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**NORTHWEST PASSAGE - TRADE ROUTE  
FOR LARGE AIR-CUSHION VEHICLES**

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# NORTHWEST PASSAGE - TRADE ROUTE FOR LARGE AIR-CUSHION VEHICLES

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## SUMMARY

For nearly 500 years seafaring nations of the North Atlantic have searched for a Northwest Passage between the Atlantic and Pacific Oceans.

This report identifies a conceptual vehicle and powerplant (a 9070-metric-ton (10 000-ton) nuclear-powered air-cushion vehicle) that could open the Northwest Passage and other Arctic passages to commercial traffic. The deciding characteristic of an air-cushion vehicle (ACV) is its ability to go over water, land, and ice; whereas a displacement ship is restricted to deep water and must impact the ice and withstand enormous ice pack pressures.

The conceptual ACV freighter has a flat-bed design which would allow it to carry a variety of cargo, such as containers, vehicles, and even modular buildings. The freighter would be 87 meters (290 ft) long, 61 meters (200 ft) wide, and have a flexible skirt 6 meters (20 ft) high. Fully loaded, the freighter would weigh 9070 metric tons, 60 percent of which would be cargo, and would have a cushion pressure of  $19\,200\text{ N/m}^2$  ( $400\text{ lb/ft}^2$ ). Its power source would be a 2300-megawatt, gas-cooled, unit-shielded thermal reactor. The freighter could cross crevices 27 meters (88 ft) wide, waves 6 meters (20 ft) high, and solid obstacles 5 meters (16 ft) high and would cruise at 185 km/hr (100 knots) on the open sea and 110 km/hr (60 knots) over ice and tundra. It would operate between North Atlantic and North Pacific ports over two different Arctic routes - a Northwest Passage and a North Polar Passage.

In addition to a description of the conceptual vehicle and its powerplant and operations, this report contains an assessment of technical feasibility, estimates of capital and operating costs, and identification of eligible cargo and markets. It also includes a comparison of distance, cost, and time for ACV freighters with that for nuclear-powered container ships, which will likely be operating in the same time period that ACV freighters could be - 1985 to 2000.

Some of the incentives for development of a nuclear-powered ACV freighter for a Northwest Passage are (1) greatly reduced transit time on many East-West trade missions; (2) competitive cost with conventional shipping for containerizable and roll-on/roll-off cargo; (3) independence from the Panama and Suez Canals; (4) applicability of the freighter concept to transportation needs throughout the world; (5) potential worldwide marketability of the ACV freighter; and (6) the Arctic-wide, all-season mobility of the freighter, which could also allow extraction of the vast mineral and fuel resources in the Arctic and thus stimulate settlement and development there.

## INTRODUCTION

For nearly 500 years seafaring nations of the North Atlantic have searched for a Northwest Passage between the Atlantic and Pacific Oceans. Such a passage through the Canadian Arctic Islands would indeed be a high prize because it would nearly halve the shipping distance between ports of the North Atlantic and the Orient, even with the Panama and Suez (when open) Canals available. Several possible Northwest or Arctic passages are indicated in figure 1, which is a map of the "top of the world." This map is derived from reference 1, which is a description of Arctic passages.

The first transit of a Northwest Passage was made by the Norwegian explorer, Roald Amundsen (who also discovered the South Pole), on a 3-year trip between 1903 and 1906. Since that time, several vessels have made passages over various routes.

The first commercial transit of a Northwest Passage was made by the icebreaker-tanker Manhattan in the fall of 1969 (ref. 2). The Manhattan sought to demonstrate the

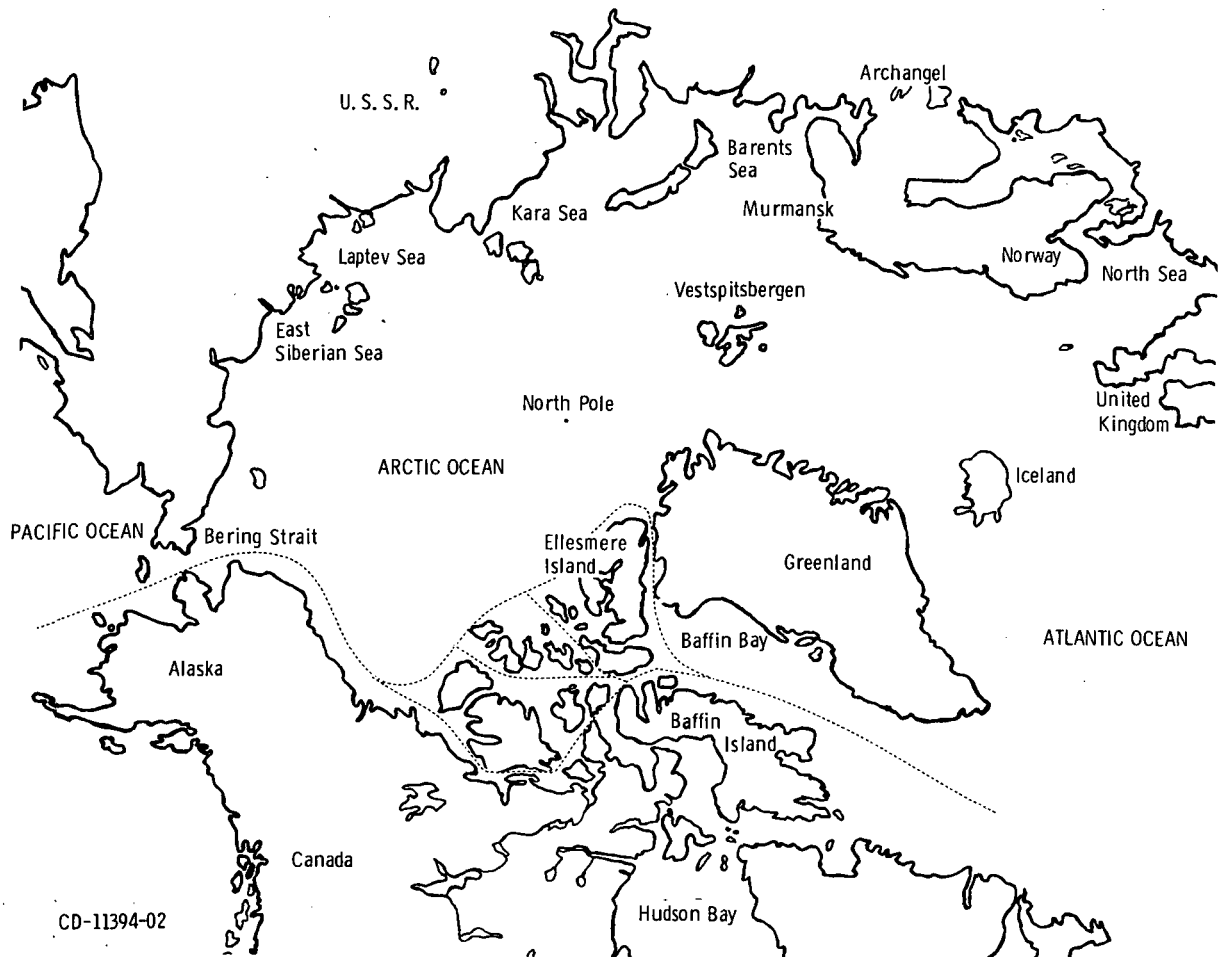


Figure 1. - Several possible Northwest or Arctic passages.

potential of large icebreaking ships for carrying oil from the Alaskan North Slope to the U.S. East Coast. The Manhattan carried one symbolic gilded barrel of oil from the Atlantic Ocean to Point Barrow, Alaska, and back to the Atlantic Ocean over the southernmost route shown in figure 1. However, that experience indicated that an icebreaker-tanker for year-round Arctic operation would require an even stronger hull and more powerful engines than the Manhattan. Thus, the resulting high cost of any icebreaking displacement ship would make this method of Arctic passage uneconomical.

Submarines, of course, would not require this icebreaking capability. The possible commercial use of nuclear cargo submarines that would make an Arctic Passage under the ice has been discussed in references 1 and 3. This transit capability was first demonstrated by the nuclear submarine Nautilus, which passed under the North Pole in 1958.

A Northeast Passage across the top of Eurasia has been used by Russia for many years. This passage is kept open as long as 150 days a year by a fleet of icebreakers, one of which is the nuclear-powered Lenin. However, international use of this passage has been hampered by territorial limit disputes (ref. 1).

Economic trends of the past two decades make a Northwest, or more generally, an Arctic Passage increasingly attractive. During this time a "world" economy that is increasingly dependent on international trade has developed. The projected growth of this world economy (fig. 2) will require a new international cargo transportation capability

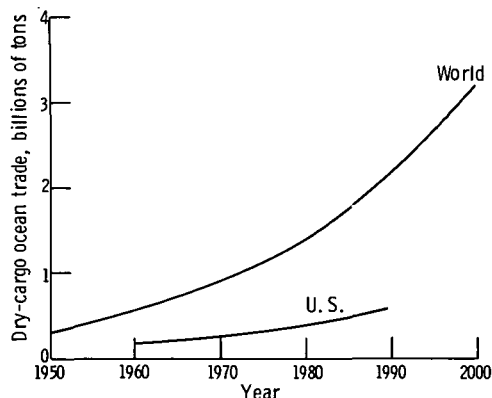


Figure 2. - Oceanborne-trade forecast.

with shorter transit times and higher productivity than at present. (A discussion of how international cargo transportation relates to interacting national economies is given in ref. 4.) This capability can be provided for East-West trade between North Pacific and North Atlantic ports by air-cushion vehicles using Arctic passages.

The purpose of this report is to identify a conceptual vehicle, a 9070-metric-ton (10 000-ton) nuclear-powered air-cushion vehicle, that could open the Northwest Passage and other Arctic passages to commercial traffic and to describe its implications. The

unique characteristic of an air-cushion vehicle (ACV), of course, is its ability to go over water, land, and ice; whereas a displacement ship is restricted to deep water and must impact the ice and withstand enormous ice pack pressure. Conceptual designs and implications of nuclear ACV's have been described previously in references 5 to 11, and those of large chemically powered ACV's in references 10 and 12 to 14.

Nuclear power, rather than chemical, is chosen for this study for three main reasons.

(1) Although chemically powered ACV's might be used initially for some Arctic routes, the fuel needed for a nonstop trans-Arctic capability (about 7400 km, or 4000 n mi) displaces a substantial amount of payload. Previous studies have indicated that nuclear-powered ACV's could carry freight more cheaply than nonstop chemically powered ACV's at distances greater than 3700 kilometers (about 2000 n mi) and that the nuclear ACV economic advantage would improve for greater ranges (ref. 8). Arctic refueling stations would increase the payload capability, but they would also increase the ACV system operating and capital costs.

(2) The topography and behavior of Arctic ice are not well known. Even once they are known and a trade route is selected, their variable nature may require Arctic ACV's to detour frequently around high ice obstacles such as 7-meter (23-ft) pressure ridges or 20-meter (65-ft) "verticals" (upended ice slabs). Nuclear-powered ACV's would have the reserve endurance for detouring with no penalty of payload reduction.

(3) The fuel autonomy of nuclear powerplants will make the complex and difficult logistics of fuel supply in such a hostile and remote region unnecessary.

