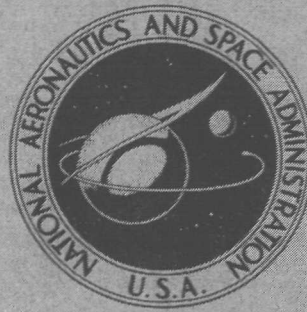NASA **TECHNICAL**
MEMORANDUM

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AIR-CUSHION TANKERS FOR ALASKAN NORTH SLOPE OIL

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16. Abstract

This report describes a concept for transporting oil from the Arctic to southern markets - 10 000-ton, chemically fueled air-cushion vehicles (ACV's) configured as tankers. Based on preliminary cost estimates the conceptual ACV tanker system as tailored to the transportation of Alaskan North Slope oil could deliver the oil for about the same price per barrel as the proposed trans-Alaska pipeline with only one-third of the capital investment. The report includes the description of the conceptual system and its operation; preliminary cost estimates; an appraisal of ACV tanker development; and a comparison of system costs, versatility, vulnerability, and ecological effect with those of the trans-Alaska pipeline.

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SUMMARY

This report describes a concept for transporting oil from the Arctic to southern markets - 10 000-ton, chemically fueled air-cushion vehicles (ACV's) configured as tankers. Based on preliminary cost estimates the conceptual ACV tanker system as tailored to the transportation of Alaskan North Slope oil could deliver the oil for about the same price per barrel as the proposed trans-Alaska pipeline with only one-third of the capital investment.

In the example considered, the ACV tankers would carry oil across polar ice from gathering centers on the North Slope to a floating port (a specially outfitted supertanker) which would trans-ship the oil to conventional displacement tankers waiting in deep, reasonably ice-free water. The position of the floating port would vary seasonally: from Prudhoe Bay in summer to south of the Bering Strait in winter, depending on the extent of the polar ice pack.

Although the ACV tanker system would be operational about 2 to 3 years after the pipeline, it should be able to match the peak pipeline flow when it is expected, about 1983. The ACV tanker system would have several advantages over the pipeline in addition to lower cost. It would be movable, could follow a variable route, and could serve multiple Arctic bases. It would not be as vulnerable to oil flow interruption and could carry the oil directly from the source to the southern refinery if desired. It should do less harm to the environment than the pipeline during installation and normal operation or from accidents and residual effects. Its capacity would be open ended and could be incremented at whatever rate is needed to keep pace with the oil flow. It has the potential to become a movable, easily incremented capacity, oil-and-mineral transportation system for the entire Arctic and to become a high-speed, not easily interrupted, fuel distribution system during national emergency.

This report includes the description of a conceptual ACV tanker system and its operation, preliminary cost estimates, an appraisal of ACV tanker development, and a comparison of the system to the trans-Alaska pipeline.

INTRODUCTION

The petroleum requirements of the United States are estimated to double between 1970 and 1985 (ref. 1). Furthermore, an important national security objective is to lessen our dependence on foreign oil, especially that from politically troubled areas (ref. 1). Alaska's North Slope would partly solve both problems. Lying above the Arctic Circle, the North Slope is conservatively estimated to contain 10 billion barrels of crude oil, which is 25 percent of all proved U.S. oil reserves.

The problem is how to transport this oil from the Arctic to southern markets. The answer is not easy because of two environmental restrictions: severity of the climate and delicacy of the ecology. These restrictions may be partly explained by a brief assessment of six alternatives which have been previously suggested for transporting the oil:

(1) The likely looking Bering Strait route (fig. 1) for icebreaker tankers would be unusually difficult except during the brief (6-week) summer because of the wind-driven pack ice at Point Barrow.

(2) The Northwest Passage route was made famous by the voyage of the icebreaker-tanker Manhattan (ref. 2). Although the Manhattan did make the passage from the Atlantic Ocean to Point Barrow and back, the experience indicated that an operational icebreaker tanker for this route must have a considerably stronger hull and deliver much
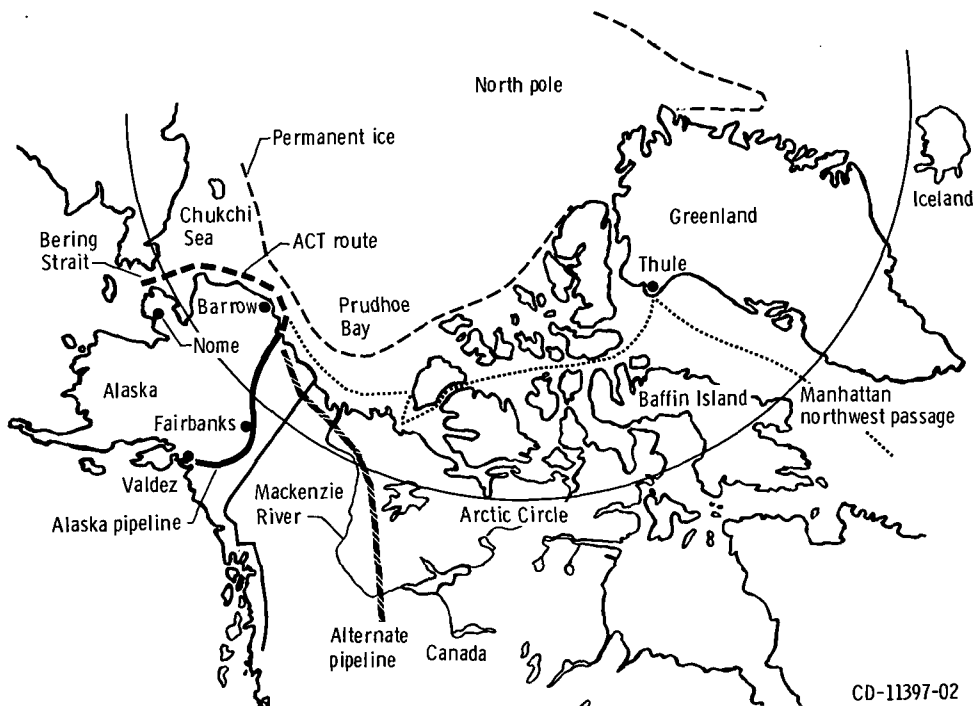

Figure 1. - North Slope oil transportation systems.

more shaft horsepower in both forward and reverse than the Manhattan. Thus, the high cost of the tankers coupled with the high cost of docking and loading facilities (30 miles offshore) that can withstand the severe pressures of the pack ice make this method unattractive.

(3) Nuclear-powered submarine tankers (ref. 3) would not require the icebreaking capability, but their capital cost would be high because of the nuclear powerplant and heavy undersea structure. Furthermore, they would also need offshore or underwater docking and loading facilities; and hence, this method is probably uneconomical.

(4) A conceptual design of a single-purpose airplane that could ferry oil from the North Slope is being evolved by the Boeing Company (ref. 4).

(5) The trans-Alaska pipeline is clearly the front-runner alternative because it appears to be within a year of beginning installation, pending litigation. Referring to figure 1, the pipeline would run from the oil fields on the North Slope almost due south through Alaska for 789 miles to a terminal port at the little fishing town of Valdez on Prince William Sound. The line would cross three mountain ranges, about 350 rivers and streams, vast tracts of permafrost terrain, and about 600 miles of some of the most seismically active land on earth.

The trans-Alaska pipeline would now be under construction except for ecological concern. A preliminary assessment of the ecological impact of the pipeline required by the National Environmental Policy Act of 1969 was released by the Department of the Interior in January 1971. Environmental groups, dissatisfied with the preliminary assessment, brought suit against the Department of the Interior, resulting in a federal court injunction against construction of the pipeline. In March 1972, an extensive environmental impact statement (ref. 5) and an economic and security analysis of the pipeline (ref. 1) were released by the Department of the Interior. Although federal approval at the executive level has been granted, the injunction and possible further public hearings will probably stall the beginning of the installation of the pipeline until at least 1973.

