Arctic Institute of North America

ARCTIC LOGISTICS SUPPORT TECHNOLOGY

Proceedings of a symposium held at Hershey, Pennsylvania

November 1 - 4, 1971

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13. ABSTRACT

This document is the proceedings of a symposium on arctic logistics support technology held at Hershey, Pennsylvania on November 1-4, 1971. Thirty-one papers were read at the symposium, and all are included in this report. The papers fall into three broad subject areas: (1) transportation, (2) life support, and (3) activity support (for special needs of field investigators). Although the papers focus on particular ARPA needs, the information they contain should prove helpful to other groups and individuals either engaged in, or planning for, research in arctic regions.

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ARCTIC
LOGISTICS
SUPPORT
TECHNOLOGY

Details of illustrations in
this document may be better
studied on microfiche

Edited by

Beverly F. Slocum

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Proceedings of a symposium held at Hershey, Pennsylvania on
November 1 - 4, 1971. The symposium was managed by the Arctic
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Naval Research and the Advanced Research Projects Agency
(ARPA).

PREFACE

In the "good old days," research in the Arctic was carried out mainly by a few dedicated men. Their activity was small scale, often exploratory, with results intended more for science and knowledge than for specific needs. The logistics requirements of these researchers, while substantial, could be taken care of without too much trouble by aircraft and other less sophisticated vehicles.

The discovery of huge oil deposits and other valuable minerals in the Arctic created an instant demand for knowledge that would serve immediate, practical needs. As a result, we see today many large, well-organized groups conducting detailed research into just about every area and aspect of the Arctic.

While the logistics demands of all this activity are staggering, the means of supplying logistics support remains much the same as in the old days. The specific purpose of the Arctic Logistics Support Technology Symposium was "to identify, examine, and propose better ways of providing support to ARPA's research efforts in the Arctic Basin." A broader goal was to provide an exchange of technological information and ideas in order to stimulate fresh approaches to all arctic research and operational support.

This proceedings presents all papers either read or distributed to participants at the symposium. The papers fall into three basic subject areas: (1) transportation, (2) life support, and (3) activity support (for special needs of investigators in the field).

Although the papers in this proceedings focus on particular ARPA needs, the information and ideas they contain should prove helpful to other groups and individuals either engaged in, or planning for, research in the Arctic.

B.F.S.

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WELCOMING ADDRESS

C. J. Wang
Advanced Research Projects Agency
Arlington, Virginia

Ladies and gentlemen, welcome to this symposium. We are very happy to see such a large turnout from what is basically a small arctic research community. We sincerely appreciate your willingness to be here tonight, to devote your expertise in support of Advanced Research Projects Agency programs. We hope you will come up with innovative ideas, and we look forward to your recommendations for new programs. We hope, with your help, that our programs can be increasingly effective and productive.

About 3 years ago, ARPA initiated its arctic research program. Many of you helped in formulating this program and in its progress to date. Since then we have been getting more deeply involved in arctic research programs. Broadly, our effort is devoted to the development of arctic operational technologies, with specific reference to arctic mobility, undersea operations, and information gathering. We are addressing the operational problems facing DoD today and those which DoD will possibly be facing in the future. Particular mention may be made of our development of the technologies of arctic surface effect vehicles and of R&D in such problem areas as under-ice acoustics, remote sensing, and cold regions construction technology. These are examples. We are running these programs at the level of something like $10 million per year. We expect to maintain this level or possibly increase the level slightly in the next few years.

Of course, ARPA's programs are only a part of the national program, and a national program must face the broad responsibility of arctic research, including operations, technology, and the sciences. Such a program undoubtedly will involve such agencies as the National Science Foundation, the National Oceanic and Atmospheric Administration, the Department of Transportation, the Department of Interior, the Department of Commerce, and the National Aeronautics and Space Administration as well as the Department of Defense.

A major part of arctic programs is logistics, and it is for this reason that we have convened this special symposium on logistics. A fact of life is that the remoteness of the Arctic and the harshness of the environment make logistics a major part of any arctic operation or research program. This applies from the planning stages right through to completion of the operation. The impact of

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logistics is felt in terms of operations costs--both dollars and manpower requirements--and operational constraints. For programs which the Department of Defense is conducting or has considered, the dollar cost of logistics ran from 20 percent to as much as 80 percent of the total program cost. This amounts to many dollars, and some very worthwhile programs could not be carried out because of the great logistics costs that would have been incurred.

Effects of limited logistics capabilities on manpower require-ments or feasibility of operations are harder to quantify, but are of no less magnitude. Thus, it is of major importance that new concepts and techniques be developed to reduce the costs of arctic operations and research programs.

It is my personal belief, as I am sure it is yours, that the Arctic is becoming more and more important and so will our arctic research efforts. Undoubtedly, in the coming years, there will be an evolution in our national arctic efforts. The success of this evolution will require the participation and devotion of many people, but in particular we can think of one person whose effort and leadership will have a most critical impact. We are indeed most fortunate to have this man as our keynote speaker tonight. We are gratified that he came here to share with us his wisdom. Ladies and gentlemen, it is my pleasure to present to you our speaker--a leader and a pioneer in his field--the new director of the Office of Polar Programs, National Science Foundation, my good friend, Joseph O. Fletcher.

KEYNOTE ADDRESS

J. O. Fletcher
National Science Foundation
Washington, D.C.

As I look around the room, I see a lot of familiar faces: scientists and engineers who are bringing new ideas and expertise to arctic operations. I know I speak for us all in saying "Welcome." We need you. The challenge is worthy of your efforts. For my part I admit to a certain bias, but I hope I may give at least the appearance of frankness shown by an old Civil War veteran, who wrote a book which he called "An Unbiased History of the Civil War, from the Southern Point of View."

My own bias goes back 22 years, to late 1949. I was just a southern boy who thought snow was a Christmas decoration.

Then I was posted to Fairbanks as commander of a B-29 reconnaissance squadron. We moved the squadron into a place called Eielson Air Force Base, but it didn't really deserve a name up until then because it was just 3 miles of concrete runway and a cluster of quonset huts.

So, we went to Eielson with 12 aircraft and tried to maintain daily missions: 16-hour flights over the Arctic Ocean and the Bering Sea. It got dark and cold (-50°C) and all the aircraft maintenance had to be done outside or in four old nose docks that covered only the front of the aircraft. Then we were ordered to change all the engines--there were only 48 of them. It seemed some bright, innovative engineer had figured out how to get more power from them by doing things to get a higher compression ratio. It was one of those good ideas prematurely put into action. The modified engines started blowing up in flight. After a few weeks of harrowing engine failures, it was discovered that certain other changes were also necessary at the factory--so we changed all 48 of them again. By this time it was March and only -35°C. We were so glad to see warmer weather and daylight that we convinced ourselves that we liked the Arctic: the old story of it feels so good when you stop. To keep my sense of humor, I was reading Stefansson's book, "The Friendly Arctic." It took me all winter to finish it.

Coming to the Arctic at that time in an operational role, I have been privilaged to witness the rapid development of our technology over the last two decades. For example, before World War I only a few pioneers were flying the Arctic: men like Byrd, Wilkins, and Eielson. During the war our Russian allies accepted aircraft at Fairbanks and ferried them to the front, but no one was

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doing much on the Arctic Ocean. After the war we set about adapting
our machines to the arctic conditions--grid navigation, radio com-
munications, celestial reference during twilight, and a lot of
things that gave us trouble until we learned how to cope with them.
On our lone polar flights we carried two radio operators and three
navigators: one taking celestial shots, one working the radar, and
one doing computations. Even so, we had some bad situations. One
of the greatest advances in arctic aviation was simply the advent
of a gyrocompass that did not process rapidly. Two years ago
I made the same flight with a California squadron. They fly jets
and cover the track in 7 hours rather than 16. They didn't carry
a radio operator and the navigator is resting most of the time. There
are just no in-flight problems.

On the ground, jet engines experience few cold weather mainte-
nance problems. In the air, they love the cold and keep turning for
thousands rather than hundreds of hours. New materials and improved
designs have eliminated most problems of leaking seals in fuel, oil,
and hydraulic lines. In short, the problems of operating large
aircraft from fixed bases seem to have been pretty well solved.

Unfortunately the same cannot be said for surface operations.
We have not applied our advanced technology very vigorously to
conducting operational activity on the surface of land, pack ice,
or ice cap. The reason is simple: We had no need to. Lacking an
arctic population and lacking economic incentives for resource
development, surface operations in the Arctic have been exploratory
and on a small scale. The old ways were good enough.

But not any longer. After millenia of no change and a few
decades of accelerating change, we now are poised on the brink
of explosive developments in the Arctic that within a decade will
make 1971 seem like a primitive frontier. The immediate reason
is oil, but I believe there will be a multitude of other spin-off
activities and enterprises that we do not see yet.

I think it is certain that in 1981 we will look back to this
day and marvel that we could have stood on the portals of such
explosive changes without perceiving either their true character
or significance any more than the social and economic consequences
of the automobile were foreseen in 1920 or the impact of the
federal highway system was foreseen in 1955.

The evidence that we stand on the portals of change is clear
enough. In a few months the Alyeska pipeline will probably get a
permit. Present cost estimates go to $3 billion. More than $1
billion will be laid out to settle native claims. Two billion
dollars have already been invested in the North Slope. But this is
just the vanguard of the future. Geological evidence snows that
most of the oil lies in the western Canadian islands, with much
of the area ice-covered sea.

We may ask if the demand is really great enough to justify development in such an environment. If the investment in the North Slope does not convince you, then consider this. The United States, with 6 percent of the world's population, now uses one-third of the world's energy. If the rest of the world came up to present U.S. energy consumption, demands would create a six-fold increase in world production. A recent oil industry forecast has Houston importing oil within 20 years. The demand for oil is there; the problem is to find it and get it out.

As with all surface operations, this boils down to devising an effective logistic and operational support system for the arctic environment. The key to efficiency is to understand and utilize the environmental factors, using our advanced technology to invent ways of exploiting their features. We must strive to make nature our ally rather than our enemy. Moreover, we must address these operational demands under new and stringent rules of engagement, for in the last 2 years we have seen the beginning of the ecological revolution. For the first time in the development of our industrial society, we refuse to accept the degradation of the air, the land, and the water. We demand that our technology preserve the quality of the environment.

If we look to the past for parallels, we find that man has a consistent record in anticipating periods of such rapid development: consistently wrong. He is consistently too conservative. We must try to improve that record. When I see populations doubling and redoubling in a lifetime; when I see rising rates of consumption all over the world; when I contemplate the enormous drain on our nonrenewable resources in the next few decades; when I see man going to the ends of the earth and to the ocean floor to recover needed resources; when I see him unlocking the energy of the atom and harnessing the rays of the sun; when I see him groping for control over his planetary environment; in short, when I comprehend the boundlessness of man's expectations and the vastness of his challenge, I am certain of one thing: The future is not for men with small dreams; it is not for men who fear innovations; it is not for timid men. No, the future is for men who dare to have great expectations and who have the courage, the persistence, the wisdom, and the patience to transform their expectations into realities. I believe that we have such men. We have them here tonight, in this very room, and during the next 3 days we will see their talents for innovation shaping the future that we will all share.

We might well keep in mind the old story of the three men who were working in a marble quarry. When asked what they were doing, one answered that he was working in a quarry. The second stated that he was cutting and shaping blocks of marble. The third responded quietly that he was helping to build a cathedral.

FUTURE SUPPORT TECHNOLOGY REQUIREMENTS OF THE ARCTIC INVESTIGATOR ON THE SURFACE AND IN THE BOUNDARY LAYER

N. Untersteiner
University of Washington
Seattle, ..shington

I will not try to open the great vistas like those just presented by Joe Fletcher. Rather I will be specific about scientific support requirements in the Arctic. I would also rather not speak specifically about AIDJEX because we really want to build the whole picture, of which AIDJEX is only one part, and also to look back a little at previous projects and activities that have been carried out. What I will try to give you is the point of view of the scientist who actively engages in arctic research and his views of present logistics and operational capabilities in the Arctic.

It is perhaps useful to remind ourselves that what we are doing in the Arctic is not all that special in terms of techniques. The only new thing that has come up lately has to do with the application of remote sensing techniques. We are making various measurements: launching radiosonde balloons to measure pressure, temperature, and humidity in the atmosphere; putting out all kinds of instrument arrays on the ice--thermometers, barometers, hydrometers--to measure what goes on at the surface (the melting, the freezing); and putting down oceanographic gear beneath the ice in the same way we do from our research vessels on the open ocean.

There is really nothing very special about this in principle. What is special is that it is cold out there, and isolated and inaccessible. It is inaccessible because of the nature of the surface that we call pack ice. Now, if we look at a small spot, we find that is is very solid and there is really nothing wrong with it. You can drive almost any kind of vehicle over it and it will be just like solid ground. What is different is that every once in a while there is a crack and pieces that are separated by the crack move relative to each other. That is really what causes all the logistics and operational problems that we have.

Obviously in this area we have three media in which to move-- the air to fly through, the ice to travel on, and the water in which to go under the ice. Defense seems to be the only sector of human endeavor which has the benefit of all existing technology. If we had the unlimited use of existing technology to do our work in the Arctic, we really would have rather small problems. We would fly and land airplanes. We would have a cargo-type nuclear submarine that would be able to put any kind of station at any place at any time of the year and then supply it. The submarine could deliver

any cargo that we would reasonably need for scientific research.
But things are not that way, and we have to work within a realistic
framework.

Turning to more specific things, I would like to single out
two. Everyone in this room has a notion of how our research stations
are being established now. There really has been very little
change in the last 15 years or so. The last major advance, mentioned
by Joe Fletcher earlier, was the turbine and jet engines that have
made airplanes more reliable. I would like to concentrate on two
things. One is the difficulty of flying in summer, and the other
is the breakup of ice which stops our work.

In early June the snow cover begins to melt, the surface
becomes soft, and there is practically no way that fixed-wing
aircraft can land on the ice because the surface is very hard, very
rough, and pockmarked with meltwater puddles. There is no landing
gear that can take that kind of a surface. From about mid-June to
mid-September, you neither get people in and out nor easily move
camps around. You more or less have to stay put, and that has many
limiting consequences for the conduct of a scientific research
project.

The other specific item is the breakup of floes and stations.
An expensive camp and a lot of people can be put on an ice floe
that looks very large and solid. Yet there is no certainty that the
floe is going to last. Just as likely, it will break up tomorrow
as next year. The first long-term station that we had on sea ice
was in IGY, and that one happened to last for nearly 12 months
without any trouble.

When a floe breaks up, most of our problems involve immobility.
Our buildings are immobile; our supply dumps are immobile; and
particularly our fuel dumps are immobile. We have no vehicle which
can negotiate cracks in the ice. We have caterpillars, tractors,
weasels, road graders, and more recently skidoos. All these vehicles
which I mention are stopped by just a few feet of open water in
the ice. If 150 drums of fuel happen to be on the other side, there
is practically no way to retrieve that fuel, and I am told that a
drum of fuel costs about $300 delivered locally up on the ice.

These two things together really add up to one thing--a lack
of mobility in every respect: long range in the summer that pre-
vents us from moving people, camps, and equipment around; and short-
range at all times of the year that allows us to deal with ice
breakup.

Of course, these may not be such serious limitations as changes
occur in the style of future research projects in the Arctic. If it
turns out that everything is done remotely and automatically, then
mobility might not be such a serious problem, but I think that
stage of development is a long time away. Even though all the earth
sciences tend to automation of observation, it will be a long time

until we have reached a sufficient level of perfection. So for
perhaps the next 10 years, we will continue to have manned stations
in the Arctic and these will need mobility. This will make it neces-
sary for us to go to predetermined locations at a predetermined
time of the year and put the instrument out and in many cases pick
it up. Even the sophisticated research activity that we will
have in the future will not eliminate completely the need for
mobility on the ice; therefore, the shortcomings I have pointed out
will still be in existence.

FUTURE SUPPORT TECHNOLOGY
REQUIREMENTS OF THE ARCTIC RESEARCH INVESTIGATOR
IN THE UNDERSEA ENVIRONMENT

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Several questions immediately come to mind when the broad
subject of the needs of the arctic research investigator in the
undersea environment is addressed. First, what will research
investigators likely study under the ice, in the sea, and on the
sea bottom, and how will the research be accomplished? Second,
what services will users of the Arctic Ocean environment likely
need in the years ahead? Third, what might the undersea investigator
be able to count on in the way of developing undersea scientific
systems in the future? To answer these questions this paper discusses
the needs of research investigators and others for arctic undersea
systems, with particular emphasis on resource assessment and manage-
ment issues in this fragile water environment. The need for further
mapping of the arctic continental shelves and the role of NOAA in
leading the national civilian undersea program are also described.

UNDERSEA SCIENCE--THE MICROSCALE INVESTIGATION

Two types of manned facilities appear to be evolving in the
civil undersea science and technology program. They are, respectively,
the small manned submersibles of various types which feature the
ability to dive deeply and allow detailed scientific observation
in the sea beyond diver depths; and the shallow, diver-depth
undersea laboratory. Both of these systems are limited at present
by the need for logistics support. Because of the likelihood that
others at this symposium will address the research tasks that small
deep-diving submersible vehicles can perform, this paper will
concentrate on undersea laboratory approaches.

The needs of the arctic undersea research investigator to which
the shallow continental shelf undersea laboratory might be devoted
are typically as follows (*Arctic* has been taken to include areas
north of 65°):

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*The views expressed in this paper are those of the author and
do not necessarily represent those of this agency.

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For living resources

Identify life cycles

Identify causes of failures or successes of fish-stocking techniques

Determine effects of predators, pollution, and harvesting

Improve harvesting devices for groundfish and shellfish

Determine accuracy of devices used for fish censuses

Extend estuarine ecological studies out into the open sea

Evaluate effects of nonliving resource exploitation on living resource populations

Conduct studies of nonresource and endangered species of marine mammals

For nonliving resources, geophysics, and ice studies

Inventory mineral resources

Chart sediment littoral and downslope drift and deposition phenomera

Determine the accuracy of resource sensors

Evaluate the effect of resource exploitation techniques on surrounding bottom terrain

Identify dissipation and decay rates, and movement of solid wastes and oxidized heavy oils on the bottom

Verify accuracy of pollutant sensors and required spatial distribution

Correlate offshore geologic and bathymetric anomalies with their land extensions.

Chart the grooves and furrows on the bottom made by the keels of ice pressure ridges and ice islands

Locate offshore freshwater fissures and aquifers

Conduct geochemical and trace element studies in water columns

Study the underside of ice floes

Study the ice from below while "parked" at the undersurface of ice islands for extended periods

Measure water mass flow rates and thermal conditions in selected locations

By providing an undersea laboratory with associated "daughter" vehicles, both manned and unmanned, the reach of the system's sensing capabilities can be greatly extended. One example of such a daughter vehicle would be the University of Washington's unmanned survey vehicle being built for use under Ice Island T-3. Another would be a series of data buoys deployed under the ice. By providing a self-contained power source, such as an isotope thermoelectric heat source or a small nuclear reactor power plant, the undersea lab would achieve a high degree of autonomy. Under these conditions the only need for logistic support would be in emergencies or in rotating scientists and their equipment.

An undersea laboratory "parked" under an ice island such as T-3 could also be partially supported by airdrop via a vertical passage from the surface through the ice.

Undersea laboratory concepts are currently under study in NOAA along with their power source and long-term life support requirements. The intention is to provide better ways to conduct scientific work in the sea. The extension of the undersea scientific research to the polar regions is logical. The requirements posed by the arctic environment will be factored into advanced system designs, as identified by the operational needs of research investigators. This symposium can serve as a useful forum and one of the means for identifying such needs.

NAUTICAL CHARTING AND MARINE GEOPHYSICAL MAPPING NEEDS--THE MACROSCALE SERVICE

Consider the types of undersea activities that must be performed in nautical charting and marine geophysical mapping. In continental margins of Alaska, particularly north of 65° through the Bering Strait to the Canadian border, nautical charts are required for safe navigation. In some cases the existing charts are based upon bathymetric data which are more than 25 years old. These large-scale charts are inadequate for modern shipping (many channels and ports need to be surveyed by modern techniques). In the same region geophysical maps are required for the evaluation of the resources and engineering characteristics of the continental shelf for the construction of offshore structures and anchorages. These latter maps, out to the edge of the continental slope, are normally prepared at a scale of 1:250,000.

Nautical chart surveys usually depend upon shore-based control for positions. Electronic positioning systems are installed at two or more shore stations. The network is then calibrated, a local coordinate system is established, and the position of natural features is determined in this local system. A survey ship's position can then be determined to better than 50 feet within the range of operation. Where marine traffic is heavy and there is danger

due to shallow depths or other hazards, bathymetric surveys are
undertaken at line spacings of a mile or less. Such detail may be
required for approximately one-fourth of the Alaskan North Slope
area today. Under optimum conditions, these critical areas might
be surveyed by surface ship in 24 ship-months. Should concrete
steps be taken to move the North Slope oil to American east coast
markets by submerged bulk oil systems, charting in this region
could become one of the highest nautical priorities.

Geophysical mapping depends upon satellite positioning and a
worldwide electronic system, such as Loran-C or Omega, for inter-
polation of position between satellite passes. Typically, bathymetric,
gravimetric, magnetic, and seismic data are observed while underway
along track lines at a 5-mile spacing. Approximately 25 percent
of the survey is devoted to crosslines in order to delineate off-
track features and to provide redundancy of data for survey evalu-
ation. Occasionally bottom samples are also obtained. Under the best
operating conditions, the geophysical survey of the region north
of Bering Strait might be completed in another 24 ship-months.
If it were deemed necessary to obtain detailed bathymetric data
throughout the region, a survey which would satisfy both the
geophysical mapping and the nautical charting programs could be
accomplished in some 60 ship-months. At the rate of 2 ice-free
months per year, 30 ship-years would be required to complete the
surveys. There are enough survey vessels under government control
and government sponsorship to accomplish this task. But without
a high national priority these ships will not be made available.

As a result, the northern Alaskan continental margins will
not be surveyed by conventional surface ships in the near future,
and detailed mapping of the continental slope and beyond is un-
likely during the 1970's. This region, therefore, could represent
an excellent opportunity for a submerged mapping system referenced
to a bottom-oriented positioning network, should such a system be
built. Survey submarines could detect microbathymetric features
and navigate by signals generated from the bottom-mounted positioning
network. Such activity could be carried on well beneath the ice
cover which would extend the normal survey system operating season
and the range of operations.

For future commercial, scientific, and military under-ice
submarine systems, detailed sea lane charts and area maps made by
a survey submarine system might well be far more useful and believ-
able to this user community. The bottom-referenced navigational
aids used by the survey submarine would be of equal value to the
user submarines in the future. Finally, as bathymetric maps are
being created by the moving survey submarine, the detailed mapping
of the underside of ice masses can simultaneously be carried out.
This would yield a body of data which could well provide new levels
of understanding of arctic phenomena.

Referring again to the theme of the symposium--Arctic Logistics Support Technology--and the needs of the arctic research investigator, it seems clear that under-ice bathymetric survey systems do not of themselves require support. Rather, such systems can potentially be the means of providing some of the arctic researcher's logistic support.

NOAA'S ARCTIC SCIENCE TODAY

The largest proportion of the current NOAA planned program of arctic research activities, as indicated in the NOAA input to the IARCC Five Year Arctic Research Plan, is related to the atmosphere and the ice. So far, very little has dealt with the under-ice and undersea environment. Two current marine activities are worth mentioning, however.

As part of the NOAA Sea Grant program, the University of Alaska is the recipient of grants-in-aid. A variety of coastal zone marine resource environmental studies are being carried out in the nearshore environment off the Alaska coast.

Another small program, funded by the National Ocean Survey's Oceanographic Buoy program office, involves building and testing a simple two-sensor buoy for use in the Arctic Ocean. It is designed to measure atmospheric pressure and the temperature of the ocean water when tethered below a hole in Ice Island T-3. This program is being carried out by the Applied Physics Laboratory of the University of Washington. Data from the buoy sensors are to be telemetered to the NIMBUS satellite as it passes overhead.

THE NATIONAL CIVILIAN UNDERSEA SCIENCE AND TECHNOLOGY PROGRAM

Under the Associate Administrator for Marine Resources, the planning and organizing of the national undersea science and technology program is now underway under NOAA leadership. The program was started in August 1971 with a modest Fiscal Year 1972 budget of approximately $1.5 million. The overall goal of the program is "to develop a national capability to work in all depths of the sea and in all oceans, and to promote research and development programs necessary to effectively use the resources of this vast region."

The Undersea Science and Technology program activities include:

    Identifying long-range goals

    Coordinating undersea scientific projects

    Fitting project objectives into long-range goals

    Funding scientific projects

    Identifying and developing advanced technology

Establishing and working with advisory panels

Providing national leadership for regional and inter-agency undersea science and technology projects

Disseminating program results, such as publishing a yearbook of accomplishments

In order to achieve a total balance, the potential for unmanned exploration and remote sensing systems is being fully integrated into the program along with manned systems, whenever the occasion dictates. The breadth of the problem also demands the use of the resources and capabilities existing in industry, the academic community, and the government to the fullest possible extent.

SOME EFFECTS OF RECENT CANADIAN STOL DEVELOPMENTS ON NORTHERN AIR TRANSPORTATION

R. Taborek
Ministry of Transport
Ottawa, Canada

Government and industry in Canada are engaged in a number of developments in STOL aviation which will have a significant impact on air transport operations in the North. These developments affect the aircraft and its systems; they affect airports and navigational facilities; and they are aimed at introducing an efficient and economic STOL transportation system into the aviation world. Pioneering in STOL is not new in Canada. Indeed, as these developments are reviewed, it will be seen that aviation, STOL, and the North are deeply rooted in Canada's heritage.

Looking back in history, during the 1920's and 1930's the airplane made its first major impact on northern development. In this era the famed bush pilot operations in the North reached such a level that Canada became one of the world's leading nations in air operations. The aircraft used in these operations were found 'to be most effective if they could take off and land in short distances, and if they could adapt to a variety of surfaces. The Fokker aircraft which Punch Dickens used to institute airmail service to Aklavik is typical (Figure 1). Most of the aircraft used in the world at this time could take off and land in short distances. Even in the late 1930's when Air Canada began commercial air service in Canada, their Lockheed 10 airliners (Figure 2) had good short field performance when operating from airfields with about 3000-foot runways.

DEVELOPMENT OF CONVENTIONAL (CTOL) AIR TRANSPORT SYSTEMS

It was the development of scheduled commercial services which led to the distinction between a conventional aircraft and a STOL aircraft. Manufacturers and operators alike became aware that by designing aircraft with higher wing loadings the economy and attractiveness of the civil airliner could be improved. For example the higher the wing loading, the less sensitive the aircraft is in its response to wind gusts--with passenger riding quality being much improved. Together with developments in structures and propulsion, the increase in wing loading has helped to reduce the operating costs of transport aircraft, from about 3 cents per seat mile during the 1930's to less than 1 cent per seat mile during the 1970's (Figure 3).

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Airmail to Aklavik-July 1929

Figure 1. Fokker Airplane Used for Airmail Service to Aklavik (1929)

CF-TCA

Figure 2. Lockheed 10A Electra Used as Air Canada's First Commercial
Air Service (1937)

These developments, however, were not without undesirable
side effects. Whereas the aircraft of the 1930's could operate
from 2,000- to 3,000-foot runways (Figure 4), the increase in wing
loading, among other things, led to a rapid increase in the runway
length. Today, major airports require runways of 10,000 to 12,000
feet. Although there are major problems in building these airports,
the most economical system for high-density, long-haul operations
is one where large airports permit the use of aircraft with the
lowest direct operating costs. This trend thus became the main
thrust of aviation development over the past 30 years. Such a
system, however, has become less suited to providing air transpor-
tation on the low density routes characteristic of many northern
operations.

DEVELOPMENT OF STOL IN THE NORTH AND IN MILITARY OPERATIONS

Although the major trend in aviation has been the development
of the conventional air transport system, a significant need has
always existed for airplanes that can operate in regions where
the density of traffic does not permit major investment in airfield
facilities. To meet this need, new aircraft have been developed
which have ever-increasing efficiency and economy, yet retain the
ability to take off and land in short distances on soft or rough
fields.

The Beaver (Figure 5) is one example of such an aircraft.
It carries a 1-ton load at speeds of about 150 mph. Experience has
shown the need to develop landing gear that can operate on very
soft surfaces to permit the greatest utilization of STOL capability.
The large low-pressure tires shown on this aircraft were developed
at the initiative of Weldy Phipps of Atlas Aviation, and they are
now in service on aircraft in the North and in other parts of
the world. Operating from soft surfaces remains a problem at which
research is being directed.

The Otter, and its successor the turbine powered Twin Otter,
shows successive STOL aircraft following the same trend to higher
speeds and wing loadings, and improved structural and aerodynamic
efficiency as for CTOL aircraft. The Twin Otter carries 2 tons at
close to 200 mph.

While these aircraft, developed in large measure to meet the
needs of the Canadian North, have played a major role in the develop-
ment of STOL technology, the limited economic activity in the North
placed a fairly low upper limit on the size of specialized aircraft
that could be developed on that economic base. Fortunately for
STOL aviation, military interest made substantial funds available
for the development of larger STOL aircraft.

An example of the continuing evolution of STOL aircraft under
the stimulus of military interest is the de Havilland Buffalo.
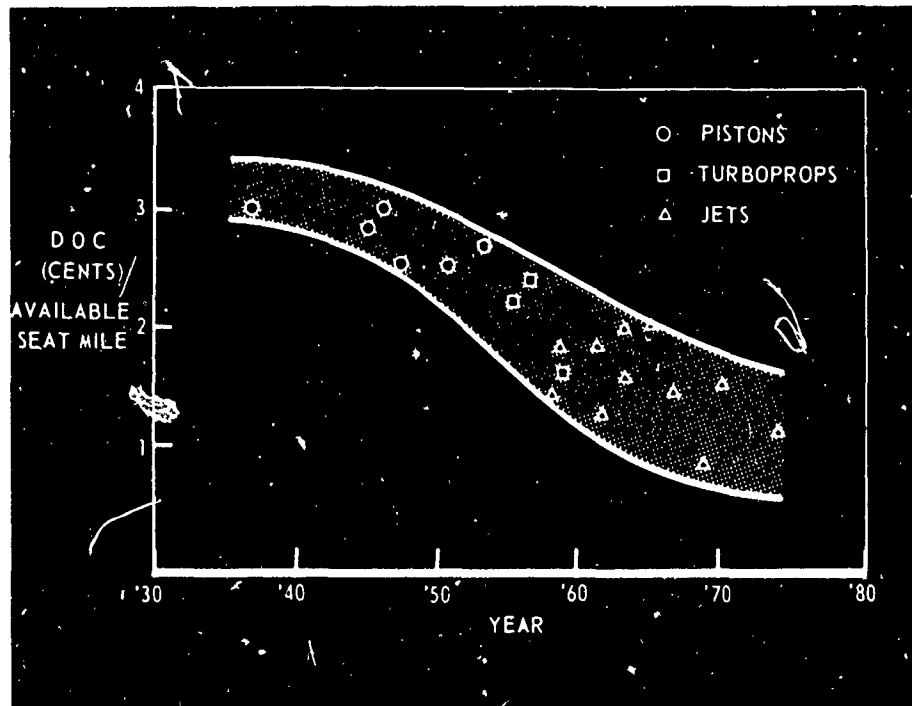Originally funded jointly by the U.S. Army, de Havilland, and the

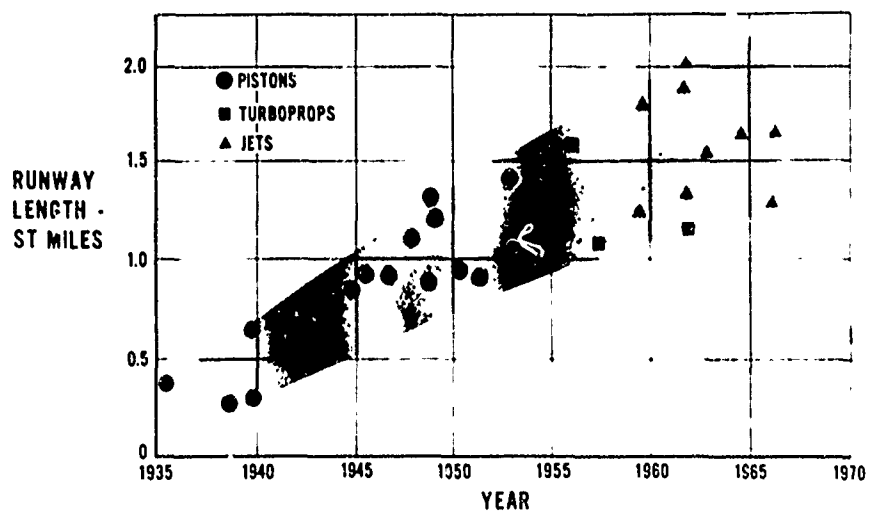Figure 3. Dollar Operating Costs Per Available Seat Mile

Figure 4. Transport Aircraft Runway Requirements

Canadian government, it is one of the larger STOL aircraft flying today, carrying a payload of 6 or 7 tons at speeds of 280 mph. This aircraft, currently in military service, is also serving as a test bed for several STOL developments.

For one test program, involving U.S. and Canadian governments and industry, the aircraft incorporates an air cushion landing gear (Figure 6). Auxiliary engines attached to the side of the fuselage provide a source of air which is ejected from the elastic-ized chamber on the bottom of the aircraft. A cushion of air is formed which will support the airplane while taxiing, landing, and taking off, and will permit its operation from the softest surfaces, including water and muskeg, and over obstacles 1 or 2 feet high. The aircraft is shown in Figure 6 in the take-off and landing configuration with the chamber expanded. In normal flight the chamber contracts and lies flush with the fuselage. Modification of this aircraft is underway, and testing will begin in late 1972. The air cushion landing principle can be developed for any size aircraft, and represents a much-needed improvement in the ability of aircraft to operate on soft surfaces.

Jet propulsion represents a significant step in aviation evolution. The Buffalo is also being used as a test bed in the development of jet-driven STOL aircraft, with U.S. and Canadian governments and industry participating. Jet STOL has lagged behind the development of comparable conventional aircraft for technical and economic reasons which will be referred to later. This flight test vehicle (Figure 7) is the culmination of a long series of wind tunnel tests, and will further develop and verify the flight characteristics of a high-lift wing for jet aircraft, known as the "Augmentor Wing." First flight of this research vehicle is scheduled for March 1972.

The results of these development programs can be applied to a variety of production designs. By way of illustration, one example might be an aircraft with the speed and capacity of the Boeing 737, the short field performance of the Twin Otter, and if required the ability to land on water or muskeg as well as on prepared surfaces. Earlier, the limited size of aircraft that the northern civil market could justifiably develop was commented on. It is interesting to note that the military forces of several nations have considered development of various jet STOL designs. To date they have been unable to obtain funds for such a development program.

THE ROLE OF CTOL AND STOL IN THE NORTH

Having reviewed the traditional line of evolution of STOL technology, both in the North and in the military, and indicated some key development programs, attention will now be turned to the interaction of CTOL and STOL in the North and in high-density airline markets.

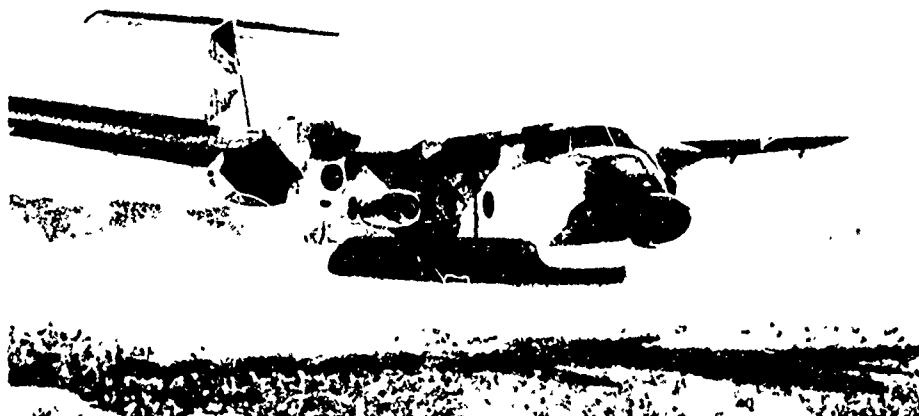Figure 5. The Beaver, a STOL Aircraft Used in the Arctic

Figure 6. Buffalo Aircraft Outfitted with an Air
Cushion Landing Gear

Figure 7. Jet STOL Aircraft with Augmentor Wing

Conventional aircraft, such as the Boeing 737, have reached an advanced state of development, and their introduction into the North, primarily on high-density routes, has had a strong and favorable impact both on the development of the northern air transportation system and on the quality of life of northern residents. CTOL aircraft currently carry the major share of traffic to the six major hubs in the north and carry a significant portion of the traffic which distributes cargo from these hubs to its ultimate destination (Figure 8). The conventional air transport system and the STOL transport system would be complementary, and a combination of both should lead to a more effective and economical air transport system.

In general the conventional aircraft is more suited to high-density long-range traffic, whereas the STOL system is more suited to short-range low-density traffic. One attempt to quantify this relationship for northern operations (Figure 9) predicts the STOL system to be more economical for stage lengths of less than 150 miles with almost any traffic density, and for longer stage lengths with traffic densities of less than 1,000 to 5,000 tons per year. These areas of preference arise from trade-offs of assumed lower direct operating costs and higher airport capital costs for CTOL aircraft. The preferred areas are not sensitive to the assumed ratio of CTOL to STOL airport costs.

Specification of areas of preference is more theoretical than real at the moment. The existence of a highly developed conventional air system in southern areas offers economies from the standpoint of being able to serve a point through scheduling of a carrier's existing fleet, or of purchasing any of a variety of used aircraft for the role. In either case initial capital investment in aircraft is minimized, which is particularly attractive in northern operations where utilization tends to be low and uncertain. As the density of northern operations cannot justify major equipment development, the introduction of STOL into the North will be significantly aided by developments on southern intercity routes.

INTERCITY STOL AIR TRANSPORT SYSTEMS

The development of a new air transport system includes the elements of the aircraft and the airport. It also includes the development of regulations, avionics, and ground electronics that permit effective use. The system must be made attractive to passengers, and the equipment necessary for handling passengers and baggage must be developed. The Canadian government, led by the Ministry of Transport in participation with the Canadian aerospace industry, has embarked on a $15 million experimental program which will focus experience in these areas on a passenger-carrying demonstration service between the downtown areas of Ottawa and Montreal. Planning of the demonstration service is well underway, with the first passenger-carrying flights scheduled to commence in May 1973.
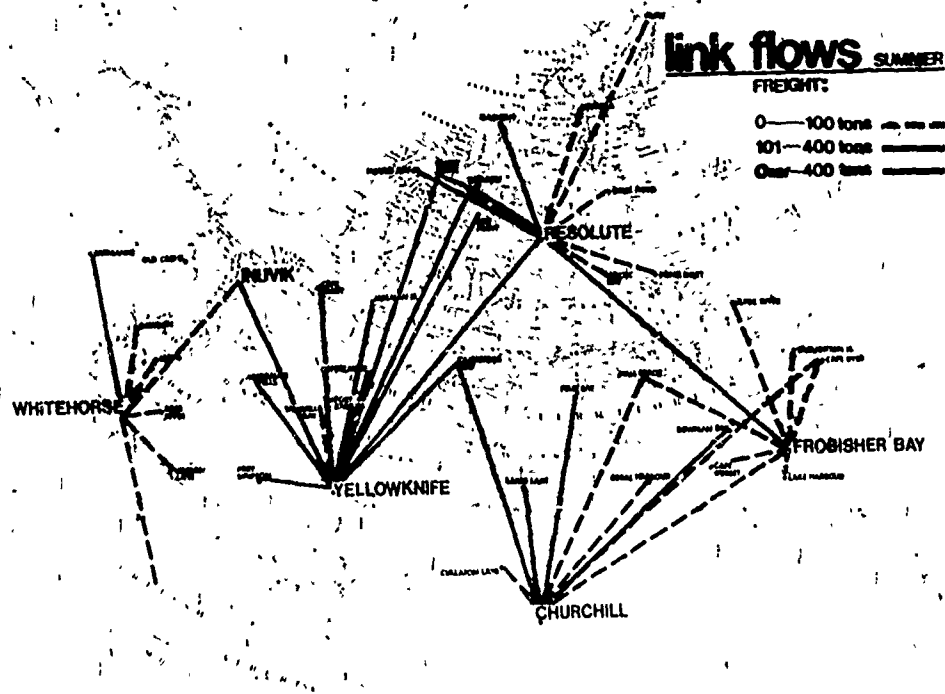
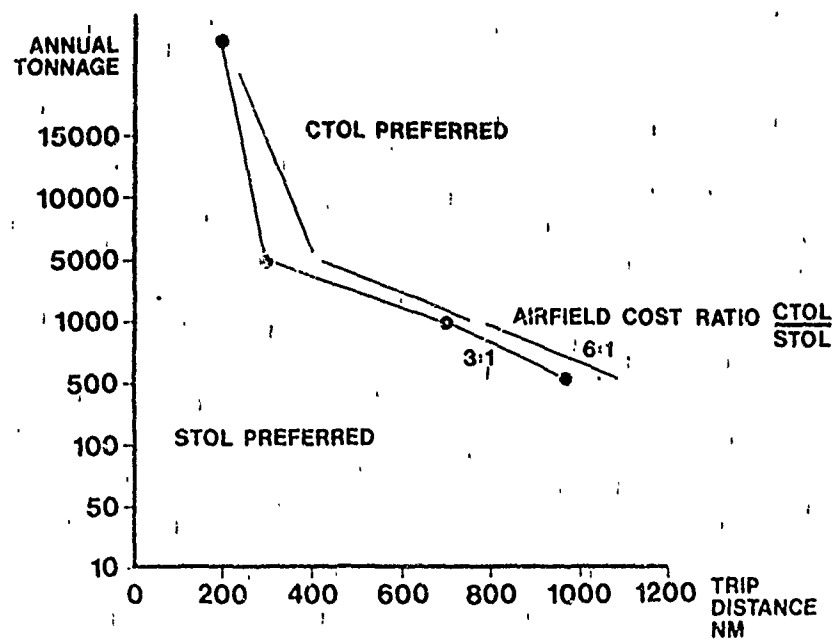Figure 8. Aircraft Cargo Distribution Links in Canada

Figure 9. Areas of Preference (STOL Versus CTOL)

Many of the objectives of the demonstration service are primarily directed at intercity STOL services. There are a number of areas, however, which will directly benefit northern air transport operations. Foremost among these are testing and use of advanced avionics and ground electronics, and the evolution of regulations which will permit the development of new STOL aircraft.

The service is to be started with de Havilland Twin Otters. This aircraft figures prominently in northern operations and is in wide use in commuter airline operations in the United States. While it is perhaps slower and smaller than desirable for such an experiment, the STOL aircraft available today has characteristics that best meet the needs of this market.

One objective of the demonstration is to verify STOL port dimensions for transport category IFR operations. The basic dimensions of the STOL port runway are a length of about 2,000 feet and a width of 100 feet. Numerous refinements to the STOL port dimensions will be developed and verified. Of particular interest will be the siting and use of a microwave instrument landing system.

The conventional instrument landing system (ILS) is not well suited to STOL operations. The beam is very sensitive to objects in its vicinity, giving reflections and echoes which vary. In siting the system, a distance of some 2,500 feet from the runway threshold must be kept relatively clear of obstructions. This is difficult, if not impossible, in city areas, and indeed in many instances in the North. Of particular interest in the northern context is the high capital cost of installing a conventional ILS (some $350,000). Operation and maintenance costs are similarly high, both largely the result of the sensitivity of the beam.

On the other hand, the microwave landing systems currently being evaluated for the STOL port cost $40,000 to $80,000. Also the beams are not sensitive to obstacles and are very stable, so the need for flight checks is reduced. These and other factors should provide economic justification for the installation of landing systems at sites with considerably less traffic density.

The demonstration service will also play a role in the development of operating regulations for STOL aircraft. While regulations for conventional aircraft are well developed, there are no regulations in force today which specifically recognize the unique character of STOL aircraft. Low wing loading STOL aircraft, such as those to be used on this service, can operate within the existing regulations and can be used to provide the operating experience for developing regulations which recognize the use of engine power to generate lift on a wing.

This is particularly important for jet-driven STOL aircraft. For travel at jet speeds, STOL aircraft must use small wings to achieve high wing loadings. Otherwise riding qualities are intolerable.

To generate very high lift on a small wing, engine power must be
used to assist in developing the lift. Regulations which recognize
the principle of powered lift are then an essential prerequisite
to the development of jet STOL aircraft.

As an illustration, consider a number of methods of generating
high lift. The conventional flap deflects the free-stream air around
the wing downward to increase lift (Figure 10). Its lifting
capability is limited by the phenomenon of stalling. This, in turn,
limits the aircraft to the use of a moderately large wing, which
limits cruise comfort and efficiency. The effect of power is not
considered. Propeller-driven STOL aircraft are designed to use the
slipstream from the propellers to keep the airflow attached when
the wing would otherwise stall, thus providing higher lift. Current
regulations limit the benefits which can be claimed for this effect.

Jet-driven aircraft have no slipstream as such, and hence are
unable to take advantage of this extra source of lift in achieving
STOL performance. The development of jet STOL has therefore been
focused on a means of developing lift from engine power. One approach
is the blown boundary layer control system, where air from the engine
is ducted through the wing and blown out of a slot over the flap.
The Augmentor Wing concept is a further development of this
principle. This concept is the most promising at the moment, and it
is to be flight tested on the Buffalo aircraft. Other concepts
visualize using the thrust from small engines mounted vertically
to provide lift, or using large diameter fan engines to blow air
over the flaps in a manner analogous to propellers.

While there are a number of technical problems to be resolved,
the introduction of larger, faster STOL aircraft depends largely on
proving a market which justifies the large investments required to
develop these aircraft. As mentioned earlier the military forces
of several countries have not been able to justify the development
costs of jet STOL aircraft. If successful the STOL demonstration
program could provide that market base, leading to the development
of advanced propeller-driven and ultimately jet-driven civil STOL
aircraft.

SUMMARY

The traditional civil air transport needs of the North and
military air transport requirements around the world will lead to
the development of faster and more efficient aircraft with short
and soft field performance.

The introduction of STOL into intercity markets will stimulate
many developments of direct benefit to the North. In the near term,
for example, this will lead to certification of cheaper and more
effective landing systems. In the long term, intercity STOL will
provide a market base to assist in the development of larger
propeller and jet STOL aircraft.

CONVENTIONAL PASSIVE FLAP	• USES CURRENT AERODYNAMIC / STRUCTURAL TECHNOLOGY • REQUIRES LOWEST T/W RATIO TO MATCH TAKEOFF • MODERATE WING LOADINGS, CRUISE COMFORT MAY BE MARGINAL
BLOWING BLC FLAP	• REQUIRES ADDITIONAL AERODYNAMIC DEVELOPMENT • SPECIAL BLEED ENGINE DEVELOPMENT (C_μ's $\approx$ 0.10) • HIGH WING LOADINGS, SATISFACTORY FOR CRUISE COMFORT
AUGMENTOR WING	• FLIGHT TEST VEHICLE UNDER ACTIVE DEVELOPMENT • REQUIRES SPECIAL HIGH BLEED ENGINES (C_μ's $\approx$ 0.4) • HIGH WING LOADINGS, SATISFACTORY FOR CRUISE COMFORT
AUXILIARY LIFT FAN AND PASSIVE FLAP	• CONSIDERABLE DEVELOPMENT REQUIRED IN ALL AREAS • POTENTIAL FOR DIRECT DEVELOPMENT TO VTOL • FIRST COSTS & OPER COSTS 20-30% HIGHER THAN OTHER SYST • VERY HIGH WING LOADINGS, CRUISE COMFORT SATISFACTORY
EXTERNAL JET FLAP	• CONSIDERABLE AERODYNAMIC DEVELOPMENT NECCESSARY • HAS SEVERE STABILITY AND CONTROL PROBLEMS • HIGH WING LOADINGS, CRUISE COMFORT SATISFACTORY

Figure 10. Comparison of High Lift Systems (STOL Aircraft)

LONG-RANGE HELICOPTERS

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Helicopters will be particularly useful in the Arctic where it is so difficult to construct surface facilities and where there is a need to transport small tonnages to many places. Helicopters can be used to great advantage in distributing goods from hubs where low-cost, high-performance aircraft can deposit the tonnage required for a large area. However, somewhat increased range over that currently achievable with high payloads and other improvements would greatly enhance operational efficiencies. This paper will delineate the need for these improvements through an accounting of experiences involving helicopters in the Arctic during the past 3 years.

Some 3 years ago a Sikorsky S-64 Skycrane helicopter was taken to arctic Alaska along with our North Slope oil exploration teams. The S-64 configuration features a large, uninterrupted cargo space under the fuselage. The helicopter is maneuvered by an aft-facing pilot who can actually fly the machine looking backward and simultaneously operate the hook. The Skycrane, or any helicopter for that matter, is currently best suited for short-range work. While helicopters can go long distances with midair refueling, they are most suitable for short-range gap crossing. The S-64 now being used commercially has a payload of about 20,000 pounds with a range of 25 miles, but the payload falls off to around 15,000 pounds at 180 miles.

There were several very good reasons for using the S-64 at Prudhoe Bay. That summer, during final explorations in preparation for the lease sale, the only way the oil rigs could be moved was by Skycrane. Two rigs were packaged especially for the S-64. They were moved in by Hercules to the runways and from there the entire rigs and camp facility with all support supplies were flown to the site by the S-64. In this way the move was made during the summer without any road construction and with no damage to the tundra.

That is how it started in the Arctic. Then in July and August 1969, a trial was conducted for the Department of Transport to determine the flexibility of a transport system using large helicopters in conjunction with ships. At Cape Dorset about 1,100 tons were moved. The following year with a more suitable vessel, the Fort Saint Louis, calls were made at five ports and roughly 2,700 tons moved. That second year effort was much more successful than the first year since the vessel had a large 300-foot unobstructed

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deck on which the helicopter could be based and from which cargo could be moved rapidly. The first vessel, the Sir John Crosby, was so configured that the helicopter had to stay at about 100-foot altitude, making operation very difficult and unloading quite slow.

Interesting to note is that Sikorsky's original aim was to build a helicopter capable of moving complete houses without concern for terrain restrictions. During this past year an experiment has been carried out along these lines with a factory-built housing program. The great limitation on factory-built housing is over-the-road transportation. The house used for flight test was 28 by 24 feet and designed to be picked up by the upper corners. No one had tried this before, and some very interesting aerodynamic effects were encountered.

During the first flight, an attempt was made to ease the house off the ground, but the aircraft ballooned the house about 30 feet off the ground. This surprised the pilot somewhat, but more of concern was that the house tried to get into syncronization with the rotor. The pilot got the house on the ground without damaging anything, but it was a bit tense for a few moments. The problems were solved with a rig which restrains the house, and flights are now made at about 80 knots. This may have some potential. This aircraft could just as well carry people in a suitable pod. The same dynamics are being used on the Marine Corps CH-53, which will carry about 46 passengers. It will cruise at about 160 or 170 knots. The dynamics now under development will up this to over 200 knots and about 70 passengers.

During 1971, our third year in the Arctic, some 7,000 tons were carried using two vessels, the Fort Saint Louis and her sister ship. Operations were conducted in Hudson Bay under adverse ice conditions. In some cases the ship was unable to get closer than 22 miles to its destination. In any event, the operation was scheduled and completed in 31 days against a plan of 30 days. During the trip, cargo off-loading was modified to increase the cargo and back load from the final port of call, and take some cargo out to another port. Tremendous flexibility and reliability in both schedule and operations were demonstrated using this system. The capabilities of both surface and air are maximized. Cargo can be scheduled for a port, and except for unusual conditions it can make that schedule, even in the Arctic, because of the inherent operational flexibilities.

Several things can be done, however, to make operations more efficient. In the first place, where possible the cargo should be containerized and packaged to take advantage of the maximum payload of the aircraft. There should be two aircraft serving a fleet of vessels, with each vessel configured for aircraft rendezvous (one aircraft can generally handle three vessels). The helicopter need not travel with the ship, but can fly directly to the first port of call, thus freeing it for other work while the ship is enroute.

This program has tripled just about each of the 3 years it has been underway (some 20,000 tons is now planned to be loaded next summer). The same aircraft that will be used in next summer's work is going to the James Bay area this fall (November 1971) and transfer fuel at Quebec's new hydroelectric project. The fuel is about 100 miles from the people and machinery that need it.

In conclusion, it should be recognized that no claim is made that helicopters are the total answer for all arctic logistic problems. However, they can be an important and integral part of a system that can increase the productivity and the reliability of operations in the Arctic. Under development at the present time are the dynamic components for a 3-engine helicopter that will have a payload of about 16 tons and another one which will have four engines and a payload of about 50 tons. There is no practical limit to the size for these machines. Like airplanes, the only practical limit is finding a customer. Such large helicopters will be very expensive to build; but like the Boeing 747, if the volume of work to be done is there, they can be very productive and profitable.

LIGHT AND MEDIUM VTOL AIRCRAFT
IN PRESENT AND FUTURE ARCTIC LOGISTICS

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Bell Helicopter Company
Euless, Texas

In the late 1940's, the military realized the potential of the helicopter in arctic regions. First uses were with the Navy and Coast Guard icebreakers on exploratory and supply missions above the Arctic Circle. These early helicopters functioned as the eyes of the ship, guiding it through ice floes and speeding transit operations. These aircraft were also used for limited administrative flights of personnel and supplies and also assisted hydrographic surveys by positioning lightweight instrumentation at key points. As these small machines became available to commercial operators, they were used in the Arctic for high-priority construction projects and for limited oil line and pipeline surveys.

The helicopters had many limitations: their reciprocating engines were highly susceptible to icing; their limited instrumentation restricted them to daylight flights; and their load-carrying capability, even in arctic temperatures, was limited to about 500 to 600 pounds. These limitations have not excluded this type of aircraft from use even today on special projects, and improvements have been made in engine performance and instrumentation.

The big breakthrough in the light helicopter was the introduction of the turbine engine. The lightweight turboshaft with its high reliability, low weight, and low fuel consumption allowed the helicopter to finally achieve a payload-to-gross-weight ratio which put it on a paying basis. External loads increased 150 percent to 1,600 pounds, and maintenance to vital components was reduced appreciably. Various configurations of landing gear were utilized. Pontoons and ski-type gear could be utilized in tundra and muskeg areas. Also, emergency flotation gear allowed these aircraft to be safely operated over the open sea to offshore oil rigs.

Simultaneously with the advent of the light jet helicopter, the medium jet helicopter made its appearance. These commercial machines, as well as the early H-13, are derivatives of military technology. However, they were easily adapted to commercial operations. Figure 1 shows the largest of the Bell medium helicopters, the model 205A, on floats. This helicopter has an external load capacity of 5,000 pounds. It can carry 13 passengers or an equivalent amount of cargo in its 220-cubic-foot cabin for 300 miles. For the medium range, development of larger engines and dynamic components
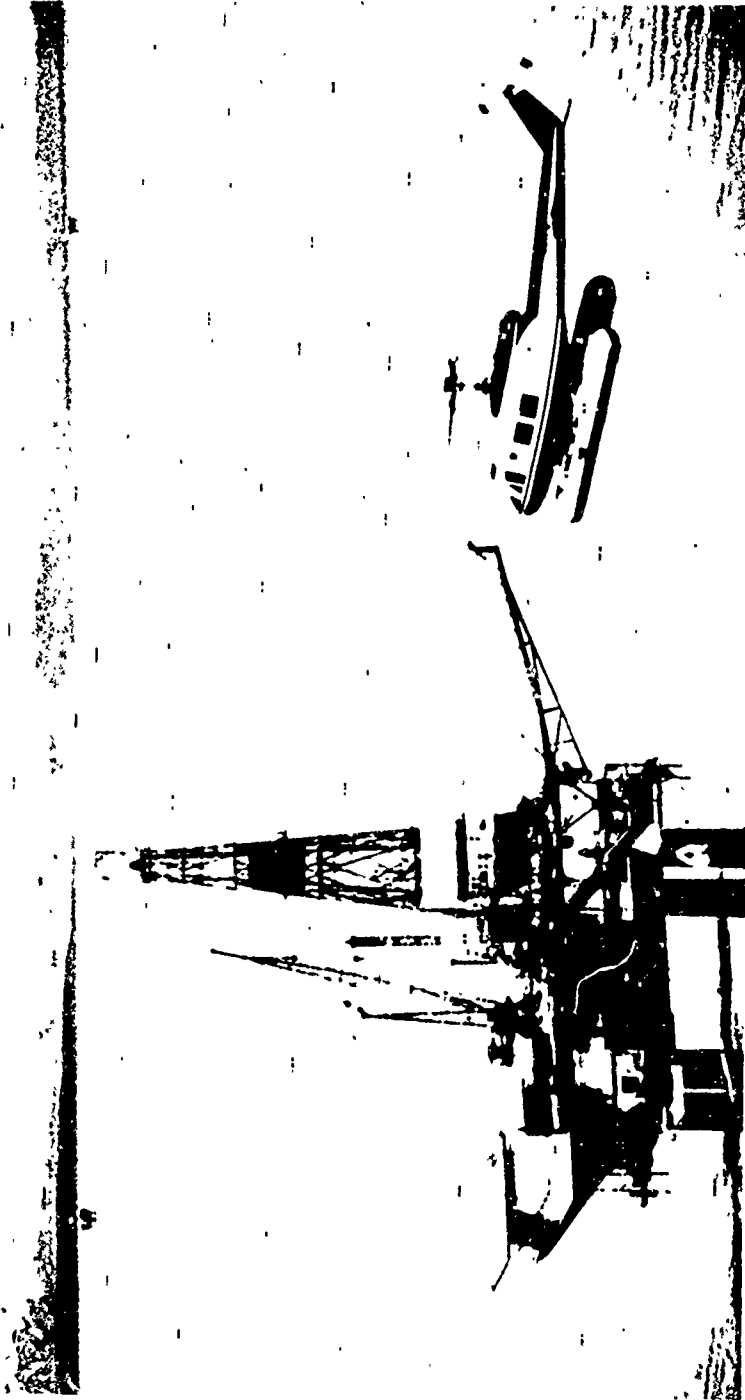
Figure 1. Model 205A Helicopter

yielded the HueyTug with a 2,850-shaft-horsepower engine and an 8,000-pound lift capability. This aircraft is still under the 15,000-pound gross weight class and is completely air transportable in Hercules (C-130) aircraft.

For added reliability a twin-engine medium helicopter has also been developed (the Model 212 or military UH-1N). This helicopter has the capabilities of the earlier medium jets with the increased reliability of the twin engines. The engine itself is unique. Two PT6 engines manufactured by United Aircraft of Canada were coupled to a gearbox with a single output shaft (Figure 2). This combination resulted in the T400-CP-400 engine which produces 1,800 shaft horsepower. The configuration of this engine makes it ideal for arctic operations, as shown in Figure 3. The air intake is so constructed that it passes air over a series of deflectors, and the engine air is taken from a plenum chamber. This system precludes direct intake of snow, ice, or abrasive particles which would damage engine compressors.

In addition to engine improvements, a great deal of development in avionics has also taken place. Shown in Figures 4 and 5 is the installation of a radar antenna in a rotor blade. This antenna, turning at approximately 325 rpm, gives a high definition radar picture for a range of approximately 10 to 15 miles. The clarity of the presentation is so precise that it is possible to tell a plowed field from a grass field. Vertical reference presently is done through an additional antenna. However, the utilization of the tail rotor as a vertical antenna is being tested.

Avionics have also been developed for automatically bringing a helicopter to a hover over any type of surface--land or water. It was developed for Navy missions where sonars were placed in the water for detection of submarines. Not only does this system bring the aircraft to a hover in instrument conditions, but also it allows egression to a safe speed and altitude upon completion of the hover. This would be very useful for unique weather conditions (such as white-out) encountered in the Arctic.

As development of the oil finds above the Arctic Circle are requiring transport over great distances, arctic logistics have been extended. The present helicopters, with their short range and low speed,   hardly function in an effective manner for the future logistics r   .rements in the Arctic. The addition of jet engines to an existing helicopter, such as shown in Figure 6, will significantly increase speed. This particular craft achieved 274 knots in level flight, but its configuration decreases payloads and ranges to a point where it is very inefficient.

Several designs are being investigated to achieve a more efficient high-speed helicopter. Figure 7 shows a variable diameter rotor. When fully extended, it is 25 feet in diameter. Shown in this sequence, it is reduced in the lower right to 16 feet. The principle of operation of this type of rotor is somewhat like the

Figure 2. T400-CP-400 Engine
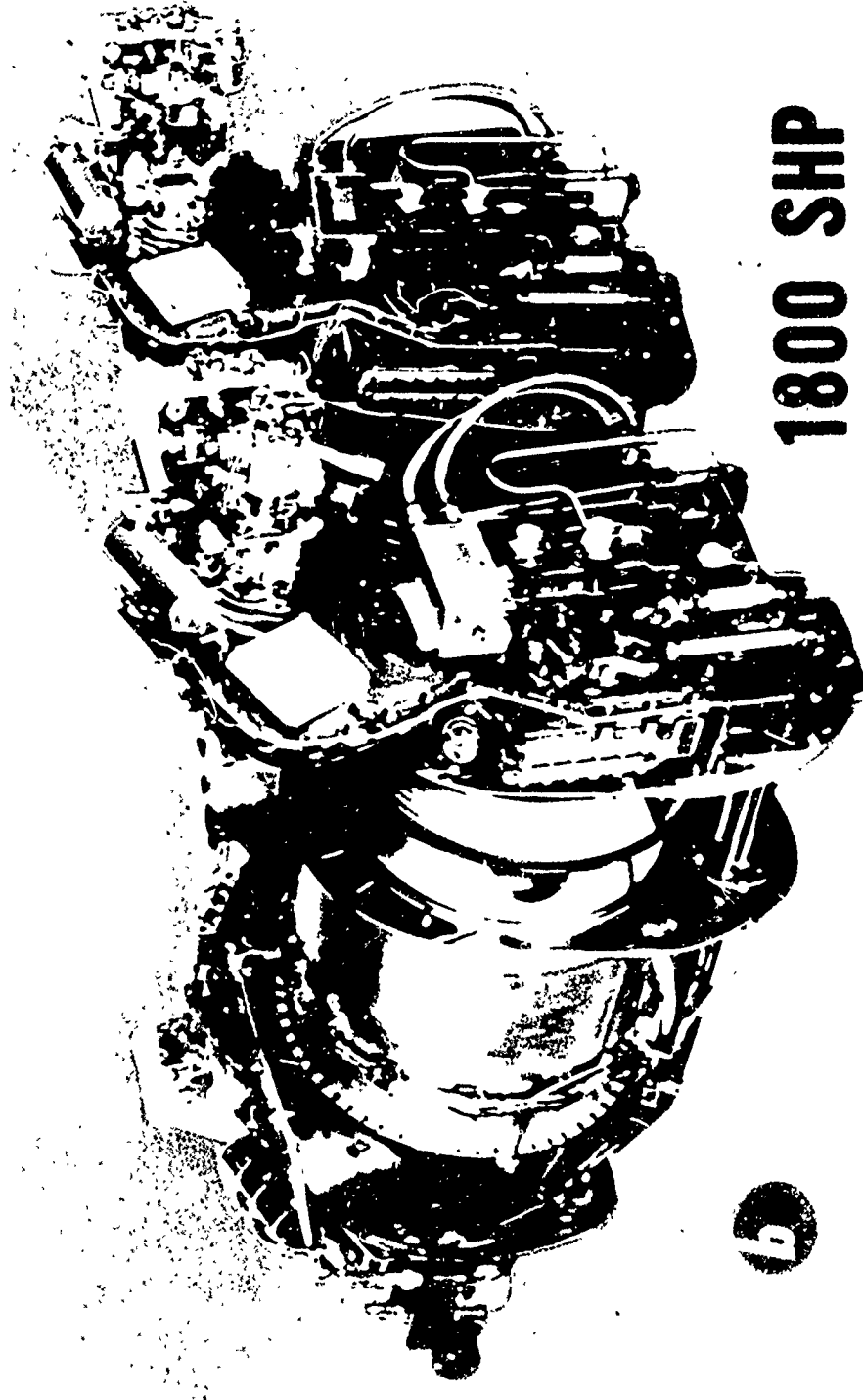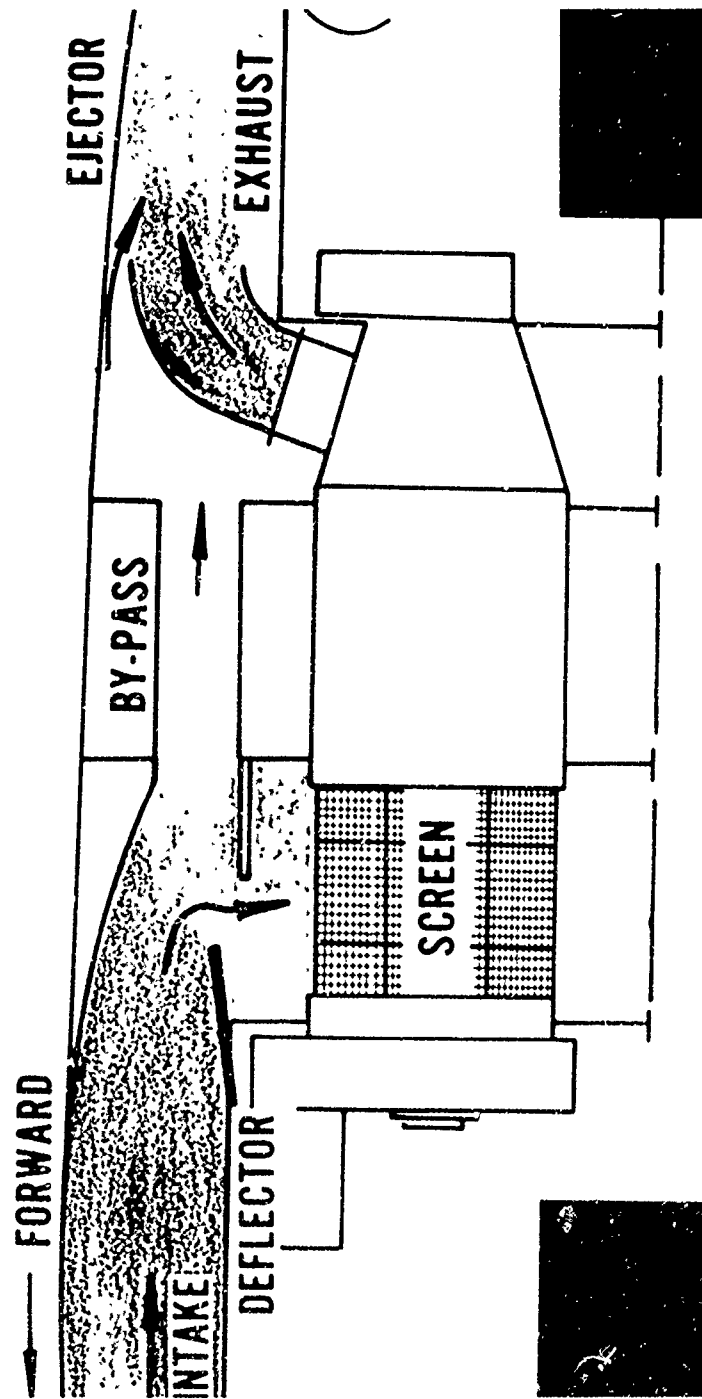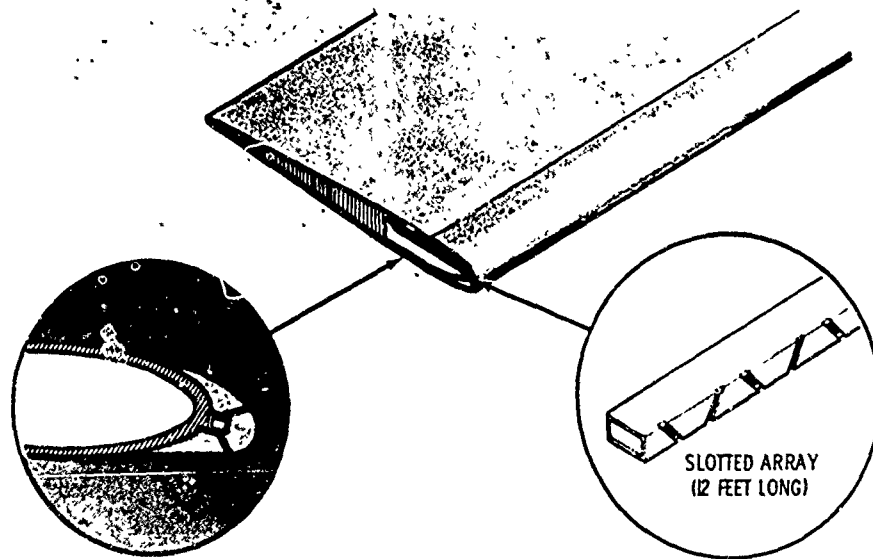
Figure 3. T400-CP-400 Internal Diagram

Figure 4. AH-1 Antenna Installation

SLOTTED ARRAY
(12 FEET LONG)

Figure 5. AH-1 Antenna Mounted in Rotor Blade

Figure 6. Jet Engine Mounted on Existing Helicopter

Figure 7. Variable Diameter Rotor.

rock on a string that you might have whirled about your head when you were a boy. You were continually pulling toward you to maintain the rock in a level plane. This principle is applied to the moving outer part of the rotor blade which is attached to the central hub through a series of straps working with centrifugal force and through the application of centripetal force the blade is retracted to a smaller diameter. The idea here is to reduce the size and drag of the rotor system and to achieve higher speed with the presently installed power.

Looking again at the helicopter and trying to project the requirements of range and speed for the short-haul arctic mission, the helicopter is restricted. In order to carry light to medium cargos, the vertical lift machine must be able to compete with comparable fixed-wing aircraft. To achieve this end, a speed in the area of 300 to 400 knots would be ideal. Efforts at Bell have been directed to putting the helicopter reliability and dependability that has been gained over the past decade to use in developing a VTOL aircraft of the future with increased capability.

In the 1960's, the XV-3 aircraft (known as a proprotor VTOL) was developed (Figure 8). A helicopter, in order to achieve speed in forward flight, must tilt its rotor blade. With the XV-3, rotors were used and tilted through a 90-degree angle to achieve both forward and vertical flight. This test bed was underpowered, because of a small reciprocating engine. It carried only a small payload, but it was highly successful in proving the concept. Over 200 flights were made and full autorotative power-off landings in the vertical mode were tested. Also, the aircraft had good STOL characteristics when the rotors were set at intermediate angles. The XV-3 also pointed out several problems quite similar to those experienced in the early Lockheed Electras, with pylon instability and stresses in the wing support structure. Bell embarked on an extensive engineering and wind tunnel testing program on proprotor configurations. A 25-foot flight-worthy model of the latest proprotor configuration was tested in the Ames wind tunnel. Bell is now building the dynamic components necessary for a flying test article for this size aircraft, a mockup of which is shown in Figure 9. Even this small aircraft would have good capability for short-haul arctic missions. Weighing about 12,000 pounds, it could carry 10 people or 2,000 pounds of cargo over a distance of 500 nautical miles. It could land at and take off from unprepared sites.

Along with the development of new VTOL concepts, the industry has been looking for something which would give the payload breakthrough similar to that of the jet engine. Presently, the use of composite material, either boron or graphite fibers or similar derivatives, has been limited to nonstructural panels and similar applications. With the increasing knowledge and availability of these materials, a new lightweight construction will possibly be achieved. Through decreased weight and increased strength of the

Figure 8. XV-3 Proprotor VTOL Aircraft

Figure 9. Proprotor VTOL Aircraft under Test
by Bell Helicopter Company

aircraft structure, higher payloads can be expected. These materials will also be less susceptible to the arctic environment, and their resistance to deterioration will assure longer life.

As mentioned earlier, to compete with fixed-wing aircraft, higher speeds with comparable payloads must be achieved. At Bell, the proprotor is seen as only the first step to ultimate VTOL aircraft. The proprotor is here now. It will be flying in the next few years. The folding proprotor is a logical follow-on (Figure 10). Utilizing compound engines, which can function both as thrust and shaft engines, this is a concept for the 1980's. The aircraft will have the speed of the present Boeing 727, and since its rotors are only used for vertical flight they will be optimized for hover and will be highly efficient for short-range cargo hauling. This is the ideal among the VTOL's of the future--the speed and range of the modern jet with the capabilities of the most efficient helicopter.

Figure 10. Folding Proprotor (Concept Design)

THE NEW COAST GUARD ICEBREAKER CLASS:
ITS DESIGN AND ITS FUTURE

H. E. Fallon
U.S. Coast Guard
Washington, D.C.

The icebreaker represents a highly specialized area of ship design. When the first U.S. icebreakers (the WIND class) were designed, little significant design information was available. Our design knowledge has expanded greatly, yet the final test of this knowledge, which grows almost daily, is still to be proven by an operational unit.

The Coast Guard is now constructing a new 400-foot icebreaker to replace the aging WIND class. A review of all design aspects of this ship is too detailed for inclusion here and would probably be of interest to only a few. Some aspects of the design which may be of general interest will be highlighted. Figure 1 is an artist's concept of the ship.

Semiempirical relationships have been developed which allow the designer to make predictions of ice resistance. In this area it must be mentioned that studies are continuing to predict ice resistance more accurately, with attempts being made to determine the individual components that are required to (1) break the ice, (2) turn and push aside the floes, and (3) overcome the hull and ice friction. This will lead to a better determination of the most efficient method of breaking ice.

The new icebreaker will utilize the grillage system (Figure 2) of construction instead of the more traditional truss system used in the WIND and GLACIER classes. The grillage system is more effective in resisting impact penetration and progressive failures of surrounding structure. Ice frames will be spaced on 16-inch centers, with the ice belt plating 1-3/4 inches thick. Fully loaded, the ship's draft is 30 feet. Its displacement is 12,000 tons.