Thus, although large chemically powered ACV's might open the Northwest Passage, they probably will serve only in a limited capacity. Nuclear-powered ACV's, on the other hand, offer the important incentives of nonstop port-to-port, as well as trans-Arctic, capability at lower cost and with fuel autonomy in the remote Arctic region. Thus, they will probably be necessary for large-scale, long-term operations.

This report contains a description of the conceptual vehicle, including its nuclear powerplant and operations, an assessment of its technical feasibility, estimates of the capital and operating costs, and identification of eligible cargo and markets. It also includes a comparison of distance, cost, and time for ACV freighters with that for nuclear-powered container ships, which will likely be operating in the same time period that ACV freighters could be - 1985 to 2000.

Portions of the information about ACV design and costs, Arctic conditions and shipping environment, and container ship specifications and costs were derived from conversations with Bell Aerosystems, Inc.; the Cleveland Port Authority (Trade Development Department); Arctic Systems, Ltd.; and Sea-Land Service, Inc.

## DESCRIPTION OF THE AIR-CUSHION FREIGHTER

The great advantage of an air-cushion vehicle is that it can go over Arctic ice; a displacement ship must go through or around the ice. An ACV could, in fact, cross most of the terrains that characterize the Arctic: open water, broken ice, tundra, and pack ice with ridges and crevices.

### Vehicle

One flexible-skirt design that can give an ACV its mobility is shown in figures 3 and 4. This is the single-skirt - peripheral-jet concept of the British (ref. 15). However, the multiple-skirt concept (fig. 5) of the French (refs. 16 and 17) could also have been used.

The flat-bed design of a 9070-metric-ton (10 000-ton) nuclear ACV freighter is shown in figure 6; its specifications are given in table I. The flat-bed design allows the

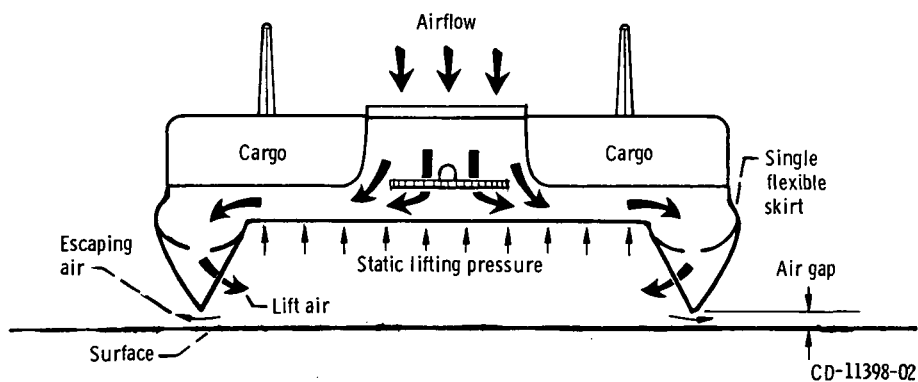


Figure 3. - Air-cushion-vehicle peripheral-jet - single-flexible-skirt principle.

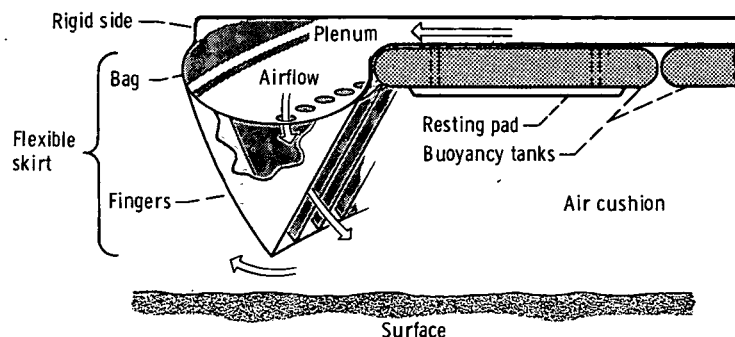


Figure 4. - Cutaway view of airflow through flexible skirt.

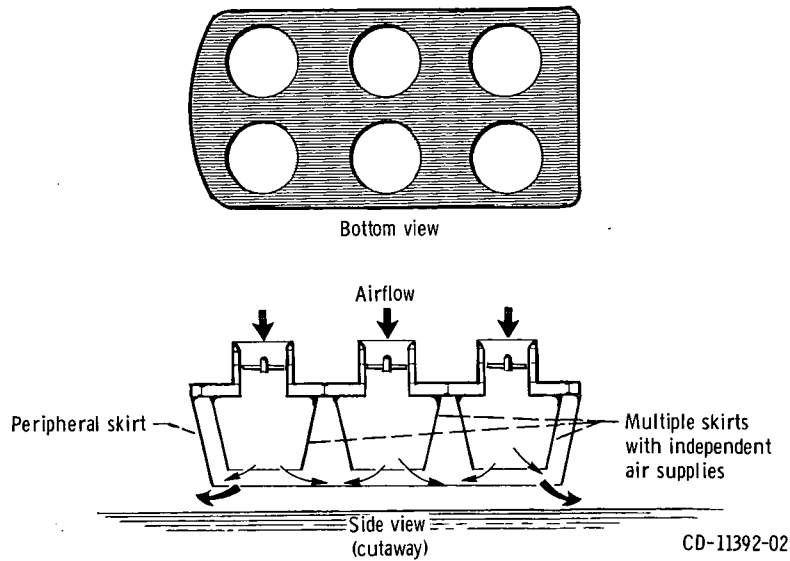
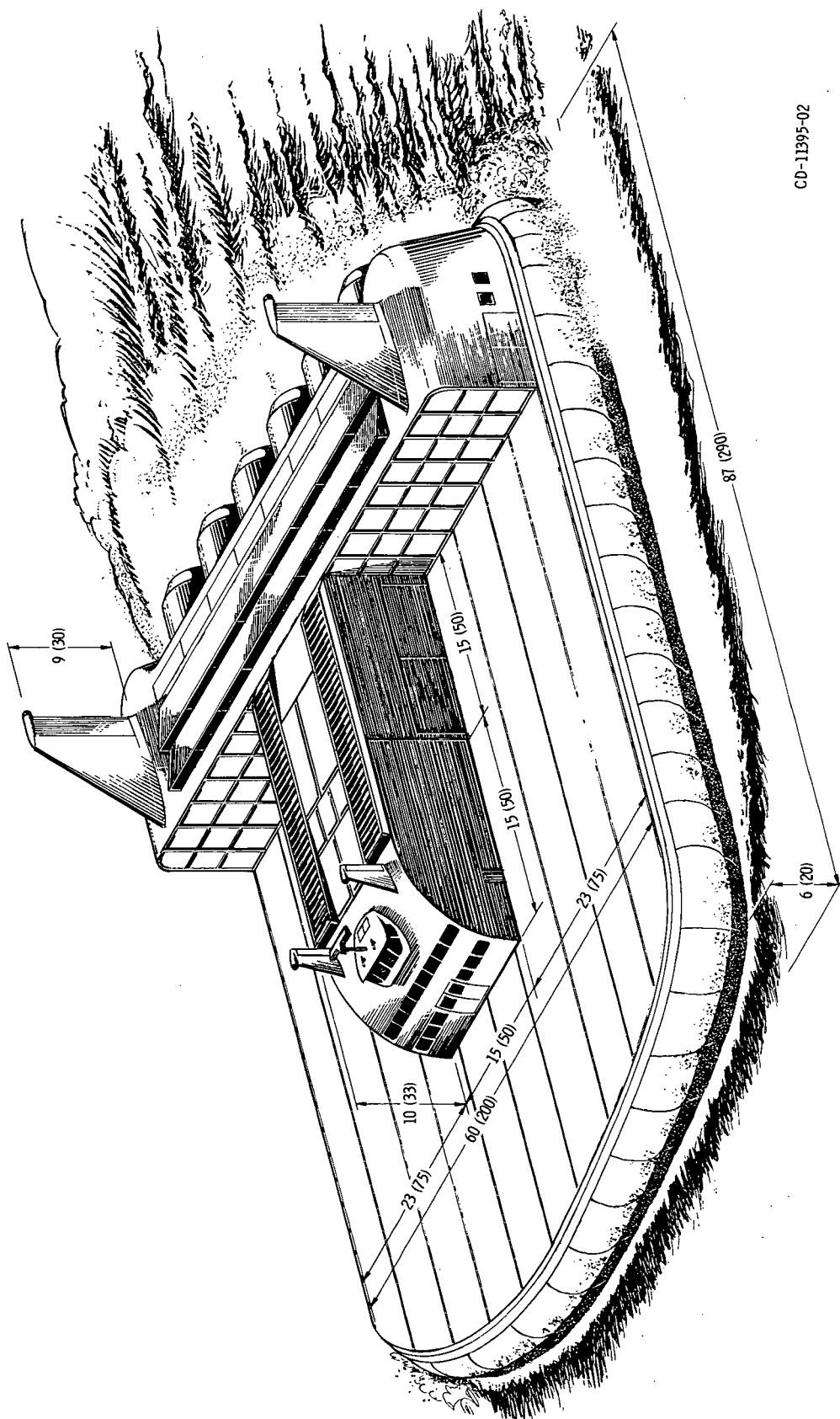


Figure 5. - Air-cushion-vehicle multiple-flexible-skirt principle.

TABLE I. - SPECIFICATIONS OF NUCLEAR AIR-CUSHION FREIGHTER

Weight, metric tons(tons):	
Gross . . . . .	9070(10 000)
Structure . . . . .	2270(2500)
Engine . . . . .	190(210)
Emergency fuel . . . . .	585(645)
Reactor core . . . . .	105(115)
Reactor shield . . . . .	490(540)
Payload . . . . .	5430(5990)
Operating parameters:	
Base pressure, $N/m^2(lb/ft^2)$ . . . . .	19 200(400)
Daylight clearance, cm(in.) . . . . .	7.6(3)
Velocity, km/hr(knots) . . . . .	185(100)
Emergency chemical range, km(n mi) . . . . .	925(500)
Power:	
Lift/drag ratio . . . . .	16
Specific fuel consumption, kg/kw-hr(lb/hp-hr) . . . . .	0.213(0.35)
Thrust/shaft-horsepower ratio, N/kW(lb/hp) . . . . .	9.75(1.64)
Shaft horsepower, MW(hp) . . . . .	569(763 000)
Thermal efficiency . . . . .	0.25
Reactor thermal power, MW . . . . .	2277
Dimensions, m(ft):	
Length . . . . .	87.4(290)
Breadth . . . . .	61.0(200)
Rigid-structure height . . . . .	10.1(33)
Flexible-skirt height . . . . .	6.1(20)
Cushion area . . . . .	83.9 by 56.4(275 by 185)





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Figure 6. - 9070-Metric-ton (10 000-ton) nuclear air-cushion-vehicle-freighter flat-bed design. Dimensions are in meters (ft).

freighter to carry a variety of cargo, such as containers, vehicles, and even modular buildings. The cargo area would be covered by contoured fiberglass or aluminum sections when underway to improve the aerodynamic profile and to protect the cargo. This contoured covering is shown in figure 7, which is an artist's rendering of an earlier conceptual ACV freighter (ref. 9) weighing 4535 metric tons (5000 tons).