(6) Referring also to figure 1, the Alaska-Canada pipeline would cross eastward from the North Slope to the MacKenzie River delta and go south through the Canadian Northwest Territory to Edmonton, Alberta. There the oil would enter a large existing North American distribution system. Although this route would be less likely to have earthquakes, it would be three times as long as the trans-Alaska route, cost perhaps twice as much, go into operation 3 years later, and would merely shift the location of the ecological problems.

This report describes a new alternative - 10 000-ton, chemically powered air-cushion vehicles (ACV's), configured as tankers, which would carry oil from the North Slope to a floating port where the oil would be trans-shipped to displacement tankers waiting in deep, reasonably ice-free water. The position of the floating port would vary seasonally from Prudhoe Bay to south of the Bering Strait, depending on the extent of the

polar ice pack. This method is referred to as the air-cushion tanker (ACT) system.

This report includes the description of a conceptual ACT system and its operation, preliminary cost estimates, an appraisal of ACT development, and a comparison of the ACT system to the trans-Alaska pipeline. (In the remainder of the report "pipeline" will refer to the trans-Alaska pipeline.) The design, operational, and cost information for each component of the ACT system was obtained from industrial experts.

Although oil is the dominant problem, there is still a matter of 1000 cubic feet of natural gas that accompanies each barrel of crude oil. However, because the gas can be reinjected into domes and cheaply stored there for years, its transportation can be independent of the oil transportation. This report also provides a brief description and cost estimate of the facilities needed for a similar ACT system for the natural gas.

The ACT system for oil transportation described in this report is tailored to the North Slope to provide a comparison with conventional means of moving oil. But the concept and general design features can be readily applied to other geographic areas, in particular the entire Canadian Arctic, whose oil reserves are expected to greatly exceed those of the North Slope.

DESCRIPTION OF AIR-CUSHION TANKER SYSTEM

The great advantage of an air-cushion tanker (ACT) is that it will go over ice and over land, whereas a displacement tanker such as the Manhattan must constantly impact the ice and must remain 30 miles offshore in Prudhoe Bay.

Vehicles

An ACV can cross open water, broken ice, crevices, tundra, and pack ice with ridges - the terrain that characterizes the Arctic. The flexible-skirt principle that gives any ACV its mobility is shown in figure 2. Either the multiple-skirt concept of the French (ref. 6) or the single-flexible-skirt concept (shown in figs. 2 and 3) of the British (ref. 7) would be used.

Assessment, design, and operation of ACV's as a transportation system for North Canadian and Arctic environments are discussed in references 8 to 12. The largest operational ACV's (in use since 1971) are 250-ton transporters used for carrying construction equipment in Arctic oil fields (ref. 12). And the feasibility of ACV's as large as 700 tons gross weight to be used for the same purpose has been studied (ref. 9). However, most of the operational data for ACV's of this size come from experience with the 168-ton SR.N4 hovercraft (fig. 3). These hovercraft have been in ferry operation across the
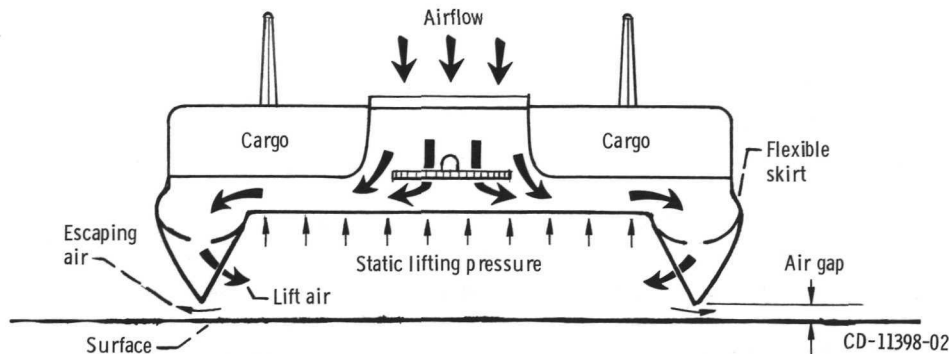
Figure 2. - Air-cushion-vehicle peripheral-jet - single-flexible-skirt principle.
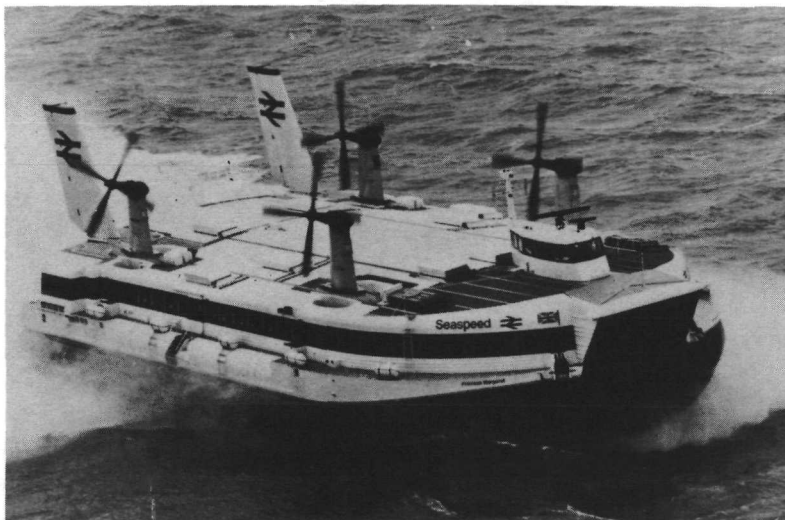

Figure 3. - British Hovercraft Ltd. SR. N4 air-cushion vehicle.

English Channel since 1968 and have proved to be reliable and technically and econom-ically practical. Multithousand-ton ACV's (both chemically and nuclear powered) have only been studied conceptually (refs. 13 to 17). Thus, the extrapolation of design, opera-tional, and cost data from about 200 tons to 10 000 tons must be recognized as only an estimate.

The basic ACT specifications appear in table I; an artist's conception is shown in figure 4. The fully loaded ACT weighs 10 000 tons and can carry a payload (including oil cargo and fuel) of about 7000 tons. It is chemically powered with a 1500-nautical-mile range (with payload carried only halfway) and will cruise at 60 knots. The chemical fuel may be either partly refined or centrifuged crude oil or liquefied natural gas (LNG).

The ACT can cross deep crevices 90 feet wide, waves 20 feet high, and solid

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TABLE I. - SPECIFICATIONS FOR AIR-CUSHION TANKER

[Propulsion: air propellers and chemical engines; fuel: (1) crude oil centrifuged or distilled below 500° F, or (2) liquified natural gas; range, 1500-n-mi round trip (100-percent payload one way, no payload back); cargo, 10 cylindrical tanks each 23 ft high, 40 ft in diameter, weighing 37 tons, and each holding 5000 barrels of oil.]