The ship will have three shafts to improve reliability and maneuverability over the WIND class. An even power distribution between shafts will be used. This provides less thrust unloading of the wing screws due to propeller interaction and gives better performance in the near bollard condition.

The propulsion system for an icebreaker must produce power with high efficiency over a broad range and have high rates of change of power. The system must have a low susceptibility to damage in a hostile environment, low maintenance, and allow containment in a minimum geometry to reduce the beam required due to ice resistance on the hull.
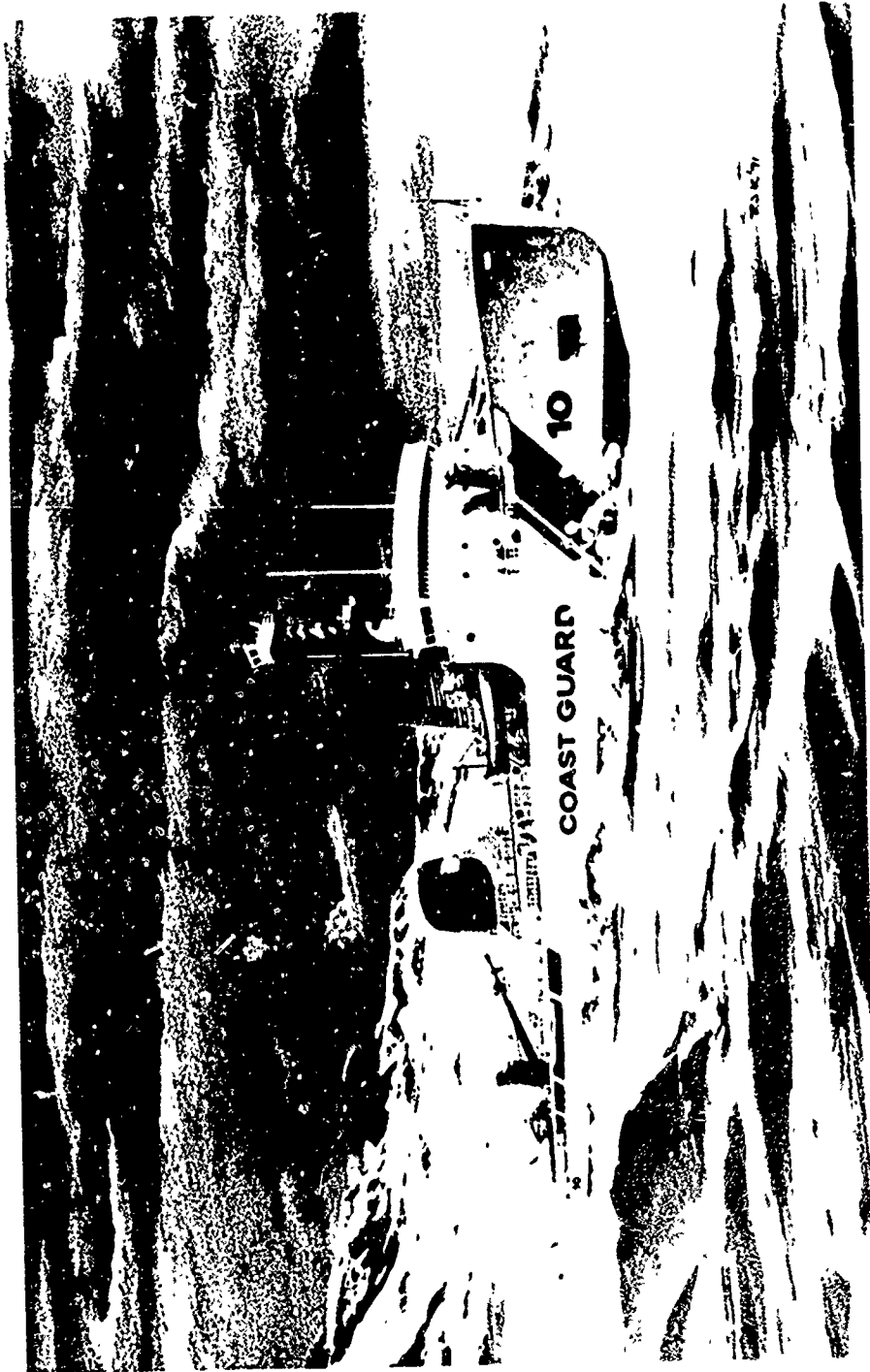
Figure 1. Artist Concept of 400-foot Coast Guard Icebreaker (WAGB-10)

Figure 2. Grillage System of WAGB-10

In a departure from conventional practice, a Combined Diesel
or Gas Turbine Plant (CODOG), consisting of an 18,000-shp diesel-
electric plant and 60,000 shp in gas turbines, has been specified.
Normal operations, including icebreaking, will be in the diesel-
electric mode, with the gas turbines being used when 18,000 shp
will not suffice. The ship will have a free-running speed of about
17 knots, and it will continuously break 4 feet of ice in the diesel-
electric mode, 6 feet of ice in the gas turbine mode, and 21 feet
of ice by ramming.

The gas turbine was selected for its well-known weight-to-
power ratio and size advantages as well as for its cost limitations
to achieve maximum horsepower. In addition, the gas turbine possesses
torque characteristics which are advantageous in icebreaking. Stall
torque to full load torque ratios of 2.5 are characteristic, and
these are desirable when a propeller loads down in ice. To reduce
the problems of reversing in both the diesel and gas turbine modes,
a controllable pitch (CP) propeller is utilized. The CP propeller
has a great influence on the design aside from its ability to reverse
large amounts of power.

An analysis of failures in fixed pitch propellers in existing
icebreakers shows that many happened when the propeller was stopped
and then encountered ice. Every reversal or stop of a fixed pitch
system presents this opportunity for damage. A CP system avoids
this and also has higher efficiency over the broad ranges of power.
A typical cruising speed would require no more than 7,000 shp,
while the ice breaking mode could require up to full power from
the gas turbines. Considering these factors, plus the long cruising
run before the vessel reaches its operating area, the favorable
effect on vessel endurance and, consequently, size and cost is
evident. The rate of reversal also indicates significant advantages
of the CP system in the ramming mode, since the speed of advance
obtained before impact is a function of the speed of reversal.
The CP system should provide a 20-percent advantage over the fixed
pitch propeller in the ramming mode.

Figure 3 shows the outboard profile of the ship. Note that the
ship is fitted for helicopter operations. It has an aloft conning
station, a forward cargo crane, two aft boat and helicopter cranes,
and an oceanographic boom (not visible in the figure).

The inboard profile (Figure 4) shows that all quarters and
living spaces (shaded) are on or above the second deck, with every-
thing below that level being reserved for machinery and stowage.
The gas turbines require the large intake and exhaust trunks shown.

The two forward machinery spaces contain six main propulsion
diesel generators and the three service diesel generators (Figure 5).
The main propulsion generators provide alternating current which
is rectified to direct current which, in turn, drives the main
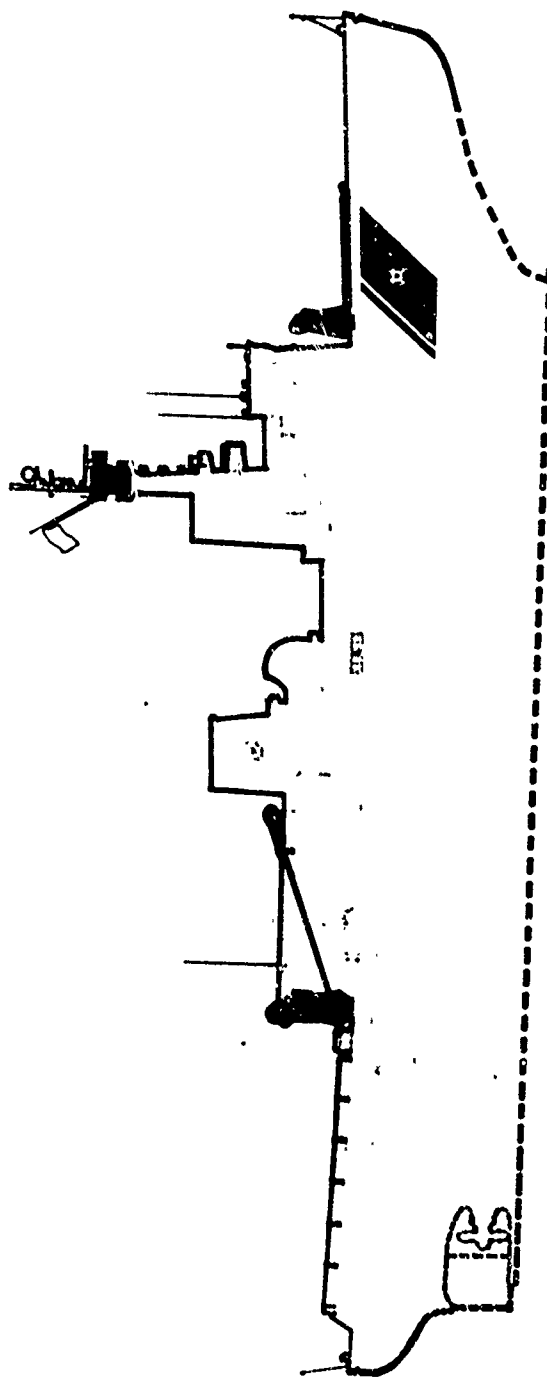propulsion motors mounted on the shafts in the after spaces. The

Figure 3. Outboard Profile of WAGB-10
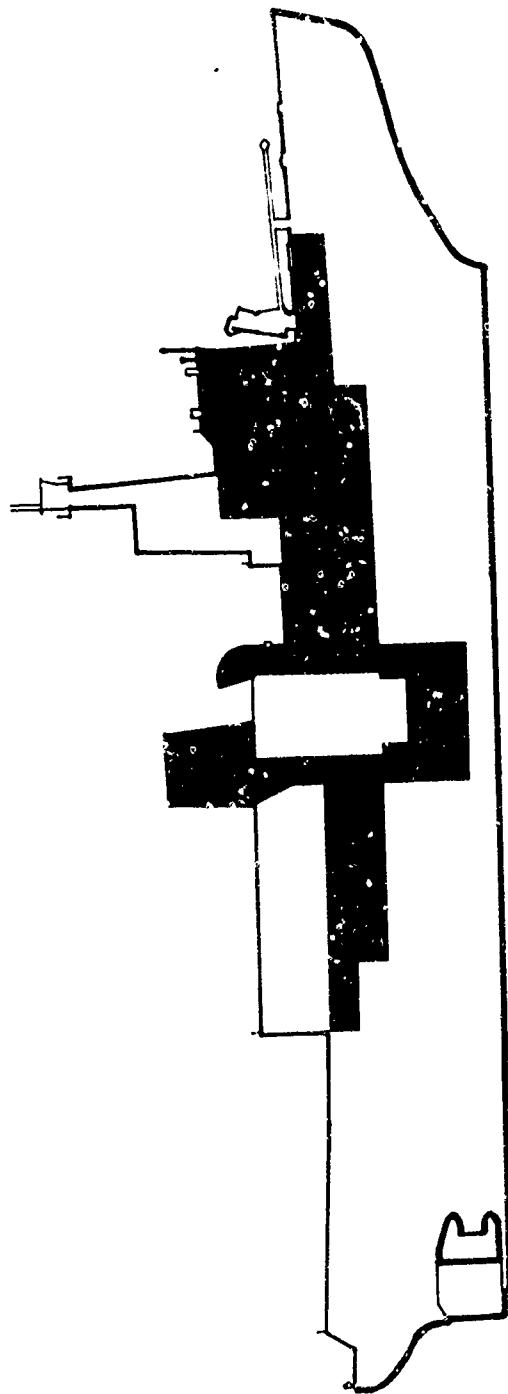
Figure 4. Inboard Profile of WAGB-10
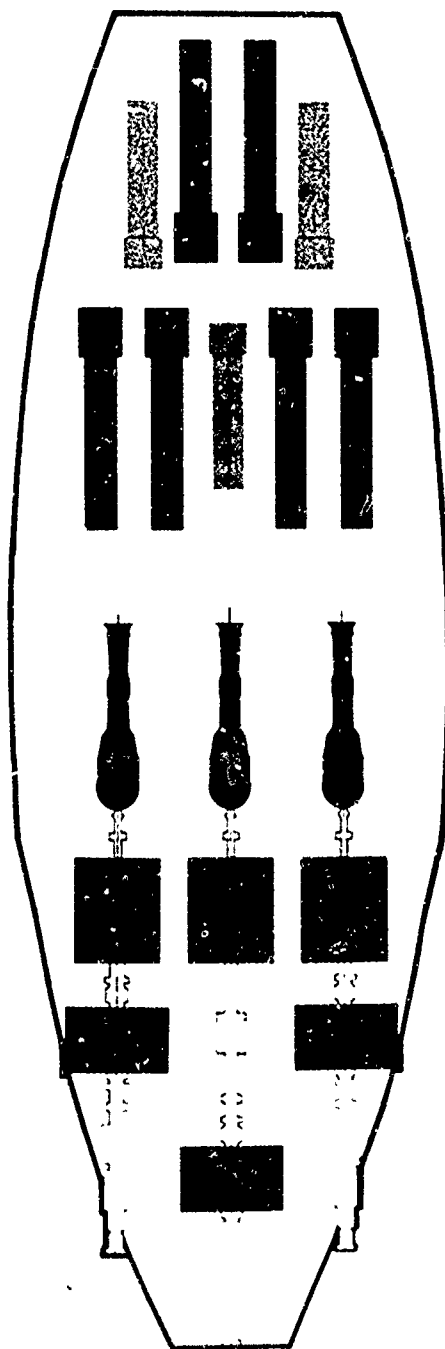
Figure 5. Propulsion System of WAGB-10

shafts extend forward of the motors where they are connected to reduction gears through a clutch. The gears are powered by the gas turbines installed in the space forward of the reduction gears.

This ship will have a central hydraulic system which will be powered by three pumps in a single compartment. The hydraulic fluid will power the following equipment: anchor windlass, cargo and boat or helicopter booms, boat hoisting winch, oceanographic boom and winches, towing capstan, and heeling system. Since normally no more than one or two of these equipments would be in operation at the same time, the central hydraulic system permits the installation of fewer hydraulic pumps and electric drive motors.

The oceanographic and meteorological data collection and processing system includes an oceanographic wet lab, a dry laboratory, two portable 80- by 14-foot vans, a meteorological laboratory, and an oceanographic data center. The wet laboratory houses two hydrographic winches in a sheltered compartment which also serves for the initial processing of oceanographic samples. A hydraulic over-the-side boom, located immediately aft or the wet laboratory, is controlled by an operator inside the laboratory, as are the winches. The operator will have a complete view of operations from the deck to the water's edge through a plastic bubble provided in the ship's side.

The sewage system collects, retains, and ejects waste materials and water. Ejection is to shore connections on deck or overboard through the hull. In laying out this system, four zones are created. Zones 1 and 4 are the forward and after-most zones and control only clear drains. These are conducted directly overboard or collected in the bilge system for discharge through the water separator. Zones 2 and 3 each contain a collection station which houses the retention and ejection facilities. Space is provided here for later installation of sewage treatment plants. Shipboard treatment of all drains within Zones 2 and 3 will be added when a suitable treatment plant is developed.

The new icebreaker will enter the Coast Guard fleet in 1974 and will exceed the operating capability and effectiveness of the GLACIER and the WIND class icebreakers. The physical dimensions alone, however, cannot indicate the true measure of difference between the old and new classes of vessels.

One obvious difference between the WIND class vessels and the WAGB-10 class is the sustained crusing speeds of 13 and 17 knots, respectively. Because of the long distances these ships must travel in going to the polar regions from their home ports in the United States, this 4-knot difference is significant. The increased transit speed will result in a savings of about 25 percent of present icebreaker transit days. The days thus saved will be used for other operating missions.

As an example, the new WAGB-10 class will make the voyage between the United States and New Zealand for Antarctic operations in 21 days as compared to 28 days for present icebreakers. Two of these icebreakers deployed to Antarctica would therefore save 1 month in transit time. Similarly, savings in transit time to the northern polar regions will be realized with the WAGB-10. ·

In addition to the difference in transit time in open water going to and from the polar regions, this ship can navigate approximately twice the thickness of ice (6 feet as compared to 3 feet) as the WIND class without being forced to stop, back down, and ram. Maximum ice thickness which can be broken by ramming will also be twice that of the WIND class (21 feet versus 11 feet). These increased icebreaking capabilities coupled with increased transit speed are particularly valuable in polar operations where support activities must be conducted within a limited and specific time period due to ice conditions that prohibit traffic movement.

The ability of the new icebreaker to penetrate heavier ice creates the possibility of performing missions which simply could not be done with a WIND class or any other U.S. icebreaker. This will allow information to be obtained about the polar regions which has been inaccessible. For example, the new vessel will have the capability to circumnavigate Greenland, a task now impossible for U.S. icebreakers.

Using a WAGB-10 class vessel in lieu of a WIND class will allow an expansion of the time period during which an icebreaker can operate in a specific area. The new vessel can maintain its presence and continue its operation in seasonal ice which would be too heavy for a WIND vessel. This, in effect, will extend the usable on-scene days in a given area. Additionally, the improved icebreaking capability of the new class will reduce the time lost by a vessel temporarily beset in the ice and will also increase the probability of completing an assigned mission.

One major activity of icebreakers in both the nortnern and southern polar regions is the escort of nonicebreaking supply vessels. The 33-percent increase in beam over the WIND class will enable the new class to perform escort and convoy duty much more effectively. The 83.5-foot beam of this icebreaker will provide a wider path through the ice for nonicebreaking vessels. This will faciliate the movement of wider vessels than can now be accommodated effectively by the WIND class.

In summary, the new WAGB-10 class icebreaker will be superior in all respects to the GLACIER and WIND class icebreakers. It will be able to complete present mission requirements more success-fully and perform missions which are now impossible. The larger physical size and total shaft horsepower available will allow the new class to be 25-percent more productive in transit, and perhaps equally as much in ice. A decrease in the number of icebreakers in an area without a change in the level of support will be possible by allowing less time but more multimission operation for accomplish-ing a project.

SHIPS TO TRANSIT THE ARCTIC OCEAN

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Arctic icebreaking ships could have the capability for sustained operations in the Arctic Basin, including use as stationary or mobile platforms. As a mobile platform, these ships could resupply remote stations or provide escort service to bring other ships or structures into arctic waters. Furthermore, these ships could act as a base of operations or directly participate in multidisciplinary activities. As a base of operations, they could supply heat, water, power, helicopters, hovercraft, skimobiles, long-range communication, on-board computers, carpentry and machine shops, accommodations, and recreational facilities. Simultaneously, they could participate directly in such operations as meteorological studies, ice surveys, ice physics, bottom profiling, bottom photography, bottom coring, acoustic experiments, magnetic surveys, bathythermography, water sampling, positioning scientific buoys, and support of small underwater research vehicles. The services provided by these icebreaking ships imply the capability for operating in and transiting the Arctic Ocean during all seasons.

Although no existing ships have the stated all-round capabilities, the technology for designing and building these icebreaking ships is available today. Such a ship would have three times the capabilities of the largest current U.S. icebreaker and more than twice the capability of the largest U.S. icebreaker presently under construction. The horsepower of one such "arctic icebreaker" would be greater than the combined total horsepower rating of all operational U.S. icebreakers, including those under construction. It is for this reason, plus consideration of the regions in which the ship will operate, that the classification "arctic icebreaker" has been assigned.

The primary purpose of this paper is to present a conceptual design of an icebreaker capable of transiting the Arctic Ocean. The paper is presented in three sections. Initially, arctic ice conditions are reviewed so that the operational requirements can be determined. The second section presents a conceptual design of an arctic icebreaker to meet these operational requirements and presents a series of icebreaker performance curves. These curves provide the base data upon which the principal characteristics of the ship are determined. The concluding section reviews those areas requiring engineering development, the methods and tools available to conduct that research, and a brief discussion of the efforts in progress.

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ICE CONDITIONS IN THE ARCTIC

Arctic ice conditions are usually defined in general terms, such as miltiyear ice, pressure ridges, hummock ice fields, ice fields under pressure, and polynyas. However, a concise description of the ice environment along potential routes will ultimately be required if meaningful missions, ship shaft horsepower, and endurance are to be established. This means that ice data must be defined in terms of thickness, area of coverage, strengths, snow cover, and other variables. Although this level of detail is not available, some generalized statements can be made to provide guidance in determining the required icebreaking capability.

Pressure ridges constitute one of the more difficult ice conditions for icebreakers. Although pressure ridges in excess of 100 feet in depth and 20 feet in height are reported, it should be accepted that the arctic ships will not be going through the ice field blindfolded. There is no reason why pressure ridges having depths over 40 feet cannot be avoided with improved ice navigation devices. Also, it is reported that the strength of pressure ridges decreases with depth of submergence and hence passage through pressure ridges, although difficult, is not impossible.

On a more optimistic note, Breslau (1) and Mookhoek (2) report that as much as 10 percent open water exists during winter in locations near land masses and increases significantly during the summer months. On the other hand, Weeks (3) reports that open water in the central arctic basin is less than 5 percent in the winter and averages about 5 to 8 percent in the summer. Furthermore, the number of pressure ridges per mile decreases sharply in the summer, and the ice cover is extensively covered with melt ponds.

For purposes of establishing a seasonal ice profile of the Arctic Ocean, Wittmann's (4) graph of generalized ice thickness is used and is shown in Figure 1. It shows thicknesses of about 10.5 feet and 7.5 feet for winter and summer ice, respectively, with only 3 months having ice thicknesses greater than 10 feet. For the conceptual design of the arctic icebreaker, a continuous icebreaking capability of 10 feet will be required. Ice thicknesses in excess of this value and ice fields under pressure will also be encountered and must be considered in the overall performance of the icebreaker.

CONCEPTUAL DESIGN OF ARCTIC ICEBREAKING SHIP

The conceptual design of an arctic icebreaking ship basically follows the procedure outlined by Melberg (5). In this paper, the procedure will be shortened considerably by first starting with icebreaking requirements, calculating icebreaking resistance as a function of beam, selecting a beam, determining the ice breaking capability as a function of speed, discussing special features of the ship, and presenting the principal ship characteristics including an estimate of cost.

FIGURE 1

GENERALIZED ICE THICKNESS FOR CENTRAL ARCTIC PACK
(from Arctic Sea Ice, Wittmann pg. 248, Nat. Acdy, of Science Preprint 598, Dec 1958)

FEET

12

10

8

6

4

JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEPT | OCT | NOV | DEC

MONTH
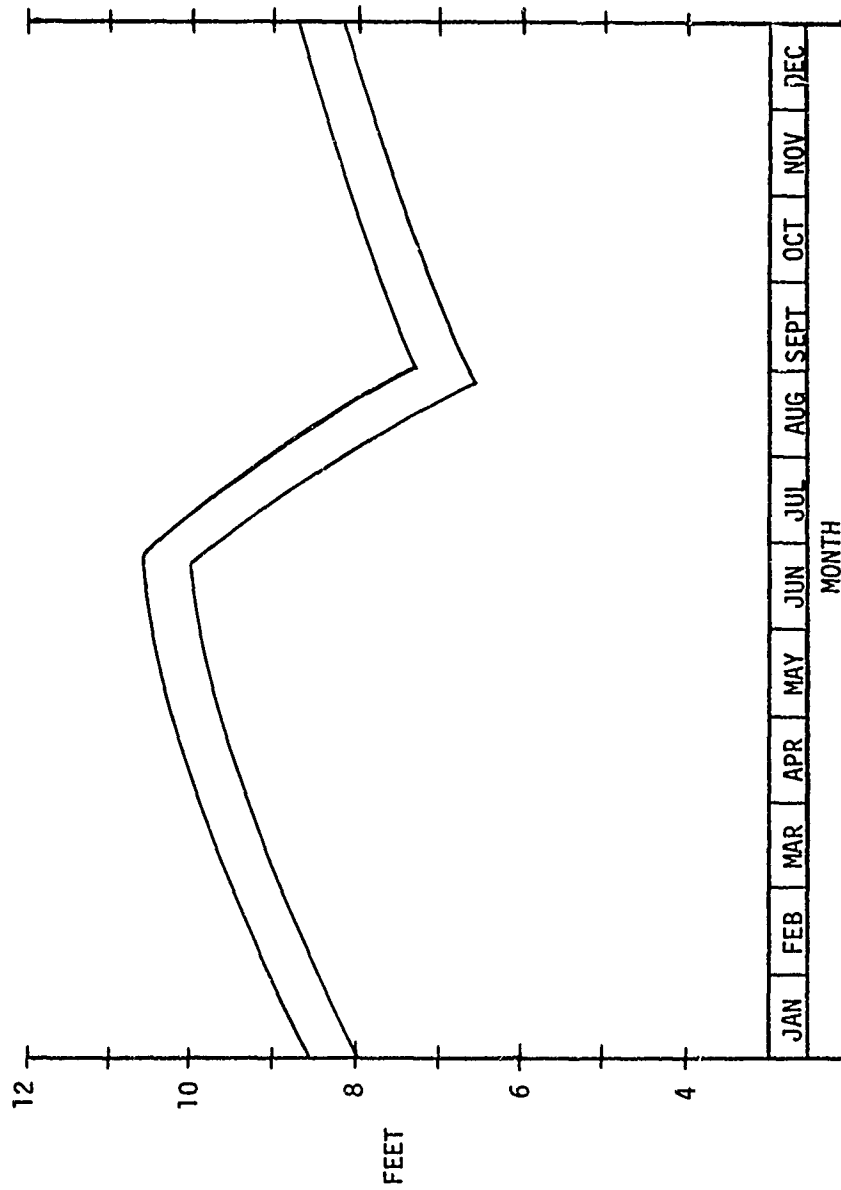
Calculation of Icebreaking Resistance

Having established the requirement for continuous breaking of 10-foot-thick ice, the icebreaking resistance equation developed by Kashteljan (6) is used, since it gives satisfactory results for a first approximation of icebreaking resistance.

$$R_{IB} = 0.004B \; \mu_0 \sigma \; h + 3.6 \; B \; \mu_0 \gamma_i h^2 + 0.00332 \frac{B^{1.65}}{\eta_2} \; h \nu$$

where

R_{IB} = icebreaking resistance (tons)

h = ice thickness, feet

ν = ship speed, ft/sec

B = beam of icebreaker, feet

σ = flexural ice strength, tons/sq.ft.

γ_i = weight density of ice, tons/cu. ft.

μ_0, η_2 = hull coefficients (dimensionless)

Substituting in the equation for σ = 2.74 tons/sq. ft., γ = 0.0257 ton/cu. ft., μ_0 = 1.4, η_2 = 3.0, and for the remaining variables (beam, ice thickness, and velocity) the icebreaking resistance is calculated. The values of μ_0 and η_2 selected are representative of efficient icebreaking hull forms. The effect of beam on icebreaking resistance is shown in Figure 2 for given values of ice thickness and velocity. The minimum beam is indicated, but it is limited by requirements of beached intact stability (icebreaker grounded on an ice sheet) and by the size of the propellers.

Determination of Icebreaking Capability

The shaft horsepower required for the arctic icebreaker must produce propeller thrust equal to the icebreaking resistance at the desired speed. Initially, a beam of 95 feet has been selected with a triple-screw propulsion plant of 70,000 shp per shaft (210,000 shp total). Calculations to determine propeller thrust at t'is horsepower for various speeds are plotted in Figure 3. The intersection of the propeller thrust curve with the icebreaking resistance curve gives ship performance: at 2 knots, 10 feet continuous icebreaking; at 6 knots, over 9 feet continuous icebreaking; etc. Note that several detailed calculations have been omitted from the above discussion and that the most critical elements in the design are the propeller, after-body, and bow. The propellers will dictate the beam of the ship and the amount of horsepower that can effectively be used. To maximize the capability of the ship, the propulsion machinery and propeller must be specifically designed for operation in ice and not for efficient operation in open water. Compromising the basic icebreaking mission will result in an inefficient icebreaking ship.

FIGURE 2

ICEBREAKING RESISTANCE AS A FUNCTION OF BEAM
(SHIP SPEED = 3 KNOTS)
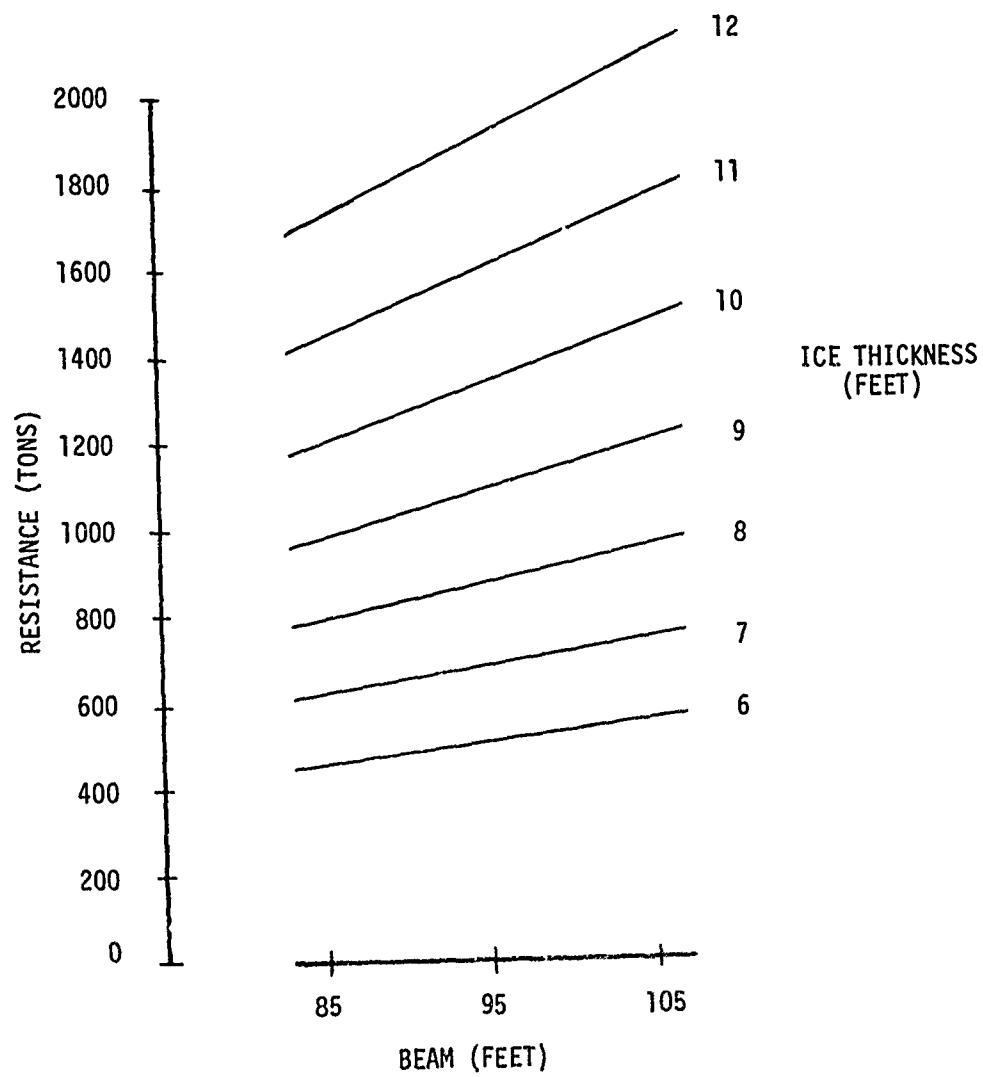
FIGURE 3

CONTINUOUS ICEBREAKING CAPABILITY
(BEAM = 95 FT) (THRUST DEDUCTION COEFFICIENT = 0.05)
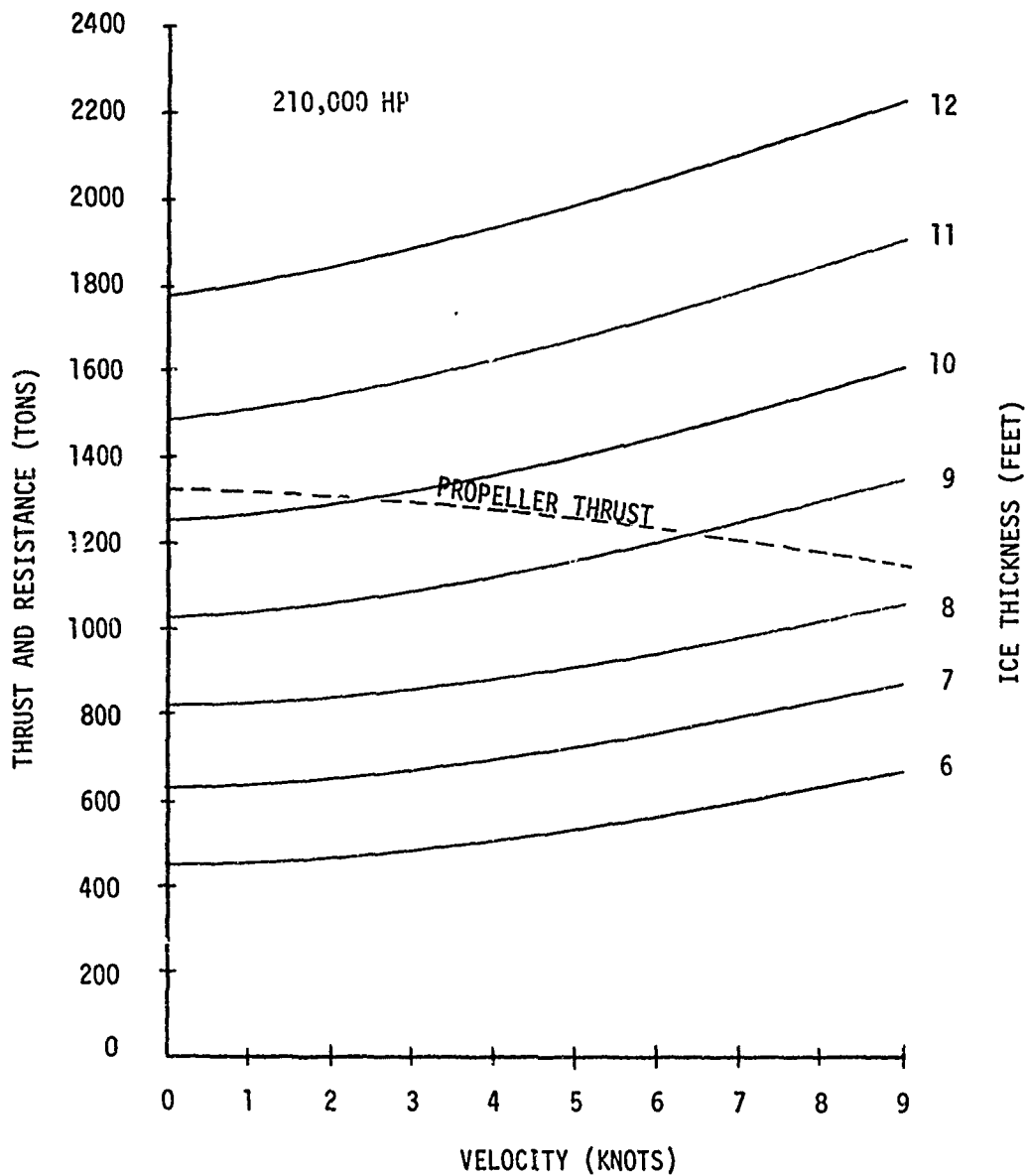
Having determined the continuous icebreaking capability of the ship, calculations to determine the ramming capability were performed. Figure 4 shows the results of both continuous and ramming mode icebreaking, as well as overall ship performance. Note that an improved icebreaking capability is possible in the summer because of deteriorating ice (melt ponds).

Special Ship Features

The propulsion machinery for the icebreaking ship should be either gas or nuclear steam turbines. Gas turbines with reverse reduction gear have the advantage of compactness, and they should be able to burn North Slope crude oil. While gas turbines have limited endurance, nuclear power has the advantage of almost unlimited endurance, but with the primary disadvantages of higher acquisition cost, larger crew, and greater cooling water requirements. Steam boilers are not recommended because of excessively large space requirements, which result in a poor layout of the machinery plant in beam-limited ships.

The hull should be designed to resist ice loads of three types: uniform loading, impact loading, and localized high-impact loading (5). The ice belt should be thicker than normal as this is the area where the greatest loads would be incurred. The type of steel, method of fabrication, and welding technology all exist today.

Crew size, based on civilian manning for operation of the ship while underway, is estimated at 60 and does not reflect scientific support capability. Civilian manning, such as the Military Sealift Command, should be considered as a means of keeping skilled people aboard the ship. Military manning would necessitate doubling the crew size and the loss of skilled personnel every 2 years due to rotation.

Principal Characteristics of Arctic Icebreaker

Having ascertained some of the basic features of the arctic icebreaking ship, an ARCTEC computer feasibility program was used to generate the principal characteristics of the ship. These characteristics are based on the least-cost icebreaking ship that fulfills requirements. A partial listing of the computer printout is tabulated below.

Overall length	604 feet
Length between perpendiculars	562 feet
Beam	95 feet
Draft	35.6 feet
Displacement	32,281 tons

FIGURE 4

TYPICAL ICEBREAKING PERFORMANCE AT FULL POWER
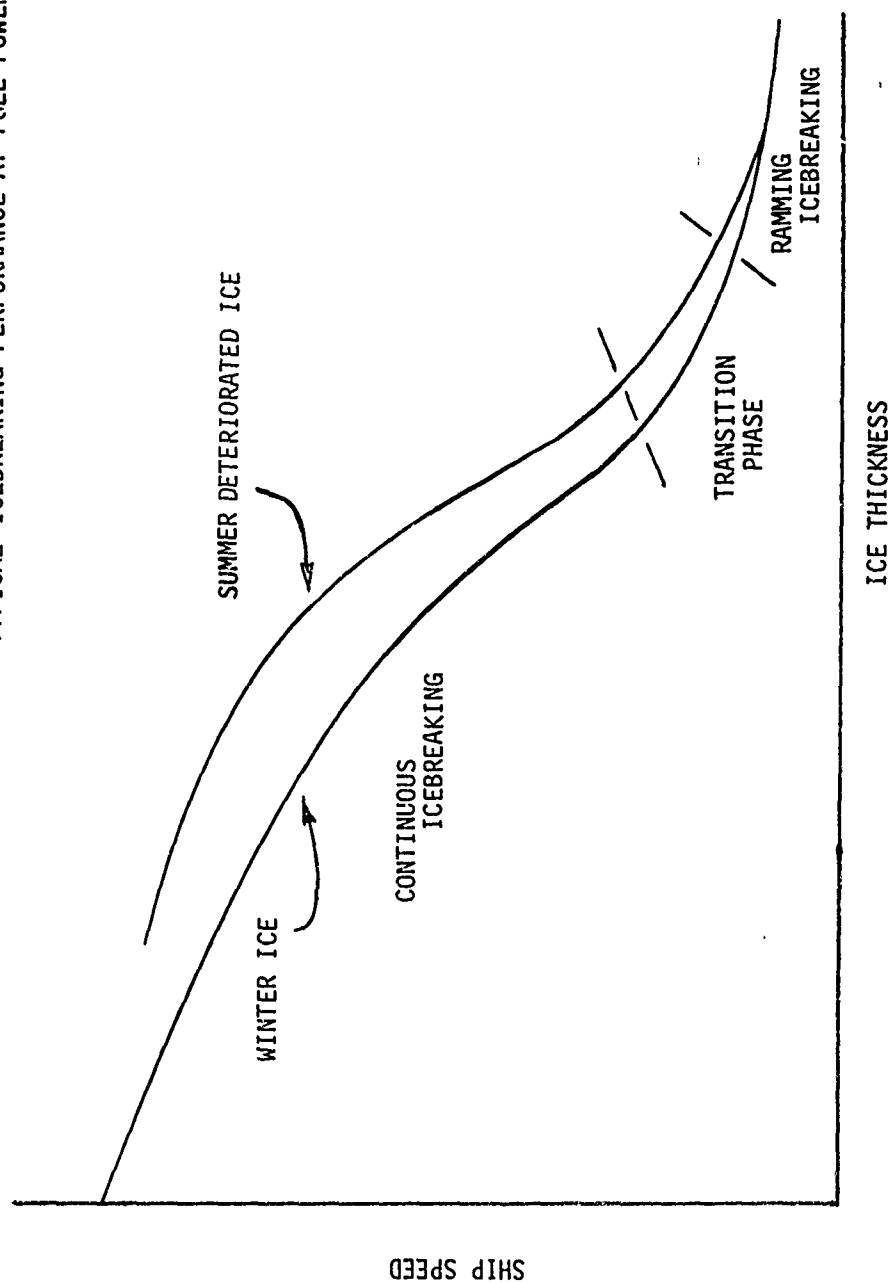
Weight of fuel	11,255 tons
Block coefficient	0.59
Cost (U.S. construction)	$95 million

NEEDS FOR ENGINEERING RESEARCH

Having arrived at the basic characteristics of a technically feasible ship to transit the Arctic, it is now desirable to review those areas where research and development can contribute to a reduction in the resistance associated with icebreaking.

One prime area requiring research is the mechanics of ice-breaking in various types of ice and the relationship to resistance. This includes better equations to describe icebreaking resistance, as present equations do not adequately cover the effect of ship length, ice sheet pressure, hull form, and skin friction.

The method of accomplishing this research is first to conduct full-scale experiments on various size ships in ice; second, to operate model ships in model ice fields to determine scaling laws; and third, to start a development program to improve icebreaking performance. The collection of full-scale data is not difficult, but it must be done accurately. This is accomplished by measuring propeller torque, rpm and thrust, ship speed, and ice thickness. At this time, two of the three classes of U.S. Coast Guard icebreakers have been tested to collect full-scale data (WIND and MACKINAW). Additionally, full-scale icebreaking tests have also been done on U.S. Coast Guard buoy tenders. Of these full-scale tests, only model icebreaking tests of the WIND class have been conducted in the United States.

These model tests were performed at the Naval Undersea Research and Development Center in San Diego, California and have given good correlation with full-scale tests (7) (8). Subsequently, the ARCTEC Ice Model Basin was completed in Savage, Maryland and additionally WIND icebreaking tests were conducted for comparison with the NEL data and full-scale data. The results (9) are presented in Figure 5 and show excellent agreement.

At present, some investigations for reducing resistance for Great Lakes ships in broken ice are in progress. The Maritime Administration is sponsoring work related to bulk carriers, and the U.S. Coast Guard is sponsoring work related to the icebreaker MACKINAW. However, the overall research activity to improve ice-breaking performance is low. Some areas requiring further investigation include: the effect of ship length, bow form, stern form, and side friction on resistance; the effect of lasers, water jets, air bubbler systems, and thrust-producing devices to reduce resistance; and methods to extract stuck ships. Recent Soviet literature has presented some of the results of their ice model experiments and can be used in the development of a research program.

FIGURE 5

PLOT OF WINDCLASS MODEL AND FULL-SCALE DIMENSIONLESS
REGRESSION EQUATIONS IN FULL-SCALE UNITS WITH ARCTIC ICE
MODEL BASIN DATA SUPERIMPOSED (VELOCITY SUBSCRIPT)

- - - - - -   FULL SCALE REGRESSION LINE

——————   MODEL REGRESSION LINE (NVC TESTS)

BEAM   62 FEET (18.9 METERS)

VELOCITY   4.94 FT/SEC

ICE STRENGTH   3.42 kg/cm^2

NO SNOW COVER
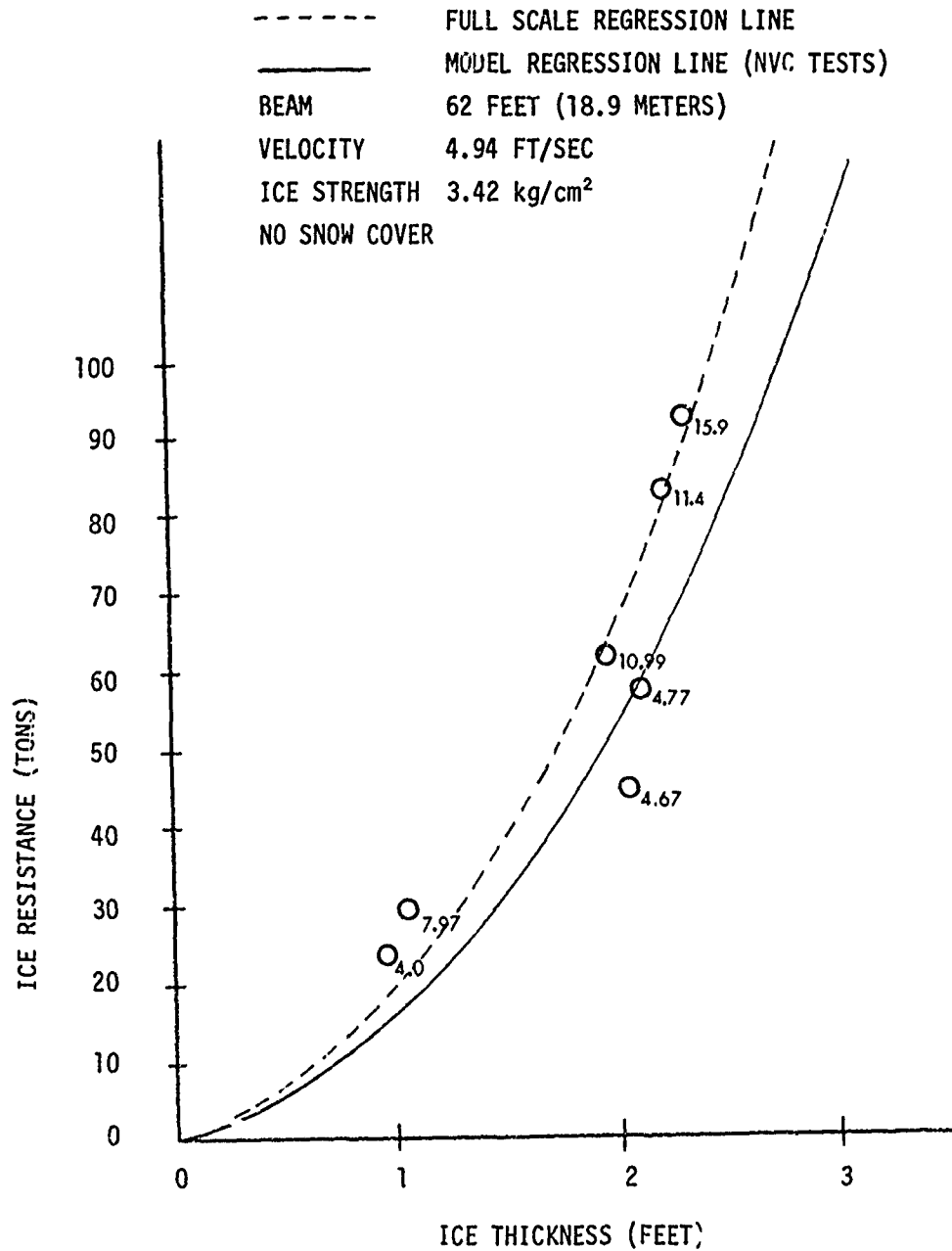
Little work has been done on pressure ridge/ship interactions, since most technical efforts have been directed at continuous icebreaking. Since pressure ridges predominate in the Arctic Ocean, comprehensive model and full-scale testing should be undertaken. Data on ice loads in the bow area due to striking pressure ridges and multiyear ice floes are definitely required. It is the collection of this type of data and subsequent research efforts that should result in a near-term improvement of 20 to 30 percent in icebreaker performance.

SUMMARY

Technology for the design and construction of icebreaking ships to transit the Arctic Ocean is available today. Facilities exist to conduct the required engineering research to improve icebreaking performance. Only recently have any attempts been made in the United States to investigate means of achieving reductions in icebreaking resistance. A 6-year research program followed by a 1-year design study and 3 years for construction should result in icebreaking ships capable of all-season operation in the Arctic.

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UNMANNED SUBMERSIBLE AS AN ARCTIC RESEARCH TOOL

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The concept of employing an unmanned submersible to collect scientific data under the arctic ice pack has been pursued seriously during the past 2 years. This activity is due largely to the increased attention that the Arctic has been receiving. Nevertheless, it could not have developed without the extensive experience that has been gained from the operation of reliable, unmanned submersibles in the open sea.

Unmanned research submersibles emerged as a recognizable class of data collection and work vehicles a little over a decade ago. An early natural division appeared at that time between tethered or cable-controlled vehicles and free-running, internally programmed or acoustically controlled vehicles. The CURV series of submersibles, which has received wide acclaim for its capability of retrieving relatively small, high-value items from the ocean floor, is a good example of the tethered approach. These vehicles, originally designed by the Naval Undersea Research and Development Center for torpedo retrieval, have now been carried through the third generation with successful performances logged in the open sea at great depths.

CURV III (Figure 1) is capable of operating at depths of 7,000 feet with an instrument suit that includes active and passive sonar, two pan and tilt television cameras, a 35mm camera, lights, and a hydraulic grasping claw. A fourth generation tethered system, known as the Remote Underwater Work System, is now on the Navy's drawing boards and will have a depth capability of 20,000 feet.

The untethered submersible approach is exemplified by the SPURV series of submersibles developed by the University of Washington's Applied Physics Laboratory. Like CURV, SPURV is also in its third generation and has been extremely successful in carrying out horizontal sampling of deep ocean physical characteristics (sound velocity, salinity and temperature). SPURV, shown in launch position in Figure 2, is tracked and commanded acoustically from a surface vessel. To date, more than 120 data acquisition runs have been made with the vehicle, some as deep as 10,000 feet. With ARPA sponsorship the Laboratory is now developing an arctic "cousin" to SPURV under an ONR contract. The design of this vehicle, called UARS, has been completed and fabrication is underway. Testing will be conducted near Ice Island T-3 during the spring of 1972. The experience gained from designing UARS and its support system is the principal basis for the concepts presented in this paper.

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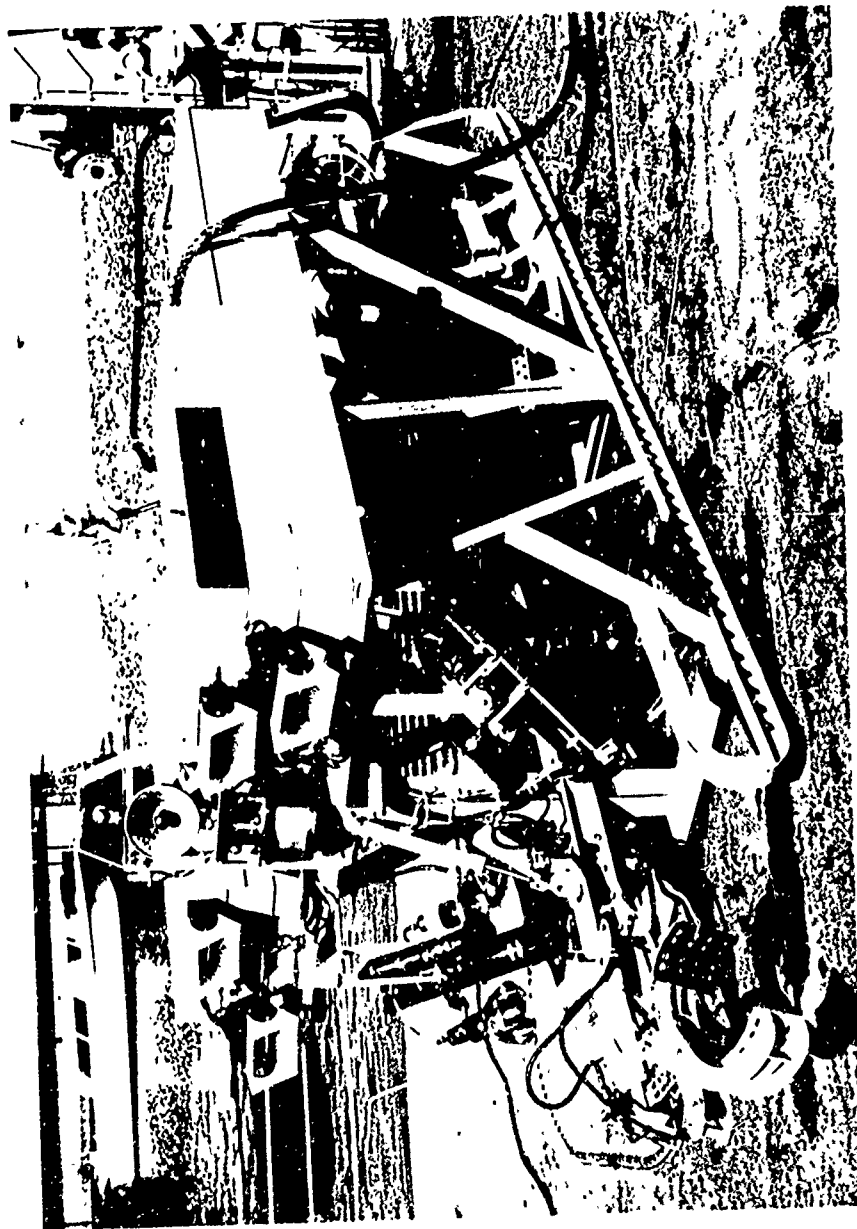
Figure 1. CURV III, One of the Latest Concepts in Tethered
Unmanned Submersibles (Photograph Courtesy
of the U.S. Navy)
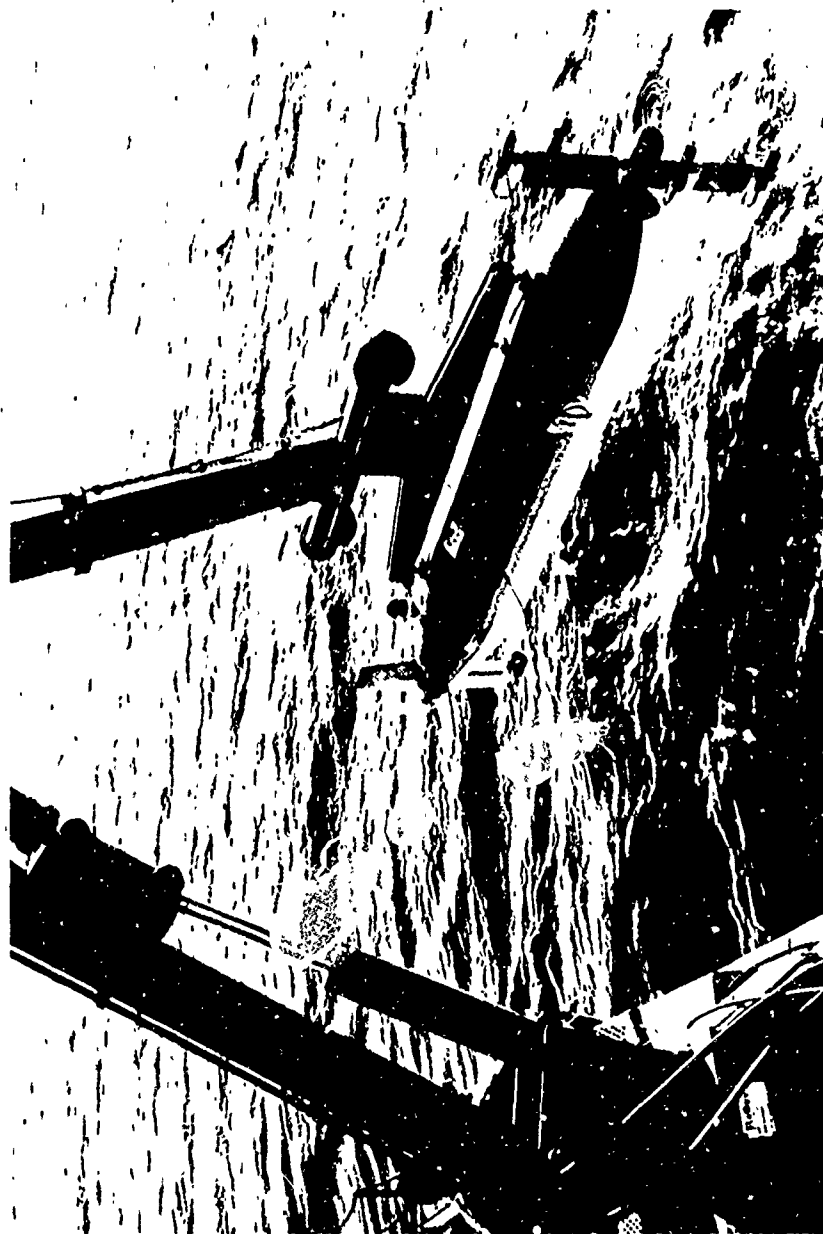
Figure 2. SPURV, a Reliable, Untethered, Deep Running
Unmanned Submersible

Both CURV and SPURV have been engaged in significant on-going programs. It is understood that both CURV II and CURV III are conducting fleet and shore facility support as well as some research work. SPURV has recently been used to collect data at Cobb Seamount in an experiment aimed at correlating oceanographic microstructure with acoustic fluctuations along a 14-mile sound transmission path. At present, the submersible is being employed with an ultrasensitive fluorometer to study deep sea diffusion processes. No arctic programs are planned for either the CURV or SPURV submersibles since extensive modification to shipboard control and tracking systems would be required for operation in the pack ice.

The only known use of a manned submersible in the Arctic was the PISCES operation in the Canadian archipelago during the summer of 1968.* Two dives in that operation were conducted a short distance under the edge of ice floes, with the PISCES securely tethered to the CCGS LABRADOR on each occasion. Realistically, existing manned submersibles cannot be envisioned in the role of routinely collecting under-ice data because of the risks to human life and the concomitant expensive and time-consuming precautions that are required. The unmanned submersible, on the other hand, is not inhibited by these considerations and consequently appears to have unique potential for scientific work in this environment.

SPECIAL REQUIREMENTS FOR UNMANNED ARCTIC SUBMERSIBLES

Access Through the Pack Ice

Since natural openings in the arctic ice (leads and polynyas) are unpredictable as to location and duration, one important consideration in attaining operational flexibility for Arctic Ocean research is to gain the ability to penetrate the ice cover quickly, precisely, and inexpensively at selected locations. When this problem was considered at APL by the designers of the UARS system, they immediately recognized as unacceptable the current "brute force" methods of sawing and chipping or blasting through the 10 to 20 feet of ice likely to be encountered. Several days are often required for this activity and considerable risk of injury can be involved.

For the UARS system, speed and precision in forming access holes were given high priority. The submersible itself requires a 4- by 12-foot hole for entry, while the elements of the command/tracking system will each need an opening approximately 1 foot in diameter. Furthermore, in the remote possibility that the submersible should exhaust its several homing options or shut down prematurely and come to rest against the undersurface of the ice, it would be necessary to locate and reach it without delay.

* Milne, A.R. "A small research submarine in the Arctic," *Arctic*, Vol. 22, No. ` pp. 69-70, March 1969.

The solution to this problem was found in the development of a simple but efficient thermal coring device which uses circulated hot water to melt a 2-inch annular or linear groove through any thickness of ice. Cores thus formed can be pushed out the bottom to clear the hole. The experimental prototype has now been brought to third generation refinement (Figure 3). Because of its portability and effectiveness, it has already been used on several other ice-cutting jobs.

Protection from Thermal Shock and Cold Soaking

Two hazards to instrumentation and equipment which must be guarded against in the Arctic are thermal shock and cold soaking. Thermal shock can rupture bonds between materials or cause other distortions which are catastrophic. Since thermal shock is a transient phenomenon in which the effect is greatest immediately after exposure, it is essential that adequate insulation be provided for sensitive elements of the submersible system during checkout before deployment and upon retrieval.

Cold soaking, on the other hand, may cause unacceptable changes in the mechanical and electrical properties of the equipment or its fuel and lubricants. Potential cold-soaking problems governed the design of the UARS system tracking buoys in that the power source and other sensitive components were placed below the ice level in the relatively warm water of the ocean.

Transportation Size Limitations

The utility of a submersible in the Arctic heavily depends upon the flexibility of its deployment. To maximize this flexibility, the UARS system was designed with weight and volume-limited components so that, if necessary, the system could be broken down into units transportable by light, single-engine, ski-equipped aircraft or helicopters. Thus, any point on the ice pack within the aircraft operating radius can be considered as a potential deployment site for UARS. However, the principal benefit which may be derived from the unitized design is the ability to fly in spare replacement units rather than to attempt troubleshooting in the field. For most deployments larger aircraft such as the Bristol Freighter or de Haviland Caribou can be used. These aircraft would allow the UARS system and its support elements to be deployed fully assembled.

Submersible Control and Recovery

Much of the operationally significant oceanography in the Arctic occurs within the first 50 meters beneath the ice. In the shallow marginal seas this depth represents approximately the full water column. It follows that arctic research submersibles, to be useful, must operate with precision and be recoverable near the ice undersurface. To avoid the hazards occasioned by large density differences, swift currents, and deep keels of ice protruding from

Figure 3a. Inventor R.E. Francois and
100,000 Btu Per Hour Thermal Ice Corer

Figure 3b. A 28-inch-Diameter
Hole Cored through 18-foot-
Thick Ice in 3 1/2 Hours

the pack, the submersible tracking and control system must be
immune to false signals. A tethered submersible with command data
links running through the cable could provide the necessary
control within the tether's scope (probably a few hundred feet).
It would also require an acoustic tracking system for position
determination.

The approach taken in the UARS system was to discard the
tether concept in favor of acoustic links to the vehicle for com-
mand, data transmission, and homing functions. In this way the
same transducers and hydrophones required for the tracking system
could be used for operational control. Using acoustic control and
tracking, there are no constraints on the geometric pattern which
the submersible may follow under the ice, but great care must be
taken in the placement of the transducers and the design of the
system electronics and logic so that the acoustic anomalies caused
by the ice canopy and density variations in adjacent water do not
confuse the vehicle or its surface director.

Much of the preliminary research work done at the Applied
Physics Laboratory leading to the design of the UARS system
focused on the development of reliable near-ice acoustic communi-
cations. The resulting design employs a special 50-kHz phase-
shift-keyed code which will provide dependable tracking and data
transmission within a 2 square mile area.

DESCRIPTION OF THE UNMANNED ARCTIC RESEARCH SUBMERSIBLE SYSTEM (UARS)

The UARS system consists of two major elements--an unmanned
submersible which serves as a mobile instrument carrier, and a
remote, acoustically controlled tracking, guidance, and recovery
system. The vehicle (Figure 4) weighs nearly 1,000 pounds, has a
length of about 10 feet, and has a diameter of 19 inches. It may
be driven at different speeds depending upon the mission. Oceano-
graphic measurements would normally be taken at 6 knots, while ice
undersurface profiling would be done at 3 knots. Tne main batteries
will supply up to 10 hours of run time. Principal acoustic com-
ponents in the vehicle system (not including the instrumentation
package) provide communications, tracking, homing, and collision
avoidance. The latter is made necessary because of the potential
presence of massive ice keels that could project downward into
the path of the on-coming submersible. The designed operating depth
of the submersible is 1,500 feet.

The initial instrumentation for UARS will feature acoustic
sensors to profile the undersurface of the pack ice. This instru-
ment package will measure surface elevations to a differential
accuracy of 0.25 foot from the vehicle path at 60 to 250 feet
below the surface. The launching procedure calls for the vehicle
to be lowered by special sling through a 4- by 12-foot hole in the
ice and released in a horizontal attitude at a depth of approxi-
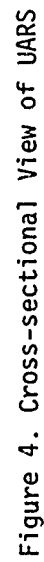
Figure 4. Cross-sectional View of UARS

mately 50 feet. Procedures and equipment to facilitate making the access hole in the ice have been mentioned.

Control Subsystems

Tracking elements in the system (Figure 5) are (1) an array of three or more RF telemetering hydrophones arranged in a pattern which defines the experiment or survey area; (2) two baseline acoustic projectors which are normally located within the survey area and provide a coordinate reference system; (3) an acoustic source aboard UARS; and (4) the timing units, data processors, and power supply which provide the basis for interpreting the acoustic signals and making rapid position calculations. The hydrophones and baseline projectors (Figures 6 and 7) are designed as free-floating buoys, but can be frozen in place, weather permitting.

In order to control the UARS precisely and to insure its reliable recovery, an acoustic communication link with the vehicle is employed. Sixteen command functions have been programmed to control UARS through this link. The system utilizes a common frequency for command, tracking, and vehicle data transmission in which all telemetric pulses are digitally coded using phase-shift-keyed modulation at a carrier frequency of 50 kHz. The large amount of information that must be acoustically transmitted to the tracking station and the restriction on pulse length (to avoid multiple-path interference) have necessitated the interspersing of coded information pulses between the tracking pulses.

The basic recovery technique (Figure 8) is to lure the vehicle back to the recovery hole by means of an acoustic homing system installed in the vehicle. This system responds to a particular signal that is transmitted at 28 kHz from a homing beacon centered in a capture net. The net will be lowered through the ice hole to the operating depth of the submersible, after which UARS will be commanded to seek the homing signal. Internally programmed homing logic, an inertial and depth-sensing guidance system, and the command/tracking receivers provide UARS with great retrieval redundancy. Should there occur a massive power interruption or other catastrophic failure, a further retrieval capability is provided. The submersible is buoyant and will rise to the undersurface of the ice, automatically lower an acoustic beacon, and release a dye marker to aid an over-the-ice search party.

To avoid collision with deep pressure ridge keels, the vehicle is equipped with a 360-kHz obstacle avoidance sonar. The rapid attenuation at this frequency allows a high pulse repetition rate (five pulses per second) so that obstacle avoidance logic can be based upon receipt of multiple valid returns. Pulse length broadening, a characteristic of the expected return from the ridge keels (as opposed to fish echoes), will be used for pulse validation.
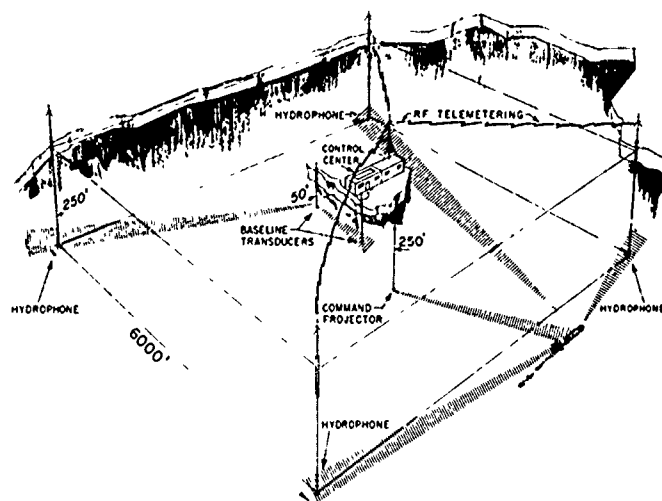
Figure 5. Tracking and Command/
Communication System Conceptual
Layout
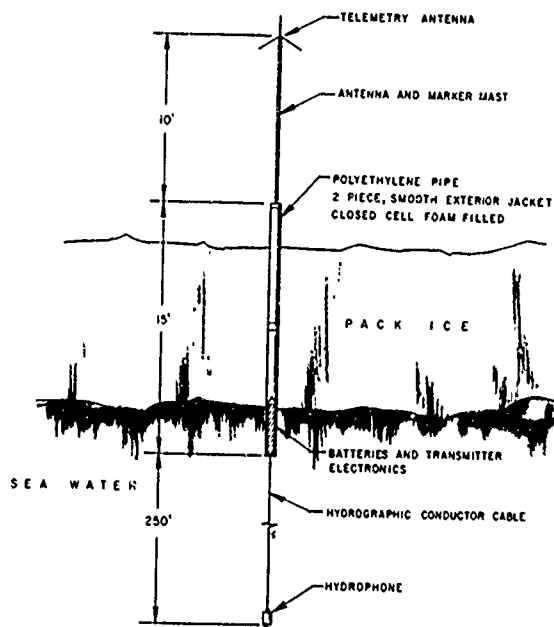
Figure 6. Tracking Hydrophone Buoy

- MARKER MAST

- COAXIAL SIGNAL CABLE TO CONTROL BUILDING ;

6'

WATERLINE

- POLYETHYLENE PIPE
2 PIECE. SMOOTH EXTERIOR JACKET
CLOSED CELL FOAM FILLED
PROVIDES STRUCTURAL PLATFORM
FOR TRANSDUCER

15'

PACK ICE

SEA. WATER

- OPEN TRUSS TYPE SUPPORT TO
LIMIT EXCURSION OF TRANSDUCER
TO 3 INCHES
8 FT SECTIONS

50'
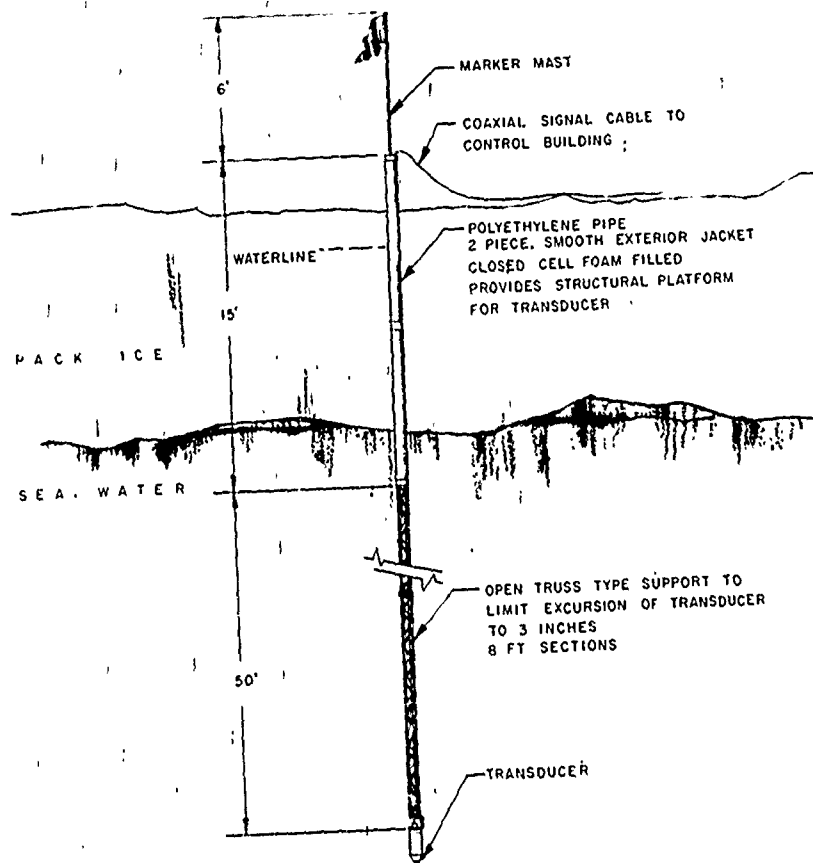
- TRANSDUCER

Figure 7. Tracking Baseline Transducer Buoy
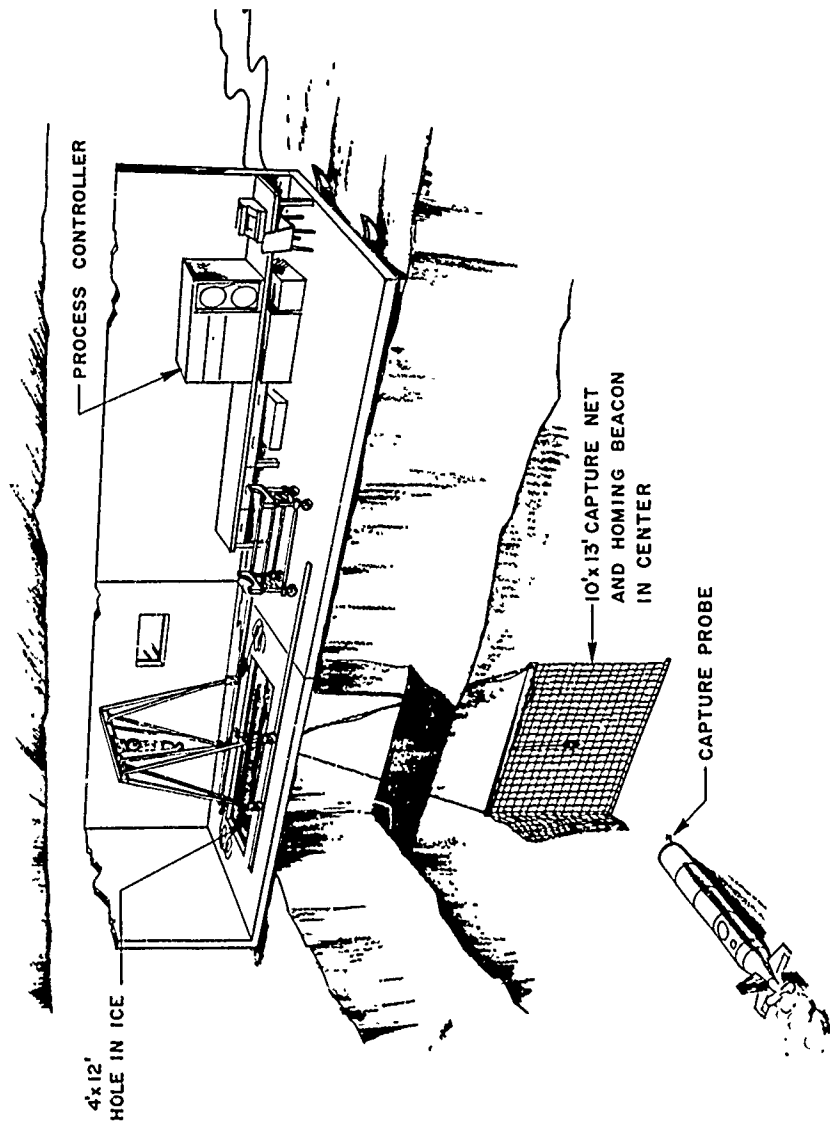
Figure 8. UARS Recovery System

When an obstacle is detected, the vehicle dives to a deeper
preprogrammed depth. After the obstacle is passed, the vehicle
can be commanded to return to the original depth. The sonar beam
is axially directed and is of sufficient width to encompass normal
pitch oscillations and trim conditions.