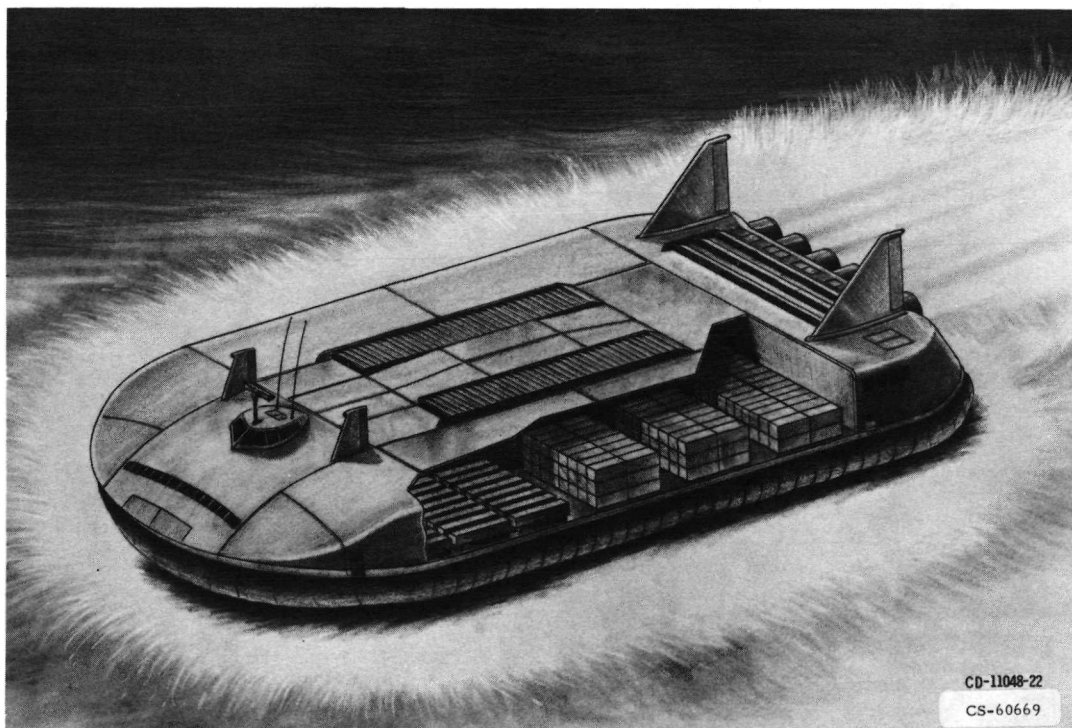


Figure 7. - 4500-Metric-ton (5000-ton), nuclear air-cushion-vehicle freighter.

Fully loaded, the ACV freighter of this study would weigh 9070 metric tons (10 000 tons) and have a cushion pressure of  $19\,200\text{ N/m}^2$  ( $400\text{ lb/ft}^2$ ). The freighter would be 87 meters (290 ft) long, 61 meters (200 ft) wide, and have a flexible skirt 6 meters (20 ft) high. It would carry about 5400 metric tons (6000 tons) of cargo and cruise at 185 km/hr (100 knots) over water and at 111 km/hr (60 knots) over ice. It could cross deep crevices 27 meters (88 ft) wide, waves 6 meters (20 ft) high, and solid obstacles 5 meters (16 ft) high. A later section, ARCTIC ROUTES, discusses the ice obstacle heights likely to be encountered.

## Power System

A schematic of the power system is shown in figure 8. Air for the cushion and for propulsion enters through louvers on the top of the craft. The air is pressurized by the fans and then passed over condensers which contain the turbine exhaust steam. The warmed, pressurized air from the lift fans goes into a plenum from which it is distributed to the peripheral jets.

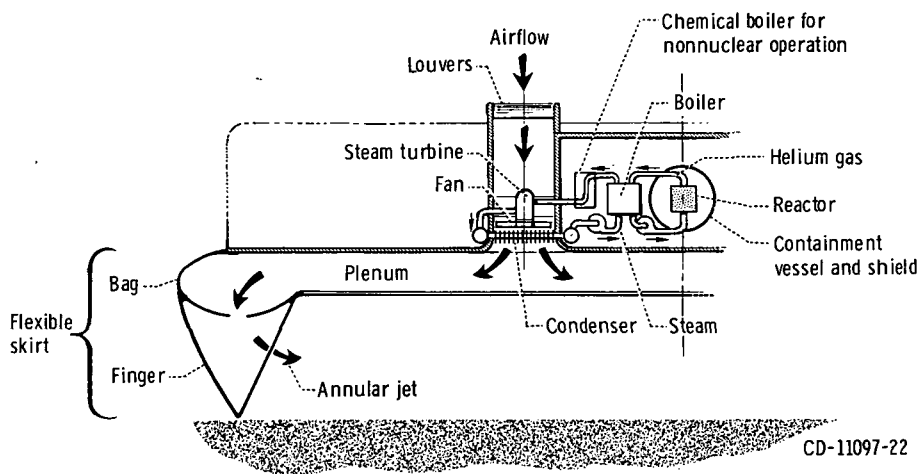


Figure 8. - Schematic drawing of steam turbine drive for lift fan.

The power for this ACV freighter could be supplied by a 2300-megawatt, gas-cooled thermal reactor and steam turbine system. Under normal operation the steam comes from a boiler heated by the hot gas from the reactor. After a reactor shutdown, steam would be generated in a chemically fired boiler. The freighter will carry enough reserve chemical fuel for a 925-kilometer (500-n mi) range at reduced speed.

The reactor core is shielded by a combination of borated water and tungsten or depleted uranium metal (fig. 9) (refs. 18 and 19). The outer diameter of the shield would be from 7 to 9 meters (about 25 to 30 ft). Just outside the shield the radiation level would be reduced to the maximum permissible general-population level, 0.25 millirem per hour.

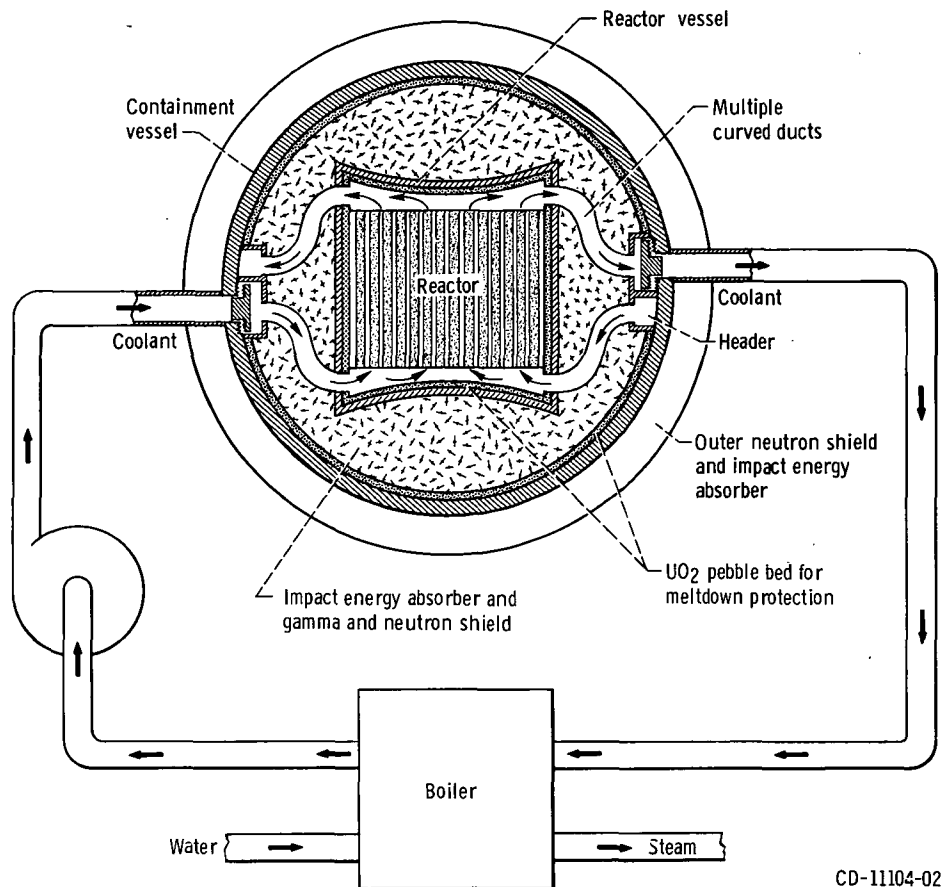


Figure 9. - Schematic drawing of a helium-cooled reactor for mobile applications.

## TECHNICAL FEASIBILITY OF LARGE NUCLEAR-POWERED AIR-CUSHION VEHICLES

Nuclear ACV freighters will require development in two major areas: large ACV's with both Arctic and ocean capability, and lightweight mobile nuclear powerplants. Summarized below is the state of the art in each of these areas.

The largest operational ACV's (in use since 1971) are 225-metric-ton non-self-propelled transporters used for carrying construction equipment in Arctic oil fields (ref. 20). However, most of the operational experience for ACV's of about this size comes from the 152-metric-ton SR.N4 hovercraft (fig. 10) (ref. 15). These hovercraft have been in ferry operation across the English Channel since 1968 and have proved to be both reliable and technically and economically practical.

Two 90-metric-ton surface-effect ships (hybrid ACV's that are restricted to water) will undergo sea trials in 1972. These vehicles are prototypes of larger surface-effect

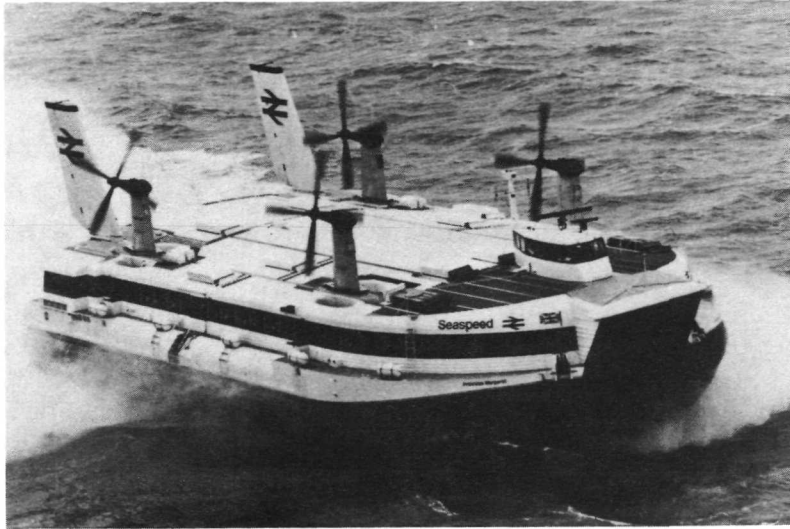


Figure 10. - British Hovercraft Ltd. SR.N4 air-cushion vehicle.

ships (destroyer size, weighing 2000 metric tons) to be built for the U.S. Navy by 1977. At least two other military development programs are underway: a 145-metric-ton amphibious assault landing craft for the Navy, and an Arctic-based ACV (as large as 900 metric tons) for the Advanced Research Projects Agency. Furthermore, on the civilian side, Arctic Systems, Ltd., may soon begin construction of a 2700-metric-ton transporter. ACV's above 3000 metric tons have only been studied conceptually (refs. 6 to 9 and 12 to 14). But according to ACV builders there appear to be no technical limitations to building "10 000 tonners" or even larger ones.