Weight, tons:	
Gross	10 000
Structure	2500
Engine.	65
Oil tanks (10)	375
Payload and fuel	7060
Operating velocity, knots	60
Parameters:	
Base pressure, lb/ft^2	400
Daylight clearance, in.	3
Power	
Shaft horsepower, hp	300 000
Lift/drag	24
Specific fuel consumption, lb/hp-hr	0.35
Thrust/shaft horsepower, lb/hp	2.82
Dimensions, ft:	
Length.	275
Breadth	185
Rigid-structure height	33
Flexible-skirt height	20

Oil tank
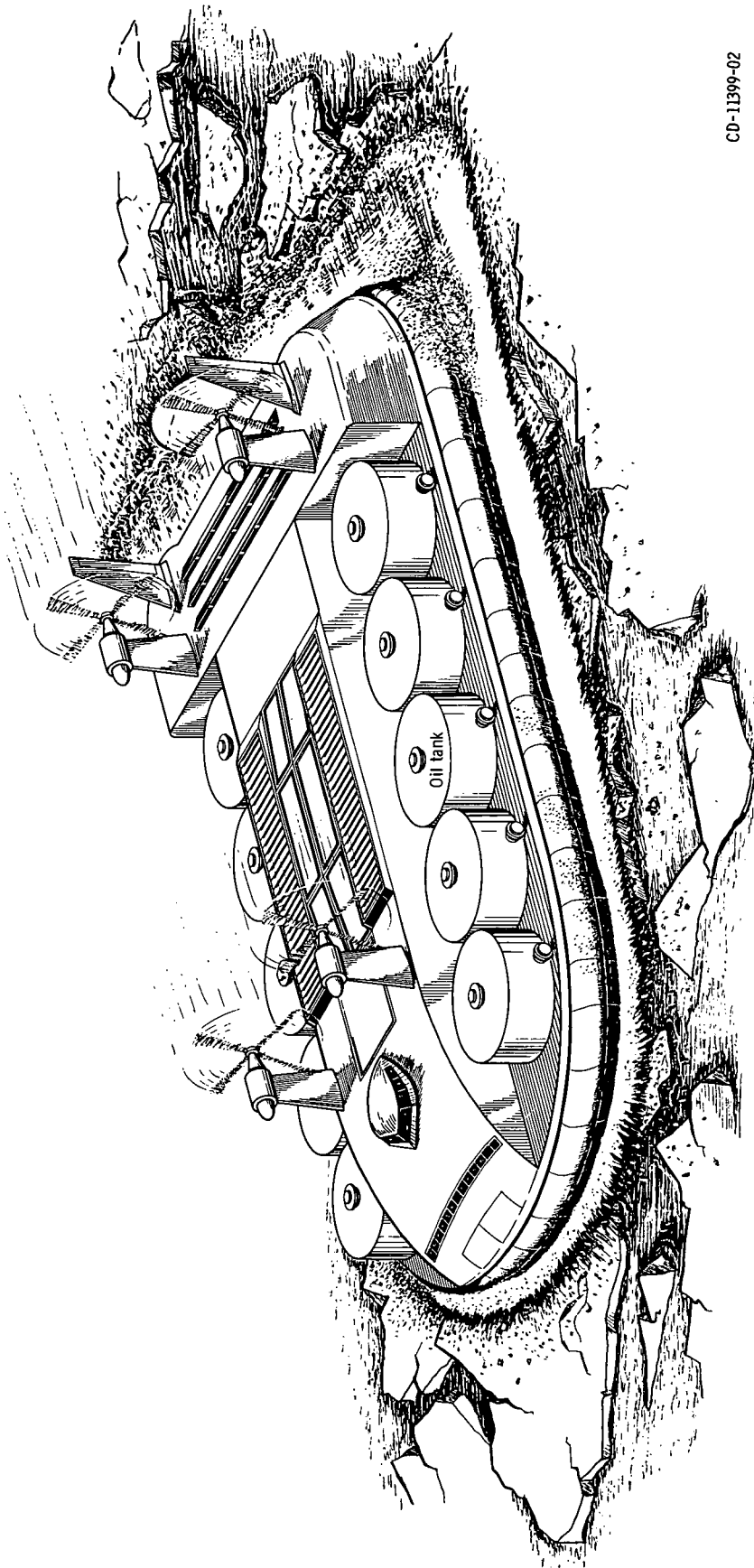
Figure 4. – 10 000-Ton air-cushion tanker.

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obstacles 17 feet high. The ice ridges on the surface of the polar ice pack may occasionally reach heights of nearly 20 feet but the average height is about 5 feet.

The ACT's have a flatbed - removable-tank configuration (fig. 4) which allows them to carry other cargo, such as supplies, construction materials, and machinery, as backhaul. (However, no backhaul is assumed in this study.) Ten cylindrical tanks (dimensions in table I) are used, each holding 5000 barrels of oil. The tanks must be insulated to keep the oil temperature above the pour point, about -7° C $(+20^O$ F), so it can be pumped.

Facilities

The other main component of the ACT system is a floating port which transfers oil from the ACT's to the displacement tankers. The port follows the edge of the polar ice as it advances and recedes with the seasons, staying as close to the ice pack as is safe for the displacement tankers in order to minimize the route length for the ACT's.

The port is simply a specially outfitted small supertanker, as shown in figure 5
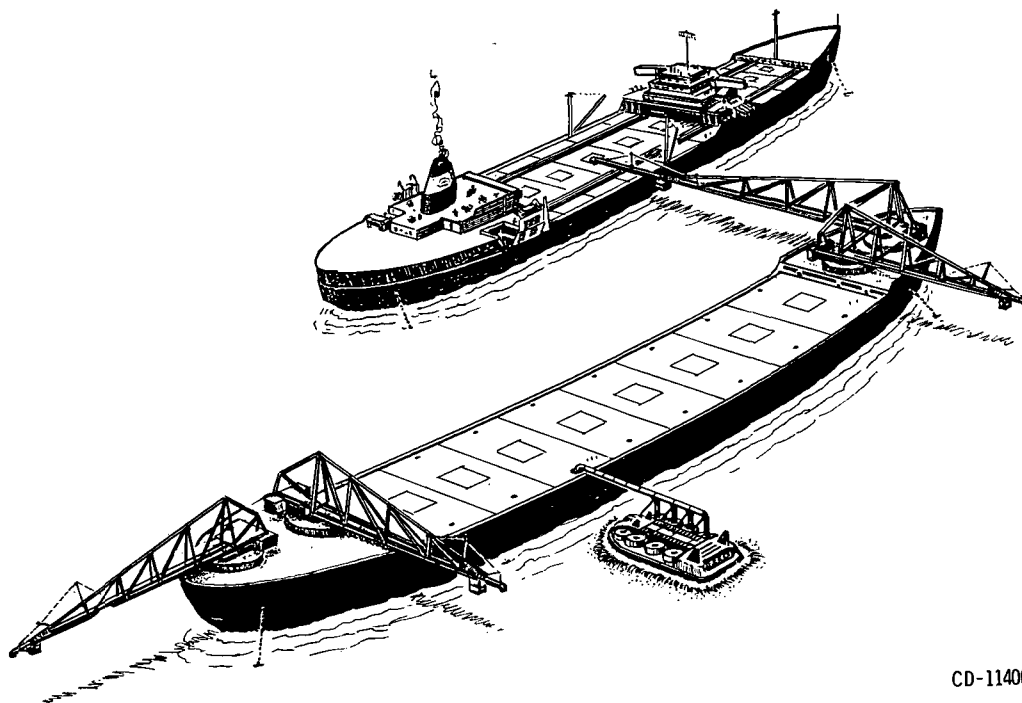
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Figure 5. - Floating port in operation.

(specifications in table II). It is 1100 feet long with a 170-foot breadth, a speed of 10 knots, and a capacity of 1 million barrels of crude oil (about 150 000 tons deadweight). Reference 18 describes some alternative designs for offshore terminals with oil storage.

Figure 5 shows the floating port in operation, transferring oil to a displacement tanker and preparing to receive oil from an ACT. (For clarity only a small part of the deck equipment and oil transfer hoses and booms is shown. Also not shown are the tugboats that would be used for maneuvering the tankers and the port.)

