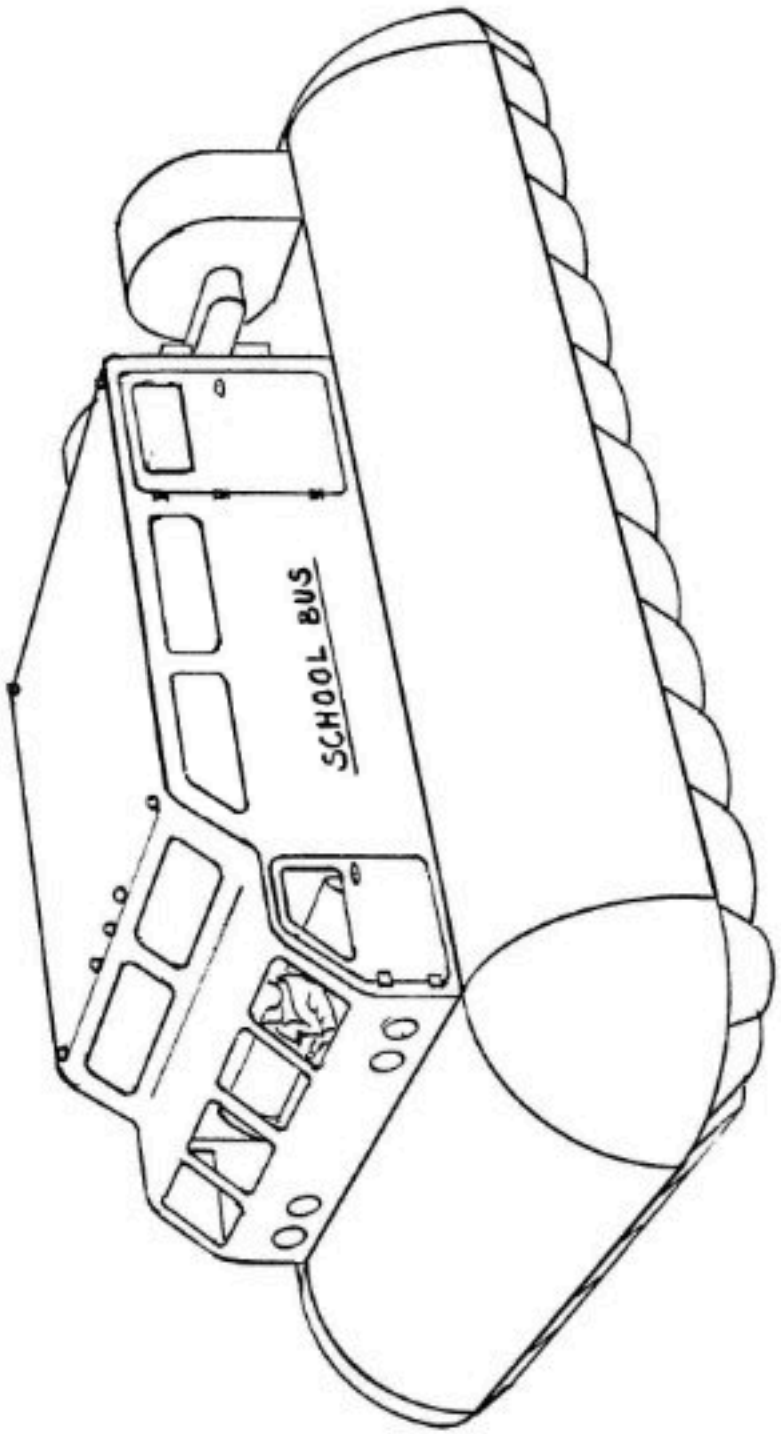


FIGURE 15 - ART-1 General Concept

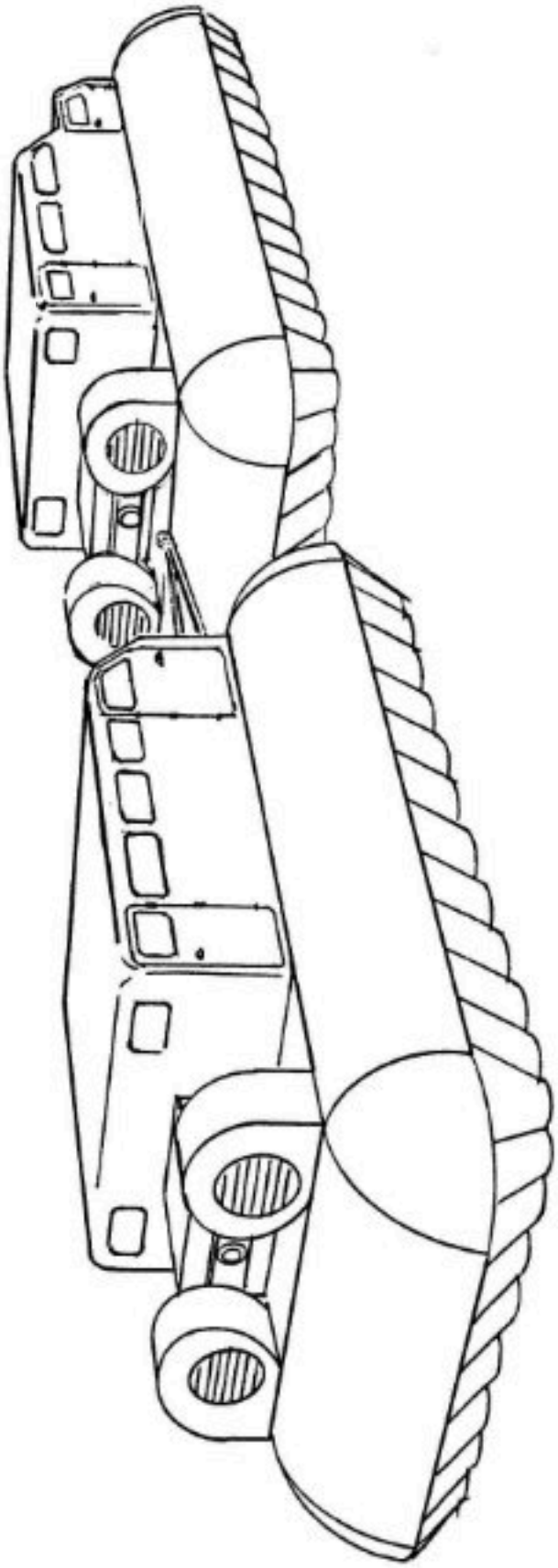


FIGURE 16 - ART-1 Tractor-Trailer

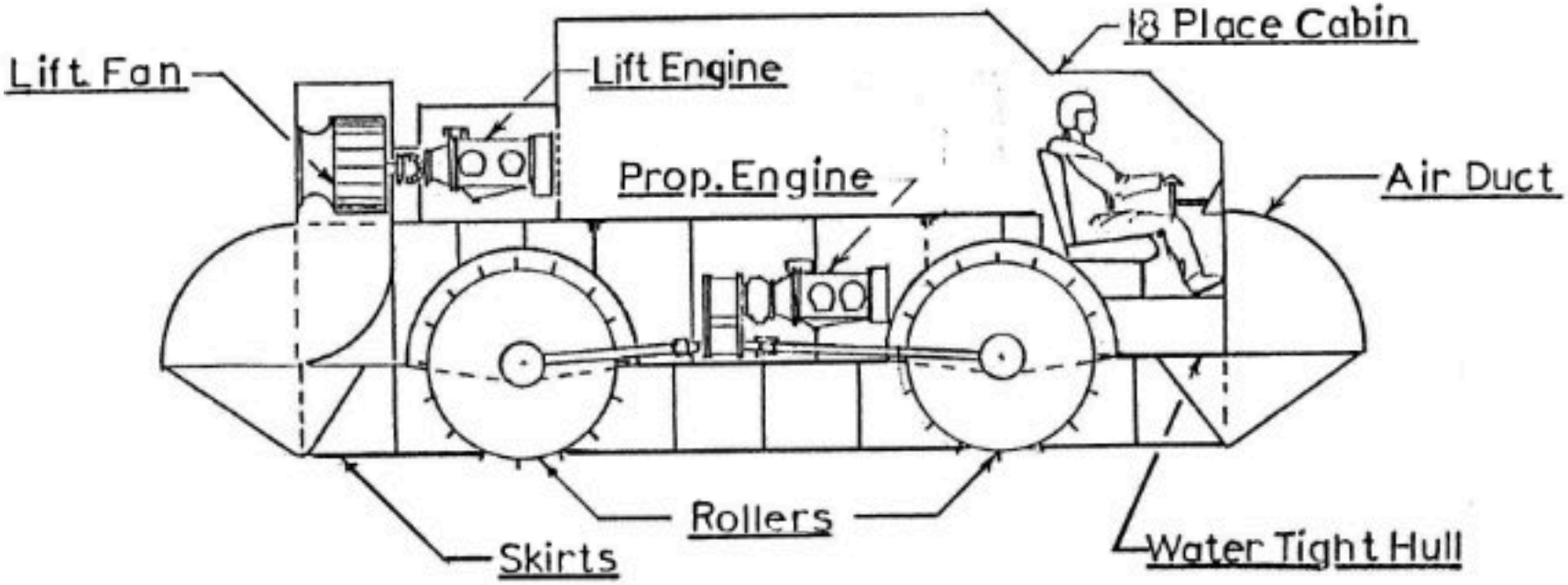


FIGURE 17 - ART-1 Inboard Profile (ACV)

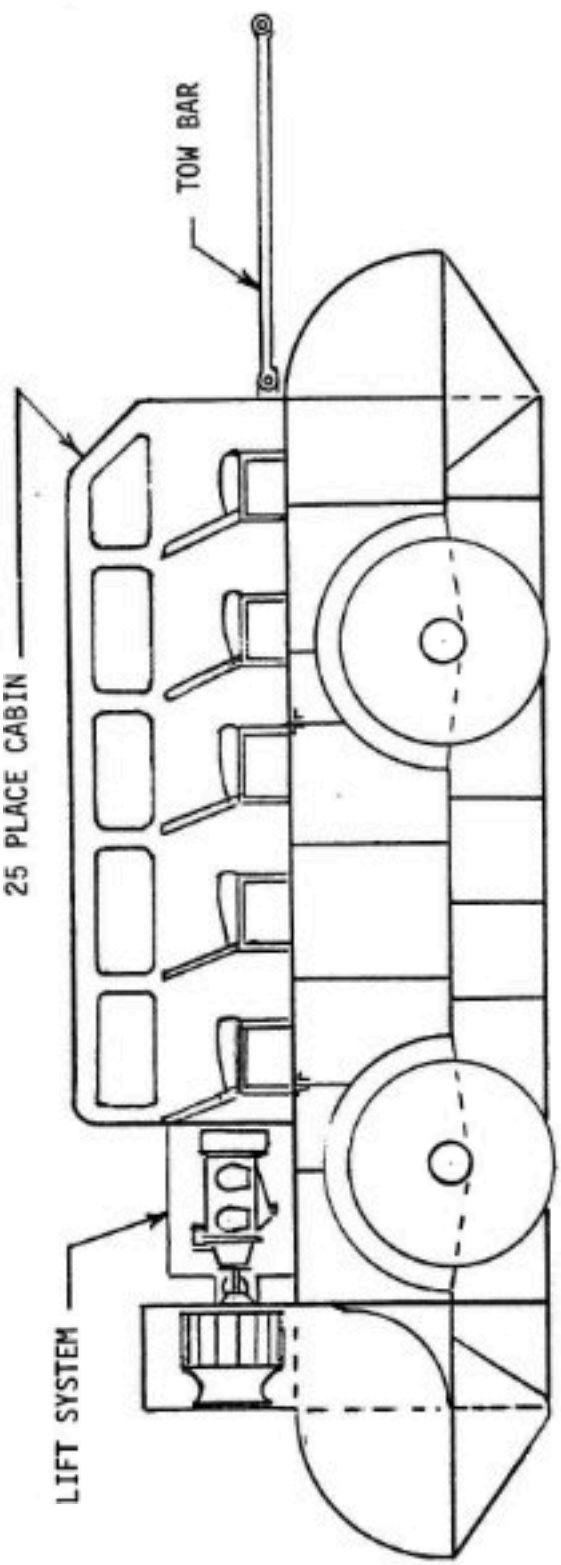


FIGURE 18 - ART-1 Inboard Profile (Trailer)

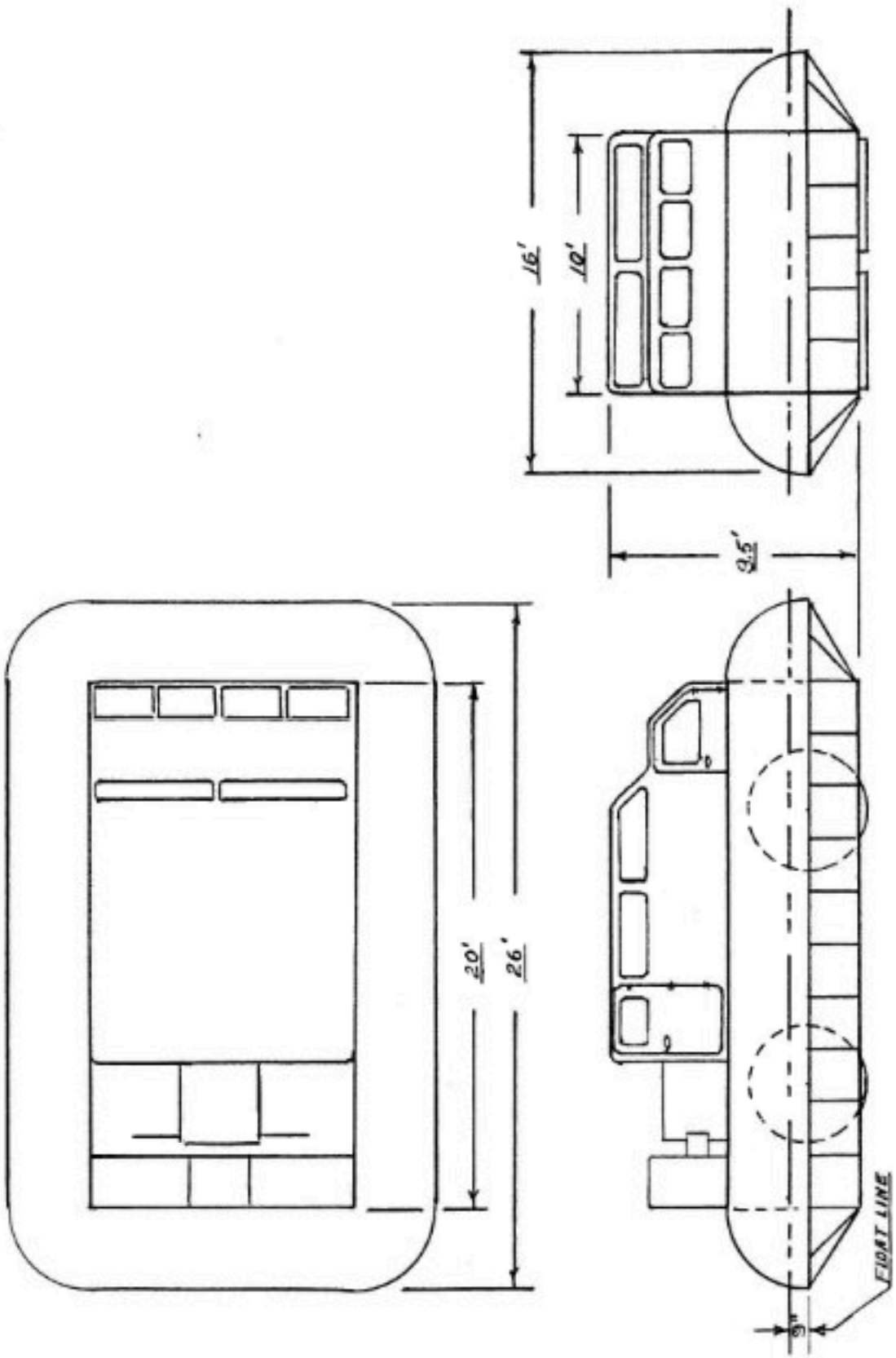


FIGURE 19 - ART-1 Three-View

Weights (Trailer):	Gross Weight	8,425 lbs.
	Payload	2,812 lbs.
	Fuel	312 lbs. (45 gals.)
	Vehicle (empty)	4,988 lbs.
Engines (Air Cooled):	Lift	65 hp.
	Propulsion	65 hp (tractor only)
Velocity (estimate):	Hard Ground	40 knots (25 knots with trailer)
	Water (on-cushion)	35 knots (20 knots with trailer)
Maximum Range (estimate):	Hard Ground or Ice (off-cushion)	500 mi. (300 miles with trailer)
	Water (on cushion)	225 mi. (100 miles with trailer)
Hard Structure Draft in Water:	nine inches	

HULL STRUCTURE

Since the ART-1 is expected to traverse both fresh and sea water in the Arctic, the structure consists of welded marine aluminum alloys. The structural arrangement comprises two watertight, compartmented side hulls supporting a center deck section. The center deck is a compartmented box-beam structure enclosing the propulsion engine space and supporting the passenger deck. The side hulls and center deck are completely watertight and contain sufficient buoyancy to provide full flotation of the loaded vehicle. Fuel tanks are integral with the hull. The cross-sectional view shown in Figure 17 indicates the machinery arrangement with the propulsion engine and gearbox between the decks and the lift engine and fans at the stern. With this arrangement, the craft c.g. location stays more or less constant with varying cargo loads and fuel usage.