As for the Arctic capability, ACV's (mostly flat-bed) for carrying oil rigs, construction equipment, and other loads in the Arctic are now being studied (ref. 21), tested (refs. 22 and 23), and used (ref. 20). An assessment of the potential of small ACV's as a transportation system for the North Canadian and Arctic environments is given in reference 24.

A mobile nuclear powerplant for an ACV will be more difficult to develop than existing land-based and marine nuclear reactors because it must be more compact, weigh much less, and be safe if involved in an impact accident. The technology for an ACV reactor may come partly from land-based, high-temperature, gas-cooled reactors (which entered the commercial market in 1971); partly from nuclear space power systems which have development goals for both reactors and power conversion systems of compactness, lightweight, and reliability; and partly from an airborne nuclear powerplant technology program at NASA's Lewis Research Center that has stressed high-burnup fuel pins, optimized shield design, and impact and meltdown safety.

In particular, the lightweight/compactness feasibility has been suggested by analytical studies which indicate that current ship-reactor weight may be reduced by at least a factor of 10 and that the reactor and shield could be enclosed in a spherical containment vessel less than 9 meters (30 ft) in diameter (ref. 18).

The safety problem of preventing radioactivity release as a result of an ACV impact accident is a critical one. In fact, of all the technological problems of an airborne reactor, impact safety has the biggest question mark. Although there are indications that impact safety may be feasible, there are many difficult technology steps between these indications and demonstrated feasibility. Nonetheless conceptual safety solutions have been suggested and are outlined here.

There are two stages of an impact accident. First, the kinetic energy of the reactor - shield - containment-vessel (RSCV) system must be absorbed during the impact without rupturing the containment vessel. Second, after the impact, the thermal energy from decaying fission products must be transferred from the RSCV system without rupturing the containment vessel.

Safety during an accident will also require prevention of uncontrolled criticality. This might be accomplished by designing the reactor so it can be made subcritical by poison addition or moderator removal. Radar sensing of impending impacts would automatically activate these safety measures, as well as close and seal all penetrations of the containment vessel. The process of sensing the need for a reactor shutdown and then preparing the reactor system for an impact must be nearly foolproof. It should be just as reliable as sensing and shutdown processes for land-based nuclear electric generating plants. The reactor must also remain completely sealed during and after the impact to prevent sea water from flooding the core and conceivably restoring criticality and to prevent fission product release.

Two techniques for kinetic energy absorption have been examined in the technology program at Lewis. One technique would surround the containment vessel with material configurations that are highly energy absorbing, such as balsa wood, frangible tubes, or metal or plastic honeycomb. This technique appears reasonable for impact velocities to about 100 m/sec (about 200 knots).

The other energy-absorbing technique examined has been simply the deformation of the containment vessel and its contents. In fact, the RSCV system would be designed so that all parts of the system would serve multiple purposes, one of which would be to absorb kinetic energy. Simulated RSCV's (0.6-m- (2-ft-) diameter models weighing about 450 kg (1000 lb) each) have impacted concrete at velocities of 195, 320, and 332 m/sec (640, 1055, and 1090 ft/sec) without rupturing. Earlier tests at lower velocities are described in reference 25.

After an impact a second stage of the accident safety problem would occur. To overcome this, the reactor and safety system must be designed so that the heat from decaying fission products will not melt through the containment vessel. One approach to

this problem is to provide enough impact energy absorber around the RSCV to ensure that the shutdown cooling system will function after an impact. Another approach is to design an RSCV which will permit the core to melt without melting through the containment vessel. Preliminary studies indicate that for the ACV both of these approaches are feasible in principle.

## COSTS FOR THE AIR-CUSHION FREIGHTER

Because ACV's of several thousand metric tons have only been studied conceptually, the extrapolation of design, construction, operational, and cost data from about 200 to 9000 metric tons must be recognized as only an estimate.

### Capital Cost

A summary of capital costs is given in table II (all costs are given in current dollars). The development cost for a chemically powered ACV (vehicle, propulsion sys-

TABLE II. - CAPITAL COSTS OF NUCLEAR AIR-CUSHION FREIGHTER<sup>a</sup>

	Air-cushion vehicle and chemical powerplant backup	Nuclear powerplant
	Cost, millions of dollars	
Development	150	<sup>b</sup> 500
Average development <sup>c</sup>	1.5	(b)
First unit	65	<sup>d</sup> 13.4
Average unit	<sup>e</sup> 37.7	<sup>f</sup> 10.3
Average unit and development share	39.2	<sup>b</sup> 10.3
Average freighter	49.5	

<sup>a</sup>Gross weight, 9070 metric tons.

<sup>b</sup>It is assumed that reactor development cost will be borne by the U.S. government.

<sup>c</sup>Based on 100-unit production series.

<sup>d</sup>Includes \$5.4 million for a water-depleted uranium shield and \$8.0 million for reactor vessel, core structure, and in-core controls. Nuclear fuel cost is not included.

<sup>e</sup>Based on a 90-percent learning factor applicable to the entire 100-unit production.

<sup>f</sup>Based on a 93-percent learning factor applicable to the first 15 reactors; the cost of the 16th to the 100th reactors is the same as the cost of the 15th one.

tem, and nuclear-to-chemical switching capability) is estimated at \$150 million. The development cost of the nuclear powerplant (about \$500 million) is assumed to be borne entirely by the U.S. Government in view of their previous support of nuclear power research and development, the potential applications and benefits (ref. 11), and the likelihood that no private company could afford it.

The cost of the first ACV (not included in the development cost) is estimated to be about \$65 million. The cost of the first reactor, \$13.4 million, taken from reference 8, includes the shield cost of \$5.4 million and the reactor vessel, core structure, and in-core controls cost of \$8.0 million but does not include fuel-element cost.

However, the cost of a production unit decreases as the cumulative production of that unit increases. This experience is the basis of the "learning curve" concept that doubling the cumulative production of a unit results in a cost reduction of a constant percentage - the learning factor.

A production run of 100 ACV freighters with a learning factor of 90 percent applicable over the full production run is assumed. However, for the nuclear powerplants a learning factor of 93 percent applicable only over the first 15 (constant cost thereafter) is used. This is the value used by the Maritime Administration for marine nuclear powerplants, as cited in reference 26.

Thus, the average cost for a nuclear ACV freighter, accounting for the cost reduction obtained by "learning," would be \$49.5 million.

## Operating Costs

ACV freighters that move on ocean routes will have characteristics of both modern ships and large aircraft. Reference 12 (volume 6 of a series), which is an assessment of surface-effect ships for the American Merchant Marine that in fact uses a cost methodology based on Air Transportation Association methods, identifies these characteristics for a surface-effect ship (SES). (An SES is a hybrid ACV that is restricted to water; it is also called a Captured Air Bubble (CAB) ship.)

In particular, from reference 12, page 8-1:

"Certain aspects of design, fabrication, and operation of the CAB ship are similar to those of subsonic transport aircraft... The operation of the CAB ship is similar in some ways to the operation of conventional ships, as well as aircraft. Therefore, the CAB ship costs used in this study have been extrapolated from each of these sources where appropriate."

In both construction and operation, a surface-independent ACV with navigation and control automated to the extent of a large aircraft should resemble an aircraft even more than an SES resembles it. Therefore, the operating cost analysis of this ACV freighter will use information from the SES study (ref. 12) with modifications that ac-



count for more recent (since 1965) design and operational data for large ACV's, large aircraft, and high-speed ships.

To determine vehicle operating costs, it is necessary to choose the load factor and utilization of the vehicle. Present aircraft, standard-body freighters, have load factors of about 72 percent (ref. 27). However, the use of larger, wide-bodied aircraft such as the Boeing 747F or the Lockheed L-500 (civilian version of the military C5A) with their greater cubic capacity are expected to increase this load factor, perhaps to 85 to 90 percent. Although reference 12 assumed load factors of 75 percent for container ships (based on 1965 marine experience), it is believed that the coming generation of container ships (such as for Sea-Land Services, Inc.) can achieve load factors of 100 percent by using computerized assignment of container location and stowing order rather than random stowing.

Because of the ACV flat-bed design and removable cargo covers, the use of computerized cargo stowing, and the fact that fewer ACV terminals (relative to ship terminals) would tend to concentrate the cargo, an ACV load factor of 100 percent seems achievable.

A utilization of 0.6 (5256 hr underway per yr) corresponding to that used in reference 12 is assumed. At an average speed of about 150 km/hr over a typical trip distance of 12 000 kilometers, about 65 one-way trips can be made each year. Using a port staytime of 12 hours (suggested as achievable in ref. 12) the dock time per year would be about 800 hours. This would leave about 2700 hours a year for major repairs and maintenance.

The estimated operating costs of a nuclear ACV freighter are given in table III.

A crew of 10 (corresponding to that in ref. 12) will be needed to allow three watches with a three-man operating crew during the multiday trips. The 10th crew member will be a steward for food preparation and serving. Each three-man operating crew will have a pilot, a navigator, and an engineer who must have nuclear reactor training. The yearly salary, overtime, and fringe-benefit cost of the 10-man crew will be \$350,000; this is \$69,000 greater than the cost assumed in reference 12 to allow for both the higher salaries needed because of the Arctic duty and the additional nuclear training required. To provide for crew rotation and shore leave, three complete 10-man crews will be needed, resulting in a total yearly cost of \$1.05 million or about \$200 per operating hour (5256 hr).

The initial insurance cost would probably be relatively high because of the lack of experience and actuarial data covering such Arctic operations. If ACV freighters operate successfully and safely for a while, the basic insurance cost should level off at about \$150 per operating hour. This is based on the Boeing 747 experience of \$73 per operating hour (ref. 28), which is about  $3.0 \times 10^{-6}$  times the vehicle capital cost. However, this factor must be increased to account for the additional Arctic risk and the presence of nuclear material.

TABLE III. - DIRECT OPERATING COSTS OF  
NUCLEAR AIR-CUSHION FREIGHTER

	Cost, dollars per operating hour <sup>a</sup>	Cost, millions of dollars per year
Crew	200	1.05
Insurance:	230	1.21
Base	150	-----
Ice risk	75	-----
Nuclear risk	5	-----
Maintenance	2000	10.51
Capital recovery <sup>b</sup>	2700	14.20
Fuel	1150	6.05
Total	6280	33.02

<sup>a</sup>Number of operating hours per year is 5256;  
this does not include dock time.

<sup>b</sup>Recovery of capital investment at 25-percent  
discount rate (includes profit before taxes  
and interest due).

In particular, the North Ice clause generally increases marine insurance by 50 to 100 percent for ships exposed to the hazard of polar ice. Because the ACV will go over the ice and will have sophisticated navigation and guidance systems on board that will allow it to easily detour around major ice obstructions, the lower limit of 50 percent is added to the base insurance cost.

Reference 26 cites nuclear third-party insurance as about \$2.40 per displacement ton per year for container ships. This same unit cost is used for the 9070-metric-ton (10 000-ton) ACV freighter. Thus, the hourly insurance cost factor is  $4.6 \times 10^{-6}$  times the ACV capital cost, and the total yearly insurance cost is about 2.4 percent of the freighter capital cost. For comparison, insurance on marine vessels may cost from 1 to 3 percent of the capital cost per year.

