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HEALTH TECHNOLOGY DEVELOPMENT
AT THE UNIVERSITY OF WASHINGTON

Final Annual Report

July 1971 - June 1972

THE UNIVERSITY OF WASHINGTON
HEALTH TECHNOLOGY DEVELOPMENT
1971-1972

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FINAL ANNUAL REPORT
JULY 1971 - JUNE 1972
DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
OFFICE OF PUBLIC AFFAIRS
WASHINGTON, D.C. 20462

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13. ABSTRACT A synopsis of the sponsored arctic technology development at the University of Washington is presented. This includes a description of the developmental progress made on the Unmanned Arctic Research Submersible (UARS), and a presentation of three recommended arctic technology projects. These projects (the development of an ice pack research support vehicle, the development of a remote acoustic telemetry link for under-ice sensor systems, and experiments in ice albedo modification) are described in detail and rationale to support their early accomplishment is given.			

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ARCTIC TECHNOLOGY DEVELOPMENT AT THE UNIVERSITY OF WASHINGTON

Semi-Annual Report

1 July 1971 - 31 December 1971

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I. GENERAL

The Arctic Technology Program being carried on within the Division of Marine Resources at the University of Washington under the sponsorship of the Advanced Research Projects Agency brings together in a common effort investigators from engineering, the arctic sciences and the Applied Physics Laboratory. Three tasks are currently being accomplished in the program: (1) The provision of an administrative mechanism through which arctic research problems can be identified and systematically solved, (2) the fabrication and testing of a portable, Unmanned Arctic Research Submersible (UARS) system, and (3) the description, in terms of application concept, cost and development time, of new, high-gain technological programs which could, in the future, provide a significant defense or scientific advantage to the U. S. in the arctic region.

At mid-year the program is on schedule with good progress to report in each project area. The principal program activity continues to be the development of the UARS system, which is now in the final stages of fabrication. A detailed review of that project is provided in Section II of this report. The Arctic Technology Advisory Committee (ATAC) which was established to provide a technical forum for the discussion of arctic research and operational needs has continued to play an important role in catalyzing new approaches to the solution of old problems. The Committee has reviewed many concepts aimed at improving arctic instrumentation and instrument platforms, logistic support, pack ice transportation and shelter technology. Committee members have also discussed many of these approaches with cognizant personnel in ARPA and ONR in order to obtain their comments and counsel.

The need for reliable and efficient pack ice transportation has received particular emphasis in view of its essentiality for supporting the deployment of UARS. During this past summer Professor B. H. Adey of the Mechanical Engineering Department was asked to study the specific requirements for a universal pack ice transportation vehicle which would meet the basic needs of arctic science. His report, Appendix I, not only develops the requirements for such a vehicle, but provides, as well, a survey of presently available equipment, and details of their inadequacies.

In addition to the pack ice vehicle, there was general agreement within the ATAC that two other concepts should be further pursued at this time. Consequently we are also preparing recommendations to ARPA which support the development of a Remote Acoustic Data Link for use with under-ice sensor systems, and the experimental study of Ice Albedo Modification as a means of creating liquid runways and other features that enhance summer logistics for remote ice islands, glacier stations, etc. A description of each of these concepts and a suggested approach are set forth in Section III of this report.

Work is also underway through the Arctic scientific community and several potential funding agencies to develop a utilization plan for the UARS system, beginning in the fall of 1972. By that time it is expected that all developmental testing will have been completed and initial ice profiling measurements made. Some of the potential applications for the system are depicted in Figures 1 through 7. Expressions of interest in using the vehicle have been received not only from agencies in the U. S. Government but from the exploration divisions of major oil companies and from branches of the Canadian government as well.

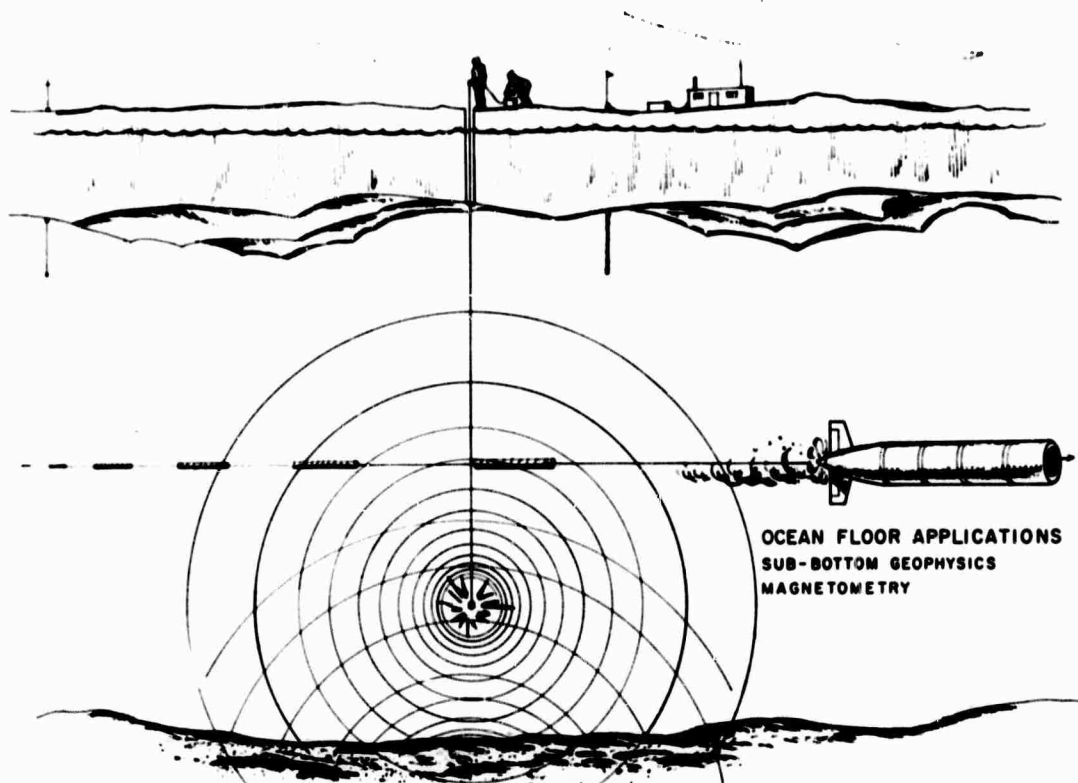


Figure 1.

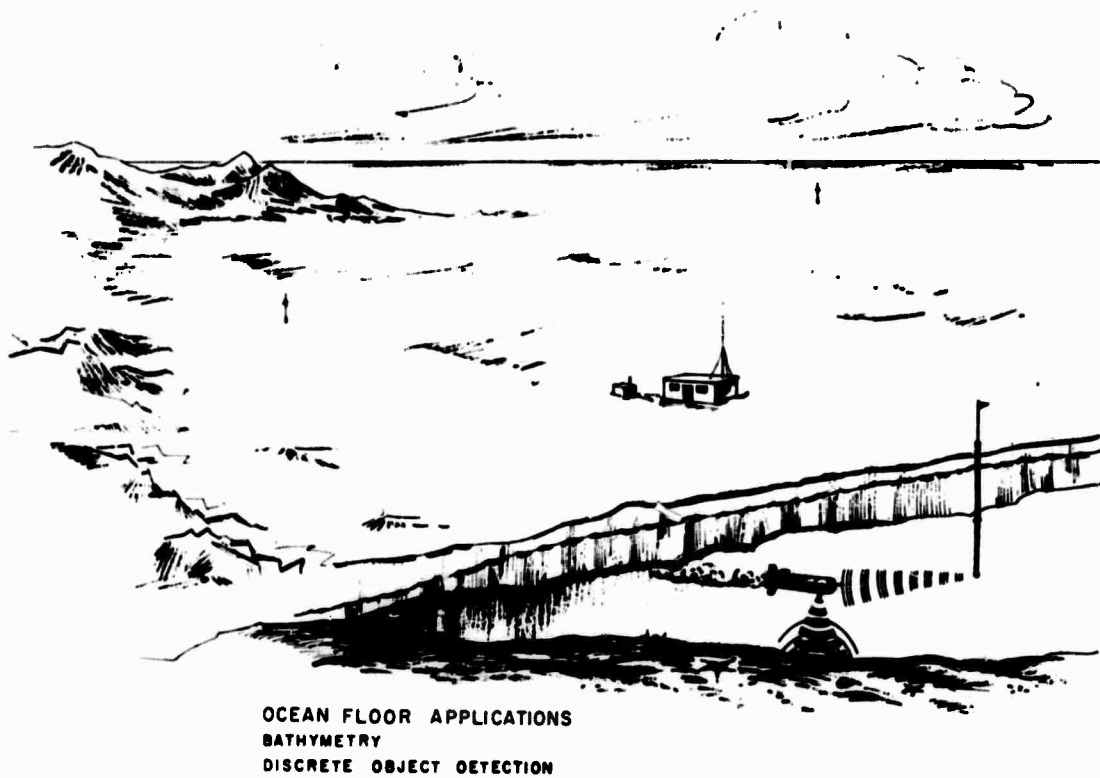


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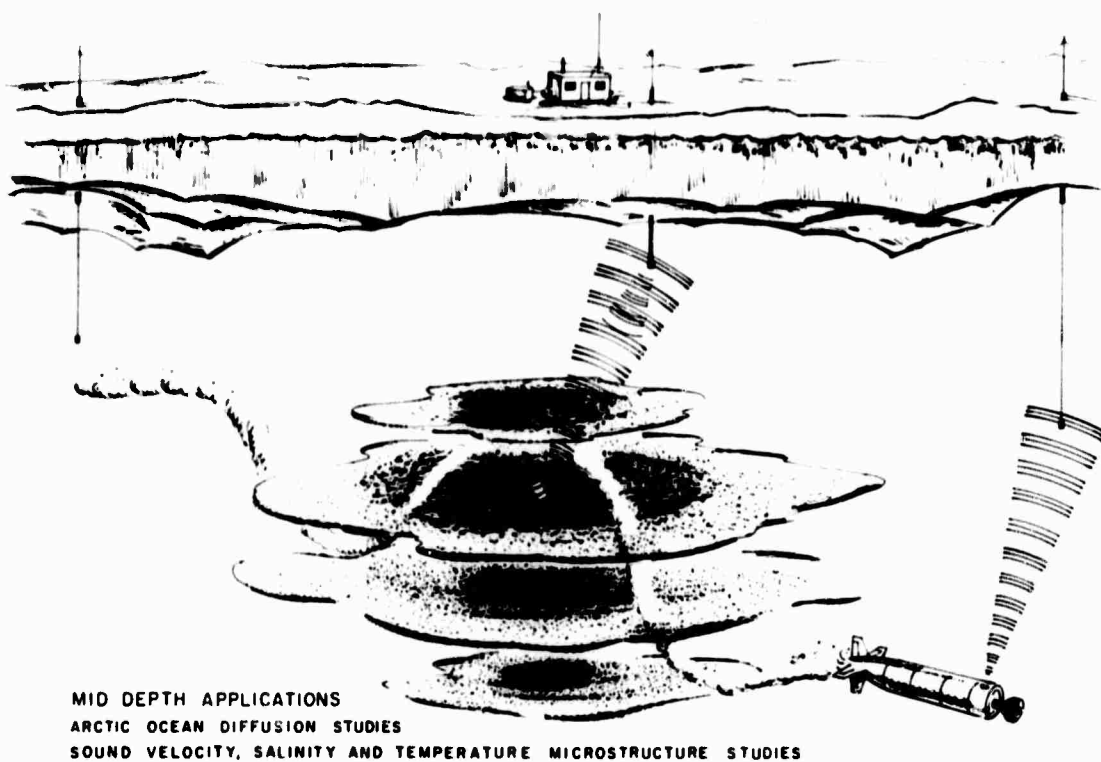


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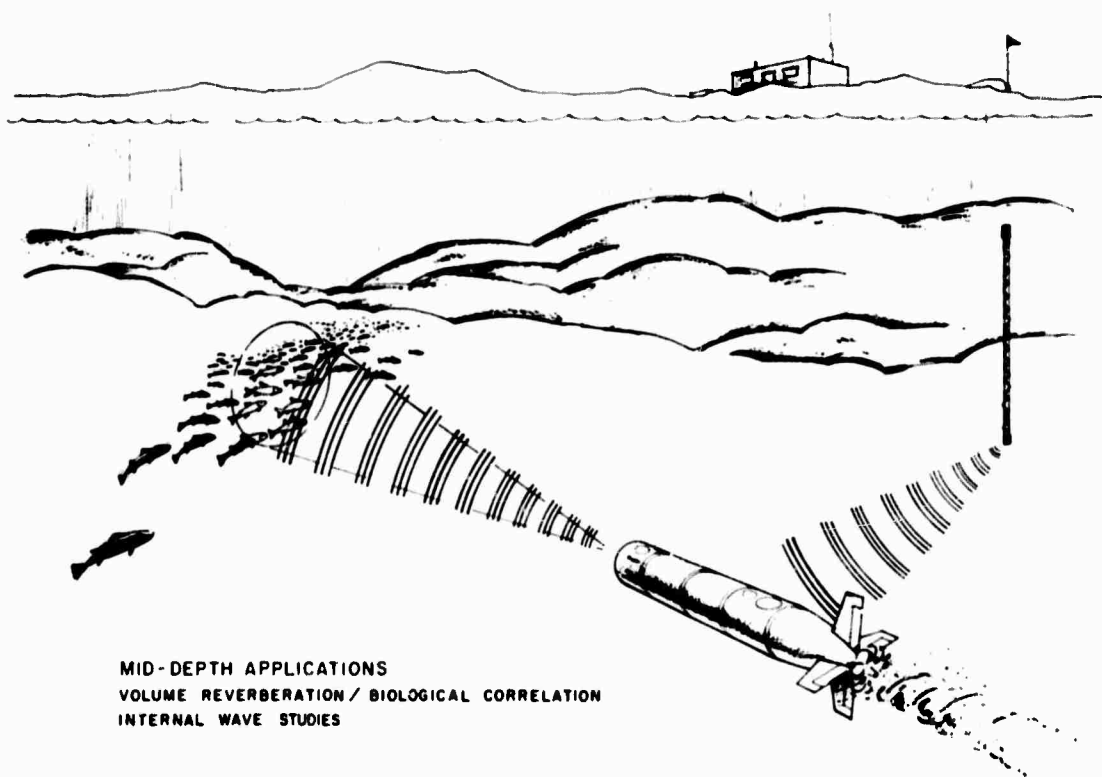


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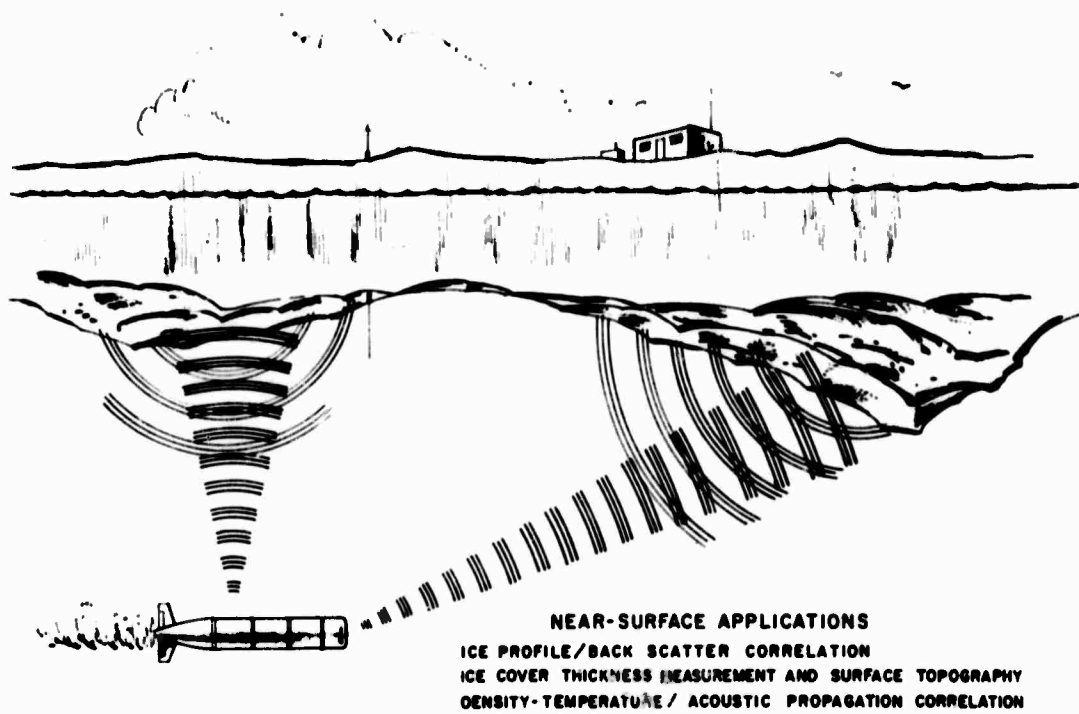


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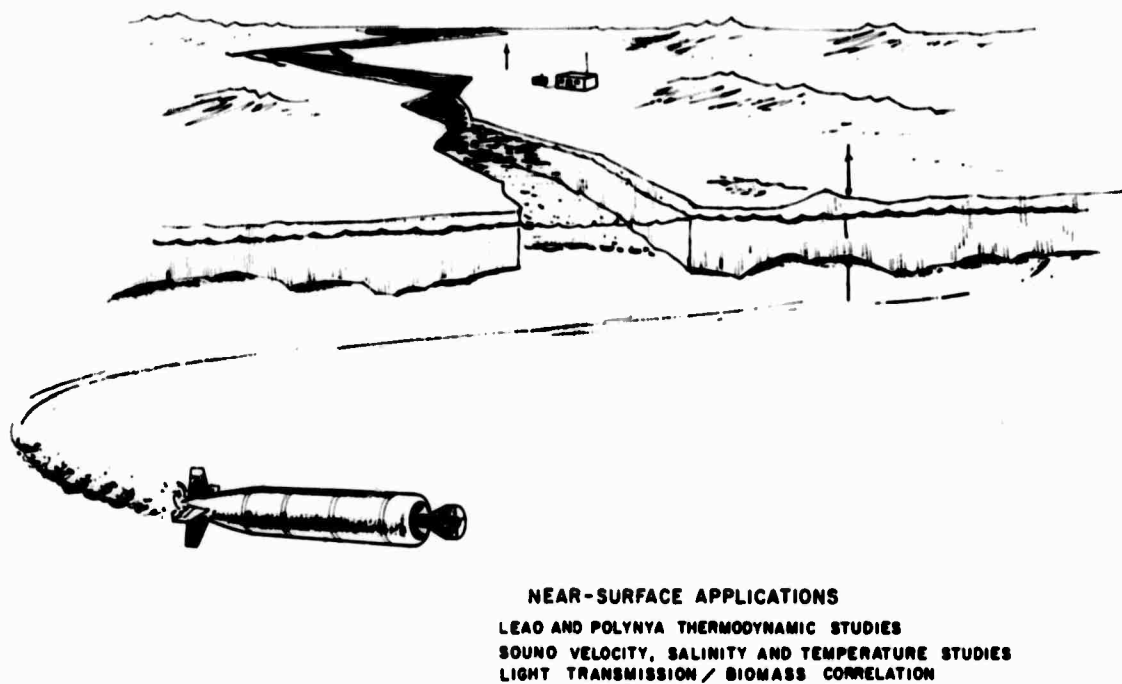
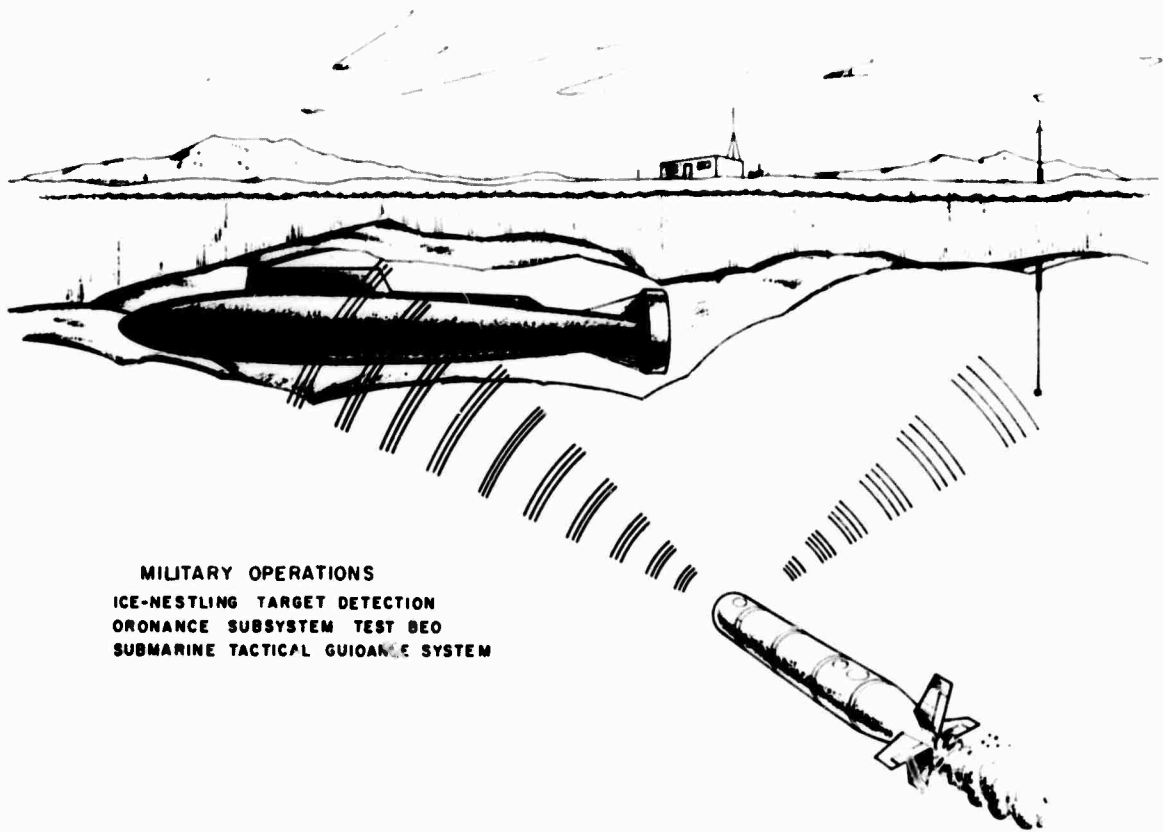


Figure 6.



MILITARY OPERATIONS
ICE-NESTLING TARGET DETECTION
SONAR SUBSYSTEM TEST BED
SUBMARINE TACTICAL GUIDANCE SYSTEM

Figure 7.