PROPULSION SYSTEM

Propulsion is provided by four low pressure tires mounted on standard Volkswagen differentials with shortened axles. The driveline will be driven through a reduction gearbox by a 65 hp Volkswagen bus engine. When operating on-cushion, the engine will operate at increased inlet air pressure provided by one lift fan. This size of craft is designed with four foot diameter rollers and thus would be capable of clearing two foot obstacles.

The Volkswagen engines are air cooled, eliminating radiators, and are proven engines in full production in many countries. These engines with

a normal rating of over 65 hp are in use in many off-road vehicles such as snowmobiles and dune buggies, as well as industrial applications.

The reduction gearbox from the engine to the propulsion shafts will use available gear ratios.

As in the other vehicles, rollers are the means of support on hard ground or ice and are the propulsors of the vehicle under all conditions. Again, the manufacture of the rollers is similar to that of low pressure tires (like the Rolligon-type) except that the tire pressures used are much lower (less than half).

LIFT SYSTEM

The lift system consists of two centrifugal fans driven through a right-angle bevel gearbox by a 65 hp Volkswagen engine. The lift fans shown are the British Rotafoil fan of two feet diameter. The skirts consist of a loop (the upper semi-circular duct) and finger cells. The air exhausting from the lift fans is fed into the loop which distributes air around the periphery of the vehicle. Air then passes through holes in the loop down into the cells and fills the air cushion space, lifting the vehicle.

PERFORMANCE OVER ICE OR HARD GROUND

Performance plots similar to the ART-40 and ART-10 (see Figure 20) are shown for level ground with no wind. The ART-1 can achieve between 40 and 50 knots at 65 hp, as shown by the lowest curve on the chart. As wind and slope conditions are added, the drag increases and horsepower requirements go up.

The force required for the rollers to break away on ice is shown for the vehicle at 8,425 lb. gross weight. It can be seen that application of greater than 30 hp at 15 knots will cause the rollers to break away and stop on ice. However, even on a 5% slope with no wind, a speed of greater than 20 knots can be maintained.

PERFORMANCE OVER WATER

The drag of the ART-1 while operating over water has been plotted for calm water operation (see Figure 21). The thrust provided by the rollers at various roller rpm's is also shown and the intersection of the thrust and drag curve indicates the speed which can be achieved. Thus, at 250 rpm, the ART-1 can achieve 28 knots in calm water and at 300 rpm, it can achieve 37 knots. The propulsion engine horsepower requirements are also shown on the plot. The Volkswagen engine is capable of a steady output of 65 horsepower if required. It is extremely difficult to estimate the performance of the tractor-trailer combination over water,

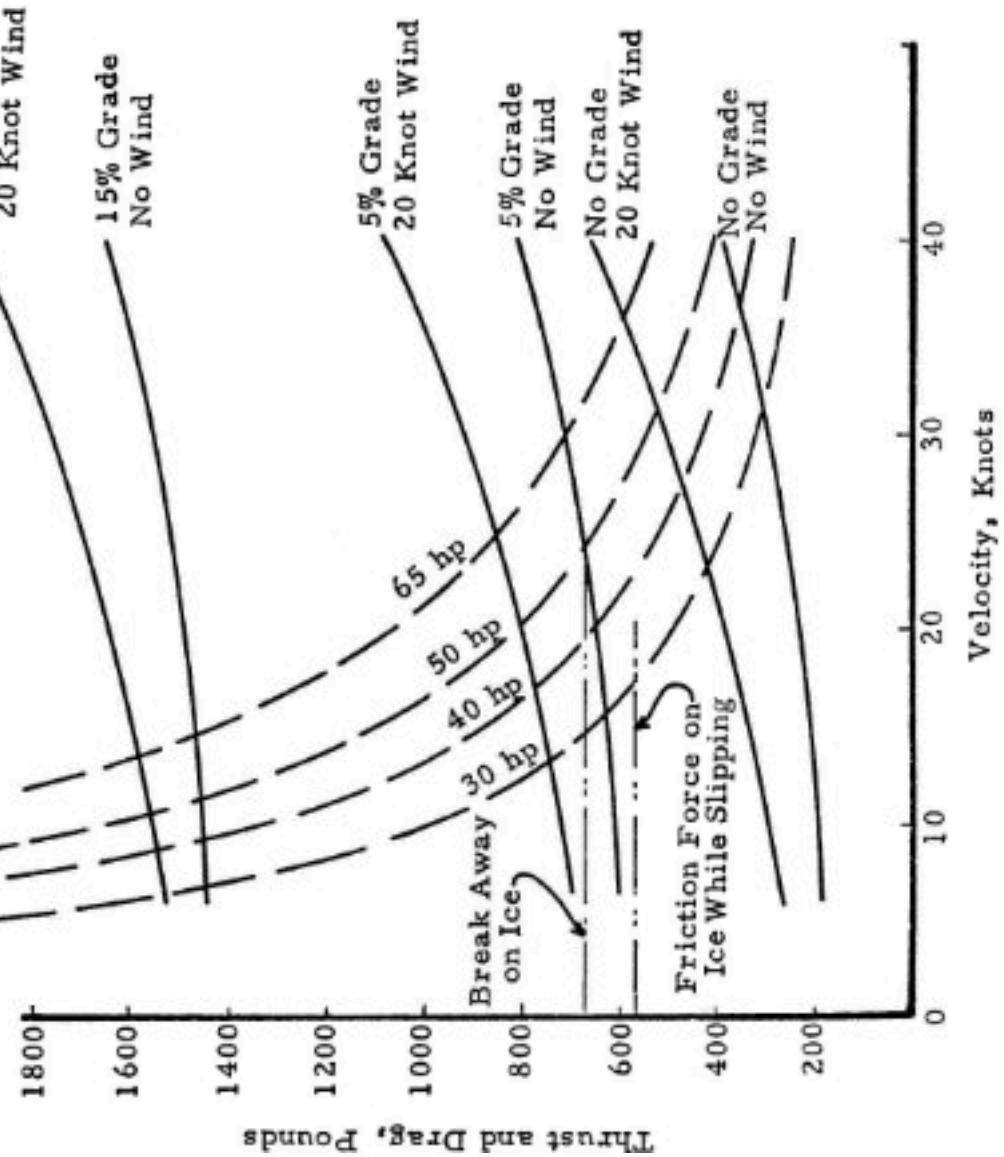


FIGURE 20 - ART-1 Performance over Hard Ground

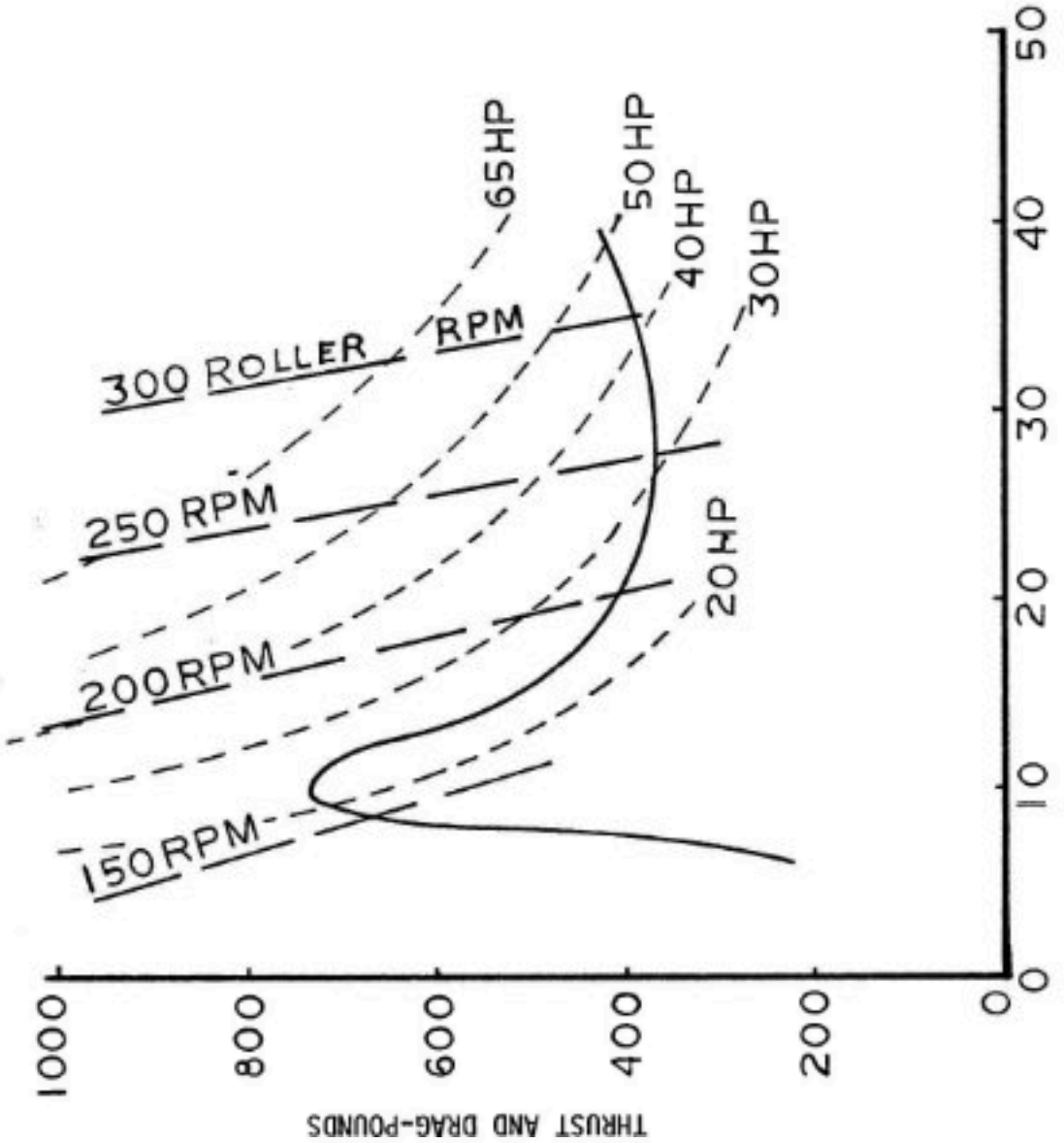


FIGURE 21 - ART-1 Performance Over Water

since no data exists for the interference effects of two cushions in tandem. Consequently, a tractor-trailer speed estimate of 20 mph is based upon establishing that speed over land and entering the water above craft hump speed.

COST OF OPERATION

Presentation of operational cost data is risky business, since ground rules tend to vary with application, terrain, locale, cargo, union rules, utilization rates, and so forth. To put things on a common ground, the Alaskan locale was chosen with fuel rates and crew rates corresponding to the "North Slope Operations". Hence, no values should be taken as absolute, but rather as relative rates as affected by vehicle size. As one expects, the larger the vehicle, the lower cost per ton-mile is achieved and, conversely, the cost per hour of craft operation tends to vary directly with its size. Cost per hour of operation based upon an annual utilization of 2000 hours with crew is as follows:

ART-1	$ 40
ART-1, plus trailer	46
ART-10	174
ART-40	938
ART-100*	1,388

Figure 22 shows plots of cost per ton-mile for each of the craft for different utilization hours and the values shown represent a 65% load factor. The ART-100 is an extrapolated estimate. The friction and power data are based on operation with 70% frozen or hard ground and 30% soft tundra or overwater operation.

The one SRN-4 point is based on experienced operation on the English Channel, but corrected for Alaskan crew and fuel costs. A final caution on these numbers is that inflation rates will probably shift them upward for the worse.

CONCLUSIONS

The lesson or experience we have gained from these marketing exercises indicates the need for considerable probing and talk back and forth to understand both the users' requirements and his economic constraints. The costs of developing a wide variety of vehicles for very special applications is prohibitive, unless a large market can be foreseen. Entrenched operators of existing but limited use equipment is a further deterent to marketing. Great care must be taken to avoid these conflicts of interest by explaining the economics, as well as avoiding the notion that the ACV will either obsolete his existing equipment or put him out of business. Often, it can be shown that he himself will benefit by becoming the operator of the ACV's as a parallel or back-up to his current business by expanding his capabilities.

*NOTE: Detail costs on the ART-100 were not calculated because of lack of design detail. However, the estimated data presented seems reasonably in keeping with the other size craft.

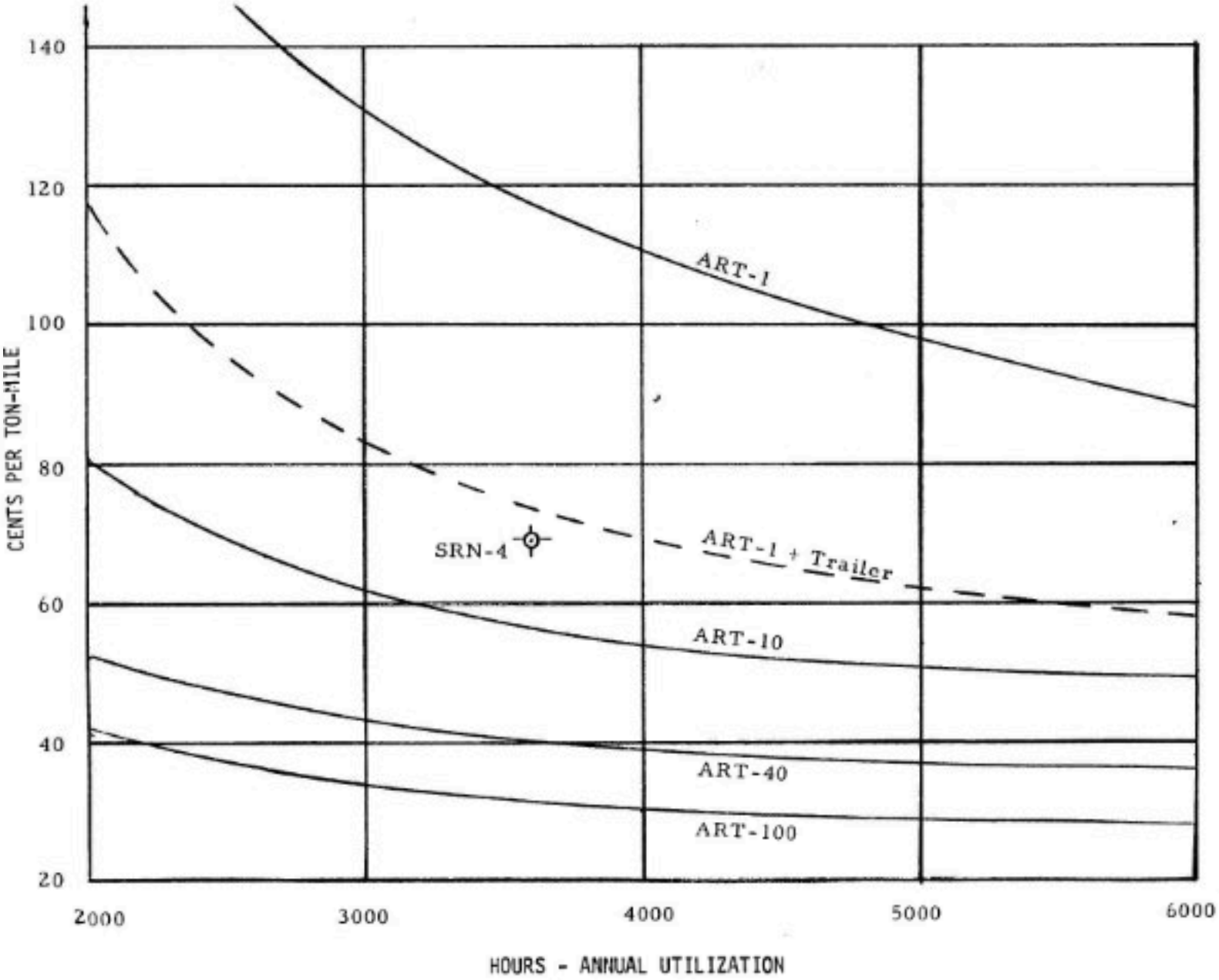


FIGURE 22 - ART Operational Costs

THE AMPHIBIOUS AIR CUSHION VEHICLE "NORTH TO THE FUTURE"

PART I

CAN ACV'S SOLVE ALASKA'S TRANSPORTATION DILEMMA

Mr. Jimmie Sober
Manager, New Project Planning
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Department of Education
State of Alaska

INTRODUCTION

The region above 60° north latitude is a vast hostile area of some 12 million square miles that includes the Arctic Ocean and her seas, much of Canada, Iceland, Norway, Sweden, Finland, and Russia, plus Greenland and Alaska. Despite the isolation and expanse of the region, development has progressed actively and purposefully, characterized by substantial settlement and growth. Such developments have necessitated the improvement and institution of numerous transportation systems, often adapted to meet the unique conditions inherent in the northern environment. One such system frequently under serious consideration is the amphibious air cushion vehicle.