Components

The pressure hull is designed for operating depths of 1,500
feet with a calculated crush depth of 2,800 feet. In designing
the pressure hull, a trade-off analysis was made for such factors
as internal volume, shape, construction material, depth capability,
weight, and payload. The resulting hull size was determined
principally by the space requirements of the components to be
carried, while the material (glass-reinforced plastic) was selected
on the basis of its strength-to-weight ratio and the maximum
vehicle operating depth. The vehicle is made up of five small
sections--a 4-section pressure hull and a flooded tailcone. Individual
sections can be separated for shipment.

Normal servicing between runs is accomplished by separating
the vehicle at the joint just aft of the battery section (Figure 4).
This provides access to the battery for charging or replacement,
to the data chassis, and to the power control panel on the front
of the data chassis. The switches for starting the vehicle, cali-
brating the instruments, initializing the gyrocompass, and performing
control system checkout are located on the front of the data chassis.
Both the data and control chassis as well as the battery are rail
mounted within the hull so that they can be removed easily for
servicing.

For a speed of 3 knots (initial research mission requirement),
the propulsion motor power was determined to be 1/4 horsepower, using
drag values and estimates of propeller and gear train efficiency.
Silver-zinc batteries will be used because their high-energy
density matches the need for the vehicle to be small and light
for portability. The vehicle will carry two battery supplies--a
main unit and a reserve unit. The main battery will provide a
normal 10-hour run capability. Should this fail, the reserve unit
will automatically switch on and provide slightly more than 2 hours
of run time to enable the vehicle to return to its recovery hole
or to an open lead.

Research Instrumentation

The ice profiling package uses two acoustic elements: (1) a
transmitter which is a 500-kHz wide beam transducer, and (2) a
receiver which is a spherical, 2-component acoustic lens with an
array of transducers located in the focal surface. In operation,
the profiling transmitter is pulsed and the reflected signal is
detected by the "fan" of multiple narrow beams in the receiver
which is perpendicular to the direction of motion of the vehicle.
The overall signal transit time provides a measurement of slant

range. Normally, the submersible will operate about 60 feet below the ice, at which depth the insonified area associated with the reflected signal is about 1 square foot. Thus, with a vehicle speed of 3 knots and a recording rate of five data sets per second, almost continuous surface sampling is possible.

The data recording system is designed to operate with a low-speed magnetic tape recorder and obtain high-resolution, high-density data over long periods of time. All data are recorded in binary form using nine tracks on 1/2-inch magnetic tape. The tape format was designed to minimize the amount of recording electronics for processing with standard equipment. All UARS acoustic subsystems have been successfully tested in the arctic under-ice environment. Some changes in the homing system logic were found necessary as a result of these tests in order to avoid ambiguities caused by reflections from under-ice protrusions.

SYSTEM APPLICATION CONCEPTS

Upon completion of development testing in the spring of 1972, the UARS system will be employed for ice profile measurements near Ice Island T-3. During the fall and in subsequent arctic work seasons, the vehicle should be available for other Arctic Ocean research. Consequently, the Applied Physics Laboratory has been working with other groups to plan a variety of scientific and military applications for the UARS system. Some of these concepts are described below.

Ocean Floor Applications

Interest has been expressed for using UARS in a receiver-recorder role in the collection of subbottom geophysical data. Since one design feature of the tracking system is its ability to locate the vehicle continuously and precisely, geologic structure can be correlated with position. This information should be useful both for petrographic research and for planning sea floor engineering under the ice. The accuracy of the system should also make the submersible a candidate for performing under-ice bathymetry. UARS could thus be used in describing the arctic continental shelf and slope (down to 1,500 feet) and most of the passages in the Canadian archipelago. By adopting a bathymetric acoustic unit as sensitive as the ice profiler now planned for UARS, the vehicle could also be employed for discrete object detection and sea floor searches beneath the ice.

Middepth Applications

Arctic scientists have been unable to make lateral measurements of important oceanographic parameters under the ice. Until the development of the thermal ice corer it was difficult even to study the vertical features of the Arctic Ocean. With the advent of a submersible that can operate freely beneath this surface barrier, the principal obstacle to data collection has been overcome.

It now remains only for scientists to develop the desired instrumentation packages for the vehicle. APL has already prepared two such sensor suits--a nose-mounted sound velocity, salinity, temperature, and depth probe, and an ultrasensitive fluorometer probe, either of which could be employed with the vehicle in the fall of 1972 to measure lateral density microstructure and diffusion parameters beneath the ice.

The Laboratory is now studying the best approach for making discrete volume reverberation/biological correlation measurements with UARS. One approach that is contemplated would couple multiple-frequency acoustic returns with high-intensity strobe photography to obtain the desired correlation. The submersible has sufficient buoyancy to accommodate the equipment, and auxiliary instrument ports are available in the hull. However, an internal rearrangement of existing vehicle sensors might be necessary for the forward-looking photographic unit. Other techniques for collecting biological and water samples with UARS are also being devised.

Near-surface Applications

From the standpoint of scientific and military interest, the near-surface regime in the Arctic Ocean ranks highest. This is because the combined effects of ice cover, currents, and heat transfer processes which take place in this region create a changing operational environment that is not well understood. A number of near-surface experiments involving UARS are now being planned. Among these is a concept to extend the use of the vehicle profiling instrumentation by coupling it with the forward-looking collision avoidance transducer, so that correlatable data can be obtained for improved near-ice sonar performance. Undersurface topographic features that can be generated from the profiling data will also be of value in predicting the spreading rate of oil spills or in locating where an oil recovery tap might be most effectively placed.

There is interest in studying the dynamic thermal structure of the ocean beneath open leads and polynyas, since these "heat ducts" may play a significant role in fundamental global heat balance. Some of the anomalies in near-surface acoustic transmission may also be caused by the localized high thermal gradients beneath these features. UARS instrumentation for this role is now under consideration.

UARS could play a direct role in under-ice defense operations through its use as an accurately locatable target for ordnance practice purposes; as a submarine or ordnance subsystem test bed; or as an active, searching probe for the location of ice-nestling submarines. The refinement of reliable techniques in the latter area of detecting foreign objects resting against the ice would be of particular interest to arctic strategic defense planners.

CONCLUSION

Unmanned submersibles can play an important and unique research role in the Arctic. They are not inexpensive tools, but for certain tasks they appear to be essential. Because of the significant operational cost of the UARS system (estimated to be $150,000 to $200,000 per year), many valuable research projects will not have sufficient funds to support the vehicle independently. The Applied Physics Laboratory is, therefore, developing a cooperative, joint-use program for the vehicle, to begin in the spring of 1973. In this way the UARS system can be made available on a time-sharing basis to many modestly funded projects.

This concept should work well provided agreement can be reached among the using project managers or scientists as to general field location. The modular construction and quick-disconnect features of the submersible should permit easy packaging of instrumentation for each project. If widely separated operational locations are required, however, much of the saving that would accrue from joint use would be forfeited. Thus the problem of arctic logistic support emerges as a significant issue in the operation of an unmanned research submersible.

MAN IN THE POLAR SEA

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The program of this symposium is directed toward sustained
operations in the Arctic Basin. This writer feels that our area
of interest should include boreal regions; for example, the Bering
and Chukchi seas. On the eastern coast of the North American
continent, polar areas extend down almost to the U.S.-Canadian
border. Therefore, much of this report will have these areas
in mind.

Unfortunately, many people have a psychological impediment with
regard to polar exploration. As an example, a caption in last month's
National Geographic Magazine in an article on the North Slope
read, "In an endless battle with the cold, oilmen add modern
technology to old-fashioned determination while camping on unoccupied
North Slope wasteland." This is an atavistic type of mentality
which persists, unfortunately, in spite of the fact that the North
is not a wasteland. In fact, data are now available on primary
productivity which indicate that the edge of the Arctic contains
some of the most productive waters in the world in terms of
primary, secondary, and even tertiary productivity. This productivity
must be taken into account in our arctic development programs.

A recent AINA report pointed out that the polar regions are
in need of development and that perhaps it would be necessary to
go north for the truly enormous quantities of fresh water needed
for the irrigation of our arid lands and to flush the accumulating
waste products of man's making there. Since these areas are so
biologically productive, our thinking in regard to this needs
amending.

What is polar science anyway? Actually there is no such thing.
There is polar technology, but not polar science. Polar science
is not a discipline, because disciplines cross geographical
boundaries. Given the premise that there is only polar technology,
that the polar regions extend all over the earth, and that these
areas have an immense productivity that cannot be jeopardized,
it is appropriate to explore the means by which the subice hydro-
sphere can be investigated.

In another AINA report published in 1968, the following
statement appeared: "A good case can be made for giving up trying
to look under the water from above and for getting down into the
medium and finding out what features there in that environment
can be used for tracking. A submarine satellite is a hopeful

objective." Previous talks have shown that there is now the
possibility of such satellites, which could make going into the
environment a lot easier than trying to combat the air-ice-water
interfaces.

We thus come to man-in-the-sea technology. This technology
is still pretty Mickey Mouse in terms of its scientific productivity.
As a matter of fact, it has been overengineered without enough
regard to the missions which this engineering should accomplish.
It is especially important to put a mission before technology,
particularly in polar work where the environment is tough enough
and where overengineering that gets between the scientist and his
work is definitely not needed. There are too many submersibles
that are setting on the shelf at the moment; more that will do
the same are not needed. Therefore, the mission must preempt
technology.

In underwater work, equipment is needed that is simple, yet
multipurpose. Equipment must also be self-contained, yet economical.

A cross section of ice in the Bering Sea looks pretty sterile,
but at the interface between the ice and the water there is a
growth of diatoms which contributes to and in a sense determines
the high productivity of the Bering Sea. The bottom of the Bering
Sea is also very rich. This productivity is reflected all the way
up the trophic structure and supports marine mammals with high
reproductive rates. These primary producers are the organisms
we have to avoid impinging upon too much.

In the Arctic it has been necessary to operate from land
stations using dog sleds or snowmobiles to get out on the ice for
diving operations. A diver in this environment is protected by
3/4-inch foam neoprene over his chest in several layers, and 3/8
inch over his head, legs, and arms. He can tolerate the cold in
air for long periods; under water he is less well-adapted. Down
to 30 feet he can tolerate the environment for about an hour if
there are no leaks in the suit.

There are safety techniques involved in diving, including a ver-
tical line which the diver grasps as he descends. "ᵦ must be careful
in deep waters that the compressibility of the suit does not cause
him to "take a down angle" (near the surface he may rise too
rapidly). He must suit and weight for a particular depth, go to that
depth on a descending line, and then make lateral excursions only.
A current o. 0.3 knot is enough to make it difficult for a diver
to return to the hole through which he descended, and the next
nearest hole may be miles away. To avoid current drift problems,
a horizontal drift line is attached to the main descent line, and
the diver orients to that line in waters where there are substantial
currents.

A few years ago a new technology came on the scene, the closed-circuit rebreather. Th re is now available a family of four or five mixed-gas scuba units which extend diver capability considerably. These units are very costly (about $6,000 or more each). Diving through the ice with them is relatively safe and silent, but there are still major limitations on the time that can be spent in the water. With standard scuba gear, total time in the water on a single dive is limited to about 2 to 3 hours when near the surface and when using a triple-tank unit. The time available for work at depth, however, decreases drastically as depth increases (at a depth of 100 feet, a triple-tank unit lasts only a quarter as long). The newer closed-circuit equipment allows dives of up to 4 hours, irrespective of depth, and it has the advantage of eliminating bubbles which frequently interfere with work.

An additional problem that free divers face arises from the low temperature of polar water. After about 35 minutes in surface waters where suit compression is minimal, the diver's temperature and heartbeat begin to drop significantly. Even when resting in the water, the diver's body, in an effort to keep warm, is actually using up energy at a rate equal to trotting up a long flight of stairs. Work is underway on heated suits, but the energy and heat flow requirements are very large, so these will not be any cure-all. Any advances in the technology of diver's suits and other items will be of considerable help in the future, but alternatives must be considered. One alternative is a subice observation chamber.

The first subice observation chamber was built by the National Science Foundation and was used in Antarctica. The chamber is rather small--about 30 inches in diameter--but one can stay in it for long lengths of time. Overall, these chambers are a fine concept. Two men can lower a chamber into the water after attaching instruments to its outside. Divers can be utilized to assist in the chamber's operation.

Another family of devices utilizes twin hemispheres of acrylics and plastics. This kind of chamber is in use by the Naval Undersea Research and Development Center in San Diego in a boat called *Sea-See*. One concept is to attach such a chamber to a mobile hut deployed on the sea ice.

Still another family of devices is the submersible. Chambers and submersibles share many common developmental problems, sub-systems, and operating characteristics, with the principal difference being the mobility of the submersible. The submersible that has been used most in northern waters is PISCES I, built in and operated out of Vancouver by International Hydrodynamics. The capability of a submersible to carry scientific investigators and their instruments down into the medium which is being explored cannot be underestimated.

Due to the coldness of polar water, submersibles with their self-contained life support systems and large energy capacities are of greater relative value than in more temperate waters. Submersibles such as the PISCES, the Perry submarines, the Nekton, and the Nemo can operate to depths of several hundred or several thousand feet, depending upon the vehicle. Flank speeds are up to several knots, and cruising speeds are 1 to 3 knots. Such speeds are more than really required, particularly for biological work. These submersibles range from 3 to 10 tons. Underwater cruising ranges run about 20 miles, but lateral excursions are not favored. Rental charges run from about $1,000 to $5,000 a day, which is not too excessive when considering the work they can do and their cost ($300,000 to $2,000,000).

These submersibles are designed for operation from a surface support ship, which can house the away-from-home scientific laboratory for rapid analysis of data. It is worth noting that in arctic waters these submersibles would not encounter the one problem that has appeared in operations in more temperate waters; that is, problems of launch and retrieval by their support ships in rough seas. In the Arctic, sea state zero prevails as long as there is sea ice.

Additional developmental work and modification to existing submersibles must be done before under-ice operation can be sustained in near-freezing water. In addition, the technology exists for attachment of a piggy-back submersible chamber over the forward escape trunk of a nuclear submarine. Such a device would provide a marvelous subice laboratory, even a lock-out capability for divers, yet not interfere with the submarine's normal arctic operations. Hopefully, ways can be found to use nuclear submarines for subice work, for in no other way will long excursions presently become possible.

USE OF SURFACE EFFECT VEHICLES
FOR LONG-RANGE ARCTIC MISSIONS

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The ability of a surface effect vehicle (SEV) to operate over all types of surfaces at high speed has led to its consideration for arctic use, both military and commercial. Programs are underway to develop the SEV technology needed for effective and reliable operation in the Arctic. This paper will evaluate the applicability of SEVs to certain postulated long-range arctic missions in the 1980 time frame.

CURRENT SEV STATUS

Both military and commercial operations have demonstrated that the SEV is capable of performing useful work under adverse conditions and in difficult environments. Nine years of operating experience (through 1970) has resulted in more than 100,000 hours of commercial operations and over 30,000 hours of military operations. Commercial operations include the transportation of more than 4 million fare-paying passengers. In these operations, SEVs have been used in such environments as marine, jungle, desert, and Arctic.

SEVs have been operated in 12- to 14-foot waves, in 20-foot swells, and in 12-foot plunging surf. Shoal, rock-strewn rivers, river rapids, and sand bars have been traversed to demonstrate the obstacle capability of these vehicles. In the Arctic, operations have been conducted at temperatures of -45°F and in zero visibility. In addition, operations have been conducted in the Arctic during river ice breakup, over melted and frozen tundra, and over ice ridges 10 feet high.

Other SEV operations have been conducted by military agencies of both U.S. and foreign governments. These include combat operations in Vietnam, patrol and logistics operations in Malaya, and border patrol operations in several mideastern countries. Trials were conducted earlier this year by the U.S. Coast Guard in conjunction with the U.S. Navy for the ARPA Arctic SEV Program near Point Barrow, Alaska. Additional arctic SEV experience includes Greenland and Canadian winter arctic trials, Alaska North Slope oil exploration

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and logistic operations, oil exploration and logistics operations in Vestspitsbergen and Norway, and a hydrographic survey of the Arctic Ocean.

The experience gained in SEV operations in 61 countries points to a mobility that is not available in any other vehicle. This experience also clearly shows that the SEV is not a replacement for other air, ground, and water vehicles. Rather, it is a vehicle that can play a useful role in arctic transportation.

MISSIONS AND REQUIREMENTS

Exploration in the Arctic to establish a foundation for efficient operations in that environment will require several types of transportation, including SEVs. Of several missions for a long-range SEV in support of quick-reaction data gathering, three are important: (1) the process of quick-reaction data gathering, (2) search and rescue under circumstances ranging from a submarine accident to some lesser situation, and (3) logistic support of extended operations.

In each of these missions an operating range of 1,000 miles is assumed as the extreme case. Significantly less ranges may be adequate for some missions, but the capability must be available to evaluate the SEV on a reasonable basis. Cruise and dash speeds are equally important, from the standpoints of time and economics. Speeds of 60 to 90 knots appear optimum when considering these factors and technical feasibility.

The missions which have been postulated will require a platform for specialized tasks. The quick-reaction data gathering mission may require temporary housing for scientific personnel and operating crew at a site where data are being gathered. The search and rescue mission, in addition to a need for temporary housing at the rescue site, may require a special capability such as drilling through ice for access to a submarine accident. The logistics mission can also be expected to require temporary housing while emergency maintenance or repair is being provided for a disabled vehicle. For relatively short missions (10 days) 240 cubic feet per man should be provided for 5 to 15 persons.

Since each mission can involve the need to remain at a site for a long period of time, it is essential to consider the surface conditions which will prevail during the stay. Most of the tasks to be performed will involve the acquisition of data, or search and rescue over ice or water. Thus each vehicle must be able to cope with changing surface conditions, such as ice breakup, rapidly flowing or rough water, and moving ice floes or ice islands.

SPECIAL PROBLEMS

The following discussion identifies and evaluates the more significant deleterious effects of selected elements of the arctic

environment upon SEV operations. The evaluation covers qualitative considerations of the interactions of these elements with SEV subsystems and explores the criteria derived therefrom.

Temperature

The range of temperature extremes presents an awesome challenge to designers of vehicle systems for the Arctic. For example, in selecting structural and plating materials, care must be exercised to ensure adequate material resilience at the lower temperatures while retaining sufficient strength at higher temperatures, and to minimize the weight penalty that might be associated with such selection. Further, the choice of dissimilar materials must be minimized, or avoided entirely, to preclude the expansion/contraction anomalies that could result over the extreme range of temperatures. Failure to do this could lead to the high internal stresses that result in structural damage or failure.

Skirt materials become less flexible in low temperatures. In fact, an SEV whose skirt materials have been cold soaked without periodic operation of the lift system may become so rigid that the skirt system would be unable to attain the flexibility for normal operation. Even aside from this extreme case, however, there is also the problem of reduction of skirt flexibility due to low temperatures, with a resultant increase in drag during skirt contact with water or unyielding surfaces.

The extreme operational temperature range of the Arctic imposes a constraint on the design or selection of fans, turbines, and other machinery which must utilize air as their functional medium. This constraint derives from the dependency of the air density upon the temperature and necessitates a design choice for the upper limit of ambient temperatures to be encountered. If the operating requirements of speed, slope climbing, and vehicle gross weight are independent of temperature, then the design choice imposes the penalty of excessive capability at the low end of the temperature range. This penalty could take the form of higher initial costs, increased machinery weight, and higher fuel flows.

Maintenance of an SEV in low temperatures requires special attention. Skirt systems must be designed so that personnel can perform minor repairs rapidly with gloved hands, or replace skirt segments at a remote site with special tools or equipment carried aboard the SEV. Exposed machinery, such as propellers, control devices, and actuators must also be integrated into the system design to facilitate low-temperature maintenance. Here, too, repairs must be done with gloved hands using on-board special tools or equipment.

Wind and Water

The two major effects of wind on a vehicle system are chill factor and aerodynamic loads. The chill factor pertains to heat

loss as a function of wind velocity. This is a well-documented
phenomenon for which design criteria are available. The preferred
design approach is to provide the smallest exposure area to the wind
through which heat transfer may occur as well as to insulate
against such heat transfer. For the skirt system, however, this
is not possible. Much of the heat generated by the working skirt
system will be lost to air movement, so little improvement in
flexibility at low ambient temperatures can be expected from
this source.

Aerodynamic loads due to wind may result in reduced forward
velocity (headwind), limited deceleration rates (tailwind), or
directional control problems (crosswind, gusts, etc.). These
problems are not unique to the Arctic but must be faced in vehicles
designed for all areas of operation.

Operations over arctic waters will generally involve conditions
and resultant effects typical of any overwater operation. As a
function of sea state, the SEV will be subjected to slamming
loads which will limit the speed of the vehicle, both for structural
and safety reasons. Since the SEV has been mostly used in overwater
operations, much knowledge and data are available to support
acceptable designs for such applications. In a similar vein, the
problems of corrosion and erosion have been well documented.

The primary problem of operations over arctic waters is that
of icing. When operating over water, spray will occur and may,
under low-temperature conditions, freeze to a vehicle. Since this
is an accumulative process, the weight growth due to ice buildup
is unacceptable and a means must be found to prevent icing. A
secondary problem of icing results from its formation within
confined spaces such as joints of structures. The expansion of the
ice as it is formed may generate loads and forces which could lead
to structural damage or even failure.

Ice buildup may also occur on external moving parts such as
controls and propellers, as well as on intakes, radar, etc. In
addition to weight and stress problems, the effectiveness of these
devices can be sharply reduced if ice buildup is permitted.
Methods of inhibiting ice buildup are available, so the important
consideration is recognition of these problems and selection of
the best means for controlling ice buildup on each subsystem.

Land/Ice

Obstacles pose the major problems to SEV operations over arctic
lands and ice. Land obstacles include steep slopes and timbered
areas which are inaccessible, and the tundra which is relatively
flat but accessible. River beds and lakes should present few
problems where access to these surfaces is possible. Ice will
generally present a unique problem, however, in that it may occur
in the form of rough, closely spaced obstacles which might exceed
the skirt height of an SEV and cause leakage or damage to the
underside of the skirt.

To negotiate an ice ridge of critical height, SEV operators
approach the obstacle at a safe speed. While this increases the
probability of negotiating the obstacle, it results in increased
forces on the SEV structure and occupants. The loads sustained
by an SEV traversing an ice ridge at high speed have not been
accurately determined. Such loads, which are incurred through the
skirts and fluctuations of the cushion pressure, depend upon the
skirt configuration, ice ridge geometry, and vehicle speed.
Analyses of present skirt configurations indicate that safety
problems can be expected; thus, development programs are required
for high-speed SEV operations over arctic obstacles. The wear and
tear of the skirts due to contacting the ice ridges has been
revealed as a significant problem, and new materials or skirt
configurations will be required as a solution.

The capacity of ice to support a vehicle, either underway
or off-cushion, will limit the allowable cushion pressure and off-
cushion bearing loads. The limitation on cushion pressure is not
expected to predominate over other parametric considerations,
but the off-cushion bearing load limits will require attention to
assure a sustained station-keeping capability on ice.

When off-cushion on the ice, melting may occur due to
increasing ambient temperature or to heat transfer from the SEV.
In either case, the SEV may stick to the ice or even partially
sink into it, creating high lift-off loads. Provision must be
made to avoid these occurrences, such as placing mats beneath the
SEV.

Other

Other environmental phenomena which represent problems in
the Arctic to vehicles in general are: magnetic anomaly, electrical
interference, and impaired visibility. In the interest of safety,
the detection of obstacles is of special significance. This is
especially true of broken ice fields, where the height of the
operator may not be sufficient for him to observe suitable passages
through the entire field. For this situation a display must be
presented to the operator that will permit him to select the shortest
passage through the field.

SEV PARAMETERS

Power to Weight Ratio

Figure 1 shows some projected values of the ratio of cruise
shaft horsepower to vehicle gross weight (in tons) at different
speeds and in different arctic surface conditions for an SEV of
approximately 300 gross tons. These values assume some advances
in SEV technology, but they are not considered unduly optimistic
for the 1980 time frame. The overwater values have a considerable

SEA STATE 3

ASSUMED AVERAGE
CALM WATER

5 FEET ICE RIDGE
EVERY 150 YARDS

SMOOTH ICE

CRUISE SPEED — KNOTS
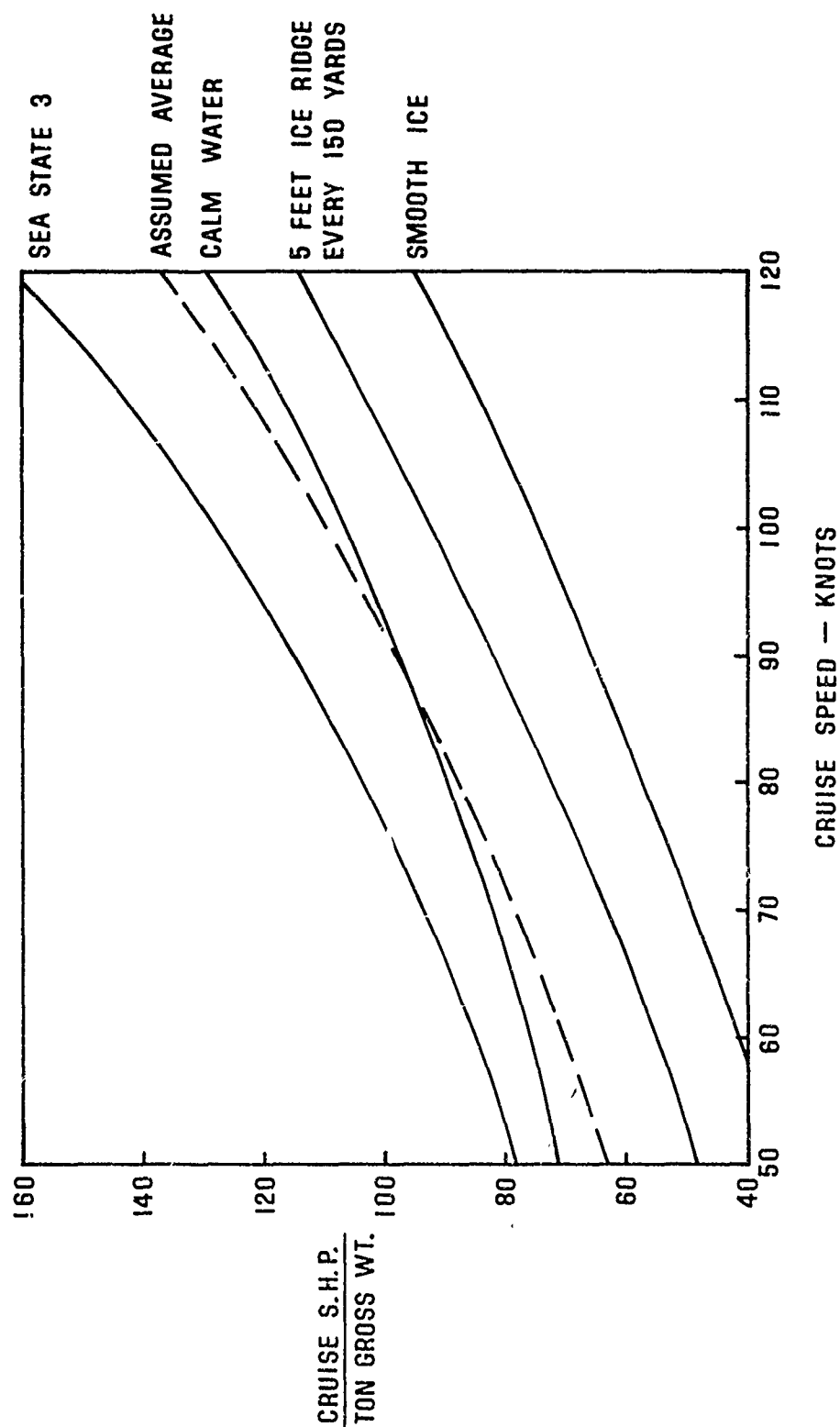
$\dfrac{\text{CRUISE S.H.P.}}{\text{TON GROSS WT.}}$

Figure 1. Power/Weight for 300-ton S.E.V.

amount of empirical data as a base, whereas the overice values
are based upon more limited data. The confidence level for an
SEV of 300 gross tons to achieve the power-to-weight ratios shown
is high, however.

Also shown in Figure 1 are the power-to-weight ratios for
assumed average surface conditions. The latter are derived from
the Sea State 3 values and the power to negotiate 5-foot ice
ridges with a 150-yard spacing. The assumed average surface
conditions are used in the evaluation of the 300-ton arctic SEV
to be discussed below.

Range and Cruise Speed

Using the power-to-weight ratios of Figure 1 for assumed
average surface conditions and a specific fuel consumption of 0.45
lb/shp/hour, the range capabilities of a 300-ton SEV have been
calculated. The range is shown in Figure 2 in terms of cruise speed
and usable fuel-to-gross-weight ratio. The figure shows that a
range of 1,000 nautical miles can be achieved by a 300-ton SEV
having a usable fuel-to-gross-weight ratio of 20 percent. Increasing
the usable fuel to gross weight ratio to 40 percent results in
a range of over 2,300 nautical miles. The figure also shows that
for these operating conditions the range is independent of cruise
speed; hence, little is lost by adjusting speed in accordance with
requirements for maneuvers.

Based upon Figure 2 a usable fuel-to-gross-weight ratio of
20 percent is selected for the 300-ton arctic SEV to be considered,
and from Figure 1 the installed maximum continuous power is fixed
at 30,000 shp. Using a cushion-pressure-to-length ratio of unity
and a length-to-beam ratio of 2, the overall vehicle dimensions
and cushion pressure are determined. These are presented in Table I,
along with principal weight and performance data. Note that a payload
of 75 tons, or 25 percent of gross weight, can be carried by the
vehicle.

The influence of arctic surface conditions upon the range
capability of the 300-ton SEV is given in Figure 3. Note that the
range varies from 840 nautical miles in Sea State 3 to 1,620 nautical
miles over continuous smooth ice. Although the cruise speed for
maximum range depends upon surface conditions, Figure 3 shows
that range is not very sensitive to cruise speed for each surface
condition considered.

Mobility

One advantage of the SEV over other surface craft is its
ability to operate at high speed over all types of surfaces
(liquid to solid), and its ability to negotiate high obstacles.
Two questions about mobility that must be asked of the SEV are:
(1) what proportion of arctic obstacles can it safely and com-
fortably negotiate? and (2) can it identify and avoid obstacles
that are beyond its capabilities?
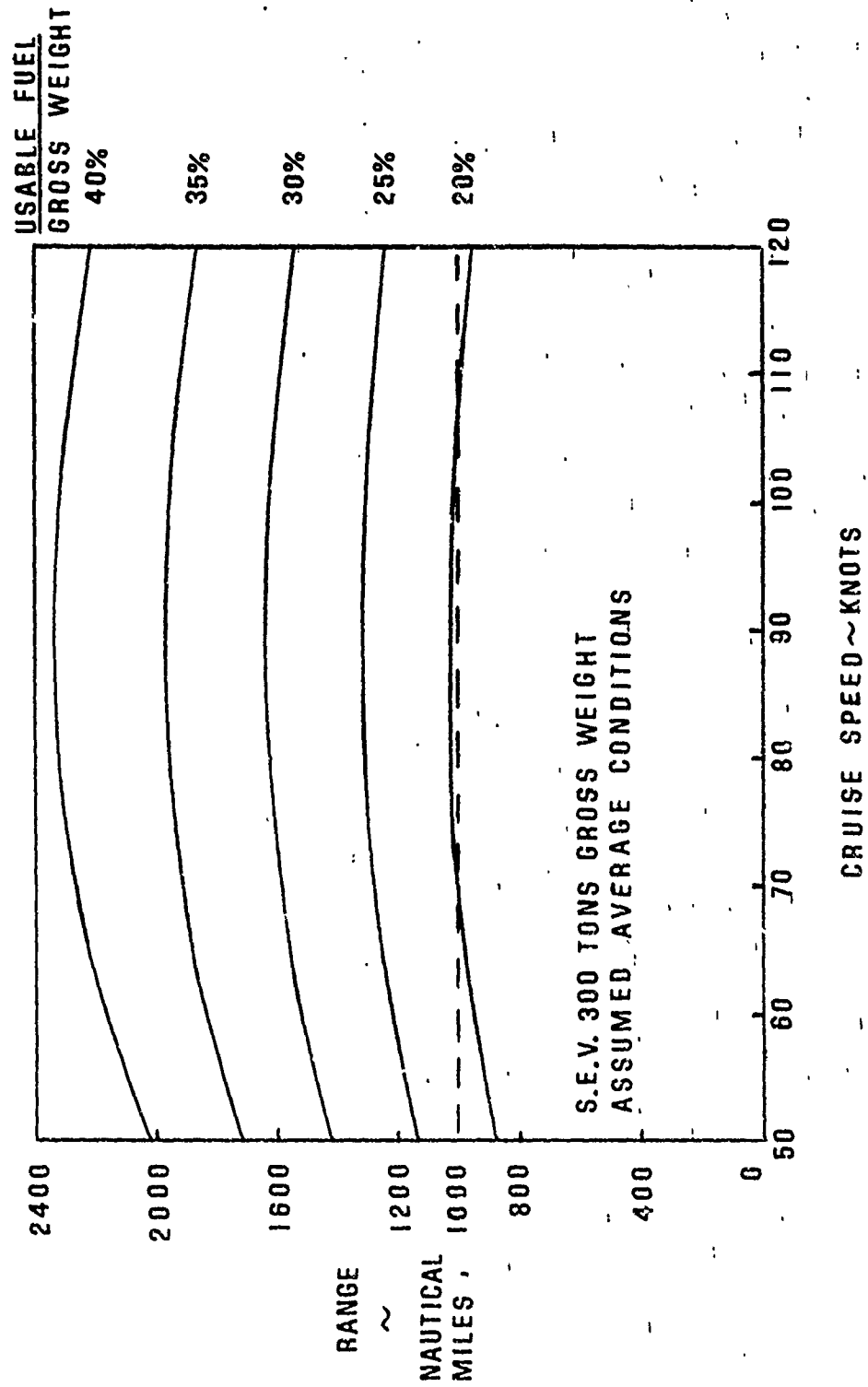
Figure 2. Effect of Cruise Speed on Range
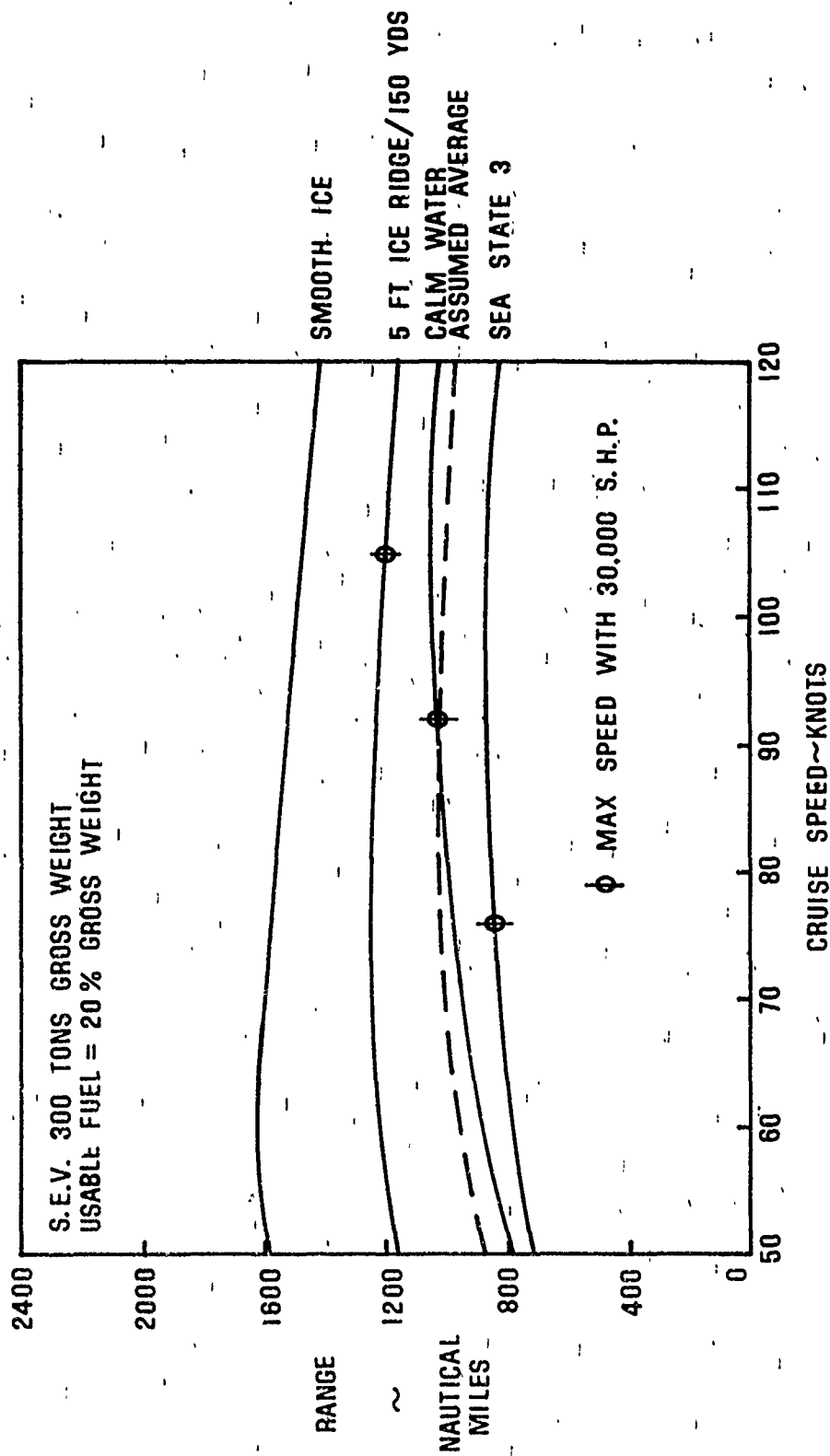
Figure 3. Effect of Surface Conditions on Range

Table I

ARCTIC SEV DATA

Empty Weight	165 tons	Length	125 ft
Payload	75 tons	Width	58 ft
Fuel Weight	60 tons	Cargo deck	80 by 32 ft
Gross Weight	300 tons	Range (average conditions)	1,030 NM
Cushion Pressure	105 psf	Maximum speed	76 kts
Installed Power (maximum continuous)	30,000 shp	Sea state 3	76 kts
		Smooth Ice	125 kts
		Max height ice ridge	12 ft

The 300-ton arctic SEV could have a hard structure clearance on cushion of about 10 feet, using present techniques for stabilizing the vehicle in roll. Based upon current operational experience, steep obstacles of about 12 feet in height can then be safely negotiated. In general, however, the shape of an ice ridge is not vertical; rather, its shape is such that an SEV receives a nose-up pitching moment immediately before reaching the point of maximum height.

Although knowledge is lacking about the changing surface geometry in the Arctic, both in time and place, a vehicle with a 12-foot obstacle height capability should negotiate about 90 percent of the ice ridges. Those areas completely bounded by ice ridges which have a height greater than 12 feet at all points are a small proportion of the total, probably less than 1 percent. Thus, less than 1 percent of the Arctic should prove inaccessible to a 300-ton SEV.

The problem of obstacle detection was discussed above. A need exists to determine obstacle-sensing and maneuvering capabilities before the mobility of the SEV in the Arctic can be fully established. Some methods for improving SEV maneuverability over ice include thrust vectoring at high speed and surface contact controls at low speed.

Reliability and Maintainability

The problems of operating with high reliability and of making repairs both quickly and economically in the Arctic have not been fully solved for the SEV. Much progress has been made in SEV operations in temperate climates. With careful design, choice of

materials and components, and development of maintenance procedures and equipment, one can expect to achieve satisfactory SEV reliability and maintainability in the Arctic.

Platform Suitability

One of the strongest factors in favor of the SEV for the missions under consideration is the large size of its platform in terms of its gross weight. For missions which require working and living space, these vehicles have a space-limited rather than a weight-limited situation. The best SEV is one that is lightly loaded (Figure 4). As the cushion pressure increases, the structural weight reduces for a given gross weight. For the data in Figure 4, the saving in structural weight is used for additional fuel. The increase in usable fuel, however, is offset by the rise in power requirement as the cushion pressure increases significantly until, at a cruise speed of 60 knots, the maximum range occurs at a cushion pressure of about 130 lb per square foot. At a cruise speed of 120 knots, the cushion pressure for maximum range approaches 200 lb per square foot. For the SEV under consideration, little loss in range arises for larger craft with a cushion pressure close to 100 lb per square foot, particularly for cruise speeds of less than 100 knots. For a typical SEV the loading per unit platform area is only about 5 percent less than the cushion pressure.

A measure of a vehicle's compatibility is how completely its cargo space can be filled without exceeding its payload-carrying capability. The C-130 aircraft can carry 23 tons (118 lb per square foot of cargo deck area). The amphibious assault landing craft (JEFF A), now being designed by Aerojet-General for the U.S. Navy (Figure 5), has a payload to cargo deck area ratio of only 54 lb per square foot. Many present SEVs are operating with payloads of far lower density.

The SEV under consideration here has a payload to cargo deck area ratio of 58 lb per square foot. For example, the vehicle could carry 12 containers, each 20 by 8 by 8 feet, with walkways between containers. The containers may be considered modules, with each serving different functions (working, eating, sleeping, etc.). Modules would be interchangeable, with selection depending upon the mission.

A typical breakdown of payload for this 300-ton SEV could be as follows:

Quarters (3 containers 20 by 8 by 8 feet)	3.8 tons
Storage space (1 container)	1.3 tons
Working space (8 containers)	10.2 tons
Insulation	2.5 tons
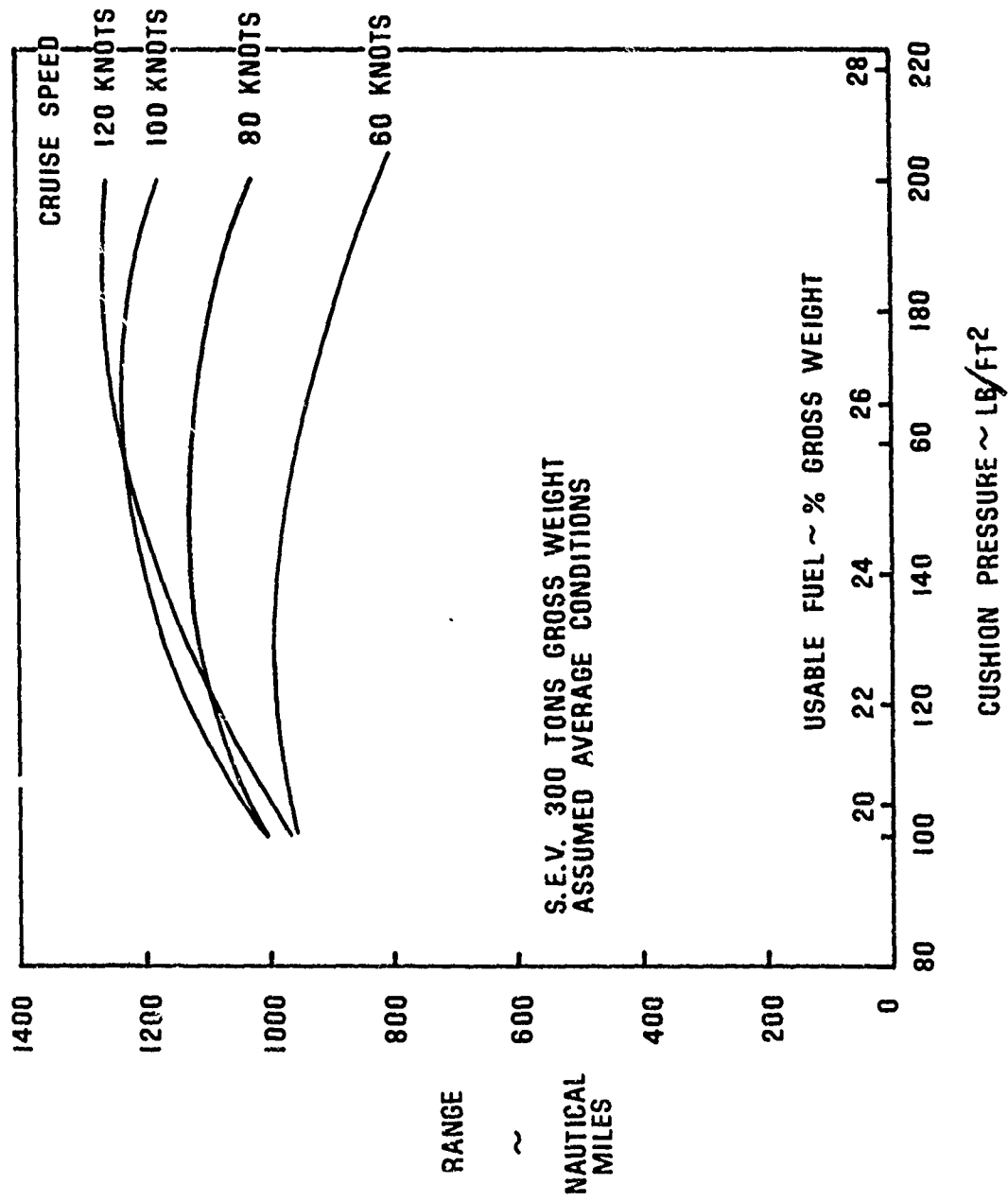
Figure 4. Effect of Cushion Pressure on Range

AALC C150-50
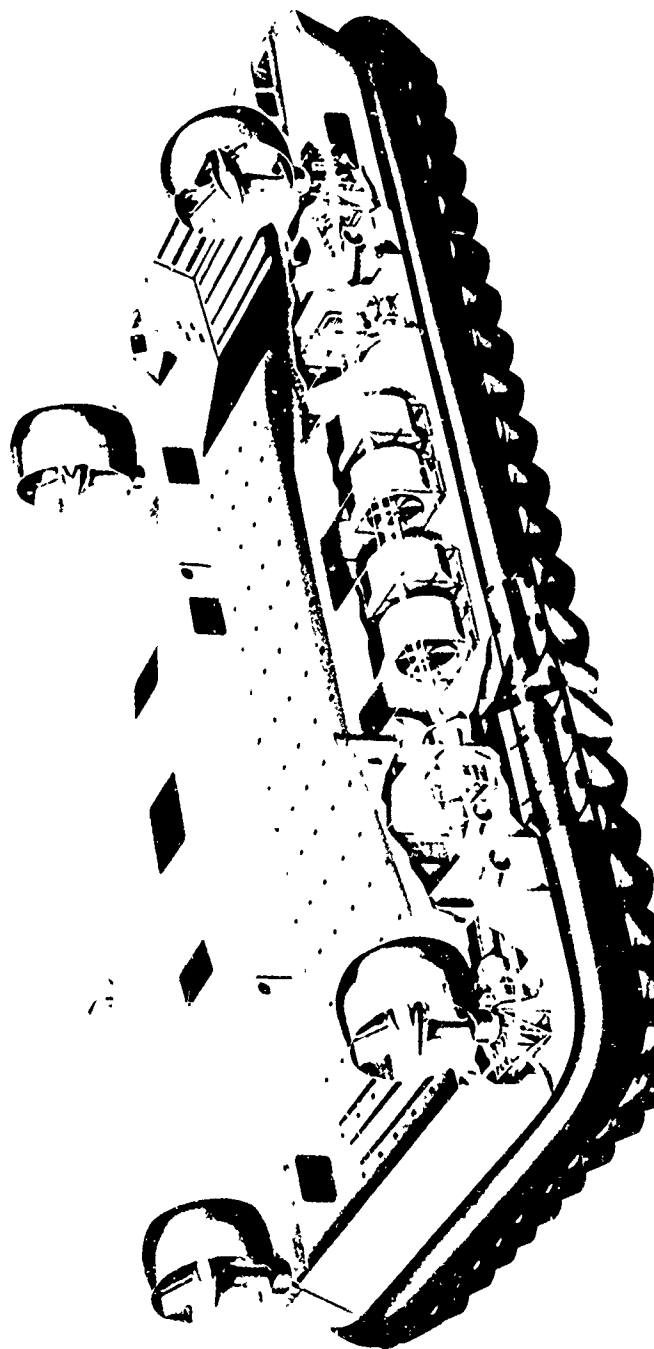
Figure 5. Amphibian Assault Landing Craft C150-50
(Aerojet-General Corporation)

Furnishings	0.5 ton
Life support machinery and fuel	3.0 tons
Provisions and sanitation	1.2 tons
Equipment, tools, instrumentation	50.5 tons
Personnel (15 including carry-ons)	2.0 tons
Total	75.0 tons

For arctic missions, there is the real danger of changing surface conditions; e.g., ice breakup while on site. This leads to the requirement that the complex of working and living accommodations be mobile. The air cushion platform ideally meets this requirement, since it can hover or rest upon any type of surface.

Operating Cost

When a vehicle is used strictly for transportation, the cost per ton mile is frequently used as one measure of its cost effectiveness. In a situation where the vehicle is space limited, "cents per payload volume mile" or "cents per cargo deck area mile" are more relevant parameters. For arctic missions, however, transporting personnel, equipment, and supplies from base to site is only a part of the total system cost for getting the job done. Therefore in comparing vehicles for arctic missions, it is more appropriate to consider the cost associated with keeping the vehicle in operational readiness than to consider the cost of transportation only.

For this reason the annual costs of operating the 300-ton arctic SEV are presented in Figure 6. The cost for government missions is depicted by solid lines, and the additional costs of insurance and interest for commercial operations are shown by the broken lines. These costs are based upon the following:

First cost of SEV with spares	$5.88 million
Service life	10 years
Interest rate	7.0%
Insurance rate (on first cost)	5.0%
Operating crew (per year)	$55,600
Engine first cost (total)	$1.72 million
Engine salvage value, percentage of first cost	20%

UTILIZATION — HOUR
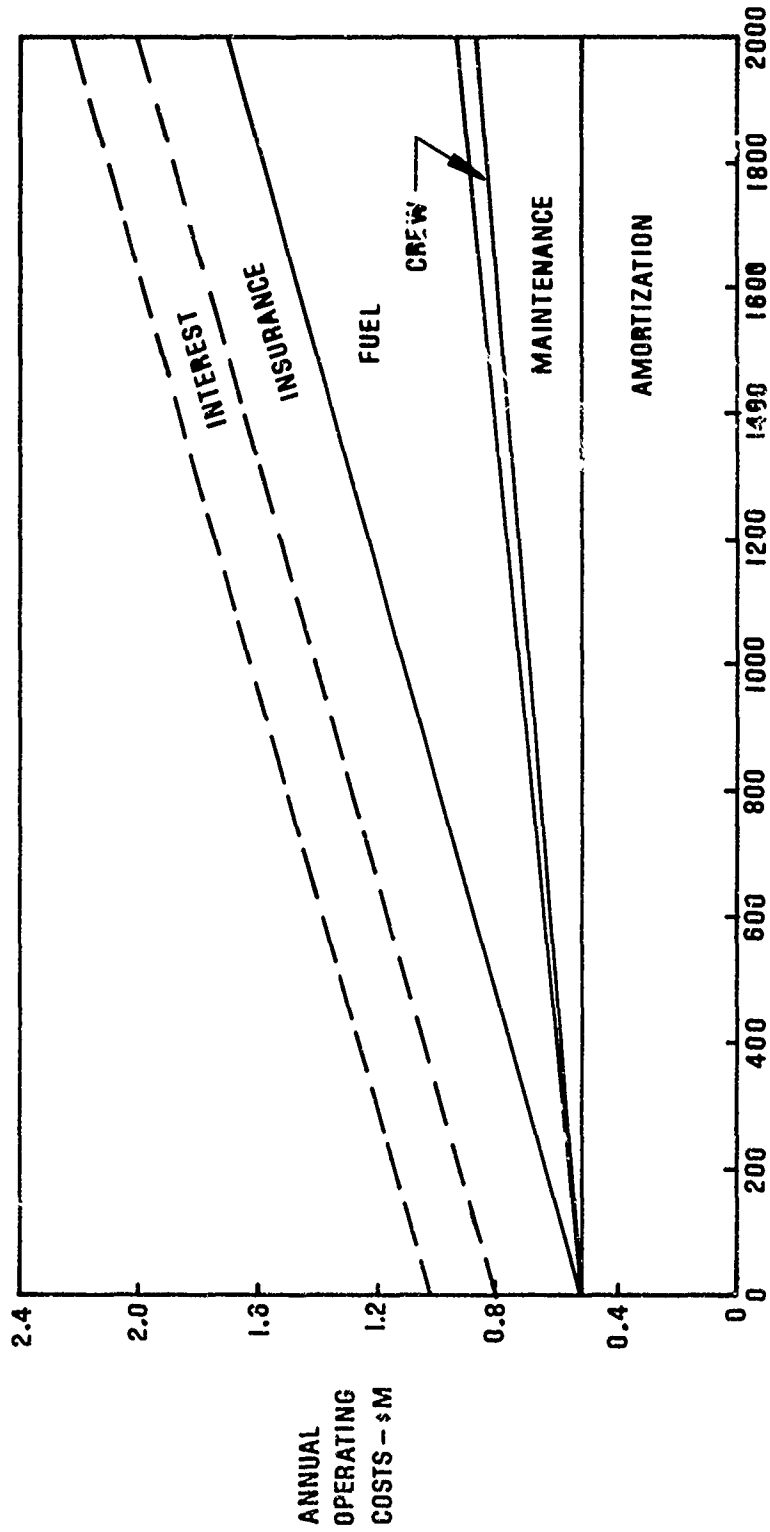
Figure 6. Operating Cost of 300-ton Arctic S.E.V.

Hull and spares salvage value	10%
Approximate maintenance cost per operating hour	$185
Fuel cost (1,000 gallons)	$300 ·
Average lubricating oil cost (10 gallons)	$14

Note that the assumed fuel cost is less than the present-day costs, but in the time frame under consideration cheaper fuel should be available in the Arctic.

To reach any conclusion regarding the operating cost of the 300-ton arctic SEV is not possible at this time. No vehicle (airborne, submersible, or surface) has the precise capability of the SEV in the role under consideration, and consequently any comparative cost-effectiveness studies must be done with care.

CONCLUSION

For the postulated arctic missions it is concluded that the SEV is worth more quantitative evaluation. The speed, range, and mobility of 300-ton SEVs are considered appropriate, and the mobile air cushion platform is quite suitable for accommodating working and living modules.

Reliability and maintainability have not yet reached satisfactory levels, but confidence prevails that these will be achieved. Cost-effectiveness has not been fully evaluated. For a valid comparison with other candidate vehicles, however, consideration must be given to complete mission costs rather than for using popular transportation cost parameters.

SURFACE EFFECT VEHICLES FOR ARCTIC
CARGO HAUL AND DISTRIBUTION,

R. H. Miller
Boeing Company
Seattle, Washington

This paper addresses arctic transportation, both short range and on-site. A liberal interpretation of short-range is used, ranging from 0 to 500 miles. Although most of the information presented will apply to overland operation, many of the general points will pertain to transportation over the arctic pack ice. Over the pack ice, however, the design criteria for vehicles will be more severe than for overland operations. Important design concepts for cargo vehicles will also be presented. Several of the major technical problems of surface effect vehicle (SEV) operation in the Arctic will be discussed, and some economic comparisons will be made between SEVs and other transportation means.

Figure 1 shows an artist concept of some of the missions for which SEVs can be utilized in the Arctic. Most missions can be broken into two categories--line haul or distribution. An example of a line haul mission would be a scientific logistics mission from the North Slope to an ice station. Another would be the transport of cargo from a port or rail head to a village or town. The cargo would be line hauled into a general area by some other means, such as by rail or air, and then distributed with an SEV throughout the area. An example of a distribution mission would be oil field development, where materials would be flown to a central air field and then transported to the well sites by an SEV. Another example would be cargo distribution by an SEV within a village area.

Prior to developing vehicle preliminary designs, it is necessary to consider the important vehicle design parameters required in an economically competitive transportation concept. We will examine the operating costs of cargo SEVs, recognizing that there are uncertainties in these costs, even for vehicles operating in a more favorable environment. Figure 2 shows the relationships between direct operating cost (DOC) and vehicle payload. The auxiliary scale shows the relationship of gross weight to payload. Note that operating costs decrease with increasing vehicle size. Below approximately 100 tons of payload, the DOC is quite sensitive to vehicle size. Above this payload, which corresponds to a vehicle gross weight of about 400,000 lb, the DOC is reasonably insensitive to vehicle size. This led to the selection of a payload goal of about 100 tons for our baseline vehicle design.

The economic analysis of the SEV is similar to that of a cargo airplane. This is illustrated by the operating cost break-
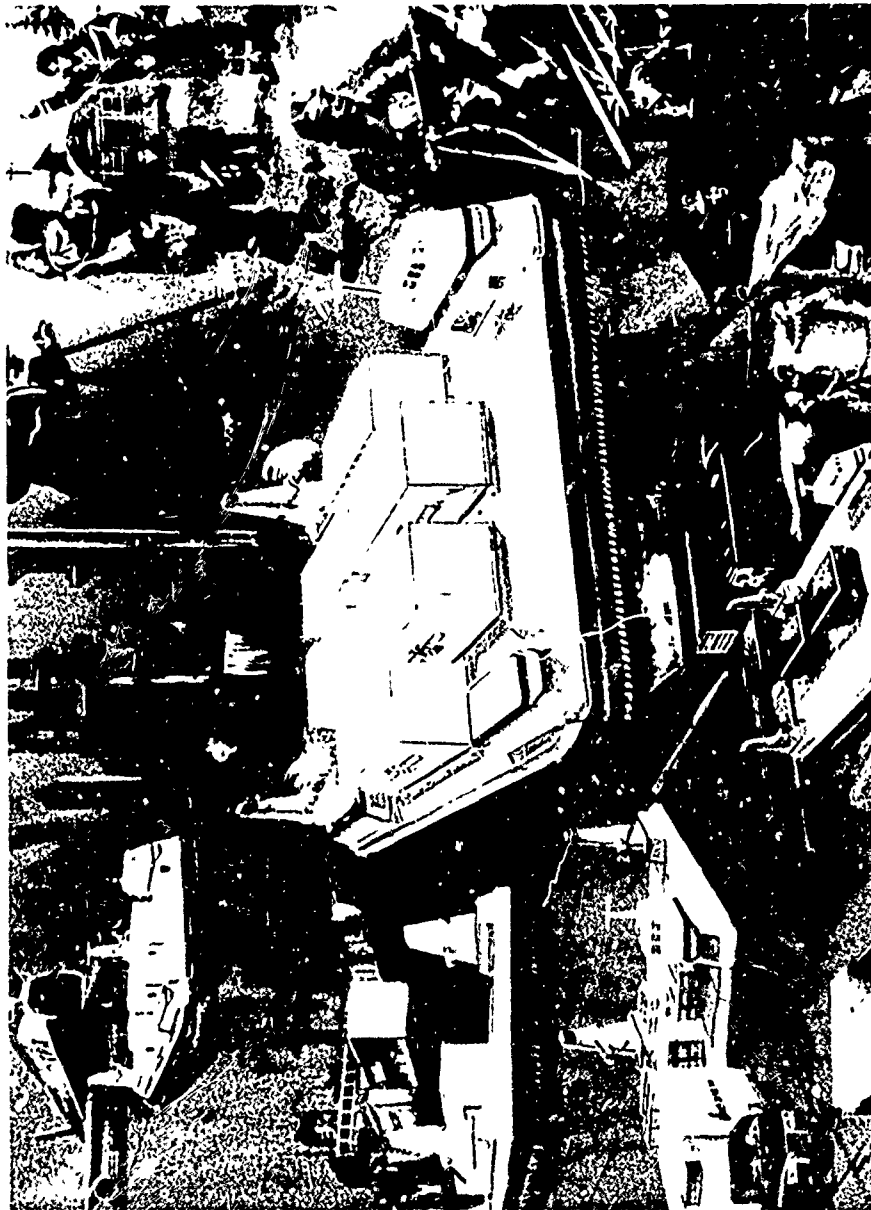
Figure 1. Artist Concept of Potential Cargo SEV Missions

down shown in Figure 2. Note that the maintenance cost is a high percentage of the total direct operating cost. The primary reason for this is the problem of skirt wear. Skirt finger life on current vehicles operating on water is between 500 and 1,000 hours. The maintenance data shown in Figure 2 were based on the assumption that skirt finger life in arctic operations will be about 1,000 hours. If the skirt life is less than this, the DOC will increase substantially from that shown in the figure.

A DOC of 5 to 10 cents per ton mile was selected as a goal for the arctic cargo SEV for preliminary design purposes. This was based on comparisons with potentially competitive systems. The cargo airplane is the primary line haul cargo carrier in the Arctic. The Hercules airplane, at the same 500-mile range shown in Figure 2, has a DOC of 11 to 12 cents per ton mile. The Boeing 747 at this range would have a DOC in the neighborhood of 5 to 6 cents per ton mile. A truck operating in the Arctic on a gravel road has a DOC of about 5 cents per ton mile.

Arctic cargo vessels (ACVs) operating overland in the Arctic will be on a hard surface most of the time. Arctic rivers are frozen from 6 to 9 months a year, depending on location. Most current SEVs are designed primarily for overwater operation. It appears reasonable to convert the arctic SEV for hard surface operation. Figure 3 compares the economics of water optimized vehicles with hard surface optimized designs. Note that the land optimized vehicle has a lower DOC. Therefore, for the overland arctic mission, we elected to optimize vehicles for hard surface operation; and for the small percentage of time that the vehicle must operate on water, we will take the penalty associated with water operation.

Figure 4 shows the conceptual design for a 100-ton payload vehicle. It has a maximum range of 1,000 miles and a nominal range of about 500 miles. It uses gas turbines for the lift and propulsion systems. Its flatbed truck concept allows it to carry a variety of payloads, including disassembled oil rigs, containerized cargo, and large earth-moving equipment. In an effort to reduce the initial and operating costs of this vehicle, the design was kept simple. The propulsion engines are fixed, with lateral control effected by rudders and puff ports. One disadvantage of this control concept is that in order to turn the vehicle it must be yawed. We later found that this was unacceptable for most overland missions, and the control concept was modified to a vectored-thrust configuration. The engines were relocated fore and aft on rotating pylons. The combination of rudders, puff ports, and vectoring engines results in no yaw during turns (that is, the vehicle rotates at the same rate as the flight path). The modified configuration is shown in Figure 5.

Figure 6 shows a smaller conceptual design with a 25-ton payload. This design has an efficient beam structure which results
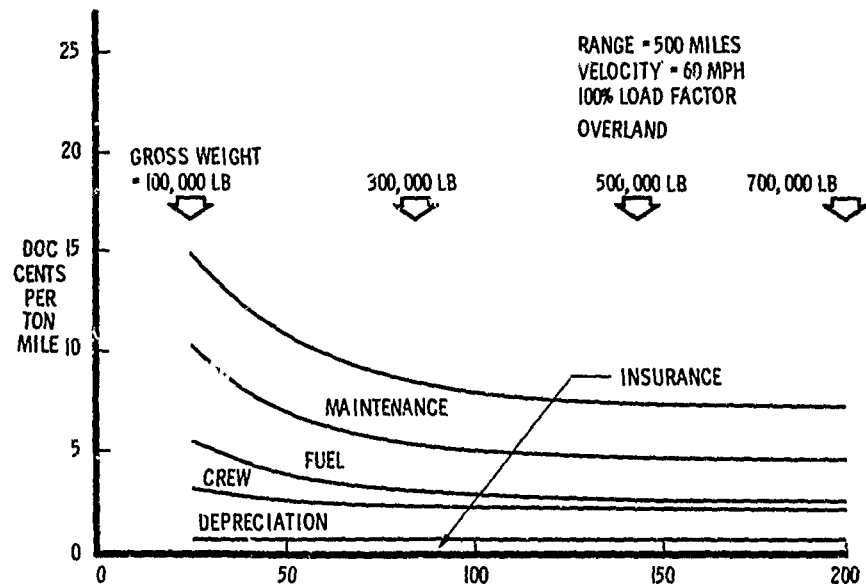
Figure 2. Contributors to SEV Operating
Cost
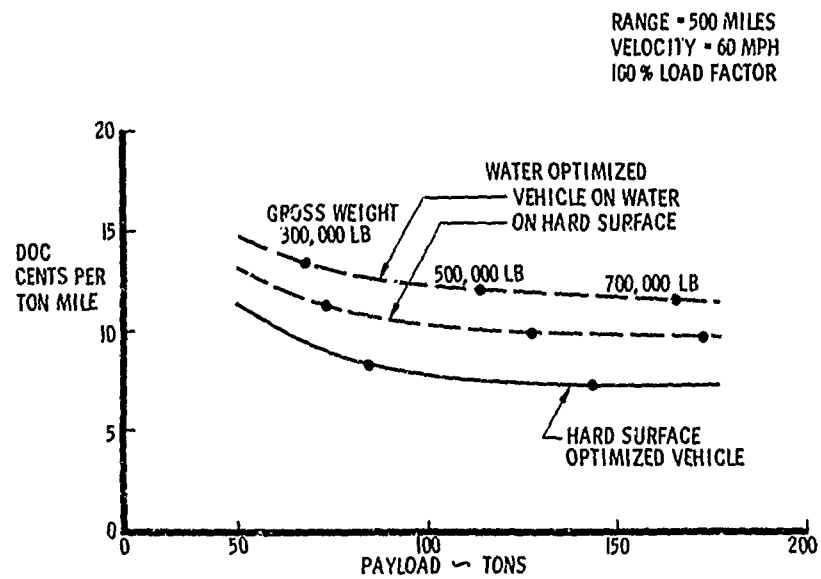
Figure 3. Comparison of Hard Surface
and Water Vehicle

GROSS WEIGHT	450 000 LB
PAYLOAD WEIGHT	100 TONS
RANGE	1,000 MILES
AVERAGE VELOCITY	80 MPH
MAXIMUM VELOCITY	90 MPH
MAXIMUM SLOPE	2½ DEGREES
CARGO AREA	4 000 SQ FT
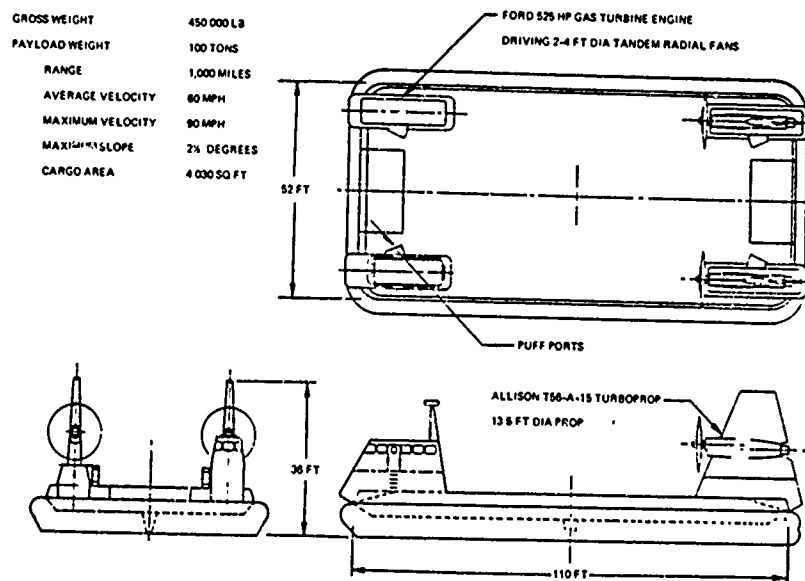
Figure 4. Arctic Cargo ACV (Boeing Model 730-72)
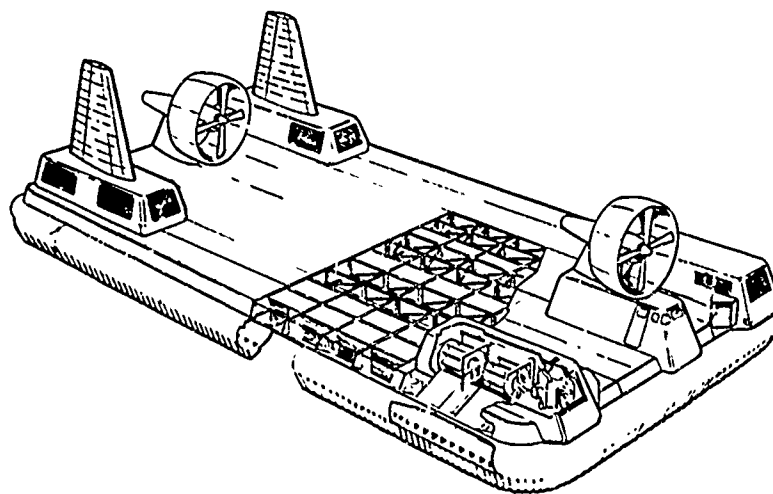
Figure 5. Arctic Cargo SEV (Boeing Model 730-72)

WEIGHT

EMPTY	45,000
PAYLOAD	50,000
FUEL	7,000
GROSS WEIGHT	105,000
CARGO SPACE	10 FT X 54 FT
RANGE	750 MI
CRUISE CONDITION, LEVEL LAND	

SPEED

| CRUISE | 60 MPH |
| MAXIMUM | 80 MPH |

SLOPE CLIMBING

CONTINUOUS	3.6°
CONTINUOUS AT 60 MPH	1.2°
OBSTACLE CLEARANCE	3 FT.
NOMINAL GAP HEIGHT	.1 FT.

34'   54'   24'   26'   10'   6'
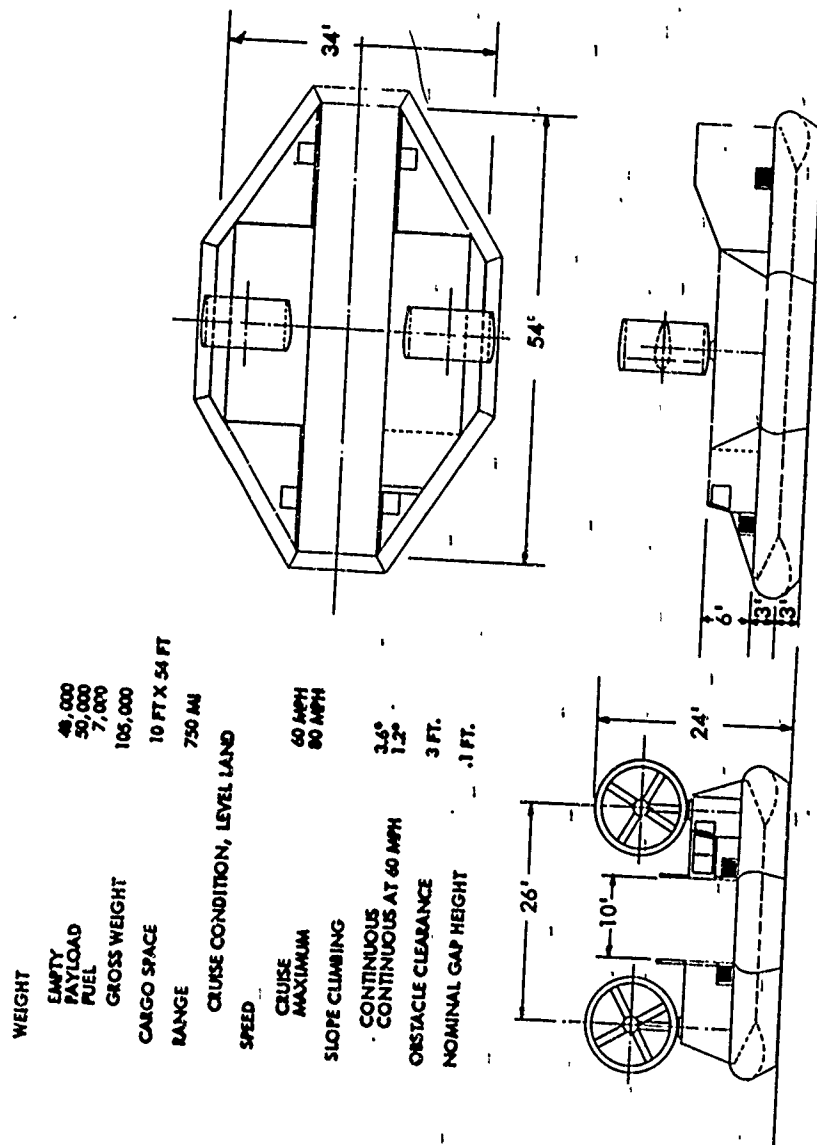
Figure 6. Arctic Cargo SEV (25-ton Payload)

in a low, structural weight fraction. This design has vectored thrust and an integrated lift and propulsion system. With a 25-ton payload, it has a maximum range of about 750 miles. The center cargo bay very nicely handles the containerized cargo from a Lockheed Hercules. As noted earlier, a vehicle of this size has higher operating costs than a 100-ton payload vehicle.

An inherent characteristic of any high-cost vehicle is that low operating costs require high productivity, and that high productivity necessitates high cruise velocity. Figure 7 illustrates the relationship between DOC and cruise velocity. Note that the operating cost continually drops with increased velocity. Thus, a cruise velocity as high as 100 mph would be desirable. For design purposes, however, we selected a cruise speed of about 60 mph. A higher cruise speed was not selected because of the uncertainty of overland operation due to the problems of SEV ride quality and maneuverability. Figure 7 also shows that the DOC is relatively insensitive to range from 250 to 1,000 miles.

One of the major technical problems of the SEV is poor maneuverability. This is illustrated in Figure 8 which shows vehicle turn radius as a function of velocity. Two different control techniques are shown: fixed engines which require vehicle yaw to turn and vectored engines. The effect of crosswind is also shown. At 60 mph, both control systems have nearly the same turning capabilities. In both cases the turn radius is poor, over 1-1/2 miles at 60 mph. This will be a major problem when trying to avoid obstacles without slowing down.