II. UARS DEVELOPMENT

1. General

The design of this system, with the exception of those portions which were major hardware dependent, was essentially completed in June 1971 and is currently being fabricated. When completed and tested in local waters it will be taken to the Arctic and tested operationally both in the deep basins and in the shallow marginal seas. The objective is to provide a technological capability to conduct under-ice research with unmanned, untethered vehicles. A complete technical description of the system is given in Reference (1).

UARS is a compact vehicle which weighs approximately 1000 pounds, has a length slightly over nine feet, and a diameter of 19 inches. To accomplish its ice undersurface profiling mission it will travel at 3 knots. At this speed its main batteries will supply up to 10 hours of run time.

The principal acoustic components carried are for communication, tracking correlation, 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 oncoming submersible. The initial instrumentation suite of UARS will also feature acoustic sensors incorporated into an ice profiler that is capable of measuring surface elevations to a differential accuracy of 0.25 feet.

The launching procedure calls for the vehicle to be lowered by special sling through a 4 x 12 foot hole in the ice and released from a horizontal position at a depth of approximately 150 feet. Procedures and equipment have been developed to facilitate making the access hole in the ice.

Tracking elements in the system 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 are designed as free-floating buoys, but can be frozen in place, weather permitting. At the power levels and frequencies used, each hydrophone will have an effective range of 9000 feet for tracking the submersible. The command/communication components will utilize the same acoustic frequency as the tracking elements. Sixteen command functions may be used to control UARS.

The retrieval concept will employ a snaring net containing a homing beacon. This will be lowered through the ice hole to the operating depth of the submersible and UARS will be commanded to seek the homing signal.

Ref. 1. - "Arctic Technology Development at the University of Washington".
Annual Report, 1 June 1970 - 30 June 1971

Internally programmed logic, an inertial and depth-sensing guidance system, and the command/tracking receivers provide UARS with great retrieval redundancy. However, in the event of massive power interruption or other catastrophic failure, a further retrieval capability is provided. The submersible is positively buoyant and will rise to the undersurface of the ice and automatically lower an acoustic beacon to aid an over-the-ice search party. A full array of recovery tools will be available for such an operation.

During the present program phase, the principal effort has been that of fabricating and procuring system components and integrating them into subsystems for checkout purposes. Further acoustic system tests in shallow water, melt-season conditions were accomplished in conjunction with the 1971 MIZPAC (Marginal Ice Zone, Pacific) oceanographic program in which we participated. These tests complemented a similar set of UARS acoustic system tests made during April 1971 at Fletcher's Ice Island (T-3) in the central Arctic basin. Acoustic system analog recordings at various points in each system have permitted development of appropriate signal processing logic to insure proper system operation in rather unique acoustic environments.

Another related program (in conjunction with the Naval Ordnance Laboratory) permitted further refinement of the Thermal Ice Cutter, a device developed under this contract for making deep holes in pack ice and for removing instrumentation that has been frozen into the pack ice.

These subjects are discussed in greater detail in the following sections.

2. Acoustics for Unmanned Arctic Research Submersible (UARS)

2.1 Summary

The acoustic-link guidance and tracking system, the acoustic avoidance/profiling systems and the homing system for the UARS were evaluated in the MIZ environment during August 1971. The location was nominally in the Chukchi Sea, northwest of Barrow.

The UARS guidance and tracking functions are handled in a single acoustical system, operating at 50 kHz, using single frequency pulses modulated with phase-shift-keyed (PSK) information. The tracking function (i.e., UARS-to-tracking array) operates synchronously -- pulse arrival times being related to known transmission times for range/range tracking. The guidance function imposes binary data on the tracking pulse by $\pm 90^\circ$ phase shifts of the carrier. Each data bit is 5 cycles in length, and three recognition bits make up the leading edge of the pulse.

The UARS collision avoidance system utilizes a narrow beam, forward-looking sonar, operating at 360 kHz to detect ice keels projecting to depths below the vehicle track. The profiling experiment instrumentation includes a multi-beam acoustic array to scan vertically an under-ice surface that has been insonified by a 500 kHz source.

In deep water, UARS homing will be accomplished using phase comparison between two hydrophone elements closely spaced ($3/8$ acoustic wavelength separation) which are presented with a 28 kHz acoustic pulse from a transmitter beacon. The geometry is chosen so that the first echo lags the main pulse. In the marginal zone, the water depth precludes this approach and tests were conducted to obtain data necessary to devise appropriate alternative logic, or if necessary, a different homing system.

Three immediate conclusions were derived from the UARS-MIZPAC experiments.

- (1) In the marginal ice zone, the combination of shallow water and changeable oceanography makes the performance of any near-horizontal-viewing sonar system quite variable.
- (2) Acoustic telemetry word lengths are severely limited by multipathing effects due to both the in-medium and boundary factors associated with the experimental area.
- (3) Alternative control logic for the present UARS system must be provided to satisfy both the acoustic limitations and present experimental objectives of operating in the marginal ice zone.

2.2 Methods and Instrumentation

2.2.1 Field Equipment

The electronic equipment used in the field was primarily the battery-powered developmental breadboard circuitry of the PSK, avoidance, and homing systems, supplemented by battery-powered oscilloscopes, signal generators, and meters. A battery-powered Pemco 7-channel tape recorder and sufficient battery chargers to support the experiments were included. All the data were recorded on 1200 ft reels of 7-channel, $1/4$ inch width magnetic tape. Three reels of PSK data, eight reels of avoidance and profiling data, and six reels of homing data were taken. The acoustic transducers used were prototypes of UARS production units.

2.2.2 Field Procedures

2.2.2.1 Guidance and Tracking Tests

On 5 August, at Camp Bravo, the PSK transmitting system was set up at the edge of the floe, about 150 yards from the equipment tent. Water depth was 50 m. The acoustic elements for the receiver (at the tent) and for the transmitter (at the edge of the floe) were lowered to 25 m. The direct acoustic pulse (Figure 2.1) was used to trigger the oscilloscope, and the first and second echoes (Figure 2.2) were visually observed. Tape 1 was recorded at 1200 hours, with various gain settings for the receiver using: Channel 1 - Voice, and Channel 2 - Signal.

The PSK transmitting system was operated from the ARPA Surface Effect Vehicle (in conjunction with synoptic oceanographic drops) at a distance of about $\frac{1}{2}$ mile, with intervening ice cover of $\frac{7}{8}$ to $\frac{8}{8}$. Tape 2 was recorded at 1800 hours with various receiver gain settings.

At the conclusion of 2 hours of synoptic oceanographic drops the PSK system was again tested. The ice cover was identical but the floe had drifted over new bottom, and the oceanographic description of the water was considerably different. Tape 3 was recorded at 2015 hours, using various receiver gains as before.

2.2.2.2 Avoidance and Profiling Tests

On 6 August, at Camp Bravo, the avoidance sonar was set up in the ice hole used for oceanographic measurements. The tilt head employed was the same unit used during the April T-3 tests which were described in the previous annual report.

Collision avoidance sonar tests were made at 360 kHz with the transducer 22 ft below the lower surface of 14-ft thick ice. The tilt head was swept through an angle of -45° to $+90^\circ$. (That is, from 45° below horizontal, in order to scan the bottom, to vertical, in order to scan the under-ice surface at all grazing angles.) This simulated both avoidance and profiling tests.

Tapes 4 and 5 were recorded with the transducer at 0° relative bearing (Bravo reference line) and with 70 ft of water under the transducer. Tapes 6 and 7 were recorded for a 270° relative bearing in 150 ft of water at 2230 hours. Tapes 8 and 9 were recorded for a 180° relative bearing in 150 ft of water at 2310 hours. Tapes 10 and 11 were recorded for a 90° relative bearing in 200 ft of water at 2330 hours. The channels used for recording were as follows:

- Channel 1 - Direct, Voice
- Channel 2 - Direct, 80 kHz i.f. echo replica
- Channel 3 - Direct, transmit trigger
- Channel 4 - Direct, 10 kHz reference frequency
- Channel 5 - FM, detected pulse envelope
- Channel 6 - FM, avoidance signal logic
- Channel 7 - FM, tilt angle (analog frequency)

2.2.2.3 Homing System Tests

On 8 August, the phase sensing homing transducer, mounted on a pipe rotator, was installed in the oceanographic measurement hole at 45 ft depth. The transmitting transducer, 200 yd distant at the floe's edge, was lowered to 55 ft. Water depth was 120 ft, with continuous ice 10-20 ft thick above the transmission path. For the phased tests the 28 kHz transmitter was operated

in two modes: either CW or pulsed at 4 pps with a pulse length of 4 msec, both at 10 watt power level. Tape channels were as follows:

- Channel 1 - Voice
- Channel 2 - Homing channel #1
- Channel 3 - Homing channel #2
- Channel 4 - 10 kHz ref signal
- Channel 5 - Angle output

Tape 14 was recorded with pulsed operation; tape 15 was recorded with CW operation.

On 10 August, in order to test the feasibility of a pulse-steered (rather than phase steered) system, two hydrophones were mounted on a T-bar with 21-inch (10λ) separation. This system was installed 30 ft below the surface in the oceanographic measurement hole. The transmitting transducer was lowered to 90 ft depth at the edge of the floe, 200 yd away. Water depth was 200 ft. The transmitted pulse amplitude was set so that both receiver channels were strongly saturated. The pulse length was 1.5 msec at 4 pps.

The receiving array was rotated 540°. Recorder channels were as before. Tape 16 was recorded with strongly saturating pulses. For tape 17 the transmitted pulse amplitude was decreased to a level which saturated only the direct pulse.

2.2.3 Data Analysis

2.2.3.1 Guidance and Tracking

The magnetic tapes have been replayed in the Laboratory and selected, representative traces have been photographed. Although complete analysis will require further work, preliminary results are presented here.

The PSK system was designed to utilize minimum pulse length in the water so that boundary-produced echoes would lag behind the main pulse sufficiently to provide unambiguous data transmission. At a distance of 150 yd, with full receiver gain, decoding was erroneous but the scope presentation indicated that visible reverberation lasted for about 1 sec (Figure 2.3) so that overlapping echoes interfered with each subsequent transmission. If, in the vehicle, receiver sensitivity is set for best long-range guidance, tracking and control at close ranges may be reverberation-limited under the marginal ice.

The first echo delay is approximately given by the expression

$$\Delta t = \frac{2 \cdot (d_1) (d_2)}{(d_3) (c)}$$

where d_1 and d_2 are distances of the transmit and receive transducers from their nearest respective echo-producing boundaries, d_3 is the separation distance and c is the speed of sound.

For $d_1 = d_2 = 67$ ft, and $d_3 = 450$ ft, and assuming $c = 5$ ft/msec,

$$t = \frac{2 \cdot 67 \cdot 67}{450.5} = 4 \text{ msec}$$

Since the deepest ice ridge and highest intervening bottom is not precisely known, this value is in reasonable agreement with the observed echo delays of about 3.5 msec.

When the PSK system was first tested at 1000 yd, it was observed that the "valid trip" criterion was almost always met, indicating that the initial portion of the pulse presented the proper 0-0-1 bit sequence required for recognition (Figs. 2.4-2.8). Further, there were almost no noise rejections, indicating that pulse amplitude remained high for the full pulse duration. However, no more than 10% of the decoded words were entirely correct. Frequently, runs of three and four identical incorrect answers were observed. Thus, the phase-altering phenomenon which caused the last part of the word to be scrambled did not change the recognition characteristics of the pulse (the early part of the word). When the received pulse was viewed on an oscilloscope, there frequently appeared to be a lower amplitude precursor pulse of several tenths of a millisecond, followed by a saturation amplitude full length pulse (see Figs. 2.4, 2.7 and 2.8). The precursor pulse appeared to be able to supply recognition characteristics (0-0-1 bits), causing the following main pulse (which started again with 0-0-1 recognition bits) to be read as data by the decoder. The data which was still arriving after the decoder had filled was truncated.

Photographs of several pulses show precursor pulse length from 0.2 to 0.7 msec which suggests that a first echo may indeed be stronger than the main pulse, partially overlapping the main pulse and providing sufficiently phase-stable behavior to change the received code to an erroneous but time-stable value.

In an isovelocity medium, the geometry would give rise to a 0.6 msec delay between arrival of the first (direct path) and the second or surface echo pulse. This is in the range of observed values. However, the shorter differences in pulse arrival are probably due to propagation along different velocity paths in the medium itself and are not necessarily related to boundary echoes.

When the system was operated at the same stations 2 hours later, the conditions of the medium had changed so that the decoder again recognized all "valid" pulses, but at this time the anomalies noted above were not present and the answers were correct (see Fig. 2.9). The initial pulse was observed to be strong and steady, and no echoes were seen -- at least none of an amplitude sufficient to decrease the integrity of the phase-coded word. Error-free telemetry would have resulted under these conditions.

2.2.3.2 Collision Avoidance and Profiling

It is desirable to understand the characteristics -- at grazing and normal incidence angles -- of acoustic reflections from the ice/water interface,

in order to determine system parameters. The reflection and scattering process is still somewhat obscure, since it appears that there are many "types" of ice; classification categories are needed in this respect, and further field work is essential.

Photographs of returns from the bottom and from the underside of the ice as the beam was vertically scanned, are shown in Figs. 2.10 through 2.15, from tapes 4 and 5. Of special interest are Figs. 2.13 and 2.14, which show separated under-ice returns from keels or projections at differing distances.

2.2.3.3 Homing

The reverberation causes a scatter in steering angle computations. However, the standard deviation of the angle computations is only about 16 degrees. If these observations are averaged, good steering can be obtained. It is possible to average "mathematically" or in an analog sense before commanding the control actuator; however, the vehicle response time is slow enough that physical averaging of heading will occur even if rudder throws are implemented which correspond to each angle computation. In practice, control will be effected by a combination of these two methods.

The pulse steering tests in which the direction of the acoustic signal is determined by measuring the time of arrival difference at two spaced hydrophones indicated that this approach provides a backup means of implementing homing control.

2.3 Discussion of Results

Data analysis is not complete; in fact this report presents only tentative results. Nevertheless these results are considered noteworthy and are summarized below:

- (1) The PSK data transmission utilizing the word length planned for deep water varies from highly effective to non-effective in the MIZ depending on the oceanographic conditions. Initial insights were obtained in this regard and more field tests must be made to establish a practical code length.
- (2) High-frequency, narrow-beam echo-ranging from upward-looking transducers is feasible for determining ice undersurface character. Further work in this regard should be coupled with physical examination of this ice structure, and with the related oceanography. The performance of the UARS profiling system should be excellent when sensing ice similar to that found in MIZPAC under summer conditions. There appear to be sufficient difference (pattern recognition) in the return from the sea bottom and the under-ice canopy that the obstacle avoidance sonar will be effective in distinguishing between the two.
- (3) The UARS homing system described in Reference (1) should adequately cope with the acoustic vagaries of MIZPAC. However, it appears that reductions in beacon pulse repetition rate and corresponding receiver logic changes should be made to optimize performance in the MIZ.

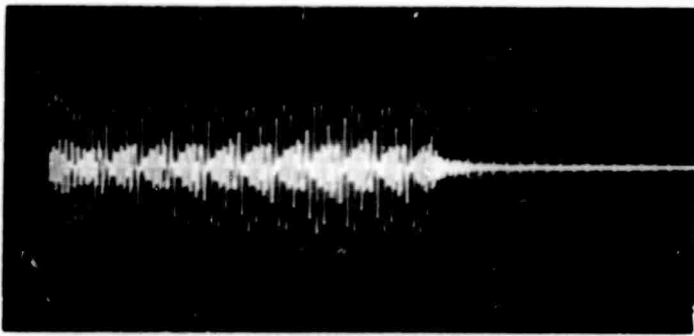


Figure 2.1
PSK pulse as received from 150 yd. Receiver gain just barely high enough to trip PSK decoder. 0.2 msec/div.

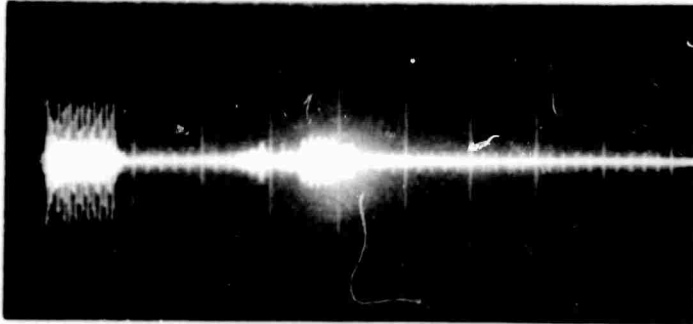


Figure 2.2
PSK pulse as received from 150 yd, showing echoes from bottom and ice cover. 1 msec/div.

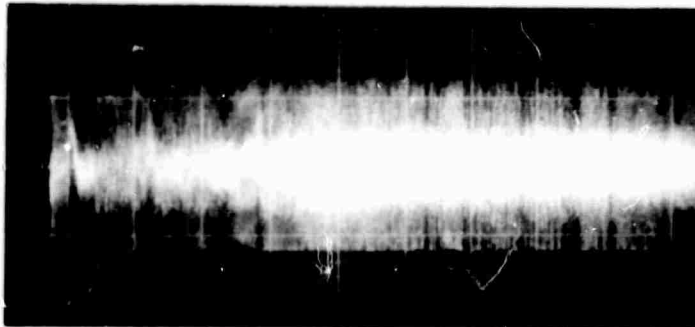


Figure 2.3
PSK pulse as received from 150 yd, with receiver gain set to maximum, showing reverberation at saturation levels. 5 msec/div.

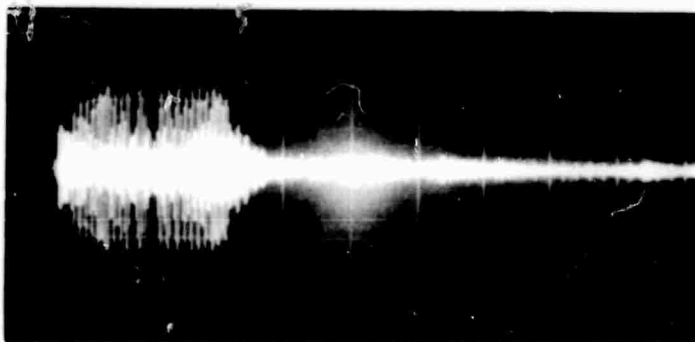


Figure 2.4
PSK pulse as received from 1000 yd, at various receiver gains, showing effects of higher echo amplitudes. Pulses were validated, but answers were incorrect.

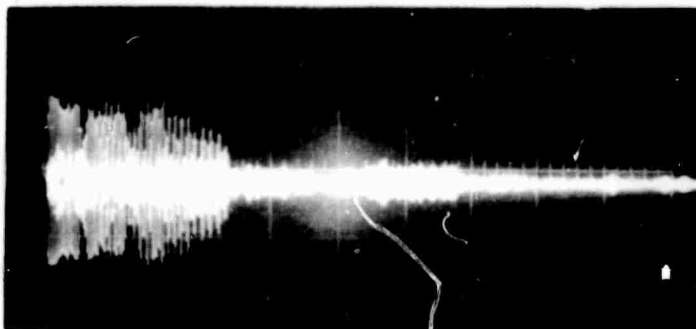


Figure 2.5
same as Fig. 2.4

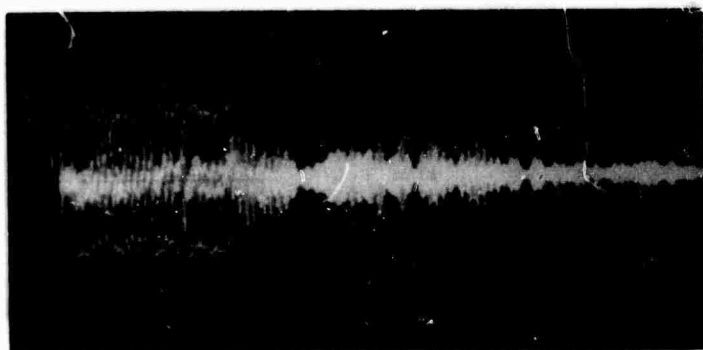


Figure 2.6
same as Fig. 2.4

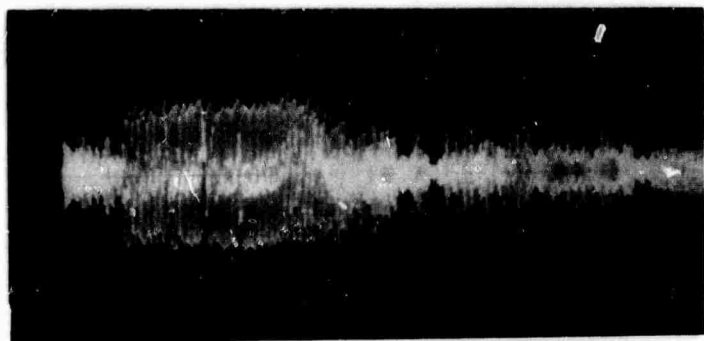


Figure 2.7
same as Fig. 2.4



Figure 2.8
same as Fig. 2.4

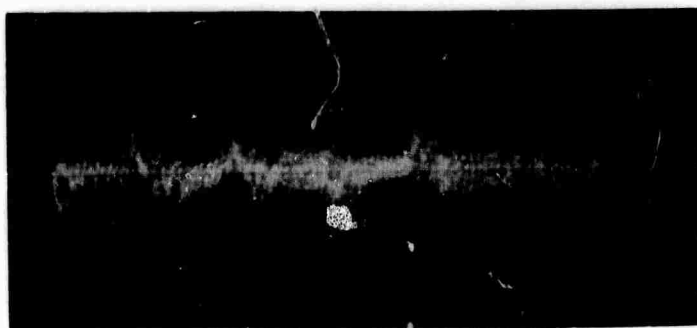


Figure 2.9
PSK pulse from 1000 yd, with
maximum receiver gain. Pulse
was validated and answer was
correct.

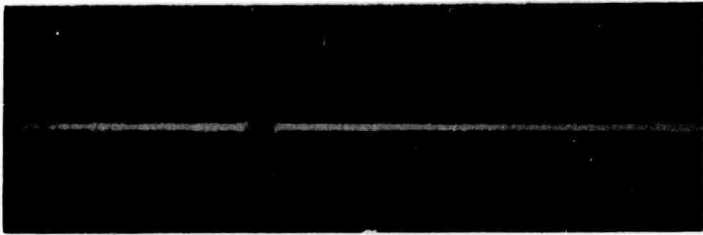


Figure 2.10
Avoidance sonar, echoes from
bottom. Depth under transducer
~70 ft. Full scale ~250 ft.
Depression angle ~50°

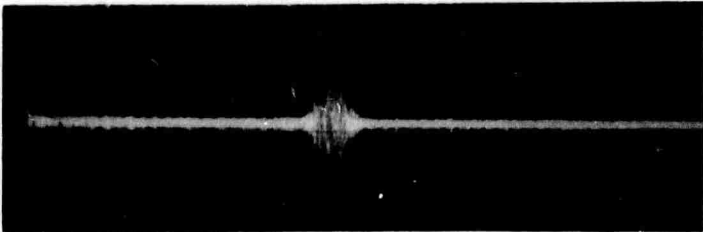


Figure 2.11
same as Fig. 2.10, with de-
pression angle ~40°.

