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# A KINETIC-ENERGY PENETRATOR FOR THE DEPLOYMENT OF INSTRUMENTATION BELOW SEA-ICE

by

G.E. Booker and J.M. Jones

CENTRE DE RECHERCHES POUR LA DEFENSE

DEFENCE RESEARCH ESTABLISHMENT

VALCARTIER

Tel: (418) 844-4271

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## RESUME

Nous présentons un concept expérimental pour le déploiement d'instruments de télémesure sous la banquise arctique au moyen d'un pénétrateur en chute libre et examinons quelques-uns des aspects les plus complexes du système. Ce document présente les résultats des expériences en laboratoire qui ont conduit à la sélection d'un profil de tête pour les prototypes de grandeur réelle essayés dans l'Arctique et les observations importantes qui en découlent.

Ces résultats, désappointants dans certains domaines, démontrent toutefois que le principe est réalisable et indiquent quels éléments du premier modèle doivent être modifiés. (NC)

## ABSTRACT

An experimental design of a system for deploying telemetry instrumentation beneath Arctic sea-ice by means of a free-fall penetrator is presented and some of its more difficult design areas are noted. Results of laboratory experiments leading to the selection of a nose shape for prototype full scale models tested in the Arctic and significant observations derived from the results are also discussed.

Results obtained from the Arctic trials were disappointing in some respects but they show that the basic concept is feasible and indicate which areas in the original design require modification. (U)

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## 1.0 INTRODUCTION

The objective of this work was to carry out a hardware study of the problems involved in deploying an instrumentation telemetry package below Arctic sea-ice from an aircraft. A preliminary survey (1) had indicated that such a project was feasible. There were, however, several practical problems associated with the deployment system which required investigation since the actual type of instrumentation involved might encompass a wide range of requirements.

A military requirement might call for the deployment of an acoustic listening device whereas an oceanographer would be more interested in measuring current flow, temperature and salinity of the water. The purpose of this work was to prove the feasibility of a deployment system and identify the various practical problems and limitations which might occur during the development of such a system; not to design an end item. A sonobuoy type of instrument pack was chosen for the study because it was assumed this would require the solution of most, if not all, the problems that would be inherent in the design of other types of instrumentation systems.

A similar project has been investigated by the Sandia Corporation (2, 3) under the sponsorship of the U.S. Coast Guard. They employed an air dropped penetrometer to determine ice thickness by telemetry measurement of projectile retardation during its passage through sea-ice. However, the instrumentation was only required to survive during the passage of the projectile through the ice and therefore did not encounter all of the problems associated with deploying a package under the ice. Problems related to maintaining communication between the instruments under the ice and their telemetry receiving station for lengthy time periods did not have to be solved in that system.

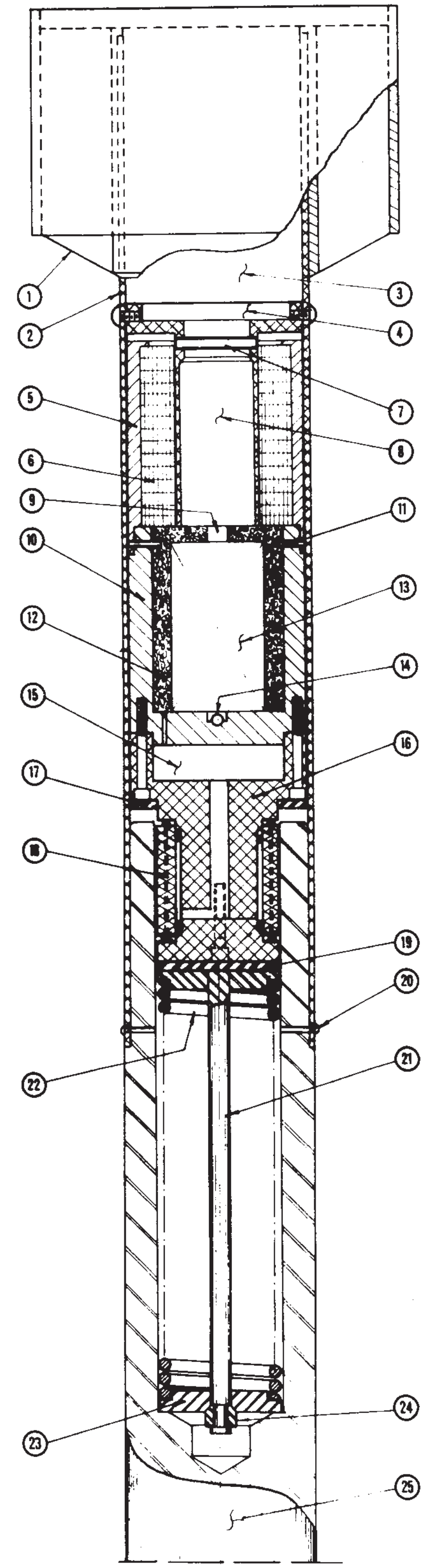
## 2.0 DESIGN CONCEPT

The following objectives and requirements were used as design criteria in the development of the penetrator concept illustrated in Figure 1:

a) the projectile should be capable of penetrating a minimum of eight feet of Arctic sea-ice when dropped from an altitude not exceeding 5,000 ft.

b) the projectile should not ricochet when striking the ice at an oblique angle up to 45°, from a plane normal to the surface, but should assume the shortest possible path through the ice consistent with its angle of attack.

c) the tail section should stay on the surface of the ice and remain in the hole made by the nose section.




LEGEND

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| 25. | PENETRATOR BODY |

FIGURE 1 - Prototype Penetrator Assembly

d) an instrumented package should be deployed to a depth of 100 ft below the surface of the ice at the end of an electrical communication cable attached to a transmitter in the tail section.

e) the telemetry system should be capable of withstanding impact loads of 5,000g and transmit data for a minimum of 30 minutes to an over-flying aircraft.

f) the instrument package should separate from the nose section as soon as possible after entering the water under the ice.

g) the telemetry in the prototype penetrators should be capable of communicating with existing receiving equipment on an CF Argus aircraft.

The foregoing requirements, taken in conjunction with other design factors detailed in later paragraphs, indicated that the deployment system should function in the following manner. Upon impact with the ice, resistive forces retard the forward movement of the penetrator and oppose the kinetic energy acquired by the individual components of the penetrator assembly during its free-fall period to the ice. The total kinetic energy of the penetrator assembly is available to overcome this resistance at the moment of impact but, as penetration progresses, changes in levels of retardation and differences between the kinetic energy of the various sub-assemblies cause the following sequence of events to occur, providing the penetrator has acquired sufficient kinetic energy to allow it to completely overcome the resistance of the ice and enter the water below.

a) the penetrator remains in the form of a complete assembly (Figure 1) until it has penetrated the ice to a depth at which its tail fins contact the ice surface. During this period, the instrument package sub-assembly moves forward depressing the spring of the ejector assembly to unlock the ejector piston retaining collets and arm the ejector assembly for action when a correct balance of forces occurs.

b) additional resistive force comes into play when the tail fins contact the ice surface creating an imbalance between the forces acting on the body and tail sections of the penetrometer assembly. This causes the two units to separate, whereupon the forward motion of the light tail section is arrested close to the surface of the ice but the much heavier body section maintains forward motion. The instrumentation package remains in contact with the body section and follows it through the ice since it is not affected by the aforenoted additional resistance force.

c) resistive forces decline sharply when the projectile breaks through the ice and the decelerating force on the instrument package is reduced to a value below the spring force. Thus the package is ejected rearward. The instrument package is pushed out of the immediate wake of the body section and becomes subject to the resistive and drag forces of the water to quickly attain a terminal velocity.

d) when the instrument package has deployed all of its cable, it is brought to a halt by a shock unit capable of absorbing the residual kinetic energy of the package at a rate that will not induce a breaking strain in the cable.

# 3.0 PROTOTYPE DESIGN

## 3.1 Arbitrary Design Limits

For any design problem some design limits or criteria must be pre-set as a foundation from which the solution can evolve. In this case, the following basic limits were adopted to serve as a design base:

| | | |
|---|---|---|
| Projectile weight | 50 | lb max. |
| Body diameter | 2.5 | in |
| Tail diameter | 4.875 | in max. |
| Overall length | 54 | in max. |
| Instrument package | 3 | lb max. |
| Tail section, empty | 3 | lb max. |
| Tail section, c/w Transmitter | 4 | lb max. |
| Communication cable, 3 conductors | 100 | ft |

## 3.2 Nose Design Criteria

The premise that the penetrators would be dropped from an Argus aircraft inferred that they would have a relatively high horizontal velocity ($\geq$ 150 knots) at the moment of launch. This predicated that they would strike the ice at some angle less than 90° from the plane of the ice surface and that:

a) the nose of the penetrator might ricochet off the ice surface instead of penetrating.

b) the nose section could be subjected to severe bending moments during the initial stage of penetration.

c) the penetration capability of the projectile should be greater than the thickness of the ice it was expected to penetrate since the length of its path through the ice would be $\geq$ T/Cos a.

where

T = thickness of the ice
a = angle of impact

Laboratory experiments (Appendix A) were conducted to determine the best shape for the nose of the penetrator and the form shown in Figure 2 was selected.