As noted above, in order to achieve low operating costs we need to have high productivity, which in turn requires high cruise velocity. The SEVs have poor turning and maneuvering capability which could be inconsistent with achieving high cruise velocity. This led us to the concept of a semiprepared guideway path. The main feature of this concept is a presurveyed route that would minimize distance, turns, and slopes. Surface preparation would be minimum. In many areas over open terrain, the guideway would simply consist of sets of guideposts set at about 1/4-mile intervals. The posts would have radar reflectors for all-weather operations, day or night. In some areas obstacles and trees would have to be removed. The disturbance of the surface would be minimized. The guideway could possibly utilize future road rights-of-way. The advantage of the guideway concept is that it allows a more optimum vehicle and results in much higher block speeds.

Figure 9 shows a potential guideway system in Alaska. The SEV system would serve as an interim system until there is sufficient cargo volume to warrant a road or railroad system. Preliminary studies indicate that the guideway paths are feasible for SEVs. The main distribution point would be Nenana, which is on
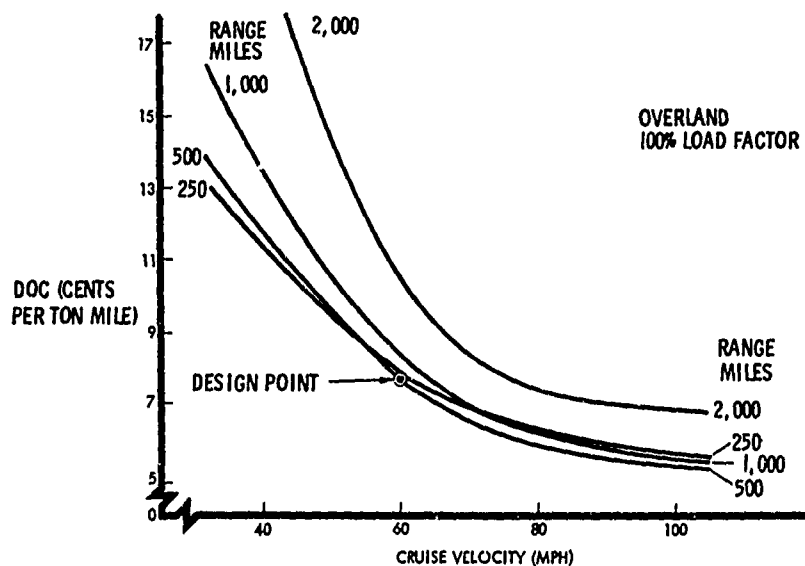
Figure 7. Cruise Velocity Choice (225-ton Vehicle)
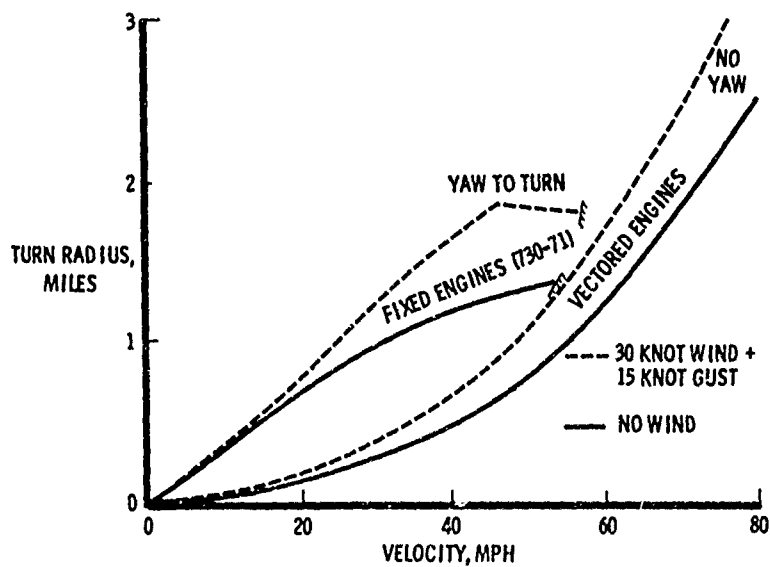
Figure 8. Vehicle Control Authority Trades
(225-ton Vehicle)
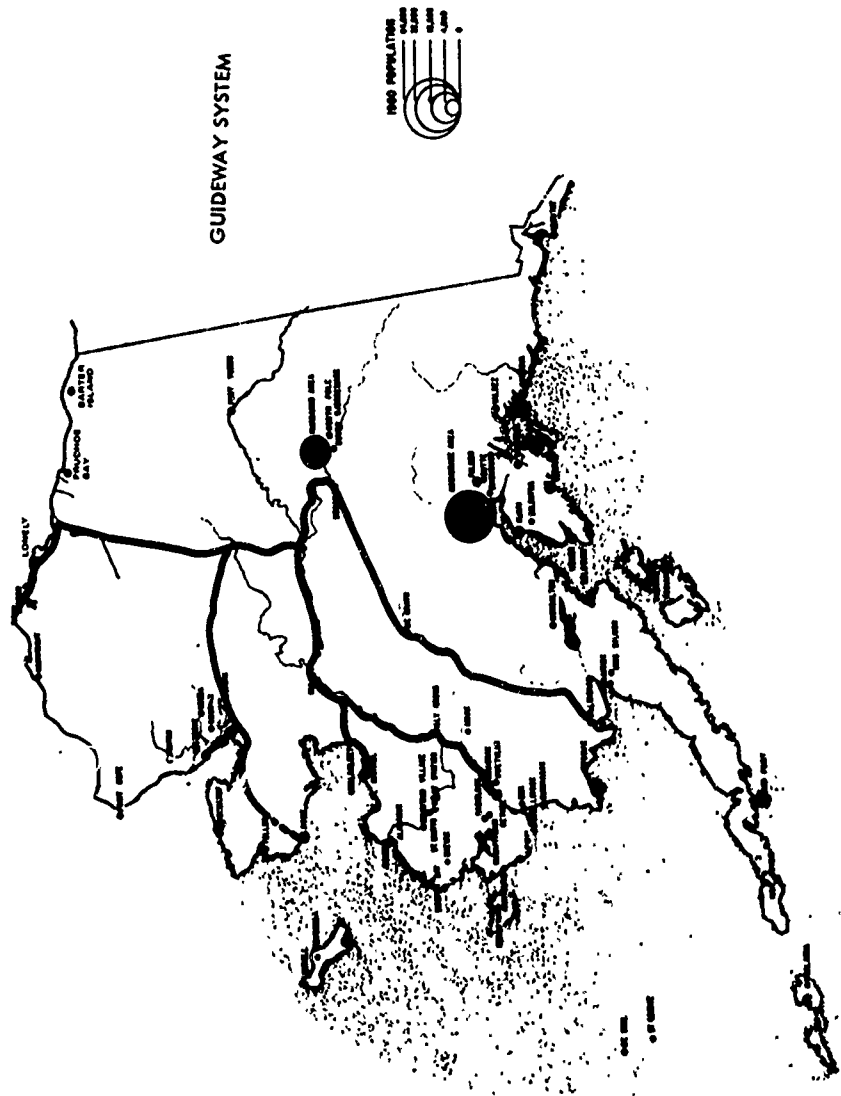
Figure 9. Potential Alaskan SEV Guideway System

the Alaska railroad. Guideways would extend to the villages of Dillingham, Bethel, St. Michael, Nome, Kotzebue, Prudhoe Bay, and Point Barrow.

The emphasis on obtaining high block speed and the uncertainty of SEV overland maneuverability and obstacle avoidance led to the development of a unique engineering tool for evaluating SEV maneuvering and control concepts. Figure 10 illustrates the SEV visual flight control simulator which is an adaptation of the Boeing Space Flight Simulator. This simulator consists of three major elements (Figure 10). A central computer contains programs of the SEV control and dynamic characteristics. The computer is tied into a servoed television camera on a movable track which traverses an arctic terrain model. The computer is also tied into a simulated SEV cockpit. A wide-angle projector throws the television picture on a wide-angle screen in front of the cockput.

With this facility the pilot can "fly" the vehicle over simulated arctic terrain. The camera responds in real time just as the actual vehicle would. Different vehicle designs and control concepts can be evaluated simply by reprogramming the computer. The effects of turns, winds, and slopes can be evaluated with the pilot in the loop. The terrain model simulates a 5-mile section of arctic terrain. Figures 11, 12, and 13 are photographs of the major elements of the simulator. Figure 14 shows a model of a small section of arctic pack ice to be used with the simulator.

Studies with the visual flight simulator quickly showed that the ideal SEV turning characteristics shown in Figure 8 could not be attained on a 300-foot-wide guideway. For example, Figure 15 shows the turning capability with the pilot in the loop for the two control concepts previously discussed: yaw to turn and vectored engines. When the vehicle required yaw to turn, it was very difficult for the pilot to sense his flight path vector and to anticipate corrections far enough in advance. Consequently he either had to slow down or run off the guideway. It was determined that the vehicle must have a tracked turn (that is, no yaw) in order for the pilot to adequately sense his flight path and anticipate maneuvers. This required vectored engines for control. Figure 15 shows that near ideal maneuvering capability was attained with vectored engines.

A direct operating cost model was developed to evaluate the SEV over potential routes and missions. The model considers type of terrain (slopes and turns), type of surface (hard surface or water), vehicle characteristics (including turning performance, slope performance and changing gross weight as fuel is depleted), season of the year (river frozen or thawed), and load factor. Flight control simulator results were used for maneuvering capability characteristics with turns and slopes.
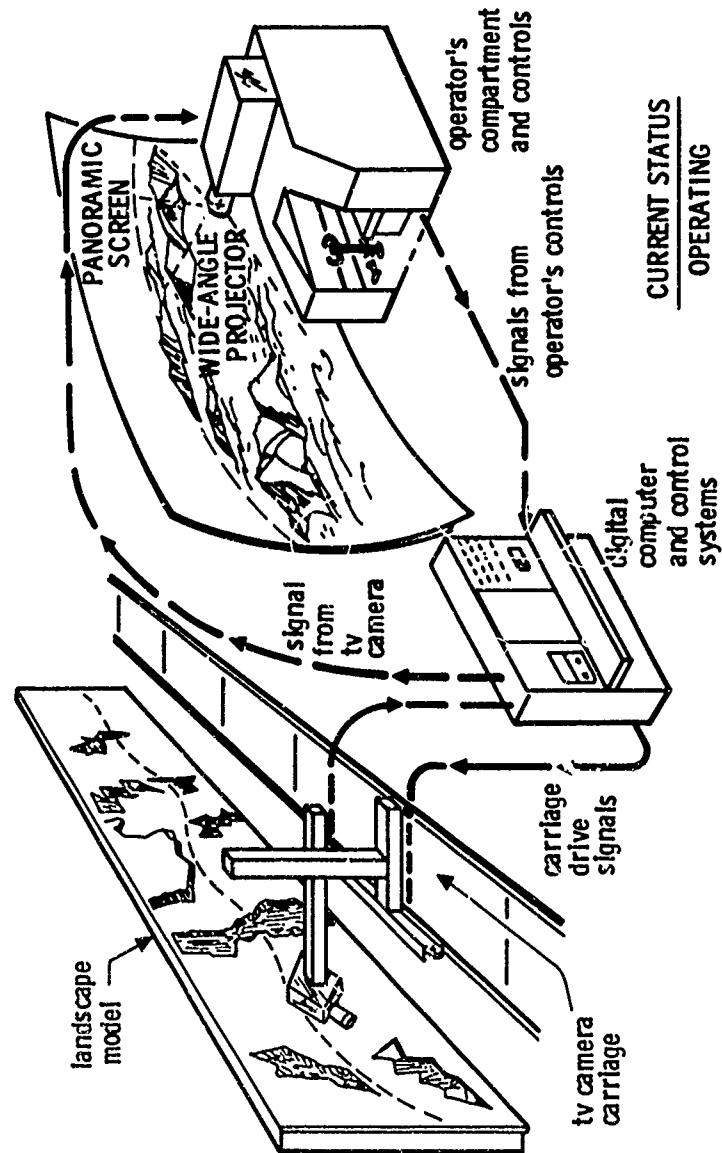
Figure 10. SEV Visual Flight Simulator (Space Flight Simulator Adaptation)

Figure 11. Servoed Television Pickup System Viewing
Arctic Terrain Model

Figure 12. Arctic Terrain Model

Figure 13. Crew Station and Projected Scene Used for SEV Simulation
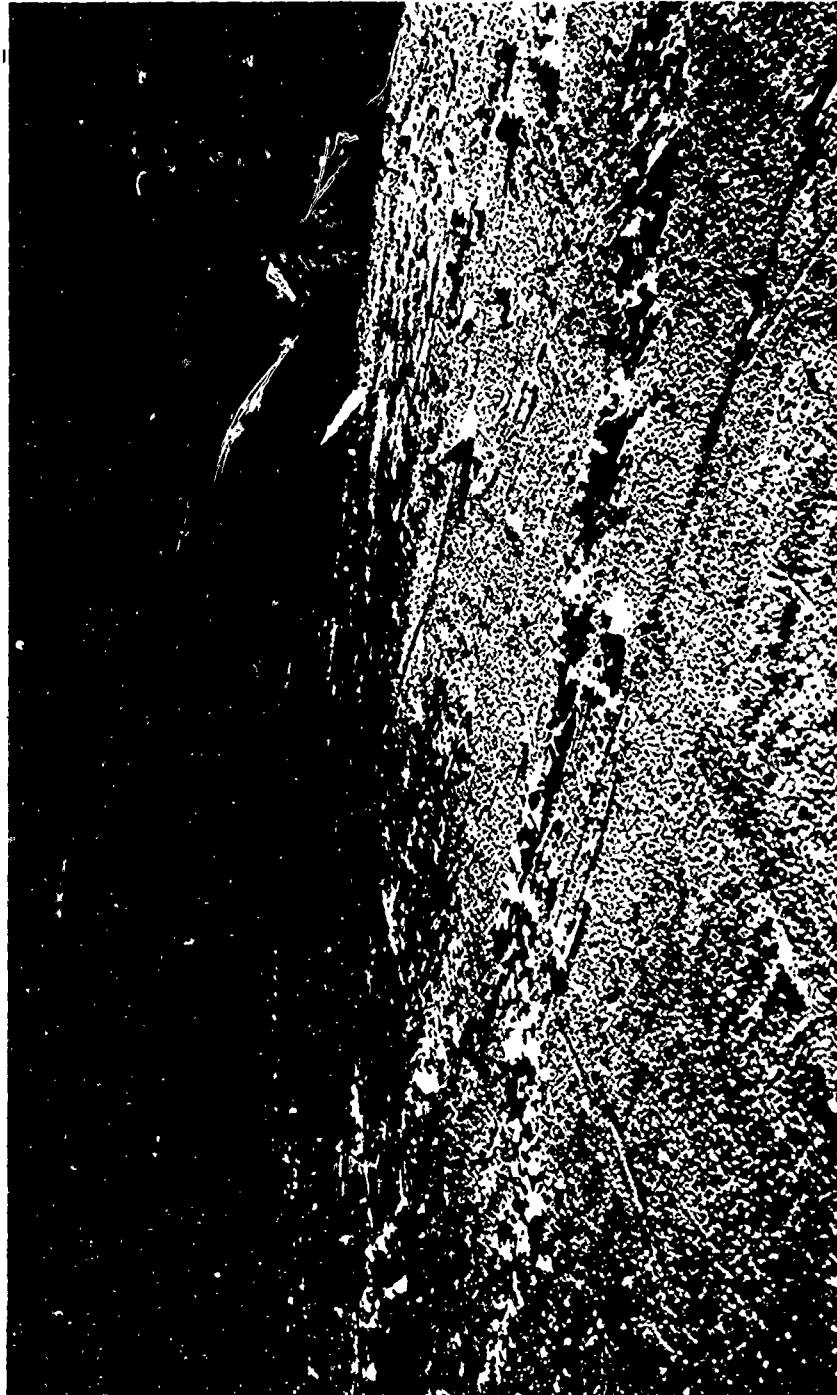
Figure 14. Arctic Pack Ice Model
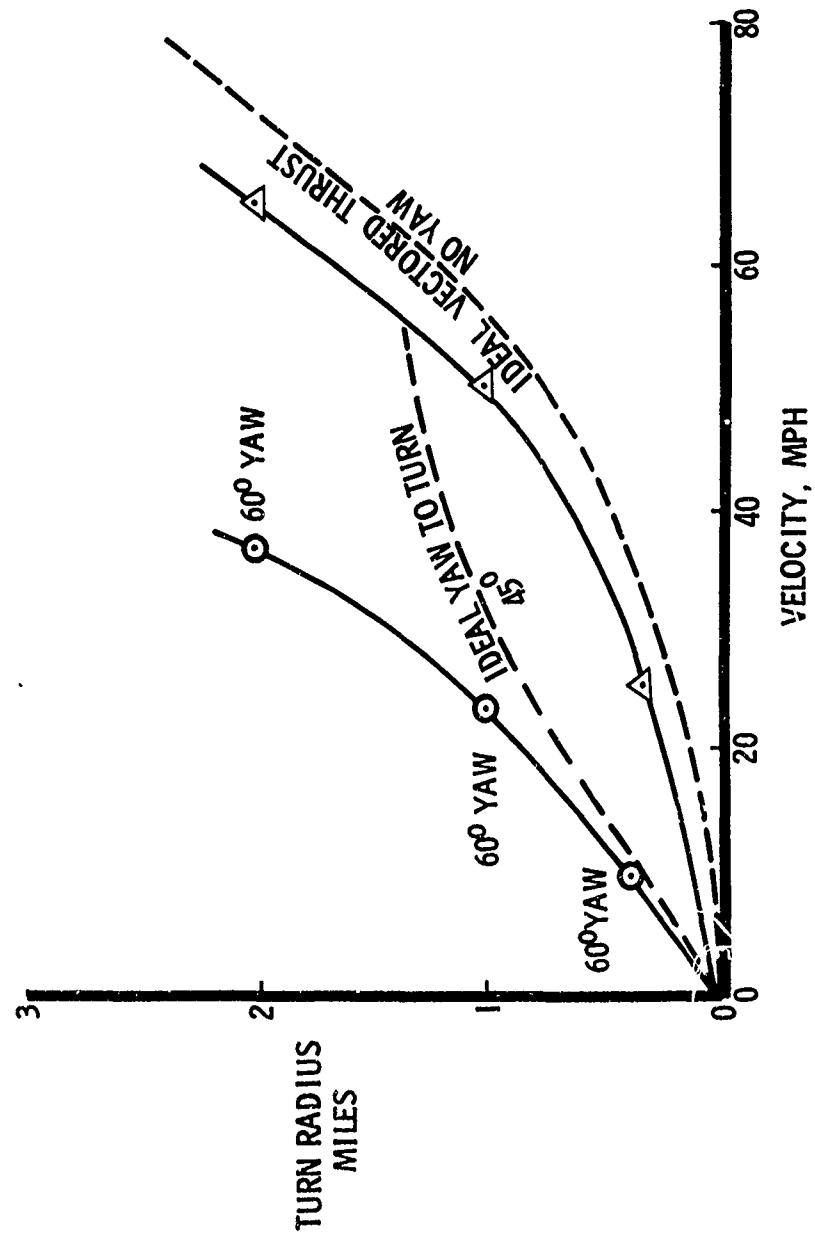
Figure 15. Vehicle Control Authority with Pilot in the Loop (225-ton
Vehicle, 300-foot-wide Guideway)

Figure 16 shows the calculated block speed for a 567-mile route from Nenana to Prudhoe Bay. Block speeds are shown for the two different control concepts, with and without the pilot in the loop. During winter operation, ideal block speed (100 percent pilot efficiency) was determined to be about 42 mph for the yaw-to-turn concept. With the pilot in the loop, this would drop to 26 mph. For vectored thrust, the block speeds with and without the pilot in the loop are both about 50 mph. The results for summer operation are about the same; however, the block speeds are somewhat lower due to some water operation. The land optimized vehicle has a reduced block speed in the summer when stretches of water must be traversed.

High block speed results in high productivity, which is required to attain low operating costs. The data from Figure 16 were transposed into direct operating costs (presented in Figure 17). The yaw-to-turn case has an ideal DOC of about 11 cents per ton mile. With the pilot in the loop, it is about 18 cents per ton mile. With vectored thrust, however, the DOC is less than 10 cents per ton mile in both cases. In the summer the direct operating cost increases somewhat due to water operations.

Figure 18 shows a comparison of the total transportation cost for a line haul mission of 250 air miles with zero back haul as a function of tonnage per year. The SEV is compared with airplane and truck transportation. The SEV and truck data correspond to 100 percent and 150 percent of air miles. This is considered to bracket the actual distance a land vehicle must travel. The total transportation cost shows direct and indirect operating costs, including the amortized costs of guideways and roads. Airplane data represent costs with and without the amortized cost of one airfield. Note that at a 250-mile range the SEV appears to be competitive with the airplane over the complete range of tonnage. At about 200,000 tons per year, however, it becomes more economically feasible to build a gravel road in the Arctic and use a truck system.

Figure 19 shows the effect of mission range at a fixed line haul of 100,000 tons per year (the volume at which the SEV appears the most competitive). In this case, the SEV always has lower costs than the truck. However, the Hercules airplane becomes competitive at a range of about 250 miles if the SEV has to go 50 percent further. If the SEV can fly a straighter course, the airplane does not become competitive until a range of up to 900 miles.

Several cargo distribution missions were evaluated. Figure 20 shows distribution costs for oil field development at Prudhoe Bay. Two different SEV sizes (50-ton and 250-ton gross weight) are compared with a truck system operating on gravel roads. For this distribution system, there is little cost difference between the large and small SEVs. This results from the poor load factor
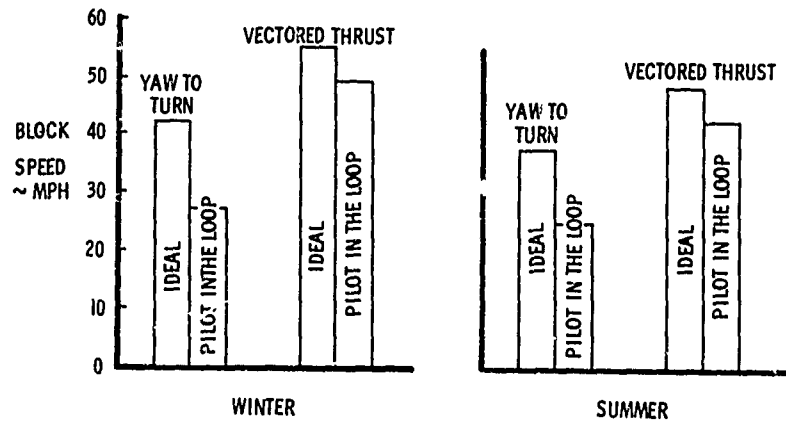
Figure 16. Control Concept Impact on Block Speed
(225-ton Vehicle, Nenana to Prudhoe Bay--
567 Miles)
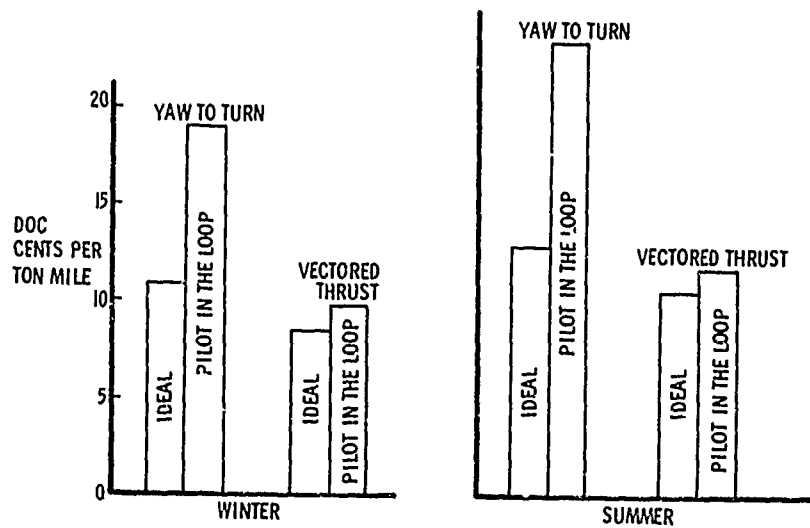
Figure 17. Control Concept Impact on Productivity
(225-ton Vehicle, Nenana to Prudhoe Bay--
567 Miles)
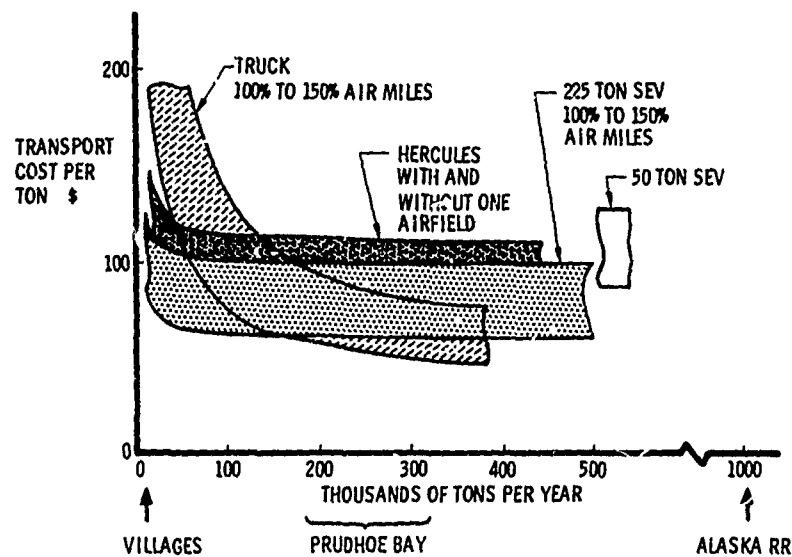
Figure 18. Transport Cost Comparisons (Line Haul
of 250 Air Miles with Zero Backhaul)
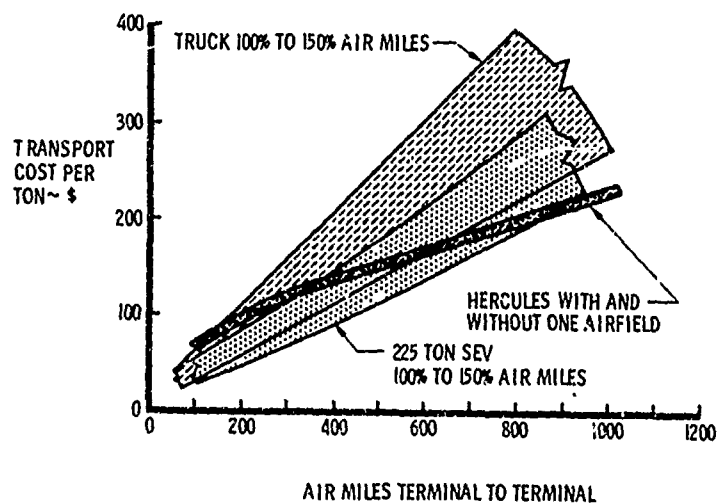
Figure 19. Transport Cost Comparisons (Line Haul
of 100,000 Tons Per Year with Zero Backhaul)
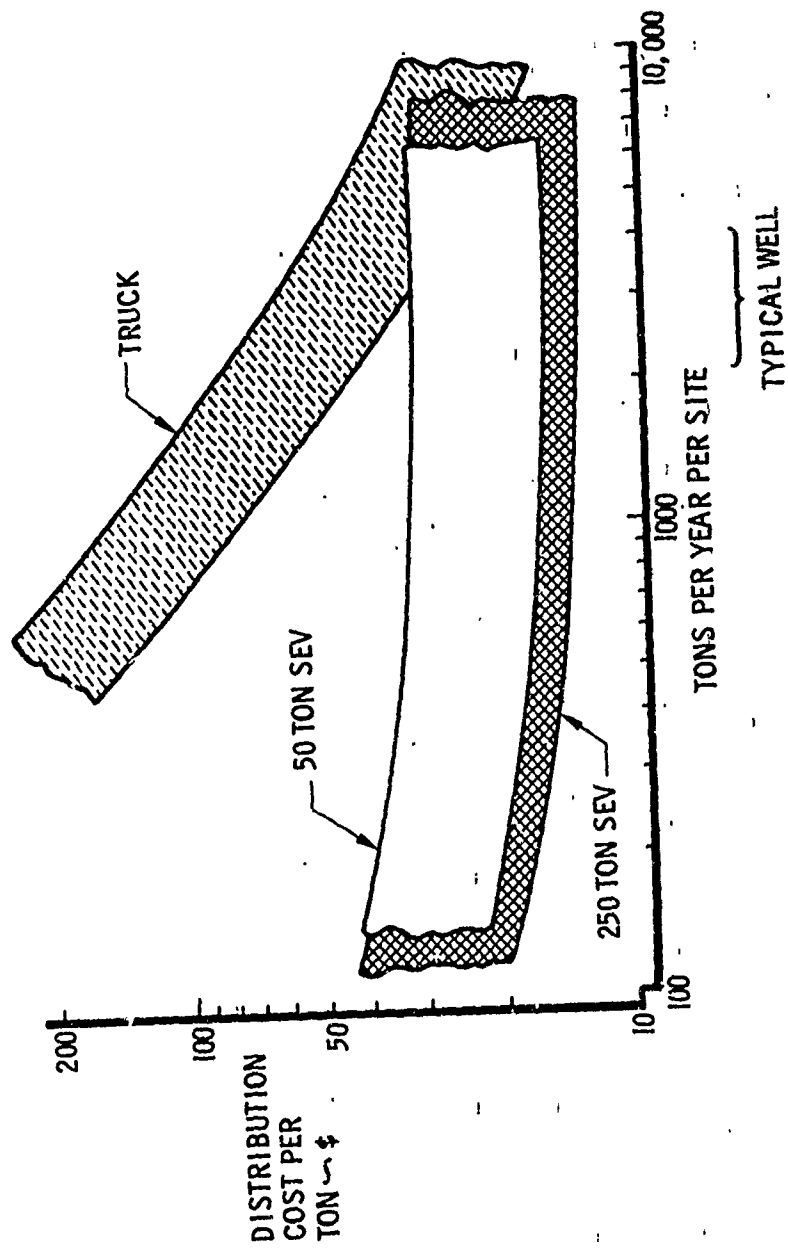
Figure 20. Cargo Distribution Cost Comparisons (Prudhoe Bay)

of the large SEV for small volumes per well site. The truck system becomes competitive with the SEV system at about 10,000 tons annually per site.

From these comparisons we can conclude that the SEV appears to fill a gap in the ground transportation systems in the Arctic. It is competitive with other transportation systems for line haul missions that have low to medium range and low annual tonnages. It could act as an interim system until the tonnage builds up to the point where a road or railroad system becomes economically feasible. The cargo SEV appears competitive with other systems for certain cargo distribution missions.

In conclusion, the SEVs appear to compete with other cargo systems in the Arctic for certain missions, primarily those of small annual cargo volume and short to medium range. In order to obtain competitive costs, however, an optimized vehicle is required, a clear guideway over land is desirable, and high maneuverability is necessary to maintain high block speeds. There are uncertainties in the economics, and many technical problems still exist. Many of these uncertainties could be reduced or eliminated through a technology and demonstration program.

ALL-SEASON VEHICLE FOR SEA ICE

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This paper delineates the capabilities of the Cushman TRACKSTER, an all-season double-tracked vehicle similar to a small military tank. Primarily, the TRACKSTER provides over-the-snow transportation for up to four passengers, or for one passenger and 800 pounds of cargo. Secondarily, it functions as a transport vehicle over rough or swampy terrains. Figure 1 shows the TRACKSTER passing over rough mountaintop terrain similar to jagged sea ice.

Reliability and performance were the main criteria for the design of this vehicle for off-road work or transportation. The TRACKSTER is powered by a 25-horsepower, 2-cycle, 2-cylinder Outboard Marine Corporation engine. Battery ignition and a capacitor-discharge ignition system improve reliability. The transmission is twin hydrostatic, with a final 6:1 gear reduction to the main drive shafts. The hydrostatic transmissions are operated with a mixture of Type F and Military Specification 5606 arctic transmission fluid. This mixture allows the operator to start the engine and drive off without warming the transmission at -35°F. Lower temperatures would require a mixture of fluid with a greater proportion of 5606 fluid. Below -35°F, the battery would need to be warmed or charged, and warming the fuel system would sometimes be necessary.

TARP COVER

A fitted tarpaulin accessory (Figure 2) keeps snow out of the vehicle and engine compartment. The cover fits very securely, and drifting snow will enter only in small amounts. If a heat supply is placed under this cover, the operational part of the TRACKSTER is kept warm enough to operate at temperatures to -60°F. The rubber tracks may become too stiff to operate below -65°F.

FLOTATION MODEL

For both summer and winter operations, the flotation model TRACKSTER would be best for arctic use. When the flotation collar is attached, the vehicle will not sink even if it is filled with water. The vehicle is not amphibious, so the flotation collar is merely a safety device for crossing small areas of water. Climbing out of water onto the ice would require a winch accessory or a second TRACKSTER.

Figure 1. Mountaintop Terrain Similar to Jagged Sea Ice
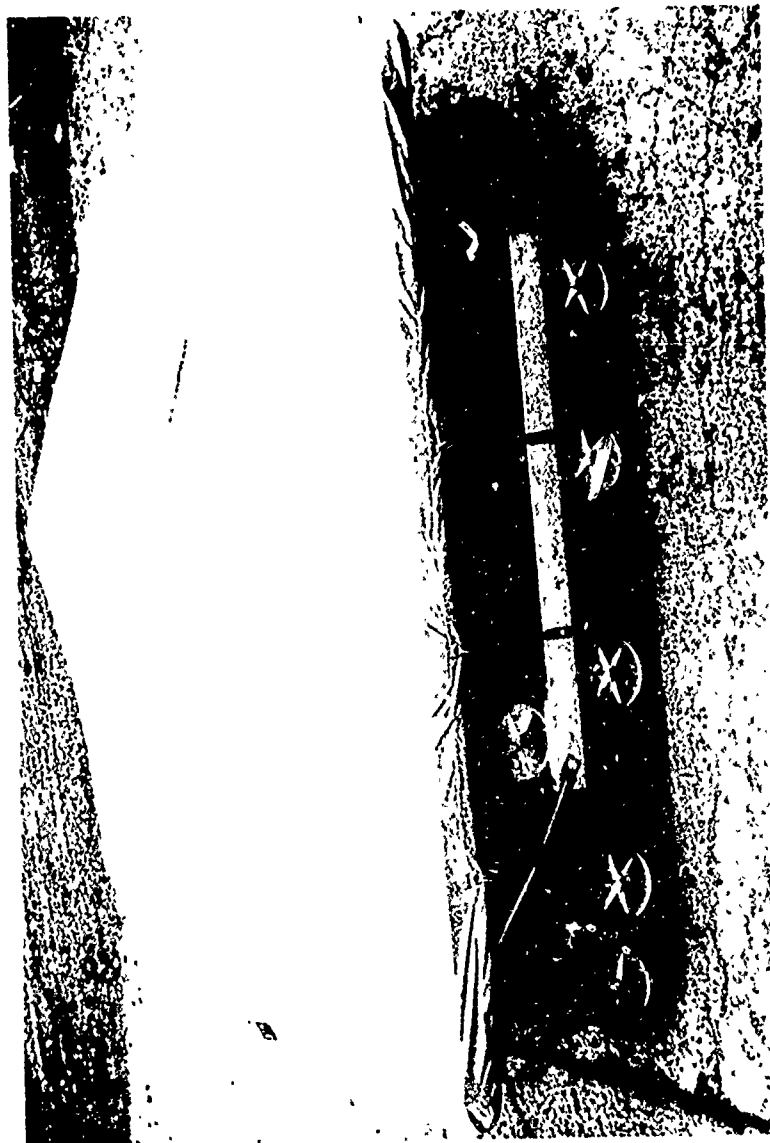
Figure 2. Tarpaulin Prevents Snow from Entering Engine and Passenger Compartments

For winter operation, the flotation collar acts as a wind barrier. The vehicle is generally equipped with a short windshield and heat deflectors which blow hot engine air back on the passengers. This air flow is normally 100° above the ambient temperature. The vehicles were operated continuously one night during a blizzard rescue operation with a wind chill index near -60°F. The 50- to 60-mph sidewinds caused discomfort after about 1 hour. A flotation collar would have broken the wind and allowed the heated air to do its job. A further factor leading to discomfort was the lack of special clothing other than snowmobile suits.

GRADEABILITY AND SNOW CAPABILITY

The TRACKSTER is a proven over-the-snow vehicle. It has not yet been proved capable of scaling sea ice pressure ridges. Because of its low center of gravity and extreme slope capabilities, however, it may be an answer to scaling these obstacles. The U.S. Coast Guard has purchased two TRACKSTER vehicles for this purpose, but their comments are not yet available.

A side slope of 45° (Figure 3) does not cause instability if normal surfaces exist. Climbing a grade of 45° is common; grades of 30° are common on snow; and grades approaching 45° on snow are possible with metal cleats and good snow conditions. Sharpened and hardened steel screws, bolted through the track, will add traction while operating on ice. A transverse steel cleat causes a very rough ride on hard surfaces and is not recommended.

WINCH

A winch kit is a recommended safety feature when crossing pressure ridges, both for climbing and for descending the far side. Where possible, one vehicle should accompany another as a safety precaution. If one vehicle becomes disabled by mechanical failure or terrain conditions, the second vehicle becomes a necessity.

DRAWBAR

The TRACKSTER has a normal drawbar pull of 1,000 pounds or 1,500 pounds with smaller drive sprockets (Figure 4). These drawbars depend upon traction conditions and usually require added weight on the vehicle. The top speed is 16 mph with standard sprockets and 13 mph with the smaller drive sprockets. Generally, the 13-mph vehicle will be better for all arctic uses. If the snow is deep, more power is required. When the ice is rough, 5 mph is more than adequate for top speed. Also, because of increased friction in bearings and increased track stiffness due to low temperatures, the smaller sprocket with its higher torque is recommended.
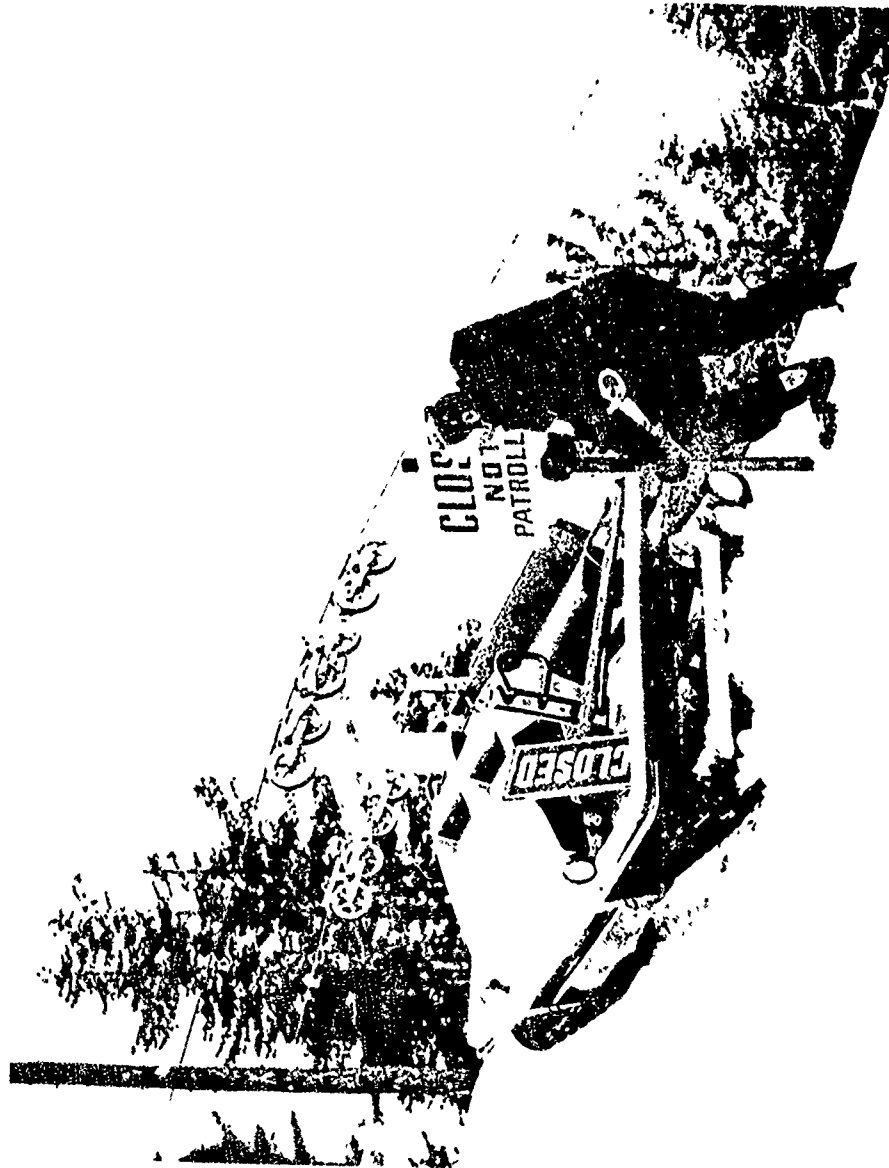
Figure 3. TRACKSTER Stability Illustrated in Ski Area

Figure 4. Drawbar Pull (1,000 to 1,500 Pounds) Moves
Heavy Materials

GROUND PRESSURE

The track system has over 2,000 square inches of ground contact area. This results in an unloaded ground pressure of 0.50 psi and a fully loaded vehicle ground pressure of less than 1 psi. These pressures are acceptable for over-the-snow vehicles and are causing interest among environmentalists for tundra applications. Since the standard track has an all-rubber surface, it does very little tearing or cutting of fragile plant systems. The vehicle operator should exercise good judgment in off-road conditions and avoid spin turns which cause severe plant damage.

FUEL MIXTURE

The gas tank capacity is 10 U.S. gallons, which will operate the vehicle for a range of approximately 80 miles, depending on load and terrain. The gasoline must be mixed with oil to lubricate the 2-cycle engine. Outboard Marine Corporation 50:1 oil has a diluent which allows it to mix with gasoline at low temperatures. Other 30 or 40 weight oils will work but are hard to mix.

CONTROLS

A single T-handle provides complete control of the vehicle (speed, steering, direction, and braking). The T-handle precisely and smoothly controls the movement of the TRACKSTER. If moving down a steep incline, the single T-handle will slow or stop the tracks, provided the operator pulls back on the handle. The controls are so sensitive that a novice operator can balance the vehicle on a log. A driver with a bit of experience can move the vehicle in and through obstacles which clear the sides by distances of less than an inch.

The T-handle is linked to the hydrostatic transmissions which are part of a completely enclosed hydraulic transmission system. Engine speed is controlled by a variable-speed governor, which means that a driver can set the governor and drive the vehicle with one hand. This is an advantage in cold areas because the thumb cools off quickly, even when mittens are worn. The driver can switch hands as often as he chooses and stick his cold hand in the warm air heater area. Even cold feet can be placed into this warm area to improve comfort and safety of the driver and passengers.

COLD ROOM TESTS

Cold room tests show that the battery cables and cab window materials begin to cause problems at -50°F. Tests on the production cab show that window materials hold up better if the cab remains unheated when not in use. Thus, low-temperature battery cable insulation is basically the only change necessary in order for the TRACKSTER to perform its job well in weather conditions of the Arctic Basin.

Specifications

Dimensions: Length - 92 inches   Weight - 1,040 pounds
              Width - 62 inches   Track width - 15-1/2 inches
              Height - 41 inches

Features:
  Engine   25 HP, 2-cycle, 2-cylinder, air cooled, electric
                    start, governor controlled
  Battery   Std. automotive 12 V, 67 amp hr
  Body   3/16 to 1/4 inch thick fiberglass
  Suspension   Bogie wheels individually suspended by torsi-
                    lastic springs, leaf springs, or shear mounts
  Drive sprockets Steel casting
  Bogie wheels   Die-cast aluminum with triple-lip seals to
                    protect ball bearings
  Carrying space Cargo bin in rear, plus 12 inch wide shelf
                    space along sides
  Lubrication   None required
  Fuel capacity   10 gallons
  Color   Sea green

Performance: Turning radius - 0
                Speed - 16 mph forward, 7 mph reverse
                Ground pressure - 0.5 to 1.0 psi, depending on load
                Drawbar - 1,000 lb, depending on ground condition,
                          1,500 lb with small drive sprockets

Accessories: Windshield and warmer set
                Snowplow
                Cab
                Auxiliary drive pulley
                Rub rails
                7-tooth sprocket
                Rear tonneau cover on flotation model
                Winch kit
                Winch bracket
                Trailer
                Ski-area snow grooming equipment
                Hour meter
                Radio noise suppression
                Exhaust spark arrester
                Underbelly aluminum skid plate

MOBILE LABORATORIES AND WORK PLATFORMS

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This paper discusses current hardware in air cushion vehicles, particularly as this hardware relates to the Arctic. In terms of arctic transportation, a number of situations will likely center around a system that has a base camp, either on land or on the pack ice, that is linked to southern Canada or the "Lower 48." This base camp is surrounded by satellite camps which may be drill rigs, seismic parties, small stations for measuring ice flow direction, etc. A mobile link would be established from the base camp to the satellites (Figure 1).

The base camp is concerned with management of the whole system. It is clearly the center of logistics and communications with the south, and it probably contains at least a limited data-processing and analysis capability. The satellite camps could be manned or unmanned, but they probably will involve continuous data gathering or at least continuous activity of some sort, such as core drilling. They should be mobile to accommodate research movement and expansion, although not necessarily self-propelled (Figure 2).

The mobile units that provide transportation between the base camp and the satellites should be designed so that the surveillance or work area can be extended beyond the limits of static satellites. These mobile units should also be able to respond to unusual data inputs from a satellite measuring station, which may indicate a peculiar occurrence in the area between the satellite and the mobile unit. There is often a need to respond to such situations on a real-time or nearly real-time basis.

In addition to routine mobile unit requirements, there is an emergency transportation need within the system and, eventually, a need to reposition the satellite camps as research expands and m . In the long term the base camp itself may have to be moved.

A typical transportation flow pattern (Figure 3) would see men and materials coming up from the south by aircraft, ship, or barge to a northern terminal, perhaps Inuvik on the Mackenzie River or Fairbanks in Alaska. Movement from this terminal to base camp will likely be by aircraft, perhaps a Hercules C-130. In this phase of the operation, some kind of base camp airfield is required. It should be an airstrip and not an airfield in the accepted sense. Here, the use of an air cushion landing system offers potential benefits.
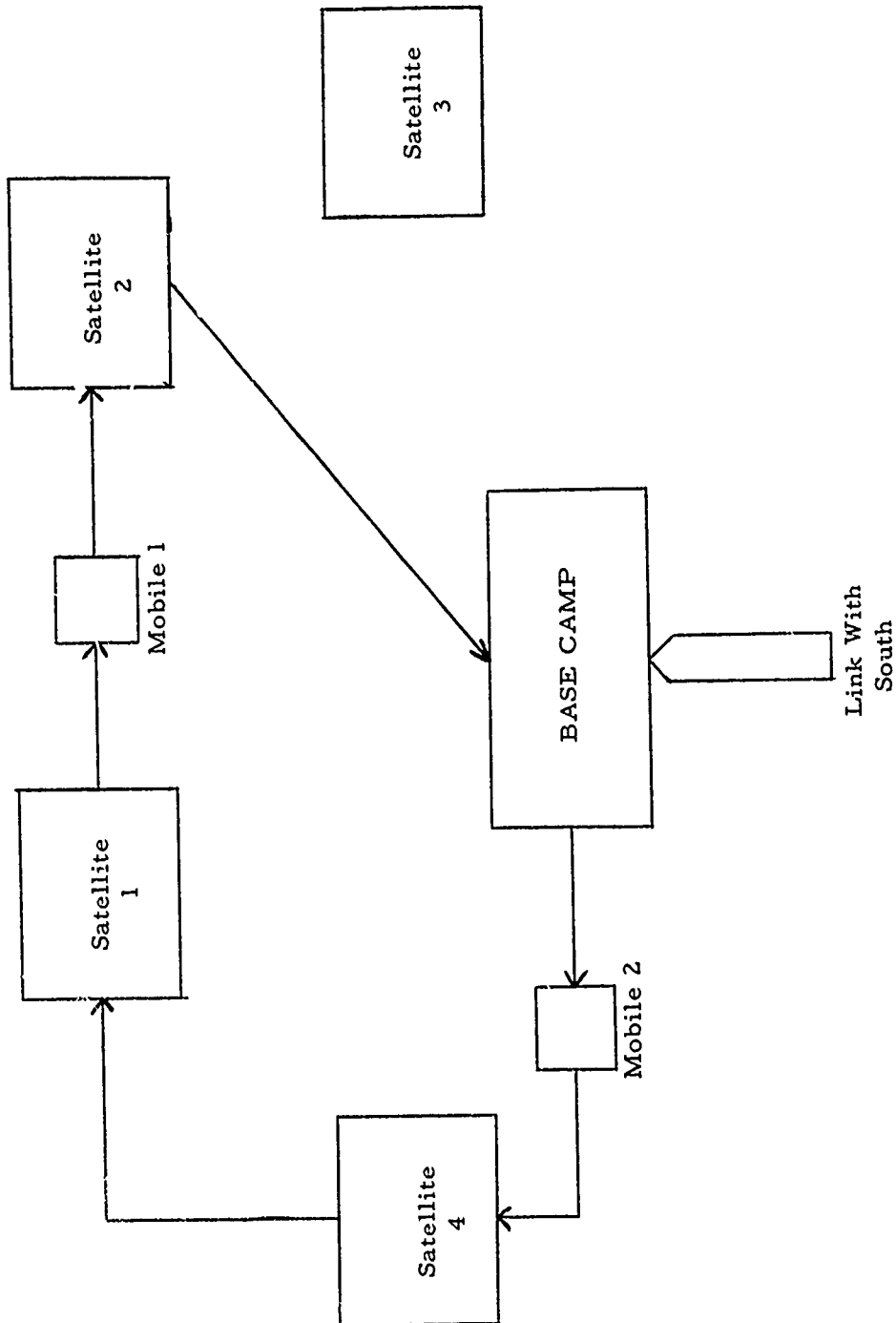
Figure 1. ARCTIC LABORATORY/WORK PLATFORM SYSTEM

BASE CAMP (S)

OPERATION MANAGEMENT
COMMUNICATION CENTER
LOGISTIC LINK WITH SOUTH
DATA PROCESSING AND ANALYSIS
SYSTEM LOGISTIC CENTER

SATELLITES

MANNED/UNMANNED
CONTINUOUS DATA GATHERING
MOVABLE AS SEARCH MOVES/EXPANDS

MOBILE UNITS

INTERNAL LOGISTIC LINKS
EXTEND SURVEILLANCE AREA
RESPOND UNUSUAL DATA INPUTS
EMERGENCY TRANSPORTATION
REPOSITION SATELLITES

Figure 2. SYSTEM UNIT FUNCTIONS
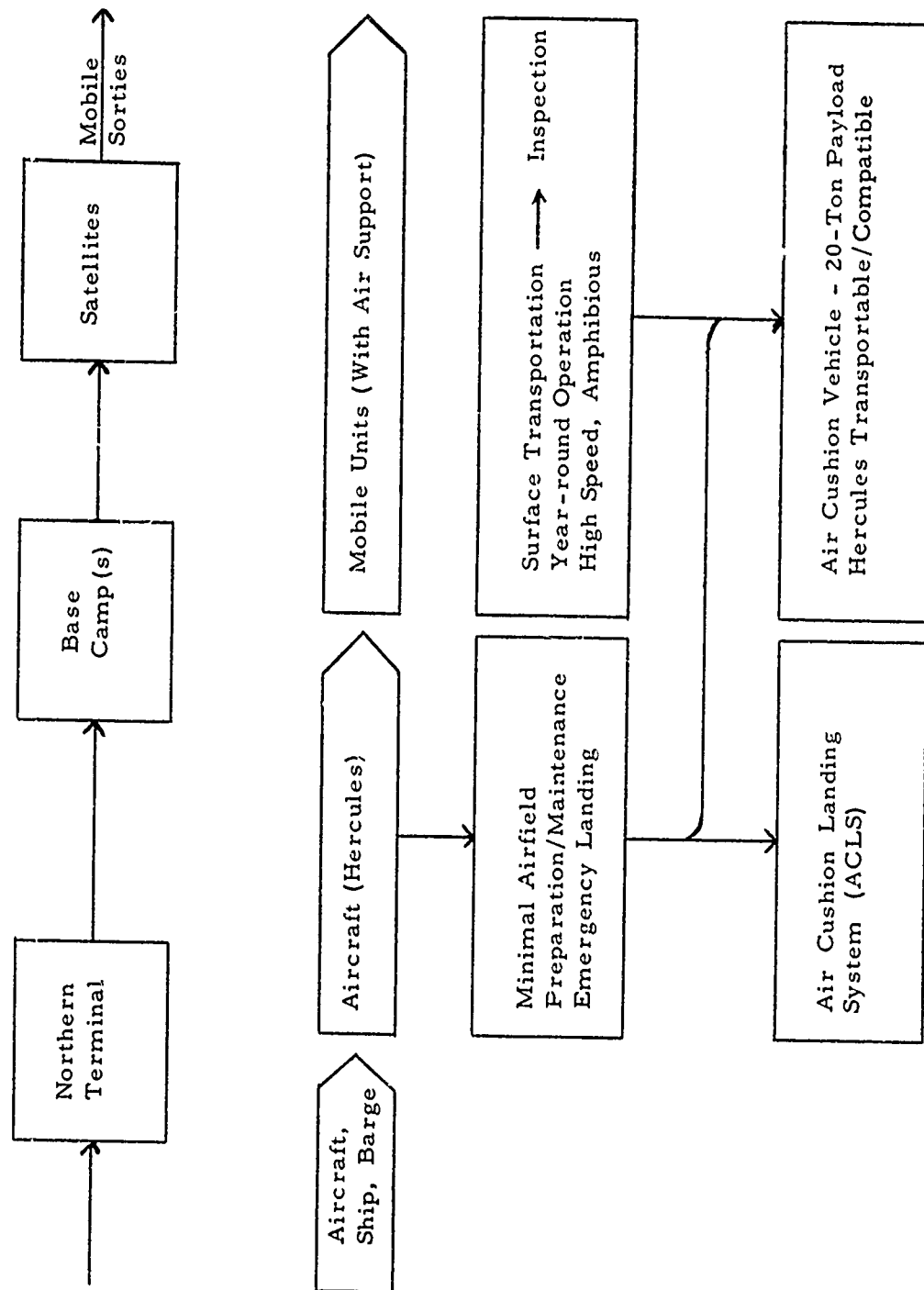
Figure 3. TRANSPORTATION FLOW PATTERN

Air support is included within the system because, regardless of the type of surface transportation used (especially on the ice pack), there will be occasions when nothing is likely to move without some kind of overhead reconnaissance support.

From base camp out to satellite areas, surface transportation is basically preferred because detailed inspections of the surface can be made and year-round operation becomes feasible without elaborate equipment. Because of the nature of the northern land and sea areas, there is a need for amphibious capabilities in any surface transportation. High-speed vehicles are desirable in that the total satellite/base system is dynamic and needs the capability to respond rapidly to unusual situations. We recommend the amphibious air cushion vehicle for this role.

The capacity of the air cushion vehicle should match the payload weights and sizes involved in the base camp input system. In the near term, this means a maximum Hercules load of about 20 tons. The vehicle itself and everything associated with it must be transportable by the Hercules. In general terms, air cushion vehicle technology, as it exists today, can provide a reasonably compact vehicle with a 20-ton payload matched to a range of about 100 miles at a "difficult terrain" cruising speed of about 20 to 30 mph. Higher speeds cannot be realistically assumed on a day-to-day basis, although this typical ACV would have a smooth ice maximum speed of between 50 and 60 mph. With this 20-ton payload, current technology indicates that a skirt height of around 6 feet is possible.

With such a vehicle, trade-offs between payload and range can be made to suit the needs of mobile platform operators. For example, an 8-man camp package, which might well be one of the satellite camps, could weigh about 15,000 pounds. This could consist of two or three 8 by 8 by 20 foot living and working units, plus eight men with provisions and equipment. In theoretical terms, these could be hauled about 600 miles over a time period of about 20 hours at an average speed of 30 mph. In arctic operations of this nature, enough fuel should be carried for a round trip rather than for one way. In practice, this would amount to about a 200- to 250-mile trip capability with enough fuel for emergencies (Figure 4).

So far, consideration has been given to the type of vehicle which might be best suited for this kind of work. Reservations are often expressed about air cushion vehicles with regard to obstacle clearance, low-temperature effects, and so forth. It might therefore be rewarding to discuss what has already been achieved and, by implication, what is possible for the near term.

There is now a substantial backlog of arctic-related experience with the Bell Aerospace/British Hovercraft family of craft. For
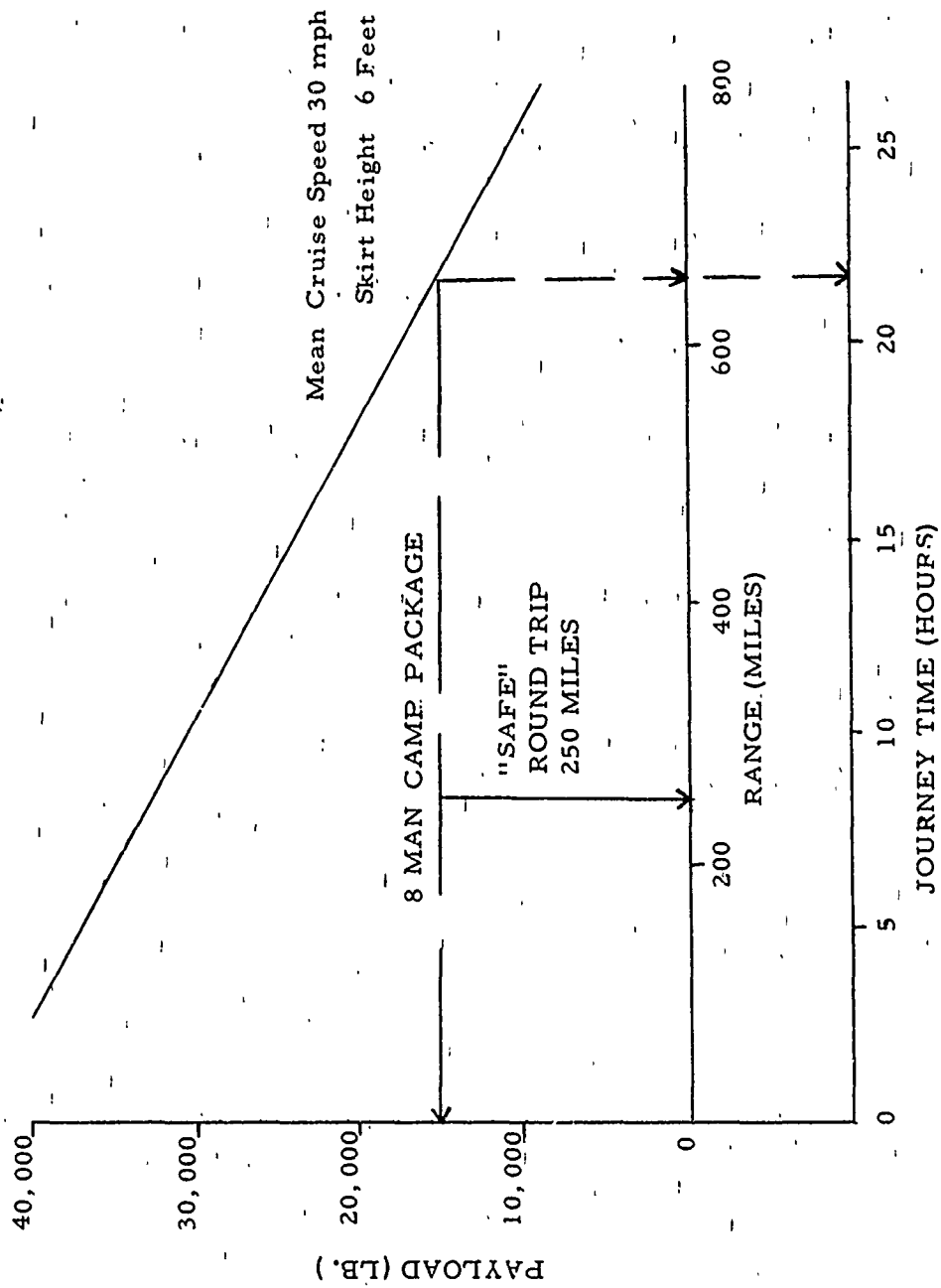
Figure 4. TYPICAL 20-TON PAYLOAD ACV

example, SK-5 winter trials were recently conducted in Houghton,
Michigan in which the vehicle reached 80 knots on smooth ice and
negotiated 6-foot-high ridges. In this instance, temperatures
were a little below 0°F, but SR.N6 trials have been conducted
at -40°F. As early as 1963-1964, CRREL operated on the Greenland
Ice Cap with one of the early Bell experimental 2-seat vehicles
(the SK-3). (See Figure 5.) A wealth of military SK-5 experience
in marsh areas, which are often analogous to summer conditions
in the Arctic, is also available.

From a manufacturer's point of view, the results of the
recent ARPA/U.S. Coast Guard SK-5 tests in the Arctic have been
most encouraging (Figure 6). The SK-5, with its 5-ton payload,
has been an extremely useful step in accelerating the state of
the art. However, this vehicle is neither capable of hauling
a 20-ton Hercules payload nor is its configuration suitable for
mobile platform work.

A program has been launched to develop a vehicle which
will meet these platform requirements, not only for scientific
field research activities but also for many other existing and
potential arctic applications. This new vehicle, the Model 7380
"Voyageur" (Figures 7 and 8), is a joint project between Bell
Aerospace Canada and the Canadian government. The vehicle utilizes
the proven working machinery of the Bell SK-5's (with two of
everything--propellers, fans, etc.) and features a large, unobstructed
flat deck which can accept a Hercules payload without restrictions.
If superstructure is needed, it can be added to meet particular
needs. The Voyageur will have no difficulty, for example, in carrying
an 8 by 8 by 20 foot portable unit, and either depositing it at
a satellite camp or carrying it along as a mobile workshop. The
vehicle is 65 feet long overall by 33 feet wide. The flat deck
cargo space is 40 feet long to match up with both the longest
Hercules payload and the largest containers. The payload is 20
to 25 tons. The vehicle breaks down into modules, the largest of
which is 40 feet long by 3 feet deep by 8 feet wide.

The first Voyageur will be operating by December (1971),
so its first trial run will be in snow, assuming there is snow in
Grand Bend, Ontario by that time. Voyageur craft should be
operating in the Arctic next year, most probably in the Mackenzie
delta.

Under study are a variety of demountable modules, useful
not only for exploration and research but also for remote area
sociological work--clinics, libraries, educational and training
posts, business and banking modules, etc. These are important
applications because they represent benefits from technology which
can and should be enjoyed by Northern native populations.

Air cushion landing systems for aircraft are also being
developed. The basic hardware was devised several years ago by
the Bell Aerospace Company, and has been extensively tested on a
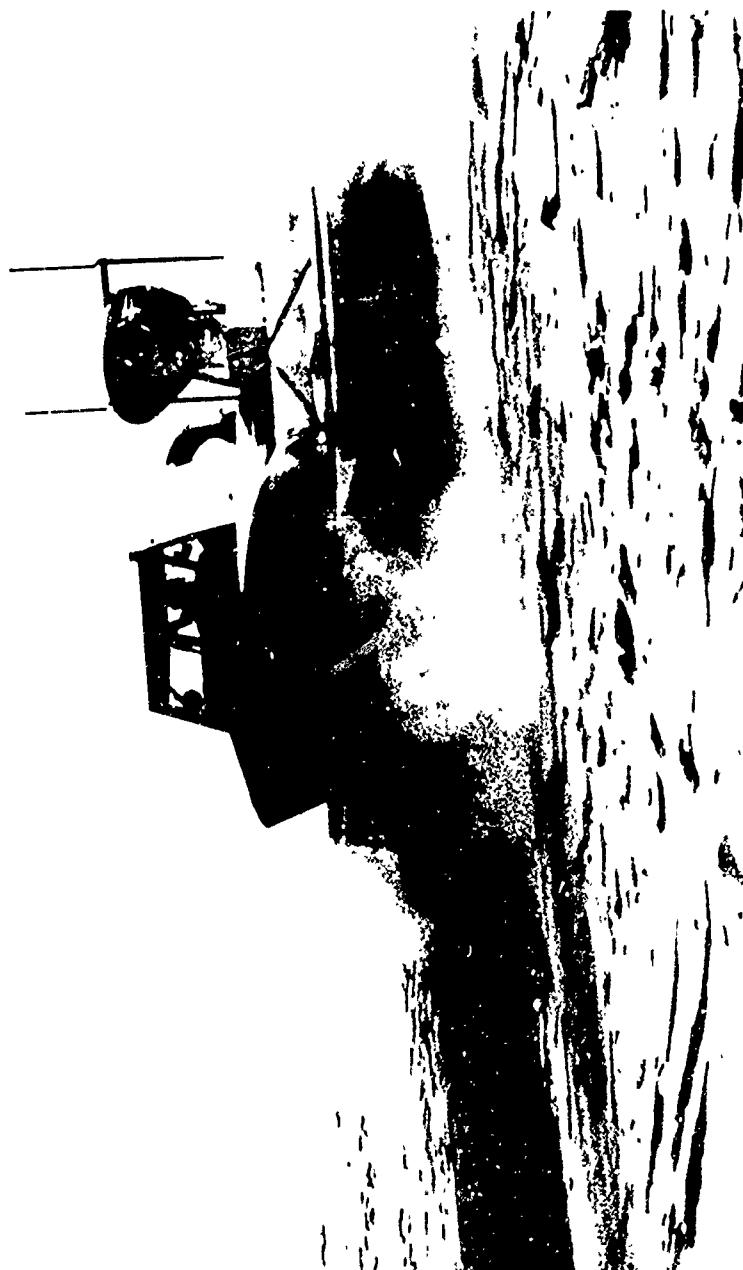
Figure 5. Sk-3 During CREEL Greenland Ice Cap Trials (Bell Aerospace Company Photograph)
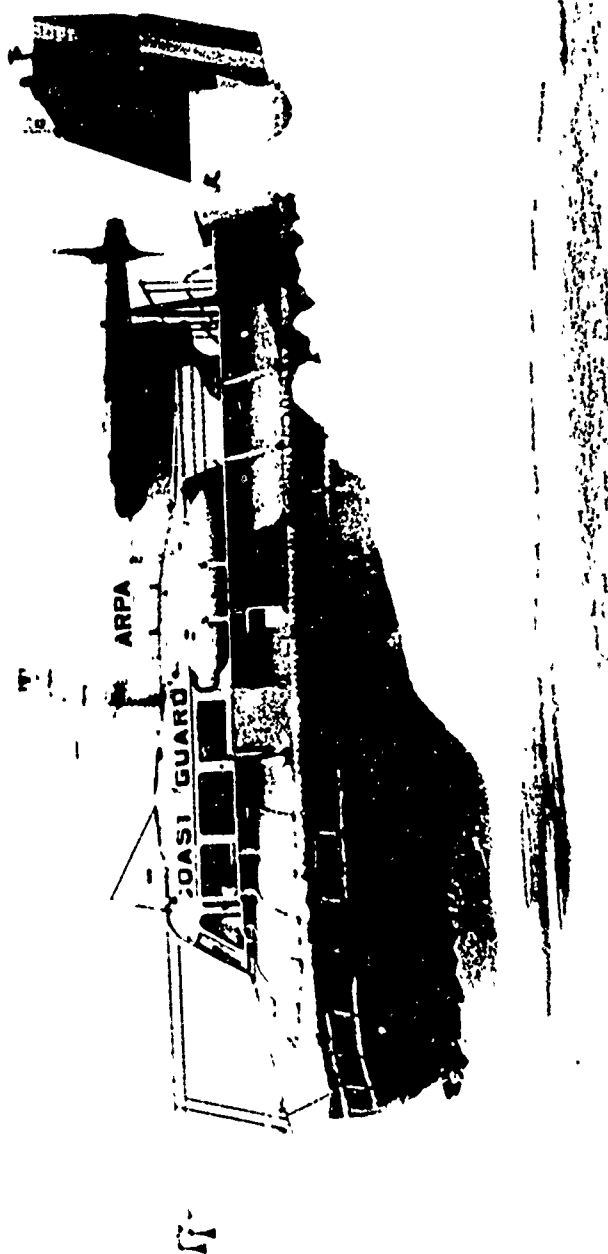
Figure 6. SK-5 During ARPA/USCG Point Barrow Trials (Bell Aerospace Company Photograph)
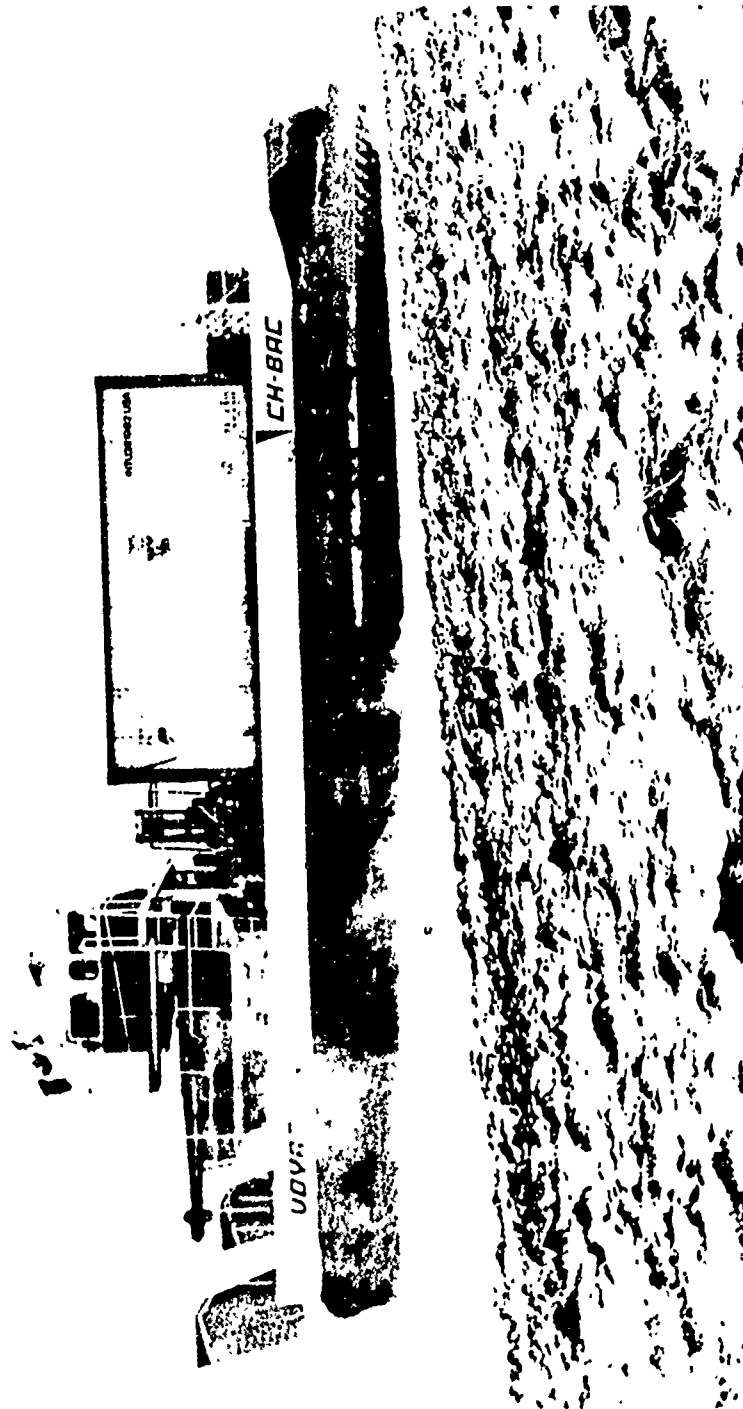
Figure 7. Voyageur During Overland Trials at Grand Bend, Ontario (Bell Aerospace Company Photograph)
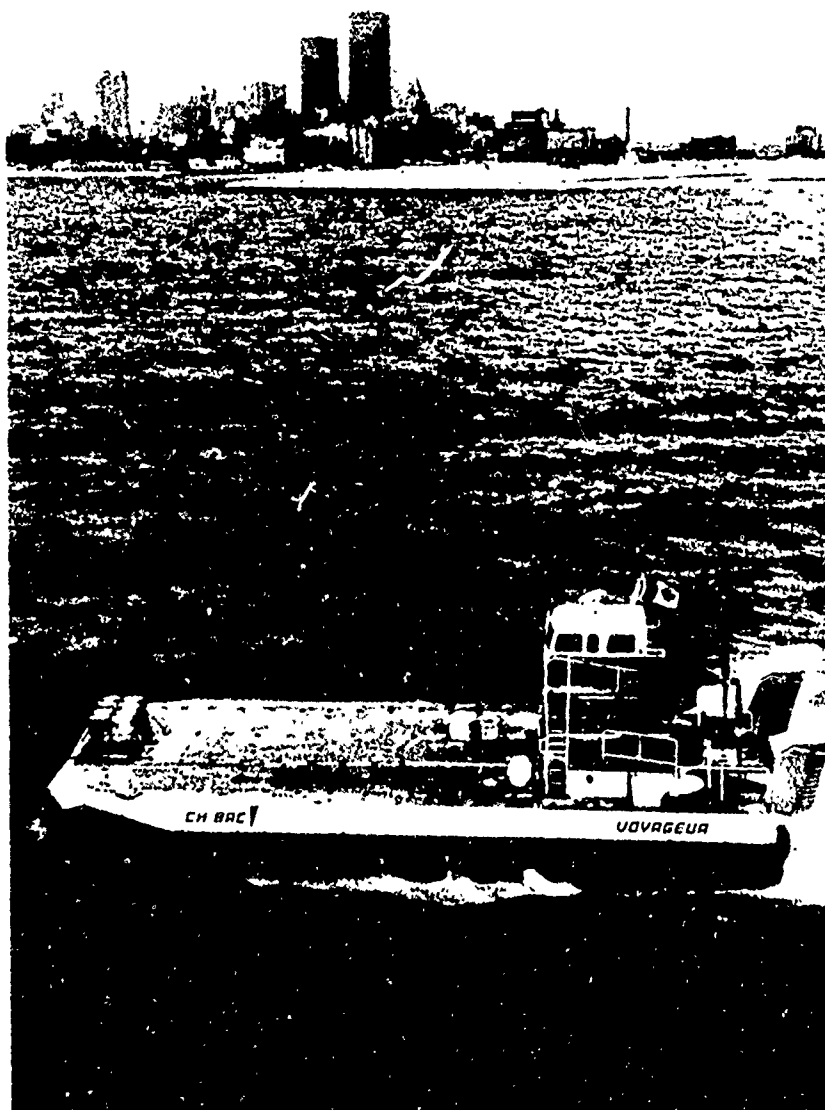
Figure 6. Voyageur During Shore Ice/Overwater Trials at
Toronto, Canada (Bell Aerospace Company Photograph
Taken After Symposium)

modified Lake Amphibian (Figure 9). Such a system has the virtues
of an air cushion vehicle in the sense that it can make an airplane
amphibious. The obstacle clearance is directly related to the
size of the airplane and therefore to the depth of the cushion.
This is a branch of air cushion technology that must not be over-
looked for use in the Arctic.

