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Ice Penetration by Air Delivered Weapons (U)

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5/8/07

M. M. Hightower, C. W. Young

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

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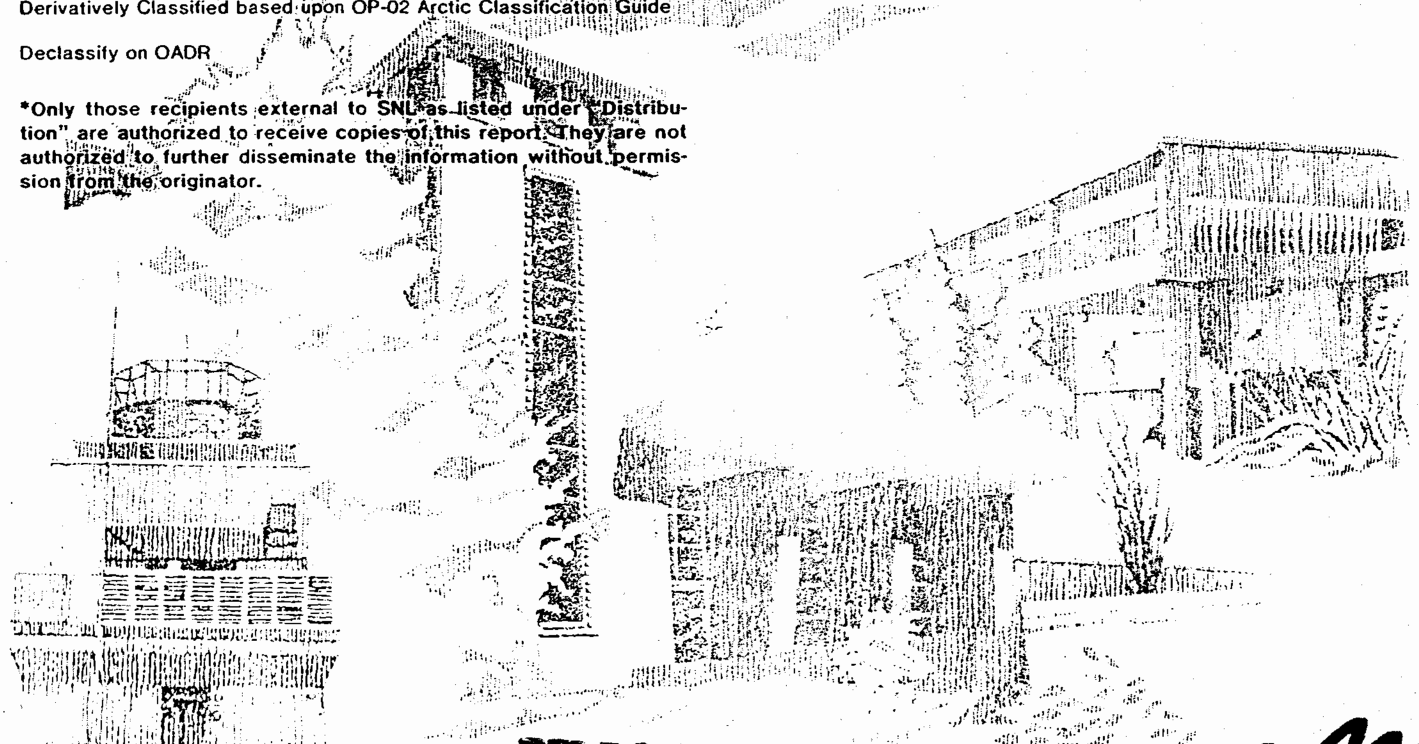

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ICE PENETRATION BY AIR DELIVERED WEAPONS (U)*

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May 1986

ABSTRACT

Throughout history, there has been considerable interest in developing weapons to penetrate various targets. In recent years, the emphasis has been directed toward developing weapons which can penetrate hard targets such as rocks, concrete, and thick sea ice, and still function properly. In this report, an overview is presented of the important factors to consider when designing a weapon to penetrate thick sea ice. This discussion is based on both theoretical and experimental results of several programs conducted by Sandia on ice penetration. Additionally, the results of a recent Naval Air Systems Command (NAVAIR)-funded program to determine the ice penetration capability of several conventional air-delivered Naval weapons, including mines, torpedoes, and destructors will be presented.