### 3.3 Tail Design Criteria

Two main factors had to be considered when designing the tail section:

a) its maximum diameter could not exceed 4.875 in if the penetrators were to be launched from the sonobuoy chute of an Argus aircraft yet it must supply sufficient lift to ensure that the projectile was aerodynamically stable in flight.

b) it had to be as light as possible, consistent with sufficient strength, since the amplitude of the forces it would be subjected to would primarily be a function of the kinetic energy of the assembly on impact with the ice.

### 3.4 Tail Design

The basic mechanical assembly of the tail unit (Figure 3) consists of an aluminum tube, a plastic fin section, and an aluminum bulkhead. It is attached to the body of the penetrator by two 'Parker-Kaylon' #4-40 nylon screws (shear pins) which have a total shear strength of 50-60 lbs.

The plastic fin section was compression moulded from a glass reinforced polyester material - Vibrin-Mat G-1600 produced by the U.S. Rubber Co. The fins are bonded to the aluminum tube with 'Armstrong A12' adhesive cement mixed in the proportion of 2 parts epoxy to 3 parts catalyst. Mating surfaces were roughened prior to bonding as follows.

a) aluminum - sandblasted
b) plastic - machined turned spiral groove .005 deep, 64 turns per in.

Laboratory tests at -20°F indicated that the bond could withstand greater loads than could be transferred to it by the plastic fins. The static shear strength of the six fins was found to be approximately 5,000 lb.

### 3.5 Body Design

The original design for the 50 lb penetrator called for a 2.50 in diameter body. This was reduced to 2.45 in on the first group

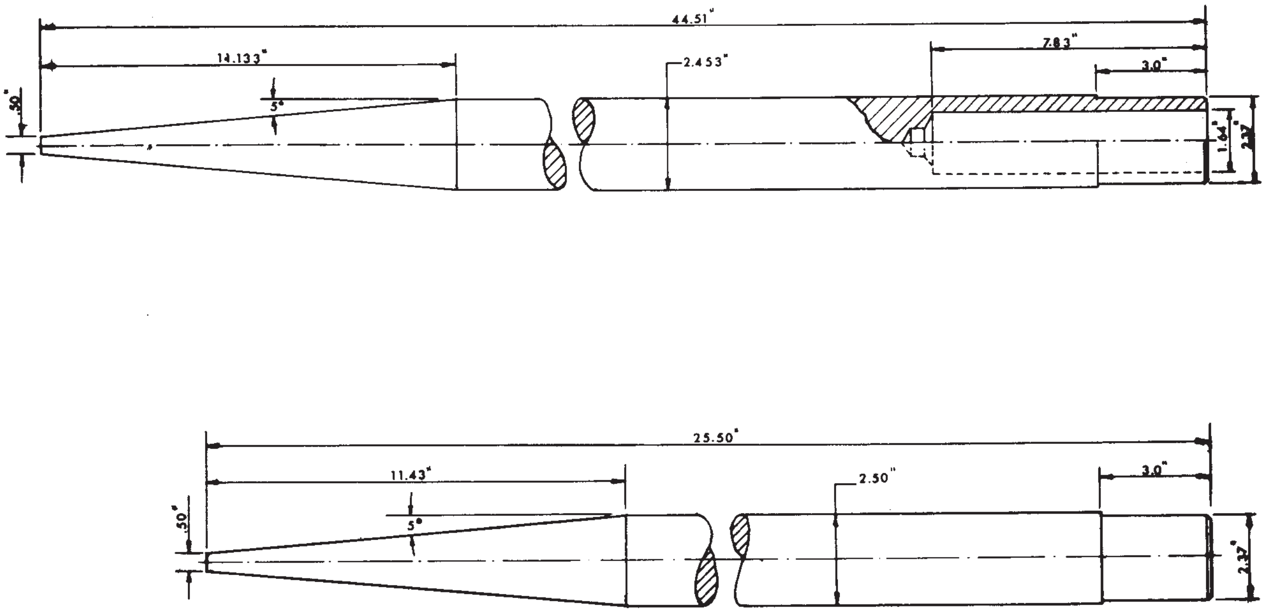



FIGURE 2 - Penetrator Bodies

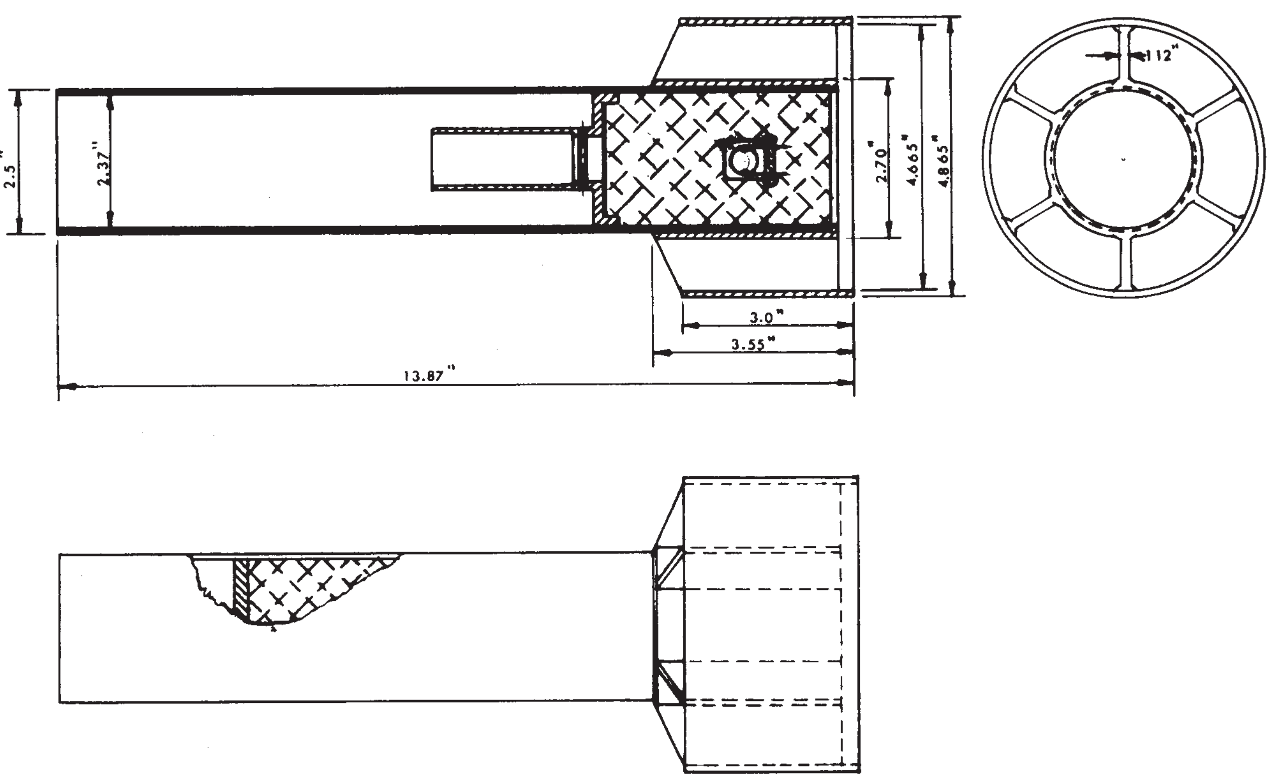



FIGURE 3 - Tail Assemblies (as assembled for Arctic trials)

of bodies manufactured as a matter of expediency since the surface of steel stock on hand was too rough to allow an acceptable finish to be machined at 2.50 in diameter.

The bodies were made from AISI 4340 steel which was heat treated after machining to final dimensions to provide increased yield strength at decreasing cross-sectional area. AISI 4340 steel was selected both for its heat treating and cold temperature characteristics.

The rear of the body was reduced in diameter to support the tail section upon impact with the ice and was recessed to provide a storage compartment for the ejector assembly and protection for the hydrophone crystal.