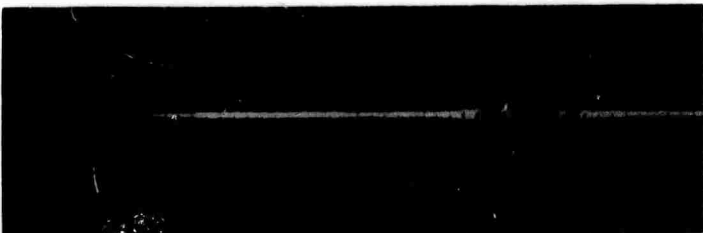


Figure 2.12
same as Fig. 2.10, with de-
pression angle ~20°.

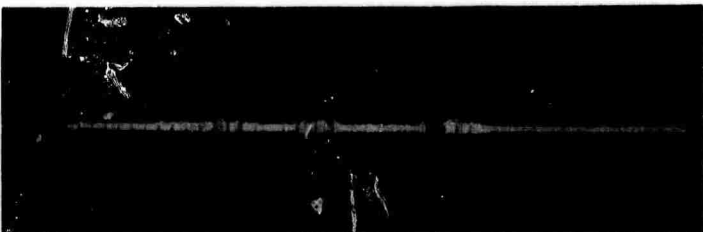


Figure 2.13
Avoidance sonar, echoes from
under-ice surface. Ice canopy
distance, 22 ft. Full scale,
250 ft. Elevation angle 5°.

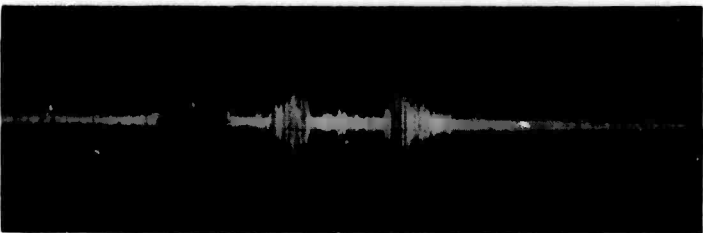


Figure 2.14
same as Fig. 2.13, with 10°
elevation angle.

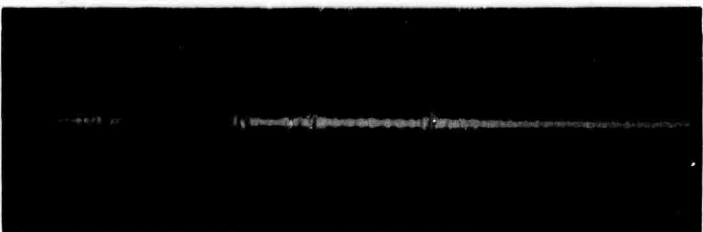


Figure 2.15
same as Fig. 2.13, with 15°
elevation angle.

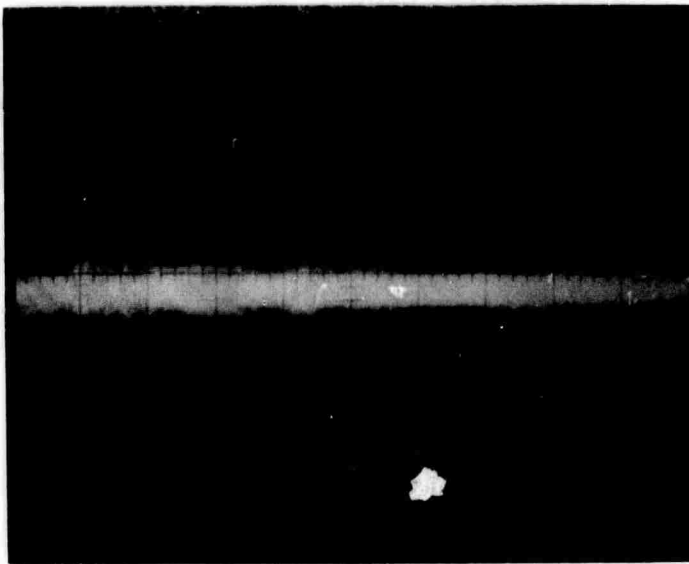


Figure 2.16
Phased homing system. A 4 msec pulse from one channel, with echoes.

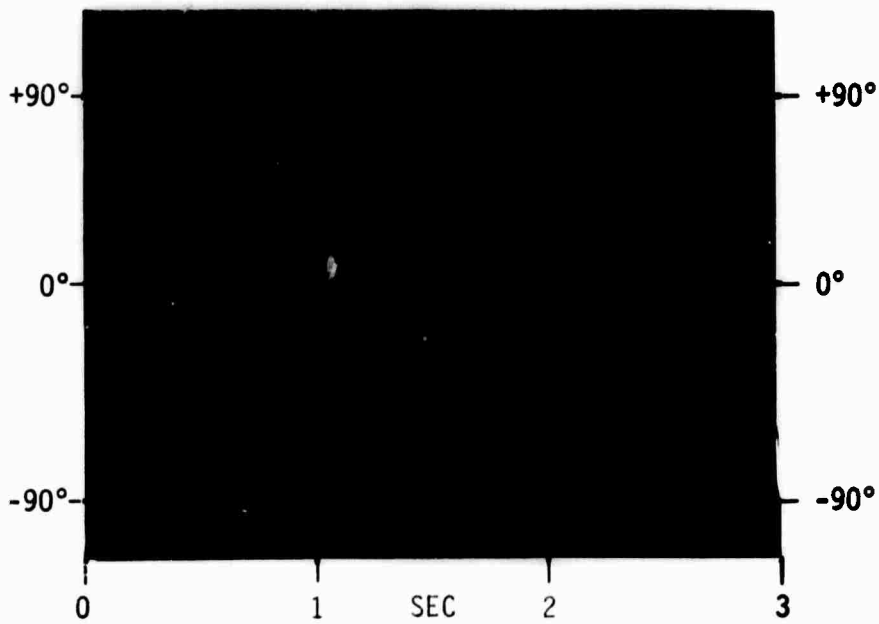


Figure 2.17
Phased homing system. Angle calculations from ~10 consecutive pulses.

3. System Fabrication Progress and Testing

3.1 Current Activities

During the period to which this report applies, a major effort has been expended on the fabrication of system components and their test and check-out. Some idea of the scope of this effort can be gained by reviewing photographs of a few of the major components of the vehicle. A cross sectional view of UARS, Figure 3.1, provides a position location guide for the components which will be discussed. Since two vehicles are being assembled, some of the pictures will show both parts.

The nose section is shown in Figure 3.2. This section is machined from an aluminum forging and has four instrumentation ports on the cylindrical section of the nose.

The battery and instrumentation sections are shown in Figures 3.3, 3.4 and 3.5. These are identical sections made of filament-wound fiberglass formed over and bonded to aluminum end rings and ribs. Figure 3.3 illustrates the machining of the aluminum rings and rough turning of the fiberglass section prior to final machining of the fiberglass section by grinding, Figure 3.4. The ground sections are surface-coated with a clear epoxy sealer and cured while rotating in an infrared heat-field, Figure 3.5.

The next portion of the vehicle hull houses the profiler transducer and is called the Profiler Section. It is shown in the rough machining process in Figure 3.6. Like the nose section, it is made from a cylindrical aluminum forging with the interior machined to form ribs and bosses for mounting the various acoustic devices. To ensure dimensional stability of the finished section, each part is first roughed to approximate size, including boring of the instrumentation ports. Next the interior is completed, then the ports, and finally, the sections, including the tailcone, are assembled and machined to the desired external contour. The tailcone, also a filament-wound fiberglass-aluminum composite, is shown in Figure 3.7, partially machined.

Some of the joint rings which couple the sections together are shown in Figure 3.8. The rings are cut in two equal semi-circular segments and re-joined over the flanges of the mated hull sections to provide an easy method of connecting the sections.

The battery trays and some miscellaneous internal hardware are shown in Figure 3.9. The data chassis is shown in Figure 3.10. The data recorder is mounted on one end of this chassis. Three smaller chassis (not shown) are

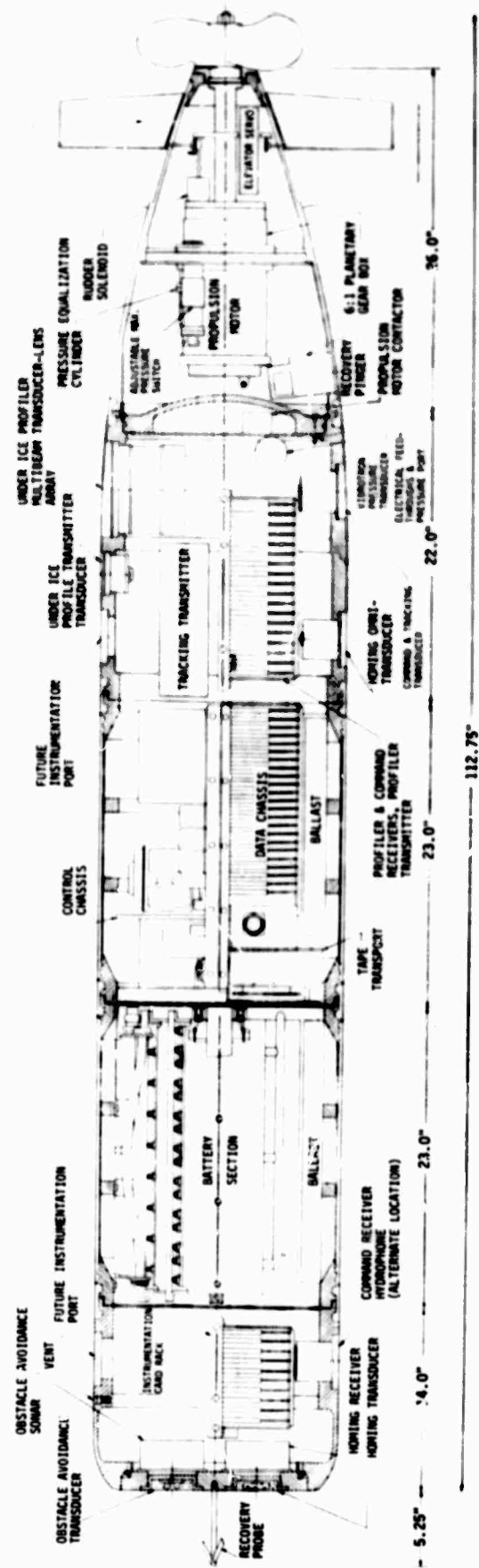


Fig. 3.1. Cross sectional view of UARS

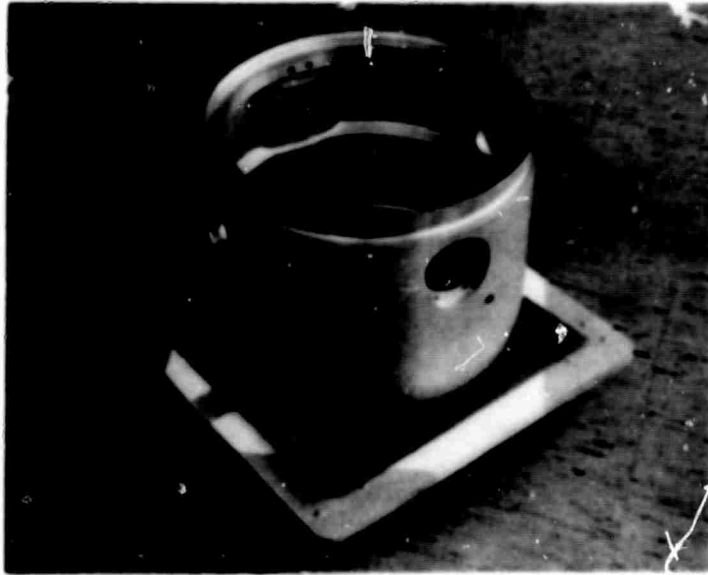


Fig. 3.2. Nose section

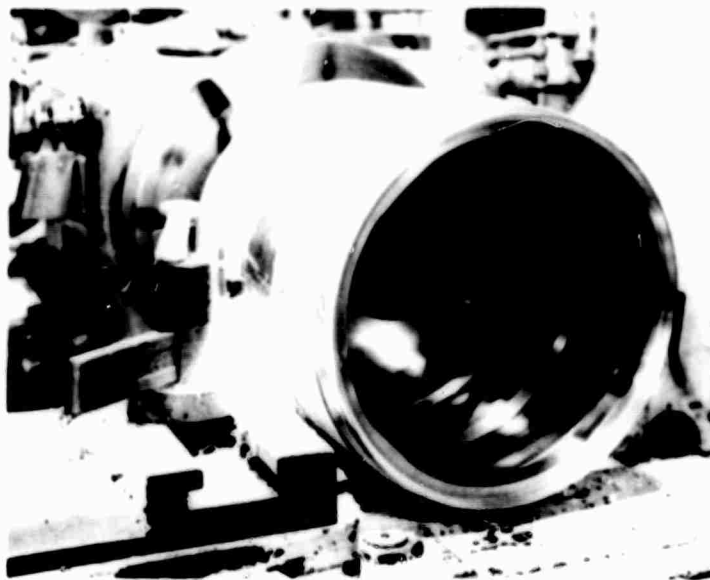


Fig. 3.3. Machining of hull section



Fig. 3.4. Grinding of fiberglass hull

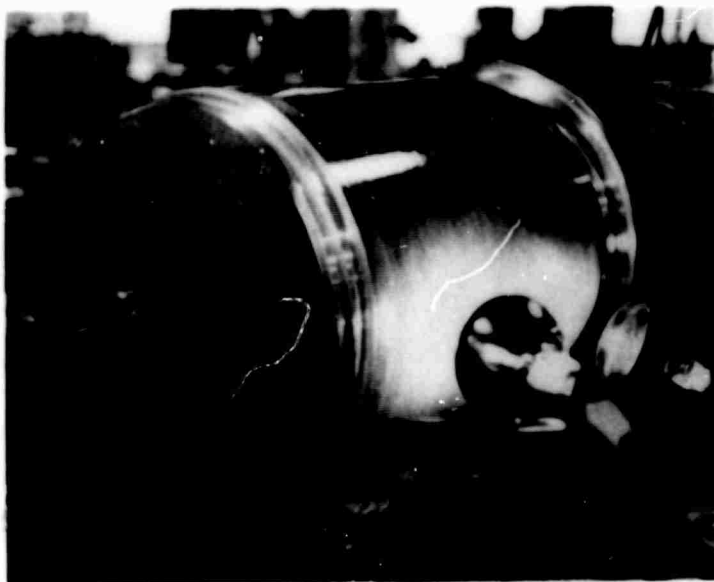


Fig. 3.5. Drying epoxy coating

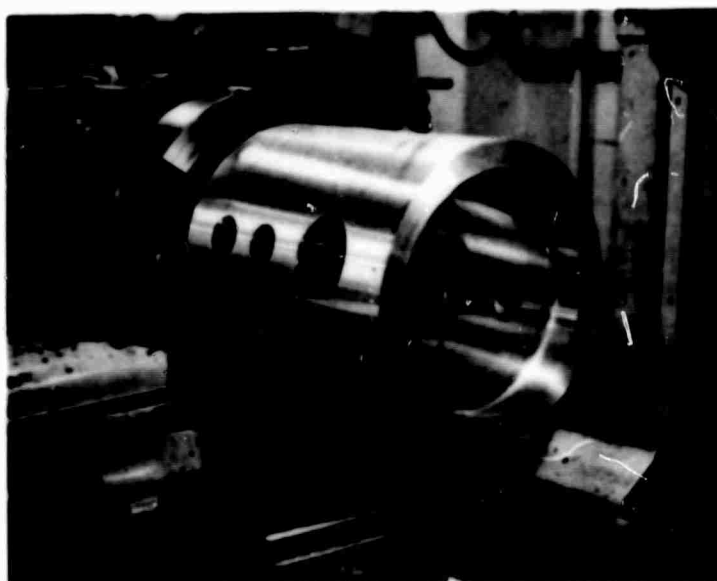


Fig. 3.6. Profiler section



**Fig. 3.7. Tailcone,
partially machined**

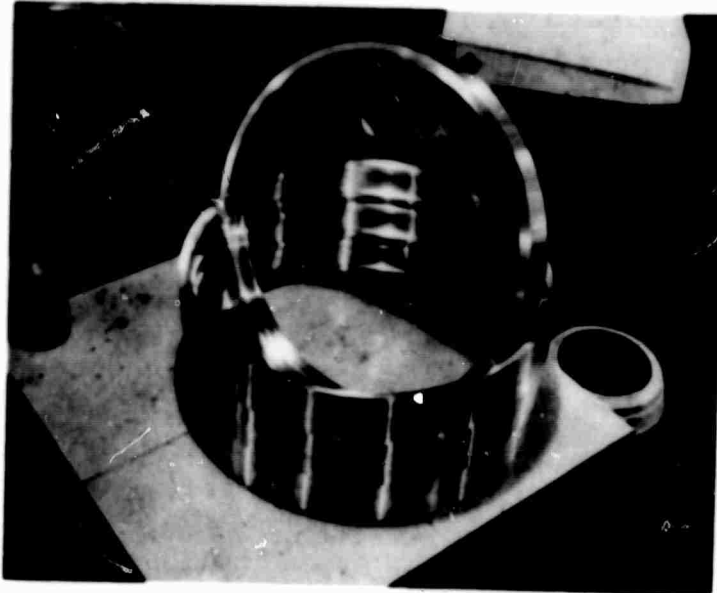


Fig. 3.8. Joint rings

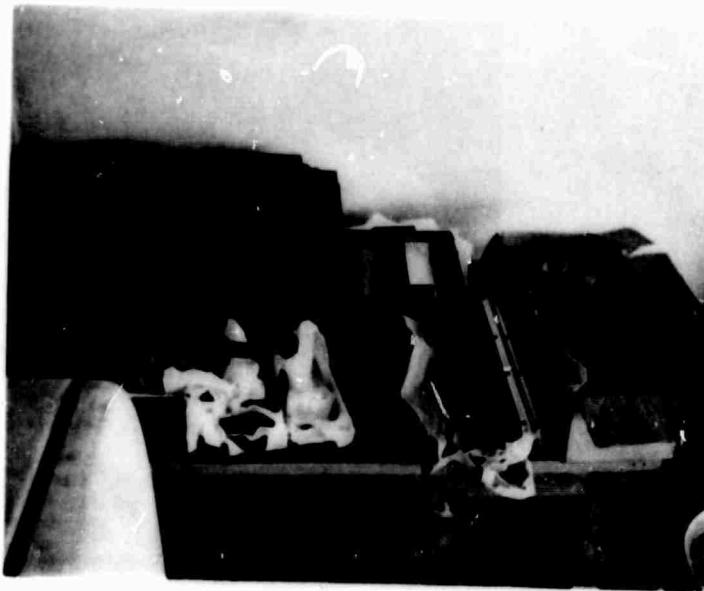


Fig. 3.9. Internal hardware

provided for instrumentation (present and future) in the vehicle nose section and for the profiler system which is housed in its section. The tracking system transmitter is configured to be mounted in the upper half of the profiler section. All three chassis are supported on U-shaped rails afixed to the sides of the various body sections.

The pressure bulkhead at the aft end of the profiler section is shown in the machining process in Figure 3.11. The assembled "canned" motor and gear reduction system is shown in Figure 3.12. The spider serves as a mount for control surface actuators and also as the motor-to-tailcone support.

3.2 Test Program

The test program has been concerned primarily with subsystem performance tests, both functional and environmental. The operating temperature of most of the field system (tracking hydrophones, projector systems, vehicle system) is approximately 0°C since these systems reach thermal equilibrium at sea temperature. The most severe thermal problems are related to the transition phase from low temperature storage and transport to the final environment. The test program combines thermal cycling with functional testing and has been fruitful in pin-pointing potential problems. For example, the difference in the thermal expansion of the material used in the tracking hydrophone and baseline transducer buoys going from 0 to -55°C relieved the "O" ring seal interference, so that at best, breathing in the atmosphere would occur during storage and transport, and at worst, sea water would be ingested through the joint before thermal recovery to design dimensions could occur. This problem was solved by including a rubber "belly band" around the joint to provide a secondary seal.

Another problem arose with the multibeam acoustic lens used in the profiler. The original design utilized a two component (acrylic and silicone rubber) lens. After long-term exposure to low temperature (-50°C, simulating shipping environment), separation of the interface between the two materials occurred, allowing air to become entrapped as the operating temperature was reached. The air interface decoupled the lens elements and destroyed the acoustic performance of the system. Consequently, it was necessary to redesign the lens using a solid-liquid (acrylic-fluorocarbon) approach. In this design, the potential expansion and creep problems associated with the previous lens are overcome by pressuring the liquid lens element with an accumulator. A lens of this design is being fabricated at the present time.