*This work was supported by NAVAIR.
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LIST OF TABLES

I. WEAPON DESIGN CONSIDERATIONS FOR ICE PENETRATION

Several factors govern the design of an air-delivered, ice penetrating weapon, including: (1) ice type and thickness to be penetrated; (2) impact conditions; (3) release conditions; and (4) system constraints. These factors define the loading on a weapon and determine the mechanical complexity of the system. In this section, information on ice penetration requirements are presented, followed by a discussion on how the factors listed above affect ice penetration and their importance in the design of an optimum ice penetrating weapon within given system constraints.

Ice Thickness Penetration Requirements

The term "sea ice" refers to several types of ice, each of which varies in age, thickness, and material properties. Sea ice can generally be divided into three categories. Based on age, they are: refrozen leads, annual ice, and multiyear ice. Refrozen leads occur when sections of ice separate, developing narrow channels or open water. These channels normally quickly freeze, giving rise to the name refrozen leads. Since the water is quickly frozen, the ice is relatively thin when compared to other ice types and contains a high concentration of brine, making it soft or weak.

Annual ice is ice which freezes and thaws each year. This ice is frozen slowly throughout the winter and therefore is stronger and contains a lower concentration of brine. Annual ice is typically five to seven feet thick but can be up to 10 feet thick during a severe winter.

Multiyear or pack ice lasts throughout the year, continuing to build up each year and becoming very thick. Pack ice is generally greater than 10 feet thick, and the partial thawing each summer and refreezing each winter tends to leach out the brine and eliminate voids, resulting in a very hard or strong ice.

Table I. Summary of Approximate Constitutive Equations for Various Types and Thicknesses of Ice [2]

Ice Type	Thickness (ft)	Density (ρ, gm/cm^3)	Shear Strength ($\sigma_1-\sigma_2$, psi)	Compressibility K, Kbar
Multiyear Pack Ice / Thick Annual Sea Ice	>10	.90	1750	40
Thin Multiyear Pack Ice / Annual Sea Ice	5-10	.90	1300	40
Thin Annual Sea Ice (Refrozen Leads)	2-4	.90	1300	20

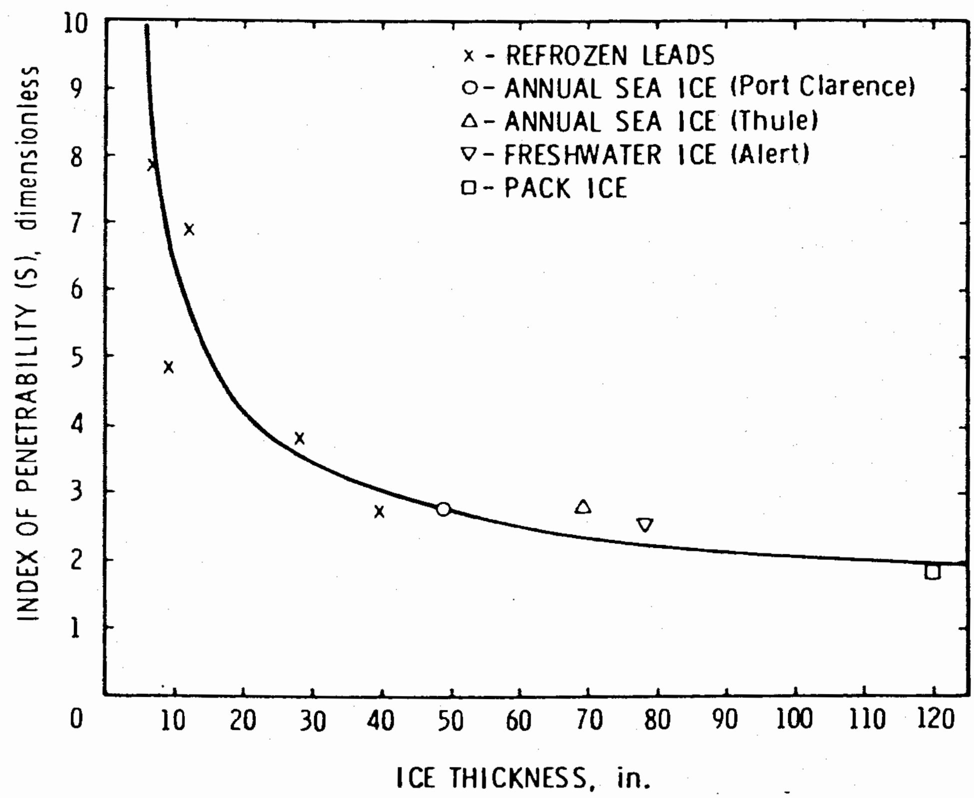

Figure 1. Relationship Between Ice Thickness and Penetrability [1]