The oil is transferred to the port from an ACT by one of eight pairs of extendable flexible hoses (200-foot maximum extension). The oil is then transferred to a displacement tanker by any of four revolving loading booms. These booms are 450 feet long, shorter than the discharge booms of existing dredges.

The oil pumping rates that would be required for this floating port appear feasible, as indicated by a discussion of oil terminals at sea given in reference 19. However, the techniques for oil transfer between two floating platforms (port and displacement tanker or ACT) that will accommodate heavy continuous vehicle traffic will need to be developed. And the particular constraints of Arctic seas and weather conditions and extremely low acceptable oil spillage will affect these oil transfer techniques as well as the equipment design.

The already planned storage for about five million barrels at gathering centers on the North Slope is assumed adequate for the ACT system. However, storage must be provided for about half a million barrels of fuel, and pumps and berths will be needed to load the ACT's with both cargo oil and fuel oil.

Most of the 41 (33 new) displacement tankers that would be required to handle the pipeline oil would shuttle between Valdez and the U.S. west coast (a round trip of about 4000 n mi). Tankers linking with the ACT system would have to travel an extra 2000 nau-

TABLE II. - SPECIFICATIONS OF FLOATING PORT

Vessel, specially designed supertanker:	
Length, ft	1100
Beam, ft	170
Draft, ft	60
Speed, knots	10
Displacement, tons	250 000
Oil deadweight, tons	150 000
Oil capacity, barrels	1 million
Oil collection from ACT's by eight pairs of pumps with extendable (200-ft) hoses distributed around the port:	
Pumping rate per pump, tons/hr	2000
Oil transfer to displacement tankers from four larger and extendable booms (400 ft long):	
Pumping rate per pump, tons/hr	20 000
Summer utilization (peak activity and minimal breakdown)	0.9
Year-round utilization (allows for yearly maintenance downtime and normal breakdown)	0.5

tical miles average round trip (about 1 week's time). Any additional displacement tankers needed for the ACT system are accounted for in the hauling cost (for this extra 2000 n mi) included in the cost estimates (see the section Operating Costs).

At least two garage complexes will be needed for the ACT fleet. The major complex will be at some southern location, perhaps Nome on the Seward Peninsula, for weather reasons. There must also be at least one complex near the northern end of route, probably on the North Slope. The North Slope garage and other northern garage complexes would be used to perform emergency repairs to allow the ACT's to return to the main southern garage complex for complete repair.

Each garage in a complex will be large enough to house one ACT (fig. 6); the base dimensions will be 220 feet by 320 feet with a height of 70 feet. Hence, the southern com-
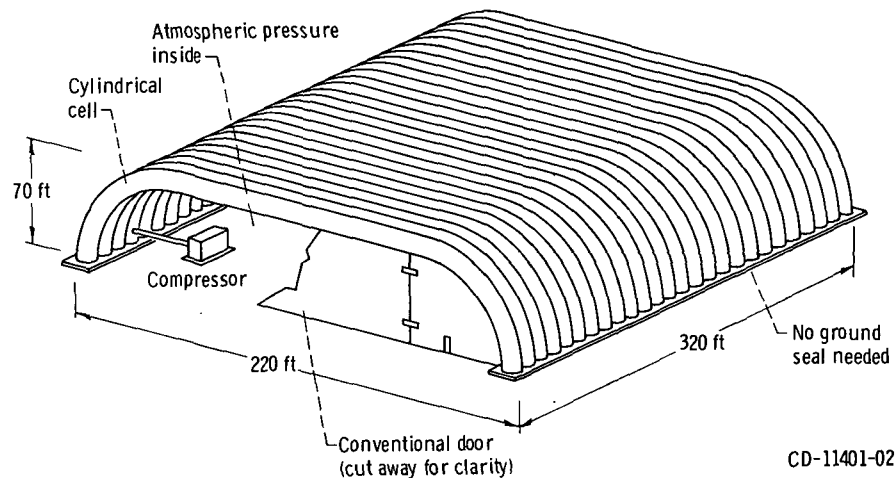

Figure 6. - Inflated-wall garage: cellular construction.

plex will consist of about 10 garages because eight of the ACT's will be scheduled for repairs at any one time. A garage will be a "shell-like" structure of cellular, inflated-wall construction (fig. 6) made of polyvinyl chloride (refs. 20 and 21). Another possible type of inflated structure is the "air house," which maintains air pressure in the entire enclosure rather than just inside a wall (ref. 21). This is the cheaper type, but to sustain the pressure when an ACT is entering or leaving will require much higher air pumping capacity. Although such large structures have not been developed for extremely cold regions, inflatable buildings of the air-house type large enough to enclose an ACT have been erected in the Great Lakes region. Furthermore, these buildings can withstand winds to 100 miles per hour (ref. 21).

A small "packaged" oil refinery with a capacity of about 1000 barrels per day is

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planned for the North Slope to supply fuel for construction machinery and for power for the oil field facilities and living quarters. (Packaged means the refineries are assembled in the south and then brought as a unit to the North Slope.) But the amount of fuel required by the ACT fleet is 80 to 100 times this refinery capacity. Thus, several "packaged" refineries of 10 000- to 20 000-barrel-per-day capacity (totaling 90 000 barrels/day) will be needed. Storage tanks will also be needed to stockpile about half a million barrels of fuel to accommodate the peak fuel needs in the winter.

Oil is chosen as the ACT fuel because it costs about 60 percent as much as LNG. Later sections discuss this more fully.

Route

From an ecological standpoint it might be desirable to minimize the ACT's time over ice or water by going over land. Although assessing the possibilities of overland routes goes beyond the scope of this report, some observations may be made. The location of the North Slope might permit the first stage of an ACT route to be almost due west from Prudhoe Bay to the Chukchi Sea passing to the south of Point Barrow. But any further overland route would probably have to detour seaward around mountains that abut the western coast of Alaska. Hence, for the purposes of this study only an overwater (ice) route is considered.

The ACT route length is elastic and depends on the season; one-way distances for various times of the year are shown in table III. In the 6-week Arctic summer, displacement tankers can pass Point Barrow (fig. 7) and anchor about 30 nautical miles offshore

TABLE III. - AIR-CUSHION-TANKER ROUTE VARIATIONS

One-way distance, n mi	Number of round trips per ACT per day[a]	Operating time over route, months	Approximate location of floating port
30	5.6	$1\frac{1}{2}$	Prudhoe Bay
210	1.9	$1\frac{1}{2}$	Just southwest of Point Barrow
320	1.3	1	Off Point Lay
410	1.1	2	Off Point Hope } In Chukchi Sea
490	.9		On Arctic Circle
580	.8		Just south of Bering Strait
670	.7		In Bering Sea at the latitude of Nome, Alaska