## 4.0 INSTRUMENTATION

### 4.1 General Specifications

The tentative specification for the under-ice sonobuoy was assumed to be similar to that of the standard AN/SSQ 517 sonobuoy. A thorough system study would be required before an exact specification could be drawn up. This was certainly beyond the scope of the present investigation. The tentative specification, presented below, was considered adequate for a system required to demonstrate the feasibility of the under-ice deployment.

| | |
|---|---|
| Transmitter | Carrier frequency in range 162.25 to 173.50 MHz<br>Power output greater than .5 watt<br>Stability ± 25 kHz of preset channel frequency at low temperatures. |
| Modulation | AM-FM with maximum deviation of ± 75 kHz. |
| Sensitivity | Minimum frequency deviation of ± 19 kHz for 440 Hz acoustic signal (at the hydrophone) at a level of 6 dB above a pressure of 1 microbar. |
| Phase relation | Positive hydrophone pressure produces positive frequency deviation. |
| Acoustic Response | Limited to frequency range 10 Hz to 4 kHz with specified frequency response. |
| Hydrophone | Omnidirectional in horizontal plane<br>Pressure tested to 300 $lb/in^2$<br>Operating depth 100 ft<br>Sensitivity - 83 dB relative to 1 volt at 400 Hz. |

| | |
|---|---|
| Power Source | Silver-chloride magnesium sea-water battery or nickel cadmium rechargeable storage battery. Minimum transmission time 15 min. |
| Operating Temperature | 28°F for instrument package and down to -30°F for the transmitter. |

## 4.2 Deployment Design Criteria

On the basis of the specification, the deployment system can now be divided up into a number of separate units. The hydrophone requires a high impedance audio amplifier or a pre-amplifier with a buffer across its terminals so as to avoid unwanted cable capacitance. Therefore, some form of high impedance amplifier is required at the lower end of the cable. The battery would most desirably be mounted at the surface. However, if this were the case it would be subject to the 5,000g loading induced by the tail unit as it stopped at the ice surface. Rather than re-design a battery to withstand 5,000 to 10,000g it was decided to locate the battery with the pre-amplifier and hydrophone at the lower end of the cable. This suggested a three-conductor cable connection between the hydrophone-battery unit and the transmitter in the tail assembly.

## 4.3 Design Problems

A major problem in the development of a system of this type is the deployment of the cable between the two units. The packaged cable spool must be capable of withstanding deceleration of 800-1,000g as the projectile is actually penetrating the ice (2, 3) and yet pay-out the cable smoothly at an initial velocity of possibly 400 ft/s. In addition it is quite possible for the penetrator to emerge from the ice at a velocity in the neighborhood of 200 ft/s. This implies that the velocity of the instrument package must be rapidly reduced to practically zero if the connecting cable is not to be broken when it has to stop the package's descent.

The ideal cable for this requirement would have three conductors, a high tensile strength and a minimum cross-sectional area. A survey of available standard three core cables showed that the majority were excessively bulky. Consequently it was decided to use three conductors of 'Spectra-Strip' multi-conductor flat cabling. Two sizes of cable were chosen for testing, 26 gauge and 24 gauge. The wire was PVC insulated according to spec. MIL-W-16878D and stated to be suitable for a temperature range of -55° to 105°C. The breaking loads for 3 core strips of cable were 27 and 46 lb respectively for the 26 and 24 gauge wires.

The tensile force induced in the cable by the high rate of deployment can be estimated from the equation for the transfer of momentum,

$$F = wV^2$$

where

$F$ = tensile force
$w$ = mass per unit length of cable
$V$ = deployment velocity
$wV^2$ = momentum change per second

The maximum rate at which any specific cable can be deployed can be determined from the following equation.

$$V_{max} = \frac{F_{max}}{w}$$

Pertinent data for the two proposed test cables is presented below.

| | | |
|---|---|---|
| Wire gauge | 26 | 24 |
| Mass per unit length, slug/ft | .00014 | .0019 |
| Max. deployment velocity, ft/s | 439 | 492 |
| Breaking strength, lb ($F_{max}$) | 27 | 46 |

When estimating maximum deployment velocities no allowance was made for the stiffness of the cables at low temperatures.

In order to reduce the possibility of cable breakage due to the initial shock or to transient high tensions in the cable, it was decided to incorporate a shock absorbing termination at the tail-unit end of the cable. The shock absorber consisted of a 3/4 in wide rayon ribbon, 3 ft long. The ribbon was doubled over and stitched with four rows of zig-zag stitches. Loops were made at the ends and the cable attached to the loops. The approximate cable tension required to rip open the stitches was 10 lb.

The ability of the shock absorber to limit cable tension was checked by dropping a weight which was attached to the shock absorber by means of a piece of the cable. This test showed that the shock absorber was most effective in limiting peak cable tension. In the proposed system (Figure 1) a strong compression spring fitted under the instrument package would be released on impact to separate the pack from the body of the penetrator when the latter had emerged from the ice. Calculations showed that, when the two units had separated so that the package was clear of the penetrators' wake, water drag on the package would cause it to slow to a terminal velocity of about 15 ft/s before the connecting cable had been fully deployed.

The mechanical design of the antenna poses another major problem. It is necessary to locate the transmitter immediately adjacent to the antenna if excessive transmission line losses are to be avoided. A number of miniature antennas might be suitable (6) however, if the antenna is to be mounted directly on the tail, it could well be covered with ice chips or snow and consequently suffer a deterioration of its radiation pattern. An attractive alternative could be to eject the transmitter and antenna unit completely clear of the tail unit: this would however considerably increase the complexity of the system. Also a minibuoy antenna similar to that on the existing sonobuoys could be used. This type of antenna is capable of pushing its way up through a certain amount of ice debris. It also has a built in ground plane to ensure a satisfactory radiation pattern and a predictable impedance to the transmitter output stage.

No concrete action has been taken toward antenna design as yet.

## 4.4 Transmitter Design

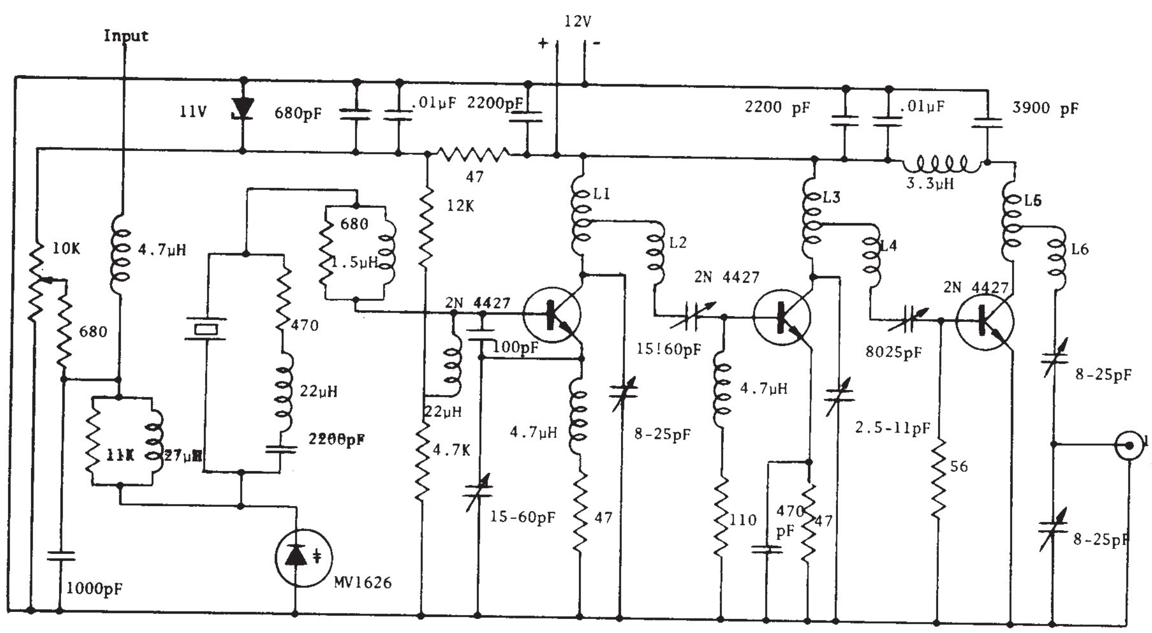
Originally, it was planned to use transmitters salvaged from existing sonobuoys in the prototype penetrators. Unfortunately, the circuit cards were too big to fit in the limited space available and, as their components could not be readily detached or rearranged, it was decided to construct a transmitter to suit our needs. The circuit selected is a compromise between that used in an AN/SSQ 517 sonobuoy and a simplified version of a design presented in Reference 4 (Figure 4). This circuit has been assembled and tested in a 'bread-board' state but final assembly and installation details have not been completed at this time.

The number of transistors was reduced to three, the first acting as a quadrupler, the second as a doubler and the third as a straight amplifier. The quadrupler was found to operate quite reliably with the crystal oscillating at its fundamental frequency. Several transistors were tried in the various stages, these included 2N3553, 2N3866, 80280, 2M5913, and the 2N4427 which was found to work equally well in all three stages. The final power output into a 50 ohm load depended on the supply voltage. At 9 volt supply, .9W of RF energy were produced; if the potential was increased to 12 volts the output increased to 1.25W.

Preliminary testing of the transmitter indicated that the modulator circuit is a weak point in the circuit design since only a 30 kHz FM deviation could be obtained. In this circuit, FM modulation is produced by 'pulling' the frequency of the crystal with a variable capacitance diode placed in series with the crystal. This type of modulator is inherently poor because it requires a low Q crystal (Q = 10,000) which is loaded by a 'lossy' circuit. To lower the Q even further, the crystal is then 'pulled' by the varicap whose capacitance varies as the square root of the applied voltage. The only advantage of such a circuit is that it is simple and cheap. A far better method, which will probably be used with future sonobuoys, is based on the phase-locked-loop principle. This transmitter will however suffice for use as a straightforward beacon.