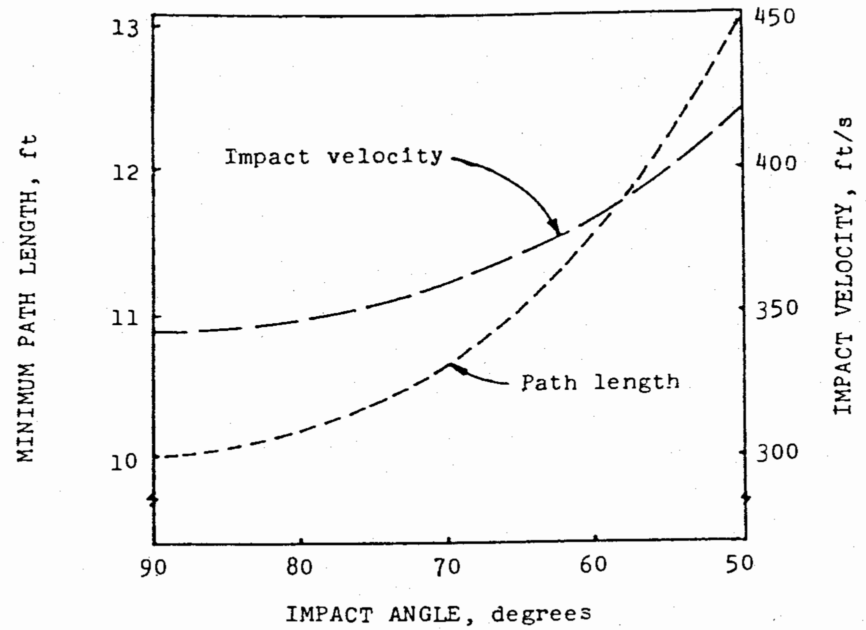

Figure 2. Velocity Required to Penetrate 10 feet of Ice at a Given Impact Angle for a 1500-lb System with a 2.2 CRH Nose

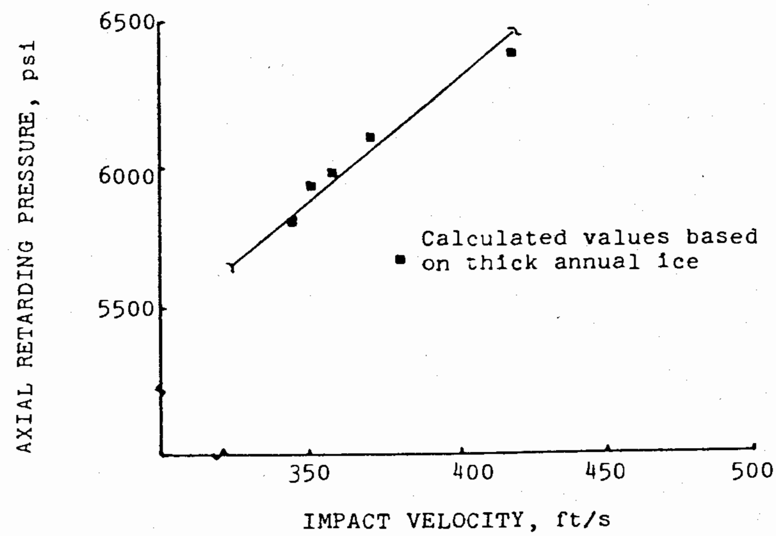

Figure 3. Axial Retarding Pressure on the Nose of a 15-inch Diameter System with a 2.2 CRH Nose at Various Impact Velocities

Effect of Angle of Attack

The angle of attack, the angle between the velocity vector and the axis of a weapon, relative to the surface of the ice, has a severe effect on penetration loads. Large angles of attack cause severe lateral loads on a weapon indicating that angles of attack need to be reduced as much as practical. Angles of attack are caused by two factors--winds and by the aerodynamic characteristics of a weapon. Since winds are variable and depend on the weather conditions, any angle of attack that they cause cannot be totally eliminated and therefore must be considered when calculating lateral loads. Angles of attack caused by the aerodynamic characteristics of a weapon can normally be controlled by designing stable aerodynamic systems.

Influence of Weapon Configuration on Penetration Performance and Loading

Two of the most obvious ways to increase the ice penetration performance of any weapon would be to increase the weight and to increase the slenderness of the nose (thus increasing the length of the weapon). The problem is that the weight and length are limited by the system constraints of the delivery system. Normally, the length and weight of the weapon are the most important constraints since they affect the size of the delivery aircraft and number of weapons which can be delivered.