Since 1963, the amphibious air cushion vehicle has operated in all of these northern areas except Iceland. The air cushion vehicle has been demonstrated. It has accomplished prodigious tasks and has proven time and time again that the concept is viable. Yet, while progress has been made, air cushion vehicles are not yet established. Business reasons and the "don't try it if it's not a sure thing" syndrome have dampened the pioneering spirit. Cost of development has become increasingly dependent upon government subsidies. Many would have us quit. "There is no need for air cushion vehicles", they say. However, if early pioneers had taken such advice, there would have been no steamship or airplane. Further complicating matters, we are more than ever plagued by expanding bureaucracy, plus real and imagined environmental concerns. As a result of the oil discoveries near Prudhoe Bay in 1968, the state has begun a phenomenal metamorphosis. Alaska's "old timers", who came to the state to enjoy its quiet, unspoiled beauty and lack of business competition, are becoming a vanishing breed. The state's population has jumped 50% in the last ten years, and newcomers, many of whom do not share traditional Alaskan viewpoints, may soon control a substantial share of economic and political power.

Alaska's state budget has also experienced substantial growth. In fiscal 1968, the state budgeted $154 million to run its business. During fiscal 1978, Alaska will spend nearly $1.1 billion.

At this time, the environmentalists, who favor maintaining the state's pristine wilderness, and business and labor, who favor business development, are locked in legislative combat. The environmentalists support U.S. House Bill 39, which sets aside 115 million acres as wilderness. This Bill would allow no exploration or industrialization of that area. The environmentalists believe that the state would generate sufficient revenue from tourism to these wilderness areas to continue future development. Business and labor leaders generally prefer development of the state's resources of timber, mining, oil and gas. They believe that U.S. House Bill 39 would prevent such development.

Meanwhile, the state's government is promoting a less restrictive bill in Congress. This Bill proposes to designate 80 million acres for distribution among four land management systems, and would allow for some development of parts of the 80 million acres not designated as wilderness.

In any event, the state is growing, and since government is responsible for the social and economic welfare of her citizens, new and improved state transportation systems undoubtedly will play a major role in meeting this requirement. This treatise describes a strong possibility for the amphibious air cushion vehicle as we look to the north for our future. We briefly comment upon the state of Alaska, some political and economic considerations, and the current transportation system. Subsequently, we identify a specific region, discuss environmental, political, and economic constraints, and hopefully generate some food for thought.

THE STATE

Alaska, the largest state in the union, encompasses an area of 375 million acres, or 586,412 square miles. This is nearly equal to the combined areas of the states of Washington, Oregon, California and Texas. Alaska is roughly equivalent in size to the Canadian province of Quebec or the provinces of Alberta and British Columbia combined. Alaska has more than twice the coastline of "The Lower 48". Its industries, other than government, which is its largest and furnishes employment for 40% of her workers, are fishing, oil and gas, lumber, mining, services and tourism. As large as it may be in size, Alaska's population of less than 400,000 - of which approximately 55,000 are Eskimo, Aleuts and Indians - barely surpasses that of the cities of Oakland, California or Ottawa, Canada. Of that total population, nearly half live within Greater Anchorage.

Alaska's transportation system consists of a state operated 2,200 mile ocean ferry system and the federally operated Alaska railroad extending some 400 miles from Seward to Fairbanks. The state has 500 airports and airfields, many of which are small, unpaved, and unable to accommodate aircraft during inclement weather. The state road network consists of 7,000 miles, mostly gravel or poorly paved, with less than

2,000 miles maintained year round. The most significant transportation advances in the state during the past ten years have been the 360-mile gravel road from the Yukon River to Prudhoe Bay and the paved 400-mile Parks Highway from Anchorage to Fairbanks.

THE REGION

Of the transportation critical areas in the state, the most suitable area for initial operation of the amphibious air cushion vehicle is located in that part of southwest Alaska drained by the lower Yukon and Kuskokwim rivers referred to as the Yukon-Kuskokwim Delta Region. The region consists of approximately 90,000 square miles, roughly equivalent in size to the states of Wyoming or Oregon, and is populated by more than 60 communities nearly isolated from the major trade centers of Anchorage and Fairbanks.

Most of this area is tundra and either water covered or so wet that surface travel by other than small boats is impractical during the summer months. Vegetation is rather sparse, and tree growth within 100 miles of the Bering seacoast is insignificant.

Natural resources within this region have not been exploited and at present produce only about 10 million dollars in gross income annually. About two-thirds of this amount is derived from commercial salmon fishing with the balance from the fur trapping and from small seasonal and periodic mining operations for gold, mercury, and platinum. Oil and gas exploration is playing a significantly larger part in the economic growth of the area, spurred by selection of large tracts of potential oil and gas bearing lands by the Alaska Native Regional and Business Corporations of the area under the Alaskan Native Claims Settlement Act of 1971.

Approximately 15,000 people live in this region, 90% of whom are native Alaskan Eskimos. About 3,000 people reside in the city of Bethel, and the remainder are clustered in the 60-odd isolated villages with populations ranging between 25 and 600 persons. The majority of the native Alaskans who reside in this region subsist by traditional hunting, fishing and gathering activities.

None of the villages of this region are connected by roads, and the intraregional transportation system for the movement of freight, mail and people is inadequate. Travel between villages is almost entirely by small aircraft and snowmobile except during the summer when heavy bulky freight is transported by barge and some personal travel is by small boat. Even with aircraft (jet aircraft serve three villages - Bethel, Aniak and St. Mary's), periods of up to three weeks with no service at all are not uncommon.

Almost every family within the region owns a small outboard motor boat which is used almost daily during the summer months. However, travel

by water during summer months is inhibited by very shallow water conditions, fluctuating tides, changing river channels, and frequent storms. Oceangoing barges are only able to off-load directly to shore at four or five locations.

Winter travel over snow and ice is increasing. Nearly every family in the region also has a snow machine which, while less than satisfactory, is used for personal travel and personal freight hauling over distances frequently as great as 60 or 80 miles. Travel by truck or car over frozen river ice is also increasing, and the city of Bethel now attempts to maintain about 100 miles of ice roads on the Kuskokwim each winter. The city receives about $900 per mile per year from the state to maintain these ice roads.

Oceangoing barges connect Bethel with Seattle five or six times each summer and three or four other locations may also receive freight direct from Seattle each year. But low volume, difficult docking, and weather conditions keep freight rates high. Smaller barges distribute freight from Bethel to the other villages, and some freight comes into the region on small barges from St. Michael (on Norton Sound) and from the railhead of Fairbanks/Nenana connected to the upper Yukon River by the Tanana River.

Studies sponsored by the U.S. Economic Development Administration have shown that direct and indirect transportation costs of goods are the single largest expenditure for residents of this region. They account for more than 50% of personal living expenses in Bethel and as much as 70% in many of the region's smaller villages.

ECONOMICAL ENVIRONMENTAL REGULATORY AND POLITICAL CONSTRAINTS

It is apparent that the existing transportation system in the Yukon-Kuskokwim Delta is inadequate as it now exists. The system does not meet the needs of the people and places great psychological and economic burdens upon them.

New alternatives are desperately needed and still must be compatible with the environmental, economic and demographic considerations of the region.

Certainly, roads are feasible, but muskeg and underlying permafrost make construction difficult and expensive at a cost of over one million dollars a mile and, because of extreme temperature variations, such roads are very expensive to maintain. Additionally, during the winter months, when the ground is frozen, roads are not always necessary because tracked and large wheeled vehicles, operating with very low ground pressure, can easily traverse much of the land mass, albeit somewhat slowly. In the summer, however, some of these vehicles have done considerable and irreparable damage to the terrain when regularly travelled routes are established. Therefore, from May through October most of these vehicles are restricted from operation.

Aircraft are in use in the area and, including helicopters, generally can reach all of the sixty villages some of the time. Forty of the villages presently have airports, but only ten are constructed for year round use, weather permitting.

The problems with the existing air transportation system - low reliability, high cost and inconvenience - are not necessarily the fault of the aircraft. Many of the airports are merely lakes or rivers used by small, low-payload float or ski planes. Those land airfields which have been constructed are sometimes several miles from the villages, because of terrain, making it difficult to off-load and transport goods and passengers to the village. Furthermore, inclement weather reduces scheduled reliability because most airports do not have all-weather capability. Cost of construction and maintenance of small village airports are on a par with bush roads, and the cost to upgrade them to an all-weather capability adds greatly to the expense.

On the marine side, although the Delta is nearly surrounded by water, water transportation still is difficult for a variety of reasons. During the winter months, ice restricts boat and barge traffic, although the frozen rivers can be used by wheeled and tracked vehicles. The coastal waters are extremely shallow and tidal which, along with National Wildlife Refuges in the area, restrict considerably the building of docking facilities. Ice and tidal actions also substantially increase the cost of constructing docking facilities. In the summer the river's depth is dependent on the amount of snow melt or rainfall in the mountains. In general, the rivers are meandering, uncharted, debris-strewn and, therefore, difficult to navigate reliably and safely.

In spite of these difficulties, air cushion vehicle technology is available to solve these unusual problems. Clearly the conventional and existing systems are inadequate and could be improved. However, contemporary technology for building roads, improving airports, dredging channels, and building docks is not practical, because these facilities cannot be maintained seasonally. The problem is one of costs. Economics will determine which system, or systems, are able to provide a certain level of service when given certain assumptions about operational requirements, system performance, and system cost. Additionally, the most economical solution may not be consistent with the need for ecological or environmental safeguards, and therefore, it will likely be necessary to put a price on certain circumstances of ecological and environmental protection.

Even in situations where the ecological and environmental threat can be minimized, along with the cost, it is still not always true that the value of solving the problem will be considered sufficient to justify the expense. For instance, assume that the villages of the Yukon-Kuskokwim Delta require the construction of a minimum of 1,000 miles of roadway for proper service. The construction alone would have a first cost well in excess of one billion dollars. Add to this cost the maintenance costs of over 12 million dollars per year and the total costs become a significant amount of money. This also does not completely

solve the problem. While people have psychologically and socially benefitted, they have not yet benefitted economically. They do not have easy access to the urban areas of Alaska or the United States so as to reduce the burden of costs for goods delivered.

We can go on to discuss the cost of year around supply by sea and air. To increase the frequency and quantity of goods furnished using these systems, would require constant dredging of channels to newly constructed and maintained ports and ice breakers on station at Seward or Kodiak, Alaska, to accompany barge traffic during the winter months.

An improved air transportation system would require building and maintaining longer runways for larger aircraft. To keep the system open year around for all weather use would require installation of instrument landing systems and manned control towers.

Either of these two systems could be improved for 200 to 300 million dollars each, with a cost of maintenance and rapair exceeding $25 million per year for the marine system and approximately $35 million for the upkeep of the airport system.

Ideally, all three systems of road, sea and air eventually will be developed, whether it be by the government alone or in conjunction with industry. However, the longer the delay, the greater the expense. Yet despite the discussed modes of land, sea and air, numerous considerations still suggest that a form of transportation outside of the traditional modes be employed in the remote regions of the Alaska Delta. A unique transportation mode for a unique environment and, also, an alternative development scheme perhaps more acceptable to those directly affected. In the meantime, the amphibious air cushion vehicle is an obvious solution.

What are the constraints affecting air cushion vehicle operation in Southwest Alaska and can they be resolved. For purposes of understanding, the amphibious air cushion vehicle under consideration should be as large and as capable as the SRN5/SK5. Anything presently in existence which is smaller, unless individually utilized, would be incapable of all but the most limited practical use.

The air cushion vehicle is one of the newest vehicles to enter the transportation scene. It has attracted considerable attention because of its unique ability to travel at high speed over a variety of difficult surfaces, or a combination of surfaces, whose load bearing properties or draft do not permit the use of conventional ground or water vehicles. Unlike all other ground or water supported vehicles, the air cushion vehicle requires no surface contact for traction and is able to move freely on any relatively level surface while supported on a self-generated cushion of air. This capability offers a solution to a majority of transportation problems.

The previously described remote relatively undeveloped Yukon-Kuskokwim tundra, surrounded by water and nearly without normal communication and transport facilities, was created just for the amphibious air cushion vehicle. There is no doubt that the vehicle has high utility in this environment.

The greatest obstacles to air cushion vehicle use in the region currently resolve themselves into six possible major constraints. They are:

- technical
- regulatory
- economic
- environmental
- ecological
- political

From the technical standpoint, there has been sufficient knowledge gained through experience to allow a manufacturer to proceed and produce an amphibious air cushion vehicle for use in the area north of 60, including the Yukon-Kuskokwim area. The primary problems to accomplishing the technical requirements and producing the vehicle may be poor internal organization and over-engineering with some companies.

On the regulatory side of the house, we have both under-regulation and over or misdirected regulation of the industry, accompanied by numerous legal perplexities. Concerning under-regulation, in the United States, operation of the air cushion vehicle over water is regulated by the United States Coast Guard. The Coast Guard first inherited its responsibilities as a result of a commercial demonstration of air cushion vehicles in a transportation mode. The demonstration took place in San Francisco from 1964 through 1966, sponsored by Housing and Urban Development. Because the vehicle operated primarily over water and was commercially applied, the Coast Guard was assumed, at the time, to be the logical agency. In addition to the normal "rules of the road", the vehicle was initially burdened with limitations to operation, which restricted its capability, but which were easy to comprehend, considering no one understood the vehicle.

Today, the Coast Guard is still the responsible agency for regulation of air cushion vehicles and to its credit, and partially due to the lack of commercial air cushion vehicle activity, has done nothing further toward regulating air cushion vehicles, choosing to wait and watch for further developments.

As concerns over-regulation, or what might be called misdirected regulation, the "Jones Act" becomes a primary obstacle. Originally designed to protect the American shipbuilding industry as a form of "Cabotage legislation", in 1969 the Jones Act was administratively applied to prohibit the use of foreign built or registered air cushion vehicles in domestic commercial American trade. Since then, the problem has only grown, much to the detriment of the industry's prospects. Until active steps are taken to find and augment solutions to the Act's effects, much of the American air cushion vehicle industry is faced with stagnation. For further elaboration on the substance and implications of the Jones Act, and other legal constraints to the successful deployment of air cushion

vehicles in Alaska, the reader is directed to the companion article, ACV's, Alaska and the Law, which is Part II of this paper.

Economically, the major constraint is under-capitalization, both from the manufacturer and from the user's position. It is a sort of a "Catch 22" where the manufacturer believes that the needs to have a 100% sure fire requirement backed up by the user's money before he will risk expenditures for production. On the other hand, the user, before he buys a product, particularly one as expensive as the air cushion vehicle, wants to at least look it over and "kick the tires".

Cost of start-up, other than the vehicles, and running the system is also a constraint and must be seriously considered in planning for an operation.

Viewing the environment, there is really no great constraint to the operation of the air cushion vehicle in the region. Certainly, it is an environment of extremes, but the air cushion has been there before and performed well. If it failed, in any sense, it was because we did not plan properly or furnish the vehicle with the minimum of support needed to make it succeed. In fact, as we have said before, the undeveloped environment of the Alaska Delta is more ideal for an air cushion vehicle than any other vehicle, or combination of vehicles, in terms of all-around service to the area as it presently exists.

Ecologically the conservationists had previously set aside by law, over one-fourth of the Delta Region as National Wildlife Refuges. Present plans incorporated in House Bill 39 would set aside another one-third of the Region. In any event, House Bill 39, if passed, could impose a constraint on more random operation of the air cushion vehicle. It is not a serious constraint, however, as it can reasonably be worked around to the satisfaction of all parties.

From the political standpoint and the producers side, we are today constrained by less aggressive executive management, who themselves have great responsibilities to their board of directors and stockholders, tight money, and fear the risk of unorthodox approaches in the pioneer spirit. Today life is very difficult, and the security of the sure thing may be a much easier road to take.