The main problem anticipated with the transmitter was the high 'impact' loading produced when the tail unit struck the ice. The anticipated deceleration was of the order of 5,000-6,000g. This level of loading, while high, is not high enough to seriously endanger the internal structure of the various solid state components. The limiting component was the crystal; an essential component in view of the close frequency tolerances required of the transmitter. Most manufacturers will guarantee their crystals up to impact shocks of only 500g, however studies have shown (5) that crystals can withstand considerably higher accelerations in certain preferred directions.

The internal structure of a sonobuoy crystal consists of a thin quartz disc, approximately 1/4 in diameter, .003 in thick, mounted on two wire spring supports (Figure 3). A high transverse loading would bring the crystal into contact with its can and lead to possible breakages. There is, however, approximately 1/8 of an inch clearance available above the crystal so that appreciable movement is possible before it comes into contact with the can. A rough calculation based on the mass of the crystal and the stiffness of the support springs indicated that the crystal could withstand impact loads of around 6,000g. The transmitter was therefore designed with the intention of mounting the crystal in the inverted position with the direction of loading along the axis of the protective can (Figure 3).




170 MHz TRANSMITTER (EXPERIMENTAL)

L1 - 3.5 turns no 16 wire 1/4" ID 1/2"L
L2 - 5 turns no 22 wire 3/16" ID (close wound)
L3 - 3 turns no 16 wire 1/4" ID 3/8"L
L4 - 2.5 turns no 16 wire 1/4" ID 1/4"L
L5 - 4 turns no 16 wire 1/4" ID 1/2"L
L6 - 3.5 turns no 16 wire 1/4" ID 3/8"L

FIGURE 4 - Transmitter Circuit

## 4.5 Audio Amplifier

In conventional sonobuoys, the audio amplifier is usually divided into two units: a pre-amplifier, consisting of an FET input stage and a buffer amplifier. A double diode shunt, using silicon diodes, is connected across the hydrophone to protect the amplifier against the high voltage developed as the hydrophone sinks. A two conductor cable is accommodated by placing the collector load resister of the buffer amplifier in the main amplifier unit at the surface. The main amplifier then provides a frequency response and gain appropriate to optimum hydrophone response. Normally the amplifier is designed with automatic gain control which adjusts the level of gain to give an output signal suitable for modulating the transmitter.

The audio amplifier designed for the experimental sonobuoy is illustrated in Figure 5. It has been considerably simplified in that it does not contain a separate pre-amplifier or automatic gain control. It incorporates a dual operational amplifier, the first stage of which acts as a high impedance voltage follower and the second as the main drive amplifier. This simplified design is extremely compact as it was originally intended to assemble it inside the hydrophone crystal assembly, however, it was eventually decided to assemble it on a circuit board and locate it in a compartment immediately above the hydrophone (Figure 1). The circuit is extremely versatile and can easily be modified to change the frequency response or an automatic gain control can be incorporated by replacing the 2.2k resistor on the inverting input with an FET supplied with an appropriate amount of feedback.

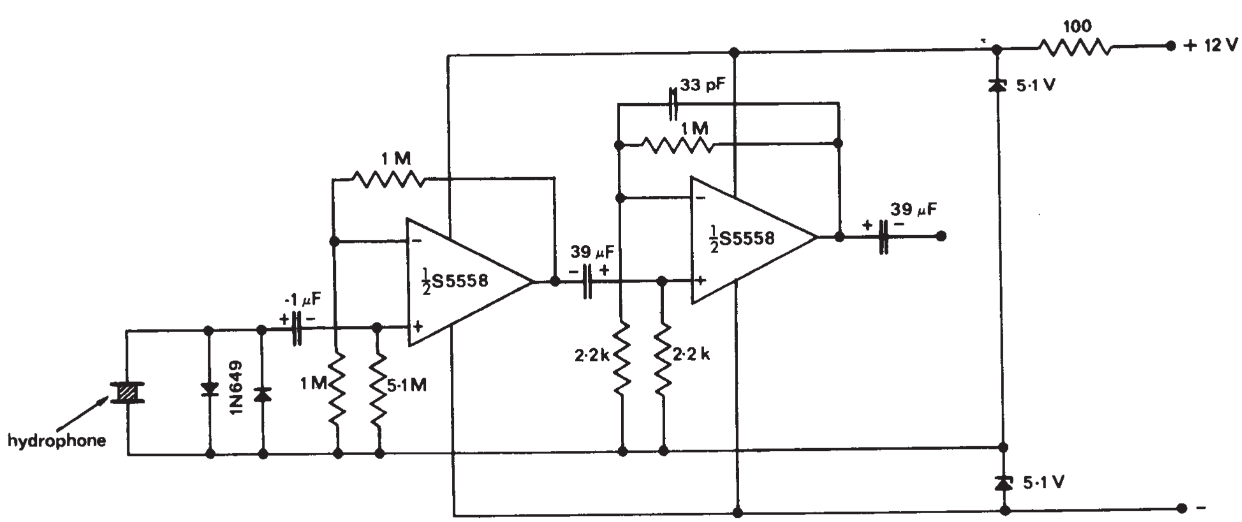



FIGURE 5 - Audio Amplifier Circuit

## 4.6 Alternate Beacon System

An alternate instrumentation package was proposed for the initial testing of the deployment system. The hydrophone and its associated amplifiers were to be replaced by a simple pulse audio-oscillator circuit and pressure activated switch (Figure 6). The pressure switch would activate the oscillator when the instrument package had descended to a depth of about 75 ft. Pulses from the oscillator would modulate the FN transmitter and be translated into a series of beeping sounds at the receiving station. The duration of the incoming signal would indicate whether or not the system had been successfully deployed and infer that a sonobuoy could have been operating for a like period. The alternate system would be a simpler package to manufacture than that required for a hydrophone, but it should be of identical size, weight and shape.

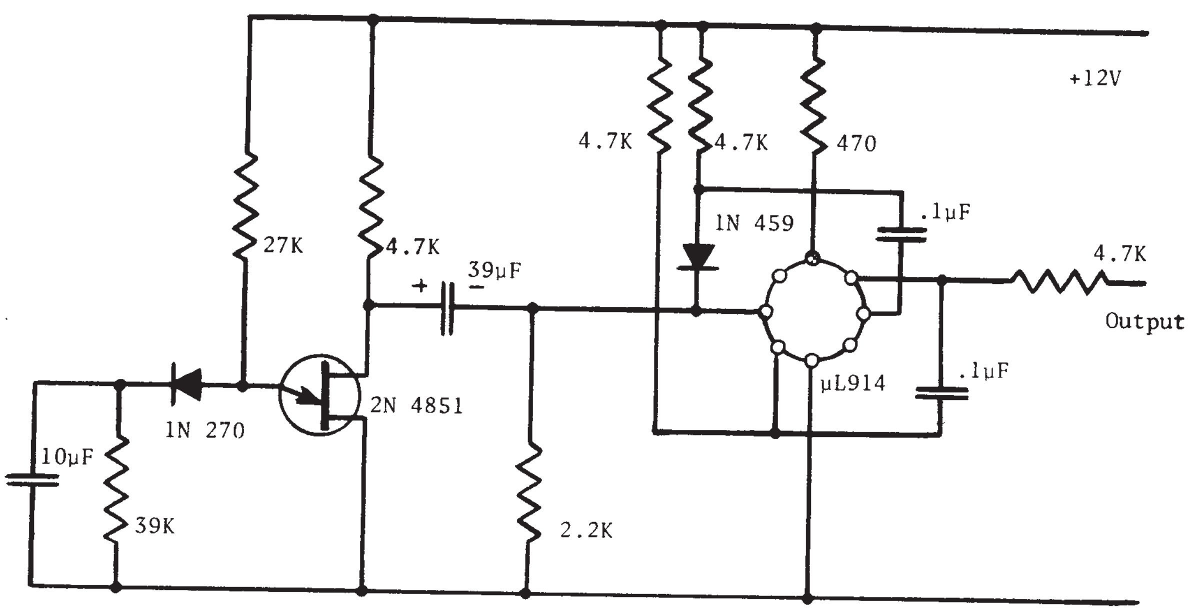



FIGURE 6 - Beeper Circuit (pulsed audio oscillator)

# 5.0 ARCTIC TRIALS

## 5.1 Objectives

The existence of DREP's trial facilities near Alert made it possible to test some of the prototype hardware under the actual conditions that the penetrators would encounter. An impromptu trial was set-up to take advantage of this opportunity to assess or determine:

a) the aerodynamic stability of the penetrators.

b) penetration performance.

c) whether or not the tail assembly and transmitter crystals could survive the shock and other forces to which they would be subjected.

d) if the various sub-assemblies would separate and function in the manner proposed in their design concept.

e) the conditions under which an antenna would be required to eject from the tail unit, and function, after the penetrator had pierced the ice.

f) if the proposed cable deployment system was satisfactory and reliable.