Tests in the Arctic have yet to be conducted, but tests have
been run in winter conditions in Buffalo, N.Y. Crosswind landings
are no problem as the aircraft does not have to be lined up
parallel to its direction of travel to land, but can crab through-
out the landing rolls. With the Lake test aircraft, measurements
of airplane performance were made before installation of the air
cushion landing system in order to permit direct comparisons.
The performance on water was found to be better with the air
cushion gear than with the original boat hull. Maneuverability
on water, even with this single-propeller airplane, is better
than with a boat hull. Braking pads have been developed so that
braking distance on solid surfaces is as good or better than
with the original wheel system.

The next step in air cushion landing gear hardware is now
underway and consists of a joint project between the U.S. Air
Force and the Canadian government. It involves fitting an air
cushion landing system to a C-115 de Havilland Buffalo.

In summary, the goal of moving cargo and people by air from
a northern terminal to a base is already attained, and should
soon be significantly improved with the introduction of the air
cushion landing system. Also, moving workshops and replenishing
supplies using high-speed amphibious surface transportation within
the base camp and satellite system is (in prototype terms) 1
month away from fulfillment with the coming roll-out of Voyageur
No. 001. At that time, the air cushion technology will be offering
real, useful hardware for the arctic community.
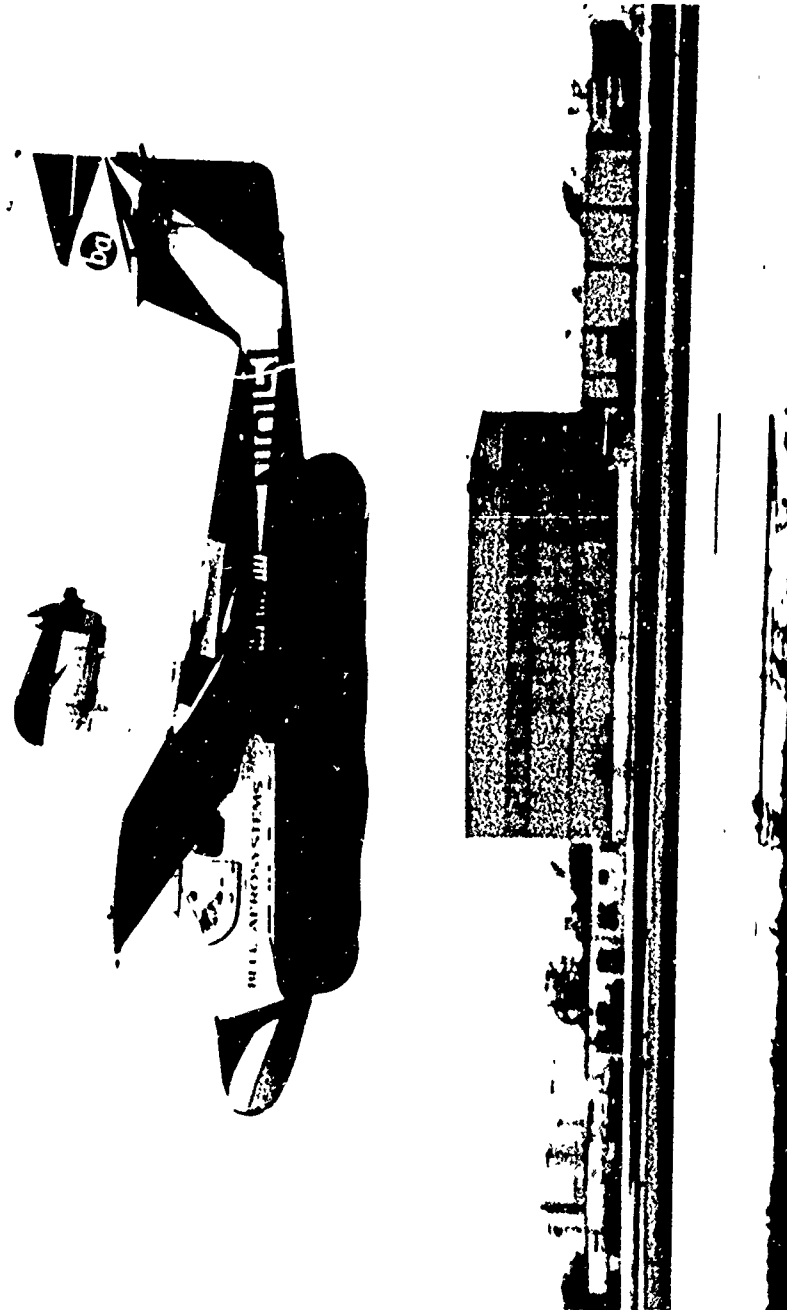
Figure 9. Air Cushion Landing System on Lake Amphibian (Bell Aerospace - Company Photograph)

ARCTIC PACK ICE TRANSPORTATION VEHICLES

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Earlier this year a group of scientists met at the University of Washington and discussed transportation problems they had encountered during their arctic research. Several experienced scientists expressed disappointment at the lack of an efficient, reliable, and low-cost surface transportation vehicle that could be used on the arctic pack ice. The impetus for this paper resulted from these informal discussions. The paper reviews the transportation needs of scientists working on the arctic pack ice, establishes vehicle specifications consistent with these needs and the requirements imposed by the arctic environment, describes vehicles currently available and presents a conceptual design of a new pack ice transportation vehicle.

For traveling long distances over the pack ice, air transportation by either helicopter or light aircraft is necessary. For relatively short distances from a base camp, however, setting up, maintaining, and removing remote stations can well be handled by a surface transportation vehicle. Considering this need for a surface transportation vehicle and the enormous expenditures in the development of military vehicles, it seems incongruous that the dog sled remains the most reliable means of surface transportation. To a large extent the "ski-doo" has supplanted the dog sled. These vehicles, however, although very versatile cannot begin to fill the requirements of payload capacity, towing ability, and amphibious characteristics that arctic scientists require in a surface transportation vehicle.

The reason military vehicles have not successfully filled the need for reliable pack ice transportation vehicles stems from their design concept. Generally, these are high-performance vehicles designed to outmaneuver, outdistance, and outshoot an enemy. These qualities are purchased at a high price in initial dollar and maintenance costs on the complex components of the vehicle.

The budget for most scientific research projects can afford neither of these costs. The arctic scientist needs the capability to travel out onto the pack ice and return reliably in absolute safety and at a reasonable cost. Unfortunately, there is currently no surface transportation vehicle which fulfills all of the requirements necessary to support research work on the arctic pack ice. Therefore, the author feels it would be wise to consider carefully the specifications outlined in this report, and to proceed with the design and construction of prototype vehicles which can meet these performance requirements.

GENERAL SPECIFICATIONS

The mission envisioned for an arctic pack ice transportation vehicle would primarily be in establishing remote scientific stations. Often, scientific observations must be made simultaneously at several locations. The vehicle would carry scientists and equipment out from a base camp onto the pack ice where they could establish, maintain, resupply, and dismantle the observation stations. The use of surface transportation would mean that no pilot or expensive aircraft would be needed. The vehicle could also perform these functions when visibility would not permit aircraft to take off.

The University of Washington is preparing experiments in which an unmanned submarine will be used to gather data under the pack ice. At least three stations are needed for tracking the submarine during the experiments. A reliable surface transportation vehicle would prove invaluable in establishing these stations and in providing rescue to the submarine should it become disabled while under the pack ice.

For carrying out a scientific mission, the vehicle need not possess excessive speed capability. High speed, in fact, might even prove detrimental. One major problem with some vehicles used in pack ice transportation is the failure of the suspension system. This indicates that these vehicles are unable to withstand the loads imposed by their own speed potential. A speed of 5 mph should be sufficient for traversing the difficult pack ice terrain. For a level dirt road, the vehicle should be able to maintain a speed of 15 mph.

In providing transportation to remote stations, the vehicle may be required to carry a party of four people and some gear. The vehicle should be of sufficient size and power to carry a 1,000-pound payload. In addition, the vehicle should be able to pull a sled with another 1,000 pounds of gear.

The use of surface transportation on the pack ice is only feasible over short distances, say 10 to 20 miles from the base camp. Beyond these distances aircraft are considered essential. Time then becomes important as well as the ability of men and machines to function after the rough treatment that must be expected when traveling on the ice surface. Therefore, a range capability of 100 miles should be sufficient in a pack ice transportation vehicle.

In order for this vehicle to carry out its mission, it must operate in severe weather and surmount or avoid the physical obstacles to be expected when traversing the pack ice. These requirements are included in Appendix A.

The final general specifications to be considered are reliability, safety, and cost. The vehicle must be absolutely reliable and require a minimum amount of maintenance. This implies that all parts are ruggedly constructed from materials that can withstand the cold.

Simplicity of design is essential in this respect. Reliability and safety are closely related because of the danger involved if the vehicle should become stranded far from base camp. In addition, safety involves several other points. The vehicle must be stable (will not roll over) in all of its designed operating modes, including transition from water to land operations. Backup survival systems must be provided so that in case of failure of the vehicle the crew would be able to survive until assistance arrived. The vehicle must also be equipped with the latest navigation and communication equipment.

For cost comparison the vehicle should not exceed the cost of a well-equipped jeep; that is, between $4,000 and $5,000. Of course, costs for prototype models may be higher. Any arctic transportation vehicle should be easily transported by existing aircraft, including Boeing 737, C-130, Bristol Freighter, and de Havilland Caribou.

MILITARY VEHICLES

The military is constantly testing and supporting the development of high-mobility combat vehicles. Extensive reports of these tests are available in which are printed long lists of the vehicles tested. Unfortunately, many of these vehicles are one-of-a-kind or are no longer produced. The author has chosen a few vehicles which satisfy some of the requirements outlined previously. The list is by no means exhaustive, and possibly some vehicles have escaped attention during the course of this study. A listing of the specifications for each military vehicle considered in this section is presented in Appendix B.

M29C Weasel (1,3,5,9,13)

The M29 is the only tracked military vehicle ever designed exclusively for snow operation. Developed during World War II, it was to be used in a planned winter invasion of Norway. Although the invasion never took place, 24,000 vehicles were built. The M29 is the standard version and the M29C is an amphibious version.

Almost 30 years after their construction, the Weasels which remain in operation have become ancient vehicles. The Weasel, however, continued to be the standard by which subsequent vehicles have been judged.

Several mechanical problems have been reported by those who have used Weasels, particularly with the track, bogey wheels, and suspension system. The life expectancy of some components is as follows(13):

Tracks: 800 to 1,500 miles; 300 miles in Antarctica(8)

Bogey wheels, sprockets, idlers: 500 miles

Transmission: 200 to 500 miles

Motor overhaul: 1,000 to 1,500 miles

Hull failure from fatigue cracks: 3,000 miles.

Considering the advances of today's technology, one would expect that these deficiencies could be eliminated in a redesigned version of the Weasel.

In addition to the mechanical problems, amphibious qualities are also lacking. Several vehicles have been sunk, mostly during attempts to climb onto a floe from refrozen leads. The vehicle slides backward and fills with water. Fortunately, in most instances passengers have been able to escape through hatches previously cut in the roof.

The cost of operating Weasels at the Naval Arctic Research Laboratory has been calculated as $4.00 per mile. This compares with the cost of $1.00 per mile for operating a jeep.(1)

M116 Husky Amphibious Cargo Carrier

The M116 is of some interest because it was designed as a successor to the Weasel. Its design appears to be an improvement; however, it is unable to climb over a vertical face at the edge of a lead. In addition, the cost is very high--$65,000.(3)

Canadair Rat(5,9,11,12)

The Canadair Rat was designed for the Canadian army. It is a light-tracked vehicle intended to carry a load and tow infantry sleds and toboggans over snow, ice, and barren wastes. The vehicle is built in two tracked units. The forward unit contains the engine and driver while the rear unit carries passengers and cargo. The use of two units permits employment of articulated steering which increases mobility under extreme muskeg or snow conditions.

The Rat does not possess the ability to climb out of the water over a vertical bank. It also does not have an enclosed cabin to shelter passengers.

It has come to my attention that a few changes have been made in the original configuration of the Rat. The specifications given here are for the original version. The new version is somewhat larger and improves on the weak points in the Rat's design. (New version is XM571 DYNATRAC, with an approximate prototype cost of $125,000).(3)

If one scrutinizes the specifications for these military vehicles, it should be clear that they are complex machines. They are expensive to purchase and maintain. Although all these vehicles are amphibious, none of them--nor any others seen by the author--would be capable of climbing out of the water over a 2-foot vertical edge.

In seeking an acceptable vehicle, then, the only alternative is
to turn to those vehicles being produced commercially.

COMMERCIAL VEHICLES

Commercial vehicles capable of traveling on the polar ice pack
come in a wide variety of shapes and sizes. They range from small
toylike recreation vehicles to large, heavy-duty oversnow transporters.

One of the smallest, yet most widely used, commercial vehicles
is the ski-doo. To a large extent, they have replaced the Eskimo
dog team. Their low price makes them quite attractive. By the time they
reach the point where they can no longer be repaired, they usually
have paid for themselves.

Several drawbacks are seen to using this vehicle in support of
the scientific missions contemplated here. First, they have no
amphibious qualities. When open water is encountered, it is neces-
sary to wait until it refreezes or attempt to circumvent it. Second,
the ski-doo provides no shelter to passengers or for overnight
accommodation. Of course, the payload capacity is much smaller
than required. And third, the arrangement of their power system precludes
efficient towing. They are high-speed, low-torque machines.

Another danger with ski-doos is being stranded without proper
preparation. Their high speed enables them to travel long distances
in a very short time. Unfortunately, many inexperienced people have
not realized that in case of a breakdown there would be no way of
retracing their path. Consequently they do not carry adequate survival
gear, with sometimes fatal consequences.

The ski-doo has earned its place in arctic transportation. It
is excellent for use around base camp and also for scientific missions
in connection with helicopter transportation to a remote station.
However, it cannot fill the specifications enumerated here.

The next larger size transportation vehicle is the all-terrain
vehicle. These have become quite popular as recreation vehicles and
are manufactured by many small companies. These vehicles generally
would have to be classed as "toys." An average size would be about
7 feet long and 4 feet wide, with a weight of 500 pounds and a
payload capacity of 500 pounds.

Size alone indicates that these vehicles are incapable of
satisfying the specifications. This does not mean that they are
useless, because their concept is sound. Mechanically they are quite
simple, and many of the ideas incorporated in their design could
be useful if properly adapted in building a larger vehicle that
could fill the specifications. Even though most of these vehicles
have been on the market for only a short time, they have stimulated
positive evolutionary steps in their own design and particularly in
the components used in construction.

Specifications for the largest and most substantial all-terrain vehicle the author has encountered are listed in Appendix C.

Arctic transportation vehicles close to the size necessary to meet the specifications outlined are built by several companies. These vehicles find their primary use at ski resorts and by utility companies in the mountain states. The companies contacted are listed below, along with some of the vehicles they manufacture. Specifications for these vehicles are also listed in Appendix C.

Bombardier Ltd.

Bombardier manufactures an extensive line of snow vehicles including the ski-doo. The one vehicle that could possibly suit the specifications would be a modified version of the Muskeg Tractor. The modifications necessary would include building up a watertight hull and cabin on the basic tractor. Even with these modifications, the vehicle floats very low in the water and certainly would not be able to climb out of the water over a 2-foot ledge. In addition, the Muskeg Tractor is quite heavy and wide, making air transportation both expensive and difficult in some of the smaller freight aircraft.

Flextrac Nodwell

Flextrac Nodwell produces a number of vehicles designed for snow or muskeg. There is only one model which meets some of the stated specifications. This vehicle would not be capable of climbing out of the water over a 2-foot ledge. The author would consider this an extremely dangerous vehicle during transition from water to pack ice because it only has a 6-inch freeboard in the rear.

Foremost Tracked Vehicles Ltd.

Vehicles manufactured by Foremost range in size from close to the 1,000-pound payload specified here up to extremely heavy-duty transporters. The vehicle closest to meeting the requirements for arctic research is called the Sure Go. Although the standard version is not amphibious, it can be modified with a "floating capability." The form of this conversion is not completely clear from the company literature. However, when similar conversions were reviewed on other vehicles, they were found to result in inadequate amphibious qualities and in the loss of any possibility of climbing over a 2-foot obstacle at the edge of a lead. In addition, the cost of this vehicle would probably run about three times the goal specified in this report.

Thiokol Chemical Corporation, Logan Division

There are several series of snow and swamp vehicles currently produced by Thiokol. The Model 604 appears to be the most suitable for the requirements of arctic transportation. Although it is amphibious, there would be no possibility of this vehicle's having the capability of climbing out of the water over a 2-foot ledge. In addition, several modifications such as the construction of a cab would be necessary for cold weather operations.

Tucker Sno-Cat Corporation

There are many different models of the basic Tucker Sno-Cat. These are the only snow vehicles which are totally different from all the rest. They ride on four tracks set on pontoons and use articulated steering to increase mobility. These vehicles have been used quite successfully in Antarctica. Unfortunately, they are not amphibious and have poor off-snow performance. Because of these limitations, none of these vehicles could be considered adequate for pack ice transportation.

OTHER FORMS OF TRANSPORTATION

Alternate forms of arctic transportation include light aircraft, helicopters, surface effect vehicles, and boats.

Boats, of course, can be used only during periods of open water. In the near-shore and river area, the open water period is of sufficient duration to make the use of boats worthwhile. For pack ice vehicles they are too limited and are not considered further.

The alternate to surface transportation is air transportation. The most widely used form of air transportation is the light plane. With very few roads available, the airplane is an essential part of northern transportation. The major problems in using light aircraft in pack ice research are cost and landing difficulties. To get an estimate of the cost, the author checked the charter rates in the Seattle area. A Cessna 180 (four-place) with pilot can be chartered for about $40 per hour. In the Arctic the price would be at least double this.

The second drawback that would be encountered in using light aircraft for short-range excursions is landing. Finding a suitable site on the pack ice is not always easy and may be dangerous. Envision the hypothetical mission of setting up a station at some coordinate location 10 miles from base camp. At best, a suitable landing site might be found at the coordinate location. At worst, the aircraft might have to land several miles away and the equipment would then have to be brought to the site on foot. In the latter case the speed and convenience advantages of the airplane would be completely lost.

The helicopter does not suffer from the landing problem encountered with light aircraft; however, it is quite a bit more expensive. Present Seattle area charter rates for a Bell E3B are $130 per hour, while a larger five-place model is about $200 per hour. One scientist has stated that charter rates of $280 per hour for a 2-man helicopter and $1,100 for a "sky crane" were quoted 2 years ago near Prudhoe Bay, Alaska. In the past, American scientists have not used helicopters at their ice stations. When used, helicopters have usually flown from supporting icebreakers.

Surface effect vehicles are currently undergoing extensive arctic testing. Almost everyone agrees that these are expensive vehicles (both initial and operating expenses). They also have encountered difficulty in climbing some pressure ridges, finding themselves sitting stranded on the top. Currently scientists are awaiting the detailed results of arctic trials.

There is no question that aircraft offer the best means of pack ice transportation when long distances are considered. Although they are quite capable of satisfying short-range transportation needs as well, their high costs would not be justified if some less expensive and reliable surface transportation vehicle were available.

A NEW ARCTIC TRANSPORTATION VEHICLE

The inadequacies of currently available surface pack ice transportation led the author to propose the basic concept for a new vehicle. A large engineering and construction effort is required to complete such a vehicle, but this would be well justified if a simple, reliable, low-cost arctic transportation vehicle resulted from the undertaking.

A schematic of a possible arctic transportation vehicle is shown in Figure 1. One of the most notable exterior features is the use of low-pressure "terra" tires rather than tracks. While there is little doubt that well-designed tracks provide superior mobility under the most difficult conditions, the simplicity of the wheeled system is also a great advantage. As previously mentioned, one of the most severe drawbacks of existing vehicles is the maintenance problem in the track and suspension system.

The tires envisioned for use on the arctic transportation vehicle (ATV) would be roughly 26 inches in diameter and have a tread width of 12 inches (a standard size terra tire). The tires would be mounted on fixed axles, eliminating a spring suspension system. This is possible because of the relatively slow speed of the vehicle and the "natural" suspension of this type of tire.

The terra tire should provide sufficient mobility for use on the pack ice. Normally the snow is wind-blown and has a very hard crust. Drifts may be encountered in the lee of pressure ridges and may cause some problems for a wheeled vehicle. Further study needs to be carried out on the surface strength of the snow in the pack ice region. In addition, it is important to examine the low temperature qualities of the terra tires, particularly the elastic qualities necessary for the suspension of the arctic transportation vehicle.

The terra tires contribute to the ATV's amphibious qualities as well. They provide a significant proportion of the vehicle's displacement and add to transverse stability. Without some additional device, however, the tires alone would not be capable of lifting the vehicle over a 2-foot difference in surface elevation between the ice and water.
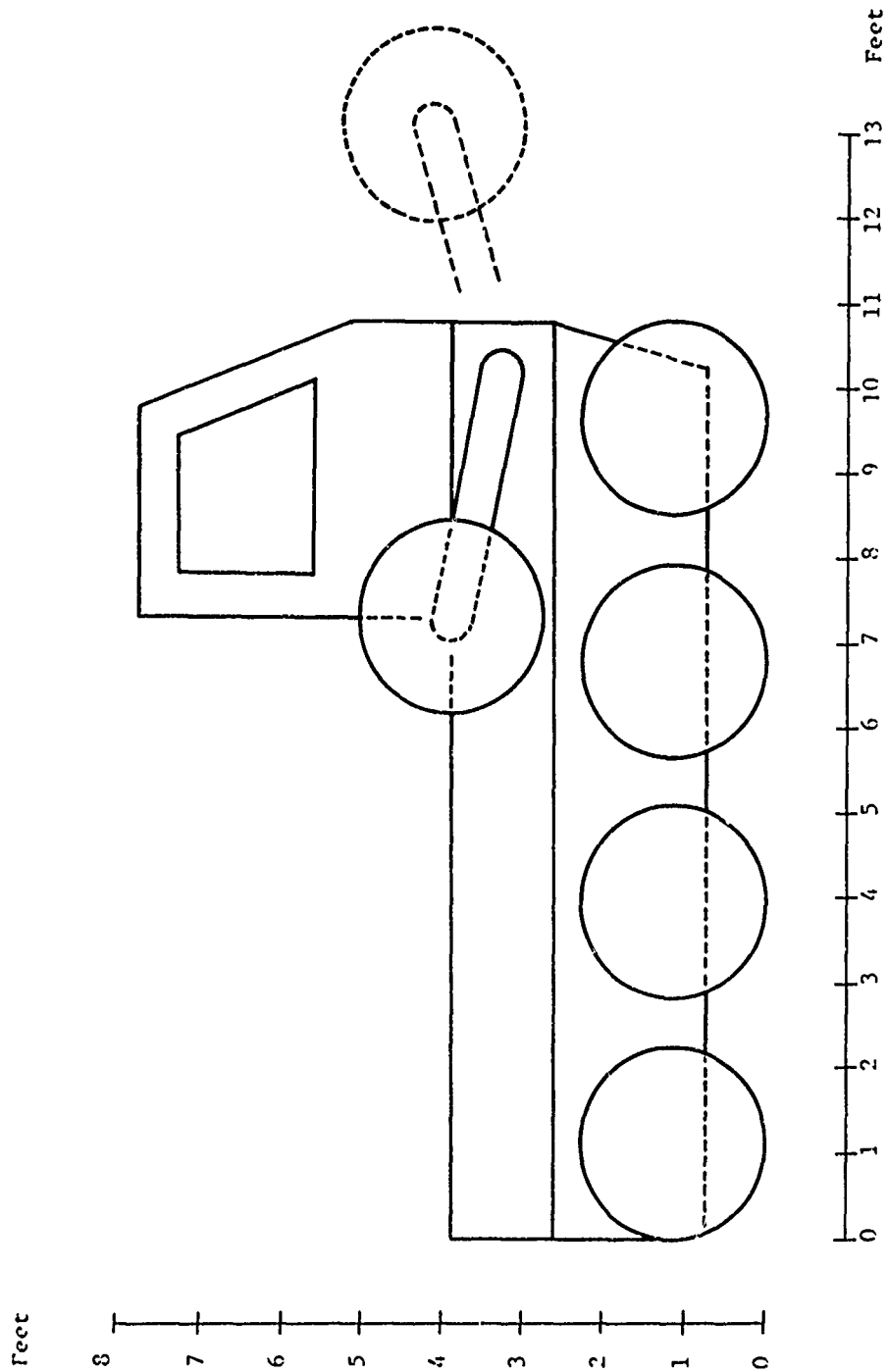
Figure 1. A Possible Arctic Transportation Vehicle

To give the ATV the required climbing ability, a set of arms could be mounted near the front of the vehicle. The arms would swing in a large circle reaching out in front of the vehicle to make contact with the ice. As the arms continued on their arc they would lift the vehicle up and then pull it forward setting the wheels down on the ice. There are two possible ways of giving the arms traction. The simplest method is to mount some form of spiked pads on the arm which would grip the ice to prevent the vehicle from slipping back into the water. A somewhat more complicated, but perhaps more useful, idea is to add a driven wheel on the end of the arm. This would require a chain drive inside the arm that would complicate the mechanism somewhat.

Traction is also an important consideration in climbing ability. It would not be difficult to supply sufficient horsepower to drive the vehicle up a 45° slope. Again the climbing arm could come in handy. A spiked driven wheel on the arm could assist in pulling the vehicle up the slope. The vehicle could also be pulled up the slope in steps as the climbing arm made several revolutions. An additional means of increasing traction would be by using a studded tire or by putting on some form of chains.

For propulsion, an engine of less than 50 horsepower should be sufficient. It should be of rugged construction with an electrical battery-starting system. Preheating could be accomplished by using a blow torch, and a backup pull starter should be furnished. The most promising engine is a 4-cycle gasoline engine. It has the startability and efficient RPM range needed.

The transmission should have at least three forward gear ratios and one reverse gear. The first gear would be mainly for towing and low-speed operation. The third gear would be for high-speed operation, with the second gear between the others. Manual shifting has not proven very successful and should be avoided even at the cost of adding some weight.

Additional propulsion, beyond spinning the wheels, is necessary for water operation. This should provide the forward thrust for the vehicle and its steering as well. One possibility is mounting an outboard motor on the stern. Another idea is to use a water jet pump. Both of these devices have the problem of water freezing if it collects and cools inside them. A final possibility is to make the spiked wheel on the climbing arm into an efficient paddle wheel. The arm could be locked into a preset position and the vehicle pulled along by the paddle wheels.

The hull for the vehicle should be made of aluminum. Watertight seals will be required on all the axles, with the water being below the top of the wheels. The more freeboard the better, provided the center of gravity can be kept low and reasonably easy access can be maintained for entering the vehicle. Some form of spray deflector will be required forward and aft. In Figure 1, the vehicle appears

in the "pickup truck" configuration. Some form of covering, such as a snap-on fiberglass or insulated "tent," should be considered for the rear of the vehicle. This would provide space for more passengers, and a sleeping and cooking area for extended operations.

Flotation and the crew's confidence in the vehicle's flotation ability are very important considerations. If sufficient void space is available (depending on vehicle weight), flotation material should be added to make this vehicle unsinkable, even if filled with water. In addition, the flotation material should be placed so that the vehicle would maintain positive stability under all conditions.

Some further equipment that should be on the vehicle include navigation and communications devices, a towing bar, and a winch for pulling itself out should it become stranded. Other things to be considered when building this vehicle include cabin heating, the possibility of increasing the ground clearance above the 9 inches shown in Figure 1, and several others. All these details will be worked out as the design engineering progresses.

CONCLUSION

The author believes there is a definite need for the moderate performance pack ice transportation vehicle discussed in this report. In order that the vehicle's performance is matched to the requirements imposed by the arctic environment, more data should be gathered. Efforts aimed at developing large area topographic maps of the pack ice would prove extremely valuable. On such maps hypothetical journeys could be attempted given a set of vehicle specifications. The trade-offs between climbing ability, amphibious qualities, speed made good, and cost could be investigated by considering these hypothetical journeys.

In addition to the topographic features, many samples of the surface qualities should also be gathered. This would provide a basis for selecting vehicle ground pressure and mobility index requirements.

While these data are being gathered, it would also be wise to try out some of the existing vehicles similar to the one proposed here. A test of one or two of the better all-terrain vehicles would indicate whether a wheeled vehicle has sufficient mobility to negotiate the severe obstacles. If reasonably successful, these tests would also clearly demonstrate modifications that would be required in this type of vehicle to better adapt it to arctic conditions.

Following the additional data gathering, refinement of specifications, and preliminary vehicle tests, a test vehicle which meets or exceeds the specifications should be built.

The need for a reliable transportation vehicle with moderate performance over pack ice is immediate for the University of Washington

arctic research program. Many other arctic scientists would also
benefit from the availability of this vehicle. The author recommends
that we proceed with all possible haste in undertaking the necessary
steps for the development of such an arctic transportation vehicle.

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APPENDIX A

SPECIFICATIONS FOR ATV

Speed   Five miles per hour over pack ice terrain and 15
                miles per hour on a level dirt road.

Payload: Up to 1,000 pounds on the vehicle. Room for four
                passengers and equipment.

Pulling: A sled with up to 1,000 pounds.

Range: 100 miles.

Amphibious: Must be capable of crossing leads and melt ponds,
                and entering or climbing out of the water with a
                2-foot elevation difference between pack ice and
                water surfaces. The vehicle must be stable at all
                times during transition and in the water.

Climbing: The vehicle should be capable of climbing up a 6-
                foot 45° slope from a dead start at the base.
                The vehicle should also be capable of climbing a
                2-foot vertical obstacle on land.

Startability: The vehicle must be capable of starting and of
                continuous operation at -60°F.

Transportability: The vehicle should be able to fit on a Boeing 737
                for travel from Seattle to Barrow, Alaska. There,
                it will be put on a C-130, Bristol Freighter, or
                de Havilland Caribou, and it must fit in any of
                these without being dismantled.

APPENDIX B

MILITARY VEHICLE SPECIFICATIONS

M29C Weasel (5)   Description: General-purpose, full-tracked,
                  amphibious tractor used for personnel and light
                  freight carrying, and for sled hauling.

                  Manufacturer: Studebaker.

                  Size: length: 192 inches.
                         width: 67 inches.
                         height: 71 inches (with ordnance canopy).

                  Weight: vehicle: 4,800 pounds (heavier with built-on
                                     cabin).
                           payload: 1,200 pounds.

Engine: Studebaker Champion 6-cylinder, 65 horsepower.

Transmission: 3 and 1 gearbox, and 2 axle ratios.

Freeboard at gross weight: 10-1/2 inch bow, 8-inch stern.

Track: Steel track plates with flexible connectors and endless rubber bands. Vehicle weight carried on 32 bogey wheels.

Track width: 20 inches.

Ground clearance: 11 inches.

Turning radius: 12 feet.

Maximum allowable speed: 36 mph.

Fuel capacity: 35 gallons.

Fuel consumption: 5 mpg; 3 mpg in Antarctic.(8)

Ground pressure: 1.9 psi (unloaded, without cabin).

Discrepancies between the figures presented in the references indicate that they should be viewed with care and that consideration be given to the conditions at the time the data were taken.

M116 Husky (18)

Description: A low-ground-pressure, full-tracked, amphibious cargo and personnel carrier.

Manufacturer: Pacific Car and Foundry.

Size: length: 185.5 inches.
      width: 85.5 inches.
      height: 80 inches.

Weight: vehicle: 6,800 pounds minimum operable.
         vehicle: 11,000 pounds combat loaded,
                    arcticized with payload.
         payload: 3,000 pounds.

Engine: Chevrolet Model V8-283, Type HD, 160 horsepower.

Transmission: GMC 4-speed automatic, fluid coupling with planetary gearing.

Track: Rubber band with 22 sections.

Track width: 20 inches.

Ground clearance: 14 inches.

Turning radius: 11 feet minimum.

Maximum speed: 37 mph.

Fuel capacity: 63 gallons.

Range: 300 miles maximum on hard surface road.

Ground pressure: 1.9 psi empty.
                  2.6 psi combat loaded.

Canadair Rat (5) Description: Light articulated cargo carrier with
                  drive on 4 tracks.

Manufacturer: Canadair Ltd.

Size: overall length: 157 inches.
       width: 48 inches.
       height: 61 inches to top of windshield.

Weight: vehicle: 1.500 pounds.
         payload: 1,000 pounds.

Engine: Volkswagon, 34 horsepower, air cooled.

Transmission: 4 forward gears, 1 reverse gear.

Track: Reinforced rubber bands with metal cross
        members. Two tracks side by side cover
        the entire width of the vehicle.

Track width: 20.5 inches.

Ground clearance: vehicle is bellyless.

Turning radius: 13 feet.

Maximum speed: 23 mph on improved roads.

Fuel capacity: 23 gallons.

Range: 200 miles (estimated).

Ground pressure: 1 psi loaded.

APPENDIX C

COMMERCIAL VEHICLE SPECIFICATIONS

LTV KID (17)   Description: All-purpose, amphibious, wheeled
                              tractor-transport.

                Manufacturer: Kinetics International Division,
                               LTV Aerospace Corporation.

                Size: length: 96 inches.
                       width: 60 inches.
                       height: 40 inches.

                Weight: vehicle: 2,200 pounds.
                         payload: 1,000 pounds.

                Engine: Wisconsin V414D air-cooled gasoline, 30
                         horsepower (diesel engine optional).

                Transmission: Vickers hydrostatic right angle.

                Tires: 8 tires, 2 or 4 plys, 23x8.50-12.

                Tracks: can be mounted over the four wheels on each
                         side.

                Ground clearance: less than 11 inches.

                Maximum speed: 25 mph.

                Fuel capacity: 10 gallons.

                Range: 100 miles.

                Ground pressure: 5.16 psi.

Bombardier   Description: General-purpose, full-tracked vehicle
Muskeg Tractor   for passenger and freight hauling.
(14)
                Size: length: 140 inches.
                       width: 87 inches.
                       height: 79 inches.

                Weight: vehicle: 6,400 pounds.
                         payload: 6,000 pounds.

                Engine: Chrysler V-8 Industrial 318 L.A., 180
                         horsepower.

                Transmission: New Process Model 435, 4 forward
                               gears, one reverse gear.

Track: reinforced rubber belts with spring steel
         crosslinks.

Track width: 28 inches.

Ground clearance: 14 inches.

Maximum speed: 25 mph.

Fuel capacity: 18.75 gallons.

Ground pressure: 1.2 psi (unloaded).

**Flextrac
Nodwell FN10
(15)**

Description: full-tracked, amphibious personnel
               and cargo carrier.

Size: length: 127 inches.
        width: 85.5 inches (with 25-inch tracks).
        height: 80 inches.

Weight: vehicle: 3,550 pounds.
          payload: 1,000 pounds.

Engine: Ford 104 CID, V-4 gasoline, 65 horsepower.

Transmission: 3 forward gears, 1 reverse gear.

Track: rubber belts and channel grousers.

Track width: 25 inches (wider snow track version
               available).

Turning radius: 138 inches.

Ground clearance: 13 inches.

Maximum speed: 22 mph.

Ground pressure: 1.0 psi (unloaded).

Freeboards: unloaded: 6.5 in front, 18 in rear.
              loaded: 10 in front, 6 in rear.

**Foremost Sure
Go(15)**

Description: full-tracked cargo and personnel carrier.

Manufacturer: Foremost Tracked Vehicles Ltd.

Size: length: 128 inches.
        width: 84 inches.
        height: 80 inches.

Weight: vehicle: 3,975 pounds.
          payload: 1,200 pounds.

Engine: Ford V4, 104 CID (standard).

Transmission: hydrostatic.

Tracks: rubber belts and channel grousers.

Track width: 24 inches.

Turning radius: spot turn.

Ground clearance: 14 inches.

Maximum speed: 16 mph.

Ground pressure: 0.9 psi (loaded).

Freeboard: "floating capability" optional.

Thiokol   Description: full-tracked, amphibious cargo and
Model 004(19)   personnel carrier.

Size: length: 160 to 180.5 inches.
       width: 97.25 inches
       height: 62.5 inches (without cab).

Weight: vehicle: 5,540 pounds (approximately).
         payload: 2,600 pounds

Engine: Ford 6-cylinder, 240 CID, 150 horsepower.

Transmission: 4 forward gears, 1 reverse gear.

Track: reinforced rubber belt with steel grousers.

Track width: 32 inches.

Ground clearance: 13.5 inches.

Turning radius: 15 feet.

Maximum speed: 37 mph.

Fuel capacity: 21 gallons (45 gallons optional).

Fuel consumption: 5 to 8 mpg.

Ground pressure: 0.87 psi (unloaded).

ICE AND TRANSPORT IN ARCTIC CANADA

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First, I will define the term "Arctic Canada." It could be
defined as that area of Canada north of the Arctic Circle. This would
not be consistent, however, with Canada's political boundaries,
noting that the provincial areas extend to 60° North, with our
territories to the North. My discussions will thus deal with Arctic
Canada as that part of Canada to the north of 60°, with one exception:
The Hudson Bay shipping route to and from Churchill through Hudson
Bay and Hudson Strait is generally referred to as Arctic Shipping,
so I wish to include this in Arctic Canada.

I lived for 4-1/2 years in the Yukon Territory, where as
meteorologist in charge of our district forecast office I had an
early introduction to the problems of transport in Arctic Canada.
In February 1947, a temperature of -81°F at Snag established an all-
time record for the North American continent. At Whitehorse, where
I was stationed, the official airport temperature fell to only
-62°F. Since we were aware of the potential the weather situation
offered to produce record low temperatures, we had set up a Stevenson
screen at our residence in the downtown area (in a valley about 200
feet below the level of the airport) for the purpose of comparing
temperatures with airport readings. As a young and eager meteorologist
in those days, I dashed out that morning to read the thermometer--
still in pajamas--noted the temperature was -63.5°F, and hustled back
into the house for some hot coffee.

That 1947 cold wave lasted about 12 days in the Yukon and all
but strangled transportation to and from the community. Immediately
prior to the cold wave, a snow slide in the mountains had severed
our rail link with Skagway, Alaska. In an attempt to open the railway,
three locomotives were deployed with a snowplow, but in the extreme
cold the steam locomotives could not generate sufficient heads of
steam to clear the track. These efforts had to be abandoned until
temperatures moderated.

Truck transport on the Alaska Highway ground to a halt. At
those temperatures tires froze, springs became brittle, and gas line
freezing and carburetor icing developed. The penalties in the event
of breakdown on the highway were too severe to risk movement. That
left air transport. The airlines did not risk operations with temper-
atures colder than -55°F. Attempts were made to plan arrivals of one
or two aircraft at times of maximum temperatures for the day. Getting
the aircraft back out was another problem. Normally after the take
off of one aircraft, the entire valley filled with ice fog and that

terminated airline operations for a period of 8 to 12 hours. The net
result was that food stuffs quickly vanished from store shelves,
the stock of fuel oil in the town was exhausted, and the cold
precluded wood cutting in the bush. Fortunately, the cold wave ended
in the nick of time.

That was 1947 and this is 1971. Technologies have changed.
Diesel locomotives can operate where the steam locomotive was inef-
fective. We now have jets instead of piston aircraft, but we still
have ice fog. We have seen improvements in motor transport, too, so
possibly today a similar cold wave would not be so serious.

In this connection, our climatologists tell me that many areas
in the Arctic are prone to temperature extremes of this magnitude.
So if you are going to work or live in Arctic Canada, you should be
prepared for periodic spells of extreme cold. My subject, however,
is somewhat broader, since it includes ice.

In 1957, the Meteorological Branch of the Department of Transport
was given responsibility for the development and operation of an ice
program in Canada. Why the Meteorlogical Branch? And how does an ice
program relate to meteorology or atmospheric science? Well, ice is
an interface between the atmosphere and bodies of water. Granted,
formation, movement, and dissipation of ice are governed in part by
atmospheric conditions, but ocean currents, water temperatures, and
tides have strong influences. Obviously, the expertise required for
an ice program could be achieved by training meteorologists in
oceanography or by training oceanographers in meteorology.

The decision to give the responsibility to the Meteorological
Branch was based on the fact that we had a large number of meteorolo-
gists engaged in operational work with expertise in handling large
volumes of data on a real-time basis, while the oceanographers in
Canada were smaller in numbers and engaged mainly in research. Further,
we had extensive communication networks on which we could transmit
ice information. Accordingly, in 1957 we began aerial ice recon-
naissance flights in Arctic Canada, and in 1958 we established an
Ice Central as a processing, forecasting, and advisory center to meet
Canada's needs for ice information.

With the growth of requirements for service and with government
reorganization, the Meteorological Branch of the Department of Transport
became the Canadian Meteorological Service in the Ministry of Transport.
This status was short lived since, in the next breath, the Government
of Canada established a new department known as the Department of
the Environment. The new department includes five services: forestry
and wildlife, water management, fisheries, environmental protection
service, and the atmospheric environment service. The latter includes
the responsibilities formerly discharged by the Canadian Meteorological
Service, including ice, plus some additional responsibilities with
regard to air quality.

Accompanying the departmental reorganization, it is inevitable
that organizational changes must take place within the Canadian

Meteorological Service components. A number of changes are planned but, pending formal government approval, I am not able to provide specific details. Accordingly, I will confine my comments to our organization for the ice program. Perhaps I should explain first that I assumed the responsibility for ice in July of this year when I was appointed to the position of Superintendent, Water and Ice.

First of all, for an ice program, as for any other scientific program, one requires a data acquisition system. We maintain a network of observational posts for shore ice observations and ice thickness measuring stations. This program is organized on a regional basis, by using our weather observers where possible and by arranging private contracts at other locations.

We have had two Douglas DC-4 aircraft under long-term charter for the past 5 years. To each of these, we assign a field ice supervisor and three ice observers. The two DC-4's have been unable to meet requirements, so from time to time supplemental aircraft have been required. This past summer, our supplemental aircraft was a DC-3 to which we assigned one field ice supervisor and two ice observers. In addition, one ice observer is assigned to each Canadian Coast Guard icebreaker working in arctic waters, except that two ice observers are assigned to Canada's two largest icebreakers, the *John A. MacDonald* and *Louis S. St. Laurent*, since for the most part these two ships work 24 hours per day.

The ice observers assigned to icebreakers take ice observations from the ship; proceed on helicopter surveys as required from the icebreaker within a radius of about 25 miles (that is, within sight of the ship); brief the Captain on ice conditions based on these observations; and provide an interpretation of ice information received from Ice Central to the Captain to assist him in decision making with respect to snip routing. The ice observer also takes weather observations on a synoptic basis.

The ice observers assigned to the aircraft take ice observations from the airborne platforms. The aircraft are equipped with precision navigation equipment since this is a most important aspect of the entire program. The aerial observations are used to direct shipping along routes which offer the easiest access through ice-congested waters. Errors in navigational accuracy could result in directing ships in the wrong direction, possibly into impassable ice conditions. The aircraft are equipped with ground mapping radar to assist in navigational accuracy and to determine positions of significant ice edges and other ice features. With these aids, ice observations are mainly visual Our ice observers are highly trained and gain experience by rotating through the aerial platform positions aboard the icebreakers. By participating in helicopter surveys, they become experienced in interpreting ice features, age of ice, etc., from shades of color and configurations of the ice floes.

The aircraft are equipped with airborne facsimile transmitters to broadcast ice observations directly to ships as tactical support. This is a frequent requirement in support of our icebreaker fleet when they are working through ice-congested waters. The procedure is for an aircraft to survey the area within 100 miles or so of the ship, map the ice on a real-time basis, and broadcast data in chart form directly to the ship. The ship's Captain then has a basis for decision with respect to routing of the ship for the next 12 to 15 hours. Such broadcasts are received by our icebreakers and by commercial vessels equipped to receive the broadcasts.

As agreed upon with WMO, Canada's aerial ice reconnaissance program ranges from the west coast of Greenland, across the Arctic, the nort' coast of Alaska, and occasionally out as far as 170° West. The normal pattern has been to base one DC-4 at Frobisher on Baffin Island for coverage of the eastern Arctic, the Hudson Bay shipping route, and southern Baffin Bay. The other DC-4 is based at Resolute and covers the High Arctic. The DC-3 is based at Inuvik and ranges westward along the northern Alaska coast where it maps the ice edge in the Beaufort Sea.

Ice observers also participate in northern patrols which are flown on a periodic basis by the Department of National Defence These are long-range flights from which much valuable supplemental ice information is obtained.

Ice Central, tne forecasting and advisory center for ice conditions, is staffed at present with an officer-in-charge, four meteorologists, and four technicians. First established in Halifax for coordination with the Royal Canadian Navy, it is now being moved to Ottawa. The Canadian Coast Guard's fleet of icebreakers is directed from the Marine Operations Centre in Ottawa and, in addition, there are numerous other Government Departments and agencies in Ottawa which have responsibilities with respect to ice-sensitive activities. The move of Ice Central to Ottawa will permit more effective support to many agencies involved with ice problems.

Ice Central receives and processes all available ice observations. Some sources are: shore station reports, ice thickness measurements, and aerial ice reconnaissance (our own); shipboard observations (including helicopter sorties); polar continental shelf aerial reports; U.S. Navy reports; Danish Meteorological Service reports (Cape Farewell area); reports from northern patrols; satellite data; meteorological information and forecasts; and oceanographic information. Based on these inputs, Ice Central produces analyses of daily ice conditions during the shipping season; daily forecasts of ice conditions; 30-day forecasts (twice a month); seasonal outlooks; summaries of ice conditions experienced during each season; advisories and consultations; and climatological records.

Data processing in Ice Central begins with present conditions. If current observations are not available for all areas, then the

meteorologist estimates the ice conditions using the latest available ice observations and considering meteorological and oceanographic conditions. In making predictions of ice conditions, numerous factors are considered; for example, mean winds, mean temperatures, accummulated melting and freezing degree days, storm tracks, ice dynamics, consideration of ice drift, pressure features, and changes in concentration that result from dynamically induced motion in pack ice. Tide tables are consulted for key areas such as restricted passages and harbors.

Analyses and short-term forecasts of ice conditions are broadcast by facsimile from Halifax and, during arctic shipping, from Frobisher and Edmonton. Special advisories are sent by message directly to icebreakers or other agencies. Long-range forecasts and seasonal outlooks are distributed by mail.

The seasonal outlook for the Arctic is prepared by using information on ice conditions at freeze-up in the fall. Locations of tough multiyear ice in the fall help identify possible troublesome areas the following season. In this connection, one of the DC-4's is now in the Arctic to acquire this information. Shore reports and ice thickness measurements are available during the winter. In the spring, the DC-4 aircraft are deployed on round-robin flights which operate near the middle of April, again in May, and in June (Figure 1). In consideration of attempts to open the navigation season earlier each year, these flights may have to be scheduled at earlier dates. With the present program limited to visual sightings, however, operations are now restricted to hours of daylight. The 30-day forecasts issued by the Northern Weather Service are to prepare these outlooks for the early part of the period, with climatological normals being used thereafter.

Improvements in accuracy of meteorological forecasts and particularly extended-range forecasts would impact directly on our ability to predict ice conditions. We have recently carried out studies to determine the feasibility of real-time computer applications in handling ice data in Ice Central procedures. A number of applications have been identified; however, extensive subjective considerations must be used in ice forecasting procedures. As we see it, extensive computer applications in this area must await developments.

In the Ice Climatology Unit, on the other hand, we plan machine processing methods from the outset. Progress is being made in the development of an ice atlas for the Eastern Seaboard and Hudson Bay. Based on 10 years of data, the essential information has been abstracted on a grid system for each 1° of longitude and 1/2° latitude. More than one-third of these data are now on punch cards. We hope to complete the punch cards and proceed with computer programming in the near future. The system we have developed lends itself to the use of a finer grid--to a tenth degree latitude and longitude. This is considered necessary to exploit to the fullest the deluge of data that will become available with remote sensing technology in this decade. The development of an ice atlas for the Arctic is a project

to which we attach high priority and intend to proceed with as quickly as possible.

At our present program level, about 60 percent of activity is devoted to Arctic Canada, and the remainder, in season, to the Great Lakes, the St. Lawrence Seaway, and the Gulf of St. Lawrence.

Figure 2 shows the main shipping routes in Arctic Canada. Shipping down the Mackenzie River and thence east and west along the north coast is shallow draft, consisting mostly of barges propelled by tugs. This activity is supported by the Icebreaker Camsell, based in Victoria, that travels northward each season through the Bering Sea and via shore leads along the northern Alaskan coast. The Camsell installs channel-marking buoys and other navigational aids in the early summer, assists shipping as required, and retrieves the navigational aids each fall. There is some shipping northward from Moosonee in James Bay while other ships are guided around the Baffin Bay ice pack to resupply the northern communities in the eastern Arctic or to find their way into the Northwest Passage.

It is interesting to note how shipping patterns have changed through the past decade. Not long ago, the resupply of northern communities was accomplished by icebreakers carrying provisions on an annual visit. With the growth in the North, this has become inadequate. The next phase of operations saw icebreakers proceeding north, each followed by a convoy of two or three ships. By this year (1971), the pattern had changed to more random shipping. With the availability of ice observations, ice forecasts, and advice from Marine Operations' ice information offices, ships proceeded on their own, requesting icebreaker support as required.

Each year, too, shipping interests are challenging Mother Nature by starting earlier and finishing later. For example, the ship *Cheslie A. Crosbie*, escorted by icebreaker *Norman McLeod Rodgers*, departed Quebec on June 29 for Hudson Strait and Douglas Harbour. Severe winter ice was encountered in Hudson Strait, with pressures so great that both ship and icebreaker were halted completely at times. By July 14, however, they were through the heavy ice and approaching Douglas Harbour. The Marine Administration points to this as further evidence that ships can operate in severe ice conditions if they are properly handled and make full use of the ice services available for the support of shipping in ice-congested waters.

In addition to extending the season of operation, shipping interests are expanding their scope as well. Each year new destinations are added to the Arctic Sealift while hydrographic and seismic surveys pursue new frontiers. For example, an article in the October 4, 1971 issue of *Oilweek* concerned new records established by the ships *Theron* and *Theta* while undertaking seismic surveys in the Arctic. The *Theron* moved northward along the west coast of Ellesmere Island through Eureka Sound, Greely Fiord, and Tanquary Fiord to within 590.5 statute miles of the North Pole. Another recent news item reported a new record in shipment of grain from Churchill to world markets in 1971.
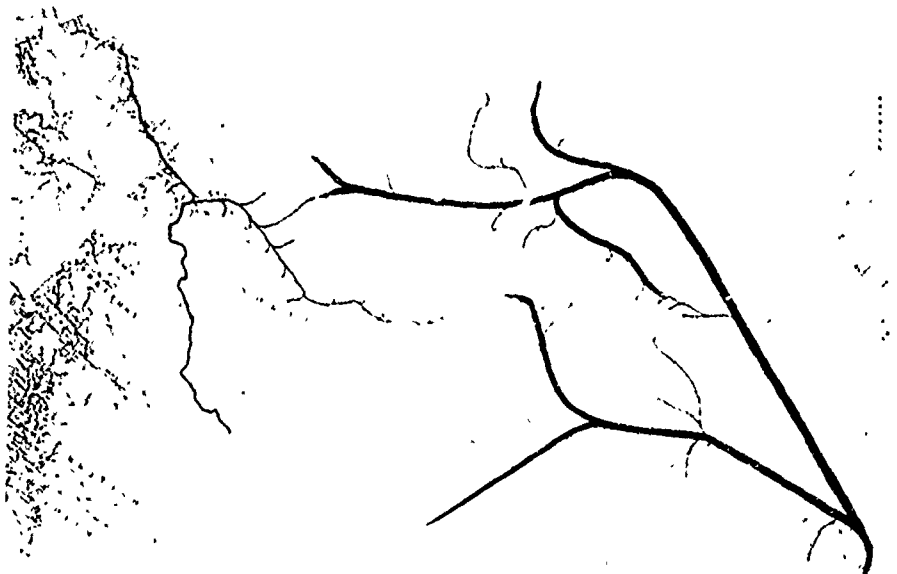
Figure 1. Round Robin Trip (May 17-24, 1971)

Figure 2. Shipping Routes in Arctic Canada

So far, I have been speaking mainly in terms of a sealift to Arctic Canada for supplying the northern communities and for supporting exploration in those areas. This seems to be reasonably under control. Transporting resources out of the Arctic, however, becomes quite another problem. Considering the millions of dollars being expended to locate arctic resources, I find it hard to believe that so many people can be wrong. Rich iron ore is known to exist in northern Baffin Land, while the oil strike at Prudhoe Bay on the northern Alaskan coast and the gas wells on King Christian Island are further evidence of arctic resources. Almost any day now, we will be faced with the problem of transporting these resources to world markets.

For a number of years investigations have been conducted to determine the feasibility of transporting iron ore by supercarriers out of northern Baffin Land. Harbour facilities present no problem, and markets are available. The economic key is the problem of ice and insurance rates for the operation. Correspondingly, Humble Oil has invested substantial sums of money in feasibility studies for the use of supertankers for the transport of oil through arctic ice. Most recently, the voyage of the supercarrier *Manhattan* through the Northwest Passage was well publicized. Interestingly, the *Manhattan* failed to traverse M'Clure Strait, with rerouting through Prince of Wales Strait and thence along the north Coast of Alaska to Prudhoe Bay and Point Barrow. Also, the *Manhattan* had to anchor about 18 miles off the Alaskan coast in order to remain in water of adequate depth.

The *Manhattan* was supported by the Canadian Coast Guard icebreaker *Sir John A. MacDonald* on this sortie. The *U.S. Northwind* began the voyage but had mechanical difficulties and was later replaced by the *Staten Island*. Our DC-4 ice reconnaissance aircraft provided support throughout the Arctic, while visual observations were supplemented by a laser profilometer and a panoramic 70mm camera. The DC-4 dropped film and recorded ice data to the *Manhattan*. The U.S. Coast Guard assisted with ice reconnaissance for the *Manhattan* using an aircraft equipped with side-looking radar.

It should be remembered that the *Manhattan* trial was not an ordinary attempt to traverse the Northwest Passage. The *Manhattan* was not seeking to avoid ice for an easy trip--she was looking for ice, all kinds of ice including tough ice, to test her reaction to it. Press reports were perhaps controversial regarding the success of the *Manhattan* but it should be noted that the *Manhattan* made another trip north the next year to test flat ice that was not found on the first trip. This was found in Pond Inlet, after which Humble Oil was apparently satisfied that they had all the information they required. To my way of thinking, that indicates success.

Recently, the *U.S. Northwind*, on a trip to an ice island in the Arctic Ocean, encountered mechanical difficulty. The icebreaker *John A. MacDonald*, supported by our DC-4 ice reconnaissance aircraft, proceeded to assist along a route that was well within the permanent arctic pack ice. This summer, Canada's largest icebreaker, the *Louis St. Laurent*, while involved with research studies including an ice drift study in the Robeson Channel, sortied north of Alert, the continent's

northernmost weather station and proceeded almost to 83° North. This is the farthest north ever for a Canadian vessel. I am told that the vessel was in no difficulty and could have proceeded farther north, but the weather deteriorated and little would have been gained by proceeding. There was, of course, the ever-present danger of the development of pressure in the ice which could trap even a powerful icebreaker.

On the subject of pressure in ice, Figure 3 is a photograph taken on the Plaisted expedition, which staged northward from Eureka to Ward Hunt Island and thence to the North Pole in April 1968 using snowmobiles. The significant feature is the ice ridge in the background which was estimated to be nearly 80 feet high at that time.

Such ridges present formidable obstacles to surface transport vehicles such as snowmobiles and hovercraft. Granted, ridges do not persist to such extreme heights unless the water is sufficiently shallow that they rest on the ocean floor. Considering the elasticity of the ice surface, the ridges subside and eventually, due to periodic melting and surface erosion, may practically disappear but may then leave a keel or inverted ridge below the surface. This sort of keel can persist for a long time and presents a serious obstacle to ships or may interfere with the passage of a submarine.

Some brief comments will now be presented on the work that is going on in Canada on remote sensing as applied to observing ice features.

Low Light Television System

We find that this system provides a good real-time image on an oscilloscope display from which open water, thin ice, and thick ice can be identified. The field of view, however, provides only a very narrow swath of coverage. Furthermore, the rotating beacon on top of the aircraft seriously interferes with the image. Operations under conditions of bright light or total darkness is not possible. Since sensors such as infrared scanners are available to provide comparable or better data under more variable conditions, we doubt that the low light television system will ever become a prime remote-sensing tool in ice reconnaissance.

Infrared Scanners

We have tested a number of systems in our ice reconnaissance program, the most successful being the one we used this summer in the high Arctic. This year, we had a real-time display aboard the aircraft, and the imagery was immediately useful in identifying ice features in addition to providing a taped record for later study.

Although the systems are of little value over cloud cover, and the swath of coverage is narrow (swath width is three times the aircraft height), they offer night capability, good resolution, and thermal data on ice cover. During winter freeze periods when air
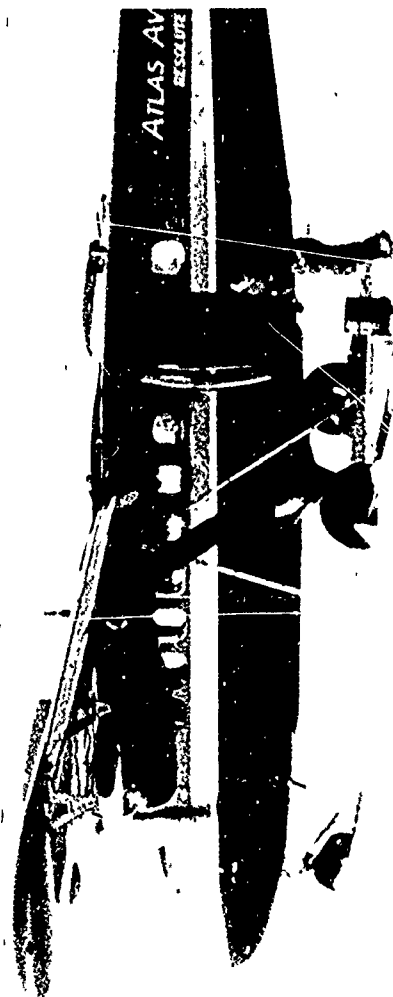
Figure 3. Aircraft on Ice with Pressure Ridge in Background (Photograph Curtesy of Mr. W. N. Bowes, Atmospheric Environment Service, Canada)

temperatures are very cold, surface temperatures of sea ice vary with ice thickness so that pressure ridges and heavy multiyear ice appear very cold and thinner ice layers are progressively warmer. The thermal imagery, therefore, provides an indication of the relative thickness of the ice floes, even if the surface is evenly covered with snow. Cracks in the ice show as hot lines while ridges appear as cold bands, except that fresh ridges show as hot lines while still wet.

The approach of the melt season can be identified with the start of "image reversal." The old ice will have lost much of its salinity and, near the melt stage, the almost salt-free surface will be close to 32°F and hence warmer than the sea water.

Laser Profilometer

This is another sensor we have been using on the DC-4 in the high Arctic. Although the laser provides only a linear trace, it is extremely accurate in recording heights of individual ridges and the frequency of their occurrence. Estimates of thickness of old ice floes or ice islands can also be made by measuring the height of an ice surface above open water. We have found the laser to be a valuable supplement to our visual program and, when used in conjunction with other remote sensors, its indication of roughness characteristics can clarify ambiguities in interpretation.

Side-Looking Radar (SLAR)

Among currently available remote sensing tools, side-looking radar appears likely to become the most useful sensor for improving and expanding the ice reconnaissance program. Primary advantages are its ability to operate effectively under nearly all weather conditions, day or night, and the large area of data coverage which is recorded on a relatively small amount of hard copy. Systems are available with ranges up to 100 km on each side of the aircraft.

We have studied two sets of side-looking radar data. One was from a test project over the St. Lawrence Seaway and the Gulf of St. Lawrence. and the other was the output from a U.S. Coast Guard flight over waters in the Northwest Passage in support of the *Manhattan* trials. We have been impressed with the detail that is available with these systems wherein it is possible to distinguish between large weathered multiyear ice floes, second-year floes, and unruptured portions of first-year ice. Ship tracks and man-made structures are generally very prominent.

Hycon Camera

The panoramic camera has proved its usefulness mainly by providing a permanent record for study in support of special projects. Our aircraft are equipped with darkroom facilities for immediate processing of film and at times unprocessed film is dropped aboard ship for processing.

Satellites

A discussion of remote sensing technologies would hardly be complete without some comment on the use of earth satellites. Briefly, the output from APT (Automatic Picture Transmission camera on U.S. meteorological satellites) is useful in identifying ice edges when visible. However, resolution is not sufficient at present to identify the detail of ice features we require. The minimum brightness mosaics received from the United States are also useful in determining ice edges.

We will be very interested in the output from the next generation of satellites--those with higher resolution. As I understand it, however, the high resolution satellites will view a narrower swath with more limited frequency. For ice observations, we require a frequency of about three times weekly. So, in spite of our interest in satellite programs, we envisage a need for airborne platforms for the remainder of this decade to meet our real-time needs. Additional data from satellites will be extremely useful for statistical studies and research.

In addition to our work with remote sensing devices, we continue to test various navigational systems in arctic areas. This past summer we tested an inertial navigation system aboard our DC-4 in the eastern Arctic. Although we did not have a facility for enroute updating of this system, the results were impressive. In our DC-3 in the western Arctic, we tested an Omega system. As is well known, radio reception has always been erratic in some arctic areas. We found that signals from Hawaii were reliably received, but signals from Norway and New York State were erratic and not dependable in many areas. We think the system has tremendous potential if the signal strength can be increased to provide reliable reception.

Statistical counts of newly calved icebergs are made as part of our ice reconnaissance program. Such icebergs may look magnificent, but they pose an ever-present menace to shipping, to offshore drilling activities, and to pipe lines and underwater cables, since these beasts at times gouge the continental shelf as they drift with the ocean currents.

The foregoing completes, in a broad way, a survey of our ice program activities in Canada. Note that I have not said much about research and that is simply because our resources have been committed primarily to our real-time program. We have provided support to numerous research programs by providing observations and assistance in the acquisition of data through the use of remote sensing devices. For example, this past summer we used a Hycon camera, a laser, and an infrared scanner in the acquisition of data over the Truelove Lowlands of Devon Island in support of an international biological program there. We have been involved in "applied" studies but have not been active in pure or basic research related to ice.

In conclusion, I would like to examine the challenge that faces us for the remainder of this decade. We already have an increasing need for ice observations at night, and our present inability to take observations through fog or low cloud is at times embarrassing since ships want to keep moving regardless of weather. The need for a remote sensing program becomes more apparent every day. To be added to this is the potential need for supercarriers to operate in the Arctic, possibly year-round through the long summer days or the long winter nights. Other requirements for ice information include building pipe lines and harbor facilities in ice-congested waters; laying communication cables; guiding submarines beneath the ice surface; etc.

In considering the fascination of the Arctic, the tourist attraction of the North, and a potential transportation system using SEVs, hovercraft, or large snowmobiles, our challenge becomes multi-fold:

1. Improve our remote sensing capability (that is, laser, infrared, side-looking radar, etc.).

2. Develop an operational facility for the measurement of ice thickness to locate the keels and hummocks which hinder the passage of ships.

3. Develop an expertise in interpretation of remote sensing imagery.

4. Develop systems to analyze and utilize the torrent of data that will become available.

How will we handle the vast quantity of data? We have choices. We can, for example, have a highly trained staff aboard the aircraft to interpret and analyze data, and then advise ships, or by relaying the raw data in real-time to the ships where trained personnel will undertake their own interpretation. Perhaps ice reconnaissance aircraft of the future should be computer equipped and programmed to receive and analyze the output from all the sensors, and then relay to ships their best track through the arctic ice along with an indication of the ice characteristics--in essence, what they need to know.

The potential of satellites must be kept in r nd. High-resolution satellites with frequent coverage and real-time or ut may soon replace airborne platforms for ice reconnaissance.

TWO REMOTE ARCTIC MEASURING SYSTEM CONCEPTS UNDER DEVELOPMENT

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At Delco Electronics-Santa Barbara, two automatic remote data collection systems are being developed for early use in the Arctic Ocean. These systems have been dubbed RAMS (Remote Arctic Measuring Station) and LAMS (Localized Arctic Measuring Station). RAMS is funded by ARPA and administered by the Arctic Branch of the Office of Naval Research. LAMS is a Delco Electronics effort. The purpose of both systems is to extend the limited data collection capabilities of manned station operation on the arctic ice pack. Early versions of both systems will be installed for system tests and data collection between November 1971 and March 1972. The advantages of these systems are·

- Adaptability to a wide variety of input sensors.

- Early availability.

- Use of existing facilities for deployment and monitoring.

- Low cost.

- Application of current technology adapted for the arctic environment.

BACKGROUND

All who have worked in the Arctic Ocean have experienced the frustrations, danger, high cost, and seasonal and geographic limitations of manned station operation. An obvious, yet almost completely neglected solution(1), is remote telemetry stations, with data being collected by shore, aircraft, ice, and satellite stations. The Russians have not neglected this area. Since the early 1950s, they have successfully employed hundreds of remote beacons and Drifting Automatic Radio-Meteorological Stations (DARMS) in the Arctic(2).

Since most U.S. arctic work is supported by the Naval Arctic Research Laboratory at Barrow, Alaska, the capabilities of that facility have constrained design considerations of the remote stations. These capabilities include:

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1. Light aircraft able to carry about 400 lb of usable cargo within a radius of around 250 miles from Barrow or several other refueling bases on the Alaskan and Canadian coasts. They can land safely on skis on the pack ice from late February through May.

2. R-4D twin-engine aircraft with wheels that can land on the pack within about 600 to 700 nautical miles from a refueling base during March and April. These aircraft, however, have seldom been used for landings on the pack ice without test landings by the light aircraft. Overflights of about 700 miles can be made at any time of the year.

3. Year-round support facilities for a data collection station plus direct capabilities for antenna erection, power, etc. Ample supplies of fuels (for example, propane, diesel oil, gasoline, and kerosene).

4. Common building materials plus machine and carpenter shops for the construction of simple housing.

5. Telephone and regular mail service for data retransmittal.

6. Ownership of abandoned DEW Line stations along the Alaskan coast.

7. Availability of Ice Island T-3, now about 1,000 miles north of Barrow, as an installed advanced base and as a receiving station for data collection.

U.S. Coast Guard icebreakers based at Barrow usually operate in the marginal ice zone between July and September and can be used for implanting remote stations during these months. The two helicopters carried by these ships can deliver about 300 lb of cargo up to 25 miles from the ship. Tubes, antennas, etc., up to 12 feet in length can be carried in these aircraft.

While the above does not represent the total U.S. capability for the deployment and monitoring of remote stations in the Arctic, they were major considerations for the development and tests for RAMS and LAMS since they are existing and available. Development costs can thus be minimized through their use.

In both systems, data are collected at manned stations via direct radio telemetry. RAMS uses a transmitter in the high-frequency band, with data being received by shore stations. The first version employs a timer to send data periodically. LAMS employs a VHF command radio for triggering data transfer to an aircraft via a low-power MF link. Both are high-capacity data systems and feature the same type of recirculating digital memory for data storage and retrieval.

DESCRIPTION OF RAMS

Selection of Propagation Mode

Because of the limited deployment seasons, available shore monitoring sites, ice movements, and costs, a target range of 100 nautical miles and a life of 1 year were decided on for developmental goals. These set constraints on power supplies and available propagation modes for the radio telemetry. DARMS uses a ground wave propagation at medium frequency and attains a mean range of 300 nautical miles. DARMS has been used mainly to monitor conditions along the Northern Sea Route, so these ranges to shore receivers have been satisfactory. However, MF would not meet the RAMS target range of 1,000 nautical miles. Lower frequencies were ruled out because of power considerations. A relay system was deemed impractical because of ice movement. Satellite retransmittal has the disadvantage of high platform costs, limited data capacity, and the unknowns of long-term satellite availability. Also, no satellite is available for possible uses of the system for military applications, should these be desired. Meteor burst transmission at VHF might be feasible but was temporarily ruled out in favor of HF ground wave and skip propagation techniques which are better known and which better fit development schedules and funding. Further, antenna sizes at HF are reasonable, and long-term arctic experience with them is available (for example, Naval Arctic Research Laboratory communications with ice stations at 6.5 MHz).

The one disadvantage of long-range HF propagation is its susceptibility to Polar Cap Absorptions (PCAs) which can cause complete outage for periods of several days. We believe this problem can be solved with DELTIC (Delay Line Time Compressor) techniques, used for years in sonar signal processing. In this application, the DELTIC takes the form of a digital recirculating memory which, even in modest size and cost, will enable the storage of data for longer periods than the expected link outages; thus, no data will be lost.

Memory

Any sensor that can be converted to a dc voltage or to digital words will be compatible with RAMS. However, the sampling period, resolution, and dynamic range must be commensurate with the memory capacity. The DELTIC accepts multiple-bit words from the sensors during each data period, stores them, and continuously recirculates them at a rate considerably higher than the input rate. After the memory is filled, the oldest input is discarded when each new word is fed in. For example, consider a single sensor interrogated once every hour and converted to a 7-bit word. This allows a resolution of one part in 128, and would require 168 bits of storage per day or 1,176 bits per week (neglecting bits for identification, separation, etc.). Low-power MOS (metallic oxide silicon) dynamic shift register modules with a 1,024-bit capacity are the size of one logic chip and cost only $12.

In the above example, if two memory chips were used (2,048 bits) and if the RAMS transmitted these data once every 6 hours, it would send out all the hourly data that sensor had taken over 12 days. It would take about 20.5 seconds to send these data each 6 hours. Note, then, that the data transmitted are highly redundant and that a DELTIC of minimal size and cost could handle both short- and long-term fades in propagation.

HF Link Analysis

The basic parameters of the HF link were obtained by using an HF propagation prediction service available from the Institute for Telecommunications Sciences of the ESSA Research Laboratory. The program provides a variety of output data which depends on the input parameters that can be provided. The important information available in this program is the reliability of the link as a function of frequency and universal time (Zulu time).

To provide this output, a number of link parameters had to be assumed. Early in the program a power level of 100 watts was selected as being compatible with solid-state hardware and with available power constraints. A vertical antenna was chosen for the transmitter, since an omnidirectional pattern was required because of possible ice pack rotation. A simple half-wave horizontal dipole was chosen for the receiving antenna, since it is economical and can be easily erected. A narrowband Frequency Shift Keying (FSK) modulation was selected because this would conserve bandwidth (allowing room for many stations in a standard voice channel); provide acceptable data rates; and comply with type recommendations of the National Data Buoy Program(3).

Using these data as inputs to the program and selecting typical transmission paths, predictions were obtained for link reliability for the months of December, March, and June. These months were selected because the amount of daylight over the transmission path affects the propagation characteristics and they cover the all-dark, the all-daylight, and the half-daylight/half-dark months.

For a path of 600 nautical miles, the program indicated that the lower frequencies (3 to 3 MHz) are best during December, the middle frequencies (6 to 7 MHz) during March, and somewhat higher frequencies (6 to 12 MHz) during June. A compromise frequency between 6 and 7 MHz was chosen since it provides a good reliability during all seasons; is compatible with an existing "oceanographic data service" frequency in the band; and has a reasonable antenna height (about 40 feet) for a vertical 1/4-wave. A path of 600 nautical miles will be used for the first test of the RAMS link starting in late November 1971.

Path lengths less than 300 nautical miles favor lower frequencies, while paths greater than 800 nautical miles favor higher frequencies. If the RAMS station is expected to be in one of those zones for a large portion of its life, two other oceanographic data service frequencies are available. These are in the 4- to 5-MHz and 8- to

9-Mhz bands. The final RAMS station may be capable of operation
at these frequencies and may be switched via an aircraft VHF or
shore HF command link.

Antennas for the transmitting station can be a 1/4-wave Vertical
Ground Plane (VGP), a Directional Discontinuity Ring Radiator (DDRR),
or a Turnstile. These antennas will be tested prior to installation of
the test system, and the most promising one will be used for the
long-term tests in the Arctic. Ice breakup makes it desirable to have
a minimum horizontal profile. For this requirement the DDRR is preferred.
This antenna, however, is somewhat controversial and not much test
data on performance have been published. It is also approximately 3
db less efficient than the other two antennas.

The 1/4-wave VGP and Turnstile antennas have approximately the
same horizontal profile, but the 1/4-wave VGP is 40 feet high. However,
a loss of one or two of the 1/4-wave VGP radials due to ice damage
will not have a large effect on the pattern, but loss of one leg of
the Turnstile will have an appreciable effect on its pattern. All of
the above antennas can be designed to operate on the three bands
through the use of loading coils or matching networks.