In the State of Alaska we must contend with the "it wasn't made here" syndrome and businessmen who fear competition. They prefer the status quo and are only interested in change when it benefits them personally.

From a gross standpoint we have now identified many of the real or imagined constraints encountered towards implementing an improved mode of transportation within the area. How industry and the state propose to accommodate these constraints to alternate solutions and improve the transportation system within the state is yet a matter of conjecture.

CONCLUSION

The environmental, social, and economic conditions in Alaska clearly indicate the requirement for a unique transportation mode that is acceptable to the people and compatible with existing systems and the ecology.

One which is particularly suited to the state, simply by process of elimination, is the air cushion vehicle. Certainly, no other method offers a more economical answer to the dilemma.

Air cushion vehicles are here and established operations exist. Many tons of cargo and millions of passengers have been carried safely and reliably to their points of disembarkation. We know what the air cushion vehicle can do and what its limitations and constraints are. There is no technical deterrent to their use in the area.

The biggest problems seem to be that there are few crafts available for the latent but wide open market which exists. Also, economically, perhaps some type of subsidy is indicated as typified by airlines, ships, ferries, buses and railroads.

Finally, it is obvious to the authors that an air cushion vehicle transportation system for Alaska must be seriously considered and actively pursued in the same type of pioneering spirit for which Alaskans are known. The alternative is continued stagnation for the industry and, for the State, deprivation of reasonable, economically feasible transportation.

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THE AMPHIBIOUS AIR CUSHION VEHICLE "NORTH TO THE FUTURE"

PART II

ACVs, ALASKA AND THE LAW

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The legal questions surrounding the introduction of hovercraft into Alaska on a commercial basis are broad and, as yet, largely unanswered. Although some attempts have been made at present to introduce the air cushion vehicle (ACV) into the State as a commercial entity, progress to date has been limited and, due to a multiplicity of reasons, successes also limited. These limitations have not been due, for the most part, to any technical deficiencies or problems with the vehicles but, rather, to numerous political and legal obstacles attendant with a new and relatively unknown transportation system in the United States. Faced with a substantial question concerning the future role of ACVs in the United States' transportation scheme, most political and legal units have opted for a conservative approach to the problem. As a result, few, if any, legal questions regarding hovercraft have been definitively answered. Moreover, of those questions which have been answered, the answers have been largely unsatisfactory and rigidly structured in an often frustrating attempt to fix a new and innovative development into a generally non-applicable, contemporary framework.

Of the legal questions most prevalent in the ACV field in the United States and, more specifically, Alaska, future operators are faced with largely unanswered imponderables including the Jones Act, environmental obstacles, regulating commissions, operating restrictions, land use permits, and, depending on area staffing, customs and immigration. These are the main areas, but numerous other considerations also exist and must be considered in turn. However, for the purpose of this investigation, this paper will confine itself to a brief outline of the six major areas outlined above.

THE JONES ACT

Substantive Considerations

The Jones Act, by far, is the greatest obstacle to the immediate initiation of successful commercial ACV operations in the United States. And, with one exception, Alaska is no exception in this area. This exception

is the Yukon River, and will be discussed shortly.

For an extensive discussion of the substance of the Jones Act, the reader is directed to an article written by the author appearing in the July 1976, issue of Hovering Craft and Hydrofoil, entitled: "Dear Mr. Jones, et al: A Hovercraft is a Hovercraft". This article, although relatively extensive in nature, deals only with the substantive aspects of what the Act is and its general effects on the industry. A procedural account of how to deal with the Act has yet to appear, although some discussion will be had in the present paper.

By way of substance, the common name "Jones Act" relative to ACVs is not the "Jones Act" which relates to injured seamen. The Jones Act affecting injuries at sea is actually a much more prevalent act, and has been the subject of numerous cases and articles. Nevertheless, Senator Wesley L. Jones, of the State of Washington, sponsored both acts, and, for the purpose of hovercraft operators and shipbuilders, the act of most concern is actually the lesser of the two "Jones Acts". This Act, first enacted in 1920 as part of the Merchant Marine Act of 1920, prohibits the commercial operation of vessels directly between points in the United States if the vessels have not been constructed within the United States. A form of cabotage legislation with beginnings in the mid-1800's, the Act serves as the "Buy-American" Act for the shipbuilding industry.

The "Jones Act" combines to produce its effect of a total prohibition through the interrelation of two different statutory enactments. 46 U.S.C. 883 prohibits the carriage of cargo, and may be read in toto without the aid of any companion statutes. Passenger carriage prohibitions, however, come into being only upon the interpretation and application of two statutes, 46 U.S.C. 11 and 46 U.S.C. 289. When read together, it becomes apparent that passenger carriage in foreign-built vessels is also prescribed.

On its face, the Jones Act does not apply to hovercraft, nor is there any rational basis why the Act should have any application to ACVs, especially when of the amphibious mode. Nevertheless, in 1969, the Treasury Dept. rendered a set of administrative determinations later resulting in a formal Treasury Dept. Decision on October 13th 1971, which placed all types of foreign-built ACVs within the penumbra of the Jones Act. This decision, T.D. 71-264(2), is short, but brutal, and has done much to stagnate and destroy any growth of the ACV operating industry within the United States:

> "Use of foreign-built hovercraft in trade. Use of a foreign-built hovercraft entirely over land not prohibited by coastwise laws ..... Hovercraft, generally known as 'air-cushion vehicles' or 'ground or surface effect machines', when used as a means of transportation of merchandise or passengers or both on water or in proximity to and dependent upon water as the supporting surface of the machine or its air cushion are 'vessels'.

> "Therefore, foreign-built hovercraft so used are subject to the prohibitions of the coastwise laws. Merely incidental operation over land will not remove the transportation from the prohibition. However, use of such machines as a means of transportation in substantial operation over land is not prohibited by such laws. Bureau telegram dated September 17, 1969. (212)"

Since the rendering of the decision, ACV operations in the United States and Alaska have been limited, at best. Furthermore, prior to receiving operating approval, all water-associated operations outside of those limited to military exercises have had to undergo a lengthly and often confusing waiver process fraught with legalities and, undoubtedly, politics. Many decisions to employ ACVs have been abandoned as a result of the Act, and the massive problems it represents.

It seems only interesting to note, in passing, that the Act with respect to ACVs has at this time succeeded in destroying the very element it was designed to encourage. Originally, the Act had as its intent the fostering of the shipbuilding industry. However, before an industry may develop, a demand must first be created. By effectively excluding the bulk of hovercraft operations from the domestic transportation realm, the United States has stifled any considerations of demand and, concomittantly, the industry's growth in the United States itself.

Procedural Considerations

A number of approaches exist for working with the Jones Act. Among these avenues are compliance, waivers, exemptions, and legislative, administrative and judicial challenge.

Compliance with the Act is most advisable when considerations of proposed operations and economics permit. Without an elaboration at this time, suffice it to say that a realistic and careful interpretation of the Act might well serve to reveal that an operator may function without violating the Act, and consequently, without the need of securing waivers or other permits. In interpreting the Act, care must be taken to evaluate not only the Act itself, but the Treasury Dept. Decision 76-264(2), as well. Possibilities for compliance exist in both realms and should not be disregarded. An example of compliance would be among the most obvious: operations purely over land.

Waivers, on the other hand, are necessary when compliance is either not feasible or, at best, unlikely. A waiver of the Jones Act must emanate from the agency charged with enforcing the Act, in this case, United States Customs.

Note 1 preceeding the Shipping Code (46 U.S.C.) provides for both mandatory and discretionary waivers to the provisions of the Title depending

on the agency sponsoring the request. Hence, if the Dept. of Defense requests a waiver, such a request must be honored by Customs as mandatory in nature. For all other requesting agencies, the granting of permission is a discretionary act vested in the Customs Dept. It becomes apparent, then, that the best avenue to pursue in securing a waiver is through a request to the Dept. of Defense, the agency which carries mandatory power in this area. Finally, the substance of the waiver request and the determining factors utilized in reaching a decision vary from department to department and from case to case. Such is largely a matter of decision, determination, experience and guesswork.

Exemptions are blanket provisions whereas waivers are usually circumscribed in scope and duration. By other description, an exemption could be classified as a permanent waiver. By their nature, exemptions are much more difficult to obtain but, for the same reasons, are also much more desirable. To date, all exemptions to the Jones Act have taken the form of statutory amendments to the Act. An example of an exemption is the provision allowing freight traffic on the Yukon River until the completion of the Alaska Railroad. Although technically not permanent in nature, this provision still falls within the ambit of an exemption, being a semi-permanent blanket provision.

Exemptions may also take the form of private, as opposed to public legislation. Where public legislation has as its goal the benefit of a general, non-specified body of individuals (such as the Yukon River exemption), private legislation has a specific beneficiary in mind, and may be, additionally, of a more limited scope. Both still require passage by Congress. An example of a private legislative exemption to the Jones Act may be found in the permission given to the State of Alaska to operate the ferry Wickersham for a limited period of time in contravention to the Act.

Ultimately, challenge to the Jones Act will be in order. According to Mr. C. William Hart of the U.S. Customs Dept., Carriers Rulings Branch, the Jones Act as it relates to hovercraft has yet to meet any challenge, most operations being complacent to request waivers whenever possible. Moreover, few cases have been litigated over the Jones Act in other areas. As such, the Act is woefully in need of scrutiny. Challenge may be had either legislatively, judicially, or administratively.

Legislative challenge is the most reliable means of achieving a desired result. As discussed under exemptions, in effect, an amendment is introduced into Congress, passed, and the Act is altered to reflect the change. Unfortunately, all is not so simple despite the advantages of legislative challenges. The Jones Act still is an area of major concern and sanctity in the maritime circles and, accordingly, any challenge or threat to the perceived integrity of the Act generally is carefully evaluated and, usually, opposed by such major interests as shipbuilders, seamen's unions, and manufacturing states. Politics becomes an essential element in any proposal to change the Act. Again, it should be noted, however, that in addition to public legislation which would result in a

blanket amendment or exemption to the Act, there also is the realm of private, specialized legislation which might exempt special, particularized interests from the Act's operation. As stated before, this legislation, however, is also quite difficult to obtain and requires considerable persuasion.

Judicially, challenge to the Jones Act may be either by a request for a declaratory judgment as to the definitions or applicability of the Act, by appeal from a denied administrative permit application, or by taking the defense in an enforcement action brought by the Customs Dept. for violation of the Act. All methods are possible and, for the most part, equally feasible. Theoretically, however, a challenge to the Act might be best from the position of one accused of violating the Act. Standing to sue is apparent and, more importantly, the burden becomes the criminal element of "beyond a reasonable doubt" which falls upon the government. As such, it may well be that the defense position is the wisest means of launching the offense.

No matter what the method, United States operators still must contend first with the Jones Act up until such time as an acceptable American machine is built or the restrictions of the Act relative to hovercraft are lifted. Nevertheless, despite the operation of the Act, ACV operations in the United States still are not precluded, but only limited. Methods are available for coping with the Act, and any potential operator can be encouraged in that regard. Still, before embarking on any domestic United States operations, it is imperative that sufficient time and expertise be devoted to the Act in order to avoid future complications.

ENVIRONMENTAL OBSTACLES

Any operator contemplating operations in the United States must address a contemporary topic of increasing social importance: the environment. As an innovative development in the realm of off-road transportation, the ACV faces environmental obstacles, despite its generally heralded position as a pro-environmental device. Of primary concern to environmentalists, according to Mr. Bill Clithero, Acting Project Director, PET IV, of the U.S. Bureau of Land Management, Fairbanks, are two considerations which must be addressed.

The first consideration is the effect which the vehicle may have on the supporting surface for the air cushion. Specifically, concern has been devoted to the interaction between ACVs and the delicate arctic tundra. Although the general persuasion of the agency at this time appears to be to allow ACV use in the Arctic, no formal determination will be made until a formal application is pending, according to Mr. Clithero.

The second consideration concerns the effect of noise and movement upon wildlife in the affected areas. Although studies have shown that ACVs are generally tolerated by most animals, concern still exists on the part of agencies as to the effect of ACVs upon nesting fowl. This

concern is understandable, considering Alaska's position as a major United States nesting area for migratory fowl and, as such, the problem must be addressed by the industry. Ideally, a compromise between environmental needs and transportation demands might be achieved whereby both interests might be accommodated. Both sides appear willing, since the ACV does pose a much less drastic environmental alternative to more fundamental forms of transport. Still, only time, study and evaluation will tell.

Due to the limitations of the presentation, an indepth analysis of the precise environmental clearance procedures will not be attempted at this time. Suffice it to say, however, that six publics exist, all of which must be addressed: The federal government, the state government, the local government, the Alaskan natives, the private landowner, and the public generally. Normally, the public will always be a party, either directly via the media, special interest groups, and as concerned individuals, or indirectly via the representative governmental units of federal, state, and local rule. Obviously, substantial overlap exists. Furthermore, a substantial portion of the Alaskan public is represented by the various native associations, of which twelve profit corporations exist in Alaska.

Depending upon the funding, the nature of the operation and client, and the land to be traversed, one or all of the six aforementioned publics might need to be approached for environmental clearance. Specific environmental provisions for the federal government may be found generally in Title 42 of the U.S. Code, Sections 4321, et seq, as well as the administrative regulations enacted pursuant to the statutes available at 40 C.F.R., et seq. Alaska state environmental provisions may be found generally in Title 46 of the Alaska Statutes and Title 18 of the Alaska Administrative Code. With respect to the remaining four publics of local, native, private and public entities, the answer largely is found in the realm of explanation, understanding, and contractual permission. In many respects, the answer largely boils down to educating those affected as to the benefits of ACV operations as opposed to the perceived burdens.

LAND USE PERMITS

An area largely unaddressed at this time in the realm of the ACV relates to land use permits. Despite its amphibious capability, until recently, little problem has existed regarding the land use restrictions of ACVs, primarily because little use has been made of the overland capabilities to any widespread degree requiring extensive permission from landowners, and generally, it has been at the landowner's request that such overland use have been accomplished.

However, with the advent of more sophisticated ACVs capable of extensive overland travel, especially in arctic regions conducive to such travel, consideration now must be given to the implications of extensive, overland routing.

Both the Federal Constitution and the Alaska Constitution and the supportive and interpretive case law provide, essentially, that land may not be taken for public use without due process and just compensation. Moreover, the taking of land for private use, absent emergency circumstances, is absolutely prohibited and any attempt may constitute trespass, which is punishable both criminally and by civil compensatory and punitive damages. Accordingly, in the area of land use, the ACV question must be evaluated from two positions: that of the State and the operator (or the operatory under State charter), and that of the private individual as an operator.

In cases where the State is an operator, or where the individual is under contract to the State, the question of land utilization is simplified from the operator's perspective. The crossing of Federal or State lands presents little problem, although permits must be obtained, and such might be conditioned on compliance with other requirements such as the previously-discussed environment. When such operations cross non-governmental lands, however, more specific clearances should be obtained.

The necessary clearances may be obtained through two avenues. First, voluntary permission from the landowner may be sought, via a license, easement, or purchase of a fee simple estate along planned corridors. Much depends on the anticipated frequency of use and disruption to the landowner. Second, in situations of necessity, both the Federal and State governments and, to some extent, the local governments, may avail themselves to the power of eminent domain, or condemnation. Under specified procedures, private land may be taken for public uses, if statutory authority, necessity, and elements of just compensation are provided. As such, when routes are known and the public is the operator or direct beneficiary, it is likely that the necessary authorization for overland travel may be acquired.

When, however, the public is not a beneficiary or operator of ACVs, additional problems are raised. Absent express statutory condemnation provisions for private operation, which are unlikely, permission of the landowners must be obtained by the private operator. As discussed under the environment, supra, these landowners may be five in number: The federal government, the state government, the local government, the native interests, and the private landowners (the public, as an entity, finds its representation in one or all of the five groups). Absent permission, which might be conditioned on numerous unspecified factors depending on the landowner, the ACV operator is a trespasser. At this time, there is no solution to this problem when land operations are necessitated, absent diplomacy, expert negotiations, and flexibility of routes. Due to the possible problems with land use permits, if substantial difficulty is contemplated, the private ACV operator would be well advised to stick to navigable waterways, which, traditionally, lie in the public domain. Unfortunately, confinement to such waterways often raises another factor which must be addressed: The Jones Act.

ALASKA TRANSPORTATION COMMISSION

First created in 1966, the Alaska Transportation Commission (ATC) is charged with the certification, registration, and rate control of various transportation modes in Alaska. To date, only two ventures have been subject to ACV control: Skimmers, Inc., and Pacific Hovercraft, Inc. Both companies, which operated in Alaska on a limited basis, received ATC letters of authorization subject to insurance requirements and compliance with U.S. Coast Guard safety regulations. Both companies, furthermore, are now dormant, with no future operations anticipated.