Further control system work associated with ballast placement was also carried out. The analytical and simulation studies showed that the center of gravity of the vehicle must be kept only slightly below the center of buoyancy in order to avoid axial moment shifts during dive or climb. This reduced the roll righting moment to the point where instability problems, particularly at low vehicle speeds, were occurring. Roll control using differential elevator actuation was implemented to solve this potential problem. Since independent servos were needed for both elevators, it was decided to provide complete

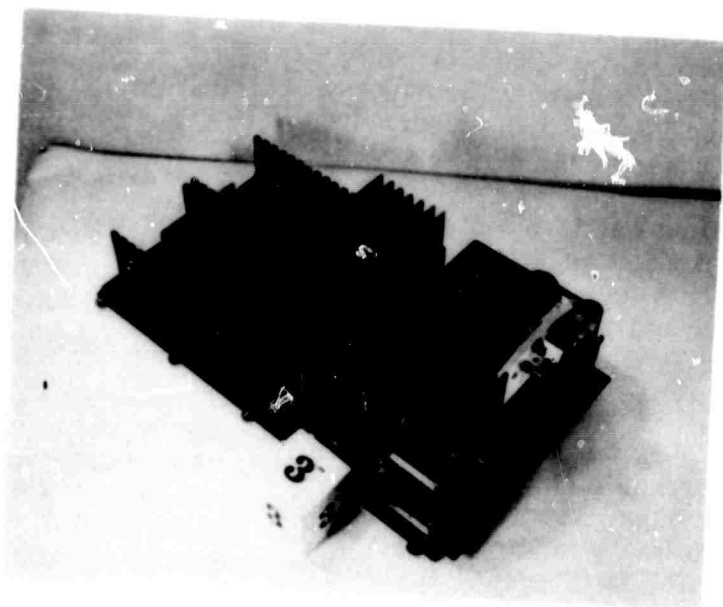


Fig. 3.10. Data chassis



Fig. 3.11. Aft bulkhead

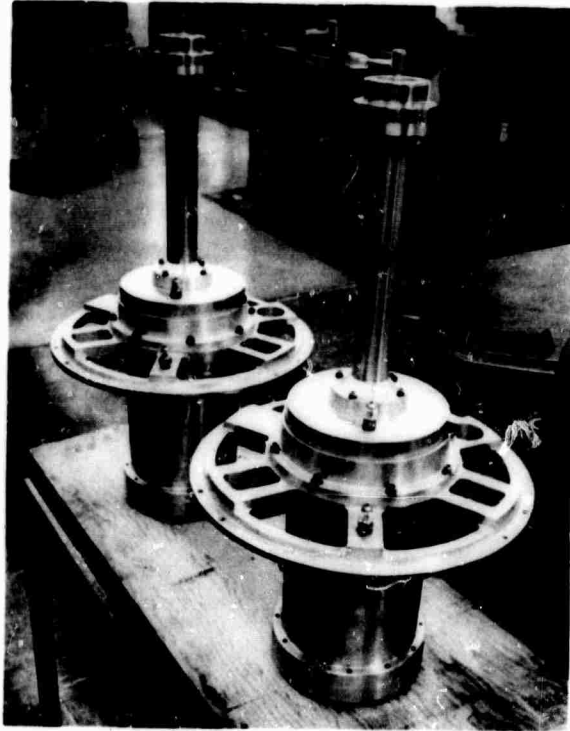


Fig. 3.12. Propulsion assembly

triaxial control, using identical servo actuators (three per vehicle). In the present vehicle, "bang-bang" rudder control (rather than proportional) will be employed, using the servo as a substitute for the previous solenoid.

The process controller hardware, the heart of which is a mini-computer, has just been received at the Laboratory. The complete system is undergoing software and hardware tests. The control programs are being checked out. One of the remaining hardware tasks is modifying the standard 800 bit-per-inch tape units to accept the 320 bit-per-inch format of the vehicle tape.

Authorization to operate the RF telemetry link at 74.65 MHz with 5 watts power was received from the FCC in late August. The system has been designed and checked out. In operation, the tracking hydrophone receiver/RF transmitter system will receive an acoustic signal from the vehicle (or other source), and recognize the validation code. It will then turn on the RF transmitter, transmit the remainder of the coded message (with small, fixed time delay) to the receiver which is coupled to the control processor, and finally turn off the transmitter at the end of the word. The "ON" time of each RF transmitter will be about 1.2 msec per second, during vehicle operations. The acoustic receiver, which requires very small power, will be "ON" throughout the entire deployment period.

4. Thermal Cutting or Coring of Ice

4.1 General Problem and Solution

The UARS system requires a nominal 4 x 12 rectangular hydrohole in the ice for normal vehicle launch and recovery. Holes must also be made for inserting the acoustic transducers (associated with the vehicle tracking, command guidance and communication system) through the sea ice and a nondestructive technique is required for recovering this instrumentation after it has frozen into the ice. In the event of a system failure wherein UARS is unable to return to the recovery hole, the vehicle will come to rest against the ice under-surface where it can be located with the emergency recovery acoustic system. A recovery hole must be made of sufficient diameter, (2.5 feet minimum) so that the vehicle appendages will clear.

The technique that has been developed to answer these requirements utilizes thermal energy in the form of warm water, delivered to the ice in a controlled manner to cut a groove of the desired shape. A delivery manifold of the desired "cookie cutter" shape delivers the water uniformly along the manifold through a series of closely spaced small diameter downward directed orifices. Melting of the ice is caused almost entirely by convective heat transfer. A similar suction manifold is mounted directly above the cutting manifold. The idea is to pick up the mixed melt and delivery water for reheating at the heat source, after prior discard of the excess water. A "dry" hole is desired, so that refreezing between adjacent perpendicular surfaces

of the cut will not occur. This is important mainly during the cold season because the ice temperature varies exponentially from atmospheric temperature at the surface to the sea temperature at the bottom. During the summer Arctic season, it is preferable to return all the excess water to the groove since this prevents the seeping in of colder water through the porous ice. When penetration is completed, sea water floods the groove and the core is left floating in the water. If the coring was done around an instrument, it is then free to be recovered.

Assuming that the hole in the ice is desired (rather than the core sample) the technique used to dispose of the core is to push it out (down) through the hole where it can drift away under adjacent ice. This requires only $1/4$ the energy and $1/8$ the maximum force that lifting the core would entail. Furthermore, it is easy for a man to push downward with a force equal to his weight (as in climbing a ladder), while lifting a significant portion of his weight is extremely difficult.

The original model used to test the thermal coring concept was fabricated from a modified three burner Coleman gasoline stove which heated an insulated pan of water. The design was engineered to operate at low temperatures and performed satisfactorily at -27°F on T-3 during April 1971 (Reference 1). This model transferred about 20,000 BTU per hour to the melting zone and produced a slot whose length-depth product exceeded 10 feet square per hour.

Further development of the thermal corer was accomplished through the joint sponsorship between ARPA-ONR, under this contract, and the Naval Ordnance Laboratory. That experimental program took place in the Greenland Sea where holes of 28 inch diameter were made with an improved version of the device. These holes were made at a five-foot-per-hour rate yielding a groove length-depth product of 35 ft square per hour. The system delivered about 80,000 BTU per hour to the ice. The delivery rate was approximately $\frac{1}{2}$ gallon of warm water per foot of groove; the delivery temperature was 100°F and the return (and discard) temperature was 55°F , which provided 10,800 BTU/hr per lineal foot of groove. If one assumes that the ice temperature initially was just at the freezing point, about 167 BTU per pound of ice would be required to melt and heat it to 55°F , the discard temperature. Then, assuming an ice density of 56 pounds per cubic foot, the computed groove width would be 2.77 inches. The measured groove widths were between 2.5 and 3 inches. This range of variation is entirely explainable by the slight liquid content of the later summer ice.

It was possible to vary the delivery rate, and since the heat input rate was constant, a decrease in delivery rate would increase delivery temperature and vice versa. However, lower delivery rate and higher delivery temperature tended to broaden the groove width and reduce the vertical cutting rate. The half-gallon-per-lineal-foot delivery rate was the maximum attainable with the system and cutter head used. The width obtained is very nearly optimum from a practical viewpoint in that clearance is needed for delivery and suction hoses and the cutting head guides; and small deviations in straightness of cut must be accommodated.

4.2 Brief Description of Operational System

An operational system for cutting holes or removing instrumentation that is frozen into the ice has been developed which uses thermal energy in the form of warm water for melting ice. The reason for using warm water as a working fluid instead of other means is that the impedance match between water and ice is excellent from a convective heat transfer viewpoint, whereas radiant or conductive heat transfer to ice is notoriously poor. Steam as a working medium is inefficient for use in a practical system because of its low heat capacity per unit volume. For example, water at 212°F has about 250 times the energy-density of saturated steam at the same temperature. This means that the flow velocity through a given size hose would have to be 250 times as great with steam as compared to water for the same delivered energy under these conditions.

The operational system uses water, uniformly distributed through a series of downward facing orifices on the underside of a delivery manifold so that turbulent scour of the ice directly below the manifold occurs. A cutting head with an outer diameter slightly greater than 26 inches is shown in Figure 4.1. The lower tube is the delivery manifold; the upper tube is a suction manifold through which the mixed melt and delivered water is drawn back to the heat source as explained in the preceding section.

Propane is used as a fuel in the heat exchanger because of its match with efficient heat transfer equipment as well as its overall safety and reliability. Propane burning equipment operates with a gas pressure of approximately $\frac{1}{2}$ psig which is equivalent to the vapor pressure of this fuel at -40°F. The energy to vaporize the quantity of fuel required cannot be reliably drawn from the atmosphere so the design provides for supplying this heat from the warm water in the system.

A schematic diagram of the system is shown in Figure 4.2. The propane fuel tank absorbs heat from the atmosphere, at temperatures to -40°F, to supply energy for the transfer of liquid propane to the vaporizer coil within the preheater tank. An electrical heating strip on the vaporizer provides energy to vaporize enough fuel to supply the ring burner for starting the system. Once the snow or ice in the melt tank becomes liquid and covers the vaporizer coils, then sufficient heat is available to vaporize the full fuel requirements of the system. A small torch line is provided for igniting the burners (ring burner and hydronic boiler pilot light), and for emergency heating of any frozen components. When sufficient water has been melted in the tank to allow filling the system, the hydronic boiler is ignited; the boiler is turned on by a manual switch which is interlocked with the delivery pump in such a way that the pump must be running whenever the main burner is ignited. The hydronic boiler utilizes a tightly-coiled copper tube that encircles the combustion chamber as a heat transfer surface. A by-pass valve is provided which allows the boiler-heated water to be delivered to either the preheat tank or to the cutting head. At start-up, the water is diverted to the preheat tank which allows the total

heat capacity of the system to be used in building up a hot water inventory (about 10 gallons) before starting any cutting. On this particular model, pressure gages, temperature gages and a flow gage were provided in order to facilitate performance testing and as an aid in system development. Continuing through the circuit, in Figure 4.2, the suction pump draws water from either the suction manifold on the cutting head or from an independent suction line which may be used for charging the system with water from other sources (a melt pond during summer, or a small hole drilled through the ice to the ocean in winter).

The hoses are built up, starting with a special type of agricultural tubing, made of material that is compatible with the low temperatures encountered in the Arctic. An electrical heating tape is first wound around each hose. This is covered with a layer of fiberglass approximately $\frac{1}{4}$ inch thick which is followed, in turn, with a wrapping of "space blanket" (aluminum-gold on mylar film). Finally the outer jacket is made of a low-temperature type of plastic sleeving.

The packaged thermal source is shown in Figure 4.3 and the system is shown in operation in Figure 4.4. The annular groove is clearly visible in Figure 4.5, where cutting is in progress. When completed, the core is pushed out the bottom of the hole with a pole. For the core size shown (about 25 inches in diameter), a force of 25 pounds per foot of core length is required. The clear hole is shown in Figure 4.6.

During experimental operations in the Greenland Sea, 28 inch diameter holes were made in ice from 14 to 18 ft thick at penetration rates of 5 ft per hour. When an 18 ft deep hole was made, only six inches of the guide pipes shown in Figure 4.7 remained above the ice at breakthrough.

In summary, the technique of thermally cutting large, deep holes through sea ice in all seasons has proven to be a quick safe and reliable procedure. A model with larger thermal capacity is under construction which will make four-foot-square hydroholes for use in the UARS project.

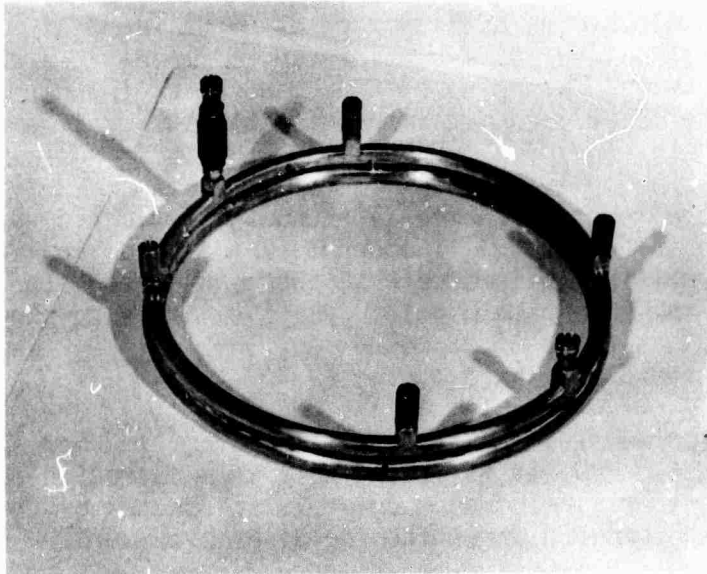


Fig. 4.1. Cutting head

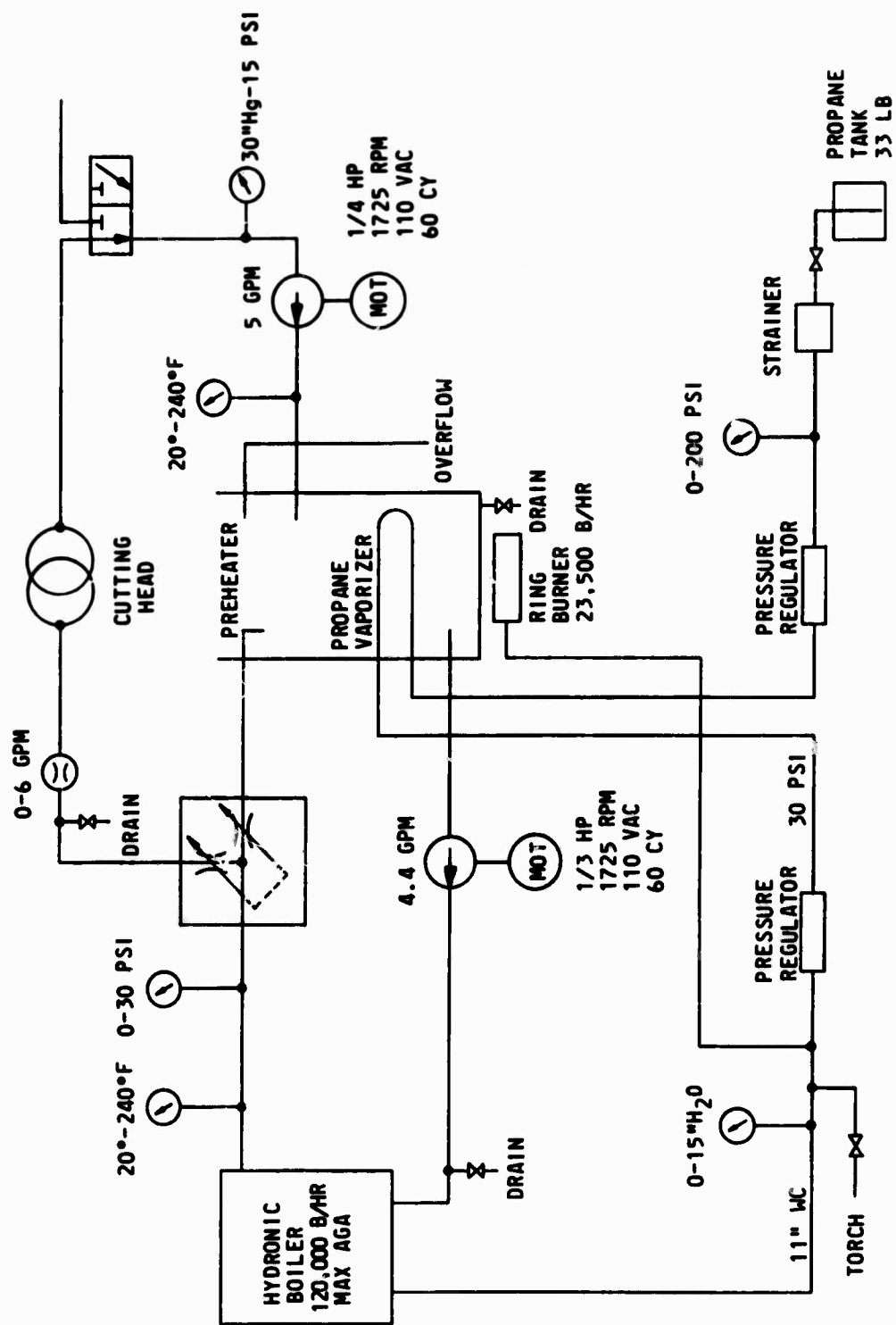


Fig. 4.2. Thermal cutter schematic

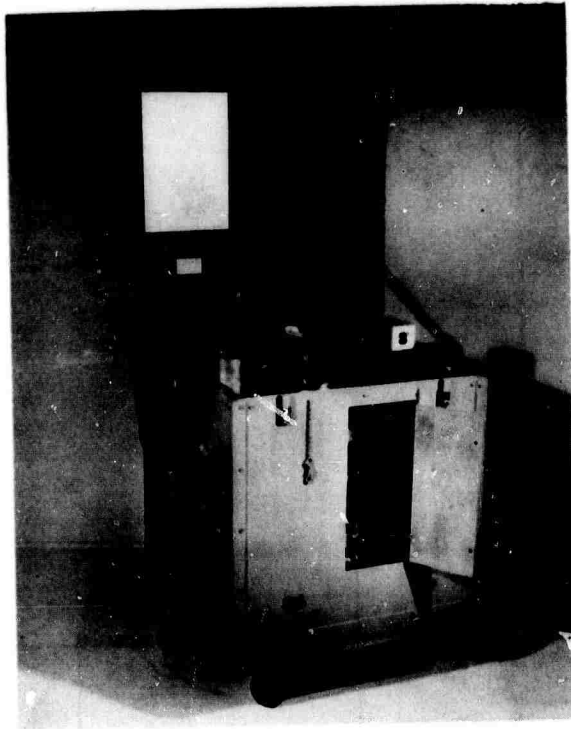


Fig. 4.3. Thermal cutter heat exchanger

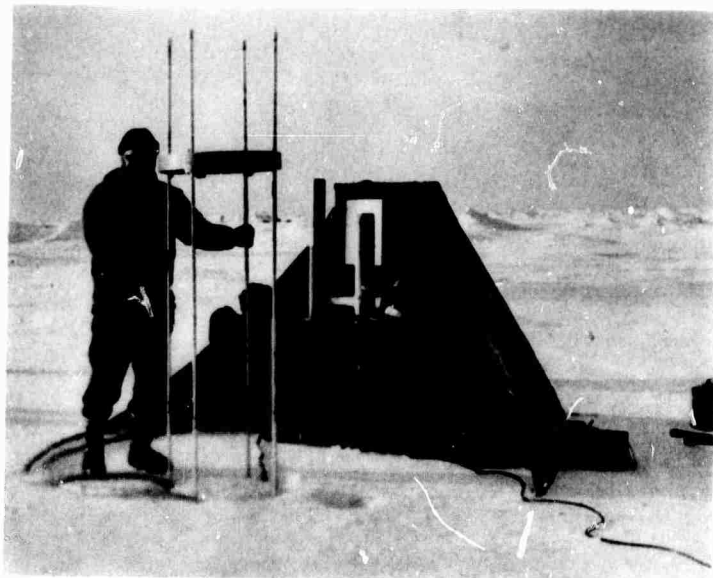


Fig. 4.4. Thermal cutting system in operation

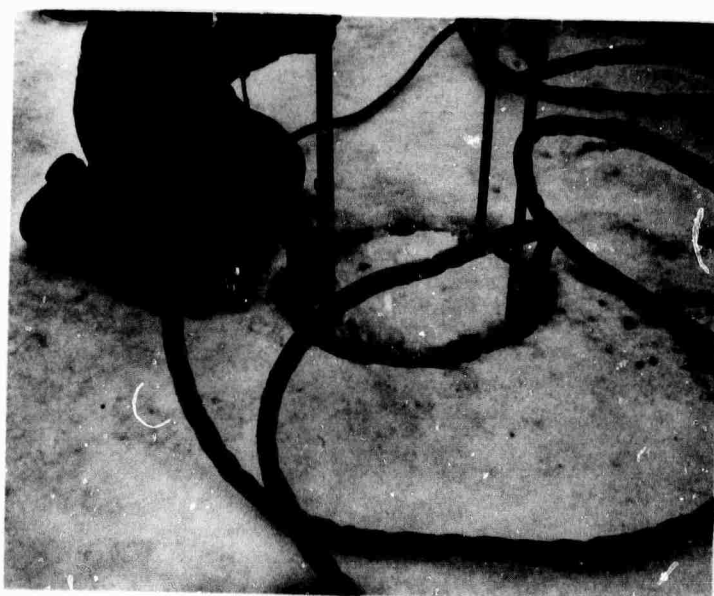


Fig. 4.5 Core cutting in process



Fig. 4.6. Finished hole

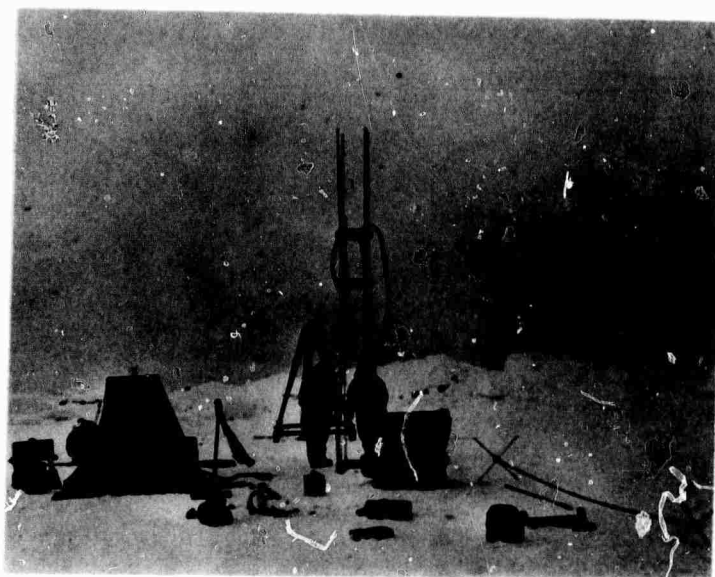


Fig. 4.7. Cutter head and guides

III. RECOMMENDED TECHNICAL RESEARCH AREAS

A. An Ice Pack Terrain Vehicle for Arctic Research

1. Introduction

A serious transportation problem faces those engaged in research work upon the arctic ice pack, namely, the inability to move men and equipment short distances (up to ten miles) at reasonable expense and with a high probability of success. Long range movement has been satisfied by heavy aircraft which utilize prepared landing strips on ice islands or heavy floes. Light planes and helicopters are reasonably effective at moderate ranges but become increasingly more expensive as the range decreases. Their use with research camps on the ice is expensive because of pilot and maintenance costs which continue regardless of use factor. Furthermore, they are limited by weather and darkness. The surface effect vehicle shows promise for many ice pack missions, but it will be expensive to operate and further development is needed.