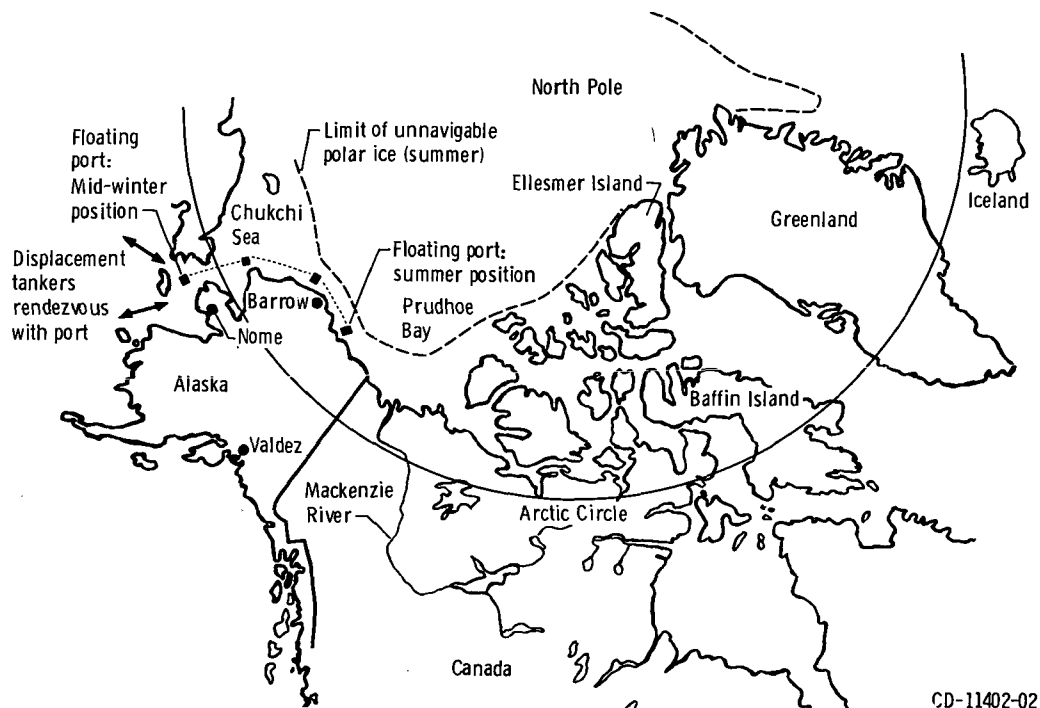[a]Based on a 1-hour turnaround time at each end, a 60-knot express speed, and a utilization of 0.7.

Figure 7. - Location of floating port.

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in Prudhoe Bay, which is shallow. Toward the end of the 6-week summer, the polar ice pack closes in on Point Barrow; for the next 46 weeks the ACT's must travel at least 200 nautical miles, passing to the north of Point Barrow and then traveling southwest and then south to the edge of the polar ice pack (some point in the Chukchi or Bering Sea). In the middle of the Arctic winter the polar ice will extend through the Bering Strait, about as far south as the latitude of Nome, and the route length will reach its maximum of about 670 nautical miles. Operation at route lengths other than the shortest and longest occurs during two separate periods, when the polar ice is advancing south and when it is receding north.

Note that there can also be multiple northern bases (oil-gathering centers). Because of their mobility the ACT's can, if desired or needed, go to all parts of the North Slope, to the MacKenzie Delta, and to the Arctic Islands.

Operations

The utilization (or fraction of time in service) of a single ACT is assumed to be 0.7; the time for maintenance, 0.3. The load factor is 1.0 on the down leg and zero on the return leg (no backhaul). For each ACT trip a turnaround time at each end of 1 hour is assumed (for filling and emptying the tanks, refueling, reduced speed at endpoints, and

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docking). Simultaneous oil transfer for several tanks, including refueling, may be necessary to achieve the turnaround time. Thus, the full-speed operating time is 4950 hours a year, the idle and slow-speed time is 1180 hours, and the maintenance downtime is 2630 hours.

Based on the route description in table III, each ACT will complete 589 round trips a year. Thus, the ACT fleet must consist of 28 vehicles. By staggering their schedules around the clock, each of the 20 ACT's that will be in operation at any one time will be more than an hour apart from the two nearest fleet members.

The operation of the ACT system will provide the same service averaged over the year as the pipeline (2 million barrels per day). But because of the variable route length the daily oil transport rate in the summer will be about nine times the rate during the winter. The extremes of operation and productivity during summer and winter are compared in table IV. The peak production will correspond to the maximum efficient rate of

TABLE IV. - SUMMER-WINTER COMPARISON OF

AIR-CUSHION-TANKER FLEET OPERATION

	Shortest route (summer), 30 n mi	Longest route (winter), 670 n mi
Volume of oil carried per ACT per day, barrels	46 100	41 300
Fuel used per ACT per trip, barrels	263	5000
Number of round trips per ACT per day	5.6	0.7
Total oil volume carried per day by 28 ACT's, barrels	7.23 million	0.81 million
Time operating at range, days	45	60
Total oil volume carried in period at range (table III), percent of year's total	44.4	6.5

withdrawing the oil, with the assumption that this rate can be reduced by a factor of 10 without appreciable collapse of the well walls.

The fleet must operate year round for at least two reasons: (1) the wells cannot be conveniently or cheaply shut down and storage for several weeks' oil is impractical; and (2) the southern oil markets will depend on a continuous oil supply although the supply rate by ACT will vary over the year.

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COSTS OF AIR-CUSHION TANKER SYSTEM

The costs of this ACT system are difficult to estimate for two reasons: (1) the system is conceptual, and thus the hardware is not precisely defined; and (2) the Arctic environment increases costs, but there is little experience to indicate how much. One mitigating circumstance is that although the entire ACT system must be designed to operate in the Arctic environment, many of the facilities can be prefabricated at more southern locations. Thus, only a small part of the system must actually be built in the Arctic. This contrasts with the pipeline, which must be constructed almost entirely under Arctic or near-Arctic conditions.

Primarily, the costs were estimated from expert opinion as follows: (1) experts from industries were consulted about each major component of the ACT system, (2) design and operational information and cost estimates were asked to account for the Arctic conditions, and (3) the high value of a quoted or referenced cost range was used. The industries or institutions contacted were Bell Aerosystems (air-cushion vehicles), Cleveland Port Authority (Alaskan ports and ice conditions and supertankers), Bethlehem Shipbuilding (offshore terminals), East Ohio Gas (gas properties and processing), and Standard Oil of Ohio (oil properties, pipeline data, and North Slope conditions).

Capital Investment

The total system capital investment (listed in table V) includes vehicles, garage complexes, floating port, and North Slope refinery and oil transfer equipment and berths.

The average capital cost per ACT of $37.7 million is comprised of a unit structure cost of about $5 per pound and a unit propulsion cost of $50 per shaft horsepower. These costs reflect a learning-curve reduction based on the production of many (28) units. This reduction rule is that doubling the cumulative production of an item results in a cost reduction of constant percentage - the learning factor - which for this study was 90 percent. The cost per vehicle also includes $3.1 million, which is a $1/28^{th}$ share of the development cost.

The total floating-port cost of $40 million is based on the cost of supertankers and oil transfer equipment for offshore supertanker terminals (ref. 19). The cost breakdown is as follows: (1) $14 million for a small (1 million barrels - 150 000 tons deadweight) supertanker that is slower (10 knots) but has a stronger hull than usual; costs for a standard supertanker of this capacity with a speed of 18 knots range from $12 million in the U.S. to about $7.5 million in Japan; (2) $5 million for four tugboats for maneuvering the port and the displacement tankers (ref. 19); (3) $16 million for a port-to-ship pumping system with a peak capacity of about 1 million tons of oil per day in the summer and a

TABLE V. - AIR-CUSHION-TANKER
SYSTEM CAPITAL INVESTMENT

	Cost, millions of dollars
Single ACT[a]	37.4
ACT fleet (28)	1047
Floating port[b]	40
North Slope loading equipment and fuel storage	10
Garage complexes:	
Southern (main)	15
Northern (several small)	15
Refinery	90
Total	1217

[a]Total cost of an ACT is based on a 90-percent learning curve for 28 vehicles and includes a 1/28th share of the development cost. The development cost is $87 million, not including the first-vehicle cost.

[b]Cost breakdown of floating port, millions of dollars: hull, 14; tugboats (4), 5; pumping systems (port to ship), 16; pumping systems (ACT to port), 5.

year-round capacity of about 110 million tons (ref. 19); (4) $5 million (estimated) for an eight-berth ACT-to-port pumping system, each berth with the capacity of about 15 000 tons per hour, which would empty an ACT in about 30 minutes.