## 5.2 Test Penetrators

Six penetrators were assembled for this trial. Physical and aerodynamic data for these assemblies are presented in Figures 7 and 8 and listed in Table I.

The short 26.8 lb projectiles were included to simulate the largest size of penetrator that one might expect to launch from existing sonobuoy chutes on an Argus aircraft. No instrumentation was installed in these units since it was assumed that they might not be able to penetrate the annual sea-ice. However, their penetration performance would supply the data required to establish a minimum weight limit for future penetrator assemblies.

TABLE I

| Penetrator Data | Reference Figure 8a | 8b | 8c |
|---|---|---|---|
| Length, in | 36.38 | 54.43 | 54.43 |
| Weight, lb | 26.83 | 44.13 | 46.9 |
| Body Weight, lb | 25.27 | 42.57 | 42.36 |
| Tail Ass'y, Weight, lb | 1.56 | 1.56 | 3.04 |
| Ejector Ass'y, Weight, lb | nil | nil | nil |
| Position of C of G (from nose), in | 16.5 | 23.78 | 24.95 |
| Normal Force Coefficient, $C_n$ | 10.83 | 10.77 | 10.77 |
| Overturning Moment Coefficient, $C_m$ | 33.43 | 46.63 | 46.63 |
| Margin of Stability (static) | 52.65% | 84.99% | 79.96% |

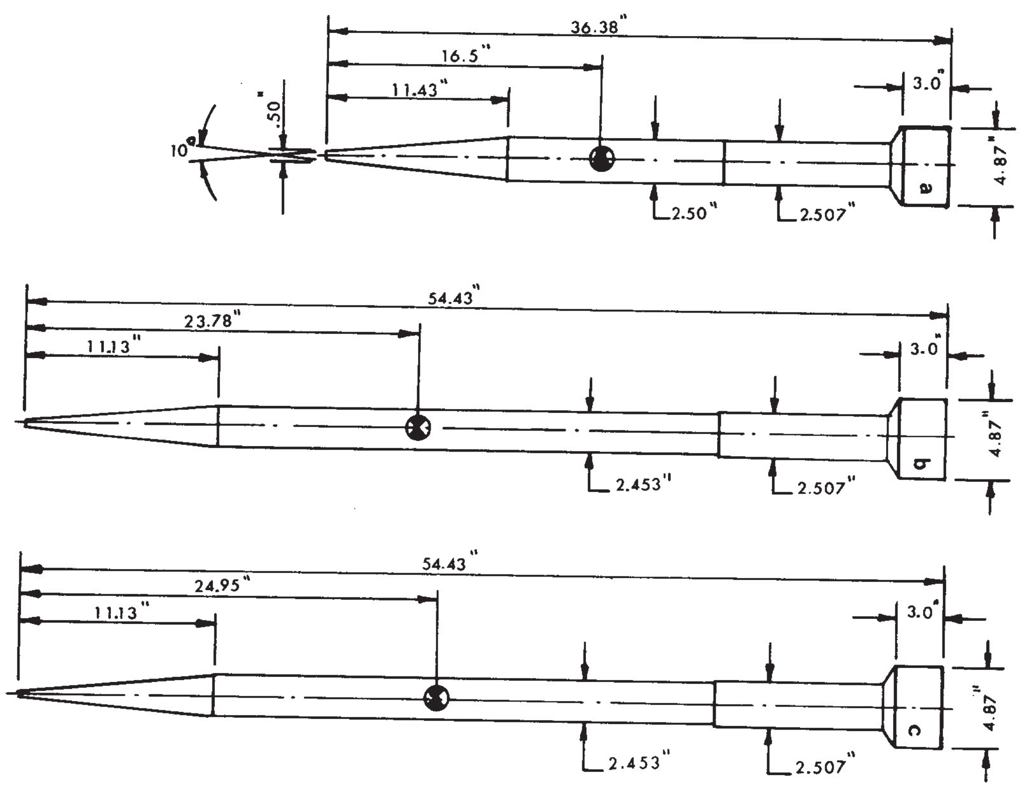



FIGURE 7 - Arctic Trial Penetrator Configurations

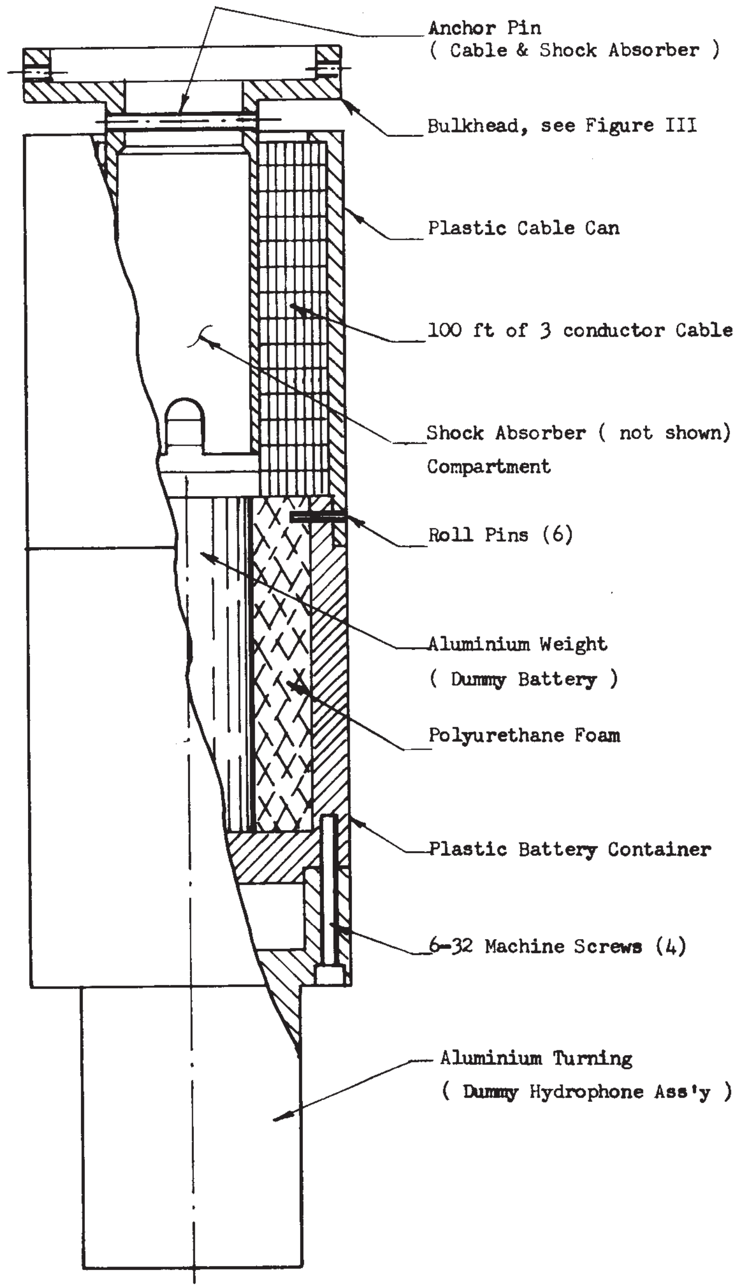



FIGURE 8 - *Dummy Instrumentation Package

## 5.3 Predicted Performance

A rough estimate of the performance that could be expected from the prototype penetrators was required before a test plan could be formulated. An empirical equation developed by Sandia (2) for estimating projectile penetration was used in conjunction with a computer programme to describe a point mass trajectory for this purpose. Calculated impact conditions for a typical penetrator having a drag coefficient of .25 and launched at different velocities and altitudes are shown in Figure 9.

Predicted penetration performance for either a 25 or 50 lb penetrator dropped from various altitudes at different launch velocities may be found in Figure 10.

The actual performance of the prototype penetrators may vary from the predicted levels by a factor of 25% since:

a) no allowance has been made for wind effects when plotting the mass point trajectories and the true level of the projectile drag coefficient was not known.

b) only an accuracy of 20% is claimed for the Sandia equation (below).

$$D = .0031\ S\ N\ \frac{W}{A}\ (V-100)$$

where

D = Depth of penetration in feet
S = Target material coefficient, approx. 2.8 for sea-ice
N = Nose shape coefficient, approx. 1.3 for a 10° cone
W = Projectile weight in lb
V = Impact velocity in ft/s
A = Cross sectional area of projectile in in$^2$

c) it has been shown by numerous investigators that sea-ice changes its mechanical properties with age, temperature and the season of the year. However, from a practical point of view, a pre-knowledge of penetration capability is only required to set release height. Even then, one has no means of knowing the exact thickness of the ice at the point of impact. This being the case one can always opt for a higher release altitude than that indicated by the data in Figures 9 and 10.