The "weasel," a military tracked vehicle of WW II vintage, has found some use on the ice and snow but has little if any water-to-ice transition ability. "A war product, the weasel has many inherent weaknesses and a short operating life. Track life varies from 800 to 1500 miles per set Bogie wheels, sprockets and idlers wear out in approximately 500 miles. Complete motor overhauling is required at 1,000 to 1,500 mile intervals and transmissions last only 200 to 500 miles. The hull itself generally fails from fatigue cracks any time after 3000 miles. Careful operation and slower speed raise these limitations somewhat, but a definite need exists for a comparable vehicle of greater dependability." (Reference 1.) Costs for operation of a weasel is estimated at \$4.00 per mile and tracks cost \$750 each (Reference 2).

For the problem at hand an inexpensive, air-transportable utility vehicle is needed. Such a vehicle would be analogous to the military "jeep," where speed and carrying capacity are low and multiple use primary.

The ice pack, at any time of the year, is not a continuous sheet, roughened by pressure ridges and hummocks. Rather, cracks, leads and thin ice over refrozen leads are to be expected on any trip of more than a few miles duration in the winter and over much shorter distances during the summer season. The ability to cross open water and ice of unknown strength safely demands an amphibious capability.

The conquest of the unique arctic terrain demands a radical departure from the concepts of existing surface transportation. A truly all-weather, all-terrain amphibious vehicle that is able to make the transition from water to ice and ice to water over a 1-2 ft step is necessary.

Ref. 1. - "U. S. Navy Arctic Engineering," Technical Publication NAVJOCKS TP-PW-11, Dept. of Navy, Bureau of Yards and Docks, Wash. D. C., 15 March 1955

Ref. 2. - Brewer, M., Memo Operation 1971 from Director, Naval Arctic Research Laboratory to All Investigators and Assistants, Naval Arctic Research Laboratory, Barrow, Alaska

2. A Research Mission Scenario

2.1 Short Range Objective

The Applied Physics Laboratory of the University of Washington is preparing for experiments in the Arctic in which the Unmanned Arctic Research Submersible (UARS) system will be used near Ice Island T-3. It will be necessary to install four tracking hydrophones through the pack ice at distances of about one mile from the submersible launch and recovery site. A suitable vehicle is necessary to install these instruments and service them when necessary. In the event of submersible propulsion failure there is the need to transport upwards of 500 pounds of location equipment and rescue gear to the point where the submersible lies below the ice. This may entail crossing open water. After locating UARS, several hours may be necessary to retrieve and load the submersible for return to base camp. The return load requirements would be increased by one thousand pounds, the submersible weight.

This mission requirement implies that terrain, weather, or season must not block the vehicle from reaching its destination. The use of two vehicles together is probably required for personnel safety on most missions. Simplicity in operation and maintenance is important since, for economic reasons, all operations will be done by ice camp personnel and the researchers themselves.

This vehicle would also provide daily transportation between the UARS base of operations and the main T-3 camp, a distance of one mile. The travel would be necessary for messing and sleeping. The vehicle would be used to tow sleds of supplies and equipment from the landing strip to the UARS operations base, a distance of 1.5 miles.

2.2 Long Range Objective

Continued national interest in the Arctic and the need to transport men and equipment over the pack ice is to be expected. More ambitious programs will venture further from existing stations to carry on scientific research and for routine data collection in the arctic basin. In particular, exploration of the arctic continental shelf will become a pressing necessity as the known resources of the world are consumed.

Arctic field operation of the prototype pack ice vehicle here described should establish guidelines for design of future vehicles intended for use in this area. Previous related work has dealt only with over snow and permafrost transportation. (Reference 3.)

3. Design Approach

A parallel study with that of Adee (Appendix I) led to a basic design concept somewhat similar to the All-Terrain Vehicles (ATV) which are now produced in quantity for the public. ATV's are not adequate to be used on pack

Ref: 3. - Arctic and Middle North Transportation, Arctic Institute of North America, Washington, D. C., December 1969

ice, but do provide useful basic design criteria and could furnish some components applicable to this problem. In the Arctic, temperature itself becomes a major design consideration in materials selection (cold soaking and thermal shock problems). Dependability is always a design problem, but in the Arctic it is particularly critical because of personnel safety considerations. Fortunately, the large commercial market that the ATV enjoys has provided experience records for many needed components. Were it not for the unique amphibious requirement including safe water entrance and exit from an ice floe with a foot or so of freeboard, the present ATV would be a good starting point for vehicle development. Unfortunately the ATV's size (determined by the dimension of a pickup truck box) makes it unstable during water entry and exit under arctic ice conditions, hence the need to start with a prototype vehicle of somewhat more general properties.

The general characteristics of such a vehicle are shown in Table 1 and are compared there with the Weasel. The vehicle design employs low pressure pneumatic tires, all driving, to provide both traction and the necessary springing. An eight wheel configuration is applicable for the problem at hand.

	<u>Prototype Vehicle</u>	<u>Weasel</u>
Overall length	144"	192"
Overall width	72"	67"
Overall height	72" with top	71" with canopy
Weight	1500 lb	4800 lb + canopy
Payload	750 lb + sled	1200 lb
Ground pressure	2.0 psi	1.9 psi light
Freeboard (gross wt.)	16" front and rear	10.5 front 8" rear
Horsepower	25	60
Horsepower/gross wt.	.111 hp/lb	.108 hp/lb
Payload/gross wt.	.50 lb/lb + sled	.22 lb/lb
Ground clearance	12"	11"
In-water propulsion/speed	Jet pump/5 mph	track motion/n.a.
Height of center of gravity	36"	NA

Table 1. Prototype Vehicle and Weasel Characteristics

The prototype vehicle should have modest speed capabilities on snow and ice but must have good water mobility. The water propulsion can be provided by jet pump and wheel rotation. Increased freeboard and additional positive flotation relative to conventional ATV's is needed. However, this alone will not assure safe and reliable transit over the typical 1 to 1.5 foot

step at the lead edge. In addition, the pitch angle of the vehicle must not exceed about 30° or the vehicle's center of gravity will move excessively and cause upset. To moderate this problem, the vehicle length could be exaggerated but this would compromise the overall design. A floatable sled offers a more effective way to increase the wheelbase if one uses the special sled coupling methods shown in Figure 1.

The climbing out process can take several forms, the simplest being that of winching from a deadman put into the ice (Figure 2). Another method uses climbing arms or a sealed cylinder actuated to lift the front of the vehicle from the water (Figure 3). Entrance to the water using the arms for buoyancy adjustment is shown in Figure 4. Traction on the cylinder during climbout would be a problem because of center of gravity shift relative to the ice edge. However, using the sled to reduce the angle of upward pitch would help, as shown in the figure. In any case, a two-man crew would seem to be the minimum.

In addition to the need for an amphibious capability, the vehicle's mobility on the ice is an important consideration. The use of low pressure pneumatic tires on a low speed vehicle makes additional suspension unnecessary. Rubber at low temperatures possesses good flexibility and toughness. The traction of tires is lower than that of tracks but the use of studs or chains adequately increases their effectiveness. The maximum incline that the vehicle can climb is a direct function of traction and the center of gravity. When a vehicle with a high center of gravity (such as the weasel) pitches, a large portion of the weight is transferred, increasing the unit loading of the track which may be detrimental to traction on soft surfaces. The prototype vehicle must have a low center of gravity to reduce this effect. The prototype vehicle could have the sled attached in such manner as to damp the change in pitch which would otherwise occur if only the wheelbase of the tractor unit was effective in moderating terrain roughness. Side-hill ability would be increased from a stability standpoint with a low center of gravity and would be a function of available traction.

Snow mobility would be nearly equal to the weasel on a unit pressure basis; however, deep snow is seldom a problem in the arctic pack ice area. To overcome high-centering problems a ground clearance of twelve inches and a semi-tunnel shape for the underside of the vehicle are suggested. A front axle located four to six inches above the other three could enable it to roll over obstacles up to sixteen inches high at moderate speed (5 mph). A winch (manual or electric) would provide extra mobility in severe cases and make the vehicle useful for moving small shelters and other sliding loads short distances. The power train could consist of engine, variable speed clutch, three speed and reverse transmission, secondary reduction, differential, and steering brakes. Components similar to those which have proven satisfactory in ATV application but of more conservative design are available. Design or development of a new power train arrangement for this application therefore seems unnecessary.

3.1 Safety

A vehicle for the arctic area must provide safe and reliable transportation at all times. Reliability can be obtained by simple, straightforward design, the use of proper materials and conservative sizing of parts. During the three decades since the weasel was designed, materials and processes have improved considerably so that a reliable cold-area vehicle design is now possible. Reliability also implies that maintenance and repair can be easily done by camp personnel with common tools and easily available parts.

Protection from the elements and emergency shelter would be provided by an enclosed cab or vehicle. On-water movement necessitates positive flotation and a self-righting hull design. Knockout windows and roof for emergency escape must be provided. Communication equipment must be included in the vehicle system.

The use of cold temperature materials for all exposed, stressed parts will prevent catastrophic failure. Most power transmission components must be warmed before operation. Therefore, these parts should be located in a machinery bay which is heatable by a fuel-fired heater prior to operation and by engine waste heat when operating. Heat for the personnel spaces of the vehicle must also be provided. Ice adherence to the hull can be minimized or prevented by surface treatment and the use of smooth, non-re-entrant body contours. The tires inherently shed the ice by flexing action and the drive system has sufficient torque to fracture any thin ice coat which may cling to the drive axles at their position of entry into the vehicle hull.

4. Probable Vehicle Costs

The practicality of the vehicle discussed herein depends to a large extent upon its cost, regardless of how effective it may prove to be. A preliminary design (schematic) has been made and stock items identified and costed. The total, per-vehicle costs of identifiable and available components was approximately \$5,600, using list prices. This also includes basic materials for the hull and sled trailer but not their fabrication costs. Assembly and fabrication costs depend very greatly upon how many vehicles would be produced at one time from a proven final design. Assuming that a minimum of four vehicles per lot were produced, a fabrication and assembly cost of about \$2 per pound appears reasonable, based upon experience with similar mechanical systems. This would result in a per-vehicle cost of about \$8,600. This price appears quite reasonable and would represent only a small portion of a research investigator's project budget. We therefore conclude that this approach is practical from a cost viewpoint.

We have not addressed the development costs of such a system. In a development cycle, two units would be necessary and basic parts costs would be approximately double those of the production unit because of parts substitution during the testing program. Design and test would require about two engineer man-years of effort and at least one year of technician support (draftsman, machinist, etc.). The development costs would thus appear to be about \$125K plus government field logistic support in the Arctic.

A consideration of these costs makes it clear why no such vehicle is likely to become available through normal commercial marketing. The development costs are high in comparison to the demand rate for the product, making the vehicle commercially unattractive in spite of its uniqueness. Since government-sponsored programs will be the principal benefactors from use of this vehicle, it is logical that the government should be the principal developer.