The cost of the oil transfer equipment on the North Slope is estimated to be $10 million. This equipment includes pumps and ACT berths for transferring the oil cargo and oil fuel to the ACT's and storage tanks to stockpile fuel for the peak period during the winter.

The cost of the garage complexes is based on the cost of inflatable structures. An inflatable polyvinyl chloride building (of the air-house type) to house an ACT in a temperate (Great Lakes region) climate would cost about $350,000 (ref. 21). If we estimate the garage cost to be doubled to $700,000 because of the inflated-wall design and cold-weather modifications, 10 of these garages for a Nome location would cost about $7 million. Thus, a capital cost of $15 million for the main southern garage complex and arbitrarily $15 million for several smaller northern complexes would provide for the initial garages and their replacement after 10 years.

Based on a cost of $1 million for a "packaged" refinery with a capacity of 1000 barrels per day on the North Slope, the cost of a refinery to supply fuel for the ACT fleet would be about $90 million (for fuel needs see the section Operating Costs). The refinery capacity (with nominal stockpiling) will handle the peak winter fuel needs of the ACT fleet.

The cost of a liquefaction plant to prepare liquefied natural gas as the sole fuel would be about 75 percent more than the oil refinery cost. This determination is based on a unit plant cost (in temperate climates) of $360 per thousand cubic feet per day of liquefaction capacity (ref. 22), specific fuel consumptions of 0.35 pound per horsepower-hour for refined crude and 0.25 pound per horsepower-hour for LNG, and the fact that 6.84 thousand cubic feet of natural gas weighs the same as one barrel of North Slope crude oil (305 lb).

The estimated total capital cost of the ACT system is about $1.2 billion, 86 percent of which is for the ACT fleet. In comparison, the capital cost of the pipeline is now estimated to be $2.5 billion (ref. 23) not including native land claims.

Operating Costs

Based on the operations discussed earlier the yearly operating costs of the vehicles and facilities are given in table VI(a). Part of the vehicle miscellaneous costs correspond to operating costs of the Boeing 747, as cited in reference 16. In particular, the crew cost per vehicle is taken to be $250 per operating hour. An all-cargo vehicle does not require a large crew and the loading and unloading of the oil will be done automatically by pumping once hoses are attached. The insurance cost per vehicle operating hour is assumed to be 3.5×10^{-6} times the vehicle capital cost, again corresponding to Boeing 747 experience. The insurance rate is thus 1.66 percent of the capital cost per year. Although marine insurance costs increase by 50 to 100 percent as ships get into ice territory, the ACT's will be going over the ice and the floating port will stay away from the ice. Hence, the insurance rate should not be substantially different from that of a Boeing 747.

The assumptions used to determine miscellaneous operating and maintenance costs for the facilities are summarized in table VI(b). The yearly operating costs of the port and the North Slope loading equipment (including maintenance) are about 12 percent of the capital cost. (The port costs are based on ref. 24.) The yearly operating costs (excluding maintenance) are assumed to be 15 percent of the capital cost for the garages, assuming they will be labor-intensive, and 6 percent of the capital cost for the refinery because of its automated operation.

Yearly garage maintenance is assumed to be 10 percent of the capital cost analogous to the yearly refinery maintenance, which is assumed to be 10 percent of the capital cost, a standard costing assumption for industrial facilities.

Extrapolations of maintenance costs (from Bell Aerosystems) for small operational ACV's indicate a cost of $3000 to $4000 per operating hour for this 10 000-ton ACT. This extrapolated maintenance cost is high mainly for two reasons: (1) the present sus-

TABLE VI. - AIR-CUSHION-TANKER SYSTEM COSTS

(a) Yearly costs

	Single ACT	Floating port	North Slope loading equipment	Garages	Refinery	Total[a]
	Cost, millions of dollars					
Miscellaneous operation (crew, insurance, and power)	2.40	5	1.2	4.5	5.4	83.3
Maintenance	9.9	(b)	(b)	3	9	289.2
Capital recovery	8.45	8.20	2.05	6.15	18.45	271.5
ACT fuel	2.26					63.3
Total	23.01	13.20	3.25	13.65	32.85	707.3

(b) Assumptions for miscellaneous operating and maintenance costs

Facility	Miscellaneous operation	Maintenance	Comments
	Yearly cost, percent of capital cost		
Floating port	[c]12	---	Includes maintenance
North Slope loading equipment	[d]12	---	Includes maintenance
Garages	[e]15	[d]10	Labor intensive
Refinery	[e]6	[f]10	Automated

[a]Includes ACT fleet cost (28 vehicles).
[b]Included under Miscellaneous operation.
[c]From ref. 24.
[d]Estimated analogous to another facility.
[e]Estimated.
[f]Standard costing assumption for industrial facilities.

ceptibility of the engines to dirt, sand, ice, or salt spray kicked up by the airflow from the cushion and (2) present 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.

The high utilization (0.7) assumed for the ACT's would make the yearly ACT maintenance cost about 50 to 57 percent of the entire yearly cost of the whole ACT system. Even if the overall ACT system were cost competitive, the maintenance cost would not likely remain so high because of the substantial extra profit to be made by reducing it. Furthermore, a high maintenance cost implies substantial downtime for maintenance, and thus the utilization assumed (0.7) might not be achievable.

A lower maintenance cost ($2000/operating hour) is assumed for three reasons: (1) to identify the degree of cost reduction needed in the economically important area of maintenance to make ACT's competitive, (2) to make the assumed utilization more credible by reducing the implied maintenance downtime, and (3) to account for the substantial opportunities for cost reduction that are outlined in the next paragraph.

There are three indications that the maintenance cost can be substantially lowered by the time the ACT's could go into service: (1) expected maturing of the relatively new technologies of flexible skirts and extensive engine air filtration within the next 6 to 8 years, (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 31-ton ACV (the N-300) for more than 500 hours "with no incident and absolutely no skirt repair" (ref. 6). The Bertin experience was not factored into the extrapolated maintenance cost.

The capital investment for each part of the ACT system is assumed to be recovered at a 20 percent discount, or interest, rate over its lifetime.

The entire ACT system is assumed to operate for 20 years, the pipeline design life. The ACT structure life is assumed to be 15 years (ref. 16); the machinery life, 10 years (ref. 16); and the other facilities, 20 years. The present value ($68 million) of the capital costs to replace the ACT machinery after 10 years is included in the cumulative operating costs. However, the present value of the cost of operating the second-generation ACT fleet (needed after 15 years) for one-third of its 15-year life is assumed to be negligible. (The capital recovery factors for 20 percent over 10, 15, and 20 years are 0.239, 0.214, and 0.205 of the capital cost each year.)

The amount of fuel needed by one ACT during a year is about 1.14 million barrels (174 000 tons). This is calculated from the Brequet range formula using information from tables I and III. The fleet demand ranges from about 42 000 barrels per day during the 6-week summer to between 87 000 and 97 000 barrels per day for the remainder of the year. The unprocessed fuel cost on the North Slope is the sum of the lift-out cost (about $1 per barrel) and the lost profit (about $1 per barrel) for a total of $2 per barrel (0.66 ¢/lb or 4.8 ¢/gal). The processing cost is assumed to be included in the refinery yearly cost.

Delivery Cost of Oil

Table VII gives the capital and cumulative costs over 20 years for both the ACT system and the pipeline. The costs of exploration and development, royalties and taxes on the oil, North Slope gathering and storage system, and new displacement tankers are not included because they are common to both the pipeline and the ACT system.