Power Supply

Batteries of all available types were considered for the RAMS
power supply, but all were discarded for reasons involving cost,
size, temperature, and installation difficulty in favor of fossil-
fueled generators. Two power supplies utilizing propane, a fuel
readily available at Barrow, were selected for development and
tests. The first is an 8-watt thermoelectric generator, with electric
restart, costing about $800 and requiring one 100-lb propane bottle
per 2-month period. The second is a 3-kilowatt, 4-cycle gasoline
engine-alternator, converted to propane, costing about $350. The
latter supply is normally off and is turned on with an electric
timer at the transmission period. Inside a well-insulated housing and
with a suitable heat exchanger, the generator will provide enough heat
to keep the housing about 0°C.

Figure 1 shows the 1/4-wave vertical antenna atop a small wanigan.
This structure is a short version of the regular NARL prefabricated
8- by 8-foot wanigan. Figure 2 is a smaller structure (5 by 4 by 4
feet) on which is mounted the DDRR antenna. Inside is a 3-kilowatt
engine-alternator that has been cycling for 4 minutes hourly without
failure since September 24, 1971. This is equivalent to about 5-1/2
months of operation at a 4-hour cycle and about 8-1/2 months at a
6-hour cycle. It has been tested for starting in a cold chamber at
-20°C. This engine-alternator is particularly attractive since it will
enable a transmitter power of 10 to 20 times above the TE cell, with
enough surplus to power, for example, a small hydrographic winch or
to charge batteries for sensor heating. As noted before, a further
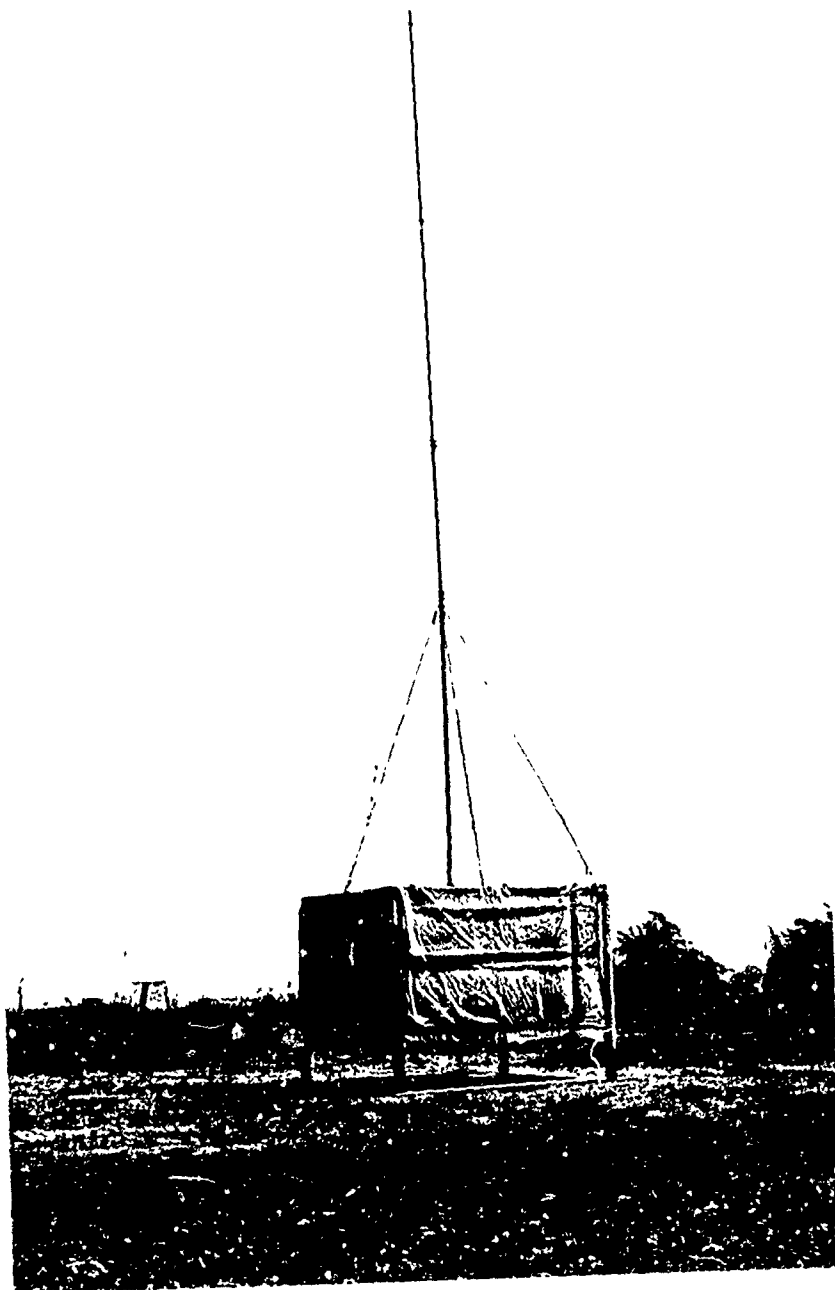advantage is its low cost, less than half that of the TE cell.

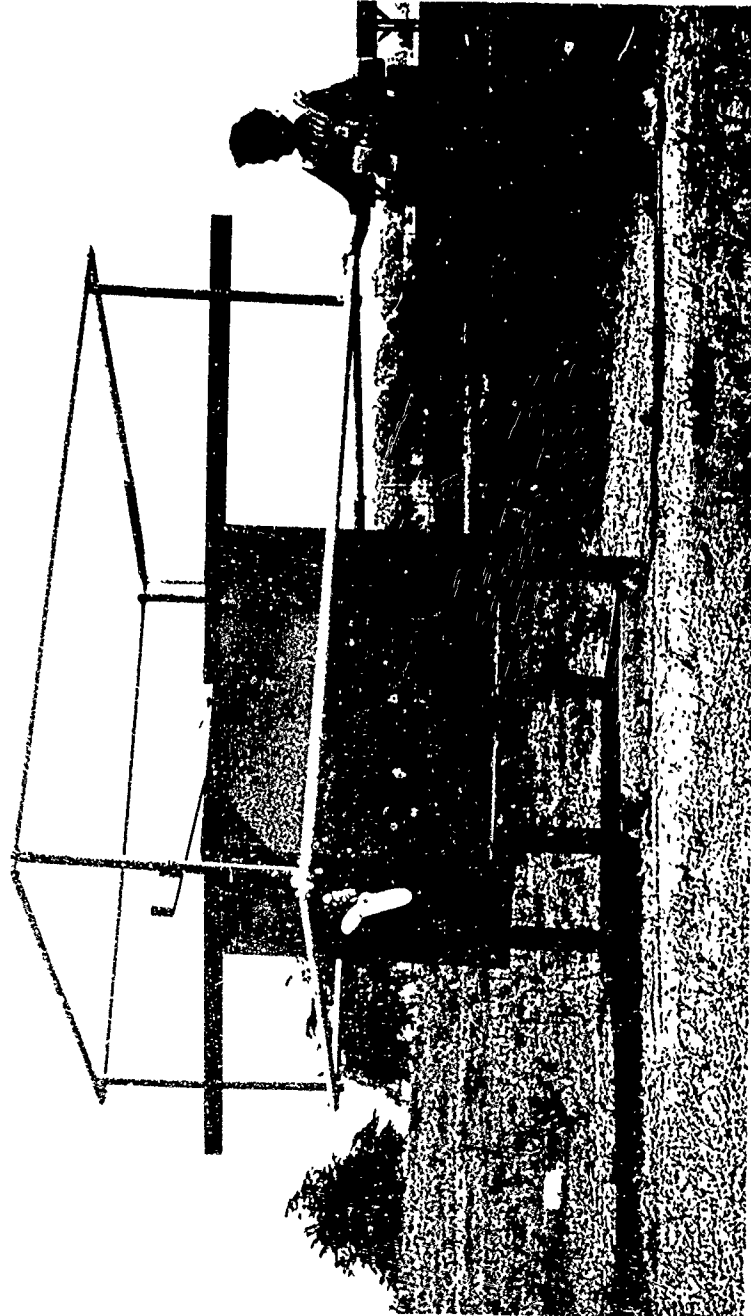Figure 1. 1/4-wave Vertical Ground Plane Antenna
Atop Wanigan

Figure 2. Directional Discontinuity Ring Radiator
Antenna Atop Hanigan

The first RAMS station, including power supply and radio transmitter only, is on its way to Barrow for long-term environmental tests. The station will be installed at a DEW Line site (PIN Main) 550 miles over pack ice from Barrow. In case of failure, this site will allow us to return to the site and determine what went wrong. Also, the site will allow us to gather radio propagation data under actual conditions. Depending on the outcome of this test, this RAMS may be available for installation at one of the manned 1972 AIDJEX camps at the end of that experiment for further tests and transmission of usable data.

Navigation

Positioning of the remote stations in the constantly moving ice pack is an important consideration. For most applications, however, extreme accuracy is not necessary. Several schemes are under consideration, including transit satellite and Omega retransmit, underwater acoustics, radio direction finding, and aircraft location using a command-on beacon. The latter two methods are likely to be used in early RAMS stations. The navigation problem will be resolved after the power supply and telemetry portions of the system have been proved.

DESCRIPTION OF LAMS

This is a low-cost, low-average-power remote data collection system intended primarily for extending the capabilities of manned ice camps and icebreakers. Periodic location and data retrieval are by aircraft. The system makes maximum use of existing radio equipment in almost any aircraft.

Each station consists of one or more sensors which are sampled periodically. Inputs are converted to digital words and stored in a DELTIC recirculating memory (Figure 3). Timing is performed by a precision clock oscillator and countdown circuit. Also included is a command receiver tuned to a fixed frequency in the regular AM-VHF aircraft band. All of the above are low-power electronic circuits which are continuously or periodically powered from a low-temperature air cell battery. The remainder of the system is normally not powered and consists of a modulator and 20-watt MF radio transmitter tuned to a fixed frequency in the aircraft ADF (Automatic Direction Finding) band.

When within about 60 nautical miles of a LAMS, the aircraft turns on its VHF radio transmitter tuned to the LAMS command receiver frequency. A preselected tone modulation for a particular LAMS is decoded at the station and power is applied to the MF transmitter. The aircraft requirement for this command function is a small encoder that contains selectable tones (one for each LAMS) that simply plugs into the aircraft's VHF radio mike jack. The modulation tone must be received for at least 5 seconds before the LAMS medium frequency transmitter is powered on. Once on, the aircraft's ADF determines the direction the aircraft must fly to reach the remote station. In
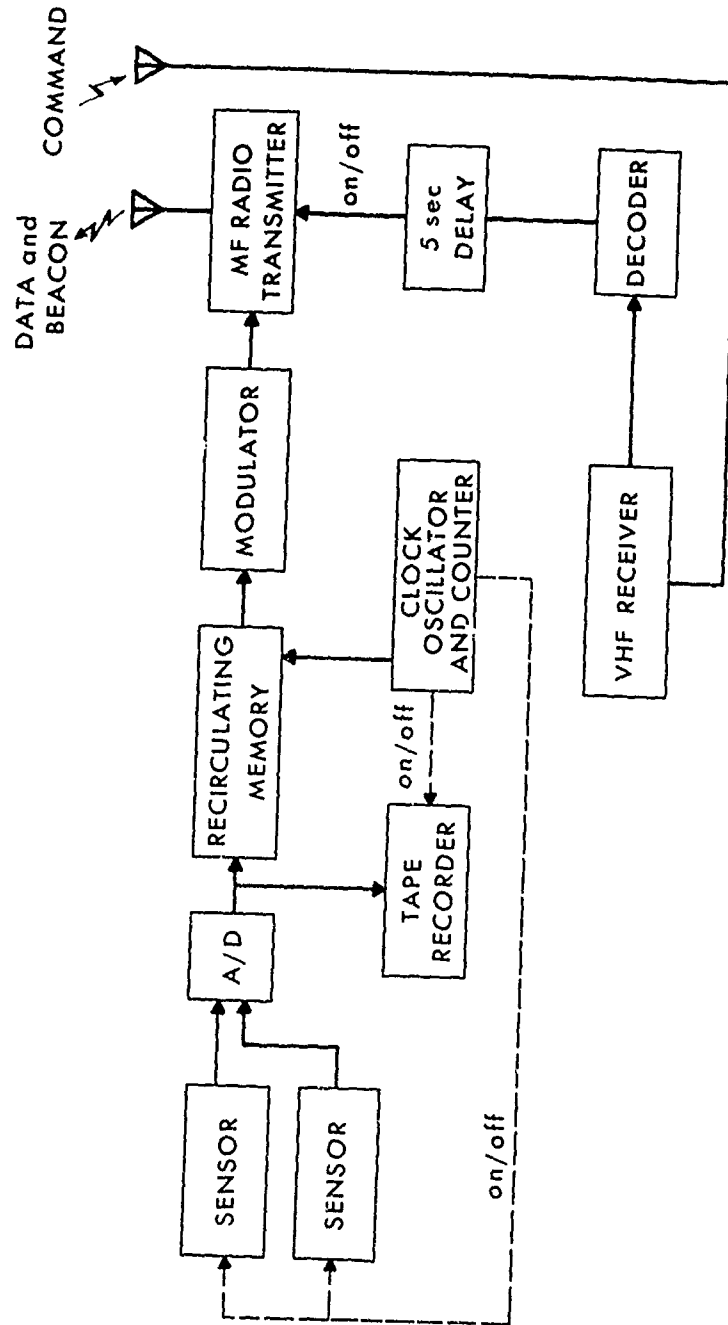
Figure 3. Block Diagram of DELTIC Recirculating Memory

the meantime, the LAMS transmitter is on and the stored digital data
from the DELTIC is sent as a frequency shift keying (FSK) modulation
over the ADF link.

For redundancy, a small cassette tape recorder is provided that
is independent of the memory and radio system. This recorder stores
the A/D periodic data outputs. If for any reason the rest of the system
malfunctions and the LAMS can be located, all data can be retrieved
from the tape.

A LAMS system is currently under development for the Project
AIDJEX 72 experiment. This will be a field of 5 to 10 stations,
located about 200 nautical miles from the main manned camp, for the
purpose of collecting barometric pressure data. In this application,
a resolution of 0.1 microbar over a range of 100 microbars, sampled
every hour, will be stored. All of these data from 30 days of operation
will be held in the DELTIC and available for aircraft retrieval any
time during that period.

CONCLUSIONS

The rationale of these developments is early availability of
working systems in the Arctic. That this will be a learning process
can be expected, and that several practical modifications will
be needed after the first field trials will be necessary; however,
we do believe that practical systems will be available to the arctic
scientific community at an early date as a result of our work with
these systems.

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USE OF INSTRUMENTATION UNDER ARCTIC CONDITIONS

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Scientific equipment is usually taken to the Arctic for data recording; that is, for measuring physical phenomena. The trend today is toward using electrical or electronic equipment for making these measurements. Therefore, I will discuss primarily electrical and electronic equipment.

The researcher in the Arctic today knows what he wants to measure and what equipment he wants to use to make the measurements. What he may not know is what equipment will perform best in the arctic environment.

The measurement process, and again I stress electronic measuring equipment, generally comprises three steps: first, sensing the physical phenomena, sometimes called the detection or transducer stage; second, processing where the signal from the transducer is processed into usable form; and third, displaying, recording, or storing the signal.

I will discuss typical components used in each of these steps with respect to what the arctic environment does to them, and I will limit my discussion to commerci.`ly available, off-the-shelf items. I will do this from the researcher's point of view; namely, that he wants to use his budget and time to pursue his particular interest rather than to fund development programs for instruments for use in the Arctic. Also, an investigator very often develops his instrumentation systems as part of a laboratory pilot study where he has protected his equipment from the harsh environment. Thus, when he goes into the field, he will use the system he has perfected or else modify it as little as possible.

Before discussing specific measurement components, I will cover the arctic environment and some of the possible ill effects it may have on measurement equipment. To begin with, there is the extreme cold temperature. This cold can be as bad on measurement equipment itself as it is on the person operating the equipment. Air temperatures in the Arctic can go as low as -70°C but, generally speaking, men can do little work at this temperature. In fact, most men cannot operate efficiently below -40°C, so this is the low limit I have set for equipment operation. However, equipment has to be stored and transported, so I have set -60°C as the

usual limit for these conditions. At the other end of the temper-
ature scale, I have set 30°C as the upper limit, as for instance
operation in a heated shelter or vehicle.

What are the effects of cold temperatures and temperature
changes on measurement equipment? One of the most vexing problems
for arctic researchers concerns the temperature coefficients of
measurement equipment and their components; that is, changing
characteristics with varying temperature. As an example, a transistor
will change its forward current transfer ratio by about 50 percent
when its temperature is changed from 23°C to -25°C. As another
example, a foil strain gauge will change its resistance to a
degree that represents about 400 microstrains with a temperature
change from -45°C to 20°C. If the desired resolution in measure-
ment is 10 microstrains, some sort of compensation is obviously
required.

Temperature coefficients are usually given by the manufacturer
so that possible equipment degradation can be estimated. It is not
always possible, however, to get temperature coefficient data over
the full temperature range at which the equipment is expected
to operate. A component may have a temperature coefficient of 50
parts per million per degree Centigrate from -20°C to 30°C, but it
could very well have a temperature coefficient of 200 or 300
parts per million below -20°C. The only sure way of checking this
is to test the equipment at the lowest expected temperature.

Another problem associated with temperature is thermal gradients.
If a piece of equipment, say a potentiometer for thermocouple
measurements or a Wheatstone bridge for thermistor measurements,
is taken from a warm environment (such as a heated vehicle) into
a cold environment, the instrument will not cool in each and every
part at the same rate. The thermal gradients set up under these
conditions can lead to large errors. The error may be due to zero
offset, nonlinearity, or full-scale shifts. Whatever the cause,
the numbers obtained during the time the instrument is adjusting
to temperature may very well be meaningless. Note that these
errors are temporary, due to differential cooling; nonetheless,
they point out that testing should not only be done on an instru-
ment at the coldest expected temperature, but also while it is
cooling to that temperature.

The problem of condensation occurs when a piece of equipment
is temperature cycled above and below the freezing point. Whether
during storage, during shipment, or during use, the moisture in
the warm air, if trapped in the instrument, will condense on
components when cooled. , condensed moisture can short out high
resistors and capacitors; or if allowed to freeze, it can damage
meter movements or cause connectors to open circuit. '

Another problem with equipment in the Arctic is transportation,
which causes vibration and shock. Measurements made on aircraft,
for instance, show vibrations between 10 and 150 Hz, with amplitudes

up to 0.1 inch. Surface vehicles and cargo ships, on the other
hand, rarely have vibrations above 15 Hz, although the amplitude
may be several inches.

Tests conducted on scientific equipment have shown that damage
during shipment results from collision or fatigue. Protecting
against collision damage is simply a matter of using proper packing
and storing techniques, but fatigue damage is another problem.
Delicate mechanical components, say panel meters, have some resonant
 requency. If this frequency coincides with that of the transpor+
vehicle, fatigue failure is a distinct possibility. Protecting
against this is not easy, since it is impossible to predict at
what frequency the transport vehicle will vibrate. Even when
this is known, the critical frequencies of the equipment are not
readily determined. The alternative is a shoc-gun approach--shock
absorbers. Even then, educated guesses have to be made if properly
designed shocks are to be used. Another pitfail is that shock
absorbers themselves are temperature sensitive and may fail in
the cold.

The low humidity of the Arctic is not generally a problem,
although electrostatic pickup may increase background noise of
sensitive systems.

Having identified a few of the problems that may crop up,
let's look at some specific components used in the measurement
process. Again, I will refer to commercially available equipment
only.

Let us consider thermocouples first, since temperature is
a common measurement made in the Arctic. There are a number of
thermocouple types available, but only one is recommended by the
ISA for measurements below 0°C. That is type T, or the copper
constantin thermocoupl . It is recommended for use over a range
of -60°C to 120°C whicn is adequ . for most expected arctic
uses.

Unfortunately, thermocouples require insulation, and not many
commercial suppliers are concerned with low-temperature insulations.
The standard plastics crack at about -26°C; teflon and nylon
are good down to -60°C. If flexibility is not a requirement,
polyvinylchlcride is acceptable. If flexed at temperatures below
-26°C, however, it will crack. Polyethylene is a possibility
since it does not crack with the cold, but it does stiffen so
it should be installed in warm areas before exposure to cold.

Strain gauges are common transducers for measuring load,
acceleration, force, strain, and pressure. There are two types
of gauges in general use: wire or foil, and semiconductor. Gauge
manufacturers will supply excellent temperature data with their
product, so predicting the effects of temperature changes is
quite easy. Foil gauges usually change about 200 to 400 microstrains
over a temperature change of -45°C to 20 C which is quite a lot

if one is looking for a 10- or 20-microstrain resolution. Gauge factors also change about 1 percent over this range. On the other hand, semiconductor gauges will change as much as 50 percent over the same temperature span and thus require elaborate temperature compensation techniques. Nonetheless, semiconductor gauges have sensitivities 50 or 60 times greater than foil gauges, so they may be the only choice for a particular measurement.

Strain gauges have two other possible problems in the Arctic. The first is the choice of a proper epoxy and the second is moisture-proofing materials. Both of these are available at temperatures down to -60°C, but sometimes they are not used on commercial transducers unless specified. Moisture proofing or hermetic sealing is a must for strain gauges in the Arctic, since moisture condensation may shunt the gauge and cause a change in resistance that appears as a recording signal to the readout device.

Another common sensing element is the variable-resistance transducer. This device measures pressure, displacement, velocity, and position. Most commercial transducers using resistance elements will tolerate -50°C temperatures. While they have a temperature coefficient over a wide range, it is usually quite small. In addition, hermetically sealed transducers are available which are quite rugged. These units withstand vibration damage up to 20 G's and 3 kHz and shock damage up to 50 G's.

A companion to variable resistance transducers is the linear variable differential transformer. This device is reliable to -65°C and is as rugged as the variable resistor. They are usually more sensitive, however.

This completes my discussion of sensor elements. Summing up, I think it is fair to say that no matter what measurement is required, there is probably a commercial transducer that will meet the requirements.

Now let's go on to processing equipment. Amplifiers, for example, are made up of electronic components each of which has a temperature coefficient. I will not discuss temperature effects for all components since data are readily available on them. The one electronic component I will discuss is the transistor. On the face of it this device seems a natural for electronic equipment in the Arctic since it is small, lightweight, quite reliable, and requires little power for operation. However, the transistor is temperature sensitive. Its amplification factor changes by 50 percent over the temperature range from -40°C to 30°C. In addition, its input bias junction changes 2.2 milivolts per degree Centigrade.

Since this clearly gives unacceptable performance, manufacturers of data amplifiers have resorted to two techniques. The first is the chopper amplifier which is a method whereby the dc signal is converted to ac, amplified, and then rectified back to dc.

By doing this, ac coupling between stages eliminates the amplification of dc bias shifts.

Another technique is to design balanced amplifiers, sometimes called differential amplifiers, so as to have equal and opposite temperature effects which cancel each other in the output. Using these techniques, data amplifier manufacturers get very excellent performance from -20°C to 40°C.

Unfortunately, this does not cover the total desired range and can limit the extent to which equipment may be used. I would like to stress that the state of the art for amplifier design is capable of developing an amplifier which would give acceptable performance from -40°C to 30°C, but the manufacturers of such equipment see no reason to develop a unit like this when there is very little demand.

A second component that is associated with signal processing is batteries. For portable field equipment batteries can be a big headache. All batteries suffer capacity losses at low temperatures, but some more than others. Dry cells will give about 6 percent of room temperature capacity when operated at -29°C. Mercury batteries will give only about 2 percent of room temperature capacity at -29°C, although they may still be a reasonable choice since they have 5:1 higher capacity per unit volume than dry cells.

One battery that is less severely reduced in capacity at low temperatures is the nickel-cadmium battery. At -15°C, these batteries give 60 percent of room temperature capacity. In addition they are rechargeable, even at low temperatures. Unfortunately, they cost about 10 to 20 times as much as dry cells of equal volume. Some battery manufacturers do not recommend their nickel-cadmium cells for use below -15°C because of case leakage, so some shopping around is required.

A special kind of battery which should be considered is the standard cell. Standard cells are used in almost all millivolt potentiometers on the market today as the reference potential. These cells are very stable, last for years, and have low-temperature coefficients. One disadvantage is that they freeze below -20°C. Once frozen, they take from 60 to 90 days after thawing to return to their reference voltage, so the standard cell is one component that must be kept warm during storage, shipping, and use.

Summing up, for processing equipment, the Arctic causes few large problems. although in some cases operating limits may be restricted to -20°C.

The third measurement step is readout and here is where problems set in. Readout devices are generally of two types: indicating or recording. The most common indicating device is the panel meter. Standard panel meters have been operated at -20°C with no problems, but mechanical zero offset is about at its limits at -20°C. Moisture

condensation can damage the delicate meter movement, although hermetically sealed units and ruggedized units are available. Meter movements may fail below -20°C because of mechanical contraction of the suspension system. If you are planning to run tests, consult the manufacturer first because specially built meters for -40°C temperatures are available. Differential shrinkage between coil windings and the core piece may also cause damage to standard units.

The oscilloscope is another indicating device in common use. Oscilloscopes will generally work without trouble down to 0°C. Lower temperatures cause high drift levels. Most oscilloscope manufacturers make at least one ruggedized unit for use at -40°C. Usually it is a general-purpose device that covers a wide range of readout applications.

Recording devices are another headache in the Arctic. Commercial units usually use a light lubrication which gets viscous at temperatures below freezing. In addition, inking systems clog or freeze. This means that storage below freezing could cause inking problems. The only solution is to keep the recorder warm, such as with a styrofoam box and lightbulbs. Light beam recorders solve the inking problem but have chart drive problems. In addition, mountings for the galvanometers in these recorders depend on a uniformly heated block in order to maintain linearity and full-scale deflection accuracy. In cold temperatures the heaters are on all the time, which means the block never warms to its operating temperature.

This completes my discussion. The instruments and components I covered amply demonstrate the possibilities available to the researcher looking for commercial equipment to solve his measurement problem. The researcher can: (1) whenever possible, select components which will perform adequately over the expected operating and storage temperature range (for instance, strain gauges, variable-resistance transducers, and thermocouples); (2) restrict his program so as to stay within the temperature limits of the device (for example, amplifiers, meters, and oscilloscopes); or (3) provide heated enclosures (as is necessary for recorders and standard cells). If these are all unacceptable, then the researcher must embark on a development or modification program to meet his special requirements.

REAL-TIME PRESENTATION OF PENETROMETER DATA*

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This paper concerns a system for handling and presenting data obtained from sea ice penetrometers.

During FY 1970, the Coast Guard funded Sandia Laboratories to demonstrate the feasibility of a sea ice penetrometer (SIP) concept that would measure ice thickness in the Arctic. In February 1970, a series of drop tests were performed in fast ice at the Bay of Clarence, Alaska, demonstrating the feasibility of remotely determining the thickness of sea ice by using instrumented air-dropped penetrometers. From these tests it appeared that an optimum ice penetrometer should weigh 50 pounds, should be 2.75 inches in diameter (Figure 1), and should impact the ice at 450 to 500 feet per second.

In April 1971, a series of drop tests were conducted in sea ice in the Arctic Ocean to proof-test the sea ice penetrometers. The tests were conducted in annual sea ice (6 feet thick) near Thule Air Base, Greenland; in pack ice (greater than 10 feet thick) near Alert, Canada; and in refrozen leads between Thule and Alert.

The penetrometer was dropped by aircraft flying at 8,000 feet. As the penetrometer perforated the ice, it sensed deceleration and transmitted the data to a receiving station in the drop aircraft. This drop altitude allowed the penetrometer sufficient time to reach terminal velocity before entering the ice. The ice thickness was determined from analysis of the deceleration-versus-time data (Figure 2). Complete deceleration data were received on 21 of the 23 tests, with ice thickness being determined with an accuracy of ± 3 inches.

Data reduction on the above tests was accomplished in the field by hand computation. This involved making a high-speed oscillograph record, then tracing the deceleration curve on graph paper. To integrate this, the squares under the curve were then counted at discrete time intervals, and another curve was plotted showing velocity versus time. This was also integrated by counting squares, and then the displacement versus time was plotted by hand. This required considerable time (more than an hour for an expert). This hour was in addition to the time required to obtain the data and play the tape back on the oscillographic recorder. A reasonable turnaround time for this system would be approximately 4 hours.
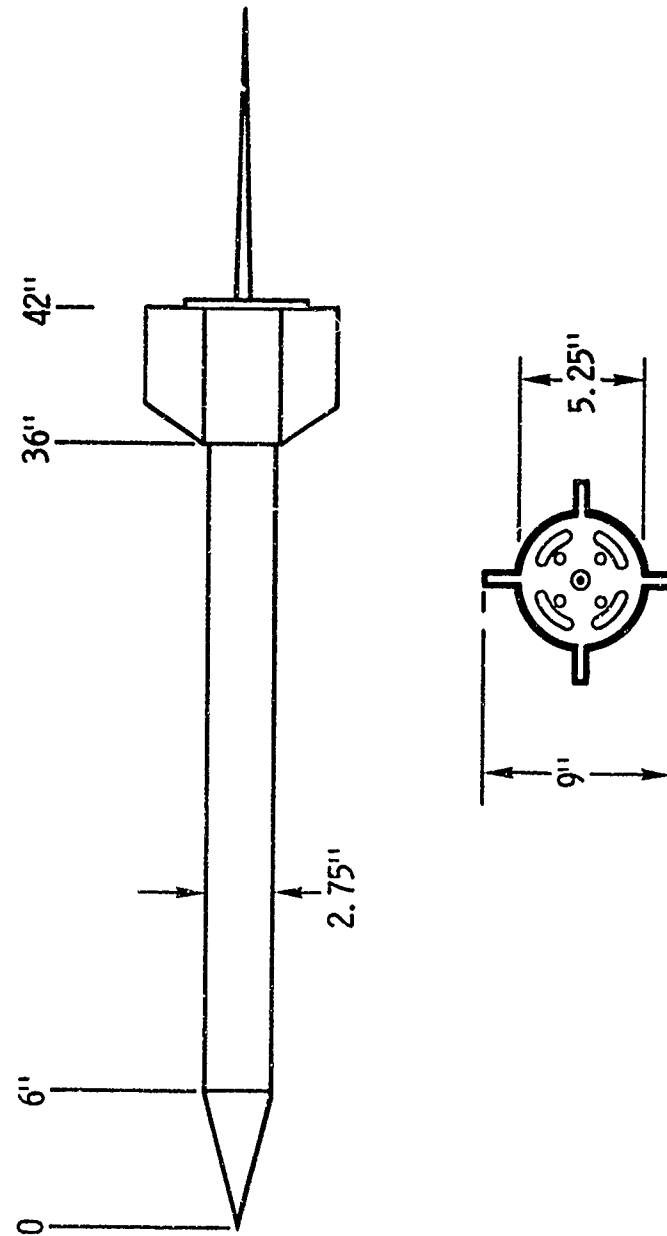
WEIGHT = 50 lb

SIP FLIGHT CONFIGURATION

Figure 1

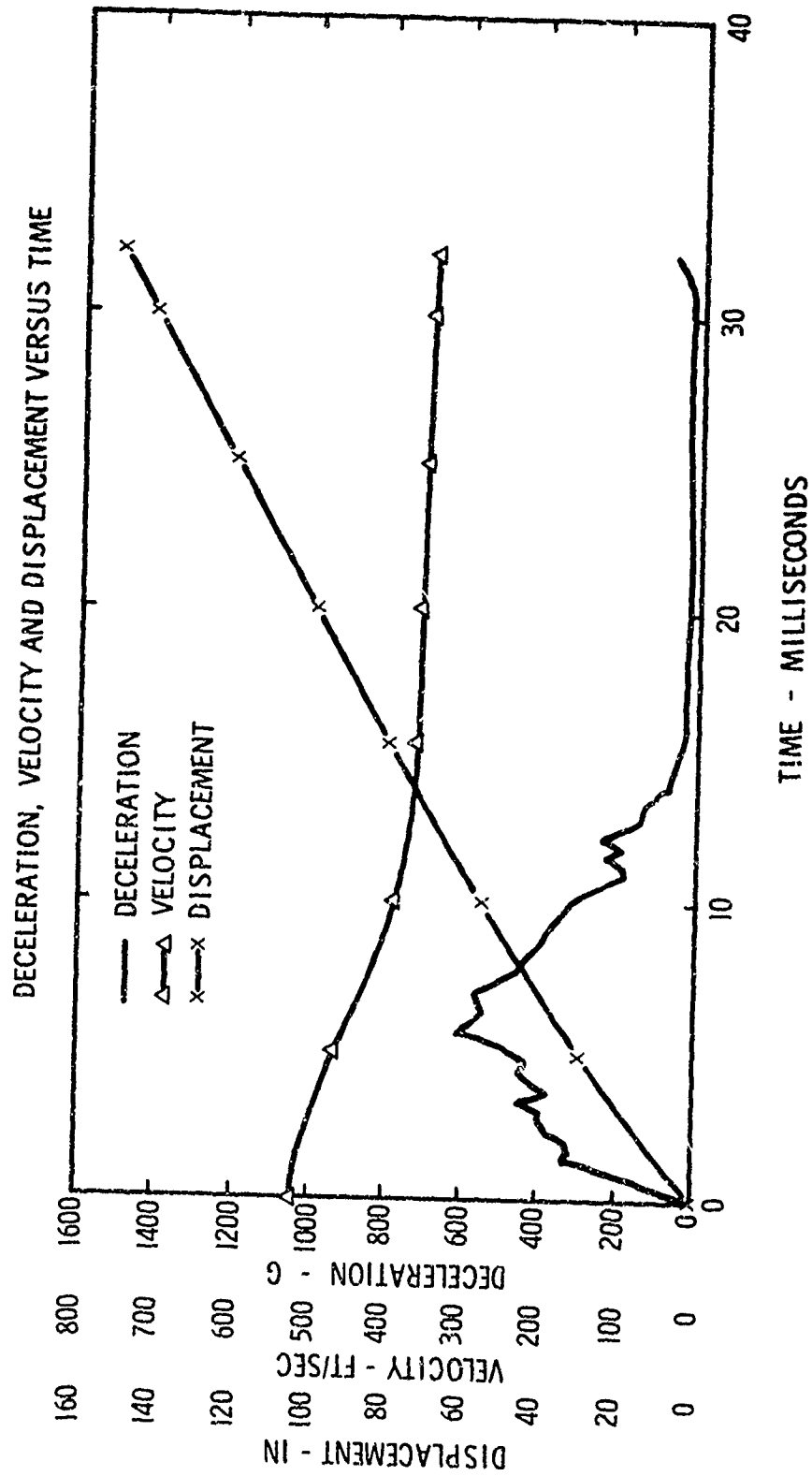DECELERATION, VELOCITY AND DISPLACEMENT VERSUS TIME

TYPICAL GRAPH OF SIP TEST

Figure 2.

A second generation system is now being developed to automate data reduction (Figure 3). The speed and sophistication of the system are compatible with the economical approach desired. The hardware costs less than $30,000. Each penetrometer is estimated to cost less than $200. The airborne system consists of an analog-to-digital converter, a PDP-8 computer with 4K of core, and an ASR-33 teletype which doubles as a plotter and an input-output device.

The system digitizes the signal at approximately 3,000 samples per second. These are discarded until the amplitude exceeds 10g's for at least six samples (2 milliseconds), and then a maximum of 314 points (105 milliseconds) are stored. These data are integrated and double integrated, and then plotted by the teletype. This is time consuming since the data can be outputted at only 10 characters per second. This could require 0.12 minute per line or more than 30 minutes to plot the entire graph. Most tests, however, can be completed in 10 to 15 minutes. Each line on the plot represents 333 microseconds of real time. In addition to the graph, the snow and ice thickness as well as the peak deceleration and possibly the velocity change between impact and ice exit are outputted.

This system has thus automated (1) the data input cycle (no vidicorder); (2) the analog-to-digital conversion; (3) the integration; (4) the data signature determinations; and (5) the sorting and calculating of snow thickness, ice thickness, velocity change, peak acceleration, and the displacement at which it occurred.

This second generation system is intentionally limited by hardware constraints because of the developmental nature of the effort. The principal limitations at this time are: (1) speed of the output device (10 characters per second); (2) single input channel; and (3) no analog or digital record to allow post-analysis. These limitations mean that certain desirable (but expensive) features are not yet automated and that output results are more abbreviated.

If a production phase is entered, with its implicit large expenditures and with the knowledge gained in Phases I and II concerning penetration technology and computer software "modeling," then an expansion of this system can be considered. In this connection certain small hardware purchases could facilitate faster and more complete real-time data analysis. The hardware costs would be increased by approximately $35,000 over the system now being developed, not including the navigation system.

The additional equipment would include a cathode-ray tube display (Figure 4) for better matching the calculation capabilities of the computer to its output device for rapid data display; an interrupt structure for multiple-channel inputs and outputs; a time generator and position monitoring navigational system for accounting information input; a camera and/or side-looking, high-resolution radar to record topographical data at the impact location; a tape
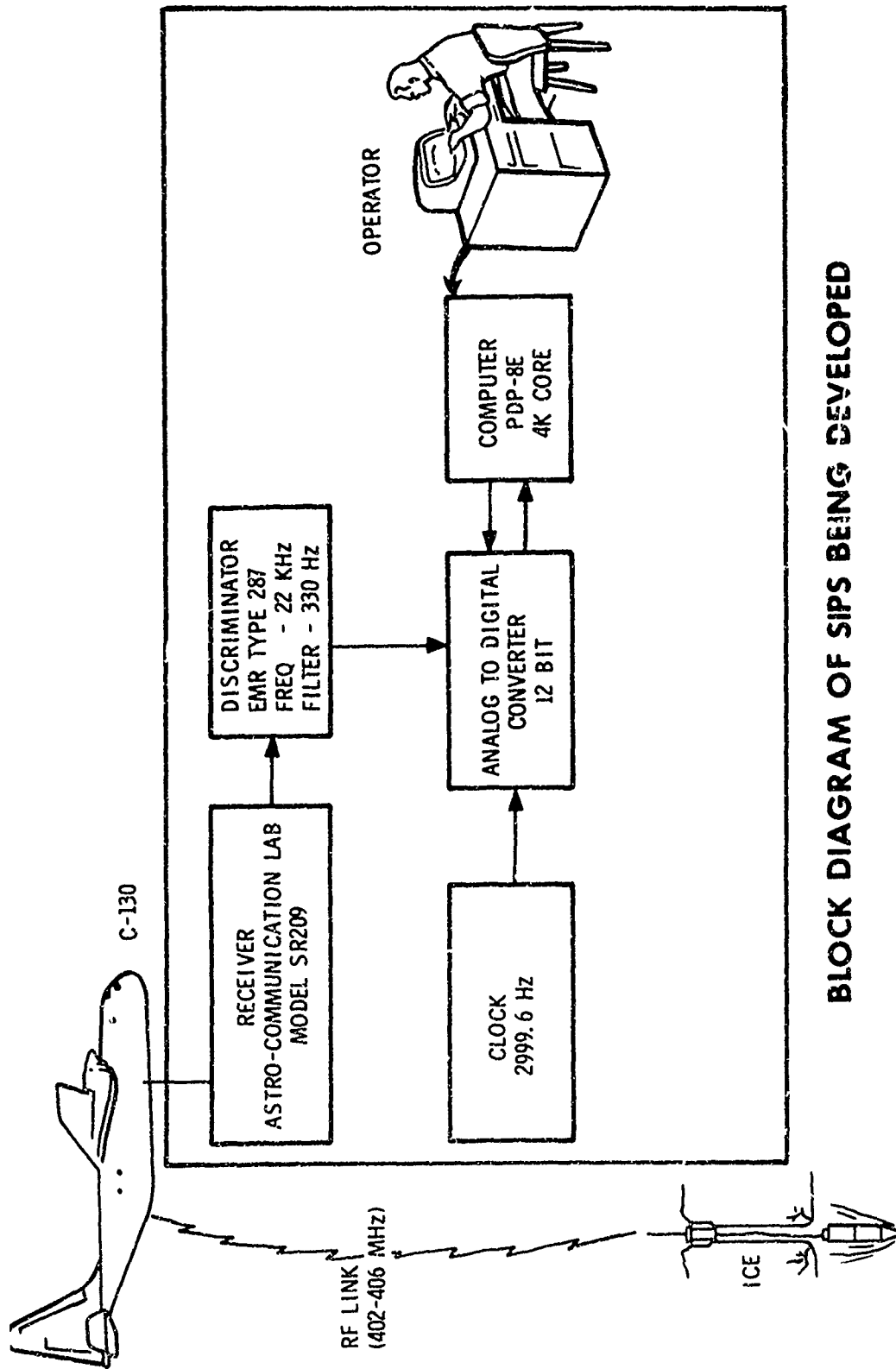
BLOCK DIAGRAM OF SIPS BEING DEVELOPED

Figure 3.
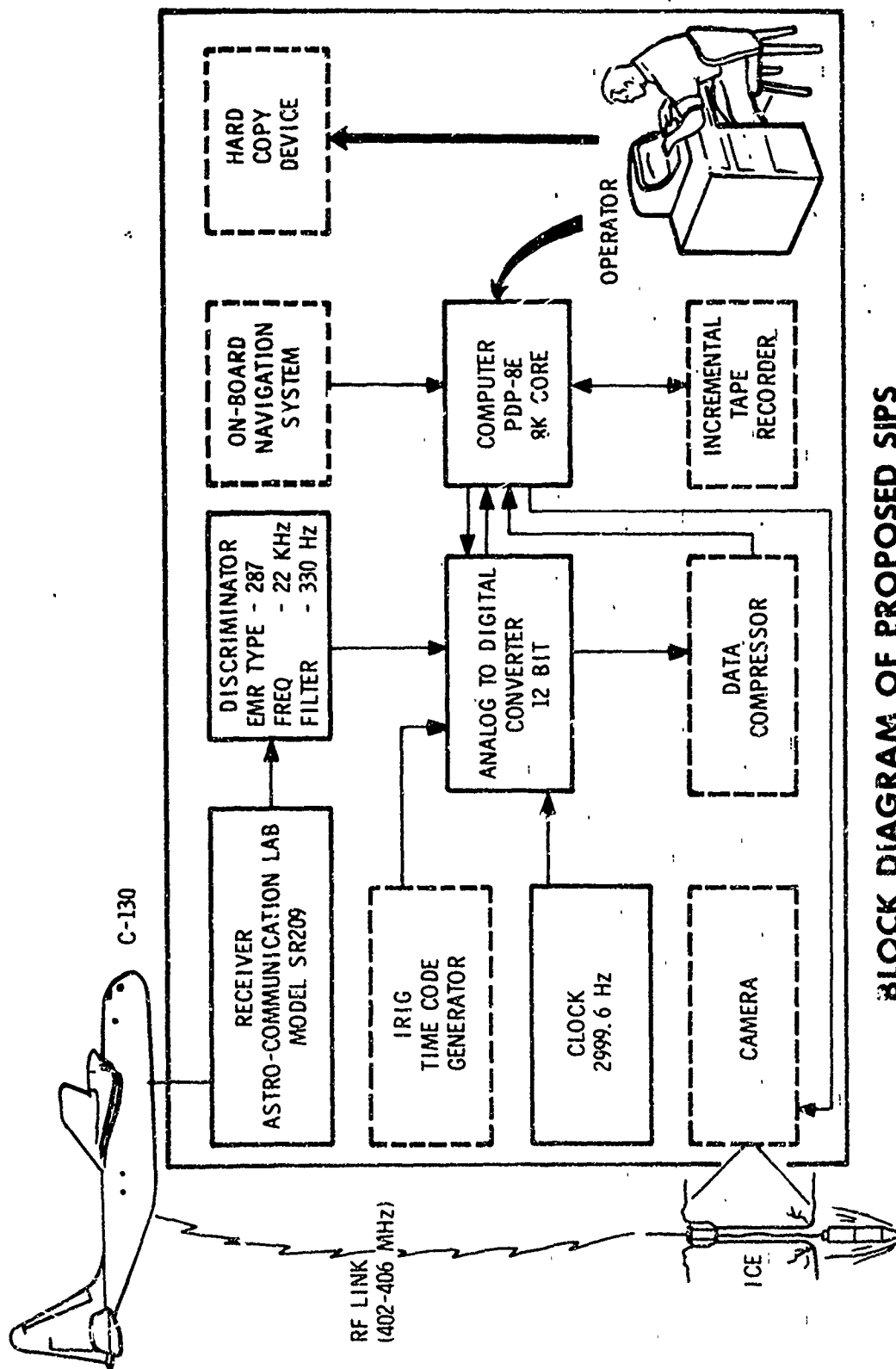
BLOCK DIAGRAM OF PROPOSED SIPS

Figure 4.

recorder for rerun purposes to provide further development data; and a data compression system to minimize storage volume. Of course all this will require a more powerful computer. These are in addition to the side-looking radar presently being experimented with during second generation development and a microwave radiometer for determining the type of ice. .

This system (Figure 5) would show the following in near real time (many of these things could be contained in a follow-on system, but would be better presented here to prove feasibility):

I.   Real-time graphic display on a cathode-ray tube of:

    A. Deceleration versus time.

    B. Velocity versus time.

    C. Displacement versus time.

These could be time expanded to give greater detail.

II.   Real-time annotation of:

    A. Snow thickness.

    B. Ice thickness.

    C. Peak deceleration.

    D. Velocity change.

    E. Type of ice (this is a possibility after more tests).

    F. Location of impact (if desired and data are provided from aircraft). This would be obtained from pilotage, VOR, or inertial navigation system to the desired accuracy.

    G. Depth at peak "g".

    H. Date of test.

    I. Time of impact.

    J. Predicted ice thickness based on the curves of "Relationship between Ice Thickness and Penetrability." Figure 6 was based on the limited number of tests that have been conducted; however, there appears to be excellent correlation between peak "g" and depth and/or type of ice.

        1. If the ice exit velocity indicated less than 50 feet per second, this could possibly indicate (because of data inaccuracies) that the penetrometer did not

FIGURE 5

PROPOSED OUTPUT OF SIP TEST

DECELERATION, VELOCITY AND DISPLACEMENT VERSUS TIME

DECELERATION,
△—△ VELOCITY
×—× DISPLACEMENT
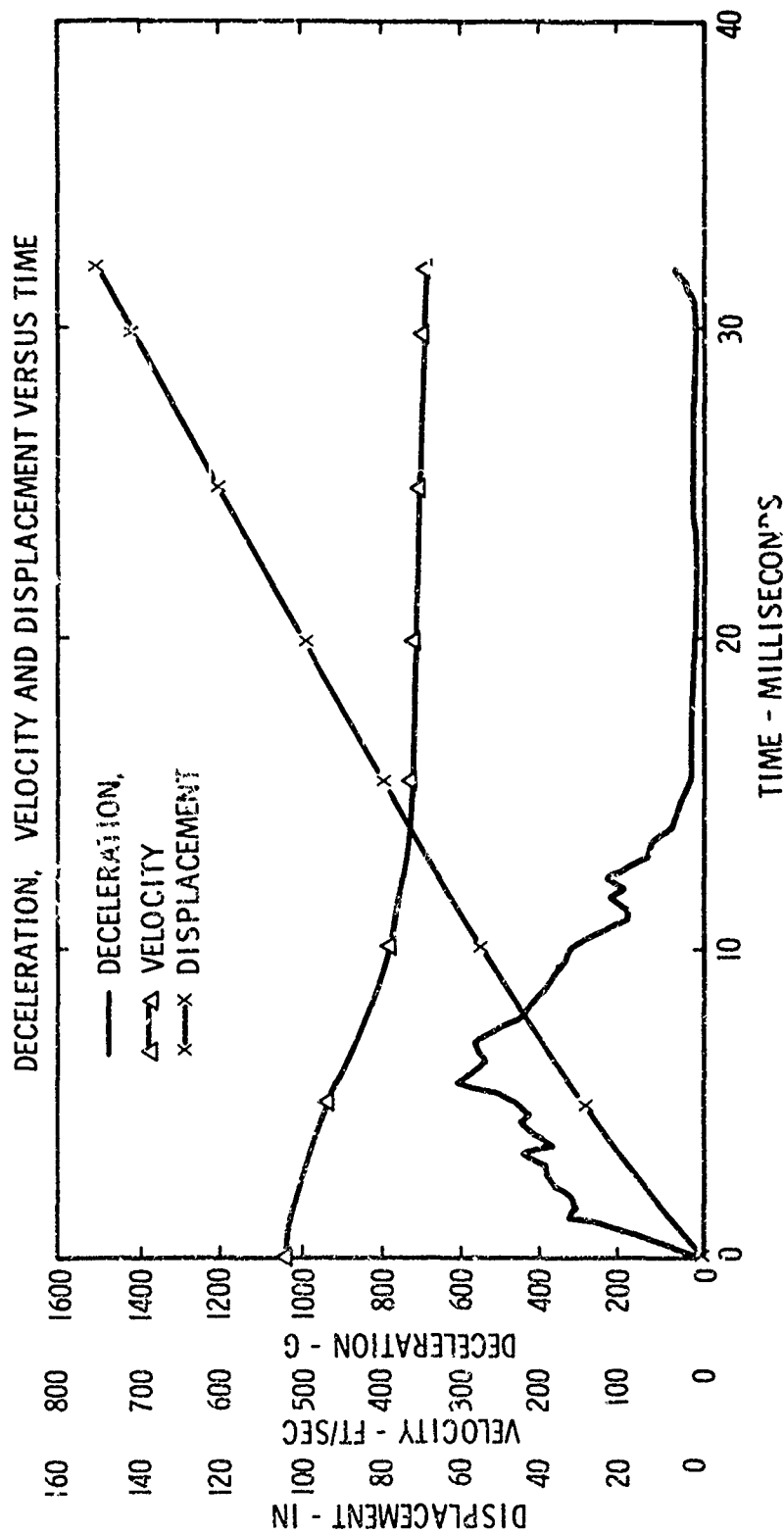
Snow thickness = 0 in.
Peak deceleration = 600 G
Type of ice – Annual Sea Ice
Location of impact – Lat.   N; Long   W
Date and Time – 041671 – 12:18:49.3
Predicted ice thickness = 74 in.   Ship penetrate?
"GOOD DATA POINT"

Ice thickness = 69 in.
Velocity change = 151 FPS
(Depth at Peak G = 34 in.)

TIME – MILLISECONDS

DECELERATION – G
VELOCITY – FT/SEC
DISPLACEMENT – IN

FIGURE 6

RELATIONSHIP BETWEEN ICE THICKNESS AND PENETRABILITY
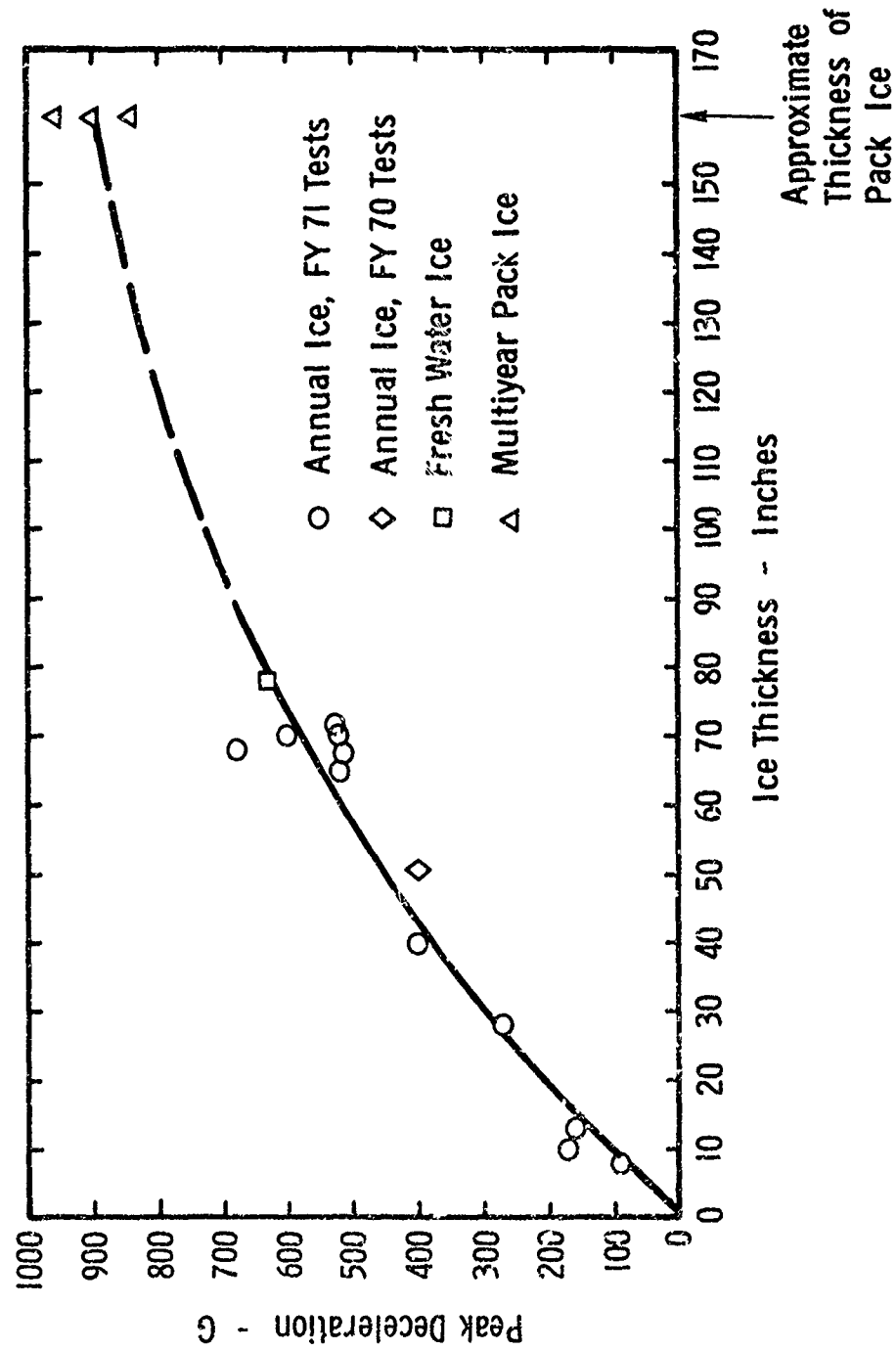
exit the ice. The predicted depth from Figure 6
could then be compared with the integrated depth.
If these two depths agreed within certain limits,
it would be considered a good data point.

2. If the predicted ice thickness from the peak "g"
    reading did not agree with the integrated depth within
    certain limits, the computer would recommend ad-
    ditional tests in that location.

A hard copy of this graph : display could be obtained for
future reference.

III. If lighting is adequate, a photograph of the surrounding
      area could be obtained at the instant after impact when the
      computer senses at least 10 g's for 2 milliseconds. The
      camera would be aimed at the predicted impact. If other
      airborne data-gathering equipment is utilized, the data
      could all be obtained simultaneously and compared to give
      better credence to the data at any one location.

IV. A permanent record of deceleration versus time should be
     stored on magnetic tape for future analysis. Only values of
     interest would be stored after compression with an appro-
     priate algorithm. It is difficult to put a price tag on the
     value of this record. If we were smart enough to predict
     all the idiosyncrasies, we could output them on the
     original display. There is always valuable information
     to be gleaned from past data, even if it is only a more
     accurate and reliable way of presenting future data. Of
     course, accurate data may be the difference between whether
     or not a ship gets through, or whether a landing is made
     safely in the case of the unimproved airstrip.

The advantages of this system, then, are:

1. Faster output for more rapid turnaround (less than 1
    minute after the test).

2. A more concise, better human-engineered format.

3. Cross-correlation of current with statistical data and
    peak "g" derivation of the type of ice with the displace-
    ment measured.

4. Adaptive data sampling based on in-flight results rather
    than a predesigned flight profile.

5. If an error is suspected, a permanent record is maintained
    for later salvage efforts.

6. An opportunity for further analysis to alleviate
    problems which cannot be foreseen.

7.   More accurate location data.

The sea ice penetrometer is just one example of how an ice penetrator can be used to gather data remotely. The technology which led to the penetrometer development can also be applied to other data acquisition systems such as:

1.   An air-delivered vehicle to implant an electronic package for measurements in the ice and at the ice surface. By properly designing the vehicle, the deceleration loads resulting from impact and penetration can be minimized. This type of vehicle could be used as a remote weather station or as a beacon.

2.   An air-delivered device can be used to penetrate the ice, suspend an electronic package in the water below the ice, and at the same time leave an antenna at the ice surface. An ice sonobuoy is one example of this concept.

3.   The penetrator can also be used to measure the depth of water below the ice and, if desired, to measure the properties of the sediments on the ocean floor.

The penetrometer concept is a method of positioning an instrument package above, in, or below the ice while leaving the question of "what is to be measured" to the imagination of the researcher.

In closing, note that only data presentation should be considered initially. The best data acquisition system is of no value unless the data are received in a usable form.

E-PHASE: A REMOTE SENSING TECHNIQUE FOR RESISTIVITY MAPPING AND SEA ICE THICKNESS MEASUREMENT

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Electrical resistivity of terrain is closely related to a number of parameters of considerable practical and economic importance. For example, gravel and sand deposits tend to be resistive, whereas soils with a high clay content are generally conductive. Ice wedges within regions of discontinuous permafrost have a higher resistivity than the surrounding terrain, and this property has been used in the past to map such features.

An airborne system called E-PHASE has been developed to produce resistivity maps at a cost which is fractional compared with ground surveys and at a speed which is at least an order of magnitude greater. The system utilizes radio frequency fields transmitted by government VLF stations and commercial broadcast stations, as well as transmitters especially installed for the survey. In the technique, the field strength of the quadrature component of the horizontal electric field of the propagated wave is measured with respect to the vertical electric field. It can be shown that the horizontal component of the electrical field is phase shifted by 45° with respect to the vertical electrical component over a homogeneous earth for a broad range of frequencies and ground resistivities. Measurement of this component is therefore related to the total horizontal field strength and can be used to derive the resistivity of the underlying terrain.

The effective depth to which the resistivity is sensed is a function of the frequency of the radiation, and surveys have been carried out using both broadcast band and very low frequencies simultaneously. These two signals provide penetration depths between 10 feet and 100 feet for the broadcast band and between 50 feet and 500 feet for very low frequencies. Simultaneous use of two or more frequencies enables layering effects to be studied and has considerable potential for mapping permafrost distribution and for locating gravel deposits.

Further theoretical study has suggested that the E-PHASE system operating at very low frequencies may be useful in mapping sea ice thickness since it can be shown that the quadrature component of the horizontal electric field measured over sea ice is linearly related to the ice thickness and almost completely independent of ice resistivity and dielectric constant over a large range of variation of these parameters. A ground unit was constructed, and preliminary

tests were carried out at Point Barrow, Alaska under the auspices of the U.S. Army Cold Regions Research and Engineering Laboratory. The results of the measurement program indicated that the sea ice exhibits large lateral changes in resistivity over distances of the order of a few feet, thus leading to significant errors in the electrical determination of the thickness. It appears possible to circumvent this problem, and further theoretical work is planned to evaluate this effect.

LOGISTICS, INSTRUMENTATION, AND GEOPHYSICAL DATA ACQUISITION IN NORTHERN GREENLAND

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The virgin exploration areas of the world are diminishing. Geophysicists and geologists must of necessity turn to remote deserts, jungles, and the Arctic for new reserves of minerals, gas, and oil. Perhaps Greenland rates as the most remote and inhospitable. Its total land area is 840,000 square miles of which 84 percent is covered by an ice cap that in places is more than 11,000 feet thick.

In the arctic summer, the areas along the coast are generally free of snow and ice. To the photogeologist, the lack of vegetation is a blessing. He is not hampered in his work by forests which obscure the geomorpnology he is attempting to define. To the aerial surveyor, however, the area presents problems of navigation, logistics, and ground control unprecedented in the more temperate zones. The aerial surveyor must cope with fog, icing conditions, magnetic storms and abnormal diurnal magnetic activity, navigational problems peculiar to the Arctic, lack of suitable maps and associated horizontal control, inaccurate elevations, lack of airfields with suitable fuels and facilities, and a myriad of other problems.

In spite of these seemingly endless difficulties, airborne magnetic surveys covering nearly 42,000 line miles and precision aerial photography covering 30,000 square miles were accomplished in less than 3 months. The experience gained on this program will point the way to the development of equipment and techniques to improve the efficiency of future acquisition and utility of data.

This program was funded by the Greenarctic Consortium, a group dedicated to the development of Greenland, its resources, and its people. Greenarctic is a long-term joint venture founded by Canadian and Danish interests. It holds a license from the Danish government to prospect for oil, gas, and metallic minerals north of 74°30' latitude. It also holds exclusive exploration rights to three additional tracts: at Thule on the northwest coast, at Hagens Fjord, and at Independence Fjord.

This first airborne survey was concerned with the evaluation of oil and gas potentials of the sedimentary basin identified by Green-arctic exploration parties during 1969 and 1970. A glance at the survey area (Figure 1) indicates the magnitude of the logistics peculiar to the area. Above 74°30' North there are only two suitable airports in Greenland: Thule Air Force Base and Station Nord. Outside Greenland, in Canada's Northwest Territories, are three airfields: Alert, Eureka,
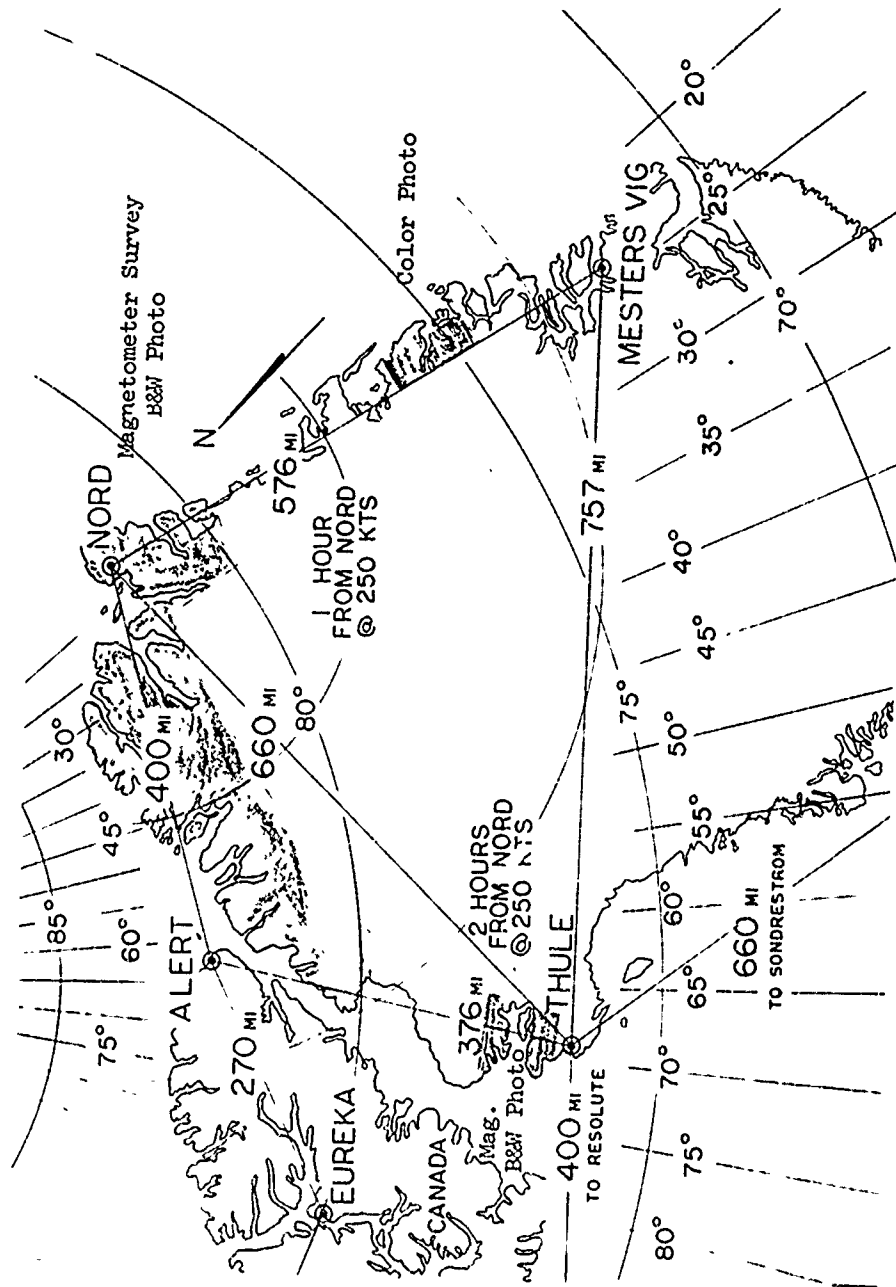
Figure 1. Greenland Survey Areas

and Resolute. Due to customs and immigration restrictions, these
fields could only be considered as emergency strips, not operational
bases; therefore, the bases selected for conducting the survey were
Thule and Nord.

The mileages shown indicate the requirement for long-range
aircraft. During the survey four diversions were made to Thule from
Peary Land while operating out of Nord. The crew learned of an emergency
strip, Jørgen Brønlunds Fjord at 82°8'N 29°W, which also could have
been used in the event of a widespread weather closure. It was not
necessary to use the strip during the survey due to continuous radio
contact with either Thule or Nord and to excellent weather reporting
by Thule and Nord forecasters.

AIRCRAFT AND SURVEY SYSTEMS

The Grumman Gulfstream I aircraft is uniquely qualified for
large reconnaissance surveys. Its twin-engine, low-wing monoplane
design ensures safety, reliability, and ease of maintenance. It is·
powered by two Rolls Royce Mark 529-8X turboprop engines and has a
design take-off gross weight of 36,000 pounds. The fuselage is
cylindrical and the landing gear is tricycle and hydraulically actuated.

The aircraft is well equipped with navigational gear for all
missions and can utilize all existing civil airway navigational facil-
ities. Two omnireceivers and DME, plus two automatic direction
finders are available for all-weather navigation. In addition, all-
weather off-airway navigation is provided by the on-board X-band
weather radar and a Doppler navigation system. The aircraft
also contains VHF, with HF single sideband voice equipment providing
primary and backup communications.

The Gulfstream's standard configuration and operating character-
istics are:

- Long-range capability: 1,800 to 2,600 nautical miles.

- Speed: 140 to 310 knots.

- High- and low-altitude capability: sea level to 30,000
  feet.

- Short runway capability (less than 5,000 feet at sea
  level).

- Pressurized cabin.

- Excellent stability.

Grumman Ecosystems has modified the standard Gulfstream I
aircraft to include:

- Two photographic bays providing for two Wild RC-8
  precision mapping cameras (Option 1), or one RC-8
  camera plus a 70mm quadricamera unit or tracking
  camera (Options 2 and 3).

- An ASQ-10A saturable core magnetometer specially
  modified for geophysical work. The sensitive detector
  is mounted in a detachable tail boom.

- An infrared line scanner.

- Barometric and radio altimeters.

- Doppler navigation equipment including computer with
  modified readout.

- Appropriate data-recording (digital and analog) equip-
  ment.

Table I summarizes these systems and their general characteristics.

OPERATIONAL DESCRIPTION

From the outset, it was assumed that all aircraft parts,
electronic equipment spares, and operating supplies for the 3-month
project would have to be on site, since commercial shipments to
Greenland would have to be routed via Copenhagen to Sondrestrom and
thence to operating bases at Thule or Nord. For this reason, all
paraphernalia was assembled at Grumman Ecosystems in Bethpage, New
York. The cargo totaled 2,500 pounds. The on-site operations crew
consisted of 11 men, plus 2 temporary project supervisors. To trans-
port these men, baggage, and cargo direct to Thule, a Grumman-owned
Gulfstream II executive jet was chartered. The Gulfstream II, with
three crew members, nine survey operations personnel and their
baggage, and 1,000 pounds of cargo, were dispatched on May 25, 1971,
arriving in Thule 6 hours later after a stop at Frobisher Bay.

Meanwhile, the Gulfstream I, with two project pilots, plane
captain, and one of the supervisors, followed with the remaining
1,500 pounds of cargo. Thus, the crew, cargo, and survey aircraft
were mobilized to the survey area in 1 day. The several boxes of
gear were sorted and unpacked, the ground magnetic monitor was set up
and calibrated, and a facility was established for film processing,
flight map preparation, and flight data handling. The Gulfstream
completed its first flight in the survey area two days later, on
the afternoon of May 27.

Operations out of Thule were routinely conducted from May 27 to
July 9, completing the magnetometer surveying from the western edge
of Washington Land to Victoria Fjord. Concurrently, arrangements
were made to deliver, by a chartered Hercules transport, 1,000
barrels (55,000 U.S. gallons) of fuel to Station Nord. Twenty-five
of these barrels were diverted to Mesters Vig for photographic
operations. The fuel was dispatched from Tromsø, Norway and stockpiled
at Nord for the Gulfstream I and its crew.

TABLE I

DATA ACQUISITION SYSTEMS

Sensors	Designation	Wavelength/Function	Data Output	Applications		
				Mapping	Geophysical Exploration	Resource Inventory
Mapping camera	RC-8 (Wild) (2) (Option 1)	Black and white, aerial color, color infrared	9" x 9" photographs	X	X	X
Quadricamera unit	500 EL (Hasselblad) (4) (Option 2)	Visible and near infrared (dependent on film emulsion and filters)	70mm photographs	X	X	X
Infrared scanner	IRSA 8 (Daedalus)	0.5-5.5 microns or 3-14 microns (may be filtered)	Continuous 70mm film converted from magnetic tape	X	X	X
Airborne magnetometer	AN/ASQ-10A Grumman modification	Earth's magnetic field	Strip chart recording (analog) or magnetic tape (digital)		X	
Tracking camera	Model 105 (Hulcher)	Any emulsion (black and white, color, etc.)	Continuous strip film 35mm		X	X

On July 9, the base of operations was moved to Nord. Two logistic trips in the Gulfstream I moved all personnel and cargo required for the Nord operations. From July 9 to August 3, the Gulfstream completed the remainder of the magnetometer survey area. Missions to complete photographic coverage of the area were also flown during this period. Operations were conducted around the clock, flying magnetometer flights during quiet magnetic periods and photographic flights during disturbed conditions and when sun angles were highest. Aerial photography north of Mesters Vig was required for mineral investigation. Kodak 2445 aerial color film was specified. The 25 barrels of fuel diverted from Nord assured the success of this mission. Taking off from Nord and flying at 25,000 feet to the designated area allowed 4 hours on station in the photographic area before proceeding to Mesters Vig for refueling. Photography was completed on the return trip to Nord.

When flying was completed in the photographic area, however, the crew was informed by radio of deteriorating weather conditions at Nord. Diversion to Thule was necessary. When weather conditions improved, the aircraft returned to Nord to move the base of operations back to Thule, completing the move by August 6. Additional magnetometer operations near Thule were carried out until departure on August 18. When the Gulfstream I braked to a stop on the ramp outside the company's executive office, the aircraft had flown almost 500 hours, had gathered some 42,000 line miles of magnetic data, and had photographed more than 30,000 square miles of Greenland.

AIRCRAFT LOGISTICAL SUPPORT

Permission to conduct magnetometer and photographic flights over Greenarctic concessions was obtained from the Directorate of Civil Aviation in Copenhagen. It was desirable to begin operations from Thule Air Force Base. Permission was granted by the U.S. Air Force for entry of personnel and aircraft, and for flight operations. Excellent support and cooperation were given by the Base Commander and all service groups under his command. Two members of the operations crew were licensed aircraft and engine mechanics, and were able to take care of all aircraft logistics from refueling to progressive maintenance. While operating from Thule, no major problems were encountered. Excellent weather reporting and forecasting from the base weather station simplified flight operations.

Station Nord is an emergency field and as such neither provides facilities for the extended stay of a large crew nor provisions for flight services. Aircraft refueling required that the fuel delivered to Nord in barrels be first transferred to a storage tank and then pumped from the storage tank into the aircraft. An electrical pump equipped with filters and transfer hoses was transported to Greenland for refueling operations. A small gasoline-powered electric generator, adequate for the power requirements of the pump, was included for ground support of the aircraft. The pump was carried in the aircraft in case of diversions to alternate airfields. This pump was required for refueling the aircraft at Mesters Vig.

Five survival packs containing the articles listed below were carried on board the aircraft at all times.

1 each	Blanket (wool)
1 each	Flashlight
2 each	Mark 13 Mod 0 flares
2 each	Dye markers
1 each	Signal mirror
1 each	Water storage bag
1 can	Emergency water
100 feet	Nylon line
1 each	Sponge
1 box	Waterproof matches
1 can	Rations
1 each	Compass
1 each	PSK 1 and 2 kit (survival kit)
1 each	7-foot lanyard with snap hook
1 each	Whistle
1 each	ACR flex saw
1 each	Mosquito net headpiece
1 each	SEEK kit part 1 and 2 (survival kits)
10 each	Concentrated food kits
1 each	Sterno stove with 2 cans fuel
1 each	Hand axe
1 each	Knife
1 pair	Snow goggles
1 each	"Day-glo" panel

Two arctic tents, sleeping bags, and air mattresses were also carried. All flight crew members were required to board the aircraft with a parka and arctic boots for every flight.

WEATHER

For planning purposes, reference was made to "World-Wide Airfield Summaries," Volume 4, November 1967, published by the U.S. Navy Weather Service. A portion of the survey area was covered by this publication. Data of interest included: largest mean precipitation; smallest mean precipitation; mean number of days with ceiling greater than 1,000 feet, 2,500 feet, etc.; and mean number of days with sky cover less than 0.3 and visibility greater than 3 miles. In general, the data indicated minimum precipitation during July, maximum during May; conditions favorable for photography in July; conditions favorable for the low flying magnetometer missions approximately 2 out of 3 days during the summer. Although this information represents average conditions, the odds were considered good for an efficient and successful project.