Extrapolations of maintenance costs (from Bell Aerosystems) for operational ACV's indicated a minimum cost of \$4000 per operating hour for a 9070-metric-ton (10 000-ton) ACV. This cost is high mainly for two reasons: (1) the susceptibility of the engines to dirt, sand, ice, or salt spray kicked up by the airflow from the cushion, and (2) high skirt wear (fatigue caused by constant flapping or flexing of the skirt rather than friction wear) and the attendant, presently tedious, process of skirt replacement.

For the utilization assumed for the ACV freighters the yearly maintenance cost would be about 42 percent of the capital cost of a freighter. Even if the overall system

were cost competitive, this maintenance cost would not likely remain high because of the substantial extra profit to be gained by reducing it. Furthermore, such a high maintenance cost implies substantial ACV downtime for maintenance and, hence, the utilization assumed (0.6) might not be achievable.

Therefore, a lower maintenance cost (\$2000 per operating hour) is assumed for the following reasons: (1) to identify the probable degree of cost reduction which must be achieved in the economically important area of maintenance if the ACV freighter is to compete for transoceanic cargo, (2) to make the assumed utilization more credible in view of the implied maintenance downtime, and (3) to account for substantial opportunities for maintenance cost reduction that are outlined in the following paragraphs.

There are three indications that a much lower maintenance cost can be achieved: (1) expected maturing of the relatively new technologies of flexible skirts and extensive particulate filtration for the engines; (2) expected development of special, efficient skirt-maintenance techniques as ACV's grow in size and applicability; and (3) the experience of the Bertin Company (France) who operated a 28-metric-ton ACV, the N-300 (ref. 17) for more than 500 hours "with no incident and absolutely no skirt repair." The Bertin experience was not factored into the extrapolated maintenance cost.

The capital investment in the ACV freighter is assumed to be recovered at a 25-percent discount rate over its lifetime. This is a rate sometimes recommended for novel, unproved, and hence high-risk programs financed by private industry. A discount rate simply means that the capital investment should be recovered at a 25-percent rate (to cover taxes, profit, and interest due), or else the investment should be made elsewhere to get that return, or to get a lower return at a lower risk. This compares with 21 percent used in reference 12.

The ACV structure life and the reactor shield life are assumed to be 15 years; the ACV machinery life and the reactor structure life are assumed to be 10 years (ref. 8). The capital recovery factors (fraction of capital costs to be recovered each year) for 25 percent over 10 and 15 years are 0.280 and 0.261.

The unit nuclear fuel cost assumed for this analysis is 50 cents per megawatt thermal per hour (ref. 8). This corresponds to \$12 per gram of uranium-235 and is equivalent to about 1.7 mills per kilowatt-hour of electrical energy for a nuclear electric powerplant with a thermal efficiency of 30 percent. The nuclear fuel cost includes nuclear fuel burnup cost, fuel-element manufacturing costs, fuel reprocessing and shipping costs, and interest charges on unburned nuclear fuel. It is intended to cover all costs associated with the nuclear fuel cycle.

Thus, the total operating cost per year for a nuclear ACV freighter is \$33 million. The ACV direct operating cost (DOC) will be about 0.8 cent per metric ton-kilometer (1.3 ¢/ton-n mi).

This cost does not include the indirect operating cost (IOC), which aircraft experience would indicate to be substantial (about 3.5 cents per metric ton-kilometer (6 ¢/

ton-n mi)). However, ACV freighters will likely use modified shipping facilities in their early stages; and the introduction of a totally new transport form should be more easily adapted to an automated, efficient, and low-cost cargo processing and handling system than an established transport form with numerous vested interests, like the aircraft.

Hence, the IOC for surface-effect ships based on advanced, automated, containerized cargo handling is used in table IV (ref. 12). The cargo handling charge (including loading/unloading and packing/unpacking of containers within the terminals) would be about 3 percent of the DOC. The terminal and port charges (such as harbor, customs, and tug fees) are assumed to be 10 percent of the DOC. Overhead allocation (offices; supplies; and legal, technical, administrative, and sales expenses) is assumed to be 15 percent of the DOC. The total IOC for the ACV freighter would be 28 percent of the DOC or about 0.2 cent per metric ton-kilometer (0.37 ¢/ton-n mi).

The total operating cost of the nuclear ACV freighter would thus be 1.0 cent per metric ton-kilometer (1.7 ¢/ton-n mi).

TABLE IV. - INDIRECT OPERATION COSTS OF NUCLEAR AIR-CUSHION FREIGHTER<sup>a</sup>

Category	Indirect operating cost, percentage of direct operating costs	Description
Cargo handling costs	3	Loading and unloading containers; packing and unpacking containers (labor, equipment, and stowage charges)
Terminal and port charges	10	Amortization and operating costs of specially constructed or modified facilities for the ACV freighter. Harbor and light dues, tags, customs fees, and pilotage.
Overhead allocation	15	General management expenses including office space; supplies; and legal, technical, and administrative personnel, and sales expenses.
Total	28	

<sup>a</sup>From ref. 12.

## ARCTIC ROUTES

Two trans-Arctic ACV routes are selected for this study (fig. 11). Exact specification of the routes is beyond the scope of this study; hence, only the regional variations of the routes are shown. One route is a North Polar Passage, which would be followed when traveling from Europe to the Orient, starting at the Greenwich Meridian ( $0^{\circ}$  longitude), passing to the east of Iceland and Greenland, across the North Pole, and then turning to about  $170^{\circ}$  W longitude to go through the Bering Strait. The other route is a Northwest Passage, which when traveling from the eastern U.S. and Canada, would pass Newfoundland, go into the Hudson Strait and across the north part of Hudson Bay, across various channels, bays, and peninsulas to the Beaufort Sea north of Alaska, then around Point Barrow, and through the Bering Strait.

The topography, behavior, and other characteristics (such as hardness and proximity to land) of polar ice are not well known. Although the average ice-ridge height

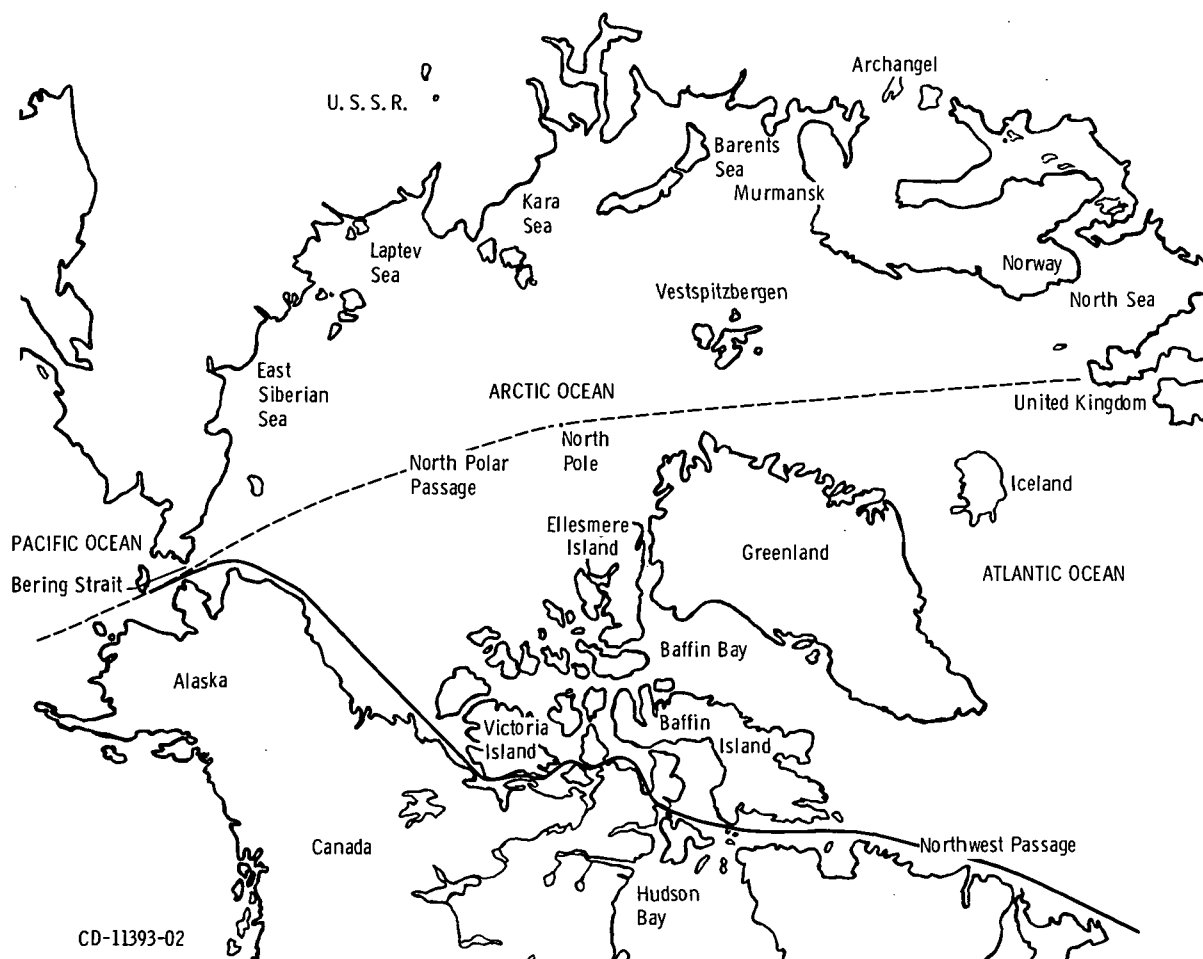


Figure 11. - Air-cushion-vehicle Arctic routes.

above the surface of the polar ice seems to be between 1 and 2 meters, occasional wind-driven pressure ridges may reach heights of nearly 7 meters (23 ft) and ice "verticals" (upended ice slabs) may reach 20 to 30 meters (65 to 100 ft). Thus, before commercial ACV routes across the Arctic can be selected, the Arctic ice must be thoroughly mapped and its behavior much better understood.

Based on the present knowledge of the general characteristics of the Arctic ice and if we assume that further Arctic studies, while uncovering the details, will confirm these general characteristics, the conceptual ACV freighter in this study should be satisfactory. The 6-meter-high flexible skirt and reduced over-ice speed (110 km/hr, or 60 knots) should be adequate for average ice conditions. Sophisticated obstacle-detection and navigation systems should allow the ACV freighter to detour around major obstructions and seek a path which will "follow" acceptable ice conditions. Thus, exact ACV trade routes through the Arctic, especially across the polar ice, might be chosen as a trip progresses.

Substantially different routes might be desirable to permit off-loading cargo from conventional ships to ACV's for the Arctic (or ice) crossing and then transferring the cargo back to another displacement ship waiting in ice-free water at the other side of the ice pack. This is a form of the "landbridge" discussed in the next section. Cargo transfer would occur at ports just south of the severe ice regions; for example, Nome, Alaska; St. Johns, Newfoundland; or perhaps somewhere on Greenland, Iceland, the Aleutians, or the Spitzbergen Islands. This cargo transfer technique might be used initially with first-generation chemically fueled ACV's making a nonstop Arctic crossing. Of if it were practical to use chemical ACV's for the entire port-to-port trip then the "cargo transfer ports" would be refueling stations.

Economic trade-off studies (beyond the scope of this study) of displacement ship fleet and chemical ACV fleet size, scheduling, operating costs, and transfer port costs could determine whether such a cargo transfer process or refueling stations might be feasible.