In 1972, hearings were held in Anchorage on the classificaton of air-cushion vehicles, but no conclusions ever resulted, since the subsequent cessation of ACV activities in the State rendered the question largely moot.

According to Mr. Robert Casey, Executive Directory of the ATC, although the initial posture of the ATC was one of interest and regulation, a laissez-faire policy eventually was adopted whereby the only requirements set forth were safety and insurance, both of which pertain to protection of the public. Subsequent ACV ventures in Alaska, specifically Science Applications' Voyageur 003 and the Mackley-Ace Yukon hoverbarges, were not even considered by the ATC. If, however, the ACV does become an active and widespread transportation mode in Alaska, ATC intervention undoubtedly will result.

On a similar note, it should be kept in mind that the ATC is the Alaska counterpart of the Federal Interstate Commerce Commission (ICC). As such, future interstate or international ACV operations will meet with not only ATC regulation, but ICC regulation as well, although such regulation has yet to be determined.

REMAINING LEGAL RESTRICTIONS

It should be pointed out that the legal environment and ACVs in the United States and Alaska is quite new. Numerous additional areas exist and will only be discussed tangentially.

CUSTOMS AND IMMIGRATION

Due to the foreign nature of ACVs both in craft and, quite often, crew, clearances must be obtained from the appropriate agencies. Duties depend on whether the ACV is to be classified as a vessel or a land vehicle and such a classification, in turn, depends on whether the ACV is intended for land or water use. Obviously, problems are inherent in amphibious craft.

In the area of customs and immigration, foreign personnel must gain employment status in the United States. Fortunately, for ACVs, this

presently is a somewhat simple task, since qualified personnel currently are relatively absent in the United States. Still, appropriate certifications of necessity must be obtained from the State of Alaska Dept. of Labor and final clearances approved through the United States Dept. of Immigration and Naturalization, a process which, at best, takes six weeks. Renewal of visas is highly contingent and dependent upon the United States and Alaska labor market, training programs for domestic personnel, and compliance with the prescribed conditions of admittance.

SAFETY AND CONSTRUCTION REGULATIONS

To date, due to a lack of development of the ACV industry in the United States, specific construction requirements are absent, although it is suspected that British requirements would be adopted and a general standard of seaworthiness and safety set forth.

Additionally, safety and operating regulations are noticeably absent, although, to date, the Coast Guard has been the primary focus since most operations have been water-oriented. Coast Guard regulations may be found generally at 46 C.F.R., et seq. Land controls also are absent, although it is anticipated that general rules of the road and safety standards applicable to negligence actions and a duty of care would apply. Until such time as ACV use becomes widespread in the United States, the area will probably continue to remain largely unregulated.

CONCLUSION

The whole question of ACVs and the Law boils down to one salient issue: Classification. Once ACVs are effectively and properly classified, proper legislation and regulations may evolve where necessary. Unfortunately, poor classification to date has seriously crippled the industry in the United States and Alaska, and only until such mistakes can be addressed effectively will the industry receive the encouragement and legal legitimacy it so needs. In short, the question no longer is one of the technical adequacy of ACVs. Rather, a new question has arisen: ACVs and The Law.

ACKNOWLEDGMENT

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AIR CUSHION ICEBREAKING - WHAT IS THE POTENTIAL

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ABSTRACT

Canada's pioneering efforts in the field of air cushion icebreaking are now being recognized, and whilst not being the catholicon for operations in ice-covered water, the principle of air cushion icebreaking is being widely acclaimed. This paper will briefly review the current achievements and will expand on the use of the data generated by these activities to further develop the technology.

Plans for the continuing development of both high-speed self-propelled ACV icebreaking and ship/bow platform combinations are discussed.

Some problem areas requiring further work are highlighted.

The paper concludes with a survey of potential applications for this revolutionary icebreaking method.

INTRODUCTION

The use of air cushion technology for breaking ice has now developed from the pure experimental stage to the point where useful operations are being performed.

Perhaps the most obvious need for icebreaking is to assist shipping in ice-covered waters. This has traditionally been accomplished by specially designed icebreaking ships, which essentially operate on the principle of applying massive force, requiring very high installed horsepower.

With economic pressures causing both industry and government to display increasing interest to extend operations in ice-infested waters, primarily as a result of expanding efforts to obtain new sources of fuel and other natural resources from the Arctic regions, ways must be found to improve our icebreaking effectiveness.

Despite concentrated efforts there have been few revolutionary advances in icebreaking technology. Although the development of more sophisticated, economical, conventional icebreakers continues, it is worth noting in these times when energy conservation is of paramount importance, that there is now a method that has considerable potential for improving our icebreaking effectiveness - that is by harnessing the principles of air cushion technology.

METHODOLOGY

Before reviewing the icebreaking experiences using this technology, I will explain two methods by which it is applied.

From early experiments it was found that there were two distinct speed regimes where the air cushion icebreaking phenomenon occurred. For simplicity these have been dubbed "low-speed" and "high-speed".

The "low-speed" method depends upon having a patch of open water from which to start; this may be the edge of the ice sheet or a hole which the ACV or nature may have made. It also depends upon having a cushion pressure head approximately the same as the ice sheet thickness. As the platform approaches the edge of an ice sheet, the air pressure generated and contained within the platform's flexible seal (skirt) system depresses the water level beneath the platform relative to the surrounding surface by an amount approximating to the air cushion pressure head. As the platform moves on to the ice sheet, the skirt rides up over the ice still maintaining its air seal. The ice sheet penetrates the pressurized air zone where the depressed water level allows an air cavity to form between the underside of the ice and the water, which extends forward and around the advancing platform, being fed from the cushion. The ice sheet under the platform, with the buoyant force of the water removed, becomes in effect a cantilever beam which eventually fails due to its own weight when the cantilevered section reaches a critical length. The overhanging ice section breaks away and the broken pieces fall into the water below, which is at a level depressed by the cushion pressure head. See Figure 1.

This phenomenon has been observed and filmed from within the cushion of ACVs on several occasions. Obviously, significant thicknesses of ice require relatively high cushion pressures.

Several investigators have derived theories to determine the lengths of the cantilever before failure and others have also attempted a formalized understanding of the overall phenomenon, Ref. 4 and 5, but due to the many theoretical approaches that may be employed, results predicted by the different methods may vary considerably and so far a theory that totally agrees with practice has proved elusive.

Presently the "high-speed" method is even less clearly defined as to a thorough understanding of the phenomenon and to its limiting parameters. This is in part due to a lack of experimental data, and partly due to the difficulty of applying any established theory. Many researchers have referenced the work carried out by Nevel, Ref. 2 and 3, but practical experience belies many of the assumptions concerning boundary conditions in the theoretical analyses and it is clear that in order to establish reliable analytical methods for developing predictor equations, further work interfacing theory and experimental testing is still required.

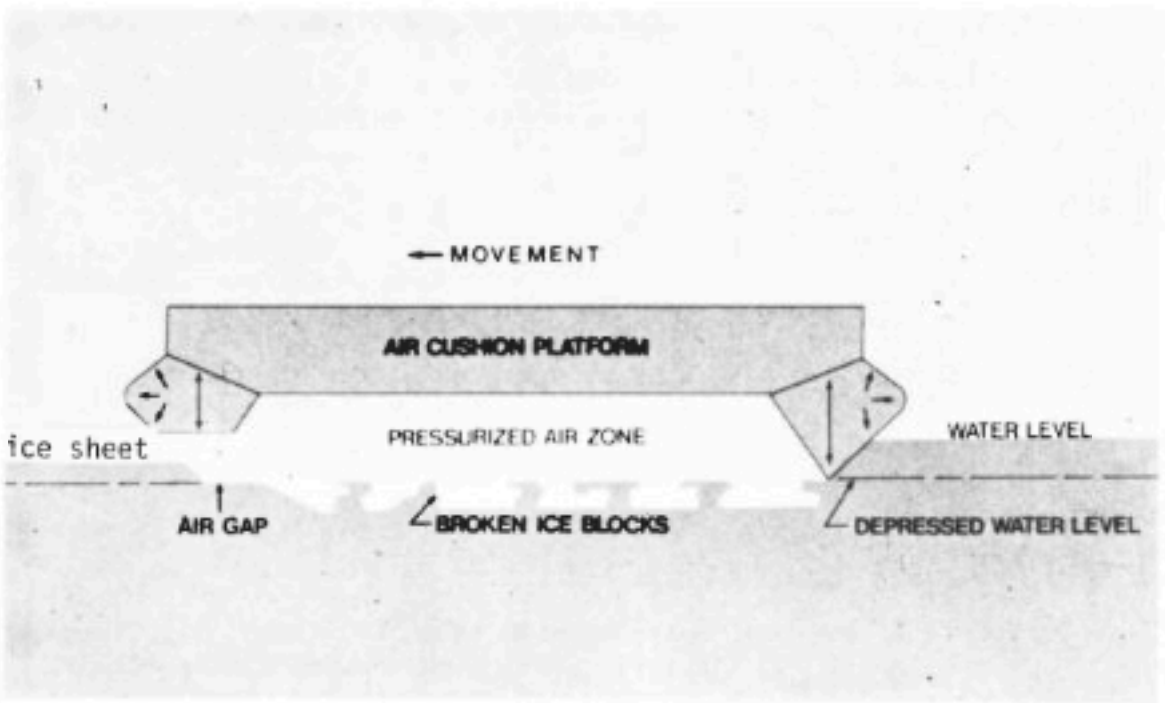


FIGURE 1 - Schematic of low-speed air cushion icebreaking

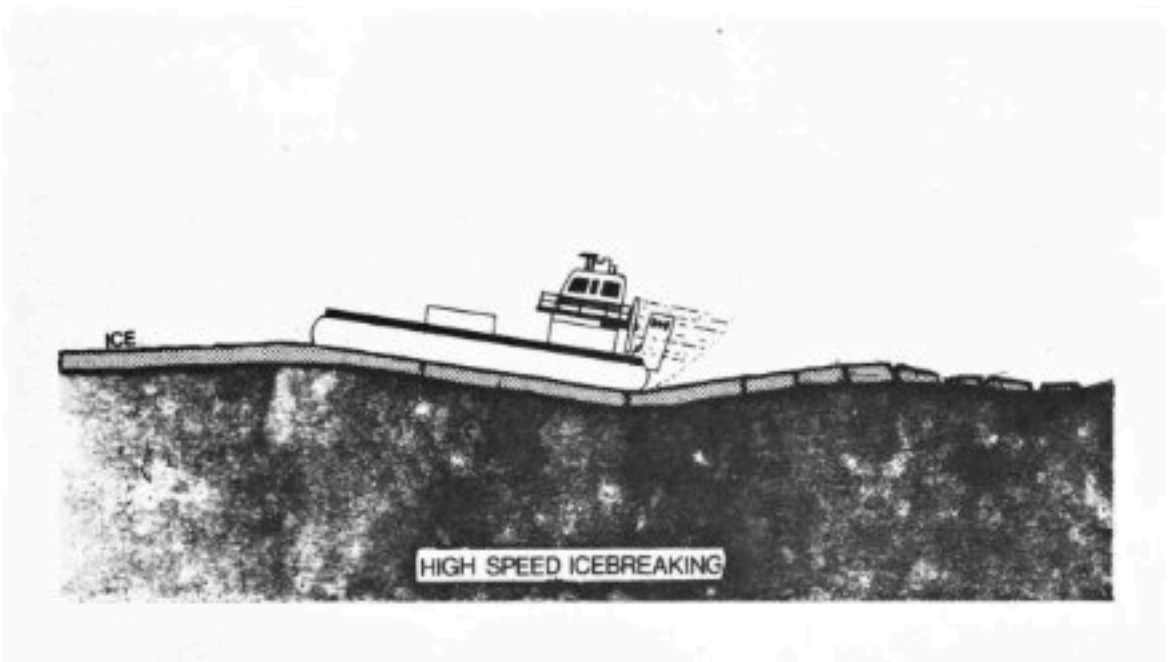


FIGURE 2 - Schematic of high-speed air cushion icebreaking

An informal understanding of the phenomenon is duscussed in Ref. 13 and 14. Basically, any vehicle moving at a critical velocity over a floating ice sheet, generates a wave pattern in the ice which can sufficiently amplify the stresses in the ice to cause failure, see Figure 2. The critical velocity depends upon various ice characteristics, thickness, and flexural strength and also the water depth. Vehicle parameters are not significant. Early experiments lead to the assumption that the wave formation was developed at a critical velocity which was coincident with the craft's over-water hump-speed. But in more recent observations the ice wave has been developed at craft speeds that do not correspond to the expected critical velocity.

Due to the 'success' of this type of icebreaking for clearance and flood control work, opportunities to conduct extensive controlled experiments have not been available but, clearly this very powerful method of ice-breaking justifies continued development.

HISTORICAL REVIEW OF AIR CUSHION ICEBREAKING

Since the birth of the modern air cushion vehicle in 1959, a multitude of craft have been built and tested in various environmental conditions around the world. Tests in cold regions revealed that the amphibious air cushion vehicle had an uncanny ability to break ice.

In winter operations in Lake Erie in 1969, Bell SK-5s broke the ice over which they travelled. Figure 3.

In tests conducted at Vaxholm, Sweden, in February 1971, the Hovermarine Hovercat 2 also broke ice. Figure 4.

Recognition of the potential of air cushion icebreaking was probably first realized after the ACT-100 air cushion transporter trials conducted by Sunoco E&P Ltd., at Yellowknife, N.W.T. during the winter of 1971/72, when the craft was towed across Great Slave Lake and broke through the ice.

After witnessing the tests, officials of the Canadian Department of Transport became very interested in the air cushion icebreaking concept and have, since 1971, initiated several full-scale and model tests to better understand and evaluate this icebreaking method.

In 1972 DOT trials with ACT-100 at Tuktoyaktuk Harbour, N.W.T. demonstrated icebreaking and air cushion cable ferry potential. Figures 5 and 6.

In the spring of 1973 tests with a Terracross H-119 towed air cushion raft were conducted in Montreal. Figure 7.

In February of 1974, tests were conducted in Toronto Harbour with a tug pushing two different air cushion rafts; Terracross H-119 and Hover-JaK HJ-15. Unseasonably warm weather curtailed testing but the icebreaking capability was again demonstrated.

In another series of tests during the spring of 1974 the Canadian Coast Guard was evaluating the self-propelled Bell Aerospace Voyageur ACV's



FIGURE 3 - Bell Aerospace SK-5s breaking ice in Lake Erie - 1969



FIGURE 4 - Hovercat 2. Breaking ice at Vaxholm, Sweden - Feb. 1971

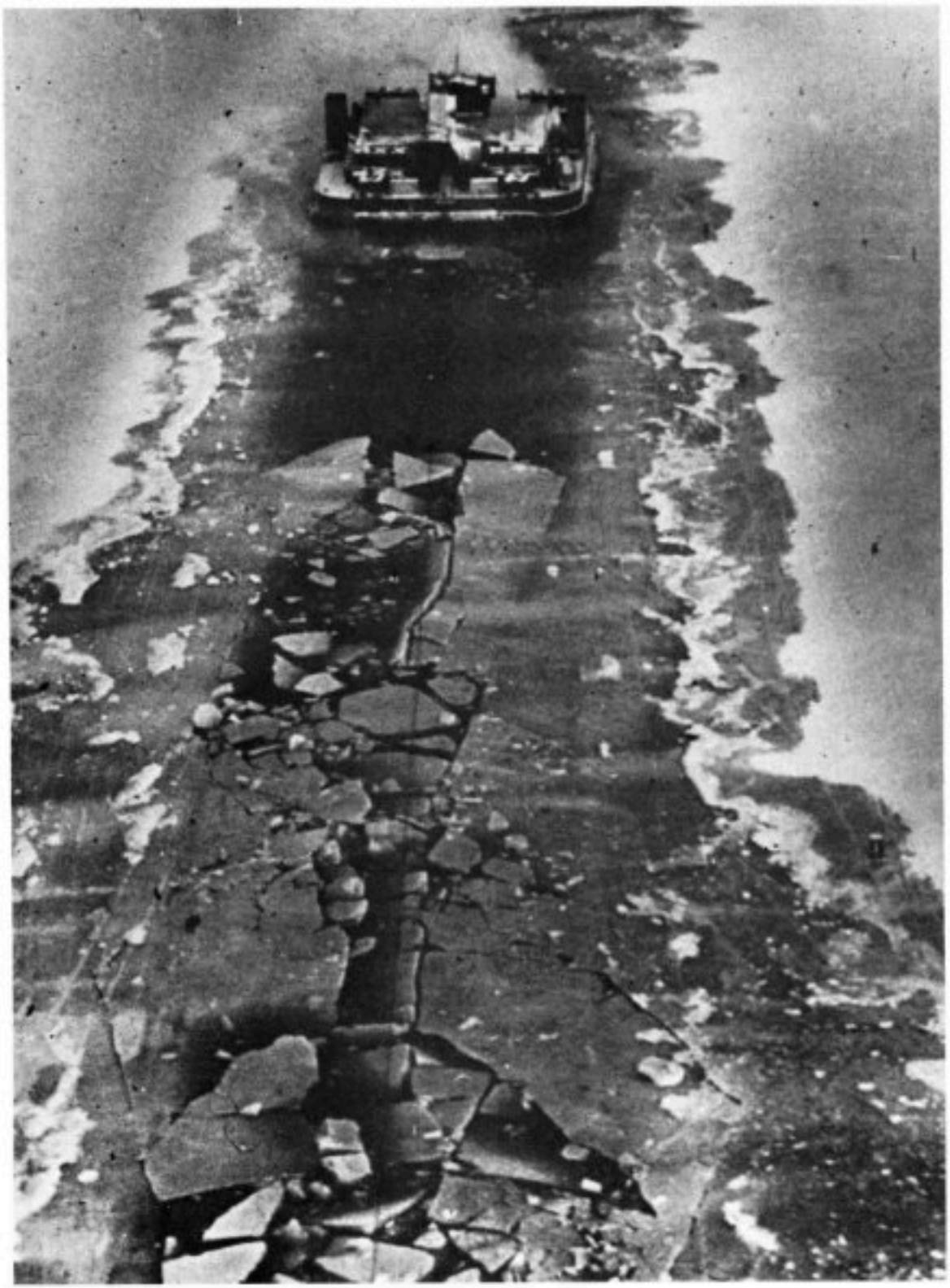


FIGURE 5 - ACT-100 breaking ice at Tuktoyaktuk Harbour, N.W.T. - 1972



FIGURE 6 - ACT-100 breaking ice at Tuktoyaktuk, N.W.T. - 1972



FIGURE 7 - Terracross H-119 raft
on icebreaking trials in Montreal - 1973

icebreaking capabilities at Parry Sound, Ontario. It was during these trials, as the craft was proceeding to the low-speed test site, that it was observed when accelerating to a velocity approaching hump-speed, a large standing wave appeared in the ice about half a craft length astern. The ice sheet over the traversed area was continually failing on the wave crest. Figure 8.