Weather conditions encountered during the summer ranged from ceiling and visibility unlimited to low clouds, fog, and icing conditions sufficient to suspend flight operations and close the airfields.

It was difficult to determine what conditions would be encountered within the survey areas, which sometimes were 200 or more miles from the operating bases and weather stations. A widespread fog or overcast condition could generally be predicted or reported, but localized conditions could never be accurately determined until reaching the operating area. Reconnaissance of the photographic areas was made in the course of flying the magnetometer missions. When conditions were good in the areas designated for photographic coverage, the magnetic work would be suspended and the aircraft would conduct photographic operations instead.

NAVIGATION AND POSITION CONTROL

In modern magnetically slaved gyro-stabilized compass systems, the inadequacy of either the gyro or the magnetic compass is eliminated by the complementary action of the other. A simple directional gyro is mounted in gimbals that provide 3 degrees of freedom. If two axes are parallel to the earth's surface, the third axis can be used as a directional reference. The gyro may be adjusted to point in a specific direction, such as a magnetic heading determined by a magnetic compass. The gyro will then maintain this specific directional line in space, except that it will drift. By coupling the systems together, gyro drift is compensated by slaving the gyro to the heading provided by the compass. In maneuvers or rough air, when the magnetic compass is unreliable, the slaving is cut off, and the gyro provides the stabilization necessary to maintain good heading information.

In Northern Greenland, the direction of the geomagnetic field is essentially vertical. The horizontal component of the earth's field is about 10 percent of the total field. The magnetic compass, therefore, becomes unreliable due to insufficient force and variation gradient. Thus the complementary action of the two systems ceases. The gyro must then provide the primary directional data without the help of the compass' guiding influence. Drift of the gyro due to the rotation of the earth may be compensated, but a random drift remains. This random drift of the gyro diverts the aircraft from its intended path and makes navigation difficult.

An airplane can be steered in flight in a systematic grid pattern over the ground by what is referred to as visual contact methods. Where good maps are available, a skilled survey pilot can accomplish a remarkably good job. In areas like Greenland, however, good maps do not exist and, lacking check points, the pilot is soon confused and unable to perform a systematic grid coverage. Combining the lack of a reliable heading reference with poor maps, performance of surveys in the Arctic without other navigational aids and position control becomes formidable.

Navigation by the Doppler navigation system and correcting for deviation by reference to the available maps proved unworkable early in the survey. Therefore, the survey was performed by using the Doppler navigation computer exclusively. Reference to the maps was made to determine starting points and to check that no gross equipment malfunctions existed. Except for unexplained departures

from the systematic grid due to gyro malfunctions and map discrepancies, area coverage was adequate for the purposes of the survey. Some lines were repeated when it was determined that coverage was inadequate.

FUTURE REQUIREMENTS

Selection of an electronic positioning system to provide navigation and position control for future exploration is of paramount importance. Hyperbolic and range systems operating with microwaves and long waves, and pulse and continuous wave systems of long, intermediate, and short ranges are all under study.

For airborne surveys, especially with fixed-wing aircraft, instantaneous fix taking and steering capability is mandatory. Ideally, the equipment should be aboard the aircraft, but at present no self-contained system is completely adequate in the areas of accuracy and precision.

For surface surveys by ships or helicopters instantaneous fixing is not so important, but accuracy of position must be known.

The importance of a common base or network for all the exploration to follow cannot be overstressed. Correlation of future work with all that has gone before will contribute to the successful development of the resources of Greenland.

CONCEPT FOR MAGNETIC GROUND CONTROL

The difficulty of establishing magnetic field monitors for control of magnetic surveys at locations within the survey area is due primarily to logistics. Most require operators, if only to change the chart paper. With the development of thermoelectric generators, extended operation appears attainable for state-of-the-art monitors far from power lines. The method of recording the information could be modified to a storage system such as magnetic tape. The tape could then be dumped at high speed on command with the inclusion of a telemetering system at the monitor location.

The logistics problem of manual installation could be solved by jettisoning from the aircraft. With a network of monitors and computer processing of the data, the diurnal effects of the earth's magnetic field may be removed from the survey data.

SATELLITE COMMUNICATIONS AND
DATA TRANSMISSION

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Clarksburg, Maryland

In this paper, I will bring you up to date on commercial satellite communications and some of the developments that we have been pursuing over the last 6 years at COMSAT. Also, I will describe how some of this development might be useful to arctic communications.

COMSAT manages the INTELSAT organization, which is made up of 84 countries throughout the world, including both communist and noncommunist countries. As manager of this system (Figure 1) since 1963, COMSAT has been engaged in developing a global satellite communication system.

The first satellite launch occurred in 1965 and was called Early Bird (INTELSAT I). It was an experimental/operational satellite weighing 83 pounds in orbit, and was launched by NASA using a Delta rocket. The satellite's antenna pointed only at Europe and the northern United States. It carried 240 circuits, meaning that it provided 480 telephone voice channels between Europe and the United States when used with standard earth stations. At that time it had more capacity than all the submarine cables in the world. The satellite cost $3.6 million and had a design lifetime of 1-1/2 years. The launch vehicle cost $4.6 million. The launch cost per circuit year (a figure of merit of satellite communications) was $20,000.

Two years later, in 1967, a larger spacecraft--INTELSAT II--was launched. It also had 240 circuits, but with the difference that it had global coverage (i.e., communication was possible between 70 degrees North and South latitude at a ground antenna look angle of 5 degrees). The cost was approximately the same as for the Early Bird, and it had a 3-year lifetime (versus 1-1/2 years for INTELSAT I). Thus, 2 years later the cost per circuit year was reduced to $10,000.

In 1968, INTELSAT III was launched by an improved Delta launch vehicle. This time the satellite antenna was despun, which means that the antenna radiated toward earth at all times rather than in all azimuth directions. The satellite had a 1,200-circuit capacity (2,400 voice channels) with global coverage antennas similar to INTELSAT II. The satellite cost was $4.5 million with a 5-year lifetime. Although the launch vehicle cost a little more ($6 million), circuit costs were now brought down by a factor of 10 to $2,000 per circuit year.
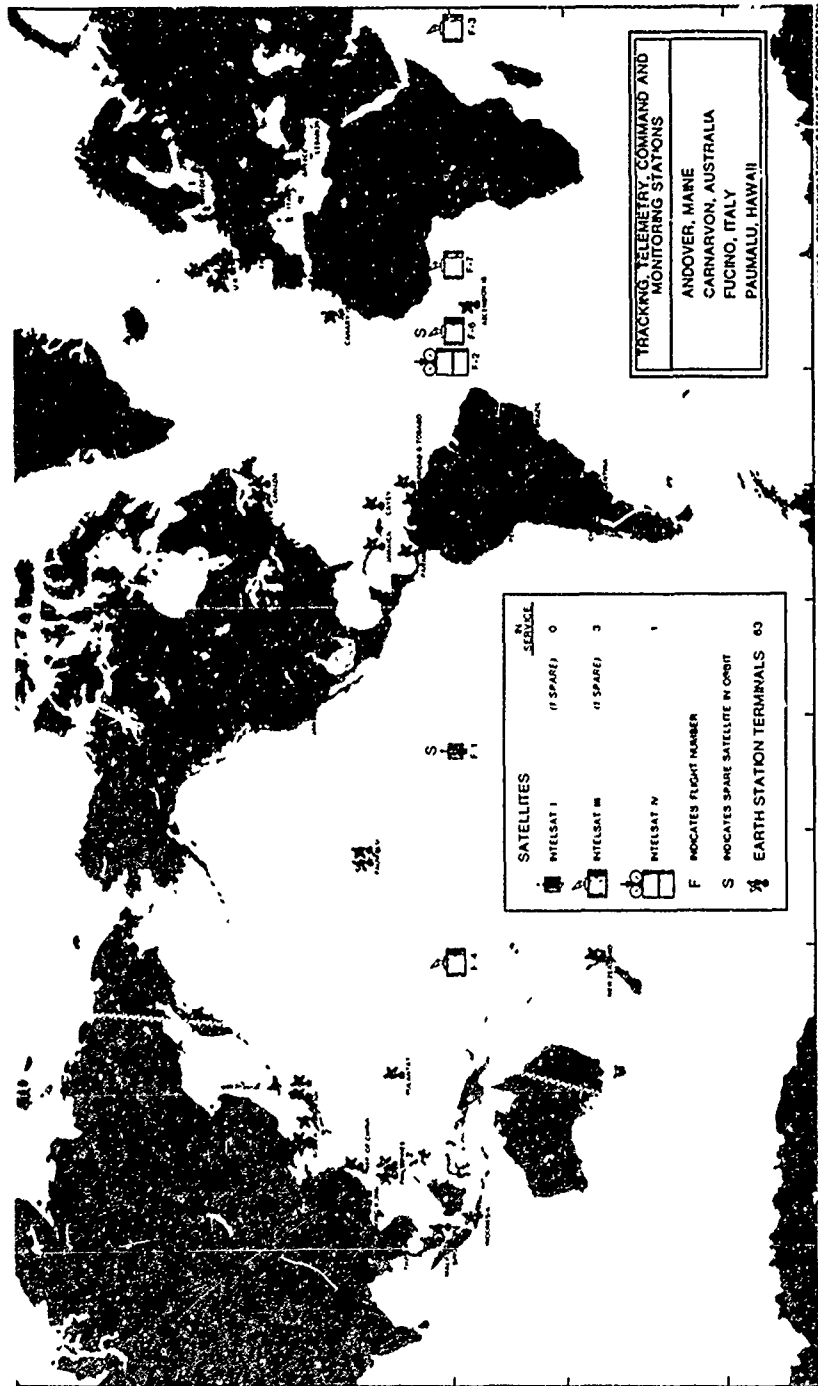
Figure 1. The INTELSAT System (December 31, 1971)

This year a much larger satellite INTELSAT IV--was launched. The satellite (Figure 2) weighed 1,485 pounds, and was built in two parts with the top despun and facing toward the earth at all times. Besides its global beams, it has two spot beams which point toward Europe and the United States. Circuit capacity increased to 6,000 circuits (12,000 voice channels). The satellite cost $10 million and the launch vehicle, an Atlas Centaur, cost $16 million. The satellite has a 7-year lifetime; therefore, the launch cost per circuit year decreased to $700. Note that from 1965 to 1971 four generations of satellites have been utilized and the cost to provide circuits in space has dropped from $20,000 to $700, indicating that satellite communications is a rapidly changing business.

The next generation of satellites--INTELSAT V--is under study and will probably be launched by the end of this decade. An INTELSAT V will have an orbital weight of about 1,600 pounds and will use the same type of launch vehicle as INTELSAT IV. Multiple spot beams are being considered with some form of spacecraft circuit switching. The INTELSAT V capacity will be around 100,000 channels. The cost will be about $12.5 million for a satellite with a 10-year life. The objective is to reduce circuit launch costs to about $30 per circuit year.

Returning to the present satellite system, INTELSAT IV includes a global beam which nominally covers the earth (Figure 3). At a ground antenna elevation angle of 5 degrees, the satellite gives coverage to about 70 degrees latitude North and South. In addition, there are spot beams that concentrate the satellite transmitter power on a given area and increase capacity on heavy traffic routes such as between the United States and Europe. With three satellites in synchronous orbit, almost the complete earth is covered (Figure 4). Satellites are now over the Atlantic, Pacific, and Indian Oceans. There are 55 standard earth stations (Figure 5) with large 100-foot dishes now in operation and over 160 interconnected links. By 1975, there will be 100 of these earth stations in operation throughout the world.

Regarding ground stations, the INTELSAT system owns the spacecraft, while individual signatories (countries) in INTELSAT own the earth stations. The United States has eight earth stations. The standard dish is about 100 feet in diameter, and it costs $4 to $6 million to establish such a station. We are now looking at different sizes, some with a dish diameter as small as 16 feet and a cost of $200,000 or less. Three standard sizes are being considered for introduction into the INTELSAT system. At first, INTELSAT traffic was between the big users such as France, Germany, and England. As the system grew, however, we had to look at the requirements of small countries, which needed only a few voice channels. For these countries smaller antennas and satellite channels which are assigned on demand seemed to be the viable solution.
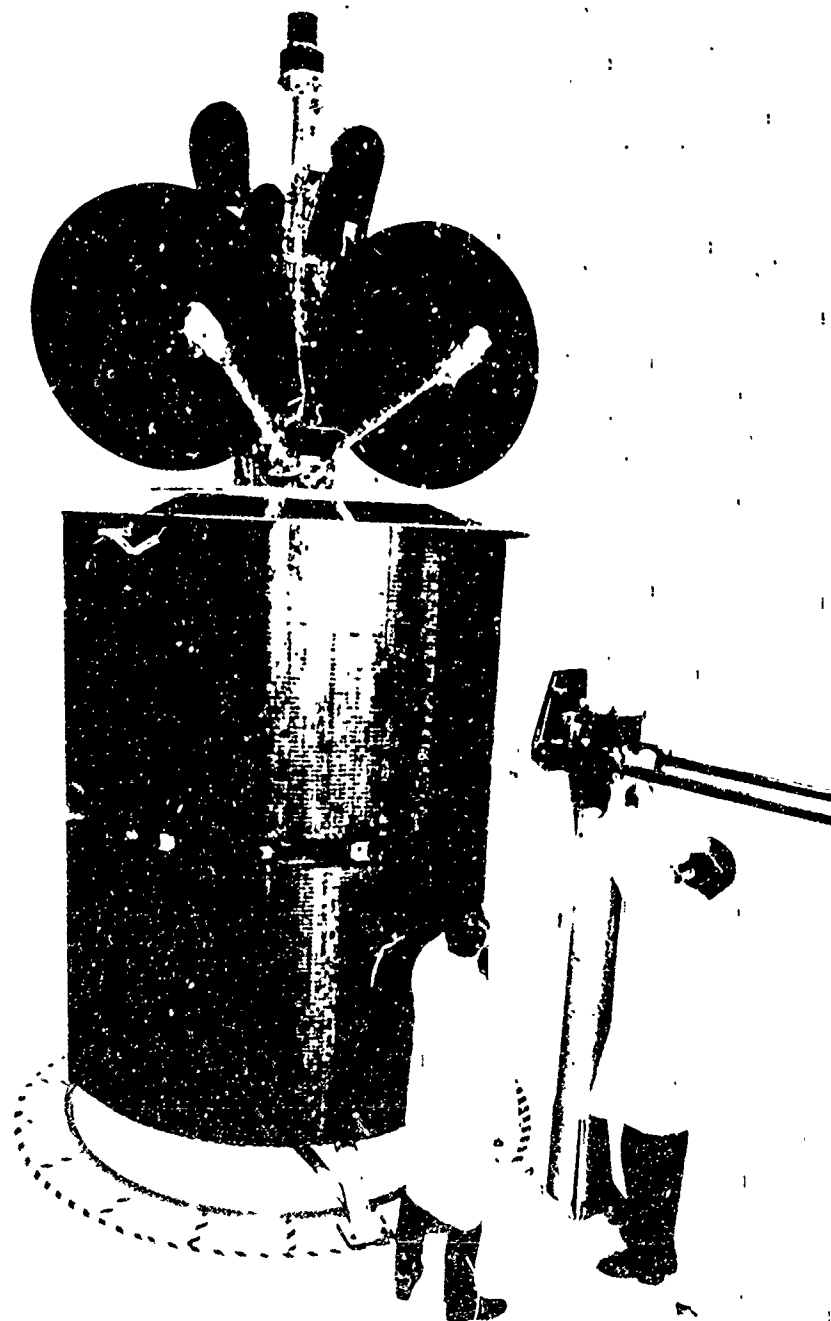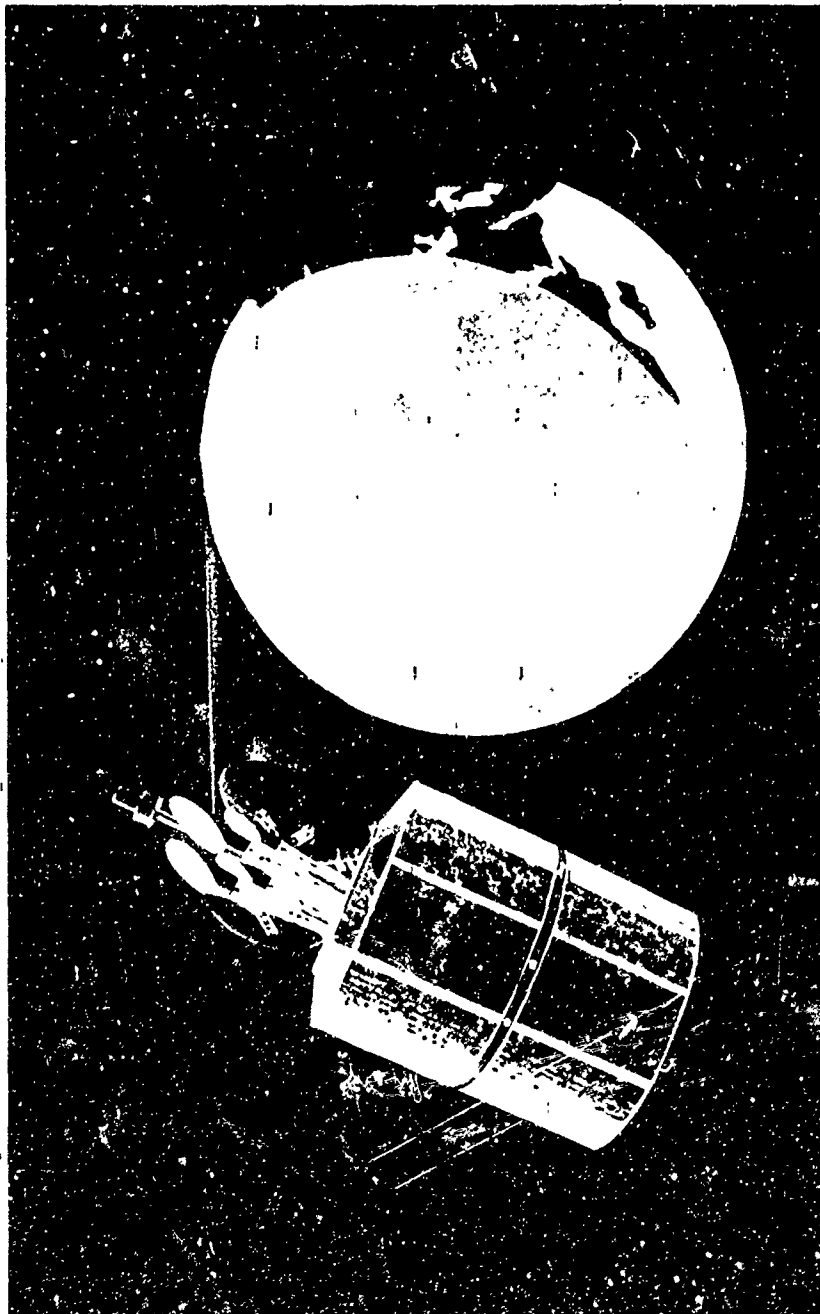
Figure 2. PUTCO IV

Figure 3. TELSAT IV Global Coverage

Figure 4. The Global System of Satellite Communications
(Map Shows Earth Station Locations, Satellites, and
Communication Links as of July 1, 1970)

Figure 5. Standard Earth Station

While the large earth stations have a capacity of thousands
of channels, it is possible to have smaller stations with one voice
circuit and one video channel. At COMSAT Laboratories there is a
complete earth station with a 16-foot dish which is called DICOM, a
Digital Communications terminal. The total earth station costs about
$100,000. It has been used for data, voice, and facsimile transmission
at data rates from 50 bits per second to 6.3 megabits per second.
This range of bit rates covers almost all of today's standards,
since 1.544 megabits is a standard T-1 terminal in the United States
corresponding to 24 PCM voice channels, and 6.3 megabits meet
requirements for Picturephone transmission.

To demonstrate the use of INTELSAT IV and small earth stations,
an 8-foot dish will be put on the *Queen Elizabeth II* as a maritime
communications experiment. Actually, an old radar antenna which had
the proper stabilization mechanism that ships need was borrowed from
Bendix and was modified for operation with INTELSAT IV. Plans call
for using the DICOM terminal and this antenna on the upper deck of
the *Queen Elizabeth II*. This terminal will transmit either fascimile,
high-quality digital voice, or data. It will thus become possible to
connect into the INTELSAT system and call any place in the world
right from the ship. The INTELSAT network reliability is 99.9 percent,
based on the last 4 to 5 years of operation. We expect that a maritime
system would have similar reliability.

The National Science Foundation has used INTELSAT satellites for
some of their Anarctica experiments. The United States, through the
COMSAT Corporation, can make use of the space segment of the
satellite communications system on a noninterrupt basis for experi-
ments that lead to new services or data. The National Science Foundation
came to COMSAT with a request to run an experiment from Anarctica
using an unmanned earth station they had had developed under contract.
The command link, for example, was tested to make sure that, from the
COMSAT earth station in Jamesburg, California, the NSF transmitter
could be turned off remotely. All preliminary tests were successful,
and there is now discussion within INTELSAT on how to handle operations
on a commercial basis; i.e., actually rent satellite capacity. This
is an example of how the INTELSAT commercial satellite system can be
used--first in an experimental mode, and then to possible standard
commercial operations.

It should also be noted that a U.S. domestic satellite system
may soon be approved by the FCC. If COMSAT is allowed to provide
this system, Puerto Rico, Alaska, Hawaii, and the United States will
be interconnected.

In this system 132 antennas would be distributed throughout the
United States. Each antenna would cost approximately $250,000. A
domestic satellite network could then connect into the INTELSAT
system and provide instantaneous communications around the globe.

To close, it should be noted that experimenters in remote areas can use small earth stations (such as the one to be used on the *Queen Elizabeth II* or the National Science Foundation antenna) to send data or communicate with any place in the world. For coverage at the poles themselves, the system can be supplemented by a medium-altitude satellite. A satellite the size of Early Bird launched into polar orbit or a slightly inclined orbit periodically would "see" both an arctic-located station and an INTELSAı station. During these periods of mutual viewing, any station at the poles has instantaneous interconnec.ion around the entire world. A satellite plus launch costing around $15 million would allow this capability. If there are sufficient users, then the system can be economically justified, especially if unmanned operation is considered. Global satellite communication is already in operation; with a relatively small incremental cost, global arctic satellite communication will be feasible.

SOME PLANNING CONSIDERATIONS FOR ARCTIC DATA MANAGEMENT

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The term *data management* has many meanings and applications. For computer programmers, it refers to software programs and routines that move data through a computer center or data-processing complex. In this context, the first data management system appeared around 1958. Since then, computer technology has evolved to meet the growing needs of large industrial management information systems. Also, computer techniques are an outgrowth of military data-processing applications concerned with the manipulation of large data banks. To the traditional communicator, however, data management implies the movement of a digital bit stream through a transmission medium.

In this paper, data management is defined as the orderly cycling of information through the entire data system--from point of origin to end user--on both a time basis and a cost-effective basis. The system and the hardware emphasize optimum man-machine interface through the shortest communication links.

Why the great interest and concern for managing data in the Arctic? To begin with, the area north of the Arctic Circle is a vast laboratory for environmental research. Scientific data have been collected there over many years in an attempt to determine the nature of the dynamic interaction of the atmosphere with the surface ice and water. Because of the hostile climate, the data are normally gathered over only short periods, at 2- to 3-month intervals during the year. More data are required on a year-round basis to enable researchers to construct scientific models from which weather changes may be forecast.

The Arctic Ocean is also virgin territory for the development of transportation. Except for Soviet shipping along the Northern Sea Route, the Arctic Ocean has been more an object of scientific study than a route to anywhere. Icebreakers, whaling ships, and the tanker *Manhattan* have made limited penetration of the ice pack. Government and industrial interests now exploring the possibilities of surface shipping and submarine transport of Alaskan oil to Europe are providing pressures for more knowledge and planning. Enroute navigational data services will be needed to control the

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movements of ships, aircraft, and land vehicles. Weather forecasts, traffic warning bulletins, and vehicle position reports are examples of daily information flow through a communication network.

Coastal communities are sparsely settled and contain the barest of modern communications. Radio broadcasting is available to some settlements, but generally television and public telephone service are lacking. However, domestic satellite systems planned by the United States and Canada will soon bring more dependable telecommunication services.

While some basic community and commercial communication needs of the Arctic are being met, little attention has been paid to the data collection requirements of scientific groups. Too little time has been spent in planning for data collection and distribution facilities, and procedures that would economically disseminate the acquired information.

In planning an effective data management system, the areas of concern are:

- Data mix and volume.

- Data format and recording.

- Data access and dissemination.

- Data quality and monitoring.

- Cost.

Arctic data consist mostly of scientific, historical, and administrative type information. (See Table I.) Scientific and engineering data comprise the greatest volume of traffic to be processed in the near future.

Scientific data may be further categorized as perishable or archival. Perishable information (for example, field data) must be handled in real time since its value is generally for the near term. On the other hand, since historical (archival) information normally has no immediate time constraint, it can be processed on a low-priority basis, usually during off-peak traffic hours. Thus, the most effective processing occurs with the intermixing of real-time and archival traffic, resulting in a balanced but continuous flow of data traffic through the communication network with minimum blocking or overloading.

Collecting large quantities of field data must be complemented by timely distribution to users. Here, the chief concern is the transmission of the data from remote locations to distant users, who may require instant availability of the information.

TABLE I

POTENTIAL ARCTIC DATA MIX

Area	Type of Data
Scientific	Environment (meteorology, oceanography, acoustics, sea ice conditions, radiation, seismology) Geology Glaciology Physiography Hydrology
Navigation	Position reports (land vehicles, aircraft, ships, submersibles) Weather conditions Sea ice conditions
Business/administration	Computer time sharing TWX/teletype Data processing (accounting, engineering)
Community	Broadcast (radio, television) Telephone Teletype
Archival	Glacier inventory Ice island data Arctic history Expedition reports Scientific findings Geographics International research reports

Area	Type of Data
Surveillance	Identity/location (airborne, surface, underwater)
Education	Library Television
Emergencies/rescue	Aircraft Surface/land craft Ships Submersibles
Medical	Patient reports Clinical records Medical histories Diagnostics

These data appear at the sensor output in either digital
(1's or 0's) or analog (continually varying waveform) format.
It would be desirable to have all sensor outputs in digital form,
but this is often impossible, due to instrument design limitations
and/or a concern by the investigator that significant information
will be lost in the conversion. Consequently, care must be exercised
in selecting the transmission medium to carry the information to
the point of distribution. Analog circuits usually carry narrowband
traffic, so they would be unsuitable (without conditioning) for,
handling higher bit rate digital traffic (above 2,400 bits per
second) where low digital error rate performance (better than 10^{-5})
and circuit cost control are necessities.

Where feasible, the data should be recorded at the sensor
location in a form which can be easily removed at each service cycle
or at the end of a particular mission which may vary from several
hours up to 6 months. If possible, all data inputs should be auto-
matically recorded in a way which readily lends itself to computers
and EDP technology. Generally, this implies digital recording on
magnetic tape. Punched cards and paper tape are also suitable where
the amount of data handled is relatively small.

Unfortunately, many of today's sensors used in arctic scientific
work are not designed with direct digital recording readouts. When
such recording equipment is not available, consideration should be
given to creating a centrally located facility where analog-to-digital
conversion may be performed. Seven- and nine-track magnetic tapes
are commonly used for storing the processor's input data. Analog-
to-digital conversion is performed in binary or binary-coded decimal
at recording densities from 200 to 800 bits per inch. Standardized
recordings should also use ASCII* character formats. All data
recorded on magnetic tape must be compatible with IBM tape transport
standards.

A sequence of standard symbols that will convey the data
through the transmission process should be developed. A format or
a series of formats should be adopted that will satisfy the data
needs of a variety of potential users. Presently, no single format
exists that encompasses the requirements of all national and inter-
national data collection agencies. Some current reporting formats
are shown in Table II. These formats must be examined from the
view of user-required parameters, ranges, and accuracies. Formats
must be flexibly structured to allow for additional measurements and
for expansion of the data base. Existing formats are designed to
perform either a real-time function or an archival function. No
single format seems to be used for both. For example, meteorological
data are processed routinely on both a real-time basis and an
archival basis, with formats and data-handling procedures being well
developed.

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*American Standard Code for Information Interchange.

TABLE II
REPORTING FORMATS
ENVIRONMENTAL DATA

Format	Basic Data	Source
SHIP	Meteorology	WMO
ARTST	Sea surface temperature	NAVOCEANO
BATHY	Bathymetry	NODC
METAR	Aircraft weather	WMO
BAXBT	Expendable ship bathy-thermograph	NODC
TDF-11	Meteorological tapes (ships and auto buoys)	NWRC
ICEAC	Aircraft ice observations	NAVOCEANO
ICESH	Shipborne ice observations	NAVOCEANO
ICECO	Shore station ice observations	NAVOCEANO
HISTD	Water-std	NODC
HIDRO	Water-temp/salinty	NODC

LEGEND:

WMO - World Meteorological Organization

NAVOCEANO - U.S. Navy Oceanographic Office

NODC - National Oceanographic Data Center (NOAA)

USCG - U.S. Coast Guard

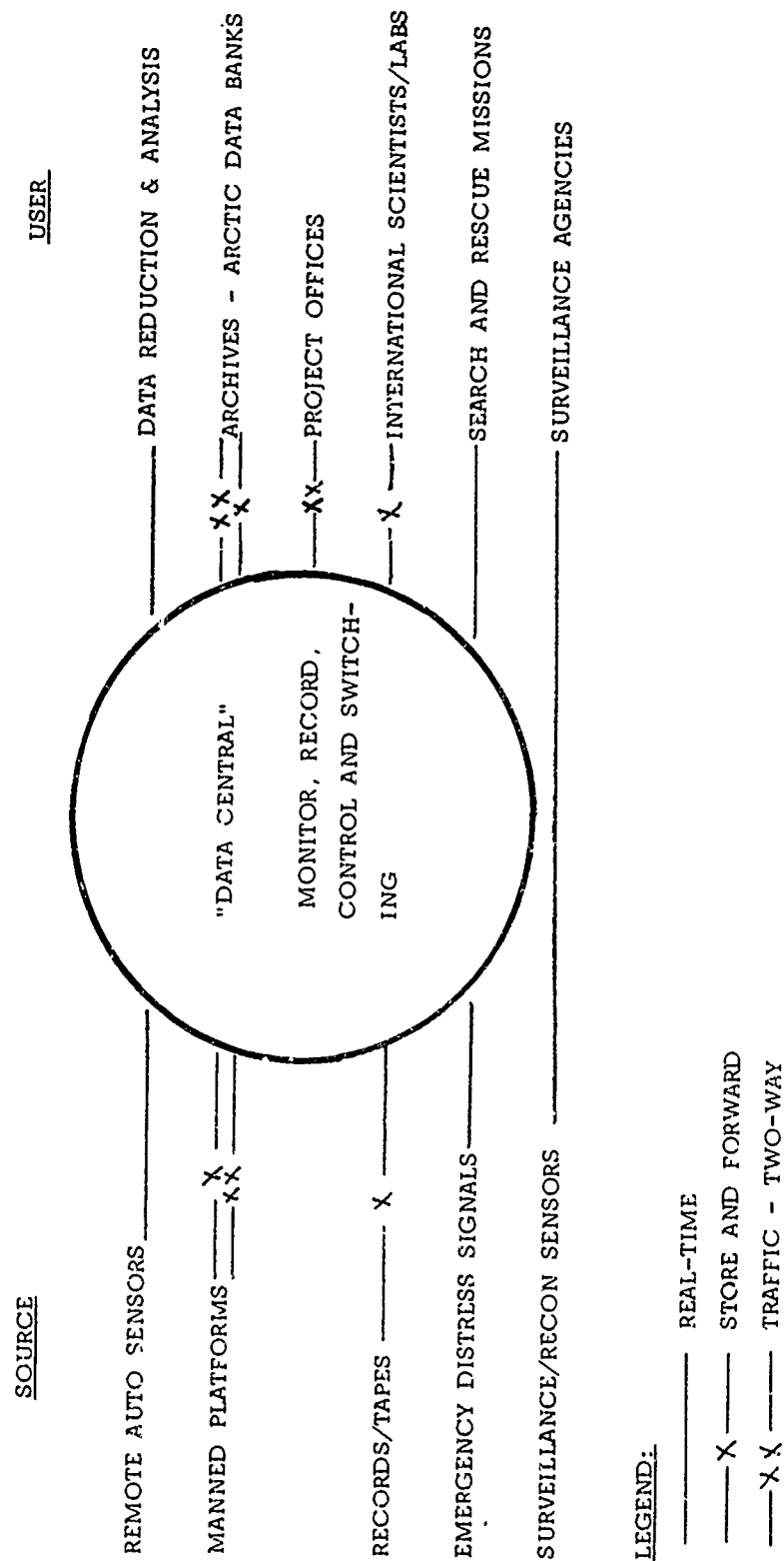NWRC - National Weather Reporting Center

The U.S. Navy Oceanographic Office and the World Meteorological Organization have developed codes for reporting sea ice conditions which have been accepted for international use. To facilitate proper routing of the data, further formatting according to the point of acquisition--below surface, surface, or above surface--is appropriate.

A matter of general concern which has considerable impact upon the routing of data and the cost of delivering such information is the sampling rate of the measured parameters. While no agreed-upon time standard exists for sampling of meteorological, oceanographic, or sea ice parameters, it would be wise to plan for some uniformity. A Coast Guard sensor workshop has recommended a 3-hour sampling interval for meteorological data and a 1-hour interval for oceanographic parameters. The desired planning goal should be to establish a single sampling rate for all data where practicable.

Access to the data should be provided at a minimum number of locations in the system (preferably at geographic sites of maximum user concentration and at sites where access to the system by unauthorized users might be more readily controlled). Some sort of changeable privacy code which becomes part of the header format should be devised. Provisions should also be made to sample and record sensor outputs on location (manned field sites) to detect equipment failures, outside interference, and experiment design errors as well as to provide protective backup against catastrophic data transmission failures. This activity should be closely coordinated with the overall data quality checking operation at a central data monitoring, control, and switching facility. Real-time data should find its way through the distribution network with a minimum of delay. This might be achieved by assigning dedi-cated circuits between the input points and the end terminals. Under normal circumstances, because of the limited availability of long-haul channels and the high cost of leased data circuits, this approach is impractical.

A more efficient solution would be to establish a centralized switching center where channels could be assigned on a demand or priority basis, thus maximizing utilization of the total communication network. This facility (Data Central) could be located at Fairbanks, Alaska or at Thule, Greenland where access and interconnection to other communication systems are readily achieved. The flow of traffic in and out of Data Central is envisioned as shown in Figure 1. Perishable information would be routed in real time through Data Central on a priority basis, while archival information would be received and dumped into a local memory bank where it would be held for transfer to permanent data banks (Archives) when circuits become available. Surveillance and Emergency/Rescue traffic would be routed instantly and directly to the cognizant user organization with Data Central functioning as a secondary monitoring point. To maintain the high order of operational capability required of a large-scale information system, Data Central is expected to perform additional services such as:

Figure 1

DATA FLOW CHART

SOURCE

REMOTE AUTO SENSORS

MANNED PLATFORMS

RECORDS/TAPES

EMERGENCY DISTRESS SIGNALS

SURVEILLANCE/RECON SENSORS

USER

DATA REDUCTION & ANALYSIS

ARCHIVES - ARCTIC DATA BANKS

PROJECT OFFICES

INTERNATIONAL SCIENTISTS/LABS

SEARCH AND RESCUE MISSIONS

SURVEILLANCE AGENCIES

"DATA CENTRAL"

MONITOR, RECORD, CONTROL AND SWITCH-ING

LEGEND:

REAL-TIME

STORE AND FORWARD

TRAFFIC - TWO-WAY

- Check format, priority, and quality of incoming data.

- Monitor condition of communication circuits.

- Validate user security.

- Generate archival records.

- Initiate polling routines for remote automatic sensor stations.

- Reproduce tapes for other users.

- Provide instrument calibration data to convert raw inputs to engineering units.

- Maintain traffic log.

- Perform circuit patching (interface with other communication systems).

- Prepare standard operating procedures for collection and distribution.

A chief concern of the investigator and experimenter is the level of accuracy of the acquired data. Accuracy is usually achieved by on-site monitoring of the instrument output. As an alternative, on-site measurements are often made with several kinds of instruments, although in any instance the quality of the data obtained is assessed by human interpretation. The technology associated with automatic sensing has reached the state where common measurement errors, equipment failures, and known anomalies are detectable and correctable. However, unpredictable variances which often plague a large-scale scientific undertaking are elements which only human intervention can remedy. Other factors which may affect the decision in favor of human intervention over automatic error detection and correction are: (1) cost of additional equipment; (2) complexities of maintenance and maintenance cost; and (3) the lack of qualified technical personnel to maintain the equipment.

Throughout this paper, inferences have been made regarding cost. Planning an effective data management system implies that one can achieve all the desired objectives for a price. Unfortunately, there are no "standard" or "typical" cost benchmarks that can be referred to as guidelines. The reason these cost parameters are not available is because no permanent large-scale data collection system exists in the Arctic Basin from which such statistics can be generated. Lacking such statistics, an appropriate guideline for achieving cost effectiveness is an awareness and control of the high-cost elements of the system. These are:

- The communication transmission network (the communication links should operate on full-time assignment and carry maximum traffic).

- The computer programming expense (the computer workload should be programmed to process only information that is necessary).

- The information handling and analysis expense (the format of the information should allow automated handling and analysis).

In any discussion concerning information flow in the arctic environment, one must not lose sight of community needs. Data services furnished easily and taken for granted in less hostile climates may become necessities for survival in the Arctic. For example, diagnostic medical information can be transmitted from urban centers to rural communities where the data can provide instruction for nurses and medical assistants. Other examples include such community necessities as education (native teachers can improve their materials and teaching techniques), mail service, newspapers, etc. The opportunity for community growth in the Arctic is limitless, bound by man's needs rather than by his technology.

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MODULAR SHELTERS FOR ARCTIC APPLICATIONS

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The concept of modular structures for remote sites, especially those subject to severe environments, has been used for many years, but only recently have advances in materials technology, construction techniques, transportation equipment, and erection procedures allowed for rather sophisticated designs. This paper will discuss (1) typical systems now under development for application in arctic environments, and (2) modular concepts for future applications.

MODULAR SHELTERS

The significant aspect of the modular shelter is that it can be used as a building block for large complexes (buildings with several thousand square feet of floorspace) which are now beginning to find use in the support of scientific and development activities in the Arctic. In the future, when even larger structures will be required in the Arctic, the modular structure concept will provide a simple solution at minimal construction costs. Foreseeable applications for large structures include offices, computer complexes, living-dining-recreation facilities, and large laboratories.

There are three purposes for providing a single large facility rather than many small facilities: (1) to facilitate movement between various areas (e.g., living and work areas, office and laboratory, etc.); (2) to minimize heating requirements (i.e., smaller overall external surface area); and (3) to reduce overall material and transportation costs. Obviously, erection costs will be higher for larger structures, but it now appears that the best configuration for a large facility is a few large buildings rather than many small ones.

Although the use of modular units for large facilities has been stressed, they are also well suited for small facilities or even single-shelter applications. In fact, the single "cube" unit is still the optimum configuration where living or working accommodations are required immediately upon arrival at the site.

Modular structures are designed in three basic configurations:

1. The cube is a prebuilt structure which is transported to the site in an erected configuration. It can be completely outfitted in the production plant with plumbing, heating equipment, furniture, and other facilities to support life. It allows for instant usage after delivery to the site, and it can be used as a single shelter or

integrated into larger complexes. The principal advantages are less on-site labor, quicker on-site utilization, and lower initial fabrication cost. Principal disadvantages include the need for large handling equipment and high transportation cost if the cube is not shipped as a self-container.

2. The knockdown unit has structural components which are prebuilt and assembled. To allow,for a small shipping package, final joining of the walls-floor-roof system, along with final assembly of electrical and plumbing systems, is done at the site. Furthermore, heating equipment and other material which are to be used in the knockdown unit are transported in a separate package. There are design concepts, however, which combine the advantages of the cube and knockdown unit to eliminate the separate packaging problem (e.g., kitchens which are cubes up to the counter tops and a folding upper wall panel which allows the roof to drop down to approximately one-half its final height). The knockdown unit can be used individually or in large complexes. Principal advantages of the knockdown unit are minimum shipping cube, self-container for shipping, ease of handling and redeployment, and short erection time (about halfway between cube and panelized structure). Principal disadvantages include higher cost than cube or panelized structures, on-site final assembly of electrical and plumbing systems, and shipment of internal equipment and furnishings in a separate container.

3. The panelized structure features prebuilt components (such as roof, floor, and walls) and preassembled electrical and plumbing systems. All final assembly of components is done on-site. Interior furnishings and equipment are shipped in separate packages. Principal advantages of the panelized structure include minimum shipping cube, low initial cost, and ease of handling at the site. Principal disadvantages are large labor requirements at the site; lengthy erection period; requirement for separate packaging material or container to transport panels, equipment, and furnishings; and potential delays in erection due to misalignment or missing components. (The last mentioned problem can be overcome by a trial erection of the structure prior to packaging for shipment.)

CONSTRUCTION TECHNIQUES

At present, most modular units are constructed of treated wood framing and plywood paneling. An exterior covering of prefinished metal (steel or aluminum) is usually placed over the basic wood structure for protection from the elements. Fiberglass or a closed-cell thermal insulation is used in the exterior wall panels. Where temperatures are below the freezing point of water for extended periods, closed-cell insulation must be used to preclude the buildup of ice in the insulation. Interior furnishings are conventional, drawn heavily from equipment which has been recently developed for operations at remote camp sites (e.g., oil well drilling sites).

The basic construction technique now used is structurally adequate, but to minimize weight and cost plastics such as polyurethane can replace the combination plywood sheeting and metal covering. At this time the technology associated with fiberglass sheeting is well developed, but the ability of plastics such as polyurethane to function as wood products in withstanding loads and accommodating fasteners (nails, screws, etc.) requires further development. A potential solution is to utilize a fiberglass-polyurethane sandwich panel for the basic thermal insulation system. Additional joint development is required, and the costs of fabricating these panels would have to be decreased to be competitive with existing materials.

Where open cell thermal insulation can be used, a prime candidate for the basic structure of the next generation of arctic modular shelters is the paper honeycomb-fiberglass faced plywood sandwich panel. Costs for this type of structure are approaching the costs of the standard wood stud panels, and this type of structure has superior strength and wear characteristics. Also, these structures allow conventional joining techniques, thereby eliminating a joint development program.

As larger facilities are needed in the Arctic for computer complexes, laboratories, and other high-density floor loading requirements, the use of aluminum structures will become more prevalent. Development work is continuing along these lines, and rather sophisticated modular shelter systems with computer deck, complete EMI shielding, and other special requirements will become available.

A complete new generation of modular shelters is now under development by various agencies of the Department of Defense for other than arctic application. Construction techniques used in these shelters emphasize the lightweight shelter concept and employ the aluminum-paper honeycomb and aluminum-foam sandwich panel technology. Although DoD shelters are usually smaller than those required in the Arctic and far more costly than those now in use, some of the concepts for maintenance and kitchen facilities have direct application to arctic uses. Also, if the DoD concepts involved the more conventional construction techniques, significant cost reductions would be possible. The entire subject of potential uses of military shelters as modular units in the Arctic certainly should be explored further.

A comparison of significant physical properties applicable to shelter performance is given in Table I.

PACKAGING AND TRANSPORTING

The concept of modular shelters is based on obtaining the economy of factory production and on minimizing labor and setup time on-site. For these reasons, all modular shelters should be built as cubes. However, packaging and transporting large cubes often result in difficult handling problems, wasted space in the cube, and excessive transportation costs. This dilemma indicates that each

TABLE I

PHYSICAL PROPERTIES OF SHELTER CONSTRUCTION MATERIALS

Material	Ultimate Tensile Strength (psi)	Density (lbs/cu ft)	Modulus of Elasticity (psi)	Thermal Conductivity (Btu/hr-ft -°F)
Fiberglass (spray up mat)	20,000	90.0	1×10^6	0.12
Fiberglass insulation	0	1.1	0	0.02
Polyurethane				
Low density foam	50	2.2	--	0.02
Medium density foam	200	6.0	--	0.02
Elastomer	15,000*	70.0	--	Low**
Polystyrene	90	2.5	-	0.02
Wood (Douglas fir)	11,000*	34.0	1.6×10^6	0.06
Steel (low carbon)	60,000	490.0	30×10^6	26.0
Aluminum (6061-T6)	38,000	163.0	10×10^6	118.0

* Flexure strength
** Exact value not available

shelter requirement must be considered along with the overall
logistics of supplying shelters at remote sites.

Packaging and transportation are two of the more costly elements
in providing shelters at remote sites. In shipping cubes to remote
sites, transportation costs are often twice the initial cost of the
shelter. To minimize transportation costs and to utilize less
expensive transportation vehicles, knockdown and panelized structures
are used, but these usually result in additional packaging costs
and on-site work. Packaging costs can be minimized if the basic
shelter structure is used as part of the package or container. This
is relatively easy for knockdown units but may be difficult for
panelized structures.

Utilization of some of the construction techniques listed
above (especially the fiberglass-coated structures) should reduce
packaging problems by allowing the basic shelter structure to act
as crating material. Also packaging schemes which make liberal use
of foamed packaging material will minimize transport damage, thereby
reducing rework costs. Unfortunately, except for generalized shelter
designs to enhance packaging characteristics, each shelter system
must be packaged separately.

Transportation of modular structures has improved since the
introduction of large tracked vehicles, helicopters, and the C-130
Hercules. Significant advances in transporting large facilities
can be expected with the introduction of heavy-life helicopters and
air-cushion vehicles.

ERECTION

When considering the overall logistics of supplying shelters,
the last element to be discussed (unless the unit is to be capable
of redeployment) is erection at the site. Simplifying the basic
structure and allowing for easy handling procedures will aid in
minimizing erection time and labor requirements. However, field
handling equipment has major shortcomings which must be overcome
if field erection techniques are to keep pace with shelter technology.

Although multistory shelter complexes can be erected with
hand-winching devices, the work can be time consuming. For example,
a crane can do the same work in one-third the time required by hand-
winching devices. At present, though, it is difficult to obtain the
services of a crane at remote sites. Highly desirable for future
construction activities would be a mobile crane with a lift capacity
of about 25,000 pounds to handle the largest cube and containers
now proposed for arctic shelter applications. Also, a modified
tracked vehicle with forklift capability is desirable.

The above discussion on the erection of shelters deals primarily
with handling devices rather than with the shelter itself. This is
due to the fact that shelter technology is surpassing field erection
handling equipment technology. To keep up with advances in shelter

technology, new developments in field handling techniques are
needed. Otherwise, the time will come when advanced shelter systems
will be available with no way of erecting them in the field. If
this situation occurs, it will be necessary to revert to a shelter
technology similar to what is available today.

CONCLUSIONS

Modular shelters for arctic applications have advanced signifi-
cantly in the last 25 years. Based on materials technology and
shelter design concepts now being developed for military and
commercial applications, it appears that significant advancements
can be made in modular shelter technology. To accomplish this,
more study and development are required in materials application
to shelter design. Evaluations should be made of shelter systems
now being developed for the military to determine their applicability
for arctic use. A systems study should also be undertaken to optimize
the overall packaging-transporting-erecting sequence associated with
deploying modular shelters in the Arctic. Finally, a parallel
study should be implemented to improve field handling equipment.

LIGHTWEIGHT ARCTIC SHELTER CONCEPTS

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The need for improving arctic mobility for both civilian and military requirements has been well established. Within the mobility concept, improved shelters are needed for a variety of arctic functions. Arctic shelters require special design attention to assure that the structures will exhibit those features necessary in the arctic environment.

The solution to mobility must encompass quality manufacturing and tireless attention to detail. HITCO's approach to the problem has been to organize its shelter effort from three standpoints-- management, manufacturing, and material.

After reviewing many candidate products, Hitcore was selected as the basic material for a new shelter study. Hitcore is an integrally woven panel material where the face skins are mechanically connected through a series of woven webs. The space formed between the face skins and webs can be foam filled for improved insultation. A task team was assigned by HITCO Shelter Management to develop a Hitcore shelter. Team members consisted of U.S. Polymeric for resin technology, Defense Products Division for manufacturing technology and stress analysis, Woven Structures Division for Hitcore woven material, and the University of Cincinnati for conceptual and compatibility designs.

After the basic design was established, a prototype was built. This original Hitcore shelter was designed by the U.S. Army Cold Regions and Research Laboratory as an air-transportable shelter which could be easily erected in remote sites. The shelter utilized the shipping container as a modular floor. Each container was 4 feet wide by 16 feet long and holds roof, arch, and wall sections to accommodate an 8-foot module.

To erect a shelter 16 feet wide by 24 feet long, three shipping containers would be required. After the contents have been removed from shipping containers, they are turned bottom up and locked together to form a continuous floor. After the floor boxes are positioned, the arches are attached to this floor and locked at the arch center point. Shelter end walls can be placed at any arch location. This design feature allows a building to be assembled with end walls only, or partitions can be arranged at 4-foot intervals. Shelter partitions can be moved at any time to accommodate different shelter functions. After the arches are located, the roof sections are positioned and secured.

A Hitcore shelter 16 feet wide, 24 feet long, and 8 feet high was tested at Eglin Air Force Base. When assembly was complete, the shelter was placed in the environmental chamber. After 18 hours in an ambient temperature of -61.6°F, the temperature at waist level was 77°F, and the temperature along the floor was 59°F.

Thermal efficiency tests of the shelter were run in an ambient of -59°F. Temperature readings were taken on the floor surface, on the ceiling surface, in the waist-high air, in the ambient air, and on the exterior roof surface. Only the waist-high air and ambient temperatures were used for thermal efficiency calculations. All electrical power input was considered to be heat input since all the operating electrical equipment contributed to shelter heating. Also, the metabolic heat gain from the four people conducting the test was included as part of the heat input. After all measurements were taken, the thermal transmission rate of the shelter was determined to be 0.1615 Btu per square foot for each degree Fahrenheit difference between interior and ambient air temperatures per hour.

At the conclusion of the thermal efficiency tests, the shelter was removed from the environmental chamber and tied down for wind load tests. Structural movement was recorded by tracing the movements of three plumb bobs hanging from the arches over targets mounted on the shelter floor. Wind velocities of 100 mph were sustained for 10 minutes, with a high of 105 mph being recorded. Wind loading produced no recordable structural movement. After the Eglin tests were concluded, certain design modifications were adopted to further improve the Hitcore shelter.

HITCO considered that the thermal properties and stability of the shelter were very good. We noticed, however, that improvement in shipping container size, arch improvement, and ease of assembly of the flexible roof would improve shelter efficiency.

With these improvements in mind, the floor box which was originally 4 feet wide and 16 feet long was redesigned and hinged at its midpoint. This change resulted in a shipping container/floor box which was 4 feet wide and 8 feet long. This size is compatible with military and international shipping constraints. Also, this size allows easier handling in the field.

Changing the shipping containers from 16 feet to 8 feet in length forced changes in the arch length. The arch was redesigned to accommodate the new length constraints. The basic shape of the arch was redesigned to improve performance. Originally the arch was a generated curve which would allow a 6-feet-tall man to stand upright 2 feet from the sidewall. With the new design, a 6-foot-tall man can stand 1-1/2 feet from the sidewall. Roof sections were changed from continuous sections to double panels. The continuous roof section was heavy and hard to handle, especially in high-wind situations. The new panel approach offers a good solution, since each panel locks directly to the arch. One man can now install the roof sections

(several were required before). Special window panels are also available for use in the sidewalls and are interchangeable with the standard roof panels.

Additional design effort to improve the Hitcore shelter will result in significant advances, such as better utilization of floor-space, improved lighting, lower noise level, better leveling capabilities, improved floor box, compatibility with shipping standards, easier installation on-site, and an improved "U" factor.

A SPACEMAN'S VIEW OF ARCTIC EXPLORATION

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'After I was asked to prepare a paper for this symposium, I went
to the encyclopedia to find out what is really meant by "Arctic."
There were several definitions, such as the area north of 66°33';
or the area north of the last stand of trees; or all those points on
the northern hemisphere which have at least one 24-hour cycle per
year of uninterrupted sunshine. All these definitions sounded pretty
theoretical, so I chose my own. For me, the Arctic is a fantastic
frontierland, a place of human courage and drama, full of adventure
for exploring minds; home of some of the most awesome animals; an
area of dynamic interactions between air, water, and ice; a weather
kitchen of the world; possibly the richest oil lands yet discovered;
and a place of fragile ecology which could be disturbed by human
interference, perhaps with tragic consequences for the ecology of
large parts of the more populated areas of the globe.

Several years ago, I had the privilege and the good fortune
of spending a week in Antarctica. That was certainly the most unusual,
the most fascinating week in my life. Under the good auspices of
Phil Smith, we flew from McMurdo to the dry valleys, to Cape Crozier,
to Byrd Station, to Plateau Station, and to the Pole. We traveled
in the middle of the austral summer, and we enjoyed sunshine with
good visibility for 24 hours every day, except for a few brief periods
of whiteout.

In the Arctic Basin, the northern summer is not the best season
to travel, even though the sun is up most of the time. The ice thaws
and breaks; the snow becomes soft; the permafrost melts at the
surface; the tundra at many places turns into a wet, soggy swamp.
For logistics operations, winter months are preferred over summer
months.

There is still another, even more profound, difference between
the south polar and the north polar regions. Antarctica is a continent
with well-defined shorelines. It is a continent for science. The
Antarctic Treaty keeps military, commercial, and private interests
out of the country. No claims of national sovereignty are acknowledged.
As a consequence, international cooperation flourishes in Antarctica;
scientific projects are underway all over the continent, many of them
with crews of international composition.

Arctic regions, in contrast to Antarctica, are a theater of military interests and activities. There is commercial exploitation, hunting and whaling, fishing, mining, and oil drilling in the Arctic Basin. The land areas of the Arctic are the northern tips of Asia, America, and Europe. North of these continental extensions, there is only water, ice, and snow, and an occasional ice island. This large and diversified region is the scene of the arctic research programs of our country and of other nations. These programs include the study of arctic land, water, ice, and snow; of the very dynamic and often violent interactions between air and ocean; of animal and plant life: of natural resources; of the interplay between man and his environment; and of the effects of nature, some of which are of particular fascination and beauty in these high northern latitudes.

These broad programs of research cover five distinct regions. First is the region below the surface, accessible by digging or drilling on land and ice and by diving into the ocean. Subsurface regions may contain minerals, ores, natural gas, and oil; the ocean contains plankton, fish, and other animals. The permafrost region under the northern tundra has been a special object of research for many years. It has been recognized as an important factor in the local ecology, but its exact role in the delicate balance of temperature and water budgets is still poorly understood.

Second, the surface--some of it covered by rock, soil, or tundra, most of it consisting of snow, ice, or water--is where many arctic animals, most plants, and most human explorers and exploiters are found. Many of the routine observations of weather, ice drift, ocean currents, and ecological factors are made on the surface, and many of the specific effects caused by human interaction with the environment will be most prominent on the surface, such as the opening of oil fields and the construction of pipelines, deposit of waste materials, oil spills, or heat disposal.

Third, the low atmosphere, with its very active and powerful interface between air and ocean, governs the exchange of heat and moisture. It influences not only the local weather, but also the climate over large portions of the earth. The observation of winds, temperatures, cloud coverage, and humidity in arctic regions will always serve importantly in global surveys of weather and climate.

Fourth, the high atmosphere with ionospheric layers, the auroras, the whistlers, and other high-altitude phenomena are of great practical interest because of their influence on radio propagation. In addition, the high atmosphere has always been a region of great scientific interest. Solar ultraviolet and X-radiations are absorbed in these layers, while cosmic rays interact there with the atmospheric gases.

Finally, the fifth region is outer space, which exhibits some peculiar features above the polar caps. Since the earth's magnetic poles are nearly coincident with the geographical poles, the Van

Allen radiation belts do not reach polar latitudes. Even very soft cosmic ray particles, however, can reach at least the upper layers of the atmosphere because there is not much of a deflecting magnetic force near the poles for particles of vertical incidence.

The common feature of these five regions of research is the requirement for observational data, and for the reduction and selective analysis of these data. Many of the required observations can be made from the surface, while others should be made from airplanes, from earth-orbiting satellites, or from subsurface apparatus.

In this need for observational data, a very interesting parallel exists between the program for polar research and the program for space exploration. The art of observing natural phenomena with a very wide array of instruments, automated as well as man-operated, has been developed to a remarkable level of precision and perfection in the framework of space exploration. Observations of the moon and planets, of cosmic ray particles and magnetic fields, of the sun and other celestial objects, and particularly of our earth from vantage points outside the atmosphere have provided us with an impressive amount of pioneering knowledge during the past 12 years. It is quite natural, therefore, that we should ask how the techniques of space exploration can be applied to programs of arctic research. This question is even more appropriate at the present time when the space program, after concentrating on the moon for 10 years, begins to turn more toward observations of the earth, and when practical benefits of space technologies to earthbound users attract more attention and interest among the people than the exploration of remote places in the universe.

The broad programs of arctic research and exploration require a number of supporting facilities, among them transportation, instruments, remote sensors, tools, equipment, data acquisition and data-handling systems, communication links, and human habitats. All of these must operate under extreme environmental conditions and with high reliability. This list is surprisingly similar to a list of space exploration requirements, even more so when consideration is given to the strong emphasis on earth observations from orbit. Indeed, many of the remote sensing systems now under development to survey the growth of crops and pastures; to monitor the use and misuse of land in populated areas; to update maps of areas which undergo rapid changes; or to observe the surface of the ocean for temperature, sea state, plankton, and even for fish, will prove very useful for the observation of arctic lands and oceans.

From the vantage point of a satellite orbit, a sensor can effectively see an area 400 to 600 km in diameter at one time and under the same condition of sun angle, depending on the satellite's altitude. Infrared and microwave sensors can take data by day or night, and microwave devices are even able to see through heavy cloud layers. Satellites flying over arctic regions in polar orbits are ideal observation posts for such phenomena as snow and ice cover, break lines in ice layers, cloud formations, plant growth, melt-water flows, ocean leads, animal migrations, oil spills, and smoke pollution.

These macroscale observations from orbit will add a new dimension to arctic research which traditionally has been carried out from the ground and from airplanes. However, satellites will not make ground observations superfluous, nor will they be the only contribution which the polar research program will receive from space technologies. One of the present arctic projects--the Arctic Ice Dynamics Joint Experiment, or AIDJEX--was established by American and Canadian scientists to study and measure during the next 5 years the effect of strains in arctic ice, and the stresses which water and wind exert upon the ice canopy. Hopefully, these studies will result in predictive computer models for the dynamics and heat budget of large ice and ocean areas.

Several drifting ice stations, manned and unmanned, will be established in the Beaufort Sea beginning in 1973. The Convair 990 airplane--equipped, operated, and owned by the National Aeronautics and Space Administration--has already flown several missions over the AIDJEX area with visual, infrared, and microwave sensors. During the next few years, ground observations at the AIDJEX stations and airplane observations will establish a data base which will eventually lead to a continuous and fully automatic monitoring system for arctic ice dynamics. This monitoring system will consist of automatic stations on the ice and polar satellites which will interrogate the ground stations and at the same time probe the atmosphere and the surface with remote sensors. The data will be relayed to a central station conveniently located at a lower latitude.

Members of NASA have already developed a microwave sensor and imager that will permit the observation of ice conditions through clouds and at night. Nimbus F, to be launched in 1973 into a polar orbit, will carry such a microwave imager. Dr. Fletcher, Director of the Office of Polar Programs of the National Science Foundation, called the sea ice cover one of the greatest variables in the environment of the earth's surface. So far, there is almost no quantitative knowledge of its large-scale properties, although these properties have a profound influence on the climate of the northern hemisphere. Remote sensing from satellites is expected to provide knowledge for a better understanding of these properties as well as the delicate balance of the processes which maintain or remove the arctic sea ice.

The AIDJEX Project, and other projects with elaborate ground observation programs, will use unmanned stations placed on the ice, or on other surfaces, for making observations of environmental factors over long periods of time. An automatic station of this kind has recently been developed at Stanford University for the Artar tic Research Program (Figure 1). Experience gained in the space program was utilized in the design of the automated systems and in the selection of high-reliability components. In later versions, an isotopic electric power source, developed for space applications, may be used with this station. The observational data of these remote stations will be transmitted to a satellite and retransmitted to a receiving station in California.
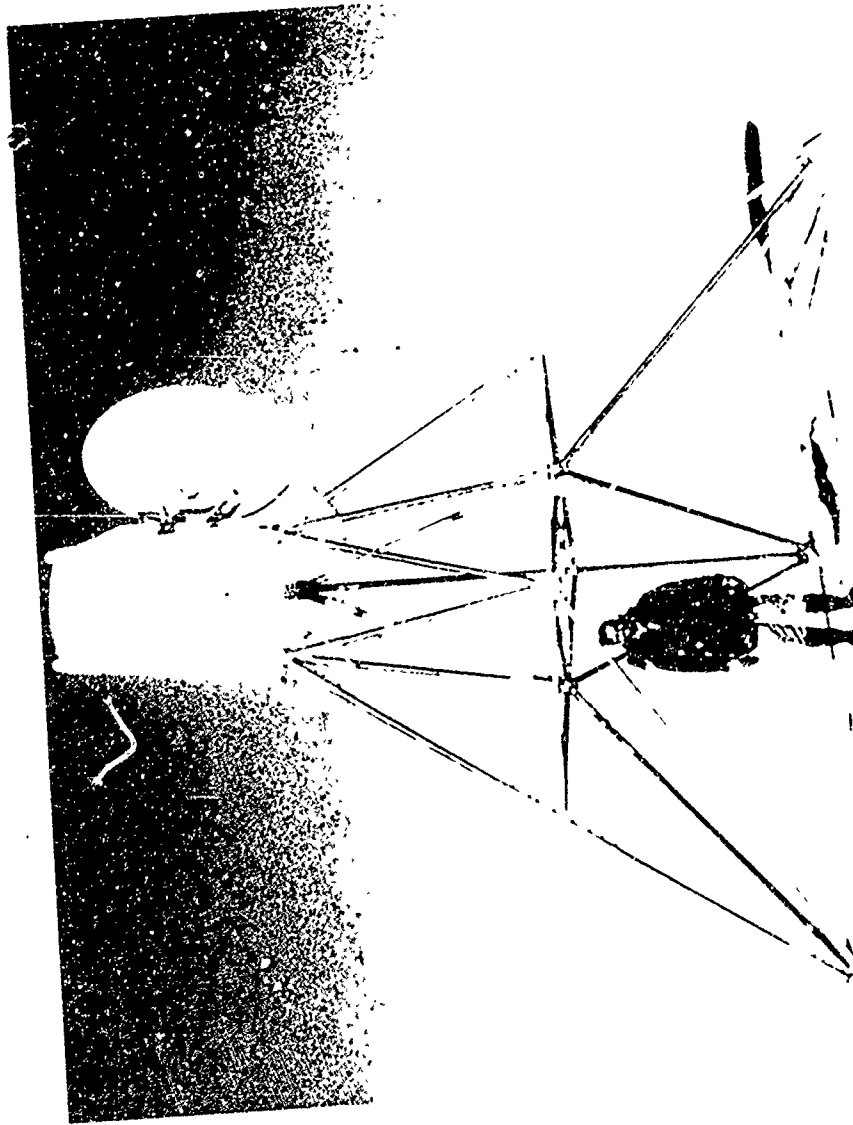
Figure 1. Automatic, Unmanned Station

Another unmanned station for observation of environmental para-
meters is the National Data Buoy (Figure 2) presently under develop-
ment in this country. (It will be tried out under NASA auspices at
the Mississippi Test Facility.) This buoy is also fully automatic.
It measures parameters of the ocean and the atmosphere, and transmits
the data to a satellite for retransmission to the users. Conceivably,
this data buoy will also find application in the arctic research
program.

Besides automatic stations, there will always be a need for
manned observation posts. The support of human observers in the
hostile environment of polar regions is not an easy task. The habitat
must provide shelter, heat, food, communications, power, and accom-
modations for technical and scientific work and for the usual functions
and needs of human beings. NASA has been engaged in planning, designing,
and testing habitable space capsules for several years.

Some effort has been expended on a modular unit which can be
used in connection with the Space Shuttle and also with the Space
Station of the 1980s. This unit contains sleeping quarters, facilities
for personal hygiene and food preparation, and room for scientists to
work. In space, it will be entirely self-contained, with air purifica-
tion, oxygen replenishment, and water recirculation. As a part of
the development program of this space laboratory unit, a ground-
based version will be built and operated in a 1-g environment (Figure 3).
This unit can accommodate a group of scientists for up to a month's
time; it can be transported by aircraft and placed by helicopter in
mountain areas, islands, glaciers, swamps, deserts, rain forests, or
ice floes. Again, it is conceivable that the earth version of this
future space laboratory will serve as a manned field station for
arctic researchers.

For several years, NASA has been operating aircraft equipped
with instruments for observations of the earth, the atmosphere, and
space. The best equipped of these aircraft is a Convair 990 which
has been used extensively for photographing the earth, for observing
auroras, meteors, and ionospheric phenomena, and for astronomical
studies. For many observations to be made by arctic researchers,
such as surveys of snow and ice fields, or ocean and tundra, of
icebergs, animals, and human settlements, of mining and oil drilling
activities, and of road building and pipeline laying, aerial monitoring
will be invaluable. The tremendous potential of viewing and photographing
from high altitudes is borne out by the impressive pictures taken from
airplanes in visual, infrared, and microwave regions. By comparing and
combining pictures taken at different wavelengths, it is possible to
extract such detailed information as vigor and health of plant
growth; kind of plants; plankton content of the ocean; surface temper-
ature of land and water; thickness of snow layers; wetness of soil
and snow; and with some further development, even the depth of the
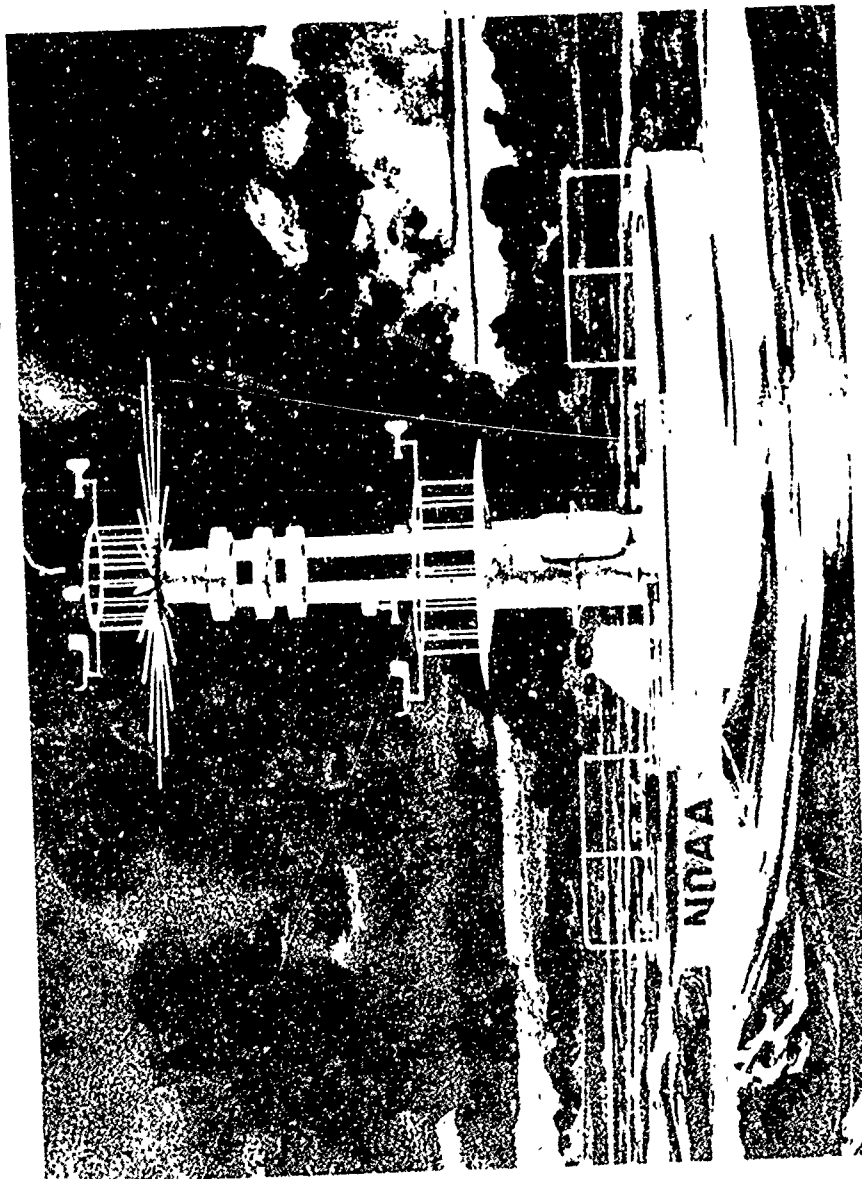permafrost.

Figure 3. Engineering Experimental Phase (EEP) Buoy

Figure 3. Ground-based Space Shuttle

As the development of photographic techniques, of electronic image tubes, and of infrared and microwave sensors progresses toward better observational capabilities, surveying will be done more by satellites than by airplanes. U.S. satellites launched into polar orbits comprise less than 10 percent of the total number of satellite launchings, but they have already returned valuable data about the polar regions. Satellites, as compared to airplanes, have the advantage of seeing a larger area with almost vertical incidence of the line of sight, and of being in constant line of sight with receiving stations on the ground. The art of resolving minute details, even from a large distance, is making rapid progress; even our present capabilities should be sufficient for most observations needed in arctic research.

The Earth Resources Technology Satellite (ERTS), to be launched in 1972 int a polar orbit (Figure 4), will carry equipment for picture-taking in the visual, infrared, and microwave regions (Figure 5). Each of its trajectories will include a 4,000-km path over the Arctic Basin. The ERTS Project will undoubtedly provide valuable support to the AIDJEX Project and to other studies in arctic and antarctic regions.

A further step in our earth-observing capabilities will be taken by Project EREP (an earth resources experiment package to be carried on the Skylab in 1973). EREP consists of cameras and sensors which will take pictures of selected areas of the earth's surface in the visual, infrared, and microwave regions. The astronauts on Skylab will monitor and watch the sensors; they will help select specific targets; and they will judge the quality of performance of some sensors. This effort is expected to contribute substantially to the development of remote sensor systems which can later be used as automated systems on unmanned satellites. Skylab will be launched into an orbit with 50° inclination. It thus cannot observe polar regions; however, the observing techniques to be developed with the help of the EREP system will be useful to arctic research on later polar-orbiting satellites.

The huge quantity of observational data which satellites with remote sensors are capable of producing will require data-handling systems of unprecedented capacity and speed. One ERTS satellite alone will produce 40,000 pictures every day. Systems for selective analysis must be fully automatic and fast. Such systems have already been built; they show, for example, only the water surfaces over a given area, or only the thickness of snow layers, or only human habitats. The arctic research program will undoubtedly profit from work in this field now underway at NASA.

Besides ground stations, airplanes, satellites, remote sensors, and data systems, there is another element which the two great exploration programs, the polar program and the space program, seem to have in common--an acute shortness of funds for supporting a strong and efficient program. NASA, with a little over $3 billion for the current fiscal year, is still considered rich by many outside observers.
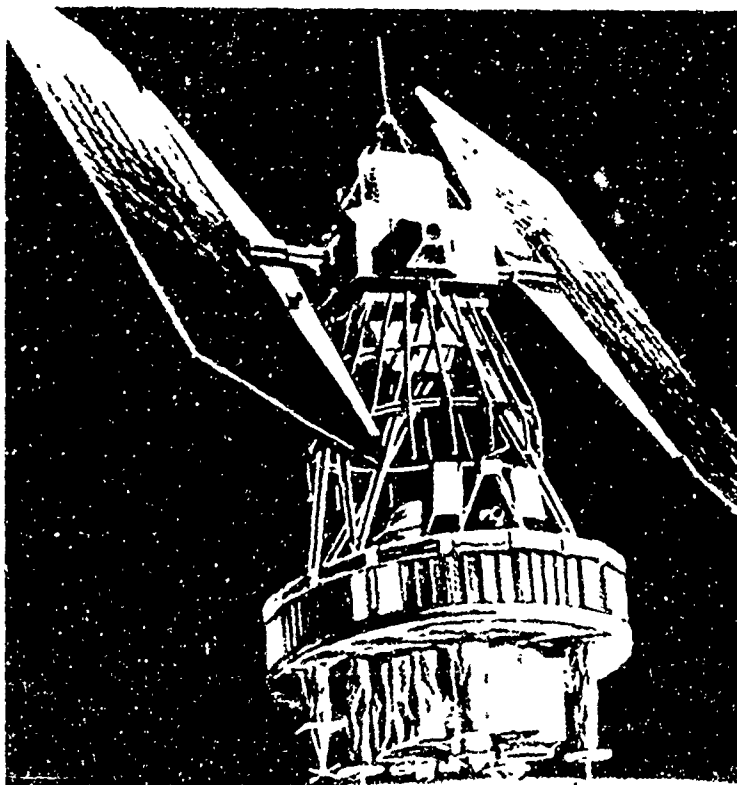
Figure 4. Artist Concept of ERTS in Earth Orbit

- 1972, POLAR CIRCULAR ORBIT, SUN-SYNCHRONOUS

- 800 kg TOTAL, 200 kg INSTRUMENTS

- 912 km ALTITUDE

- 500 WATT ELECTRIC POWER (SOLAR PANELS)

- 3 VIDICON CAMERAS, 3 SPECTRAL BANDS.

- MULTI-SPECTRAL SCANNER, 4 SPECTRAL BANDS.

- 40 000 PICTURES PER DAY.