## COMPARISON TO CONVENTIONAL EAST-WEST FREIGHT TRANSPORT

In order to judge its freight-hauling characteristics fairly, the nuclear ACV using Arctic passages must be compared to conventional vehicles that will likely be plying East-West trade routes in the same time period that the nuclear ACV could be, 1985 to 2000.

Table V compares several typical productivity and power characteristics of an existing supertanker, an existing oil-fired container ship, a next-generation (nuclear)

TABLE V. - COMPARISON OF FREIGHT-CARRIERS ON EAST-WEST ROUTES

	Supertanker	Container ship		Aircraft	Nuclear ACV
		Oil fired	Nuclear		
Payload, metric tons(tons)	180 000 (200 000)	18 000 (20 000)	27 000 (30 000)	108 <sup>a</sup> (120)	5400 (6000)
Cruising speed, km/hr(knots)	29.6(16)	38.8(21)	61(33)	835(450)	<sup>b</sup> 148(80)
Load factor	1.0	1.0	1.0	0.85	1.0
Work capacity, <sup>c</sup> metric ton-km(ton-n mi)	5 320 000 (3 200 000)	700 000 (420 000)	1 640 000 (990 000)	76 500 (46 000)	800 000 (480 000)
Route length, km(n mi)	35 200 <sup>d</sup> (19 000)	22 200 (12 000)	22 200 (12 000)	10 200 <sup>a</sup> (5500)	12 900 (7000)
Delivery rate, <sup>c</sup> metric ton/hr(ton/hr)	151(168)	31.5(35)	74(83)	<sup>e</sup> 7.0(7.7)	62(69)
Power, kW(hp)	37.3 (50 000)	23.8 (32 000)	112 (150 000)	149 (200 000)	567 (760 000)
Ratio of power to payload, W/metric ton(hp/ton)	0.21(0.25)	1.3(1.6)	4.2(5.0)	1380(1670)	105(126)
Ratio of energy to payload capacity, <sup>f</sup> kg/fuel metric ton-km(lb fuel/ton-n mi)	0.0015 (0.0055)	0.0073 (0.027)	0.014 (0.053)	0.35 (1.3)	0.12 (0.44)

<sup>a</sup>At 6500-km (3500-n mi) range the Lockheed L-500 payload is about 120 metric tons; the Boeing 747F payload is about 100 metric tons. For North Atlantic-Orient flights, it is assumed these aircraft would make one refueling stop, probably in Alaska.

<sup>b</sup>ACV speed is 100 knots over water and 60 knots over land and ice, for an average of 80 knots.

<sup>c</sup>Includes load factors.

<sup>d</sup>Assumes voyage length increases by 12 900 km (7000 n mi) because a supertanker, being too large for the Panama Canal, must "round the Horn" (southern tip of South America).

<sup>e</sup>Allows 1 hour for refueling stop.

<sup>f</sup>For comparative purposes, energy consumption for all vehicles including nuclear ones is based on specific fuel consumption 0.213 kg/kw-hr (0.35 lb/hp-hr); ACV speed used is (100 knots).

container ship, a large all-cargo aircraft, and a nuclear ACV freighter. (A similar comparison of small hovercraft to many forms of transport is given in ref. 29.)

The coming generation of oil-fired container ships will be represented by ships that move at 61 km/hr (33 knots), have a cargo deadweight of about 18 900 metric tons (21 000 tons), and require 120 000 shaft horsepower. Eight of these ships are on order for Sea-Land Service, Inc.; the first is to be delivered in August 1972.

Although the eight container ships ordered by Sea-Land are oil fired, the high power needed for such fast, large container ships should come increasingly from nuclear powerplants. Nuclear power is now competitive for ship powers above 100 000 shaft horsepower according to the Maritime Administration, which also has projected a worldwide need for about 500 ships with over 100 000 shaft horsepower by 1990 (ref. 30). Another projection by the Japan Atomic Industrial Forum is that there will be 280 nu-

clear container ships on the high seas by the year 2000 (ref. 31).

Thus, based on the container ships ordered by Sea-Land, the projections for nuclear-powered ships, and the work described in reference 26 (British Nuclear Ship Study), this study assumes the next generation of container ships will be nuclear-powered, 61-km/hr (33-knot), 27 000-metric-ton- (30 000-ton-) cargo-deadweight, 130 000- to 150 000-shaft-horsepower vessels.

One additional and relatively new means of East-West cargo transport is a hybrid sea/land mode, the landbridge. The concept of a U.S. landbridge is to include an over-land link for shipping routes between ports of Europe and the Orient. The landbridge would be an alternative to the longer all-water route through the Panama Canal. The procedure would be to transfer containers from a ship to a land carrier (probably railcars) on one U.S. coast (East, West, or Gulf), carry the containers across the country to another U.S. coast, and then transfer the containers from the railcars to another ship for completion of the trip.

A derivative of this landbridge, called a mini-landbridge, would involve Western U.S. - Europe cargo or Eastern U.S. - Japan cargo. The mini-landbridge would offer a transit time shorter by 5 to 7 days for the same price paid for the all-water Panama Canal route (ref. 32). This transit shortening is based on current ship speeds (about 20 to 25 knots); with the advent of 33-knot ships the time savings will be 3 to 5 days.

A number of factors, including the newness of the landbridge concept, possible belatedness of land carriers in offering landbridge service after many large container ships are already ordered, and implementation problems arising from the dual nature (sea/land) of this transport mode (tariffs and rates, regulations, and land carrier scheduling and capacity) make it difficult to assess the competitiveness and costs of the landbridge concept or its derivatives.

Therefore, limited to the particular example given from reference 32, only comparisons with the mini-landbridge are provided and only then for the charge per cargo ton and for trip times over the appropriate routes (later in this section).

Table VI lists typical costs per metric ton-kilometer for transporting cargo on various trans-oceanic carriers. The cost for the coming generation of 33-knot, oil-fired container ships and the cost for the nuclear container ships are assumed to remain the same as the present container ship cost. The cost increase due to higher power (needed for higher speed) is offset by cost decreases due to the "economy of size" obtained because of the large cargo deadweight and due to the use of nuclear power (ref. 30). The nuclear ACV cost would thus be about 20 percent more than the nuclear container ship costs.

For an additional comparison, aircraft costs are shown, based on projected Lockheed L-500 costs (ref. 33) and a load factor of 85 percent. The payload is approximately that of an L-500 at 6500-kilometer (3500-n mi) range, appropriate to East-West



TABLE VI. - COST COMPARISON OF MODES OF CARRYING  
TRANSOCEANIC CARGO

	Operating costs, cents/metric ton-km (cents/ton-n mi)		
	Direct	Indirect	Total
Supertanker (oil fired) <sup>a</sup>	-----	-----	0.020(0.034)
Container ship (oil fired) <sup>b</sup>	-----	-----	0.84(1.4)
Container ship (nuclear) <sup>c</sup>	-----	-----	0.84(1.4)
ACV (nuclear) <sup>d</sup>	0.8(1.3)	0.2(0.4)	1.0(1.7)
Aircraft <sup>e</sup>	2.1(3.5)	3.5(5.9)	5.6(9.4)

<sup>a</sup>From ref. 4; indirect and direct costs not available.

<sup>b</sup>Existing oil-fired container ship.

<sup>c</sup>Anticipated nuclear-powered container ship in the 1980's.

Relative to existing container ship, the cost increase due to higher power needed (for higher speed) is assumed to be offset by the cost decrease offered by the large cargo deadweight and by the use of nuclear power.

<sup>d</sup>Indirect operating costs are 28 percent of direct operating costs, based on ref. 12 (table IV).

<sup>e</sup>Based on 85-percent load factor, data from table V, and projected costs for Lockheed L-500 from ref. 33.

trips with one refueling stop, probably in Alaska. Although a supersonic transport could be available in the 1985-2000 time period, it is not considered here.

Based on the comparative operating costs in table VI, a nuclear ACV will most directly compete with nuclear-powered container ships. But the cost per metric ton-kilometer is not a complete indicator of East-West shipping costs because of the great difference in route length used by the ACV and ship.

Table VII lists the estimated displacement ship and ACV route distances between selected Atlantic and Pacific ports. The ship distances were derived from reference 34; the ACV distances were obtained from map measurements. The distance savings by using the northern trans-Arctic passages shows why they have been sought for so long. For example, trading distance between London and Tokyo would decrease by about 10 350 kilometers (5600 n mi), between London and San Francisco by about 2220 kilometers (1200 n mi), and between New York and Tokyo by about 3610 kilometers (1950 n mi). Re-opening the Suez Canal would slightly reduce the London-Tokyo savings to about 9250 kilometers (5000 n mi). The table also shows that the ship route through the Panama Canal is shorter than the ACV route for trips between the east and west coasts of the U.S.

TABLE VII. - COMPARISON OF APPROXIMATE DISTANCES BETWEEN PORTS

Mode	Route	Origin	Destination		
			Tokyo	Shanghai	San Francisco
			Approximate distance between ports, km(n mi)		
Ship <sup>a</sup>	Suez Canal	London	21 555(11 650)	19 610(10 600)	-----
ACV	North Polar Passage	London	12 340(6670)	14 465(7820)	12 245(6620)
Savings			9215(4980)	5145(2780)	-----
Ship <sup>a</sup>	Panama Canal	London	22 720(12 280)	24 355(13 165)	14 500(7840)
ACV	North Polar Passage	London	12 340(6670)	14 465(7820)	12 245(6620)
Savings			10 380(5610)	9890(5345)	2255(1220)
Ship <sup>a</sup>	Panama Canal	New York	17 965(9710)	19 580(10 585)	9740(5265)
ACV	Northwest Passage	New York	14 365(7765)	16 490(8915)	14 270(7715)
Savings			3600(1945)	3090(1670)	(b)

<sup>a</sup>From ref. 34.<sup>b</sup>Route through Northwest Passage is longer by 4530 km(2450 n mi).

TABLE VIII. - COMPARISON OF CHARGE PER CARGO METRIC TON

Mode	Route	Origin	Destination		
			Tokyo	Shanghai	San Francisco
			Charge per metric ton <sup>a</sup> , dollars		
Ship	Suez Canal	London ↓	180	165	---
	Panama Canal		190	205	120
ACV	North Polar Passage		125	145	120
Ship/rail	Landbridge <sup>b</sup>		---	---	120
Ship	Panama Canal	New York ↓	150	165	80
ACV	Northwest Passage		145	165	145
Ship/rail	Landbridge <sup>b</sup>		150	165	---
Rail <sup>c, d</sup>	-----		---	---	35
Truck <sup>c, e</sup>	-----		---	---	110

<sup>a</sup>Ship cost is 0.84 cent per metric ton-kilometer (1.4¢/ton-n mi). ACV cost is 1.0 cent per metric ton-kilometer (1.7¢/ton-n mi).

<sup>b</sup>These charges are for the mini-landbridge concept, wherein overland transport by rail across the U.S. is used (for cargo originating or terminating in U.S.) instead of the all-water route through the Panama Canal (ref. 32).

<sup>c</sup>Based on New York - San Francisco highway distance of 4850 kilometers (3011 s mi) from ref. 34.