A hastily arranged controlled experiment was organized, where the craft speed was accurately measured and the wave and ice characteristics recorded.

There was no opportunity to further exploit this discovery at Parry Sound, but the potential was immediately recognized as being a breakthrough in icebreaking, at least for inland fresh water first year ice.

The spring of 1974 was a significant milestone, not only had the Voyageur convincingly shown the potential of the high-speed method; also the ACV Icebreaking Interdepartmental Working Group of the Federal Government, recommended that the Department of Transport should investigate the effect of attaching an air cushion platform to the bow of a ship.

Model tests were conducted in synthetic ice, and indicated a dramatic reduction in resistance of the ship when the ACV platform was attached. Reference 8.

As a result of these trials, a design study was commissioned for a platform attachment to the icebreaker CCGS Montcalm.

The findings of the study, conducted by Bell Aerospace Canada, in early 1975, indicted a relatively sophisticated and expensive platform, primarily as a result of an ambitious specification. Construction of a prototype was not proceeded with, due to the expense and the need for further full-scale evidence. Figure 9.

The CCG ACV Evaluation & Development Unit was moved from Parry Sound to Montreal, and in the winter of 1974/75 the Voyageur developed the high-speed icebreaking method as well as carrying out useful ice management for flood control in Lake St. Louis and its adjacent rivers. Figure 10, Reference 9.

Not to be outdone, the CCG Vancouver Hovercraft Unit took the opportunity afforded by some unseasonably cold weather to try its hand at air cushion icebreaking; the SR.N5 broke ice and freed some fishing vessels from a frozen harbour area.

In the spring of 1975 Bell Aerospace completed a Department of Transport study for a "heavy" Voyageur, which called for increasing the weight of the existing CCG Voyageur 002 from 40000 kg to 59000 kg and evaluating the effect on the craft's icebreaking capabilities. Although feasibility was proven, justification for continuing with the concept at that time could not be made. Figure 11.

During the summer of 1975 the Department of Transport decided to set up a multi-year development program to enhance conventional icebreaking capab-



FIGURE 8 - CCG Bell Voyageur 002 breaking ice in the high-speed regime
view to stern



FIGURE 9 - CCG design study bow platform designed by
Bell Aerospace Canada



FIGURE 10 - CCG Voyageur ice breaking in Montreal area - Winter 1974/75

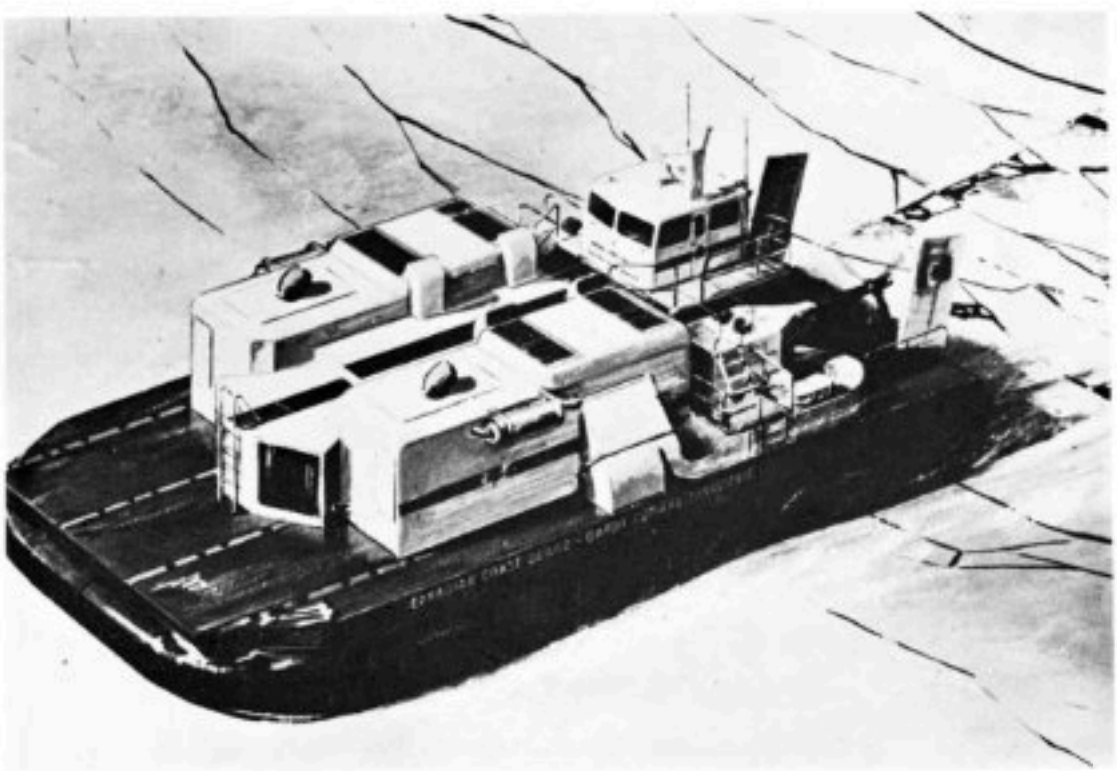


FIGURE 11 - CCG study for 'heavy' Voyageur designed by Bell Aerospace Canada

ilities by using air cushion technology, with particular regard to the approach of attaching an air cushion platform to the bow of a ship.

The first phase of this program culminated in the successful full-scale CCGS Alexander Henry/ACT-100 trials conducted at Thunder Bay, Ontario, during the winter of 1975/76. Figure 12, Reference 11.

The second year of the program 1976/77 was also carried out in Thunder Bay where the ACT-100 now re-named Iceater I, was coupled to a commercial tug, an ice class tanker and the icebreaker CCGS Griffon. Figures 13, 14 and 15.

IMMEDIATE DEVELOPMENTS

The data collected during the Thunder Bay trials so clearly indicated the advance made by improving icebreaking, that the Canadian Coast Guard issued a design requirement for an air cushion bow attachment to fit seven light to medium icebreakers. The design study was won by Hoverlift Systems Ltd. and completed in June, 1977. Figure 16.

The specification calls for a platform 22.5m long; 21.3m. wide, with a hoverheight of 2m at a cushion pressure of 10.5 Kpa. The platform is notched and capable of being mated to various CCG ships. It is hoped that construction will commence within the next few months.

The CCG bow platform was designed to fall within technology limits at this time. However, it does incorporate several novel features, which it is felt will permit a thorough evaluation of the concept within an operational environment. It is intended that the platform will be evaluated at various locales, ranging from the Great Lakes, St. Lawrence River, Maritime Regions and with possible forays into suitable Arctic regions.

Another spin off from the Thunder Bay trials; in conjuction with a study already being conducted on extention of the St. Lawrence Seaway Shipping Season, the SLSA commissioned the design and building of an air cushion bow attachment for their tug "La Prairie". This platform is being constructed by Hoverlift Systems Ltd. and should be delivered to the SLSA in early October 1977.

This coming winter it is planned to operate the tug/platform combination between St. Lambert and Montreal Harbour, carrying out channel clearing tests in sheet ice. Figure 17.

As can be imagined the subject of air cushion icebreaking has received much attention by various organizations and governments; and the Canadian Coast Guard have briefed the U.S. Coast Guard, the Soviets, and several Scandinavian countries.

As a direct result of this international cooperation the U.S. Coast Guard have made plans for testing an air cushion platform/ship combination this coming winter (1977/78) on the Illinois River. The shallow draft pusher vessel Summac will be combined with a 15.25 x 12m platform having a hoverheight of 1.2m. Figure 18.



FIGURE 12 - CCGS Alexander Henry/ACT-100 combination -
Icebreaking Trials at Thunder Bay - March 1976

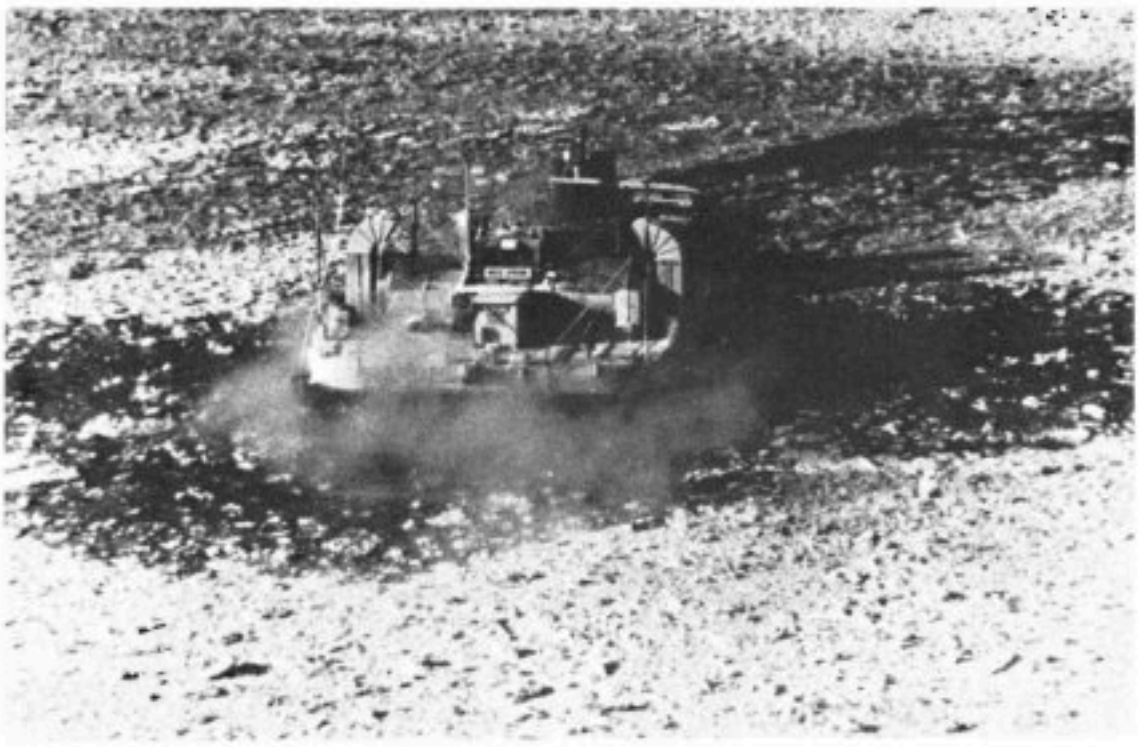


FIGURE 13 - Tug Thunder Cape/Iceater I combination -
Icebreaking Tests at Thunder Bay - January 1977



FIGURE 14 - M.V. Imperial St. Clair/Iceater I combination - Icebreaking Tests at Thunder Bay - February 1977



FIGURE 15 - CCGS Griffon/Iceater I combination - Icebreaking Tests at Thunder Bay - February 1977

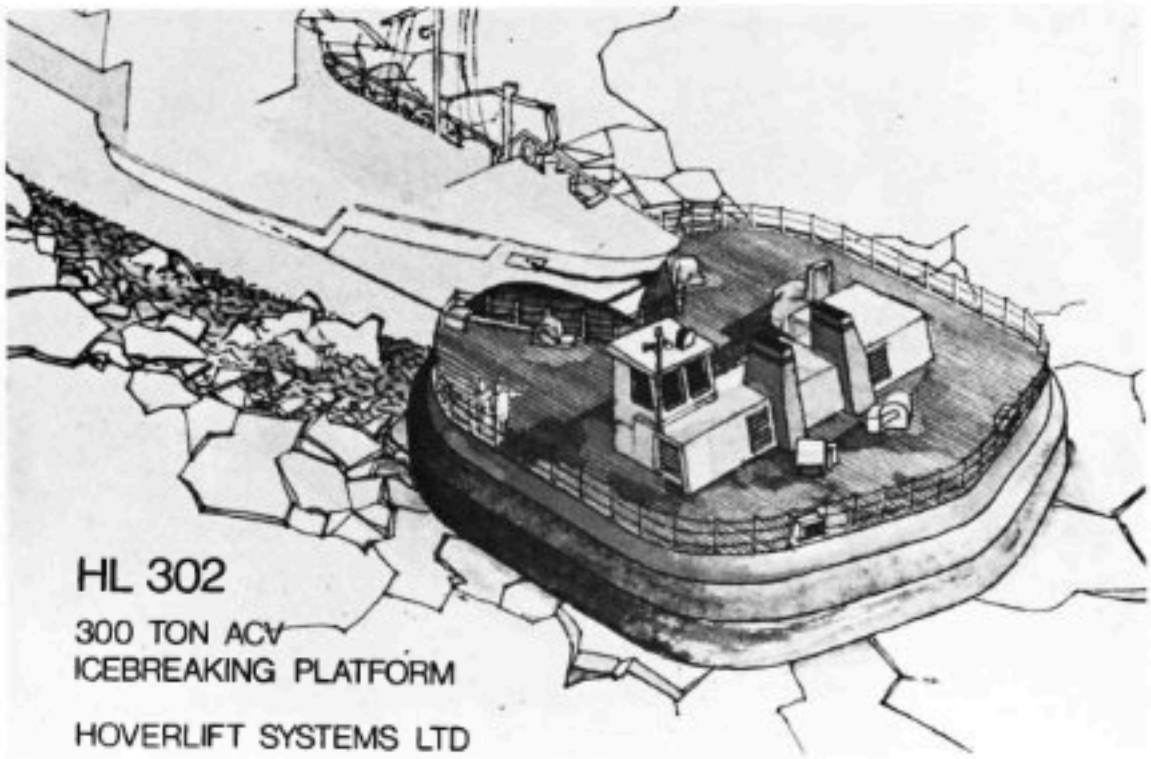


FIGURE 16 - CCG air cushion icebreaking platform designed by Hoverlift Systems Ltd.



FIGURE 17 - SLSA Tug "La Prairie"/H.S.L. platform combination shown during open water tests in Montreal - December 1977



FIGURE 18 - U.S.C.G. Summac/River Guardian platform (built by Mackley Ace) combination - shown during open water shakedown tests at Peoria, Illinois, December 1977



FIGURE 19 - CCG Voyageur ice breaking for flood control - Winter 1976/77

The planned tests will evaluate the concept in ice conditions hitherto untried by bow platforms and the results will be watched with interest.

Turning again to high-speed icebreaking; last winter 1976/77 the CCG Voyageur was commissioned as an operational unit and was used in the Laurentian Region in conjunction with conventional icebreakers in a successful coordinated ice management and flood control program. Figure 19.