	ACT system	Pipeline
Capital:[a]		
Hardware and installation	1.2×10^9	2.5×10^9
Native land claims	-------	[b]1.0×10^9
Total	1.2×10^9	3.5×10^9
Cumulative:		
Operations:		[c]1.4×10^9
ACT maintenance cost	5.5×10^9	
Other operational costs	3.2×10^9	
Investment recovery and return[d]	5.4×10^9	14.4×10^9
Displacement tanker charge[e]	1.5×10^9	--------
Total	15.6×10^9	15.8×10^9
Cost per barrel[f]	$1.07	$1.08

[a]Does not include cost of 33 new tankers because they are needed
  by both the pipeline and the ACT system.
[b]To be paid over 11 years.
[c]Continuing taxes on right-of-way and Valdez land are not included.
[d]Based on discount rate of 20 percent.
[e]Charge is 10 ¢/barrel for the extra 2000 miles (average round
  trip) the displacement tankers have to travel beyond Valdez,
  where they would go for the oil from the pipeline.
[f]Twenty-year transportation capacity is 14.6 billion barrels.

    The pertinent pipeline costs (in table VII) are from miscellaneous sources but partic-
ularly reference 25. Note that settlement of native land claims can raise the total capital
investment in the pipeline to nearly three times the investment in the ACT system. The
ACT investment would be progressive over 2 to 3 years, whereas nearly all the pipeline
investment must be made before any oil flows. The lower, progressive capital cost of
the ACT system would not only be an initial advantage but also a long-term one because
of the effective interest charges. Furthermore, as soon as one ACT is operational a re-
turn on investment can begin.

    The 20-year cumulative costs are $15.6 billion for the ACT system and $15.8 billion
for the pipeline. Note that 10 ¢ per barrel is added to the ACT system for the extra 2000
miles (average round trip) the displacement tankers must travel beyond Valdez, where
they would go for the oil from the pipeline.

    Averaged over 20 years and 14.6 billion barrels of oil the transportation cost per
barrel of oil would be about $1.07 for the ACT system and $1.08 for the pipeline.

COMPARISON OF ACT SYSTEM TO PIPELINE SYSTEM

Because the pipeline is on the verge of installation, it is a useful standard of comparison for other features of the ACT system (such as for costs, in table VII).

System Versatility

Once the pipeline is laid, it stays where it is to carry oil between fixed points. If other northern oil fields are brought in, new collection and feeder lines must be laid from the main pipeline to the new fields. At the southern end, tankers are restricted to the original port and additional lines must be laid if multiple southern ports are to be served. Also the pipeline appears to serve only one useful purpose - the delivery of oil. Once the oil is gone, the pipeline remains - useless.

On the other hand, the ACT with its surface independence can serve multiple northern and southern bases. The North Slope covers 76 000 square miles; as new wells are brought in, the ACT fleet can go directly to other gathering centers. Thus, the ACT mobility can greatly reduce the need for collection and feeder lines.

In stark contrast to the fixed location of the pipeline, ACT's allow the investment to be moved elsewhere. As new oil fields come in throughout the entire Arctic area, for example, the MacKenzie Delta and Ellesmere Island, the whole ACT system can go to them. (Pipelines from the Arctic islands to the Canadian mainland may not be feasible because of water depths of up to 1200 feet.) And if the entire north area were eventually abandoned, then the ACT's and the "pipeline" they form can be moved to other oil fields along the equator or even to the other end of the earth - Antarctica. If the ACT's are by then worn out, they can be brought south for salvage. They need not remain as a possible disturbance to the delicate northern ecology.

Whereas the pipeline has a maximum capacity of 2 million barrels per day, the ACT fleet can be expanded incrementally, in a relatively short time, to handle increases in oil production.

The ACT system offers potentially, a movable, easily incremented capacity, oil transportation system for the entire Arctic.

The ACT system offers a high-speed, not easily interruptable, fuel distribution system during national emergency.

Vulnerability

Seventy percent of the pipeline is through some of the most seismically active land on

earth. A pipeline break could spill as much as 64 000 barrels (ref. 25) of hot oil onto the tundra. The amount is designed to be limited by use of storage tanks along the line and methods of sensing a break and shutting off the oil flow through the line. The pipeline is also designed to withstand the severest earthquakes ever recorded in Alaska. However, ecologists point out that the southern port of Valdez, where a massive tank-farm complex of 10- to 20-million-barrel capacity is planned, was leveled in the 1964 earthquake.

Neither the ACT's nor the floating port would be directly affected by an earthquake; and the floating port, which is not intended to encounter the ice pack, should involve little more hazard than a conventional displacement ship in northern seas. With an ACT, potential oil spills are restricted to units of 5000 barrels for one tank or 50 000 barrels for the failure of all 10 tanks on an ACT.

The pipeline is susceptible to sabotage because its entire length could not be protected or patrolled. (About half the pipeline will be buried and the other half will be raised above the ground.) However, all parts of the ACT system are of relatively small extent and are manned.

Once dependence on the pipeline is established, long interruptions in its service would cause considerable hardships. The operation of an ACT system, consisting of many independent oil-carrying units, could not be so easily interrupted.

Ecology

The trans-Alaska pipeline will require a 100-foot-wide corridor to be cleared for 800 miles and a trench (for pipeline burial) dug for 400 miles. For most of its length the pipeline will cross permafrost and seismically active land. A parallel access road will be needed for about 400 miles along the northern half of the pipeline; a road already exists for the southern half. The oil temperature in the pipeline will vary from about 80° C on the North Slope to about 40° C at Valdez.

Ecologists have three main environmental concerns for the Arctic with regard to the effects of the pipeline (refs. 1, 25, and 26): (1) disturbance of the delicate ecological balance for vegetation (delicate because of the harsh conditions and short (60-day) growing season) where tundra is cleared or scarred, permafrost is melted, or oil is spilled; (2) interference of elevated portions of pipeline with wildlife patterns, such as caribou migration; and (3) severe erosion when the tundra (a vegetative crust over the permafrost) has been scarred and the permafrost thaws naturally during the summer or unnaurally because of the pipeline temperature or hot oil leaks or spills.

However, the pipeline as it is now planned is designed to minimize environmental impacts during normal operation and accident. Although its proponents concede that nature would be disrupted, they believe the overall impact would be small and mostly tem-

porary (ref. 25). On the other hand, ecologists feel that not enough is known about the possible environmental effects of pipeline installation, operation, and accidents and that irreparable and extensive damage to the environment may occur.

An ACT may cause a local environmental disturbance by compaction of snow or unfrozen soil from the cushion pressure, wind erosion of the surface and disturbance of plants from air escaping from under the skirt, or perhaps some wildlife disturbance from the noise. However, the ACT's will have low surface pressure, about that of a man on foot, so they are not likely to disturb or scar the tundra. The ACT's will be over water or ice about 90 percent of the operating time and only over the tundra on the North Slope where the oil fields are. Furthermore, experiments by the U.S. Coast Guard in Chukchi Sea off Point Barrow indicate that oil spills will probably spread more slowly in Arctic water than in temperate water (ref. 26) thus reducing the area affected by a spill.

Thus, except for an ACT accident (such as ripping the flotation tanks when going over high sharp obstacles and subsequently gouging the tundra), there should be little permanent change in the environment. The ACT's themselves could leave once the oil has been extracted; the pipeline is permanent. Overall, the ACT system would thus appear to cause less harm to the environment from normal installation and operation, from accidents, and from residual effects.

There is also a matter of resource depletion - how much of the oil is consumed in getting itself out? The oil pipeline (based on the coaxial oil-gas configuration in ref. 27) will require 12 pumping stations each using 68 000 horsepower. The pipeline will thus use 7.15 billion horsepower-hours per year. At a specific fuel consumption of 0.54 pound per horsepower-hour, just to pump the oil will consume 12.7 million barrels of oil per year, or about 1.7 percent of the total oil transported. Each ACT consumes 1.14 million barrels per year; the fleet consumes 32 million barrels, or about 4.5 percent of the oil transported.