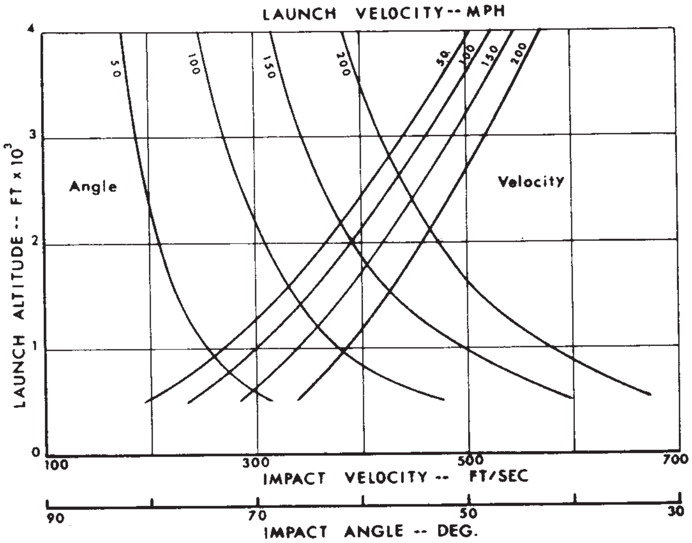



FIGURE 9 - Ballistic Curves for Impact Data for a 50 lb Penetrator (CD = .25)

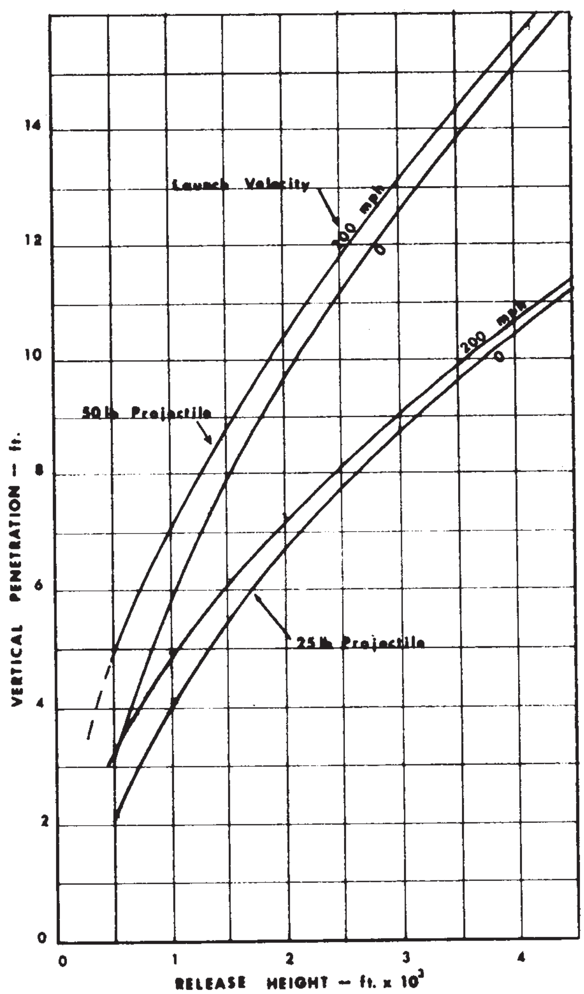



FIGURE 10 - Predicted Penetration Performance

## 5.4 Test Procedure

The penetrators were dropped from different altitudes (see Table II) onto both polar and annual sea-ice from an FH1100 helicopter hovering above the target area. In all but one test, there was little if any horizontal motion of the helicopter at the time of release. The projectiles were slung under the helicopter by a thin nylon rope and hung with their longitudinal axis inclined at an angle of approximately 30 degrees to the vertical plane (Figure 11). One end of the rope was tied to the frame of the helicopter while the other was passed through a wire loop attached to the penetrator at a point two inches behind its C of G and then attached to the cargo hook by a loop. All penetrators hung in a nose down attitude and dropped away freely when the looped end of the rope was released by unlocking the cargo hook from inside the helicopter.

## 5.5 Results

Penetration results are presented in Table II. 'Tail Depth' as listed in this table refers to the distance between the snow surface and the rear face of the tail assembly. The final column 'Est' refers to the estimated penetration capability derived from performance predictions.

All penetrators pitched and/or yawed widly during the initial stage of their drop to the ice. This was to be expected considering their attitude relative to the flight path at the moment of launch. Observers situated on the ice to one side of the target area noted that the amplitude of yaw decreased rapidly as they gained velocity and that no evidence of yaw was visible to the naked eye by the time they impacted the ice.

All three transmitter crystals recovered from tail assemblies after the tests were found to be intact and appeared to function normally in their original frequency range. They have not been tested for deviation from their actual, original, operating frequency. Otherwise they survived the impact shocks in all respects.

All three attempts to deploy a dummy instrument package failed; two because the cable broke and the other because the package failed to leave the tail section. The failures were the result of a number of circumstances which will be discussed in later paragraphs. They have provided information that can be used as a guide to a better and more successful design for the deployment system.

The plastic tails of the penetrators used for Drops 1, 2, 3 and 6 survived the impact shocks without visible damage. There was minor damage to one side of the tail drum and the two supporting fins

## TABLE II

## Arctic Trial Data

| Drop No | Ice Type | Proj. Weight (lb) | Proj. Type | Release Height (ft) | Launch Velocity (mph) | Tail Depth (in) | Penetration | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Snow (in) | Ice (in) | Est (in) |
| 1 | Polar | 26.8 | a | 2000 | 0 | 22 | 3.5 | 56.5 | 82.8 |
| 2 | Polar | 44.2 | b | 2000 | 0 | 20 | 5.0 | 71 | 111.6 |
| 3 | Annual | 25 | a | 3000 | 0 | 7 | 2.0 | 59 | 106.2 |
| 4 | Annual | 46.95 | c | 3000 | 0 | 10 | 2.0 | 59 | 144 |
| 5 | Annual | 46.95 | c | 1500 | 80 | * | 2.0 | 59+ | 100 |
| 6 | Annual | 46.95 | c | 1200 | 0 | 7 | 2.0 | 59 | 77.8 |

Note: 1. Depth of annual ice was 59 in.
2. * Tail fins became detached and the remainder of the tail assembly followed the body through the ice.

FIGURE 11 - Penetrator Slung under Helicopter Hovering over Target

adjacent to the damaged area were cracked on the tail recovered from Drop 4. On Drop 5, the plastic tail broke into two sections and became detached from the tail assembly.

The tail assemblies that survived impact shocks functioned satisfactorily in that they separated from the body and brought the tail to rest in the ice and remained in the hole pierced by the penetrator body. Unfortunately, they buried themselves a considerable distance below the ice surface (see Table II) and were covered by ice debris after coming to rest. This would have created an unfavorable environment for the erection and functioning of a transmission antenna. Figures 12 and 13 show typical conditions that occurred after ice penetration.

## 5.6 Discussion of Results

The performance of the penetrators against polar ice indicates that the predicted performance estimates given on Figures 9 and 10 are over optimistic. However, a revision of these estimates cannot be justified on the basis of the data obtained, and so will have to await further data acquisition.

An inspection of the tail units recovered from the ice surface has revealed the reason why the attempts to deploy the instrument packs below the ice were unsuccessful. On Drop 4, the package followed the penetrator through the ice but its cable broke because:

a) the shock absorber unit had been unable to function properly since it had become fouled in the unwinding cable which then wrapped itself tightly around the shock unit.

b) the insulation on the cable had cracked and shattered in a manner suggesting brittle failure and hence indicating that it was not suitable for use at the temperature, -20°F, to which it had been subjected prior to use. This factor would have reduced the breaking strength of the 26 gauge wire to approximately 15 lb, which in turn infers that it would have broken at a deployment rate of about 325 ft/s.

On Drop 5, the plastic tail unit broke into two pieces of roughly equivalent size, and the remainder of the tail assembly followed the body through the ice. This should not have happened since the tail was only subjected to approximately 72% of the impact force that the unit on Drop 4 had been able to withstand. Failure in this case was due to inadequate bonding between the plastic tail and the aluminum tail boom. An inspection of the salvaged parts revealed that only about 60% of the available bonding area had been covered with cement and that most of this was located on one of the recovered halves.