In late December 1976, the cities of Ottawa and Vanier requested a demonstration of ACV icebreaking with a view to flood control on the Rideau River. The vehicle used, selected purely on the grounds of availability was the Air Cushion Industries Ltd. AC-800, approximately 6m long by 3.5m wide, an all-up-weight of 1300 kg. The craft using the critical speed method satisfactorily demonstrated breaking ice about 20 cms thick. Figure 20.

DIRECTIONS FOR CONTINUING DEVELOPMENT

In reviewing the achievements to date, it must be remembered that the knowledge gained has been accumulated by using available hardware not specifically designed for icebreaking.

In the high-speed method the greatest thickness of sheet ice which may be broken by the Voyageur is not known, although 160 cms is the thickest recorded to date. Formal data from which generalized theories may be developed to predict icebreaking capabilities or assist in optimizing designs have not been established.

In the slow-speed method, a better understanding of the mechanism has been established, but again a generalized theory which agrees with practical demonstrations has yet to be developed.

Through the auspices of the Department of Transport's Transportation Development Centre, several theoretical studies are underway, which it is hoped will yield a further understanding of both the high and low-speed methods.

Whilst theoretical studies are essential and must continue, the operational application of air cushion icebreaking is immediate - it can be used now.

Although significant progress has been made there is still much to be learned, certain problems must be overcome in the continuing development.

** The majority of operations to date have been in first year fresh water ice and apart from operations with Voyageur over moderately rough and rafted ice, only relatively smooth ice has been experienced.

** Only very limited work in salt water ice has been accomplished and although no undue difficulties are foreseen, more experience is required.



FIGURE 20 - AC-300 ice breaking on Rideau River, Ottawa, during spring break-up 1977

** Better anti-spray skirts are required to reduce icing problems.

** Cushion pressures are limited by available fans.

** Skirt material flexibility and life at low temperatures should be improved.

** Attempts to reproduce the low-speed icebreaking action in synthetic ice modelling have indicated that development of modelling techniques is required before they can be used with confidence to assist in design work or predict performance.

** Operational techniques need refinement before the full benefit of this new form of icebreaking can be realized. Certain traditional techniques are not necessarily valid when breaking ice with air cushion technology.

Despite these and other problems that will no doubt arise during the development, the potential is significant.

POSSIBLE APPLICATIONS AND POTENTIAL

The two methods of air cushion technology icebreaking established to date are complimentary to each other, not competitive. Some tasks can be performed equally well in an icebreaking sense by either method, but generally operating costs, availability or access to an area will determine the most appropriate method for an operation. For instance, river clearance, dock and harbour clearance and escorting of ships can all be performed by either method.

Escorting of a ship in a river can also be performed by either method, but in relatively still water such as in the Great Lakes, the bow platform is more effective. Figure 21.

The slow-speed method is also probably the most effective way of extending the crossing season of a river ferry, and no doubt much attention will be focussed on the operation of Alberta Transportation's new air cushion cable ferry at La Crete, during this coming winter.

For a continuing requirement to assist ship movement in a harbour, such as a ferry terminal, the slow-speed method with cable and winch propulsion, for instance, would be a possible application. Breaking ice in a river prior to break-up to avert potential flooding could be carried out by a relatively simple and inexpensive air cushion towed raft, whereas clearing ice during break-up would more effectively be done by a self-propelled vehicle.

Obviously, ice clearance, as opposed to icebreaking, depends upon moving water to remove the ice. Clearance of large areas of ice, or ice in shallow water is most effectively carried out by a self-propelled ACV

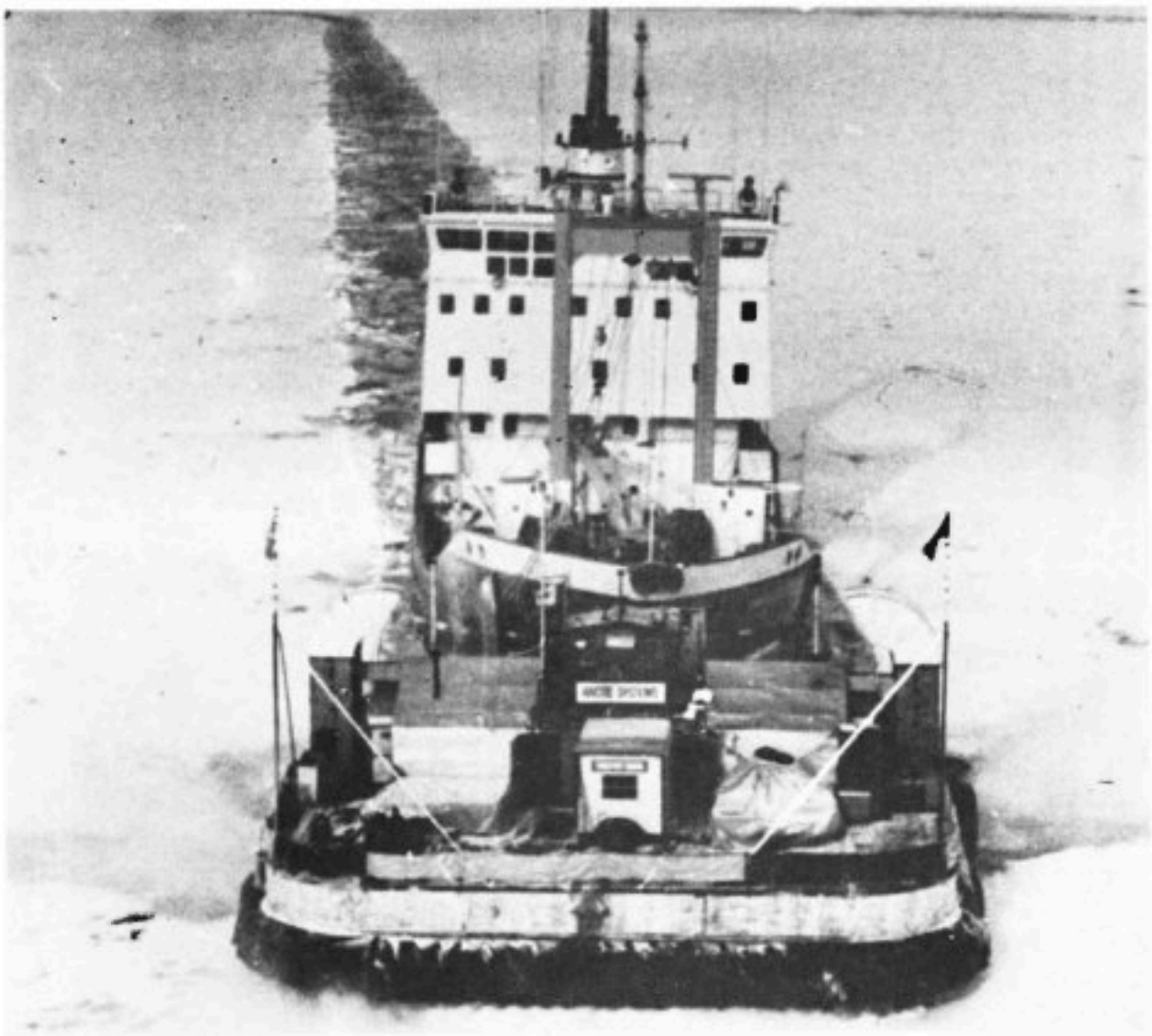


FIGURE 21 - CCGS Griffon/Iceater I combination at Thunder Bay, February, 1977
Breaking ice 86 cm thick at a speed of 7 knots

because of the craft's rapid response time and ability to operate in areas which cannot be reached by conventional vessels due to draft restrictions. This type of operation has been proven repeatedly by the Voyageur in the Montreal area.

Projecting on from the demonstrations of river icebreaking by small self-propelled ACVs, there appears to be a requirement for a self-propelled ACV that can be easily transported by road or rail and be rapidly readied for operation with a minimum of assembly. This type of craft could be quickly dispatched to the specific locations requiring an icebreaking service. Further, it could form the basis for municipalities to maintain open water channels in rivers throughout the winter months and thereby greatly reduce the spring flood hazard.

Looking further ahead, there are several ferries such as those crossing the St. Lawrence at Quebec City and in the Northumberland Strait, which could benefit from the application of a system employing the low-speed method as a semi-permanent installation for the winter season, to assist them in navigating short stretches of ice-covered waters.

Offshore supply boats could be equipped with air cushion platforms to service Arctic drill rigs. The existing craft could be used without major modification and there would be no abnormal loading on the drill platform when coming alongside, as air cushion icebreaking action does not impose the high horizontal crushing forces usual with conventional icebreaking.

As experience is gained in operating over increasingly rough ice, the application of air cushion icebreaking to the Arctic shipping routes can be considered.

Continuing development of the technology is paced by the availability of ice and equipment.

The ice, we have in abundance - future equipment could take many forms, all ultimately dependent upon need and available funding.

** Optimized and better platforms.

** Large self-propelled ACVs or

** Icebreaking Surface Effect Ships with water screws or water jet propulsion may have possibilities.

** Semi-submersible icebreaking ACVs warrant consideration.

** The integration of the air cushion principle into conventional ship design is another consideration.

The challenges being offered the air cushion designers and skirt manufacturers to develop methods and equipment capable of contesting the harsh environment and increase icebreaking effectiveness, are both interesting and potentially very rewarding.

CONCLUDING REMARKS

In concluding, it is recognized that air cushion technology is not the panacea for operation in ice-covered water, rather it is a supplementary tool with many useful purposes and applications. It has proven capabilities that are worthy of serious development programmes. I believe that by planning intelligently and accepting the challenge, we will have the opportunity to establish a solid foundation upon which to build and thence develop the potential of air cushion icebreaking, with new industrial and commercial opportunities for the benefit of the Canadian economy being significant possibilities.

ACKNOWLEDGEMENTS

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FRONTIER RESOURCE DEVELOPMENT AND AIR CUSHION TECHNOLOGY

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The principal purpose of this paper is to depict the environment in Canada's frontiers in which air cushion vehicles must operate if they are to serve industry effectively. Partly because it is the author's own field of expertise and partly because it is the most prominent industry in almost all the frontier areas, especially the offshore frontiers, most of the discussions which follow will have special relevance for the Arctic offshore oil and gas industry. It should be noted however, that there are several important mines in various stages of development along the shores of our ice-infested offshore frontiers. Discussion is also almost entirely aimed at these ice-infested water areas since these are the ones which are least familiar to the majority of the audience. Furthermore, the greater amount of present frontier activity is zeroing in on several major offshore basins in Arctic Canada.

Firstly, we shall discuss the northwestern portion of our frontier in the Beaufort Sea and the adjacent areas of the outer Mackenzie Delta. In this area of considerable geologic promise for oil and gas prospects and with recent encouragement, it is likely that industry activity will continue for many years to come.

Next, we will consider the inter-island marine areas of the Canadian Arctic Archipelago particularly those in its northwestern portions occupied by the sediments of the Sverdrup Basin. Again, this area has been the site of significant discoveries, principally of gas, and activity is likely to continue for some decades.

CLIMATIC CONDITIONS AND A.C.V. REQUIREMENTS

Before we consider these two main geographic regions in more detail, we should make brief mention of the climatic considerations with which air cushion vehicles must successfully cope in order to be of any real utility in these Arctic offshore areas. It should be stressed that for an air cushion vehicle to be of value to the oil and gas industry it must be rugged, heavy-duty, "rough-neck proof", reliable, must have a long time between overhauls of engines and other significant components, it must basically be very simple in its engineering, it must be able to operate in temperatures down to -55°C., to withstand winds up to 180 km. per hour, and it must have skirts which are flexible even at such low temperatures and be capable of beginning operations almost instantaneously under emergency conditions without any special pre-heat which

would have attendant delays. Above all, under Arctic offshore conditions, while an ACV is stationary (for periods of three months or more if it is being used as an air cushion drilling barge), the skirts must be protected from any form of ice damage, either through ice build-up over a long period or due to ice incursion related to movements of the ice floes. Means to protect the skirts are presently being researched and developed by some industrial companies whose methods are currently of a proprietory nature.

BEAUFORT SEA CONDITIONS

We shall now examine the conditions which prevail in the offshore of the first of the two main areas of interest, namely the Beaufort Sea. In much of the Canadian portion of this sea, there is a "summer" of six to sixteen weeks during which period the main offshore ice pack commonly moves away from the coast to distances of some 100-200 km. and the area is essentially ice free for most of that period. Nevertheless, there are sporadic incursions of pack ice particularly under conditions of strong northwesterly winds. Nearer the Alaskan border in the west and Banks Island in the east, the ice may be much closer to shore. In some summers the ice cover barely opens up at all. For the greater part of the year, the whole Beaufort Sea is essentially ice covered.

The character of the ice varies very considerably from the shoreline out seaward. In the inshore areas, often out to approximately the 20 metre bathymetric contour, the ice is essentially landfast and may be relatively smooth. Depending on the prevalence of storms at time of freeze-up and while the ice is thin, its relative smoothness may be broken by varying amounts of pressure ridges and rubble fields, and near the shoreline the ice may be crushed up against the shelving shore. In much of the very shallow water adjacent to the Mackenzie Delta, the ice will become sufficiently thick to freeze to bottom, in which case it is unlikely to be severely disturbed by further pressure ridging. Further offshore, in the area dominated by the so-called "Arctic Gyre", is the constantly rotating pack ice of the Arctic Ocean. This pack ice can be very rugged; it is broken up into pans of various sizes and contains a large percentage of multi-year ice, that is ice of more than two winter seasons in age. Such multi-year ice may commonly be in the four to five metre thickness range with pressure ridges frequently reaching fifteen to twenty metres and occasionally in excess of forty metres in thickness. Between the moving multi-year Arctic Pack and the landfast ice is a zone commonly known as the "Shear Zone" where the effects of the gradually rotating Arctic Pack, as it tangentially impinges upon the landfast ice, is very marked. The ice here is very much broken up. Many leads are formed and refrozen. Large pressure ridges are formed. Much of the area is occupied by enormous rubble fields.

After this rather generalized description of the three major sub-divisions of the Beaufort Sea ice, we shall examine in somewhat more detail the surface characteristics of these various ice types and again it will be necessary to generalize. It must be realized that within each of these

three major regions, there are great variations in ice form and thickness and from one year to another and within a single season there may be enormous changes.

In the oral version of this paper, it was possible to show a very large number of color slides which graphically depicted the multitude of variations which may be present within the sea-ice areas of the Beaufort Sea. In the written version, we are limited to a very few illustrations, partly because the color slides of ice do not print well in black and white, and these cannot adequately indicate the multitude of varieties of topography which may be present. As indicated previously, much of the landfast, essentially first-year ice, in the shallower water areas, is extremely smooth throughout the greater part of the year and forms excellent terrain for air cushion vehicles to traverse. It may, however, be broken up by sporadic first-year pressure ridges which have very jagged profiles and may cause considerable difficulties for shallow-skirted vehicles to traverse. At intervals within the landfast ice areas, larger fragments of multi-year ice, or occasionally of ice islands, will be found embedded within the first-year ice sheet. It has already been demonstrated that ACVs with four foot skirts, such as the SRN-6, the Voyageur and the ACT-100 can operate freely over the smoother portions of the landfast ice, but must proceed with caution in its rougher portions.

In areas within the shear zone and of moving multi-year Arctic pack-ice, ACVs will have to operate very circumspectly at moderate to slow speeds and avoid the larger obstacles. Probably an obstacle clearance of at least eight feet will be necessary to realize a useful degree of mobility. In the shear zone, ridged and rafted first-year ice, often broken up into chaotic rubble fields or jagged fragments, is interspersed with open and refrozen leads, as well as significant amounts of second-year and multi-year ice. Out in the moving Arctic pack-ice, much of the older ice has been markedly smoothed by summer ablation, but thick floes floating some feet above water level are interspersed with patches of open water, and rafting of the thick ice may form frequent formidable obstacles to transit. The ACV industry will have to move very cautiously out into such areas with only the most reliable and rugged units.

ARCTIC ISLANDS OFFSHORE CONDITIONS

Within the Arctic Archipelago, conditions tend to be somewhat more predictable than in the Beaufort Sea. Within the oil industry's main area of interest, in the western and central Sverdrup Basin, the ice has been traversed by many hundreds of tracked, wheeled and skidded vehicles, operating with few exceptions when the ice is thick, essentially landfast, and when daylight conditions prevail for reasonable periods. Such surface vehicle movements over thousands of miles of traverse, and extensive aerial observation have provided a vast amount of knowledge of surface conditions. Within the inter-island areas, conditions vary greatly from year to year, depending largely on the amount of open water which has developed in the previous year and on the prevailing conditions during and shortly after freeze-up.

In areas which have been open in summer, first-year ice will prevail in the following year and may range from extensive smooth areas with sporadic abrupt pressure ridges to generally rough conditions, resulting from stormy periods during freeze-up and while the ice is thin enough to break up easily. Such latter conditions may result in large areas being covered by jagged fragments projecting from the sheet surface, interspersed by abrupt ridges, rafted ice masses and possibly enclaves of multi-year ice fragments. Shorelines, particularly those facing north and west, may have chaotic ridges and masses of ice piled up to heights of ten or fifteen metres.