<sup>d</sup>Rail cost of about 0.75 cent per metric ton-kilometer (1.1¢/ton-s mi) assumes unit train piggyback configuration with 100 percent load factor (ref. 35).

<sup>e</sup>Truck cost of about 2.3 cents per metric ton-kilometer (3.3¢/ton-s mi) obtained from ref. 35.

Table VIII compares the charge per metric ton of transporting cargo by nuclear ACV and by nuclear container ship between the selected ports of the North Atlantic and North Pacific listed in table VII, using costs taken from table VI. The mini-landbridge transport mode charges, the same as by way of the Panama Canal, are also shown. Between Europe and the Orient the ACV charge per cargo metric ton would be as much as 30 percent less than the ship charge. Between Europe and the western U.S. and between the Orient and the eastern U.S. the charge would be about the same. But between the eastern and western U.S. coasts the ACV charge would be almost twice the ship charge.

For added information, table VIII includes the charge for New York - San Francisco freight transport by rail and by truck. These charges are based on a distance of 4850 kilometers (3011 statute miles (s mi)) and costs of 2.3 cents per metric ton-kilometer (3.3¢/ton-s mi) for trucks and 0.75 cent per metric ton-kilometer (1.1¢/ton-s mi) for rail (ref. 35).

Existing container ships can cruise at 37 to 46 km/hr (about 20 to 25 knots); the anticipated generation of nuclear container ships will cruise at 61 km/hr (33 knots); the nuclear ACV's would cruise at 185 km/hr (100 knots) at sea and 110 km/hr (60 knots) over the Arctic ice and tundra for an approximate average ACV speed of 148 km/hr (80 knots). The trip times are compared in table IX using the distances from table VII and allowing 8 hours for the Panama transit. Going by ACV, about 12 days is saved for Europe-Orient trips (with the Suez Canal closed) and about 7 days for New York - Orient or London - San Francisco trips. For New York - San Francisco trips, about 3 days would be saved, although the charge would be nearly twice as much by ACV as by ship (table VIII).

Table IX also shows trip times for the mini-landbridge mode where appropriate. Even with the 33-knot container ships, the mini-landbridge would still take 2 to 5 days longer than the ACV mode.

TABLE IX. - COMPARISON OF TRIP TIMES

Mode	Route	Origin	Destination		
			Tokyo	Shanghai	San Francisco
			Trip time, days		
Ship <sup>b</sup>	Suez Canal	London	15.1	13.7	----
ACV <sup>d</sup>	North Polar Passage	London	3.5	4.1	----
Savings			11.6	9.6	----
Ship <sup>b, c</sup>	Panama Canal	London	15.8	17.0	10.2
Ship/rail	Landbridge <sup>e</sup>	London	----	-----	~6
ACV <sup>d</sup>	North Polar Passage	London	3.5	4.1	3.4
Savings - ACV over landbridge			----	-----	~2.6
Savings - ACV over ship			12.3	12.9	6.8
Ship <sup>b, c</sup>	Panama Canal	New York	12.6	13.7	7.0
Ship/rail	Landbridge <sup>e</sup>	New York	~9	~10	----
ACV <sup>d</sup>	Northwest Passage	New York	4.0	7.5	4.0
Savings - ACV over landbridge			~5	~2.5	----
Savings - ACV over ship			8.6	6.2	3.0

<sup>a</sup>Distances taken from table VII.

<sup>b</sup>Nuclear container ship with speed of 33 knots.

<sup>c</sup>Includes 8-hr average Panama Canal transit time.

<sup>d</sup>Average speed, 80 knots.

<sup>e</sup>Mini-landbridge mode, wherein cargo either originates or terminates on one of the U.S. coasts.

There is another substantial benefit from shorter trip times. An increasing problem of shippers is the boredom at sea and the libido and alcoholism ashore that occur in shipping crews who may be at sea for 24 days and in port for 12 hours. It is increasingly difficult to attract and keep young men in the maritime service because of the comparative isolation from their families. The use of nuclear container ships with their higher speed would reduce the time at sea to about 12 days for similar voyages. If the landbridge were used, the cargo trip time might be reduced to 10 days, and the vessel and crew at-sea time would be reduced even further by the cross-country time of 2 to 3 days. However, the use of ACV freighters on Arctic passages would still offer the shortest at-sea time, between 3 and 8 days.

## ELIGIBLE CARGO

The speed, low cost, and flat-bed design of this ACV freighter make it well-suited to carry the containerized and roll-on/roll-off cargo now handled by ships and to carry wholly new types and configurations of cargo. However, supertankers and bulk/ore carriers will continue to transport inexpensive bulk cargos such as oil, liquified natural gas, grain, and ores between present sources and markets much more cheaply than a nuclear ACV could.

In a roll-on/roll-off mode (fig. 12) this ACV freighter could carry cars, tractors, road construction machinery, recreation vehicles, mobile homes, and trailer trucks and carry them to and from new ports that could never be reached by ships. It could transport large preloaded pallets of machinery or appliances fast enough to allow expensive inventories of imported goods to be reduced. ACV's could carry modular, prefabricated, and preoutfitted building units (fig. 13). A building unit might be a factory, equipment service center, educational center, hospital, barracks, field kitchen, or temporary office.

Table X lists some families of products that are presently "air eligible," that is, products having a value of at least \$2.20 per kilogram (\$1.00/lb) that now move long distances by air (ref. 36). The table also lists some products that would become air eligible if the total air-cargo cost were reduced by 25 to 35 percent. The nuclear ACV freighter described in this study could carry cargo at about one-fifth the projected cost by air freighter. Hence, all the products listed in table X would be ACV-eligible.

The nuclear ACV can provide as much as 80 percent of the time savings of jet aircraft over ships on trips between the North Atlantic and the Orient for one-fifth the cost of aircraft transport. Because of this speed, several categories of "perishables," including monthly newsprint, fresh and prepared foods, cut flowers, competitive products, and short-lived chemical compounds, might be carried by ACV.

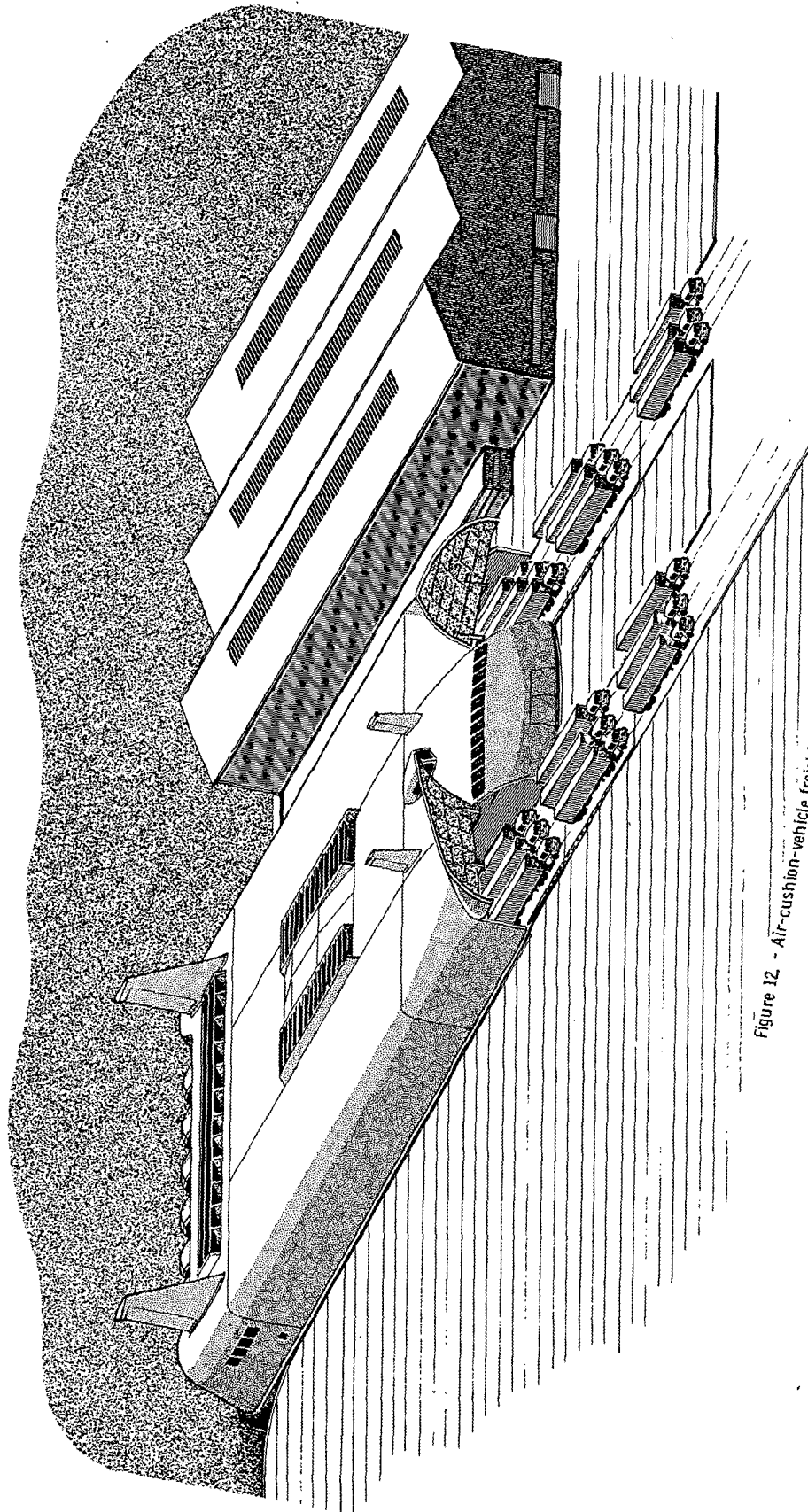


Figure 12. - Air-cushion-vehicle freighter in roll-off cargo transfer mode.