On Drop 6, the instrument pack did not leave its compartment in the tail assembly. Otherwise the penetrator performed satisfactorily in that complete penetration of the ice was achieved and the tail section

FIGURE 12 - Photographs of Ice Surface after Penetration

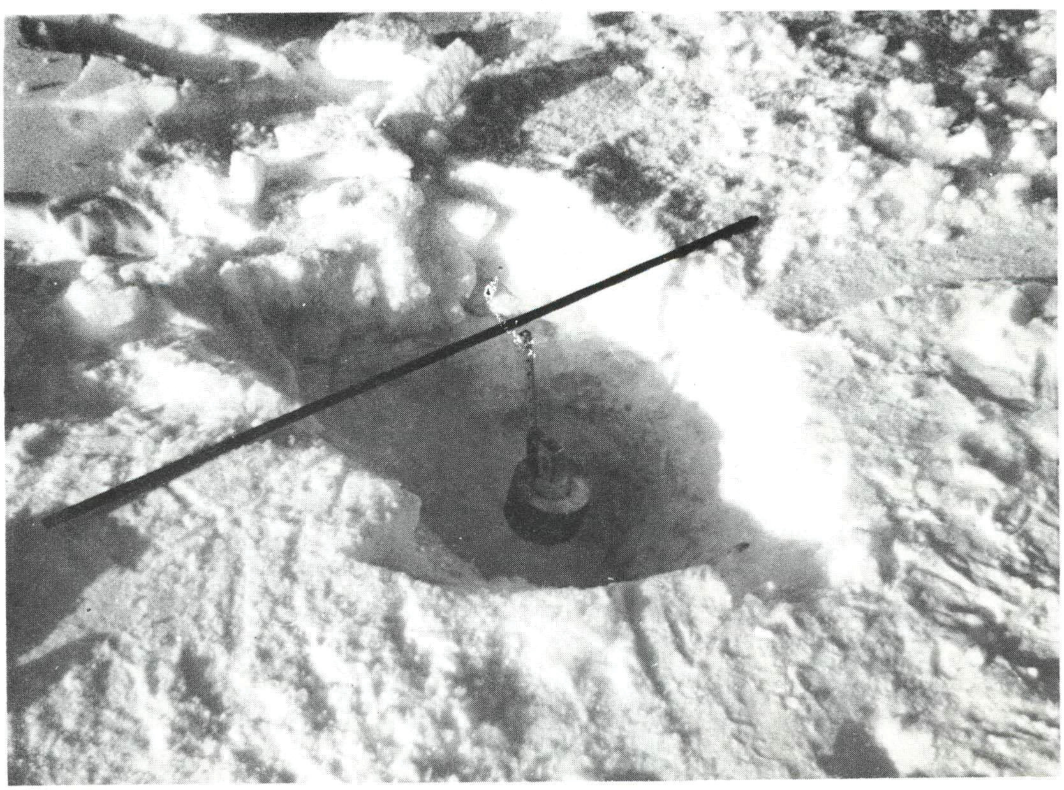


FIGURE 13 - Photograph of Penetrameter Tail after Penetration

remained close to the surface of the ice. When the penetrator was removed from the hole in the ice it was found that the instrument pack (Figure 8) was held in the tail boom by the ice debris that had been ejected rearwards by the body section as it continued to penetrate after separating from the tail. Since the instrument package fell freely out of the tail when the ice debris was removed, it can be assumed that the failure was not due to mechanical jamming. Therefore one must assume that by the time separation of the nose and body sections occurred, the velocity of the penetrator had been reduced to a level at which the inertial force of the instrument pack had fallen below the spring force of the ejector unit. This condition would allow the spring to hold the package in the tail until the body section had penetrated an additional five inches of ice and ejected a sufficient quantity of ice debris into the tail section to jam the instrument pack into its compartment.

It was noted that in all cases where the tail blocked the hole in the ice, the ice debris ejected behind the body of the penetrator plugged the hole. This plug prevented sea-water from rising to the surface of the ice or coming into contact with the tail assembly.

## 6.0 CONCLUSIONS

1. The results of the Arctic Trials were somewhat disappointing. They did, however, provide some very useful information which can be used as a guide for modifying the prototype design.

2. Suitably mounted transmitter crystals can withstand the loads imposed by the high G impact of the tail assembly upon the ice.

3. Further development of the kinetic energy penetrator design can be justified upon the basis that the basic concept has been proven sound and feasible.

## 7.0 RECOMMENDATIONS

The following approach and considerations should be adopted if further design development is undertaken.

### 7.1 Tail Assembly

A redesign of this unit should be considered since the strength of the plastic tail unit appears to be marginally low for its function and because the tail assembly becomes completely buried by ice chips when it comes to rest in the ice.

The simplest modification would be to fill the spaces between the fins of the plastic tail with a strong polyurethane foam. The foam could be keyed to the plastic if necessary. Such a modification would produce the following results.

a) A greater surface area would be presented to the ice, and the tail assembly would be heavier. Therefore, though there would be a more uniform distribution of the forces acting on the tail section in contact with the ice, they would have a greater amplitude due to both the higher mass of the tail and the larger area presented to the ice.

b) The solid tail section would deflect some of the ice chips projected rearward during penetration. This factor in conjunction with reduced tail penetration would decrease the amount of ice chips covering the tail unit when it came to rest. This simple modification is only presented, however, to indicate that a solid tail could be advantageous. Obviously a more sophisticated redesign will be required since an overall increase in the mass of the tail assembly is undesirable. One possible approach to this problem would be to relocate the transmitter components within the foamed tail instead of inside the tail boom as originally proposed. This would allow the overall length of the tail assembly to be reduced with a consequent weight reduction.

## 7.2 Instrument Package and Ejector Unit

The relationship and functions of these units must be reevaluated since it has been shown that one must not reply upon the kinetic energy of the instrument package to keep it in contact with the ejector unit when the body of the penetrator is piercing the ice. Therefore, some form of mechanical link must be provided to lock the two units together until the instrument package enters the water below the ice.

The lock could be in the form of two or three spring clips, or hinged spring-loaded arms attached to the instrument package and keyed into recesses in the body in such a manner that they could not become disengaged while the instrument pack was in the tail section or the hole made by the penetrator body while piercing the ice.

Consideration should be given to the possibility of designing the locking mechanism for a dual purpose role, i.e., as a lock and as a method for inducing the instrument pack to separate from the body soon after it enters the water. This could be accomplished by having the locking arms spring out from the body when it enters the water to serve as drag brakes. This might entirely eliminate the requirement for an ejector spring. However, if some type of ejector mechanism should still be required, it could be a simple pre-loaded compression spring since the piston, retainer and collets of the original ejector unit would no longer be required.

## 7.3 Power Supply and Communication Cable to Transmitter

The original plan to use a 3 conductor cable between a sea-water battery in the instrument pack and the transmitter in the tail section failed, chiefly because a suitable cable was not available and the substitute employed for expediency did not meet the low temperature performance standards claimed by the manufacturer. It would be wise to adopt another approach since it is not practical to have a special cable manufactured at this stage in the program.

There are several design alternatives, among which the following appear to be the most practical and attractive.

a) The first would be to use a sea-water ground path between the two units. However, this would require a larger, heavier and more powerful battery since sea-water contact resistance is relatively high, approximately 20 ohms. This would result in a drop of approximately 4 volts in the voltage input to the transmitter.

b) Another choice would entail the use of two batteries. One, a sea-water battery deployed at the end of a short two conductor cable into the water below the ice to power the transmitter. The second could be located in the instrument pack and supply power for the hydrophone pre-amplifier, which in turn could be connected to a high impedance amplifier in the tail assembly through a single conductor cable and a sea-water return path. Only a small alkaline type battery would be required to supply the 10 mA current demand of the hydrophone pre-amplifier. A pressure or impact actuated switch would be incorporated in the instrument pack to active the pre-amplifier circuit.

c) The third and most attractive solution would be a modification of the preceding proposal. In this case, a second battery and its associated switch would not be required. Instead, a two conductor cable would be used to connect the instrument pack to the tail assembly and also to tap power for the sea-water battery to drive the hydrophone pre-amplifier. Since the power demand of the hydrophone pre-amplifier is very low, line losses would be minimal even in a relatively small cored two conductor cable.

## 8.0 ACKNOWLEDGEMENTS

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# APPENDIX A

## LABORATORY INVESTIGATIONS

## 1.0 LABORATORY EXPERIMENTS

Six different scale models (Figure A1) of the proposed full scale penetrator were tested in the laboratory to determine an optimum nose shape for the prototype design. Model scale size was 0.136 full size and the weight and mass distribution were arranged proportionately so that the effects of the location of the center of gravity and transverse moment of inertia would closely simulate those of the full scale penetrator, insofar as they would affect the ricochet characteristics of the models.

The models were fired from an air-gun into 22 x 11 x 8.5 in blocks of simulated sea-ice. The blocks were prepared by freezing a brine solution (3% salt) in tanks lined with polystyrene. The polystyrene lining provided sufficient insulation so that freezing occurred from the surface downwards, not from the sides or bottom, thereby causing the ice to assume a uniform density across planes parallel to its surface but of increasing density from surface to bottom. The blocks were conditioned at a temperature of -25°F for at least twenty four hours and held at that temperature until required for immediate use in the experiments.

The selection of nose shapes to be evaluated was somewhat arbitrary but the results of prior experiments (A1) had incicated that a sharp nosed, slender (5° angle), conical nose form would produce the best penetration capability but would not be able to withstand the high bending moments that occur when the penetrator contacts the ice at an angle. It was also known that a flat nosed projectile shows very little tendency to ricochet off a target it can penetrate, even at impact angles under 45°. Therefore it was assumed that a reasonable compromise between the two extremes could be attained since ice is a very frangible material which can be expected to shatter under the impact of a highly loaded, small diameter, blunt nose section thereby offering little resistance to the projectile as it entered the ice. The length and strength of the nose section also had to be taken into consideration since both factors would be important in the final design. Additionally, it was felt that the 28° conical nose form used by Sandia and an ogive should be investigated so that directly comparable data would be available in case it was necessary to explain why they were not used for the full scale penetrator.