POLAR OBSERVATIONS: CLOUD COVER, ICE COVER, ICEBERGS.
SNOW COVER, PERMAFROST, WILDLIFE, OCEAN CURRENTS, TEMPERATURES

Figure 5. Earth Resources Technology Satellite

However, when measured against the vastness of the space program
with its innumerable projects for lunar and planetary exploration;
for solar and stellar astronomy; for space and earth physics; for
transportation systems into orbit, to the moon, to planets, and into
deep space; for a low-cost, reusable earth-to-orbit shuttle system;
for a permanent, manned orbiting space station; and for a complex
system to survey, monitor, and even manage the earth from satellite
altitudes, the NASA funds are extremely austere.

There is not much hope the situation will improve soon. Citizens
today are increasingly concerned about the immediate problems of our
country and the earth: hunger, poverty, urban congestion, over-
population, power shortage, pollution. Many feel that the money
should be spent to buy food and build houses instead of launching it
on an escape trajectory into space or burying it under the polar ice.
To these citizens, we try to explain that there is only one way to
approach a solution to these profound problems of mankind, and that
is by learning more about our earth and its environment, about the
natural processes that govern the weather and influence the growth
of crops, about the resources of our earth, and about the natural
balance between the many factors that make our planet livable for man,
animal, and plant. In particular, we try to explain that only through
science and technology, through research and exploration, and through
the constant expansion of the frontiers of human knowledge can we hope
to improve the lot of man.

We know our colleagues in the polar program face the same
problem of dwindling funds, but we also know they share our belief
that we must solve our human problems not by mending the holes but
by learning how to treat and to use our planet better. This belief,
in fact, is not a discovery of our modern times. There is an old
proverb, perhaps hundreds of years old, which says: "Give a hungry
man a fish, and you feed him for one day. Teach him how to catch a
fish, and he will not go hungry again for the rest of his life."

POWER AND HEAT PRODUCTION SYSTEMS

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In identifying power and heat production systems needed to support an arctic program, it is important to consider the evolution of these systems. In the past, conventional systems (gas turbines, internal combustion engines, diesel engines) have been used for most arctic applications. In the future as exploration expands, more reliance will be placed on advanced power systems that reduce the logistic burden and fulfill such requirements as long life, remote unattended use, and quick-reaction capability. Ultimately, the dependence on resupply can be reduced and extensive, sustained operations can be attained by relying on large energy sources such as nuclear reactors. These plants not only can provide power to a central location, but also they can serve as the primary source of energy for power systems remote from the central location. Hydrogen fuel production for powering heat engines is an example of this concept.

The arctic environment places strict life, efficiency, weight, and reliability requirements on power and heat production systems. The high transportation costs and remote use are analogous to those of the space program. Examination of power systems designed and proposed for space use is, therefore, one technique of evolving systems that meet arctic requirements. It remains, however, for such systems to pass the test of economics.

REQUIREMENTS AND CONSTRAINTS

Figure 1 summarizes some of the requirements of arctic electrical power and heat production systems. In addition to normal operation, systems must withstand the arctic environment during transport, storage, or standby. Power systems, particularly those used in remote or quick-reaction situations, must be air transportable. Protection will be required for systems which are affected by low ambient temperatures, such as batteries, fuel cells, and heat engines that use relatively high freeze point cyclic fluids. Retrieval and/or disposal after use will be needed for nuclear-powered systems, and isotope-powered systems must be safe in any foreseeable accident situation.

The types of systems can be classified as permanent, portable, or motive. Permanent systems will be emplaced for long time periods,

and they probably will not be moved within their useful lifetimes. Power levels will vary from multimegawatts for large manned bases to a few watts for remote, unattended monitoring functions. Portable systems might be reused in support of quick-reaction, information-gathering expeditions. The power level will likely be in the kilowatt range if a life support and experiment requirement has to be met. Motive power systems will be in the range of tens of kilowatts, with the reliability somewhat more critical than in the other classes. Both permanent and portable systems might furnish electrical and thermal power for heating, water and waste management, and instrument operation.

Examination of the environment versus intended use leads to constraints that the power systems must meet. Remote use and high transportation cost infer long life, minimum or no maintenance, and ideally no fuel resupply. A versatile multipurpose power system would reduce costs. A single system which can provide electrical power and thermal power for space heating, water purification, and waste disposal is preferred. Consideration is given here to systems based on technology that could be used within the next 5 years. Finally, environmental effects must be considered. Preferred systems are those which can use their waste energy to minimize pollution.

Figure 2 classifies power systems according to power level and operating time. Nuclear reactors and chemical heat engines such as gas turbines and diesels can supply megawatts of power for long time periods. Many conventional and several reactor systems have already been effectively used in arctic an' antarctic situations. Permanent large stations similar to that at McMurdo Sound that can be resupplied by ship could require these systems. Power systems for remote or quick-reaction situations in the range of watts and kilowatts have to meet more difficult requirements. Recent and anticipated developments in these power systems might meet arctic performance and cost goals.

A comparison of energy sources and conversion techniques for requirements in remote or quick-reaction situations is shown in Figure 3. All candidate power systems are adequate for permanent and portable use. Motive power systems include batteries, fuel cells, and chemical heat engines. Batteries may be considered for small vehicles that remain near an electrical recharging facility.

Low-temperature operating problems caused by increased activation and decreased electrolytic conductivity may be alleviated by using ammonia electrolytic batteries or by heating with electric or chemical sources. Fuel cells also tend to boil at low temperatures. Fuel cells using hydrogen-oxygen reactants can make use of present technology, but fuel cells using hydrocarbon or derivative fuels are not well developed. Therefore, with the widespread use of hydrocarbon fuel in the arctic, fuel cells with a hydrogen reactant do not appear to offer significant logistic advantages.
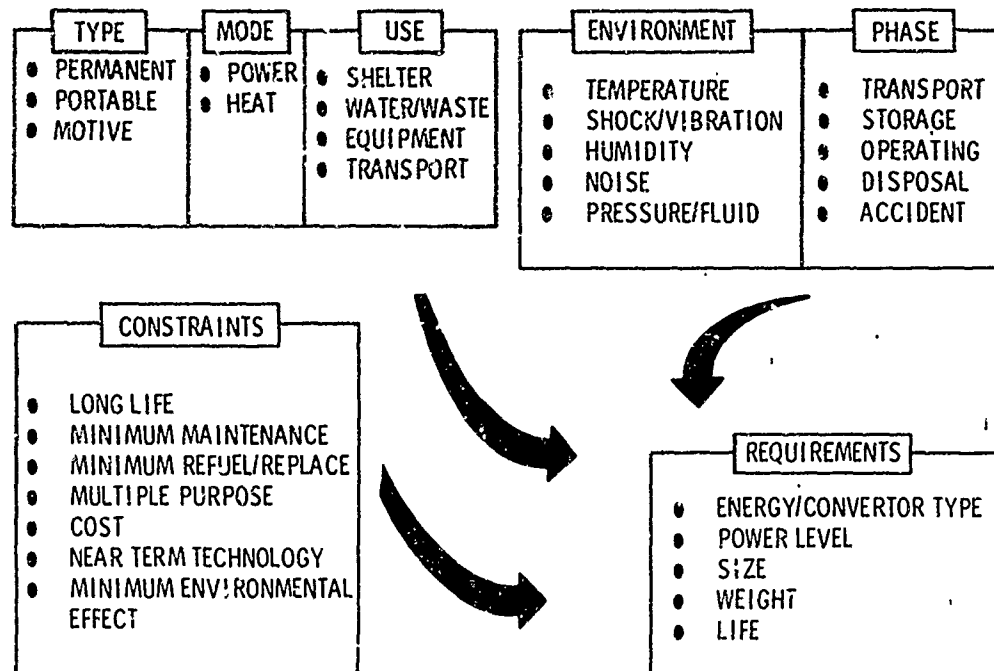
TYPE	MODE	USE
● PERMANENT	● POWER	● SHELTER
● PORTABLE	● HEAT	● WATER/WASTE
● MOTIVE		● EQUIPMENT
		● TRANSPORT

ENVIRONMENT	PHASE
● TEMPERATURE	● TRANSPORT
● SHOCK/VIBRATION	● STORAGE
● HUMIDITY	● OPERATING
● NOISE	● DISPOSAL
● PRESSURE/FLUID	● ACCIDENT

CONSTRAINTS
● LONG LIFE
● MINIMUM MAINTENANCE
● MINIMUM REFUEL/REPLACE
● MULTIPLE PURPOSE
● COST
● NEAR TERM TECHNOLOGY
● MINIMUM ENVIRONMENTAL EFFECT

REQUIREMENTS
● ENERGY/CONVERTOR TYPE
● POWER LEVEL
● SIZE
● WEIGHT
● LIFE

Figure 1.   Requirements Definition

	DAYS	MONTHS	YEARS
MEGAWATTS	● CHEMICAL HEAT ENGINES	● CHEMICAL HEAT ENGINES ● NUCLEAR REACTORS	● CHEMICAL HEAT ENGINES ● NUCLEAR REACTORS
KILOWATTS	● BATTERIES ● FUEL CELLS ● CHEMICAL HEAT ENGINES	● FUEL CELLS ● ISOTOPE HEAT ENGINES ● CHEMICAL HEAT ENGINES ● NUCLEAR REACTORS	● FUEL CELLS ● ISOTOPE HEAT ENGINES ● CHEMICAL HEAT ENGINES ● NUCLEAR REACTORS
WATTS	● BATTERIES ● FUEL CELLS ● CHEMICAL HEAT ENGINES ● CHEMICAL THERMOELECTRICS	● BATTERIES ● FUEL CELLS ● CHEMICAL HEAT ENGINES ● CHEMICAL THERMOELECTRICS ● ISOTOPE THERMOELECTRICS	● FUEL CELLS ● CHEMICAL HEAT ENGINES ● CHEMICAL THERMOELECTRICS ● ISOTOPE THERMOELECTRICS

Figure 2.   Power System Regimes

Solar power systems are performance constrained due to the long periods of winter darkness. Use of wind sources infers exposure of rotating parts to the low temperatures, and freeze-up is presently a problem. Use of these systems may be considered for auxiliary or standby power in conjunction with energy storage or other non-environmental dependent systems.

Most of the power systems have the capability of utilizing their waste heat for water and waste management, and for heating functions. Batteries are an exception.

The chemically powered system will require fuel resupply for long missions. The logistic burden can be reduced by using high efficiency cycles as well as fuels which have a high energy content. Hydrogen-oxygen or hydrogen-air fuel cells are the most efficient engines of this type. H_2-O_2 reactant consumption will be about 1 pound per kilowatt-hour, while H_2 consumption using air would be less than 0.1 pound per kilowatt-hour. This can be compared to the specific fuel consumption of 0.5 to 1.0 pound per kilowatt-hour in present internal combustion engines.

Internal combustion engines using hydrogen fuel have also been proposed for terrestrial use. Most of this development is directed at low air pollution or noise-free operation which may ultimately also be of significance in arctic operations. Hydrogen can be obtained from ammonia, water, or hydrocarbon sources. Such systems may ultimately be effective in the Arctic, with reliance on a central station nuclear power system for off-peak hours to generate the hydrogen fuel.

Thermionic systems (which are attractive in power density) and magnetohydrodynamic systems (which are highly efficient) must have further technical advances before they can be considered for arctic use.

Systems for long-term, unattended use, such as weather or seismic stations, include batteries and isotope-powered devices. Small power uses will favor batteries and isotope thermoelectric systems. Batteries will likely be restricted to a 2-year life even at low drain rates, whereas longer life is expected from the isotope systems.

From the above discussion, three advanced types of energy systems emerge as primary candidates for near-term arctic use. These include isotope thermoelectric, isotope heat engines, and chemically powered heat engines. The elimination of resupply makes the isotope systems attractive. The waste heat of the latter two systems provide for water and waste management, which further reduce logistics and waste burdens.

ISOTOPE THERMOELECTRIC SYSTEMS

Isotope thermoelectric systems can reliably furnish electrical power in the range of microwatts to a few kilowatts (Figure 4).

| ENERGY SOURCE	CONVERSION	PERMANENT	PORTABLE	MOTIVE	WASTE HEAT CAPABILITY	NO FUEL RESUPPLY	NEAR TERM TECHNOLOGY	LONG-TERM UNATTENDED USE
CHEMICAL	• BATTERIES	•	•	•		•	•	•
	• FUEL CELLS	•	•	•	•		•	
	• THERMOELECTRIC	•	•		•		•	
	• HEAT ENGINES	•	•	•	•		•,	
	• MAGNETOHYDRODYNAMICS	•	•		•			
NUCLEAR ISOTOPE	• THERMOELECTRIC	•	•		•	•	•	•
	• THERMIONIC	•	•		•	•		
	• HEAT ENGINES	•	•		•	•	•	•
SOLAR/WIND	• SOLAR VOLTAIC	•	•			•	•	
	• THERMOELECTRIC	•	•		•	•	•	
	• HEAT ENGINES	•	•		•	•	•	
	• DIRECT	•	•				•	

Figure 3. Small Power System Comparisons
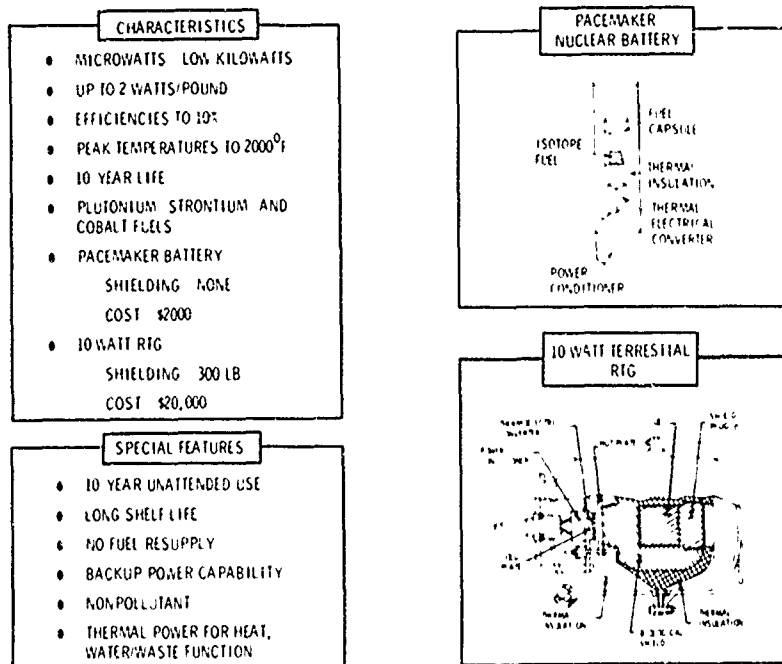
Figure 4. Isotope Thermoelectric Power System

Specific weights would range from 10^{-3} watt per pound at the microwatt level to 1 to 2 watts per pound at the upper power limit. Silicon-germanium thermoelectric generators have high efficiency at temperature levels of 2000°F, are rugged, and are long-lived. Other systems use bismuth-telluride or lead-telluride as a conversion material, but efficiencies are lower and specific power is limited to about 1 watt per pound.

The choice of isotope greatly affects the life potential, specific power, and generator cost. Plutonium-238, with a half-life of 89 years, requires little or no nuclear radiation shielding. These systems have the lowest weight, longest life, and the highest cost. Strontium-90, with a half-life of 28 years, and cobalt-60, with a half-life of 5 years, are the least costly but are the highest in weight because of the shielding requirement. As an example, a 10-watt electrical RTG designed for terrestrial application and shielded to give less than 10 mr per hour at 3 feet will weigh approximately 600 pounds. The weight of shielding using strontium-90 isotope fuel is about 300 pounds. Costs should be about $20,000 per unit in quantity production. These weight and cost differences tend to become less significant at electrical power levels below a watt.

Long-lived isotope thermoelectric systems will be an excellent choice for unattended arctic use. Systems designed for 10-year unattended use have a capability of about 80,000 watt-hours/pound at the 1-watt level. Heat to protect other equipment can be made available directly from the heat source which might be at a temperature of 2000°F or as waste from the generator cold side which could be as hot as 500°F.

Radioisotope thermoelectric generators have a long shelf life, and therefore would be useful in a quick-reaction situation or as a standby power system to protect some emergency life support function in case of prime power system failure.

The most significant development in these power systems has been the increase of operating life. The multi-Hundred Watt RTG is a space power system being developed by the Atomic Energy Commission. It is designed to furnish electrical power for the 10-year Grand Tour Mission. The generator furnishes about 150 watts and is a building block for power requirements of over 1 kilowatt. The specific power approaches 2 watts per pound, which is greater than any generator built to date.

Another significant development has been the use of plutonium isotope-fueled generators for heart pacemakers. The power level of these systems is about 200 microwatts. The weight is less than 0.1 pound. A unit cost of approximately $2,000 is anticipated. These systems have been miniaturized for implantation in the body and are also designed for a 10-year life. Generators of this type are expected to become commercially available from several U.S. and foreign manufacturers. The use of isotope fuels for this and other commercial applications is expected to decrease isotope costs.

The increasing use of reactor central station power plants will provide more radioisotopes than can be utilized in foreseen applications. Several important isotopes, such as plutonium and americium, are byproducts of spent reactor fuel recovery cycles. In the future, we can expect an increasing use of isotopes for applications which are now negated by excessive isotope fuel cost.

ISOTOPE HEAT ENGINES

Isotope-powered heat engines also may offer logistic economies. Figure 5 shows the performance of a Cobalt-60 Organic Rankine system. The system would produce 2 to 10 kilowatts with a specific power of about 1 watt per pound. Useful life is limited since the fuel has a half-life of only 5 years. Quantity production costs could be about $450,000, estimating the cobalt-60 price at $13 per watt and using a cobalt-60 fuel capsule sized at 31.4 thermal kilowatts (now being developed by the Atomic Energy Commission). It is adaptable to other power converters, such as Brayton cycles and thermoelectrics, and can also be used as a thermal power source.

This power system can be adapted to high power level, unattended situations and to small manned field stations. At a 10-kilowatt electrical power level and with an efficiency of 25 percent, 30 thermal kilowatts are available for space heating, snow melting, and potential integrating with water and waste management systems. In addition to the thermal energy, the gamma radiation from the cobalt-60 source can be used to kill bacteria in snow and ice, or in the sewage of the field station. Several waste treatment plants using cobalt-60 have been built in the United States. Although plant economics are controversial, the capability of the cobalt-60 to kill bacteria is not questioned.

CHEMICAL HEAT ENGINES

Concern with pollution has prompted chemical engine development activity by both government and commercial interests. This activity has centered on the use of low pollutant fuels such as propane and hydrogen, more efficient combustion, and lower specific fuel consumption. Development has mainly focused on engines of 100 to 250 horsepower for automotive use, with some attention being given to diesels and gas turbines used for central station power-peaking. In the future, attention will turn to engines below 100 horsepower, such as those used for small boats. This activity will benefit an arctic program by reducing air pollution. Certain inherent spinoffs, such as improved efficiency and decreased cost, may have a more substantial impact. Increased efficiency and lower fuel consumption would decrease petroleum logistic costs. Introduction of the gas turbine for high power automotive use such as trucks and buses will make available a new class of low-cost systems in the 250- to 500-horsepower range.

Figure 6 shows the characteristics of a class of low pollution external combustion engines. Power levels would be from 5 to 100 KWe, at an acquisition cost of $100 to $200 per KWe. Weights would be
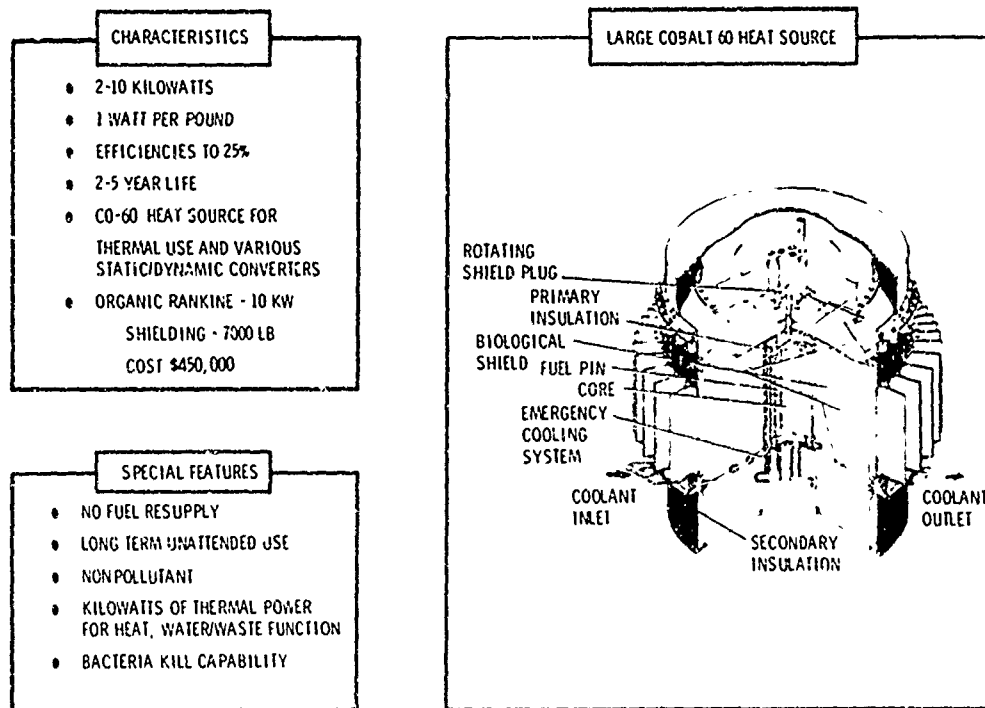
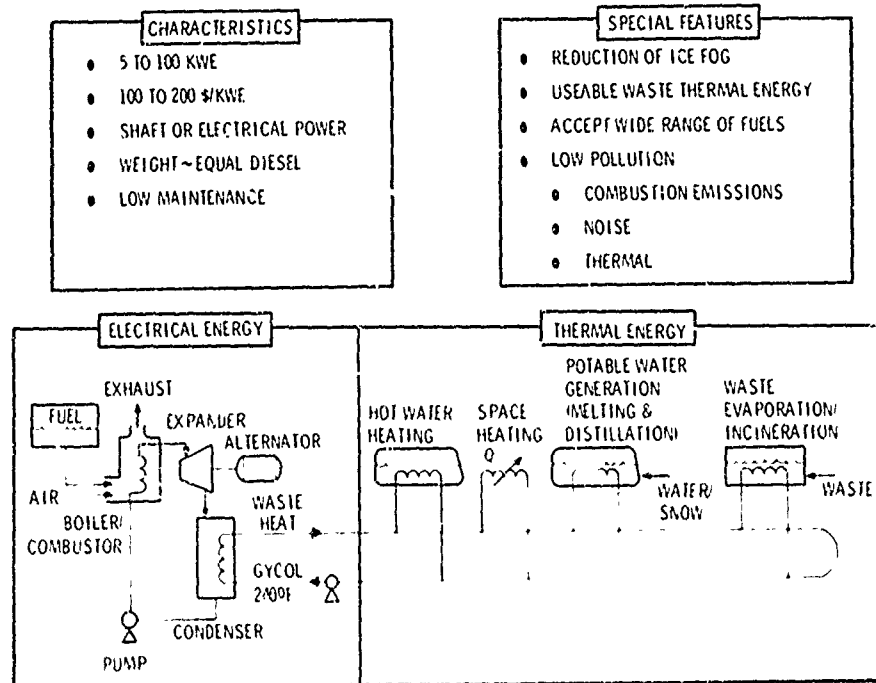Figure 5. Cobalt Organic Rankine Power System

Figure 6. Low Pollution External Combustion Engine

approximately equal to equivalently sized diesel engines. The external combustion process promises low pollution, since burning takes place continuously and more completely than in an internal combustion engine. Use of waste energy tends to cool the combustion exhaust, condense more water vapor, and reduce the arctic "ice fog" problem.

Engine coolant (as shown in Figure 6) or exhaust can be used for space heat, and water or waste management functions. Such engines have the greatest potential for versatile use in the kilowatt range, since they can be used for portable, motive, and permanent stations. For most arctic applications, these engines will result in the lowest costs.

INTEGRATED POWER LIFE SUPPORT SYSTEM

An example in the use of isotopes for life support is the Radioisotopes for Thermal Energy (RITE) program which is supported by the Atomic Energy Commission. Figure 7 illustrates a system intended for space use. All waste, including urine, feces, wash water and transport air, is purified, with the water constituent recycled and made potable. Plutonium isotope heat is used to evaporate water, catalytically pyrolize water impurities at a temperature of 1200°F, and incinerate the solid residue. The system, now in a demonstration phase, is sized to accommodate the life support needs of four men in a nominal 180-day mission. No electrical power is produced in this system.

The cobalt-60 heat source now being developed can be used for thermal energy only, or it can be coupled with a wide variety of energy conversion systems. A typical system using this heat source is shown in Figure 8. Here, it is assumed that the heat source will provide 10 kilowatts of electrical power in addition to thermal and nuclear radiation energy for the life support function. The potential water and waste functions could include sea water desalinization by distillation to provide pure water, or melting of ice and snow but with the degree of water purity being uncertain. Cobalt-60 irradiation at a level of 2.5×10^5 rads will kill bacteria in the water. Thermal and radiation energy could then be used to purify recycled water, if desired. Water might be segregated as "black" water which is toilet flush, urine, feces, etc., and as "white" water which has been used for washing and does not contain much solids. The white water could then be either recycled by irradiation and filtering for reuse as shown, or thrown away. Black water will be rendered nonpollutant by distillation and irradiation, with the solid residue being incinerated at temperatures of about 1200°F, using either thermal or electrical energy.

A 10-kilowatt electrical cobalt-60 system can have power generation efficiencies of 7 to 25 percent, depending on the conversion scheme. At an efficiency of 25 percent, some 30 kilowatts of waste heat are available at heat rejection temperatures of 200°F to 400°F. This is more than adequate for furnishing thermal energy for space heat and for satisfying the life support function for the assumed case in Figure 8.
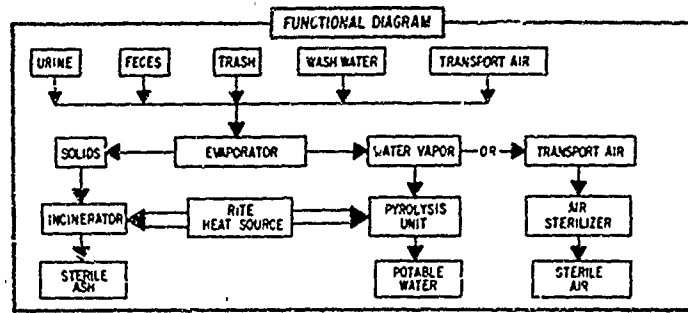
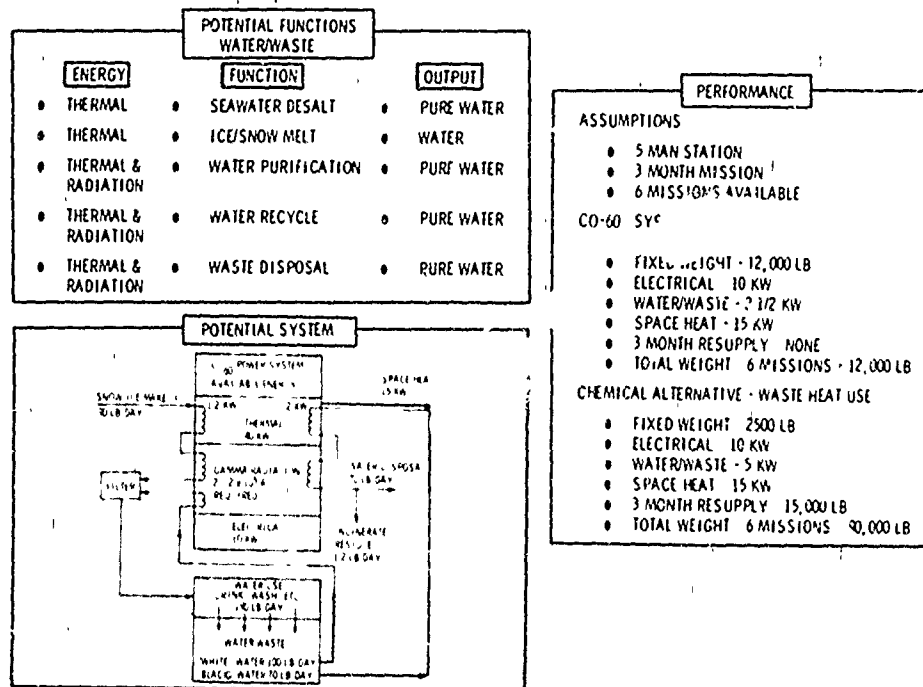Figure 7. Isotope Powered Waste Management System

Figure 8. Power System Life Support Integration Concept

The weight performance difference between a cobalt-60 system and a chemical engine for six 5-man, 3-month missions is also shown in Figure 8. The chemical engine also performs the space heat and life support function by use of its waste heat, although distillation is required to obtain pure water. The nuclear system weight of approximately 12,000 pounds is significantly less than the weight of the chemical engine (approximately 90,000 pounds). The nuclear system, though still more costly, will be used in specific situations where weight or resupply is critical.

FUTURE CONCEPTS

Future concepts for a sustained base operation would include a nuclear reactor as a prime source of electrical and thermal energy. Figure 9 identifies uses which would tend to reduce the base resupply problem with minimal environmental pollution. Thermal energy could be used for space heating, water desalinization, and waste disposal by distillation. In addition to the normal electrical uses, the plant could recharge batteries for motive or remote installations, and could reduce significantly the station petroleum product requirements by producing hydrogen fuel directly from water.

REQUIRED DEVELOPMENTS

The major developments needed in the next 5 years are summarized in Figure 10. The majority of arctic power applications will be filfilled by chemical engines. The current intensive development of low-pollution, high-efficiency engines for automotive use is concentrated at output power levels above 100-kilowatts, with little activity at lower output power levels. Arctic programs will benefit in logistics and low environment pollution with development of external combustion engines at output power levels below 100 kilowatts.

Several concepts including nuclear may be proposed for long-term, unattended use. Isotope-powered systems are available and are probably cost competitive at power levels in the fractional and low wattage ranges for missions lasting months and years. Power requirements for such missions in the low kilowatt range can be fulfilled by isotope systems currently under development, but their high cost indicates special situation use. Both of these isotope systems have had little use in the Arctic. Since the missions infer no-maintenance capability, these systems must be ultrareliable. In addition, special requirements such as space or component heating are often added late in the development cycle. These requirements may be dismissed as not being design crucial, but often they do adversely affect the system's reliable performance. Therefore, for successful use of power in a long-term, unattended situation, there must be an early definition of requirements, followed by development for the specific application, even though adaptable hardware already exists.

Integration of power systems with the life support function promises logistic be efits using either nuclear or conventionally
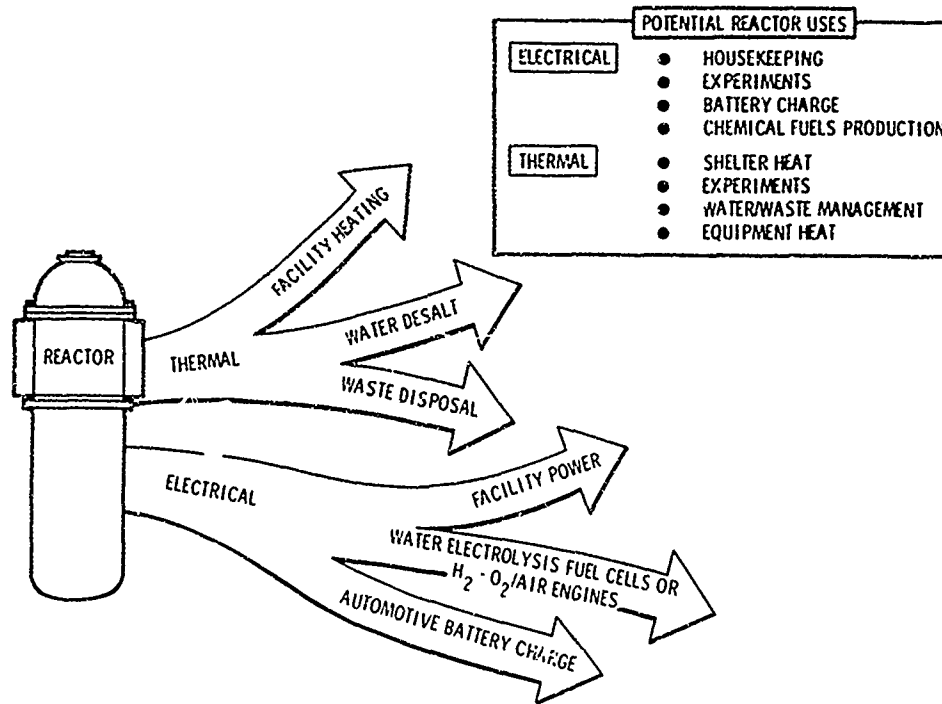
Figure 9. Future Concepts

● DEVELOP SMALL EXTERNAL COMBUSTION CHEMICAL ENGINES FOR QUICK
  REACTION, LOW COST ARCTIC USE

● DEVELOP ISOTOPE POWERED SYSTEMS FOR LONG TERM UNATTENDED ARCTIC
  USE

● DEVELOP RELIABLE INTEGRATED LIFE SUPPORT - POWER SYSTEM HARDWARE
  FOR ARCTIC USE

Figure 10. Required Developments

fueled generators. Also, nonpollution of the arctic environment by
even relatively small field parties may be a requirement of the
future. Development of reliable hardware for space and component
heating, snow melting, water purification and waste disposal,
integrated with power systems or otherwise, is required.

ARCTIC LOGISTICS SUPPORT TECHNOLOGY FOR WATER SUPPLY, AND FOR SEWAGE AND SOLID WASTE DISPOSAL

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Exciting possibilities exist for new concepts in water supply. sewage disposal, and solid waste disposal. Nowhere are such possibilities of greater concern than at polar outposts, although development of new concepts could also convert inadequate and wasteful practices to deeper purpose in temperate regions.

A review of arctic constraints, environmental management objectives, and experience leads to a number of questions and some unusual conclusions.

POLAR REGION CONSTRAINTS

The following cold region constraints are significant:

1. Cold stress is both intense and of long duration (1,2,3). Differences between interior and exterior air temperatures may exceed 140°F. Subsurface soil temperatures may be several degrees below freezing even during the warmest periods when air temperatures may be above freezing. Using Fahrenheit temperatures, at Barrow, Alaska, there are approximately 20,000 heating degree-days, 8,500 freezing degree-days, and approximately 500 "thawing" degree-days.

2. Biological reactions are generally retarded by low temperature. Aerobic reactions appear to tolerate cold stress with less deformation of anticipated response than anaerobic reactions. Putrefaction of organic material takes place slowly. Disease organisms may remain viable indefinitely under certain cold stress conditions (4,5).

3. Chemical reactions are generally retarded by cold stress. Common chemical disinfection is seriously influenced by low temperature.

4. Physical forces appear to be the dominant forces in nature in the Arctic.

5. Available fuel, transportation, supplies and materials, and skilled manpower are in short supply and relatively expensive.

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6. Almost all costs for facilities and services are high while at the same time indigenous people have a low ability to pay for facilities and services.

7. Goals for establishment and maintenance of environmental quality are now applicable to many arctic operations.

GENERAL COLD REGION OBJECTIVES

Some observers agree that the following general objectives are applicable in considering arctic water supply, sewage disposal and solid waste disposal facilities and services (6 to 13):

1. Concepts should be compatible with site conditions.

2. Each process, facility, and service should withstand thermal analysis favorably.

3. Practice should provide an effective barrier to chemical, biological, and physical insult to man or his environment.

4. Fail-safe procedures and processes should be incorporated into the system.

5. Energy and other resources should be conserved and utilized.

6. Simplicity and reliability should be incorporated into all facilities and services.

7. Requirements for skilled manpower should be kept to a minimum.

8. Facilities and services should be aesthetically acceptable and practical.

9. Maximum comfort and safety, required for man's adjustment to arctic life, should be inherent.

10. Practices should be compatible with the pattern and sequence of community development.

11. Establishment and maintenance of adequate services should be economically feasible through use of the chosen concepts.

PRACTICE AND EXPERIENCE

Little or no change has been made in basic concepts for water supply and waste disposal in decades. Much effort has been, and is being, devoted to study and perfection of technology for application

of old concepts, largely for temperate climate use. Effort to apply
existing concepts, standards, equipment, and methods to polar use has
been directed essentially toward alleviation of effects from cold
stress on conventional temperate climate systems and practices. In
lieu of adequate and detailed understanding of the ramifications
of cold stress, modification and observation of conventional system
performance under cold stress has been the only alternative. Environ-
mental management has been taken seriously only recently, insofar
as the Arctic is concerned.

With some difficulty and often at great expense, cold-stress-
modified, temperate-climate systems have been used in the arctic
basin. Although several installations have been made, operating
systems are few in comparison to need. Most northern communities and
groups have ignored the problem or dismissed the thought of adequate
facilities on grounds that proper facilities are too expensive, too
complicated, and possibly unnecessary.

There should be little wonder at the hesitancy to accept modified
conventional water supply and waste disposal practice for use in
the Arctic. Most of the concepts, technology, equipment, standards,
and practices that are employed in temperate regions are significantly
influenced by temperature. They are "heat loving" if not "heat
requiring" concepts and practices. Water supply source, treatment,
distribution, and storage are subject to undesirable response under
cold stress. Sewage collection, treatment, and disposal as well as
solid waste collection, stabilization, and disposal concepts and
practices are "heat sensitive." Heat is expensive in the Arctic and
insufficient heat will result in system failure.

CONCLUSIONS

Conventional (temperate region) concepts and practices are out
of harmony with the Arctic. It is an uphill battle to maintain heat
sensitive systems in a land largely characterized by its cold stress.
In building foundations in the Arctic, either so-called "passive"
or "active" approaches have been followed. It is even more important
that "passive" or "active" approaches in arctic water supply, sewage
disposal, and solid waste management be adopted. A passive approach
appears most promising in the far north. Systems which utilize cold
as a resource or are nonfrost susceptible offer intriguing promise.

Is there really anything wrong with using cold stress as a
resource in a land where it is dominant and for capture(14)? Can
water be stored in a frozen state instead of in heated reservoirs?
In an unsophisticated manner, indigenous people store their water
as ice. Is the freezing phenomenon an effective process for treating
both fresh water and used water? It desalts, removes dissolved and
suspended solids, and theoretically even excludes bacteria from the
ice crystal. Since water supply sources in the arctic basin may be
from ice, snow, salt water, ponds, lakes, rivers, and sometimes from

the ground, a wide range of treatment capability is necessary. If the technology and hardware for utilization of freezing as a treatment process can be developed, it would appear to offer flexibility with a minimum of plant. Could modular, portable, compatible systems be developed for water or wastes?

Would it be possible to use nonfrost susceptible transport media for transport of water or wastes? Nonfrost susceptible media might have some application as a mechanism for phase separation.

Although cold is available as a resource, man must de' end largely upon imported fuel for combustion to produce heat, light, and power. Even under the most favorable conditions, much of the energy in the utilized fuel is rejected to the environment. Is it possible to use this energy in water and waste processing?

It appears to be unsatisfactory to bury solid wastes in ice or frozen ground. Even after the best of conventional sewage treatment, some objectionable organic wastes are unstabilized. Incineration appears to offer the most promise for effective disposal of both solid wastes and sewage solids. Can such incineration be meaningfully related to heating system needs?

Joint consideration of utility needs in living unit concepts, the community plan, fuel, heat, power, light, water supply, sewage disposal, and solid waste disposal is fundamental. They are inter-related. Arctic cold stress affects each. Economy, simplicity, utility, adequacy, and acceptability are all based on the extent to which favorable interrelationship can be achieved.

Conventional processes for water supply and waste disposal require an almost continuous and large input of heat energy to be effective in the Arctic. Supplying the necessary energy through large imports of fuel is not realistic. Radical departure from conventional temperate climate concepts is indicated. Polar solutions must be developed in response to polar needs. Import of energy must be conserved and the cold resource must be exploited to fully meet water supply, sewage disposal, and solid waste management needs in the Arctic.

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MEDICAL SUPPORT AT ARCTIC RESEARCH STATIONS

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Why should medicine be a topic at a symposium on arctic logistics? The word logistics is quickly associated with such functions as transportation, procurement, and storage, but not so readily with medical aspects. Yet a glance at a dictionary will show how encompassing logistics is, and an examination of the medical activities required to support arctic research stations will reveal why healthy individuals and their maintenance affect the remaining life support systems.

In discussing the medical aspects of polar living, the environment and other available life support systems must also be taken into account, for all three are closely related and have a direct bearing upon the health of personnel.

Polar living still presents a harsh environment that can at any time demand from an individual the utmost in physical stamina and mature judgment so that he can act quickly and positively in order to survive. This require: men in excellent physical condition, well trained, and with a stable, mature personality. They must also be able to adapt psychologically to a strange, adverse environment and be congenial with others in a small group if they are to pull their share of the load, not only in their specific job area or scientific endeavor but also in the general maintenance and operation of the station.

The specific environment has a marked influence upon the degree of medical evaluation undertaken. Will the man be only at a large, well-manned station such as the Research Laboratory at Point Barrow; or will he be on a small ice island with very limited resources; or will he be at a summer camp somewhere on the tundra. In all these conditions, the primary function of any medical program should be preventive medicine, with contingency planning in cases of injury or illness. The saying "an ounce of prevention is worth a pound of cure" is even more apropos for polar areas. Not only are medical facilities limited in many places, but also easy access to the available facilities may be limited. When individuals are lost due to injury or illness, their replacement is even more difficult.

The selection of personnel is of prime importance. Particular emphasis should be placed upon the physical and psychological aspects of men destined for small polar stations and field parties, where they will be relatively isolated for weeks or months. The U.S. Navy,

in support of the National Science Foundation's Antarctic Program, annually screens personnel under consideration for deployment to the Antarctic.

The isolation and environment in Antarctica is more severe than in the Arctic, but the general need for similar physical evaluations for arctic-bound personnel is still present.

For antarctic duty all personnel--military and civilian---are given complete physical examinations, including a dental evaluation, at selected screening centers and naval hospitals. In addition to the physical examination, personnel who will winter over (spend both the summer and winter in Antarctica) are given a psychiatric evaluation.

The psychiatric screening consists of a written evaluation and a clinical interview by a psychologist and a psychiatrist. The written forms elicit relatively standard information concerning the subject's personal history, motivations, values, and personality self-descriptions. The clinical interviews are designed primarily to identify those candidates who manifest psychopathology of such magnitude as to preclude their selection to winter over. An attempt is made to describe and evaluate the attitudes, motivations, personality traits, defense mechanisms, and behavior patterns that affect work motivation, social influence, and personal adjustments in a small isolated group.

While the problems and environment encountered in the Arctic are not nearly so severe as those in the Antarctic, and such extensive evaluations are probably not required for arctic workers, nevertheless a good physical examination should be mandatory for all personnel going to small research stations or to field camps.

In the selection of personnel, physical factors should include:

1. <u>Age:</u> Normally younger, stronger, and more active men have a better chance to withstand the rigors of polar life. Other things being equal, the ideal age is between 25 and 45.

2. <u>Cardiovascular system:</u> History of heart disease should rule out any candidate. Signs of poor circulation such as cyanotic, pale, and hyperemic extremities should disqualify a person.

3. <u>Eyes, ears, nose, and throat:</u> Visual acuity should be sufficient that a man can function should his glasses become lost or broken. In cases where glasses are worn, several extra pairs should be taken along. History or evidence of chronic disease of the ears or respiratory tract should be disqualifying.

4. Skin: Extensive skin grafts or chronic skin diseases such as scleroderma and cold urticaria should not be present.

5. Psychiatric: A well-balanced, mature individual is a must in polar environments. Many people who appear to be well adjusted in our current society are unable to come to terms with the polar environment and become psychiatric casualties. Characteristics to be looked for include excessive worrying, insomnia, high levels of anxiety and tension, a history of drug use or behavioral "stress," drinking, and any serious psychoneurosis.

6. History: Any history of a potentially serious, chronic, or recurring condition which may become acute should rule out a candidate. Included are such diseases as peptic ulcer, gallbladder disease, kidney stone, "chronic appendicitis," endocrine dyscrasia, recurring headaches, and backaches.

7. Dental: A complete dental examination should be performed, including X-rays. Caries should be treated and dead teeth should be treated or removed. Since limited dental care is available and field conditions may not always permit adequate brushing of teeth, excellent dental health should be mandatory. It has been stated that the military in Alaska has more trouble with dental problems than with anything else at remote sites. In Antarctica, every effort is made to see that all persons are in Class 1 condition. Yet almost every time someone slips by with caries or bad molars, particularly the wisdom teeth, and invariably have to be evacuated to McMurdo or beyond for treatment.

The second major aspect of polar medical logistics is direct support for the personnel at the stations. In the Antarctic, because of the total lack of evacuation capability during the winter season, doctors have been considered a must at the larger stations. At the smaller ones, and during the summer season, highly trained hospital corpsmen with several years of independent duty have been chosen to provide the medical care.

Contrary to the medical support provided in the Antarctic, little professional support has been available to arctic stations. Part of the reason for not providing trained medical personnel has been the ready availability of early evacuation from most sites to adequate medical facilities in Alaska or Canada.

When planning future arctic research stations, the need for a physician must be thoroughly evaluated. How many men will be at the station? How long will they remain? Where is the closest medical facility? How long will it take to send medical help or evacuate a patient from the camp site?

If the decision is made that a physician will not be at the station, thought must be given to providing some member of the party with adequate first aid and basic medical training to take care of the minor problems that will arise. Provisions should be made for continuous radio contact and for the immediate dispatch of medical support or evacuation of the patient to adequate medical facilities.

Should a physician be selected for a large station, even he should have additional training. He should be young, healthy, and personally courageous, for in the polar regions the doctor himself usually has no medical attention. He must have professional courage and faith in himself as well, for consultations at best are by radio. This requires additional training and experience for most recent medical school graduates, because few medical schools today are producing well-rounded general practitioners. The tendency over the past few years in American medicine has been toward specialization, even during the last year in medical school and internship. Few recent graduates consider themselves capable of performing emergency surgery.

The physician must learn to practice with limited facilities. Imagination and ingenuity must be stimulated and encouraged, for polar space and logistics are so limited that medical practice must take place without all the fancy equipment, X-rays, or extensive laboratory facilities expected in most medical practices today. Providing all personnel have had adequate physical examinations, the preponderance of injuries will be traumatic. Lacerations, abrasions, and minor burns are the rule, but fractures, dislocations, and sprains are frequent enough to require some additional training in orthopedics.

The physician should also be well versed in human dynamics and plain old-fashioned psychiatry, for the Arctic produces fickle changes in the weather, unforeseeable changes in plans, frustrations from difficulties in communication and transportation, and long sexual continence. The forced isolation in close quarters, with resultant loss of privacy, causes apprehensions, tensions, and personality changes that the physician must quickly recognize and treat.

Providing the arctic physician or lay medical personnel with the tools of his profession requires farsighted planning and coordination. A standard list of drugs and supplies should be developed for each research facility that is based upon the size and isolation from other medical facilities, and upon whether a physician is present. Special handling requirements and expiration dates of many drugs present problems in drug shipment. Many drugs cannot endure freezing, but biologicals require a constant cold temperature.

Of serious concern is the long interval from the time a drug is ordered, through its receipt at the station, to its final use. Because of the discontinuous nature of polar resupply operations and uncertainty as to when the drug will be used, a drug should still have a long shelf life when delivered. The normal practice of drug suppliers is to attempt a continuous flow on a first-in, first-out basis that consumes some of the potency period. This necessitates

special efforts to ensure that drugs are shipped with the longest
possible potency times. Of course, where there is a choice of drugs,
the one without a potency limitation or with the longest potency
period should be chosen.

For personnel remaining at arctic research stations during the
winter months, it would be wise if all were given instructions in
cold weather physiology and the prevention of cold injuries. There
are five primary types of cold injury: chilblains, frostbite, freezing,
immersion foot, and general hypothermia.

Chilblains is the mildest form of dry cold injury, occurring
most often following repeated exposure of bare skin to temperatures
from -60°F to 32°F. Severity is proportional to temperature, humidity,
wind, and frequency of exposure. In accute cases the skin gets red,
swollen, hot, tender, and usually itchy. In chronic cases the skin
is red, rough, and cool.

Frostbite is the most common condition encountered in acute
exposure to extreme dry cold, below 20°F. It depends directly upon
the wind chill factor, duration of exposure, and adequacy of protection.
It is common on the face, hands, and feet, with a sudden onset of
blanching of the skin accompanied by a momentary tingling sensation.
There is considerable confusion in the literature concerning termi-
nology. The author prefers only two degrees of injury: first degree--
only blanching, followed by redness and branny desquamation; and
second degree--blister formation in 12 to 36 hours, followed by
sheet desquamation.

Freezing is when ice crystals form in tissues deep in the skin
and the immediate subcutaneous tissues. It occurs most commonly in
the feet and occasionally in the hands and ears. Untreated, it is
painless and the tissues have a pallid, yellowish color and appear
waxy. Freezing is serious and even with proper treatment loss of tissue
can take place with loss of all or part of the extremity. Even if
there is no tissue loss, residual hypesthesias, paresthesias, and
sensitivity to cold in the recovered extremity are very common.

Immersion foot, while not common in the Arctic, can result from
people walking or living on the tundra during the spring and summer
when it is wet and boggy. Dependency and immobility of extremities
aggravate the condition as does the continuous wearing of wet socks
and shoes. The foot becomes cold, swollen, and mottled. Walking
becomes difficult. The skin is anesthetic and deep sensation is
lost. This is followed by a hyperemic phase, where the foot becomes
red, swollen, and hot. Blisters form and the patient has a burning
sensation and throbbing pain. Again, tissue loss can take place
because of gangrene, and even recovered cases often retain muscle
weakness, paralysis, cold sensitivity, and recurrent deep pain.

The last problem is general hypothermia, which can be either
acute or chronic. The acute form is usually from immersion in ice
water. In water, the body core temperature falls very rapidly, and

voluntary control of the muscles is lost, generally within 5 minutes. Unless the man can get out of the water within the first few minutes, he usually will not survive.

Chronic hypothermia occurs when a man does not have adequate shelter or clothing to maintain his body core temperature when exposed to low environmental temperatures. When the core temperature drops below 95°F, the heart rate and blood pressure decrease and the body has uncontrollable shivering in an attempt to increase the body heat. When the body temperature reaches 80°F to 86°F, hallucinations, apathy, and narcosis occur. Death usually results from cardiac arrest when the core temperature reaches 75°F to 80°F.

Problems pertaining to sanitation, water, sewage, and garbage disposal have been discussed by other authors, but it is also appropriate to consider them here since they impact upon the health and welfare of all personnel. Sewage and garbage disposal should be well away from the station and in areas where the water supply cannot be contaminated. During the summer season, arctic rats and flying insects are potential sources for the spread of enteric diseases, which can assume epidemic proportions without adequate controls. Since few sources of fresh water are available in the Arctic which are isolated from inhabited areas, all water must be considered polluted and purification of the water accomplished prior to drinking. Chlorination or boiling of all water should be mandatory at all stations. With the current emphasis on decreasing the general pollution of our environment, new and novel methods must be devised to reduce the sewage and sanitation problems.

The Arctic has many infectious diseases which can present potential hazards to personnel. Pulmonary tuberculosis has been widespread in the native populations and is a potential hazard to anyone exposed to native personnel. If sanitation is defective, enteric infections such as salmonella and shigella are hazards. Another area of concern are animal-borne diseases, especially in the case of scientists working with wild animals. Most prominent are parasitic diseases such as fish tapeworm which is contracted from eating inadequately cooked fish. Tularemia, commonly known as "Rabbit Feaver" and contracted by handling infected rodents, is rare but endemic in the Arctic. Rabies is also endemic, particularly in foxes, but occasionally it is also carried by wolves and dogs.

In summary, some of the main topics that must be considered in providing medical support to personnel operating in the arctic environment have been presented. Guidelines have been given to the selection of station personnel to ensure minimal health problems. In all cases the emphasis should be on the preventive aspects of medicine, be it the selection of personnel or the sanitary conditions of the research station.

Evaluations should be made as to the need for a physician at the research stations. In cases where no physician is assigned,

someone should be provided an intensive course in emergency first aid. Provisions should be made to provide medical assistance upon request. The need for careful planning of medical logistics is stressed. The uniqueness of arctic living is primarily in the area of cold weather injury.

A CHALLENGE FOR NEW ARCTIC TECHNOLOGY

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I will share with you a few thoughts on technical innovation--based on my experiences--that I believe have some bearing on meeting the challenge of arctic problems. I sincerely believe that we are in trouble today: on land, in temperate zones, and particularly in our cities. We need more than our economy can afford, but we are bottlenecked by traditions. Fortunately, there is a significant effort today to create cities or industries on the ocean bed and in the Arctic. I am convinced that these two areas will eventually indicate to us what to do on land in the temperate zones because these two areas, the Arctic and the ocean, might free us from our binding traditions.

When I ask what creative capability would be the most important to me and to my organization if I were confronted with the problem of setting up temporary or permanent communities and facilities in the Arctic, my immediate response would be "technological improvisation." This response is based on experience, in which I have been confronted with somewhat similar problems; namely, situations in which I was required to develop a unique facility for a different environment: a project that required a drastic cost reduction or an entirely novel function, unique labor conditions and materials, etc. Later on I will cite some examples of specific projects.

Let me first define what I mean by technological improvisation. It has always been a creative tool. It has been the motivating force for the development and greatness of this nation and its industry. In general, however, we think of improvisation as an arbitrary impulsive action associated more with intuition than with science. It is a response associated with the subconscious. Technological improvisation--a term which I think I originally coined and which I hope conveys the meaning I have in mind--does not imply less technology. Quite the opposite, it requires a more thorough scientific knowledge and, what is more important, a knowledge of all technological fields rather than just in-depth specialization in one branch. To exercise creativity, imagination, and improvisation, the knowledge of technology and science, including modern methodologies such as systems analysis, should be so thorough that it becomes a sixth sense in solving a problem.

Again, improvisation is normally associated with an individual rather than with an organization or team of people; however, technological improvisation can be generated by an organized team of scientists and technicians who are properly managed. I will discuss some examples

of how this has been achieved in a few cases in which I have been involved. To find out how to develop technological improvisation with a team, let us review the normal and conventional procedures for producing a product and also analyze the human creative process. I will confine my comments to structural mechanics and civil engineering since I know these best, but I believe the logic and principles will hold for any field of endeavor.

First, the conventional process. Whenever one needs a facility, let us say an airplane hangar in the desert, we first predetermine the form of the hangar on the basis of how we would build it in temperate zones. Then we try to fit the materials and fabrication techniques which can be made available in the desert to the concept which was originated and first adapted to temperate climates. Sometimes we do introduce new material and construction techniques that are more suitable to the hot desert climate, but they are a second echelon effort. This process of concept first and production techniques second, however, is in most cases wrong, particularly with our modern technology. Many failures in undertakings and cost occurred through this kind of approach to construction in the Arctic.

On the other hand, considerable success with great economic advantage has come out of a slightly different process in which we start without any preconceived concepts, such as that for the hangar. The only starting place should be overall function and the vast knowledge of available technology in materials, fabrication, labor, etc. With this approach you end up with an entirely different hangar concept from the conventional one, but one which incorporates the optimum of all factors (nothing has been forced into it).

Let us turn now to the analysis of creative design and construction practice. It consists of the simultaneous combination of three fields of human knowledge and ability (namely, craft, the art of engineering, and science). For today's purpose I will define craft as handiwork experience gained through long periods of time, probably generations. In exercising craft one does not need to involve inner feel or any methodical reasoning. For example, one may be able to lay a good masonry wall or to drive nails through a timber connection through proper apprenticeship without any inner feel, or the ability to read or write, or a knowledge of differential calculus. Craft is almost extinct. I do not think it is essential in construction; it is definitely not needed for innovation or problem solving.

Science and specialized technology alone are too rigid and too systematized for solving problems with numerous unknowns that cannot be tabulated or mathematically evaluated. What will do the trick is a sound scientific approach mixed with the art of engineering: a "feel" of engineering. The latter is not a talent that a person is born with. It is a sixth sense that is developed through experience and through knowledge of engineering. Thus the contributions of engineering are the systematic application of scientific tools and methodology

from various fields of endeavor rather than one specialized field:
they constitute technological improvisation. Versatility is the
key ingredient and not just specialization in depth. A team of
scientists forced to use imagination, engineering "feel," and
engineering skill based on scientific principles will produce the
necessary breakthroughs. But, a word of caution: imagination and
feel that are arbitrary and cannot be backed by sound scientific
principles can do harm, and we know there have been many attempts
of this nature.

Now, let us go over some specific examples, based on my years
of experience with proven results, to exemplify what I am recommending.
You will see that I am driving at the human element, the human element
that comes on top of all the methodology that we have. I am a scientist
who has been schooled in the use of mathematics and all the tools that
we have. But when we come into new areas, we must add something--the
sixth sense that I am recommending. It has been proved that this
sixth sense can also be developed in a team working on an interdis-
ciplinary project.

First consider a bridge made out of paper. An attempt to design
one was made in some places for a year and a half. Heretofore, a
bridge was supposed to be constructed with girders and slabs, and
others tried to build girders and slabs of paper. The effort failed,
and it was an expensive failure. Instead, you take the ideas which
I have been talking about and you come up with a "molecular" concept
that is based on the inherent qualities of paper. The concept is based
on knowledge gained from other fields--not just bridge design and
paper. A bridge (Figure 1) was constructed using this concept, and it
weighed one-tenth the live load. This is just the reverse of the
usual situation. Normally, bridges weigh more than ten times the
live load. The bridge, built in Las Vegas, carries many truck movements
and cost $10,000. It can be emplaced by a helicopter and can last 50
years.

Another example concerns the airlines. They have a $10 billion
construction program over the next ten years. Up to now, the airlines
built their facilities the way they had always built them, only
bigger, so costs were rising rapidly. By taking a different approach--
and I am talking about an effort involving versatility and a lot of
knowledge put together with an open mind--$50 million worth of hangars
have been completed in Los Angeles and San Francisco at a cost saving
of 30 percent. The idea was to discard the old concepts and look at
the problem from the standpoint of what is easiest for manufacturing
to produce, since manufacturing is an important ingredient in what-
ever we want to do.

Again, this is not the normal way, since normally we come up
with a concept and then force the construction industry to produce
it. The gigantic hangar (Figure 2) that was constructed is equivalent
in area to four football fields and can house a 12-story building.
It is made of identical pieces of thin gauge metal which have been
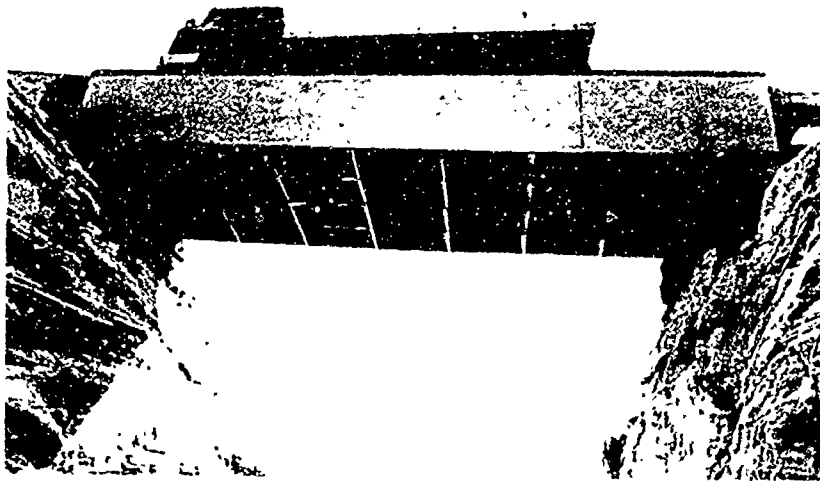produced in six different locations around the United States, shipped
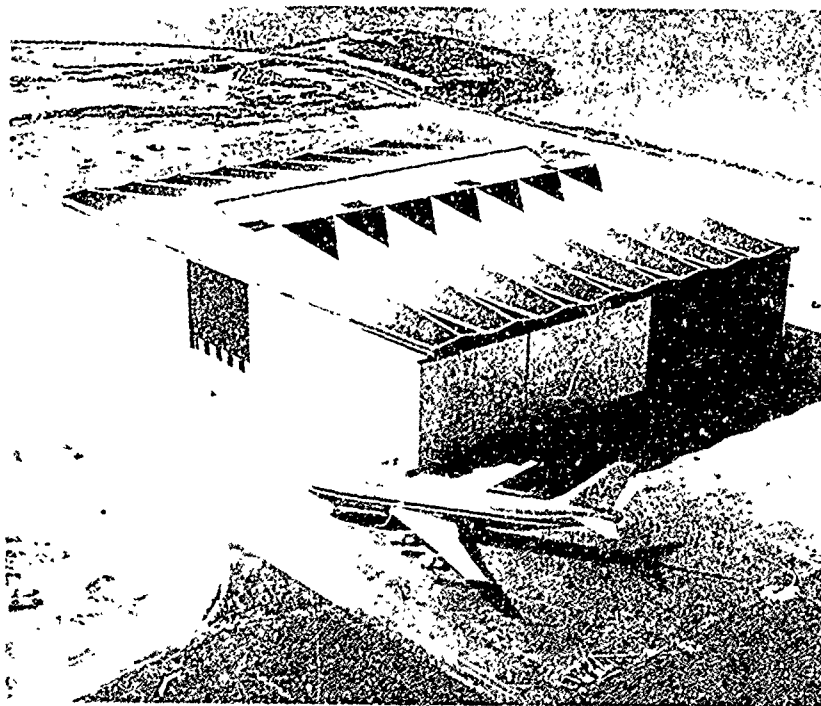
Figure 1. Paper Bridge

Figure 2. New Hangar Concept

to Los Angeles, and erected in about one-third the usual time. The whole approach is just like a chess game: what components do you shift-fit where.

Here is another example. The State Department wanted a portable theater that could be set up in Alaska, Indonesia, or in other locations with diverse climates. It had to be light and suitable for erection and dismantling by unskilled labor. A theater for 2,000 people designed by the conventional concept could never meet such specifications. However, by discarding conventional concepts, you can design a theater with but three major components (Figure 3). Everything is portable, and it is stabilized by water pressure through rubber gaskets between each fluted section. It will even withstand the force of hurricanes. It can be built by the boat industry and it will meet all requirements. The boat industry in itself would not have produced it; neither would a specialized civil engineering organization; nor even the space industry. But, by using all disciplines together with engineering improvisation, we got what was needed.

Another example involved he New York City Port Authority, which built a new pier in the water at La Guardia Airport (Figure 4 and 5). It was designed adequately in accordance with the book--like the roof of a warehouse. The pier was designed for a B-727, but then the DC-10 came on the drawing boards. Economics dictated that this new plane must land at La Guardia. So the first thought was to reinforce the whole pier so that it could accommodate a DC-10, which is three times as heavy as a B-727.

But, if you look into knowledge beyond civil engineering, you find that the response of a pier to an airplane is different from the response of a warehouse roof to snow loads. Through methodology alone it has been proved that this pier, without any strengthening, can be used for a DC-10. Again, I would like to say that neither individuals nor revolutionary scientific breakthroughs were involved. It was simply another case of improvisation.

One final example I will give is indicative of the potential that exists. A terminal costing $90 million has been designed (Figure 6). It is for Boston and is the usual type of terminal with large spurs, much space for counters, etc. Also, for other uses by the airlines a 10-foot square tube has been developed to connect the terminal with the airplane (it is 100 feet long). Through improvisation, it was found that by stacking tubes one on top of the other and one next to the other (Figure 7), you could actually create a terminal that is conceptually new and looks different, but that does the job of a terminal at a cost of only $7 million instead of $90 million. This again is a classic example. The reason the terminal cost was set at $90 million is because the first man who put lines on paper for it assumed that it would be like the ones at Dulles and elsewhere which have been built during past years.
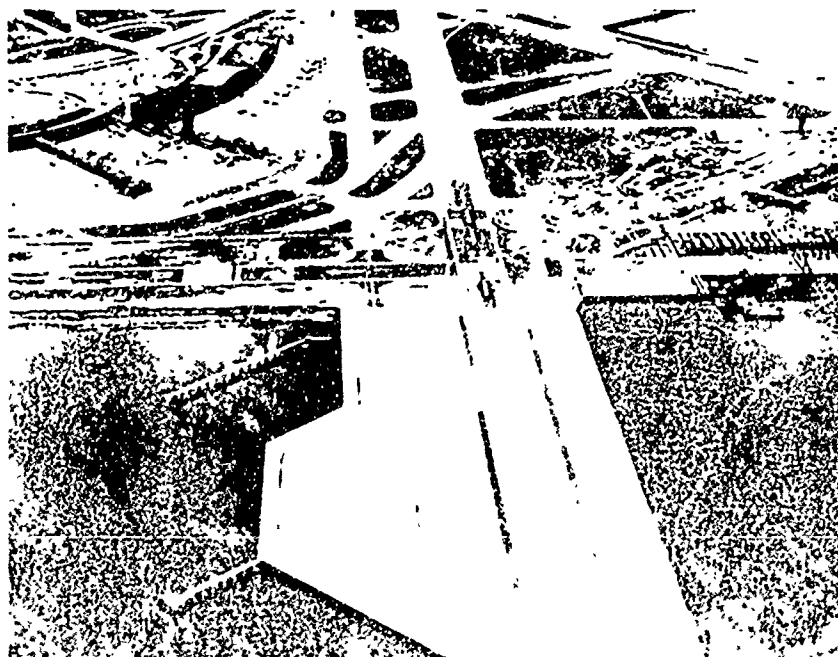
Figure 3. Portable Theater

Figure 4. La Guardia Runway Pier Extension

PILES
DECK
EDGE BEAMS
GIRDERS

INTERIOR GIRDER

EXTERIOR GIRDER

INTERIOR DECK

INTERIOR FILE
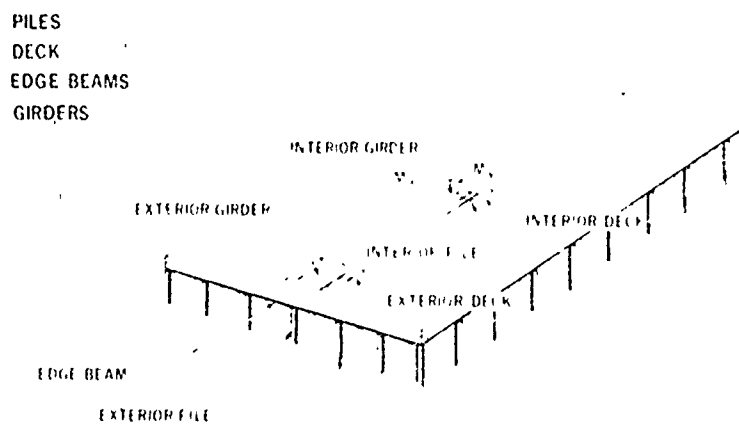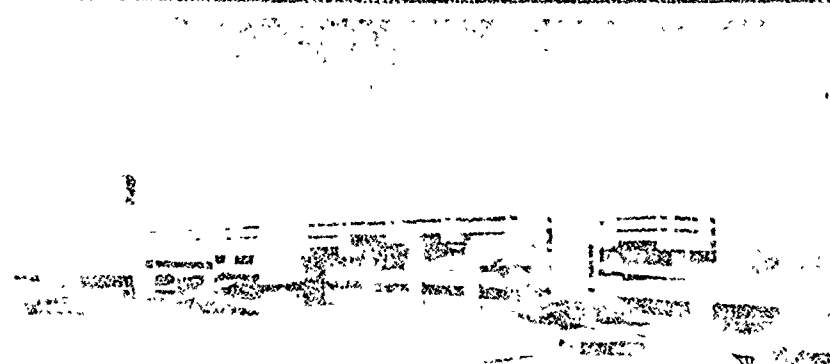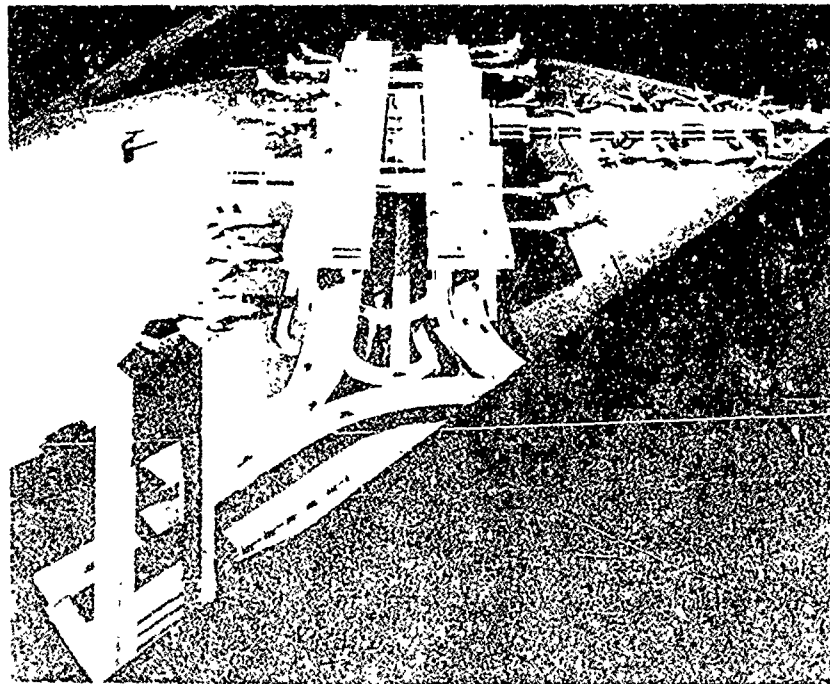
EXTERIOR DECK

EDGE BEAM

EXTERIOR FILE

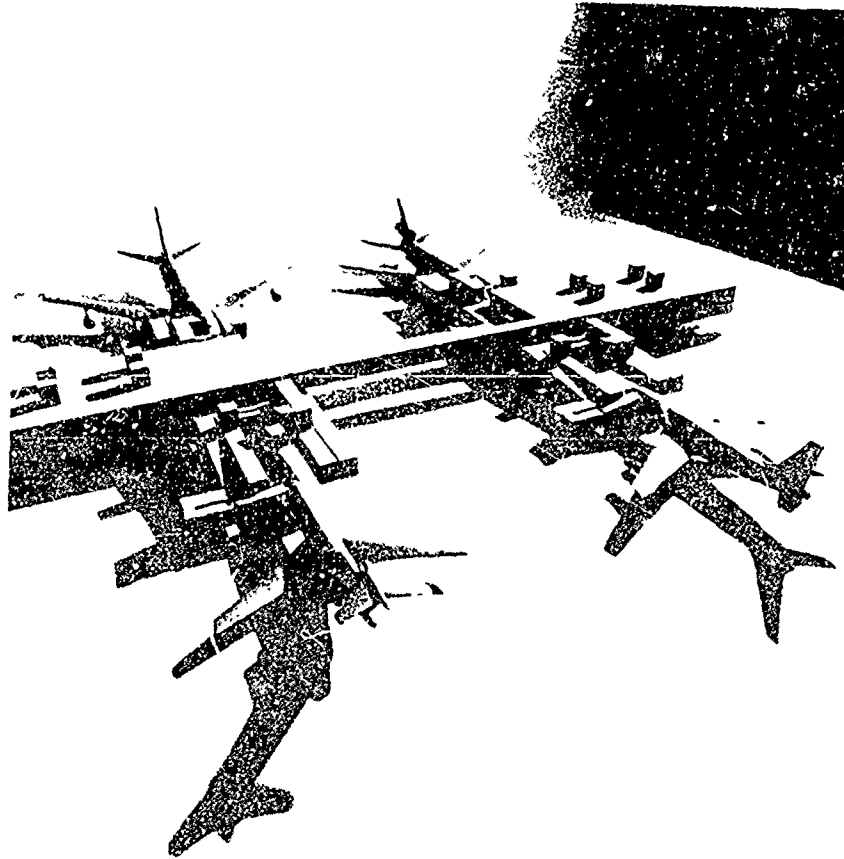Figure 5. Structural Elements of La Guardia Airport Pier

Figure 7. Airline Terminal Constructed of Tubes

Two final comments: I believe that we are at the threshold of
a revolution not only of new materials and new construction techniques
but also of new building components. We build our structures today
so that they resist loads through static material rather than
kinetic considerations. Many building loads are temporary, and
temporary loads can be resisted kinetically: by springs, oil pressure,
etc. I think that the Arctic is an ideal situation for the use
of these gadgets. I know that dollars and time represent fractions of
what would otherwise be required. Our industry today cannot take
advantage of the revolutionary materials which are available. For
example, there are materials a hundred times stronger than steel,
but we cannot use them because our concepts of structures do not
fit either the new materials or the design "books." We have to get
away from books and go back to technological improvisation.

My firm has made a study for the airline industry dealing with
their construction during the next 10 years. The study has been
tailored to anticipated progress in technology--not just construction
technology, but all technology. The interesting thing is that while
construction costs have been going up at the rate of 15 to 20 percent
per year, a construction cost curve shows that this can be reversed.
In fact, it will be possible to build in the 1980's at a fraction
of what it costs today, if it is done right.

What I have been discussing is not just in the imagination of
an author or an artist. What I have discussed is true technology,
real things taken from real projects. Novel techniques and fresh
approaches make items simpler, faster, portable, often interchangeable,
and less costly than conventional practices. With this new approach,
we can predict the kind of behavior that a structure we create will
exhibit, and we must be 100 percent right (99 percent is not good
enough). Today our methodology and simulation techniques are good
enough to allow this. That is why I said that craft is a thing of
the past, because in crafts you do the way everyone else did before
you. Let us not forget that the concepts I have shown do not require
highly skilled labor.

The challenge is here but so are the tools to meet it. What
we have to do is to gear properly for the challenge, and it will
not be by taking a house like we have here in Hershey and plunking
it down in the Arctic (this also applies to a jetty or a highway).
The availability of technology today is so vast that its potential
for man's benefit has not even been scratched. This is the great
challenge of the Arctic.