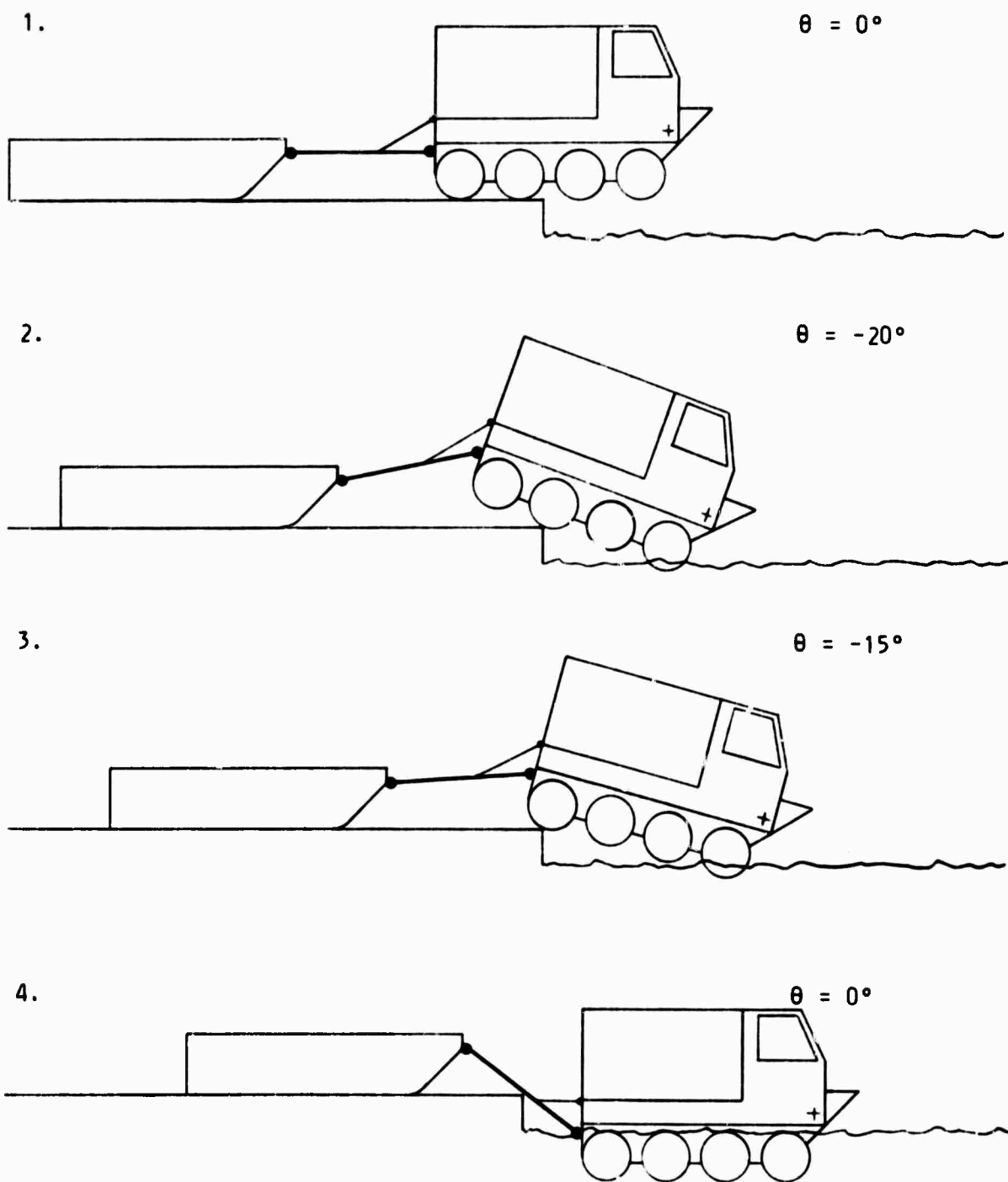


Fig. 1. Transition from ice to water, use of sled

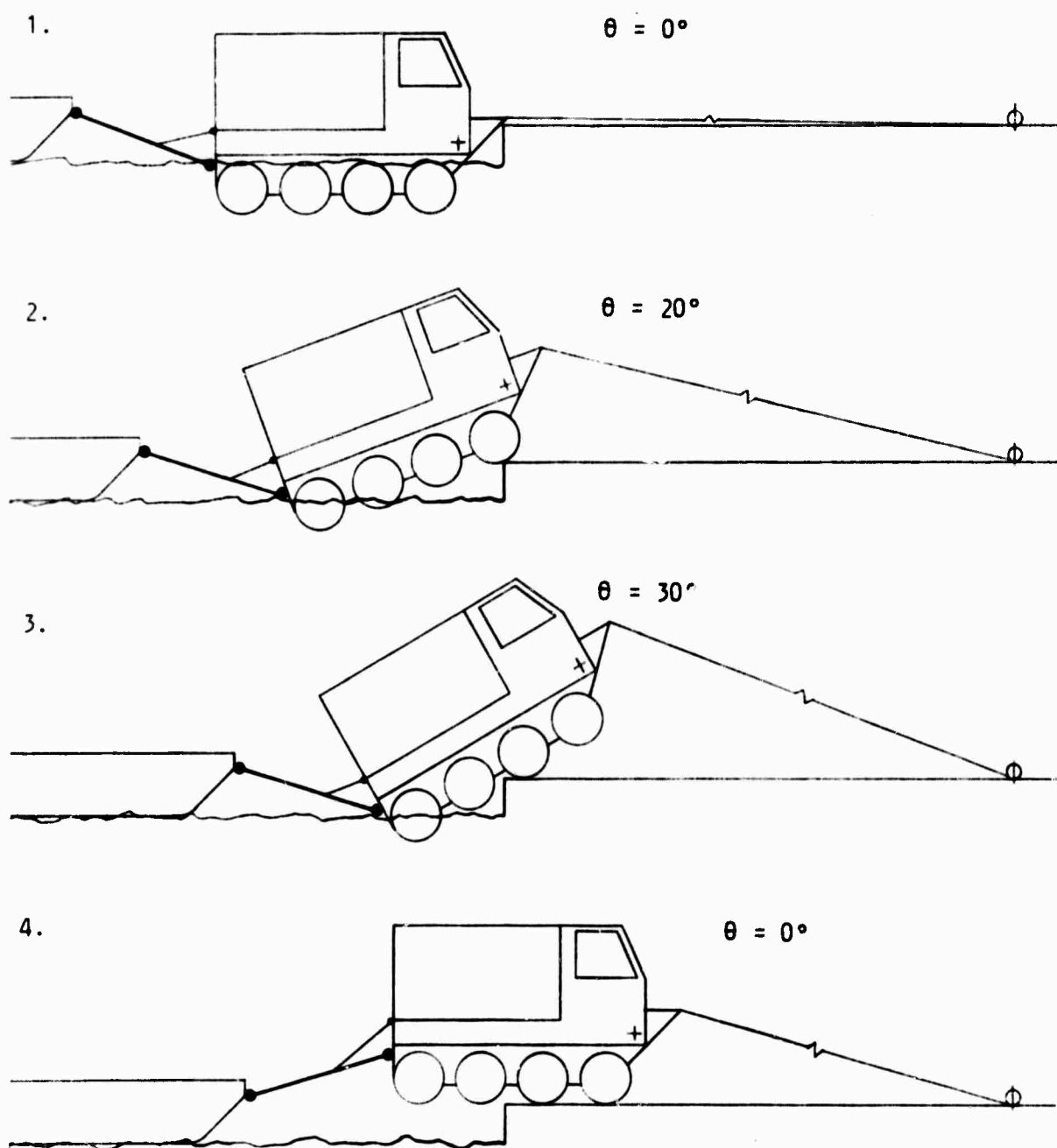


Fig. 2. Transition from water to ice, use of winch and sled

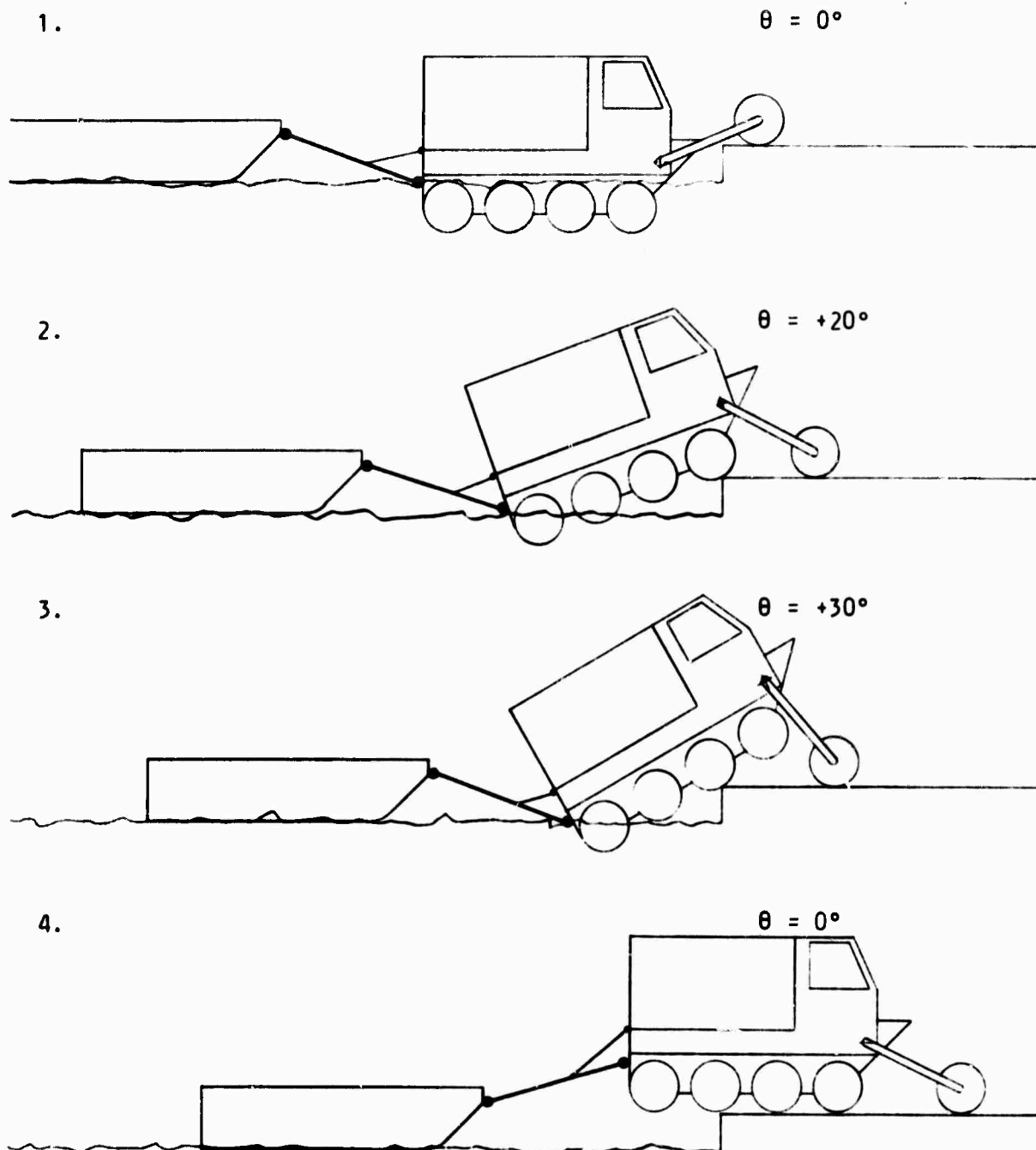


Fig. 3. Transition from water to ice, use of auxiliary arm

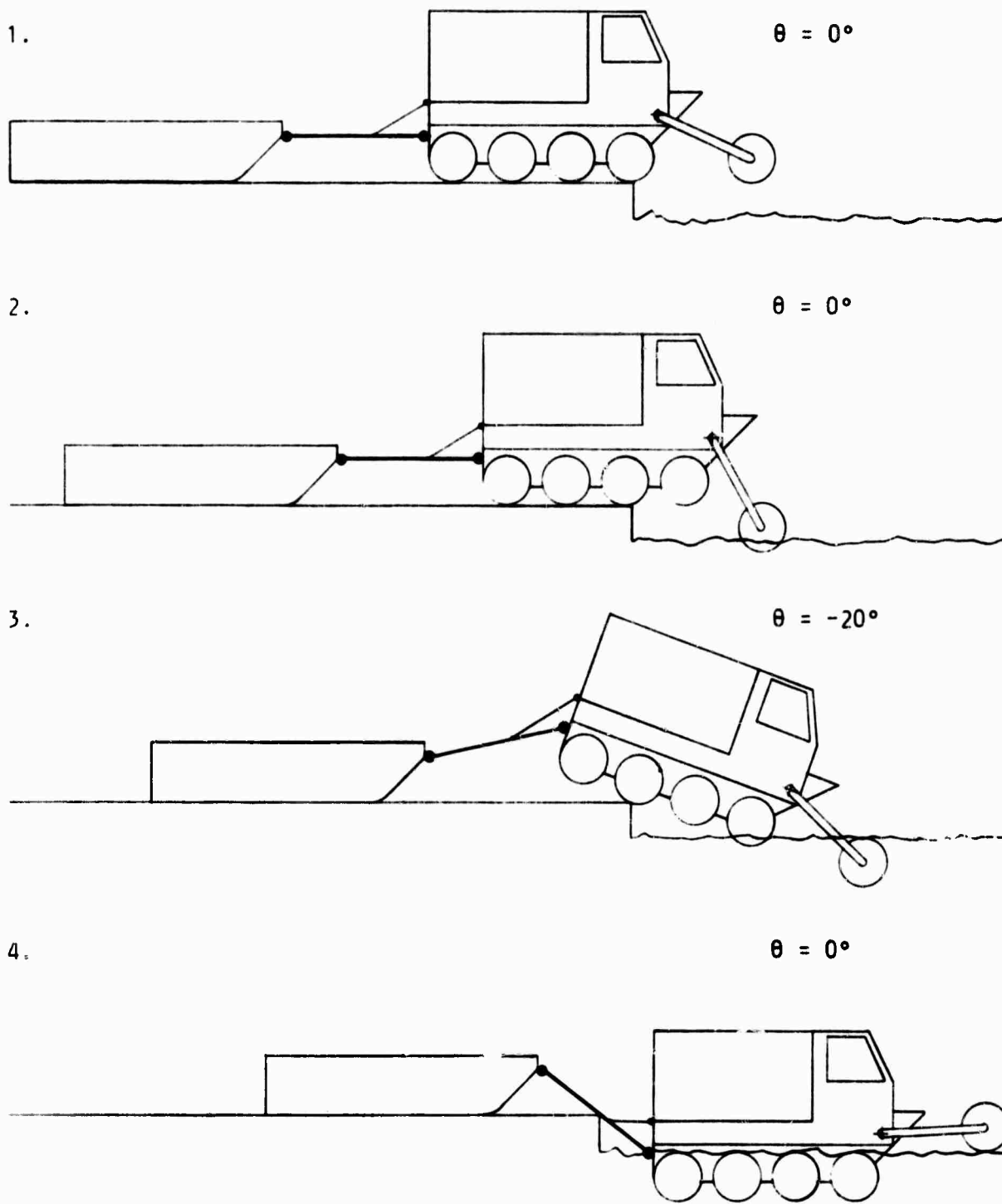


Fig. 4. Transition from ice to water, use of auxiliary arm

B. An Acoustic Data Telemetry Link for Submerged Oceanographic Sensor Systems

1. Introduction

There are a variety of underwater data buoys and sensor strings used by oceanographers to measure the properties of the sea remotely and automatically. The placement of this equipment is often intricate and time-consuming, but its retrieval can be orders of magnitude more difficult, especially for bottom-mounted systems in moderate to heavy seas. In the polar regions, where the ocean is perennially covered with a moving field of ice, the recovery problems for submerged, bottom-anchored instrumentation are so formidable that their solution has not been attempted. Even in the boreal marginal seas, where the ice normally clears annually, much valuable equipment has been lost with no indication of its fate, and perhaps worse, no data return. Often the cost of the ship and the time of the scientific team which is spent in futile search exceeds the value of the lost items. Even when recovery is successful, if the data could have been retrieved without the need to disturb the sensors, the system probably would have continued to perform effectively for two or three times as long without the cost and jeopardy of retrieval.

This discussion recommends a method of overcoming the need to recover instrumentation that has been successfully placed. The approach is to develop and employ a reliable, high-capacity acoustic telemetry link between the instrumentation and surface or submerged interrogator.

2. Technical Approach

A variety of different acoustic telemetry systems have been developed by the University of Washington Applied Physics Laboratory over the past 15 years. The principal application of these systems has been to communicate with and control unmanned, untethered submersibles which the Laboratory uses for the collection of various types of oceanographic data. The most difficult acoustic environment which we have encountered in this work is in the Arctic under ice. There the surface reflections from the ice and the distortions caused by temperature and density inhomogeneities in the water forced us to develop a short pulse, phase-shift-keyed acoustic system in order to attain reliability and accuracy needed to track and control a vehicle precisely under the ice. With this system it is now feasible to transmit and receive information at a rate of 10 kilobits per second over distances of 4-6 km or at lower rates over larger distances. Beam patterns can be made very tight to maintain an essentially secure communication system; or they can be quite broad to allow flexibility in receiver location.

The concept recommended here would be to take the existing, APL-developed phase-shift-keyed acoustic communication system and add magnetic tape storage and control systems to produce a unit which may be easily incorporated

into any submerged sensor system and interrogated from the surface or from a passing submarine. The most effective way to carry out this development would be to include it as part of a strongly supported scientific program in oceanography--one where long strings of bottom-mounted sensors are planned, or where the instrumentation must be located in ice-covered waters.

Several polar sea studies are being discussed in which this acoustic data link could be an important element. These include investigations, in the Arctic, of the mechanism and magnitude of energy and mass transfer associated with the East Greenland Current and similar research in the Norwegian Sea and in Baffin Bay. In the Antarctic, the acoustic data link would be valuable, if not essential, in work undertaken to describe and quantify with some precision the following processes: (1) Bottom water formation in the Weddell Sea, (2) the circumpolar current through the Drake Passage, and (3) the Antarctic convergence in the area of the Ross Ice Shelf.

Thus, it is recommended that the acoustic telemetry system be developed in such a way that it may be easily interfaced with any normal submerged buoy system in any funded oceanographic program. Figure 1 shows the elements of the telemetry system including their relationship to the data sensors and other buoy components. Key features of the data link would be:

- (1) A capability to receive sensor inputs over an extended period of time (perhaps 2-3 years), store them digitally on magnetic tape within the buoy and play them back through an acoustic transmitter when triggered by the correct interrogation signal.
- (2) A capability to transmit acoustically at a very high bit rate using a technique that minimizes the probability of data loss or distortion during transmission.
- (3) The system would operate equally well under polar ice or in the open ocean.
- (4) The buoy location transponder and data transmission system will use coded signals to permit secure interrogation and transmission.

With these features, the sensor system flexibility would be greatly increased over that of a non-telemetering buoy. For example, it could be programmed to take large quantities of data at certain times or over certain intervals and read it back after a short time; or it could collect and pre-process or average the data over a longer period of time if the interrogations were to be planned say only semi-annually. The sensor activation sequence could be modified remotely, if desired. Also, the tending ship could be much more efficiently utilized, since it could service (retrieve data from) an entire field of buoys during the time that it would otherwise be occupied with the recovery of just one.

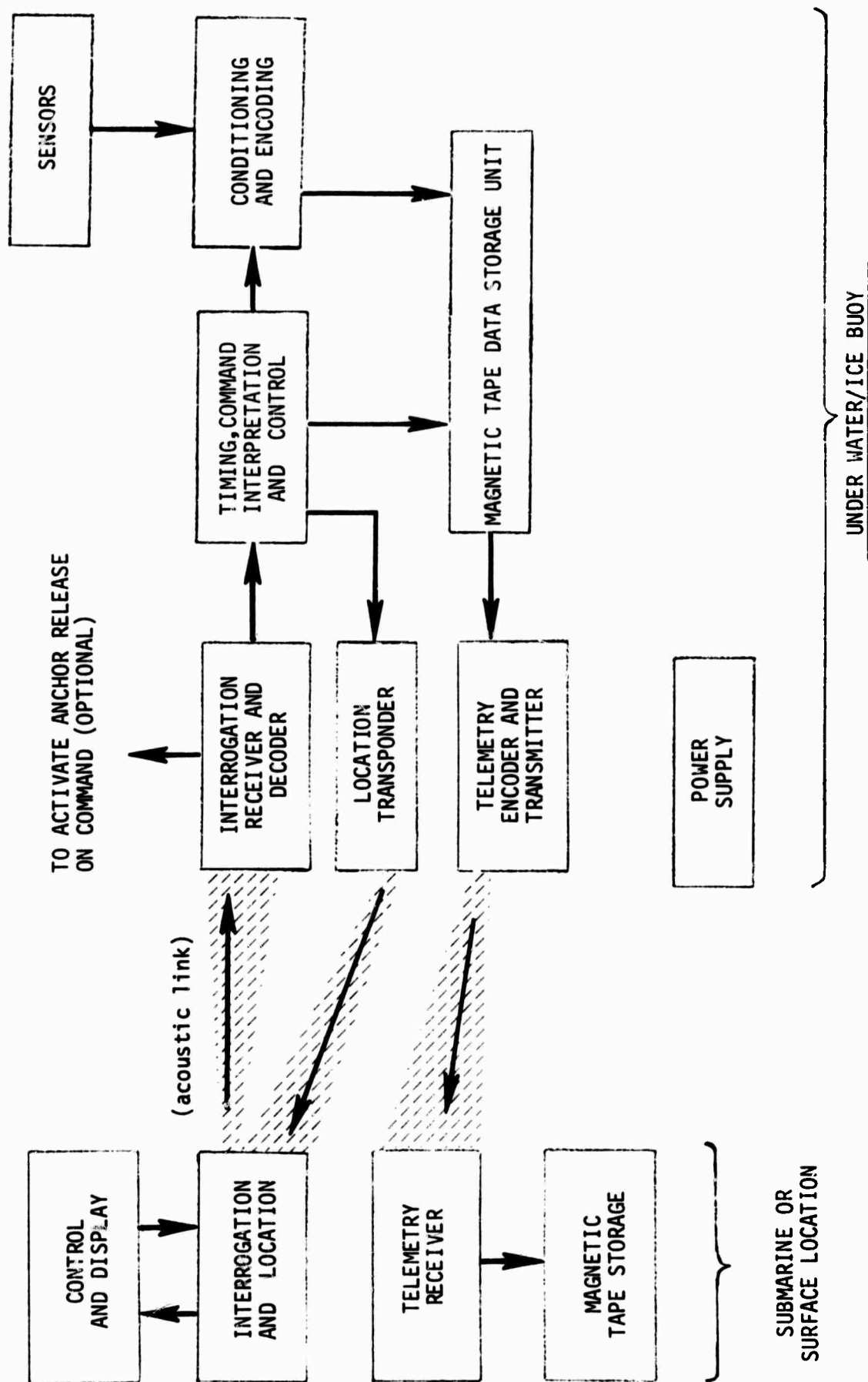


Figure 1. Acoustic Data Telemetry System Diagram

3. Specific Development Effort

In order to design, build, and test a prototype data recovery system the following steps would be necessary:

- a. Obtain an appropriate tape recorder to store the data or contract to have an existing recorder modified for this use.
- b. Design a self-contained electronics and tape recorder package which will store data or telemeter previously stored data to the surface on command.
- c. Construct three of the data gathering and transmission packages described in b. above.
- d. Design a light-weight, helicopter-transportable data receiving unit for use aboard ship or an pack ice. The unit will receive the data telemetered from the submerged transmission package, store the data on IBM-compatible magnetic tape, and display selected data.
- e. Construct one of the data receiving units described in d. above.
- f. Provide sufficient documentation to construct and maintain all of the above.
- g. Provide test equipment for system upkeep.
- h. Test the full acoustic telemetry system in local waters to develop best field checkout procedure.
- i. Operate telemetry system in deep ocean and/or polar (ice covered) environment.

Figure 2 sets forth the recommended schedule of system development. This takes place over a period of 1 1/2 years beginning in mid-calendar year 1972. It is assumed that this will be compatible with decisions to proceed on the various polar scientific programs.

4. Fund Requirements

The following tabulation summarizes the anticipated technical resource and fund requirements for the acoustic telemetry prototype system development. The figures given are believed to be conservative; and, as noted previously, cover the development of three buoy-mounted units and one surface unit.

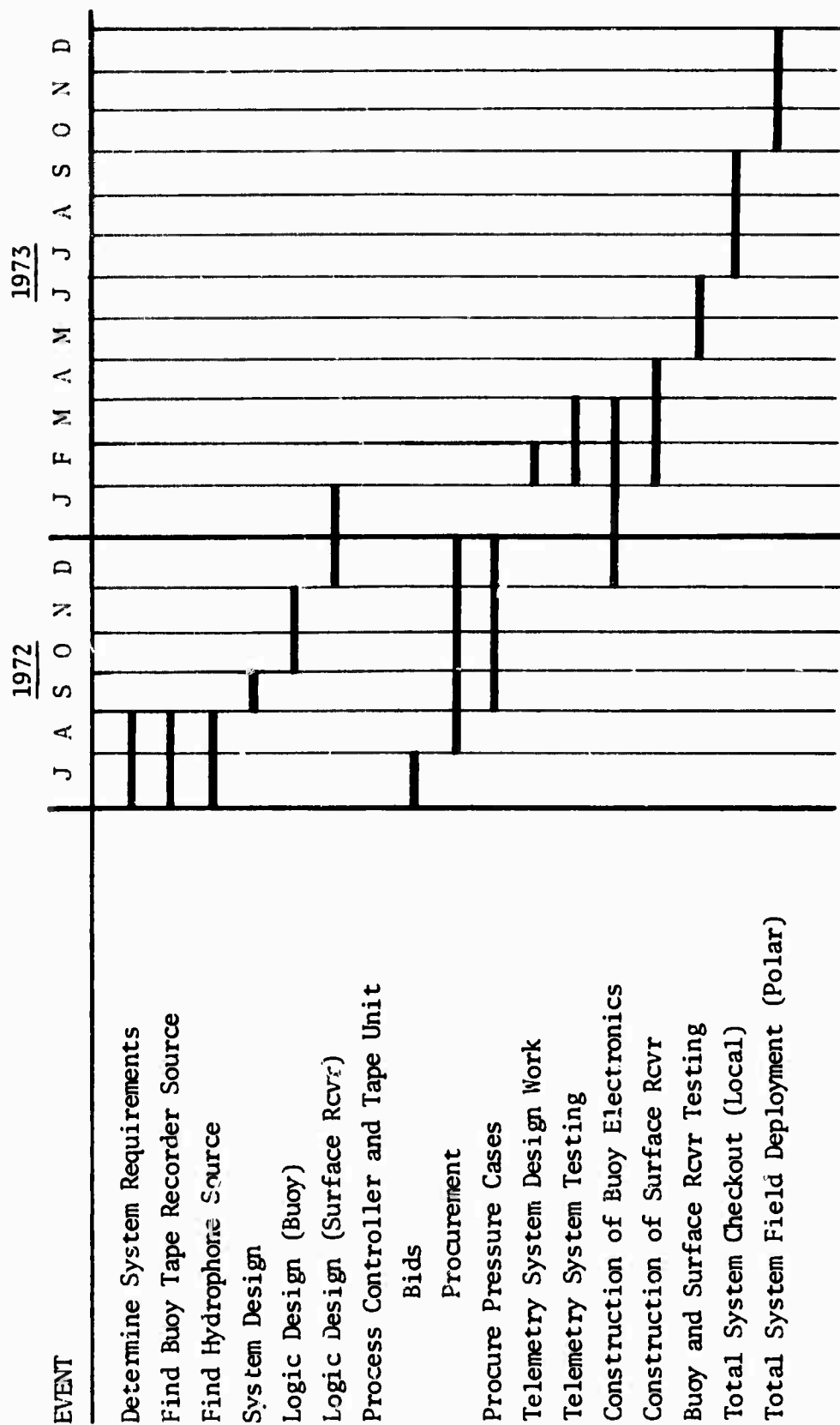


Figure 2. Time Schedule

a.	Man-Months - General		
	Liaison - with principal scientific investigator	1	
	System design	2	
	System checkout	3	
	Documentation	3	
b.	Man-Months - Buoy Design		
	Equipment search - Tape recorder and hydrophones (Time allowed for recorder development)	1	
	Logic design and test	2	
	Acoustic telemetry system design (Tailoring to application)	1	
	Telemetry system testing	2	
	Pressure case design	1	
c.	Man-Months - Topside Data System Design	2	
d.	Man-Months - Field testing and deployment	6	
		<hr/>	
	Total Man-Months	24	
	Total Cost of Time		\$80 K
e.	Hardware Costs - Buoy		
	Tape recorder development (This item may be deleted if a suitable recorder can be found)	\$30 K	
	Tape recorder (3)	15 K	
	Transducers (3)	4.5 K	
	Electronics (3 sets)	22.5 K	
	Pressure cases (3)	3 K	
		<hr/>	
	Total Buoy Hardware	\$75 K	

f. Hardware Costs - Topside Data System

Transducers (2)	3 K
Process controller and recorder (IBM format)	12 K
Display - Calcomp plotter and interface	8 K
Electronics (1 set)	10 K
Test equipment	5 K
Total	<hr/> \$38 K

g. Travel and Shipping 10 K

Total Hardware Costs \$123 K

Total Fund Requirement \$203 K

Production Costs - Future System Elements:

Bottom Package

Tape Recorder	5 K
Hydrophone	1.5 K
Electronics	7.5 K
Pressure Case	1 K
	<hr/> \$15 K

Topside Readout

Process controller and Tape unit	12 K
Display	8 K
Electronics	10 K
	<hr/> \$30 K

5. Pertinent Background Experience in Acoustic Data Transmission

This recommended approach is based upon many years of experience gained at the Applied Physics Laboratory, University of Washington, in the field of acoustic data transmission. Three kinds of modulation have been employed in the past, namely, pulse code modulation (PCM), pulse position

modulation (PPM), and frequency shift keying (FSK). PCM and PPM are suitable for low data rates and for transmitting analog type data. FSK is suitable for medium speed digital transmissions.

APL's most recent effort in under-ice data transmission uses phase shift keying (PSK) as a modulation technique and achieves very high data rates. The under-ice system transmits a 1.4 msec pulse containing 14 bits of information which is, of course, a 10 kilobit per second rate. This system has been tested for under-ice transmission and operates satisfactorily. Its first major application will take place in March 1972, when UARS is deployed near Ice Island T-3.

A recent experiment using PSK modulation at the Cobb Seamount (August 1971) returned data at a rate of 4 kilobits per second for a period of 8 days--too much data to store at the ocean bottom. Because of the undesirability of having a cable connected to the data gathering electronics, an acoustic link was used to send the data part way to the surface. This acoustic link sent data continuously rather than in bursts as our under-ice system is designed to do, but is otherwise similar to the under-ice data system. A one-watt acoustic signal at 45.8 kHz was used to transmit the data from a 1000 meter depth to a receiver at 500 meter depth. This acoustic link operated for the eight days without a detected dropout. From the 500-meter depth the data was cabled to the surface and then telemetered to a ship in the area via an FM radio link. The FM link performed with less than one dropout per hour at ranges of up to 10 miles.

C. Experimental Research on Arctic Ice Albedo Modification

1. Introduction

During the summer months in the Arctic small changes in the albedo of sea ice can cause large changes in the amount of energy absorbed by the ice. Random melting at the surface results when the absorbed energy is sufficient to cause a change in phase. Clearly the phase change could also be induced by artificial modification of the ice albedo where melting is specifically desired. The Soviets, for example, have covered large areas of ice along their arctic shipping routes with coal dust in experimental attempts to accelerate the annual melting process. Their success with this procedure was limited by practical problems relating to the coal dust; it is heavy (sp. gr. 1.2-1.8) and tends to sink rapidly into the ice where it loses its effectiveness. Consequently large quantities were needed and supply costs became unacceptable. Fletcher¹ has indicated that the introduction of a self-propagating snow lichen might be a more lasting solution; others have suggested aluminum shavings, radiation-absorptive dyes, strips of black plastic, and other products of modern technology. However, no research or experimentation is known to be in progress in this field.

The United States and Canada stand to benefit greatly from any success that is gained through the controlled melting of ice by albedo modification. The commercial payoff in greater accessibility of the North Slope marginal seas for mineral exploration, or easier passage through the Canadian Archipelago are obvious, but significant advantages would also accrue to scientific and defense activities in the Arctic. A case in point relates to the logistics of manned research stations such as Ice Island T-3. At present, fixed-wing aircraft cannot land on the island for a period of 5 months each year because of the surface degradation caused by melting. All supplies must be air dropped, and personnel can be removed only at great expense by aeri ally-refueled long range helicopter operations. Through modest experimentation, it is likely that this difficulty could be eliminated by selective degradation of the ice surface albedo leading to the creation of "liquid runways" which could be used by moderate-size float planes or amphibians throughout the summer. Conversely, by enhancing ice reflectivity or by proper insulation it may be possible to inhibit melting sufficiently to keep the winter runway surface stable in the summer, thus permitting year-round accessibility to the ice island for wheeled aircraft.

Parametric analyses of sea ice models indicate the feasibility of clearing moderate areas of ice from channels or bays using albedo reduction techniques, provided a suitable radiation-absorptive material and a means of distributing it can be developed. Maykut and Untersteiner² point out from

¹Fletcher, J. O., The Heat Budget of the Arctic Basin and its Relation to Climate, The Rand Corporation, Santa Monica, California, R-444-PR, October 1965.

²Maykut, G. A. and Untersteiner, N., Numerical Prediction of the Thermodynamic Response of Arctic Sea Ice to Environmental Changes, The Rand Corporation, Santa Monica, California, RM-6093-PR, November 1969.

their sea ice model studies that the influence of a reduced albedo is so powerful that if it were maintained at a value less than 0.50* for a few years arctic ice could be caused to vanish completely.

Before proceeding further a few comments concerning radiation heat transfer are in order. First, it is not uncommon for a material to have a high reflectivity to incident radiation at one end of the spectrum and a low reflectivity at the other. Frost is a good example, having high reflectivity at wavelengths emitted by materials near 25°C.

The second law of thermodynamics requires that a material which has a high absorptivity at a given wavelength also emit radiation efficiently at that wavelength. Thus, frost has the property of reflecting most of the incoming radiation coming from the sun, while at the same time being an effective emitter of radiation to the atmosphere. Hence, frost is well designed to survive thermal fluxes from the sun. Indeed coatings with this type of radiative properties have been developed to protect aircraft from the thermal pulses from nuclear bursts.