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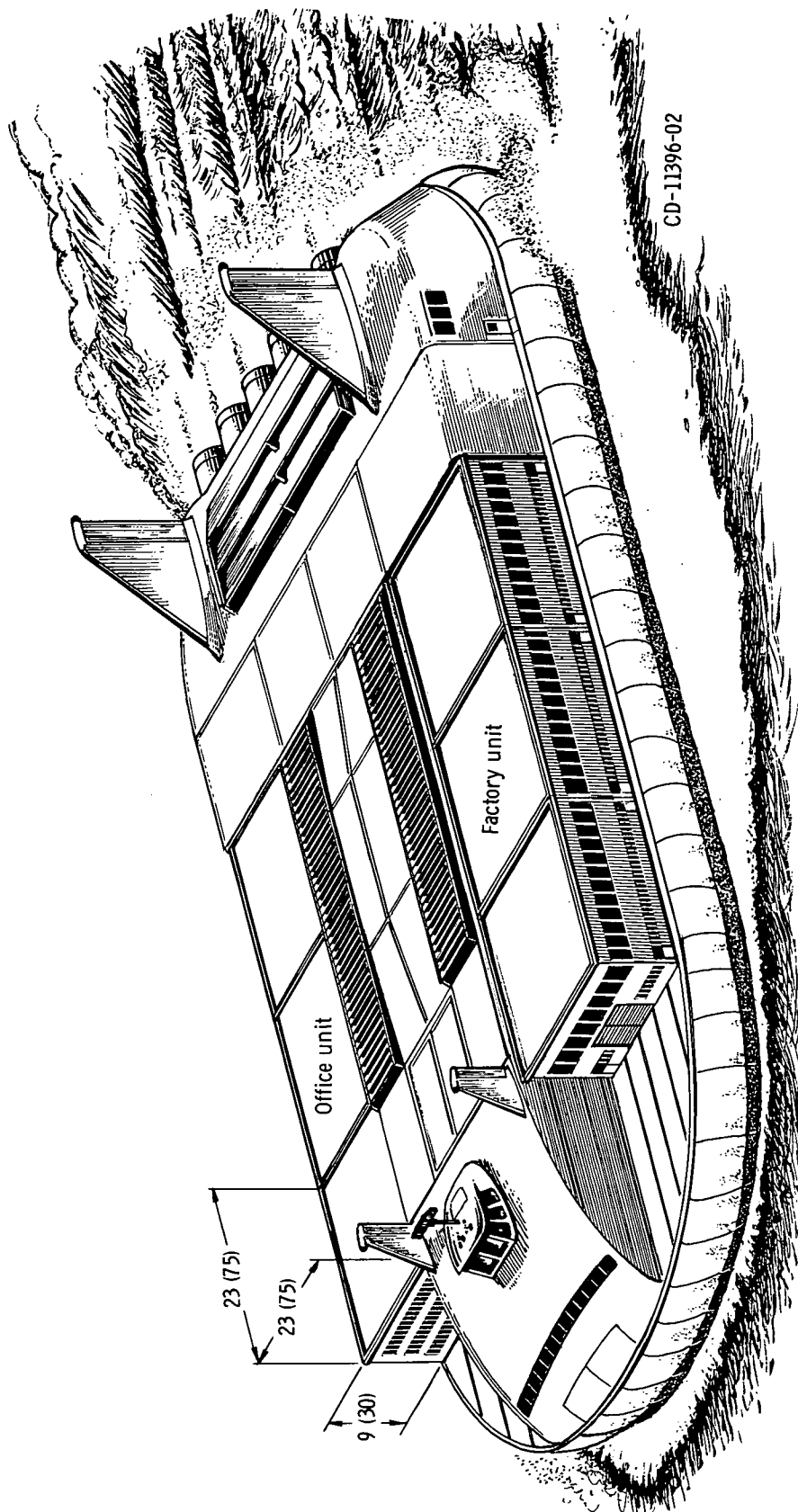


Figure 13. - Air-cushion-vehicle freighter in "mobile building" mode. Dimensions are in meters (ft).

TABLE X. - CARGO CATEGORIES THAT COULD BE HANDLED BY  
AIR-CUSHION FREIGHTER<sup>a</sup>

Products presently air-eligible (value, \$1.43 to \$2.20/kg (\$0.65 to \$1.00/lb))	Products that could become air- eligible at reduced rates (value, greater than \$2.20/kg (\$1.00/lb))
Refrigerators Automobiles Air conditioners Stoves Clothes washers Dishwashers	Electronic data processing equipment Finished apparel Optical equipment Hi-fi equipment Transistor radios

<sup>a</sup>From ref. 36.

Only highly valuable or highly perishable cargo should remain the exclusive domain of air freighters. Examples of this type of cargo are jewelry, cosmetics, daily newsprint, and small-lot highly competitive products for initial disclosure or demonstration (such as fashion clothing and electronic or optical instruments).

Those categories of cargo that are ACV-eligible from a vehicle standpoint must now be compared with the categories that are eligible from a trade-need standpoint. Table XI lists some of the potential imports and exports of the North Atlantic and Oriental countries (refs. 37 to 41). The table includes commodities (marked by an asterisk) that would usually not be ACV-eligible, mostly bulk or liquid raw materials or feed grains. These commodities are included for completeness and because they may be key parts of trade agreements which would generate the flow of ACV-eligible goods. Table XI can be generalized for ACV-eligible cargo in this way: The North Atlantic countries will export the products, tools, and machines of technology and import from the Orient both technology products and handcrafted products. From table XI there seems sufficient need for imports and exports of ACV-eligible cargo in both the North Atlantic and the Orient to assure a two-way flow. Thus, "back-haul" cargo should not be a problem.



TABLE XI. - EXAMPLES OF EAST-WEST TRADE POSSIBILITIES<sup>a</sup>

Country or region	Exports	Imports
North Atlantic	Chemicals Alcohol Fertilizer Northern beet sugar Frozen fish (Newfoundland) Pulpwood (Canada) Automobiles Electronic equipment (Boston) Calculators and computers Machinery and machine tools * Ore concentrates (Sweden and Norway) * Grain (wheat, corn, and soybeans)	Automobiles Rubber Paper and metal products Textiles
Peoples Republic of China	Bristles Edible and inedible oils Textiles * Tungsten * Antimony * Tin	Railroad equipment Aircraft and parts Trucks Consumer goods
U.S.S.R.	Chemicals Diamonds * Oil * Gas * Iron ore * Chromium * Lumber * Copper	Machinery and equipment for such industries as - Construction Agriculture Air conditioning and heating Oil and gas Food and data processing Car and truck parts Furniture making
Japan	Automobiles and motorcycles Steel Chemicals Cameras Heavy machinery Computers and electronic components Plywood products Precision instruments Cotton and synthetic textiles Textile machinery Television sets	Foodstuffs (meats, sugar) Wool * Corn and wheat * Oil * Industrial raw materials (coal, iron ore, nonferrous metal ores)

<sup>a</sup>Commodities following an asterisk will not usually be ACV eligible.

## POTENTIAL IMPACT

All mechanized or industrialized countries must trade: they must export what they can to acquire capital in order to import the services, machinery, products, and raw materials they need. The coupling of national economies is becoming more pronounced as more and more countries, seeking to raise their standard of living, change from agrarian to mechanized to industrialized societies. Arctic passages would offer a shortcut trade route between most of the major industrial and population centers of the world.

The potential trade volume between East and West that could go by ACV freighters on Arctic passages is enormous. The fast-rising industrial and economic power of Japan (refs. 38 and 40) is already generating substantial trade demand. With diplomatic and trade restrictions being eased, the Peoples Republic of China offers an untapped market of 750 million consumers (ref. 39). The Soviet Union needs machinery for many different industries (ref. 37). In the West, Europe and the Eastern U.S. (ref. 41) and Canada offer high-volume trade links, mostly in the products and tools of technology.

The competitive position of a nuclear ACV trans-oceanic freighter has been pointed out in references 8 to 10, and 12 to 14, as well as this report. However, in the freight-carrying business in particular, it is difficult to predict accurately the demand for a new service, largely because there seems to be no well-defined, complete set of rules for doing so. On the other hand, it seems clear that the introduction of a vehicle that cuts East-West trip time to one-third for the same or lower cost should have a revolutionary effect.

With world ocean-borne trade increasing at 4 percent per year (fig. 2), there is an increasing opportunity for the U.S. shipbuilding industry. Between 1960 and 1969 only 2.7 percent of 7400 merchant ships built in the world were made in the U.S. (ref. 42). However, steps have been taken to revitalize the U.S. shipbuilding industry. For example, the current Maritime Administration nuclear development program and the recently announced (June 1972) series of federally subsidized ship constructions under the Merchant Marine Act of 1970.

The nuclear ACV freighter has the potential to foster the development of both a large-ACV industry and a mobile-nuclear-powerplant industry in the U.S. for a variety of uses (refs. 9 to 11, and 43). This freighter could also find a distinct market abroad and, hence, be an aid to our future balance of payments.

Modern East-West shipping has relied on the Panama and Suez Canals. However, the Suez has been closed since the Arab-Israeli War in 1967 so that traffic leaving the North Atlantic that would have used Suez must now go around the Cape of Good Hope, South Africa, or westward through the Panama Canal and across the Pacific. In fiscal year 1969, 13 125 ships made the Panama transit, not including 1380 Vietnam-related

vessels (ref. 44). The Panama Canal, offering its short cut from the Atlantic to the Pacific, is thus both commercially and strategically important. Arctic passages with nuclear ACV freighters would offer a less vulnerable alternative. Furthermore, Arctic passages would also offer an alternative to a sea-level canal proposed as a supplement to the Panama Canal.

The Arctic is now being recognized as an abundant source of many raw materials, especially petroleum. Oil has been discovered at Prudhoe Bay in Alaska and at the MacKenzie River Delta and Ellesmere Island in Canada. The Canadian Arctic Islands have been estimated to overlie a greater oil deposit than the Middle East (ref. 1). Near Mary River, a town in the northern part of Baffin Island, lies the largest and richest iron ore deposit in North America (ref. 2). Natural gas, iron, nickel, lead, zinc, silver, copper, and uranium have been discovered in the Canadian Arctic. The U.S.S.R. has enormous oil, gas, and mineral reserves in Siberia.

As pointed out earlier, ACV's will not economically compete with oil tankers and bulk/ore carriers on open sea routes from present sources. However, with their potential Arctic-wide, year-round mobility, ACV's would provide a means of moving raw materials from remote ice-bound mines and wells to ice-free ports. There the cargo could be transferred to conventional displacement tankers and bulk/ore carriers. In fact, ACV's acting as oil tankers could serve as a high-speed fuel distribution system to allow use of Arctic oil during times of national emergency. The possibility of using ACV's configured as tankers to carry oil over the polar ice from the North Slope of Alaska around Point Barrow and south to a displacement tanker waiting in ice-free water has been described in reference 43.

The presence of vast mineral and fuel resources in the Arctic plus its potential (using ACV freighters) as a trade route between North Pacific and North Atlantic ports may be the prelude to settlement and development of the Arctic. The nuclear ACV would provide the heavy-duty transportation needed to develop or operate in this remote and hostile region. It would offer fuel autonomy, speed, and Arctic-wide mobility virtually independent of season, as well as opening the long-sought Northwest Passage to commercial traffic.

## CONCLUDING REMARKS

Nuclear-powered ACV freighters could open the Northwest Passage and other Arctic passages to commercial traffic in the time period 1985-2000. The technical and economic feasibility of small ACV's has already been demonstrated; and there appear to be no technical limitations to building large ACV's. The feasibility of lightweight mobile nuclear powerplants is suggested by development work on nuclear space power systems, by successful experiments involving high-speed impact of simulated reactor contain-

ment vessels without rupture, and by analytical studies of optimized shield designs to minimize weight.

Nuclear ACV freighters may have an operating cost of about 1.0 cent per metric ton-kilometer (1.7¢/ton-n mi). Their flat-bed design would permit them to carry containers, vehicles, and even modular housing as cargo. Their major competitor for trade between North Atlantic and North Pacific ports will likely be nuclear-powered container ships (perhaps using a landbridge).

Some of the incentives for development of a nuclear-powered ACV freighter for a Northwest Passage are (1) greatly reduced transit time on many East-West trade missions, (2) competitive cost with conventional shipping for container and roll-on/roll-off cargo, (3) independence from the Panama and Suez Canals, (4) applicability of the ACV freighter concept to transportation needs throughout the world, (5) potential world-wide marketability of the ACV freighter, and (6) the Arctic-wide, all-season mobility of the freighter which would also allow extraction of the vast mineral and fuel resources of the Arctic and would stimulate settlement and industrial development there.

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National Aeronautics and Space Administration,

Cleveland, Ohio, November 21, 1972,

501-24.

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