Experimental data are presented in Table AI and briefly discussed in the following paragraphs.

Differences between impact and rest angles listed for the various experiments are in effect a measure of the tendency of the projectiles to ricochet off the surface of their target, i.e., the greater the difference the greater the tendency to ricochet and by inference the least desirable nose form on the model being evaluated.

Evaluating the models on that basis and on the depth of penetration achieved it may be concluded that,

a) the type A models gave the best performance, and

b) the type B models were a poor second and that none of the others were worthy of further consideration since all had limited penetration capability and high ricochet tendencies.

These experiments were essentially comparative so no attempt was made to relate the depth of penetration into laboratory ice to that which might be produced by a full scale penetrator against sea-ice.

## 2.0 REFERENCES

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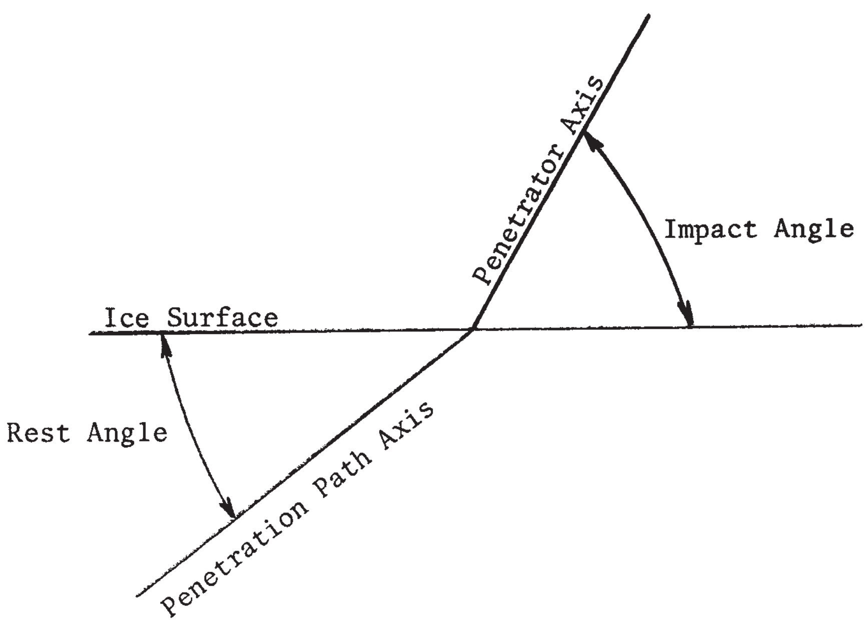
## TABLE AI

Experimental Data

| Projectile Type | Velocity (ft/s) | Angle of Impact (°) | Rest Angle (°) | Ice Depth (in) | Penetration (in) |
|---|---|---|---|---|---|
| A | 396 | 90 | 86 | 22 | complete |
| A | 357 | 45 | 39 | 8.5 | complete |
| A | 470 | 45 | 47 | 8.5 | complete |
| A* | 391 | 45 | 42 | 8.5 | complete |
| A* | 388 | 90 | 90 | 22 | complete |
| A | 388 | 45 | 50 | 8.5 | complete |
| A | 360 | 55 | 57 | 8.5 | complete |
| B | 373 | 55 | 39 | 8.5 | 10.7 |
| B | 369 | 45 | 15 | 8.5 | 12.4 |
| B* | 406 | 45 | 15 | 8.5 | 11.9 |
| C | 388 | 45 | 26 | 8.5 | 12.2 |
| C | 372 | 55 | 36 | 8.5 | complete |
| D | 394 | 45 | 24 | 8.5 | 14.5 |
| E | 390 | 90 | 85 | 22 | 14.6 |
| E* | 406 | 90 | 63 | 22 | 18.4 |
| E | 353 | 45 | 31 | 8.5 | complete |
| E | 366 | 45 | 27 | 8.5 | 10.9 |
| E | 382 | 55 | 59 | 8.5 | complete |
| F | 367 | 45 | 33 | 8.5 | 7.0 |

* Denotes shorter projectile - see text.



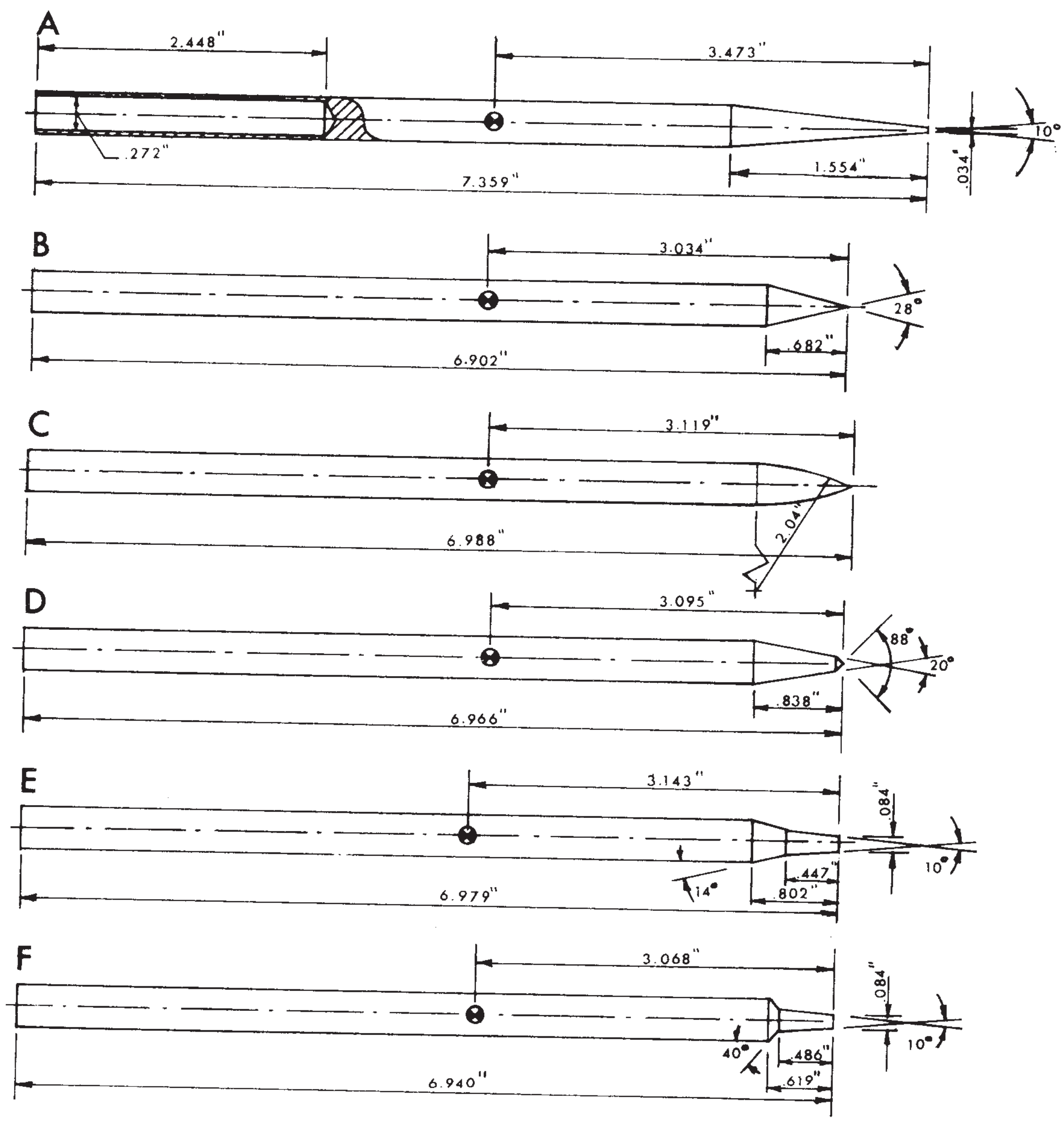



FIGURE A1 - Scale Model Penetrators

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by G.E. Booker and J.M. Jones

An experimental design of a system for deploying telemetry instrumentation beneath Arctic sea-ice by means of a free-fall penetrator is presented and some of its more difficult design areas are noted. Results of laboratory experiments leading to the selection of a nose shape for prototype full scale models tested in the Arctic and significant observations derived from the results are also discussed.

Results obtained from the Arctic trials were disappointing in some respects but they show that the basic concept is feasible and indicate which areas in the original design require modification. (U)

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Ces résultats, désappointants dans certains domaines, démontrent toutefois que le principe est réalisable et indiquent quels éléments du premier modèle doivent être modifiés. (NC)

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