In areas where break-up has not been appreciable in the previous summer, the older ice will be considerably smoothed out and should be reasonable for transit by deep-skirted ACVs. In between the various types of ice mentioned for both first and second-year conditions above, many areas in many seasons will display large expanses of relatively smooth ice interspersed by a criss-crossing network of pressure ridges at intervals from a few hundred metres to several kilometres. After examination of thousands of such ridges, it is believed that ways can be found to traverse such ridges by large deep-skirted ACVs.

In a recent study by two experienced teams, it was concluded by one that a six foot obstacle clearance would allow adequate mobility, whereas the other team, after several years study, opted for an eight foot clearance. Even with such an obstacle clearance capability it will be necessary to search out the weak spots in some of the larger ridges, so as to pass through with wide vehicles, and even then some of the obstacles may need to be smoothed off by shaving, chipping or other means. For single transits of large air-cushion drilling rigs, low travel speeds along circuitous paths should be quite satisfactory, since the movement of an intact rig will still be much faster than existing methods of moving dismantled rigs by plane with airstrip support or by trucks along prepared ice roads. When repeated ice traverses must be made by supply ACVs, greater effort to find straighter routes with somewhat more preparation will be required and such routes will be marked by radar reflectors and other means of flagging particularly for use in winter darkness. For such ACV missions, as drilling, where there is a necessity to reach a specific location, it is likely that there will always be limited areas which cannot be readily reached in a given season, but which in all likelihood should be accessible in another year.

In many areas of the Sverdrup Basin, particularly in its southeasterly areas, the ice sheet may break up in late summer in some years and the ice floes may remain free floating for, from a few days to three months depending on the area and particular season. The succeeding Fall will see young ice forming as large sheets or as refrozen leads interspersed among the older floes. Under such Summer and early Fall conditions, non-self propelled ACVs may require several different propulsion systems to cope with varying conditions. In some instances, such vehicles may be deterred from operating effectively until tug vehicles can operate safely, but, in many instances, winching operations will be practical, as long as tow cables can be carried to suitable anchor locations.

CONDITIONS IN OTHER ARCTIC OFFSHORE AREAS

Outside the Beaufort Sea and the Queen Elizabeth Islands, widespread ACV use is not likely to develop in the near future. In the oil and gas drilling fields, activity in such areas as Baffin Bay and Davis Strait is likely to be undertaken, at least in initial years, during the late Summer- early Fall open water season, when ice-strengthened marine workboats will likely cope better with the high prevalent sea-states than ACVs. In later years, as activity continues into longer seasons, with ice-breaking drillships, deep-skirted ACV supply units may find a significant role, although such units would have to cope with a heavy pack of jostling, continuously mobile, irregular ice floes.

OFFSHORE ARCTIC ACV ROLES

The potential roles of ACVs in the offshore of the Arctic are varied and differ to some extent from region to region.

The need for large deep-skirted air cushion-drilling vehicles is already apparent and their first use is expected to be in areas of modest ice movement within the landfast ice of the Arctic Archipelago. Such vehicles will considerably lengthen the drilling season now possible from static ice platforms, as the units will be able to move the rig intact to compensate for ice movement in excess of normal limitations, and it will be possible to move the complete rig at almost all times of the year. The development of such ACVs, with a load carrying capacity in excess of one thousand tons, will pave the way for a new generation of air cushion transporters for carriage of bulky objects and other supplies. It is possible that such units will provide a means of transporting gas plant modules and other such equipment which can thus be assembled in the south and moved intact to remote ice-encumbered Arctic sites. Large ACVs may also facilitate installation of pipelines, and have the potential to be "mother-ships" for sub-sea equipment maintenance or mobile workshops for other activities. For drilling ACVs, it will not be necessary to be self-propelled as slow and infrequent moves are the norm, as will be the case with movement of large modules, although self-propulsion would provide greater versatility and operational independence and flexibility.

A series of medium-large ACVs, probably with payloads in the one to five hundred ton range, are likely to find a very important role for a variety of Arctic duties and this generation will need to be self-propelled with moderate speed capability, perhaps in the fifteen to twenty k.p.h. range, using some form of surface contact such as that of the PACT-100 illustration. Such surface contact should bring greater economy than present methods of air-screw propulsion, but must still have a fully amphibious capability for transit over ice, water, ice-water mixes and gentle terrain.

Once such an economical self-propulsion system for heavy duty, deep-skirted air cushion transporters is available, a variety of new functions should develop. One important role could be as a disaster contingency air cushion transporter (DCACT), which could use its amphibious capability to combat oil spills, fight blow-outs, repair damage to artificial islands, use its fans to mix dispersants in with oil spills and perform all manner of duties where men and heavy equipment must be deployed from a safe mobile base over ice, water, swamp, sandbanks, etc. Such units could provide all-weather living facilities for men, could carry oil skimming devices, dispersants, burners, "Red Adair" style wild-well fighting equipment, dredging equipment for repairing artificial islands and possibly a light drilling rig for shallow relief well drilling. Such a unit could be stationed in the Mackenzie Delta and on the Arctic Islands and would have the ability to traverse widely over most offshore areas on a year-round basis. Outside periods of emergency, the vehicle could fulfill a variety of useful tasks while remaining on standby. Such tasks would include ice-breaking to lengthen the shipping season in harbours and other key areas, bottom sampling, minor dredging, lightering, etc.

ACV ice-breaking could play a major role in certain specific areas, for instance Mackenzie Delta navigation could be extended for another month or so, should the need arise.

In summary, therefore, we may conclude that there is ample opportunity for the ACV industry to serve in the Arctic offshore with a new generation of vehicles. Such vehicles must be exceptionally rugged and reliable, must be amenable to rapid servicing under very hostile environmental conditions, and must utilize the simplest technology compatible with the tasks to be performed. Such units will more closely resemble the products of the shipping and trucking industries, than those of the ultra-sophisticated aerospace industry. Most Arctic ice-infested environments will require deep skirts and, hence, most ACVs will necessarily be relatively large. Propulsion will tend to be by rather simple, more fuel-efficient methods than those now in common use. The Arctic offshore with its long months of winter nights, its pressure ridges, ice rubble fields, open leads, high winds, ultra cold temperatures, its facilities will be a demanding taskmaster. Only products of excellent yet simple design, will be able to meet the challenge, and the lessons of hard-learnt Arctic experience must be incorporated in such designs.

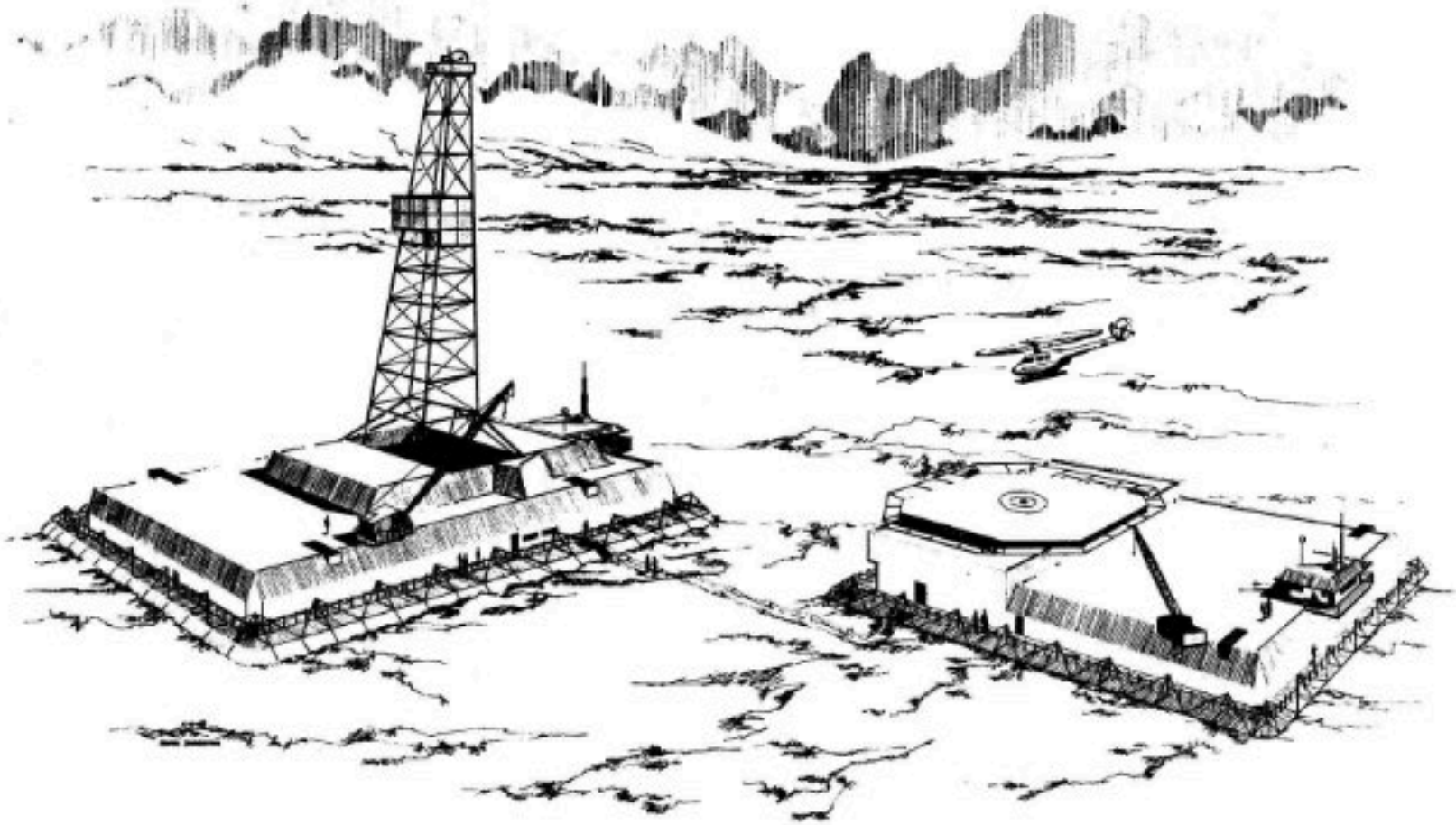


FIGURE 1 - Artist's rendering of a twin barge Air Cushion Drilling System, consisting of two main units, an Air Cushion Drilling Barge and an Air Cushion Support Barge. The latter would carry housing facilities and bulk supplies and will be designed for rapid mating with a conventional land rig for emergency relief well drilling. Medium-large air cushion transporters for supply movement may also form an ancillary part of the system (Arctic Systems Ltd., Calgary, Alberta).

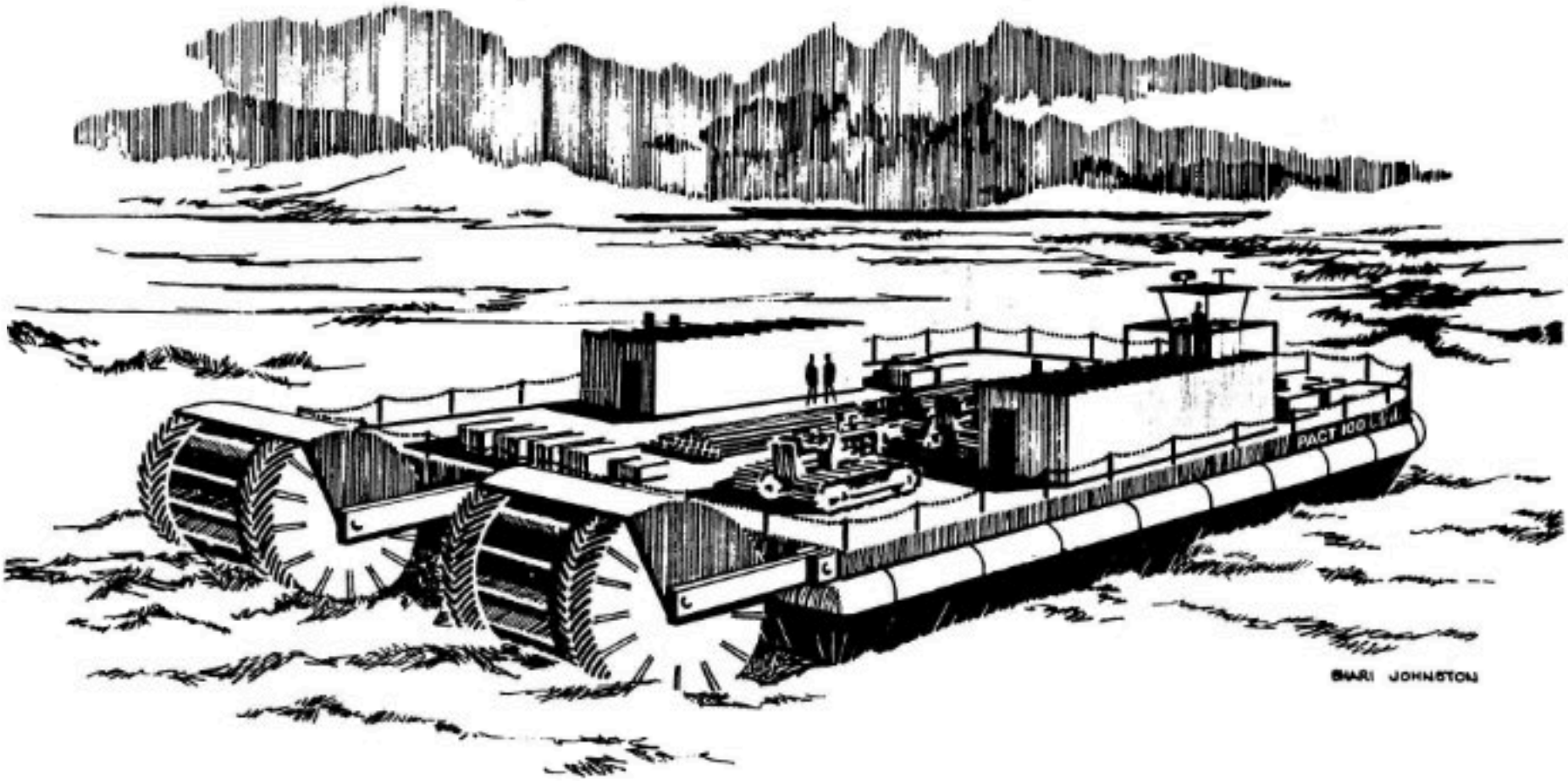


FIGURE 2 - Artist's rendering of a heavy-duty, self-propelled air cushion transporter with propulsion provided by large buoyant paddle-wheels (Arctic Systems Ltd., Calgary, Alberta).



FIGURE 3 - A British Hovercraft Corporation SRN-6 parked near a large multi-year pressure ridge in Mackenzie Bay, southern Beaufort Sea. The main ridge is surrounded by lesser ridge fragments and irregular ice rubble interspersed with smoother ice. (Photo courtesy of Gulf Oil Canada Limited)



FIGURE 4 - In the middle background, the abruptly truncated cross-section of a multi-year pressure ridge is exposed. Other ridge fragments and rubble appear to the left. Fifty miles north of Tuktoyaktuk, Beaufort Sea. (Courtesy of Gulf Oil Canada Limited).



FIGURE 5 - Irregular surface of low rubble and ridge fragments interspersed with smoother frozen leads is typical of many sea-ice areas in the Beaufort Sea. (Courtesy of Imperial Oil Limited)



FIGURE 6 - A large open lead has been partly refrozen.
Beaufort Sea. (Courtesy of Gulf Oil Canada Limited)



FIGURE 7 - Recent unfrozen cracks within a sheet of gently irregular sea-ice. Near Melville Island. (Courtesy of Panarctic Oils Limited).



FIGURE 8 - A wide refrozen lead and a narrower refrozen crack contrast sharply with the chaotic rubble surrounding them. Beaufort Sea. (Courtesy of Gulf Oil Canada Limited).



FIGURE 9 - The landfast ice on the right, in which several ice-island fragments are imbedded, contrasts strongly with the hummocked ice of the shear zone to the left. Beaufort Sea. (Courtesy of Gulf Oil Canada Limited).



FIGURE 10 - Typical air view of criss-crossing ridges and hummocks of the shear zone sea-ice, Beaufort Sea. (Courtesy of Gulf Oil Canada Limited).



FIGURE 11 - A field of hummocked first-year ice within the edge of the shear zone is abruptly separated from the relatively smooth landfast ice beyond. Within the landfast ice several ice island fragments stand high above their surroundings. Photograph taken about fifty miles north of Tuktoyaktuk, Beaufort Sea. (Courtesy of Gulf Oil Canada Limited).