Consider, a material with the reverse properties of frost. This material would be a very efficient absorber of radiation from the sun but would be an inefficient radiator of thermal energy to space. Such a material would be an obvious candidate for controlled albedo modification.

Another property of radiation heat transfer having an important bearing to albedo modification is surface roughness. A rough surface absorbs much more efficiently than a smooth one. This occurs because the incident radiation goes through multiple reflections on the surface with absorption occurring at each reflection. Thus, it is possible to make an efficient absorber out of a material with an intrinsically high reflectivity.

The low angle of incidence of sunlight at arctic latitudes permits a significant fraction (~40%) of the sunlight striking the water to be reflected. Secondly, 15-30% of the sunlight that enters the water enters the ice and is absorbed deep within the ice where it warms the ice but does not contribute to surface melting. Therefore, it is desirable to modify the surface of the water to increase its albedo and also modify either the water or the water-ice surface to prevent the penetration of short length radiation into the interior of the ice.

A cursory search has turned up a number of materials having physical properties and a bulk cost that makes them candidates for service as ice albedo modifiers (reducers). Thus, the concept of melting ice to produce a Liquid Landing Lane (LLL) for aircraft use, or accelerating channel opening does not appear unreasonable from the standpoint of materials.

*Average measured values of albedo range between 0.64 and 0.66.

The ideal material for this use should:

- (1) be highly absorptive to short wavelength radiation from the sun,
- (2) a poor emitter of the long wave length radiation from objects at the melting point of ice,
- (3) require only a small mass and volume to be used per unit of area treated,
- (4) not affect adversely the ecology of the region, and
- (5) allow for controlled dispersion or, as an alternate, lose its effectiveness over a reasonable period of time so that undesired large scale perturbations of the albedo of the surrounding area will not occur.

The types of materials that lend themselves to these specifications are categorized and discussed below:

a. Buoyant Solids

Among these are wood chips, sawdust, inert plastic powders or pellets and buoyant netting to mention a few. An advantage of buoyant materials is that by absorbing the heat at the surface they eliminate penetration of short wave radiation into the interior of the ice.

Wood chips and sawdust have the advantages of light weight, low cost, ecological acceptability (they would become water logged and sink to the bottom of the melt water eventually and would probably not cause uncontrolled melting beyond one season). They have the disadvantage of low density, therefore possibly requiring more plane flights, and may be subject to piling up or being blown off the water during windstorms. Still they warrant study as an easily applied material for the initial stages of LLL formation, especially if mechanical snow removal is not feasible.

Inert plastics such as polyethylene powders are commercially available at reasonable price and have the advantage that their density can be tailored to any desired value. Our present thinking favors a specific gravity of about 0.95 so that wind forces would be small but that water surface would be rough enough to increase the absorptivity of sunlight to high values. If it is determined that a permanently buoyant material is undesirable a material could be made to have a density that remains less than that of water for only a few months after which water absorption or chemical dissolution will increase its density above water causing it to sink from the surface. The plastic particle approaches appear to be one of the most promising at this time.

Another concept with good potential involves the use of a netting of buoyant material (waxed twine, polyethylene, etc.) which could be laid out on the surface in say 30 by 200 foot size sections. It should be possible to

fabricate a lightweight netting which has good absorptivity, adequate strength and a reasonable cost. The advantage of the netting is that it can be removed, permitting reuse in following years or when the LLL has reached the desired size.

b. Other Materials

Dyes may play a particularly important role in the early stages of LLL formation, when high initial surface fluxes are desired. At present it appears that the amount of dye required for full-depth melting of LLL may be excessive.

Soot generators also appear feasible and could prove to be an ideal way of increasing the albedo of snow thus making snow removal unnecessary. Inefficient burning of diesel fuel would be a logical source of the soot.

c. Surfactants

The thermal flux away from the surface of an LLL resulting from evaporation of water is small compared to the incoming heat flux from the sun during the melt season. However, a reduction in this evaporation heat flux seems desirable because it may make the difference between a clear or ice-covered LLL during cold spells and at the end of the melt season.

The use of surfactants to retard evaporation from large reservoirs is a widespread practice and the same techniques should be effective for an LLL. Since only very thin films of surfactants are necessary to achieve significant reductions in evaporation rates, the amounts required for arctic use would be small in weight and cost.

The list of potentially useful materials could be extended; (e.g. powdered minerals, metal shavings, etc.) undoubtedly new material concepts will be uncovered as the investigation proceeds. The point is that there is a large number of materials that can do the job of forming an LLL at reasonable cost; finding the optimal ones and field testing them is all that is required. Therefore, in view of the potential utility of ice albedo modification as a technique for arctic operational support, and in view of the availability of suitable materials for experimentation, it is recommended that a program in this area of research be undertaken as set forth in the following sections.

2. Technical Approach

The long range goal of the proposed experiment can be subdivided into two general areas: (1) The development of albedo modification techniques for practical use on ice islands, glaciers, etc., where dimensional precision of the treated area is important, and (2) the development of techniques for eliminating sea ice as an obstruction to passage in strategically important channels and bays of the Arctic. Emphasis should be given to the first of these two

goals initially since much of the information required to carry out controlled albedo modification will also be useful in planning the more ambitious channel clearing project. The immediate target should be to acquire the capability of forming liquid landing lanes suitable for use by amphibian airplanes, with a range of approximately 1000 logistic miles, e.g., the Crumman Albatross used by SAR groups and the USCG. Many benefits would be realized at T-3 or Zimmerman's Ice Island if such a project were successful, for it would make these research platforms easily accessible throughout the year.

An LLL approximately 150 feet wide by 3000 feet long with a water depth of 3.5 to 4.5 feet is adequate for these planes. A review of the literature on the heat budget of the arctic indicates that a runway of this depth can certainly be created within a few weeks of the onset of the melting season by appropriate modifications of the heat and (evaporation control) transfer characteristics of the ice-air interface.

The modifications would include reduction of the albedo of the surface of short-wave* radiation, addition of surfactants to reduce heat loss by evaporation, and modification of the ice-water interface or water medium to reduce the penetration of short-wave radiation into the ice. (This radiation serves mostly to warm the deeper ice which never melts. Hence, it is energy that is essentially lost as far as its effect on phase changes at the surface.)

Additional areas requiring investigation include the prevention of unwanted melting along the edges of the liquid landing lane, prevention or reduction of the "down time" caused by freezing during cold spells, development of optimal methods for loading and unloading the airplane, and the effects of wave action associated with airplane landings and takeoffs.

3. Specific Recommendations

To carry out an investigation leading to the demonstration of a practical LLL system will require a sequence of activities. These include scientific studies of the solar spectral radiation absorption properties of ice; experimentation with ice-albedo-modifying materials and the construction of one or more usable LLL's. This section provides a description of each major step or task required in the project.

- a. Task 1: Conduct a literature survey to determine the average fractional cloud cover, the statistics of temperature and wind variations during the summer, and to assemble the most recent research publications on the arctic heat budget.
- b. Task 2: Make preliminary calculations, possibly based upon the computer model of Maykut², to determine the relative

* Those wavelengths for which the albedo is initially high, see Maykut and Untersteiner.

benefits which may accrue from snow removal, surface absorptivity modification, evaporation control, prevention of penetration of short-wave radiation into the ice, etc. This would form the basis for a decision on which materials and techniques should be used in the field. Emphasis will be placed on finding techniques that will give a useable LLL at the earliest possible date after the commencement of melting and assure its usefulness until the fall freeze permits wheel-equipped plane operation.

- c. Task 3: Make a search for suitable materials to modify the heat and mass transfer characteristics of the arctic surface. These materials should be studied first in laboratory cold rooms and where local field conditions (glaciers, alpine lake ice, etc.) permit the determination of their effectiveness. The candidate materials should include chips, powders, buoyant netting, opaque sheets and dyes and surfactants. Material properties other than those related to albedo modification must also be taken into account, i.e., cost, eco-neutrality, handling characteristics, etc.; and the material behavior must be known when it is subjected to winds, wave action, cyclic freezing and thawing and continuous ultra-violet radiation.
- d. Task 4: Conduct small scale arctic tests of materials having the best laboratory performance record. At least three groups of tests would be worthwhile for studying the behavior of materials under arctic field conditions. First, the logistic convenience of NARL at Barrow should be used as a base to observe the materials on nearby sea ice. Adjustments in patch sizes, concentrations, rates of spreading, etc., can be studied; and the physical processes which occur at the onset of melting in the spring and freeze-up in fall can be measured in detail. The Barrow tests would be the first year field activity in the program.

During the second year larger subscale investigations should be carried out. These would be best accomplished at high latitude near or at the location of Ice Island T-3. Field verification will be required for the computer modeling effort and experiments which provide data on the absorption properties of many types of ice must be conducted. Also, practical engineering problems concerning the spreading of materials and the containing of melt water on the ice surface must be solved on the Ice Island.

The radiation absorption experiments could be done efficiently with the UARS system. Canadian Department of Environment staff members have expressed interest in a cooperative program to use the UARS at Greely Sound, Ellesmere Island for studies such as this, and the approach recommended here is to explore further the feasibility of such a joint undertaking.

The field tests at T-3 would consist of two types: one carried out on sea ice in Colby Bay where sea-water flushing would be employed, and one on the island where a series of 50x150' test areas would be laid out for analyzing different materials, distribution procedures and containment techniques.

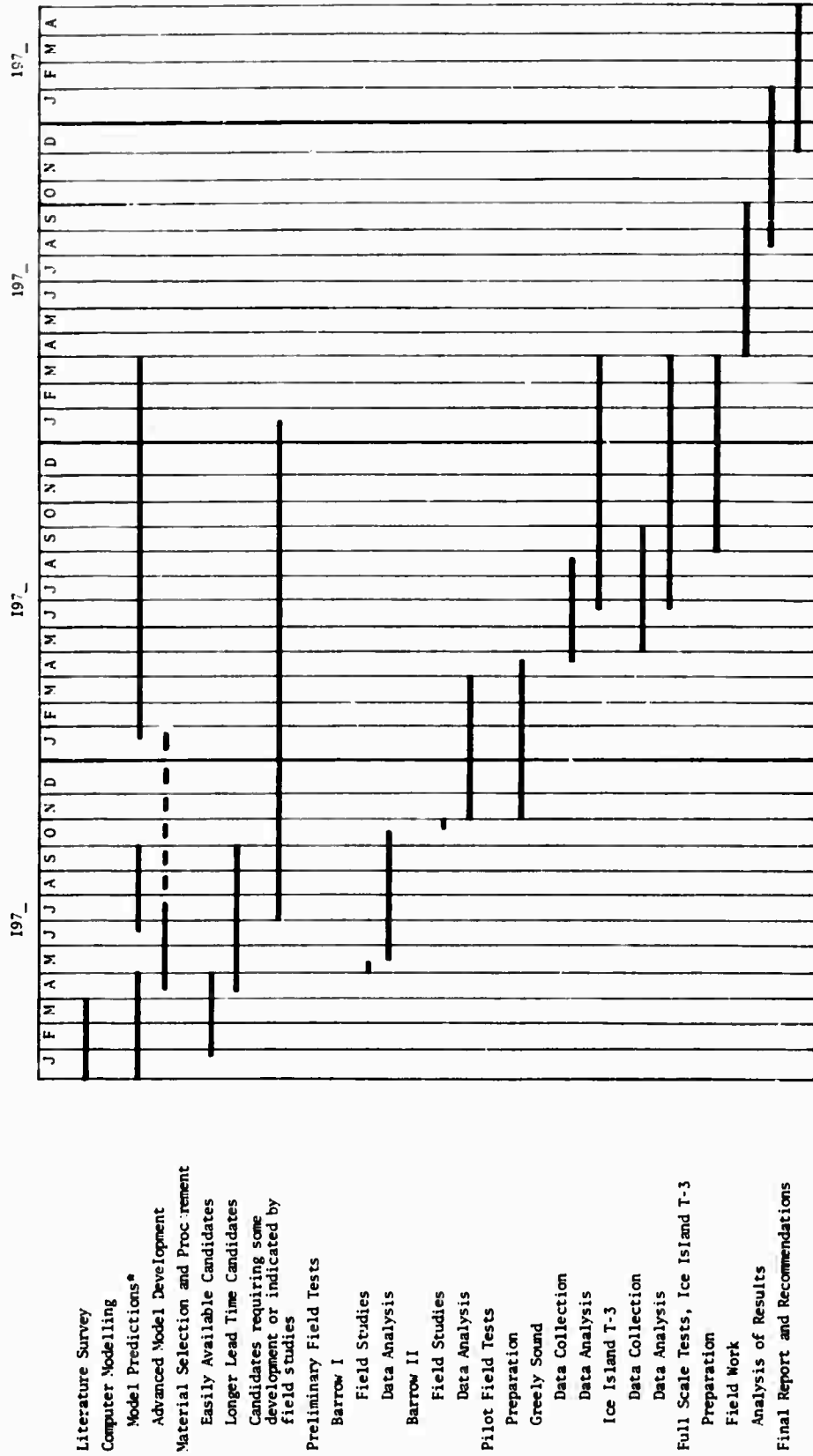
- e. Task 5: Construct and demonstrate the utility of a prototype LLL system on Ice Island T-3. In the third year the culmination of the ice albedo modification experiments would take place with the preparation and use of a full scale landing strip. Materials would be air lifted to T-3 early in the spring and applied in such a way that the useful season for the LLL is maximized.
- f. Task 6: Prepare full technical report covering the use of ice albedo modification techniques for the construction of Liquid Landing Lanes in arctic ice. This report would address all scientific and engineering aspects of the practical employment of this concept. Thus, the final report for this project would in effect, become a preliminary feasibility study relating to the other long range goal of this program: the elimination of sea ice obstructions in major arctic shipping channels.

4. Funding Requirements - LLL Program

	Program Year		
	<u>1</u>	<u>2</u>	<u>3</u>
	\$K	\$K	\$K
Professionals			
Senior Level	40	80	80
Junior Level	10	20	20
Technical Support	10	48	48
Instruments, Materials and Supplies	10	30	40
Travel, Per Diem and Arctic Premium	4.5	11	14
Transportation and Shipping	1	40*	20
Computer Time	<u>4</u>	<u>5</u>	<u>4</u>
Total (\$K)	79.5	234	226

* Includes a \$30K chartered flight to Greely Sound.

5. Schedule for Liquid Landing Lane (LLL) Program



* Initially with Maykut model; later with specially adapted models.

APPENDIX I

**A STUDY OF POLAR ICE PACK
TRANSPORTATION VEHICLES**

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Advanced Arctic Technology Program

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INTRODUCTION

Earlier this year a group of scientists meeting at the University of Washington discussed transportation problems they had encountered during the course of 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 ice pack. The impetus for this report resulted from this informal discussion. The report is an attempt to review the transportation needs of scientists working on the arctic ice pack, to establish vehicle specifications consistent with these needs and the requirements imposed by the arctic environment, to describe vehicles currently available, and to prepare a conceptual design of a new ice pack transportation vehicle.

For traveling long distances over the ice pack, air transportation by either helicopter or light aircraft is necessary. However, for relatively short distances from a base camp the tasks of setting up, maintaining and removing remote stations could 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" type vehicle has supplanted the roles formerly played by the dog sled. These vehicles, 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 type vehicles have not successfully filled the need for reliable ice pack transportation vehicles stems from their design concept. Generally these are high performance vehicles designed to out-maneuver, out-speed, and out-shoot an enemy. These qualities are purchased at a high price in initial dollar costs, 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 ice pack 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 ice pack. Therefore the author feels it would be wise to carefully consider the specifications outlined in this report and to proceed with the design and construction of prototype vehicles which are capable of meeting these performance requirements.

GENERAL SPECIFICATIONS

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

The University of Washington is currently preparing for experiments in which an unmanned submarine will be used to gather data under the ice pack. It is necessary to have at least three stations for tracking the submarine during the experiments. A reliable surface transportation vehicle would prove invaluable in establishing these stations and providing the capability to rescue the submarine if it should be disabled under the ice pack.

For purposes of carrying out a scientific mission the vehicle need not possess excessive speed. High speed, in fact, might even prove to be quite detrimental. One of the major problems with some vehicles used in ice pack transportation is the failure of the suspension system. This is an indication that these vehicles are unable to withstand the loads imposed by their own speed potential.

A speed of five miles per hour should be sufficient when traversing the difficult ice pack terrain. In the case of a level dirt road the vehicle should be capable of maintaining a speed of fifteen miles per hour.

In providing transportation to remote stations the vehicle may be required to carry a party of up to four people and some gear. The vehicle itself 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 ice pack is only feasible over fairly short distances. Remote stations 10-20 miles from the base camp are presently contemplated. Beyond these distances aircraft are considered essential. Time then becomes an important factor as well as the ability of men and machines to function after the rough treatment that should be expected when traveling on the ice surface. Therefore, a range capability of 100 miles should be sufficient in an ice pack transportation vehicle.

In order for this vehicle to carry out its mission it must be capable of operating in the most severe weather and of surmounting or avoiding the physical obstacles to be expected when traversing the ice pack. These requirements are outlined in section III, ENVIRONMENTAL SPECIFICATIONS.

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. Back-up 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 it was thought that 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.

ENVIRONMENTAL SPECIFICATIONS

The arctic ice pack environment poses a severe test of men and the equipment designed to carry them and their gear across the ice surface. In addition to extremely low temperatures, surface relief features of the ice pack present many impassable obstacles to a surface transportation vehicle. Anyone attempting a journey between points on the ice pack must resign himself to the fact that his route will necessarily be quite tortuous in order to avoid the worst obstacles.

Pressure ridges (when grounded) soaring as high as 98 feet above the waterline have been measured. The surface slopes of pressure ridges may attain angles between 30 and 70 degrees. Open water, or thin refrozen ice, may also be encountered at any place in the ice pack during any season. Melt ponds appear on the surface during June and make travel in anything but a truly amphibious vehicle slow and dangerous.

Circumvention of the most severe obstacles is the only possible way to proceed. However, this technique of avoiding obstacles may not be totally successful because of the limited view from a vehicle on the ice surface. In looking at aerial photographs of the ice pack it seems fairly easy to choose the most direct route between points. Unfortunately, the driver of a surface vehicle does not possess this overview of the terrain. Consequently, he must act like the mouse in a maze, testing, probing, and pushing the vehicle to its utmost capability in seeking to negotiate the obstacles and make progress.

The severity of the ice pack environment is compounded by the fact that conditions are far from static. Everything on the ice pack is adrift. Not only is there absolute motion of a station in the ice but there is also relative motion between stations. As a result, navigation and communication are of critical importance. Tension and compression forces are also continually changing within the ice. These forces may be relieved by the formation of new or higher pressure ridges and leads.

What follows is a compilation of information on the various features one could expect to encounter on an excursion aboard a surface transportation vehicle on the arctic ice pack.

Pressure Ridges

Pressure ridges are the result of compressive forces within the ice. When first formed they look like a pile of boulders dumped from the back of a truck. After passing through a melt season they are lower, more rounded and much of the void space between ice blocks has been filled.

There are five important considerations to be scrutinized in deciding the capability that a surface transportation vehicle must possess in order for it to cope with the pressure ridges encountered:

1. The distribution of pressure ridges over the ice pack and expected encounter rates.
2. The heights of the pressure ridges encountered.

3. The surface slope.
4. Lateral extent of this height and slope (if one traveled parallel to the ridge, how soon could one expect to find a low spot to cross?)
5. Size of the ice blocks making up a ridge.

Weeks¹⁰ has shown that the distribution of pressure ridges is roughly the same as one leaves the shore and moves beyond the shore-fast ice (about 5-10 nautical miles from shore). The most frequent encounters with pressure ridges should be expected in the Canadian Basin. Chukchi and Beaufort Sea conditions are almost identical and encounters would be slightly less frequent than in the Canadian Basin. Traveling on the ice pack in the Canadian Basin one could expect a mean of 15 pressure ridges per nautical mile and 95% of the time one would encounter less than 30 per nautical mile.

The mean height of the Canadian Basin pressure ridges is 10.2 feet and 95% of the pressure ridges are less than 19.7 feet.

This data has been gathered from the ice reconnaissance flights carried out in project BIRDSEYE. A laser profilimeter is used to measure the surface elevations. There is practically no data available which gives information on the lateral extent of pressure ridges. Generally, people with arctic experience state that the higher the pressure ridge, the less likely it is to be very long in the lateral direction.

Data contained in the laser profiles have not been completely reduced yet. There are no statistics on the slope of pressure ridges available at this time. However, a rough check of the profile traces presented by Weeks¹⁰ indicates the steepest slope to be 56° in these very short traces.

No statistical data is available on the size of the ice blocks which make up pressure ridges. From photographs, many appear to be on the order of 3 foot cubes; however, there are also quite a few that are larger than a man.

Another type of ridge called a shear ridge may be a difficult obstacle for any surface transportation vehicle. These are found at the edge of fast ice and may have a vertical face nine feet high which extends for many miles laterally without a break.

Water Obstacles

Amphibious capability is absolutely essential to efficient surface transportation. In any season one must expect to find open water which must be crossed. The number of water openings is greatest in the area beyond the fast ice but within 200 nautical miles from shore. Findings of project BIRDSEYE indicate about 1.7 (winter) water openings per nautical mile in this area. Ice cover in this area averages 99% in the water and 78% in the summer. In the central Arctic Basin 0.56 water openings per mile, 99% (winter), 92% (summer) average ice covering correspond to the figures above.

The ability to travel on both land and water is not sufficient for safe operation on the ice pack. Leads generally have a vertical edge. The vehicle then must

be able to safely lift itself out of the water and over this edge. No statistical data is available on the distribution of the elevation difference between water-line and ice to be expected at the edge of a lead. Experienced arctic workers classify the drop-off at the edge of a lead as:

1 foot, about average

2 feet, high

3 feet, very high and unusual.

The vehicle is not forced to climb out of a lead at the most difficult spot. A careful driver would survey the lead before entering and find the easiest spot to climb out of the water. In an emergency, a dead man could be driven into the ice and the vehicle would use a winch to pull itself out of the water.

Summer conditions on the ice pack find much of the surface covered with melt ponds or open water separating the ice floes. As long as the vehicle possesses the ability to climb out of open leads these obstacles would not be expected to cause any additional problems. Passengers probably would find the ride very uncomfortable over this type of terrain and speed probably would have to be reduced.

Hummocks and Sastrugi

Hummock fields, where: "Essentially all the ice is broken and distributed in chaotic fashion"¹⁰ may cause severe problems for a surface transportation vehicle if the hummocks are very tall and closely packed. One must depend on driver perception to recognize and avoid large hummock fields. Again, no data is available on the extent and distribution of hummock fields on the ice pack.