DEVELOPMENT OF AN ACT SYSTEM

The design of a 10 000-ton ACT must include high utilization and low maintenance cost as key goals. It would take about 6 years to design, develop, and build an operational 10 000-ton ACT; and this would be the pacing item for the ACT system.

The ACT system could begin operation about 3 years after the pipeline, based on the pipeline's earliest operational date, 1976. However, the peak capacity of the pipeline (2 million barrels per day) will not be achieved until about 1983 (ref. 28). At that time the U.S. west coast oil deficit will also be about 2 million barrels per day, offering a ready market for the North Slope oil (ref. 28). By using aircraft assembly techniques rather than shipbuilding techniques, additional ACT's could be built fairly quickly. In

fact, the members of the ACT fleet might be brought into operation at a rate comparable to southern market expansion, spreading the investment over about 4 years. Thus, by about 1983 a full fleet of 28 ACT tankers could be available to carry oil at the projected pipeline rate.

ACT SYSTEM FOR NATURAL GAS

Because natural gas can be reinjected into underground domes, it can be stored at little cost. In fact the present plans are to install the Alaska-Canada gas pipeline about 3 years after the trans-Alaska oil pipeline goes into operation. This section briefly describes an ACT system for transporting the gas as liquefied natural gas (LNG). The description identifies the facilities needed, the interaction between them, and their unit costs.

The ACT system for gas would require an ACT fleet, a floating LNG transfer port, garages, a gas liquefaction plant on the North Slope, LNG displacement tankers, and a regasification plant at a southern location. LNG would be used as the ACT fuel, so no oil refinery would be needed.

It is likely, however, that an ACT system for gas would be used in conjunction with an ACT system for oil. Hence, the floating port, the garages, and even the ACT fleet (because of the versatile flatbed design) might be shared. Although the gas in the gaseous state can be stored at almost no cost, once it is liquefied it must be transported because of the high expense of cryogenic storage. A capital investment to increase the fleet of LNG displacement tankers would be needed to handle the production. Furthermore, a regasification plant may not always require full operation for the North Slope LNG; hence, it would likely serve other sources.

On the North Slope, natural gas and oil occur naturally in the ratio of about 1000 cubic feet of gas to 1 barrel of oil. However, it takes 6.84 thousand cubic feet of gas to weigh as much as 1 barrel of oil (305 lb). Consequently, the size of an ACT fleet for LNG might vary seasonally in contrast to the assumed constant year-round ACT fleet for oil. The variation would depend on the capacity of the liquefaction plant.

As an example, three particular combinations are (1) to carry a year's supply of gas in the 45-day summer would require 10 ACT's and a liquefaction capacity of 16.2 billion cubic feet per day (Bcf/D); (2) to operate year round, as would the oil ACT system, would require four ACT's and a liquefaction capacity of 7.1 Bcf/D; and (3) to transport the same amount every day all year would require one ACT at the minimum summer range and 10 ACT's at the maximum winter range and a liquefaction capacity of 2 Bcf/D. Directly coupled to whatever combination is chosen are the LNG transportation rate,

TABLE VIII. - NORTH SLOPE NATURAL-GAS TRANSPORTATION - MISCELLANEOUS INFORMATION

[Current quotation of Alaska-Canada pipeline cost, $5 billion. 10^3 cubic feet of gas equals 0.3 barrel of liquid natural gas (LNG).]

Oil production rate, barrels/day	2×10^6
Gas production rate, billion cu ft/day	2
ACT capacity, cu ft (barrels of LNG):	
Maximum	0.32×10^9 (96 000)
Minimum	0.29×10^9 (87 000)
Weight of 10^3 cubic feet of gas, lb (percent of weight of 1 barrel of oil).	44.8 (14.7)
ACT cost, millions of dollars	37.4
Unit ACT system capital cost (excluding refinery), millions of dollars/ACT.	41
Liquefaction plant cost[a], dollars/thousand cu ft/day	360
LNG tanker cost (750 000-barrel capacity), millions of dollars	60
Regasification plant cost, dollars/thousand cu ft/day	200

[a]From ref. 22.

TABLE IX. - NORTH SLOPE NATURAL-GAS

PROCESSING AND TRANSPORTATION

COSTS

	Cost, cents/1000 ft^3
Wellhead[a]	20
LNG production[a,b]	33
ACT[c]	13
LNG ship[a,d]	8
Regasification[a]	10
Total using ACT system[e]	92
Total using pipeline[a,f]	80

[a]From ref. 22.
[b]Based on capital charges of 25 percent per year (including operation, maintenance, and capital recovery) for a liquefaction plant unit cost of $360 per thousand cu ft/day.
[c]Over 20 years, the ACT transportation cost per thousand cu ft of gas would be roughly 15 percent of the cost per barrel of oil (according to the weight ratio).
[d]Per 1000 n mi shipping distance.
[e]Assumes 2000 n mi from floating port to Los Angeles.
[f]Cost by Alaska-Canada pipeline to Los Angeles.

the seasons of operation, the number of LNG displacement tankers needed, and the regasification capacity.

Thus, without defining the capacity and year-round operation of the entire system, the capital and operating costs of the ACT system for gas cannot accurately be estimated. However, to facilitate rough cost estimates, tables VIII and IX are provided with information (taken largely from ref. 22) that is generally independent of the system capacity. Table VIII lists miscellaneous information about an ACT system for gas; it includes the unit capital costs of the gas handling facilities. Table IX lists the cost per thousand cubic feet of gas for the various stages of gas processing and transportation.

CONCLUSIONS

Based on this conceptual design and preliminary cost estimates an air-cushion tanker (ACT) system for transporting oil is attractive for many reasons. In the particular example used in this report, the ACT system offers the potential of a North Slope oil transportation system that could deliver oil at about the same price as the proposed trans-Alaska pipeline (including native land claims) with only one-third of the capital investment.

The ACT development cost (about 7 percent of the total investment) would be spent over 5 years, and the remainder of the ACT investment would be over an additional 5 years. The oil can begin flowing with the first ACT and incrementally increase over 4 years. Hence, a return on investment would begin with the first operational ACT. In contrast, nearly all the pipeline investment must be made in about 3 years before any oil can flow or any return on investment can begin.

The ACT cost estimate assumes that a 35-percent reduction of the extrapolated maintenance cost for the ACT's is achievable. Furthermore, the ACT's will require a vehicle development program; and thus, the ACT system would begin to operate about 3 years later than the pipeline, if the pipeline installation is completed at its earliest date, 1976. The ACT fleet could, however, match the pipeline flow when it reaches its peak in 1983. Also, the ACT system would transport oil at a seasonally varying rate in contrast to the pipeline's constant year-round rate.

The ACT system has several advantages over the pipeline in addition to the estimate of a lower capital cost. It is movable, can follow a variable route, can serve multiple Arctic bases in contrast to the fixed route and end points of the pipeline, is not as vulnerable to oil-flow interruption, and could be a complete oil transportation system by itself - carrying oil from source to refinery.

The ACT system should also do less harm to the environment than the pipeline during installation and normal operation or from accidents or residual effects.

In general, an ACT system has a significant advantage in that its capacity is open ended and can be incremented at whatever rate is needed to keep pace with the oil flow. In contrast, a pipeline has a limited capacity which must be determined years before the extent of oil deposits are known.

An ACT system has the potential to become a movable, easily incremented capacity, oil transportation system for the entire Arctic.

The ACT system also has the potential to become a high-speed fuel distribution system during national emergency.

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