Areas of sastrugi should not prove to be impassable to a vehicle of moderate performance. The scale of surface obstacles would be about "1 foot high and 2 feet wide." (Appendix A, Interview with Professor Coachman) Passenger comfort would probably require slow speeds in these areas.

Snow Cover

Total annual precipitation in the arctic is relatively low. A rough figure of 30 cm¹⁰ would be indicative of the average snow build-up. Drifts may be expected to form in the lee of pressure ridges. In most areas the snow has a hard crust which may enable it to support a vehicle with higher ground pressure than soft loose snows are capable of supporting. This is an important consideration when choosing between a tracked or a wheeled vehicle and deserves more attention than it has received in the literature.

Temperature

The coldest mean temperature during the year is -40°F and the absolute minimum is -60°F.

SUMMARY, MODERATE PERFORMANCE VEHICLE SPECIFICATIONS

<u>Speed:</u>	Five miles per hour over ice pack terrain and fifteen miles per hour on a level dirt road.
<u>Payload:</u>	Up to 1,000 pounds on the vehicle. Room for four passengers and equipment.
<u>Pulling:</u>	A sled with up to 1,000 pounds.
<u>Range:</u>	100 miles.
<u>Amphibious:</u>	Must be capable of crossing leads and melt ponds and entering or climbing out of the water with a two-foot elevation difference between ice pack and water surfaces. The vehicle must be stable at all times during transition and in the water.
<u>Climbing:</u>	The vehicle should be capable of climbing up a 45° slope 6 feet tall from a dead start at the base. Considering the amphibious requirements the vehicle should also be capable of climbing a two-foot vertical obstacle on land.
<u>Startability:</u>	The vehicle must be capable of starting and of continuous operation at -60°F.
<u>Transportability:</u>	Vehicle should be able to fit on a Boeing 737 for travel from Seattle to Barrow, Alaska. From there it will be put on a C-130, Bristol Freighter or a Dehavilland Carribou and must fit on any of these without being dismantled.

MILITARY VEHICLES

The military is constantly testing and supporting the development of high mobility combat vehicles. There are extensive reports of these tests available in which long lists of the vehicles tested are printed. Unfortunately, many of these vehicles are one-of-a-kind or are no longer produced. The author has attempted to choose a few vehicles which satisfy some of the requirements outlined previously. The list is by no means exhaustive and it is also possible that some vehicles have completely escaped the author's attention during the course of this study.

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 wintertime invasion of Norway. Although the invasion never took place, 24,000 vehicles were built. The M29 is the standard version and the M29C an amphibian.

Almost thirty years after their construction those weasels which remain in operation have become ancient vehicles. The Weasel, however, has become the standard by which subsequent vehicles have been judged.

There are several mechanical problems which 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: 800-1500 miles; 300 miles in Antarctic⁸;

bogey wheels, sprockets, idlers: 500 miles;

transmission: 200-500 miles;

motor overhaul: 1000-1500 miles;

hull failure from fatigue cracks: 3000 miles.

Considering the advancement of today's technology one would expect that these deficiencies could be eliminated in a redesigned version of the original weasel.

In addition to the mechanical problems, the 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, passengers have been able to get out through escape hatches which have been cut in the roof.

The cost of operating Weasels at the Naval Arctic Research Laboratory has been calculated to be \$4.00 per mile. This compares with the cost of operating a jeep of \$1.00 per mile.¹

M29C Weasel Specifications⁵

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

Manufacturer: Studebaker

Size: length: 192 in.

width: 67 in.

height: 71 in. (with ordnance canopy)

Weight: vehicle: 4800 lb (heavier with built-on cabin)

payload: 1200 lb

Engine: Studebaker Champion 6-cylinder, 65 h. p.

Transmission: 3 and 1 gearbox and 2 axle ratios

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

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

Track width: 20 in.

Ground clearance: 11 in.

Turning radius: 12 ft.

Maximum allowable speed: 36 mph

Fuel capacity: 35 gal.

Fuel consumption: 5 mpg; 3 mpg in Antarctic^a

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 consideration given to the conditions at the time the data was taken.

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 would be unable to climb over a vertical face at the edge of a lead. In addition, the cost is very high: \$65,000.³

M116 Husky Specifications¹⁷

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

Manufacturer: Pacific Car and Foundry

Size: length: 185.5 in.

width: 85.5 in.

height: 80.0 in.

weight: vehicle: 6800 lb minimum operable

vehicle: 11000 lb combat loaded, articulated with payload

payload: 3000 lb

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

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

Track: Rubber band with 22 sections

Track width: 20 in.

Ground clearance: 14 in.

Turning radius: 11 ft. minimum

Maximum speed: 37 mph.

Fuel capacity: 63 gal.

Range: 300 miles maximum on hard surface road

Ground pressure: 1.9 psi empty
2.6 psi combat loaded

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 two infantry sleds and tobaggans 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 there have been a few changes 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, which costs approximately \$125,000.)³

Canadair Rat Specifications⁵

Description: Light articulated cargo carrier with drive on 4 tracks.

Manufacturer: Canadair Ltd.

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

Weight: vehicle: 1500 lb.
payload: 1000 lb.

Engine: Volkswagon 34 hp. air cooled

Transmission: 4 forward, 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 in.

Ground clearance: Vehicle is bellyless

Turning radius: 13 ft.

Maximum speed: 23 mph on improved roads

Fuel capacity: 23 gal.

Range: 200 miles (estimated)

Ground pressure: 1 psi loaded

It should be clear from the specifications that these vehicles are complex military machines. They would be 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 toy-like recreation vehicles to large, heavy-duty, oversnow transporters.

One of the smallest, yet most widely used, commercial vehicles is the "ski-doo" type. They have effectively replaced the Eskimo dog teams to a large extent. 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.

There are several drawbacks to using this type vehicle in support of the scientific mission contemplated here. First, they have no amphibious qualities. When open water is encountered, it is necessary to wait until it refreezes or attempt to circumvent it. The "ski-doo" provides no shelter to passengers or for overnight accommodation. Of course the payload capacity is much smaller than required. Finally, the arrangement of their power system precludes efficient towing. They are high-speed, low-torque machines.

Another danger which has become apparent since the "ski-doo's" have become popular 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 already 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 is not capable of filling 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. From personal experience with one particular brand all terrain vehicle, I know that I would not stake my life on this form of transportation. These vehicles generally would have to be classed as "toys." An average size would be about seven feet long and four 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 they are useless, because their concept is sound. Mechanically they are quite simple, and many of the ideas incorporated

in their design could be quite useful if one were attempting to build a larger vehicle that could fill the specifications. Even though most of these vehicles have been on the market for a short time there is evidence that they have stimulated positive evolutionary steps in their own design and particularly in the components used in construction.

Specifications are given below for the largest and most substantial "all terrain" vehicle the author has encountered.

KID Specifications^{1 6}

Description: All-purpose amphibious, wheeled tractor-transport

Manufacturer: Kinetics International Division, LTV Aerospace Corporation

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

Weight: vehicle: 2200 lb.
payload: 1000 lb.

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

Transmission: Vickers hydrostatic right angle

Tires: 8 tires, 2 or 4 plys, 23 x 8.50 - 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 gal.

Range: 100 miles

Ground pressure: 5.16 psi

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.

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 two-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.

Muskeg Tractor Specifications¹⁴

Description: General purpose, full-tracked vehicle for passenger and freight hauling.

Size: length: 140 in.
width: 87 in.
height: 79 in.
weight: vehicle: 6400 lb.
payload: 6000 lb.

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

Transmission: New Process Model 435, 4 forward 1 reverse speeds

Track: Reinforced rubber belts with spring steel cross links

Track width: 28 in.

Ground clearance: 14 in.

Maximum speed: 25 mph.

Fuel capacity: 18.75 gal.

Ground pressure: 1.2 psi (unloaded)

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 two-foot ledge. The author would consider this an extremely dangerous vehicle during transition from water to ice pack because it only has a six-inch free-board in the rear.

Flextrac Nodwell FN 10 Specifications (2-man cab version)¹⁵

Description: Full-tracked amphibious personnel and cargo carrier

Size: length: 127 in.
width: 85.5 in. (with 25 in. tracks)
height: 80 in.

Weight: vehicle: 3550 lb.
payload: 1000 lb.

Engine: Ford 104 C.I.D. V-4 gasoline, 65 hp.

Transmission: 3 forward, 1 reverse speed

Track: Rubber belts and channel grousers

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

Turning radius: 138 in.

Ground clearance: 13 in.

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 Tracked Vehicles Ltd.

It was brought to the author's attention that Foremost was building an amphibious tracked vehicle in the size range required. At the time of writing this paper the author was awaiting information from this company.

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 having the capability of climbing out of the water over a two-foot ledge.

In addition, several modifications such as the construction of a cab would be necessary for cold weather operations.

Thiokol Model 604 Specifications¹⁰

Description: Full-tracked, amphibious cargo and personnel carrier

Size: length: 160-180.5 in.
width: 97.25 in.
height: 62.5 in. (without cab)

Weight: vehicle: 5540 lb. (approximately)
payload: 2600 lb.

Engine: Ford 6-cylinder, 240 C.I.D., 150 hp.

Transmission: 4 speeds forward, 1 reverse

Track: Reinforced rubber belt with steel grousers

Track width: 32 in.

Ground clearance: 13.5 in.

Turning radius: 15 ft.

Maximum speed: 37 mph

Fuel capacity: 21 gal. (45 gal. optional)

Fuel consumption: 5-8 miles per gal.

Ground pressure: 0.87 psi (unloaded)

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 quite successfully used 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 to meet the ice pack transportation requirements.

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 their use 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 ice pack 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 (4 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 ice pack is not always easy and may be dangerous. Envision the hypothetical mission of setting up a station at some coordinate location ten 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 then 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 charter rates for a Bell E3B are \$130 per hour while a larger five-place model is about \$200 per hour in the Seattle area. One scientist has stated that charter rates of \$280

per hour for a two-man helicopter and \$1100 for a "sky crane" were quoted two years ago in the Prudhoe Bay area of Alaska. In the past, American scientists have not used helicopters at their ice stations. When used they have usually had ice breakers from which to fly.

Surface effect vehicles are currently undergoing extensive arctic testing. Most 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 on the top stranded. Currently scientists are awaiting the detailed results of their arctic trials.

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

A NEW ARCTIC TRANSPORTATION VEHICLE

The inadequacies of currently available surface ice pack 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 and would be well justified if a simple, reliable, low cost arctic transportation vehicle resulted from the undertaking.

A new 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 snow pack. 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 ice pack region. In addition, it is important to examine the low temperature qualities of the "terra" tires, particularly the elastic qualities important to the suspension of the ATV.

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. However, without some additional device the tires alone would not be capable of lifting the vehicle over a two-foot difference in surface elevation between the ice and the water.

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 ATV 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 complicating the mechanism somewhat.

Traction is also the most important consideration in climbing ability. It would not be difficult to supply sufficient horsepower to drive the vehicle up a 45° slope, but it probably would lose traction at a lesser angle. The author does not believe a wheeled vehicle, such as that proposed, could climb 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 ATV 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 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. Pre-heating should be accomplished by using a blow torch, and a back-up pull starter should be furnished. The most promising engine is a four-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. 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 pre-set 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 line 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 "pick-up truck" configuration. Some form of covering such as a snap on fiberglass or insulated "tent" should be provided for the rear of the vehicle. This would provide space for more passengers and 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) sufficient 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 includes navigation and communications devices, a towing bar, and a winch for pulling itself out should it become stranded.

There are many other things that would have to be considered when building this vehicle. These include cabin heating, the possibility of increasing the ground clearance above the nine inches shown in Figure 1, and several others. All these details should be worked out as the design engineering progresses and the parts begin to fit together.

CONCLUSION

It is the author's opinion that there is a definite need for the moderate performance vehicle discussed in this report. The need in fact is urgent for support of operations planned by University of Washington scientists for the spring and summer of 1972. Under the circumstances it would be wise to move with all possible haste in seeking support for the engineering and construction of this vehicle.

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APPENDICES

Appendix A: Interview notes.

Appendix B: Size restrictions for cargo airplanes.

APPENDIX A: INTERVIEW NOTES

INTERVIEW NOTES (IN PERSON): DR. HOWARD BLOOD, DIRECTOR,
APPLIED PHYSICS LABORATORY -- 29 JULY 1971

General Comments

This project grew from an informal discussion among several professors, people from APL, and Dr. Wang from ARPA.

There are many problems with surface effect vehicles including cost (about 100-mile range).

They wanted something that was a step above what is now available.

Current Possible Uses in Support of APL Operations

Supporting submarine operations

1. Move out several (10-20) miles and call submarine to a spot.
2. Tending tracking system (a few stations away from base camp).
3. Recovery of lost submarine (submarine is equipped with a pinger to aid the search).

Current APL operations are in the marginal ice area 100 miles off Point Barrow. They have rubber boats, helicopters, and a surface effect vehicle. There are two base camps and they are acoustically transmitting between them. At times the area has 50% ice cover, 50% water.

Other Sources of Information

Ron McGregor - Office of Naval Research would have transportation cost figures (he will have Bob Francois check on this).

Dean Haugen - Electrical Engineering (he will return in 2 weeks from the Arctic).

Present Polar Transportation

Does not feel Hovercraft will prove useful in Arctic Ice Pack research because they are expensive and he feels will be unable to go over pressure ridges. This will increase the distance they must travel to move between points (to go around pressure ridges) and further increase their operating costs.

Ski-doo is adequate for camp use. The 2-cycle engine is a problem and they are often being repaired. This is offset by their small cost. One cannot go very far from a camp on a ski-doo because they are unable to cross leads or areas of thin ice.

Weasels are also adequate around camp. He has heard that several have been sunk around T-3.

Helicopters are the primary mode of transportation whenever movement of any distance more than a couple of miles is contemplated. He has used Bell 204, 205 for his work. With gas turbines starting is no problem. They are expensive and consume a great deal of fuel, but are presently the only means of moving over the Ice Pack.

Other tracked vehicles have been used. Success has been obtained by Dr. E. L. Lewis in Fjord work using truck-like tracked vehicles. (He thought these were built by Bombardier.) The Nodwell 6x6 trucks have also been used.

At the present time he does not believe there is a need for a new surface Ice Pack transportation vehicle. They have always used helicopters very satisfactorily. However, he did note that if a vehicle was available he probably could think of several uses in short order.

New Vehicle Specifications

Should be capable of being carried in a C-130 or Bristol Freighter Aircraft.

Vehicle should be equipped with a winch so that it could pull itself out of a lead.

Heaters should be provided for warming the engine if cold starts are desired.

An engine such as the Briggs & Stratton he has used on several occasions successfully.

His Conception of a Polar Transportation Vehicle

Something like the new all terrain recreation vehicles (such as AMPHI-CAT).

Perhaps you could use a diesel engine that ran all the time and supplied electricity to individual electric motors on each wheel. If the vehicle was out overnight the diesel generator then would supply the "hotel" load when the vehicle wasn't moving.

Operating Conditions

Pressure Ridges: He has measured one 40 feet high and about 1/4 of a mile long. New pressure ridges look like piles of boulders and average about 6 feet high.

Leads: These are found at any time of year and are a limiting factor for current surface transportation vehicles. For the size of the step at the edge of a lead figure that the ice is 2-3 meters thick with 70-80% of that underwater.

Sastrugi: One may also encounter areas of sastrugi. Expected surface roughness would be about 1 foot high and 2 feet wide.

In the summertime the ice is covered with melt ponds so the vehicle would have to traverse these.

Other Sources of Information

Weeks, Hibler -- CRREL

Jim Smith -- Oceanography (Statistical distribution of pressure ridges)

Bill Campbell -- USC&GC (Surface topography)

Dick Tripp -- Oceanography

INTERVIEW NOTES (IN PERSON): MR. JOHN DERMODY -- 29 JULY 1971

Present Polar Transportation

The light plane or helicopter is the most important for out-of-base scientific work. They are not normally allowed to remain out (with scientific team) overnight. Consequently, these aircraft operate as a ferry service. They are expensive and one loses the ability of movement without them.

New Vehicle Specifications

The ability to always return safely.

Range: 50 miles round trip for one day. During subsequent discussion this was modified to 15 miles.

Speed: So that it could get to the desired location in 1-1/2 to 2 hours.

Payload: To carry 3-4 men and around 300 pounds of gear. For overnight missions it should be able to pull a sled. (Last time he went out onto the ice pack for 4 days and 3 nights he used a dog team. There were 3 men and 10 dogs. They carried about 1500 pounds of gear.

Starting at -40° F.

The ability to travel at night so that it is possible to arrive at daybreak.

The vehicle does not have to climb pressure ridges over 6 feet high, but may try to avoid them.

Amphibious capability is important (he has used a dog team and carried a kayak for crossing open water).

Should carry communication and navigation equipment -- radio, odometer (1/10 mile division), homing device, etc.

If large wheels will travel over the snow they would be preferable.

Operating Conditions

Leads: Maximum drop off 3 feet.

Other Sources of Information

Arnie Hansen - Office of Naval Research, Chicago Office.

**INTERVIEW NOTES (IN PERSON): MR. JHORMUND KUMMEN, SENIOR
PROJECT ENGINEER, MILITARY PROGRAMS, PACIFIC CAR & FOUNDRY,
10 AUGUST, 1 SEPTEMBER 1971**

**I was referred to Mr. Kummen by Mr. Laffaw who is in charge of Military
Programs at Pacific Car & Foundry.**

Current Possible Vehicles

**We went through several lists of vehicles that have been tested for military
purposes and came to the conclusion that nothing was available to suit our
specifications.**

He suggested looking at:

**Thiokol Model 1301 Spryte
Wolverine chain drive recreation vehicle**

New Vehicle

90-100 inch wheelbase is required to surmount obstacles.

Open tracks for mobility.

Mobility index of about 15-20.

**Two-cycle engines can reach 80 hp with a weight of only 100 lb and can be
hand started.**

Transmissions:

**Salsbury - California company (3.29 to 1)
Dayco
Brake on transmission line**

Other Sources of Information

Foremost Vehicles in Canada - Bruce Nodwell

**Dave Symmington - Seattle entrepreneur, distributor of spare parts for
Weasels**

INTERVIEW NOTES (TELEPHONE): PROFESSOR MYRON SWARM -- 16 JULY 1971

Professor Swarm's experience has been in the Antarctic. There he has not run into transportation problems because the Navy has handled them.

Suggested three Electrical Engineering graduate students who might have some ideas:

**Bob Willard
Jim Rodgers
Al Chandler**

INTERVIEW NOTES (TELEPHONE): PROFESSOR NORBERT UNTERSTEINER --
13 JULY 1971

Present Polar Transportation Vehicles

Generally opposed to Hovercraft as a waste of machinery.

People have used caterpillars, ski-doo's and weasels.

The weasel is an ancient vehicle. Although it is supposed to be amphibious, many have been sunk in ice pack use. One problem is that the weasel may traverse an area of thin ice without breaking through, but when it attempts to climb up onto a floe (a typical surface elevation difference of about one foot), the front of the track lifts increasing the pressure at the rear of the track on the thin ice. The weasel then slowly sinks back despite efforts to pull itself up onto the floe. This is a process that takes enough time so that the occupants usually have time to jump out before the vehicle sinks.

Tracked vehicles are very difficult to repair under the field conditions found in ice pack research. In addition scientists (particularly non-engineer types) are not experts at mechanical repair.

New Vehicle Specifications

Extremely simple and durable.

Range: Up to 100 miles.

Speed: Does not have to go fast.

Payload: A few men and supplies.

Drawbar pull: Enough to pull a sled weighing 2000 pounds. (This would be a sled with a hut, couple of drums of fuel, gear, food.)

Engine: Preferably not a diesel or a gasoline engine because of starting problems, but possibly a gas turbine if there is one available.

Highest priority: Ability to crash down onto thin ice and churn its way through and climb out again without hesitation.

Probable mission: Go 10-20 miles from a base camp and set up a sub-station for a matter of hours, days or weeks. For instance, deploying an array of hydrophones.

His Conception of a Polar Transportation Vehicle

Size: About 12 ft. long and 7 ft. wide.

Rides on tires about 5 ft. in diameter and 2 ft. wide.

Highly amphibious: Climbing ability is secondary because you can usually find a way around obstructions, but if you can't go through the water the vehicle's utility is low.

Detachable cabin top: This allows scientific party to use this as an over-night shelter. At other times (during a snow survey) you may want to get in and out every couple of hundred yards. For this no cabin top would be needed.

Interior size: Level area for people to sleep, seats, stove, etc.

Traction similar to a swamp vehicle.

Operating Conditions

Snow: The snow usually has a very hard crust due to the sublimation process. Areas of deep loose snow are rare. Snow normally only accumulates during a storm and might be found on the lee side of pressure ridges, in which case digging the vehicle out would be possible if it got stuck. As a worst condition one might use 2 ft. of loose snow.

Pressure ridges: Pressure ridges are made up of chaotic ice chunks (if they have not been through a melt season) and typically are 4 to 7 ft. high. The higher the pressure ridge the less frequent the occurrence and the shorter the length. The way to cross the high pressure ridges is to ride parallel until a low spot is found.

Leads: Leads may be found anywhere and if reasonably efficient travel is to be accomplished they must be crossed. They may be from 20-200 yards in width. A typical vertical drop to the water would be one foot. A high drop 2 ft. and very rarely 3 ft. A vehicle might stop before plunging into a lead to be sure of a position of getting out if there was a steep bank.

During the month of June the surface may become "slushy" and melt ponds soon appear which may be 3 ft. deep. Traveling over the puddled terrain may be very hard because the edges of the puddles are undercut and steep. This could cause a very rough ride.

APPENDIX B: SIZE RESTRICTIONS FOR CARGO AIRPLANES*

Boeing 737: (p. 291, 1970/71 edition)

Side Cargo Door (Model 737-200C/QC)

Height: 7 ft. 2 in.

Width: 11 ft. 2 in.

Maximum Payload: 29,393 lb. (Model 737-200(D))

Bristol Freighter/Aviation Traders (p. 153, 1968/69 edition)

Side Cargo Door:

Height: 10 ft. 3 in.

Width: 6 ft. 4 in.

Maximum Payload: 36,390 lb.

NOTE: This appears to be larger than the "Bristol Freighter" as it has been called by several people during the study. This discrepancy should be checked carefully.

C-7 DeHavilland Caribou (p. 19, 1970/71 edition)

Rear Cargo Door:

Height: 6 ft. 3 in.

Width: 6 ft 1-1/2 in.

Maximum Payload: 8,740 lb.

C-130 (p. 381, 1970/71 edition)

Rear Cargo Door: (Standard C-130 E)

Height: 9 ft. 1 in.

Width: 10 ft

Maximum Payload: 45,000 lb.

*All data found in Jane's All the World's Aircraft.