The following ice penetration equation was developed to fit data from a substantial number of Arctic tests [2, 4, 5, 6]:

$$D = .0026 \left(T_i\right)^{-.4} (W/A)^{.6} (N) \ln(50 + .06\, W^2)(V-100)$$

where

D = Penetration Depth (ft)

T_i = Ice Thickness (ft)

W = Weight (lbs)

to be more slender. This makes the weapon even more efficient causing a substantial decrease in both the axial and lateral loading on a weapon. The major disadvantage of increasing the length of a weapon is that the increased length can substantially increase the bending stresses caused by the lateral loads because of the increased moment arm of the weapon. Therefore, a careful look at the variation in length possible in a weapon should be made so that a near optimum design, from both a penetration and loading viewpoint, can be determined.

Nose Shape Effect

From the penetration equation presented previously, the nose performance coefficient (N) is an important parameter for ice penetration. From [1], as the slenderness of the nose increases, so does the nose performance coefficient, causing the weapon to be a more efficient penetrator. This is shown in Figure 5 where two penetrators similar in design, except for the nose shape, impacted the same target at the same impact conditions. The flat-nosed penetrator experienced a higher sustained loading and therefore did not penetrate as deep as the penetrator with the more slender 2.2 CRH nose. Data from [1] indicates that the penetration performance of a weapon can be increased by as much as a factor of two by using a slender nose. The axial and lateral loads would be reduced by a similar factor.

Two considerations must be kept in mind when designing a nose shape. First, as mentioned before, a slender nose generally requires a longer weapon length, with the problems this presents discussed earlier. Second, very slender noses may not be structurally adequate to survive hard impacts. Therefore, it is important to evaluate the effects of the variation in nose shape on the structural integrity of the weapon and on the overall loading.

Weapon System Constraints

On top of all the variables which must be considered when trying to design an ice penetrating weapon, there are several other constraints that must be placed on the weapon system. These constraints vary depending on the type of weapon, whether bottom mine, moored mine, torpedo, etc., the areas of the ocean in which they will be used, and the targets these weapons will engage. Practical constraints are also placed on these systems by the type of aircraft able to deliver them. These additional factors which have to be considered when developing an ice penetrating weapon system, including weapon type and use and aircraft constraints, are presented below.

Weapon Use Constraints

In the previous section, it was illustrated how important it is to maintain selected impact velocities, impact angles, and angles of attack. Trying to maintain the most beneficial impact conditions may greatly increase the complexity of an ice penetrating weapon system because of the effectiveness constraints of a particular weapon. Ice penetrating weapon systems may be divided into two categories: target weapons and area weapons.

An area weapon, such as bottom or moored mines, would be used in a general area with many placed randomly throughout the area. Therefore, the CEP of a single weapon would not be important, and some scatter of the weapons could be tolerated. Figure 6 shows the release conditions required to enable a nonretarded 2.2 CRH, 1500-lb weapon system to impact at a minimum 55° impact angle at the velocities required to penetrate 10 feet of ice. As can be seen from this figure, release altitudes in excess of 2500 feet are required to attain the required impact velocity and impact angle. Some scatter would be expected if dropped from this height, but for general area weapons where the CEP is not important, a simple, aerodynamically-stable, free fall weapon system could attain an adequate impact velocity and impact angle.

A target weapon, such as destructors and torpedoes, is used against a specific target and therefore needs to be delivered with a generally small CEP. This would probably require either a low-level delivery to prevent scatter or a guided weapon system. A guided weapon system can be very complicated, while low-level deliveries do not generally provide acceptable impact velocities and impact angles for ice penetration in either free-fall or retarded configurations. Low-level deliveries would probably require that a weapon system be retarded to attain the required impact angles and then be boosted to attain the required impact velocities. Therefore, either a guided or low-level delivery of a target weapon could substantially increase the complexity of an ice penetrating system in order to meet survivable impact conditions.

Aircraft Constraints

The two systems suggested for delivery of ice penetrating weapons are the P3 and B52 aircraft which have practical system constraints as listed in Table 2. [7,8].

Table II. Practical Delivery System Constraints for Ice Penetrating Weapons

SYSTEM	PRACTICAL SYSTEM CONSTRAINTS			
	Number of Weapons	Weight (lbs)	Diameter (inches)	Length (inches)
B52 (Bomb Bay) (2 Clip System)	8-12	2500	24	150
B52 (Wing Pylon) (Each Wing)	5	2500	24	150
P3 (Bomb Bay)	3	1600	21	133
P3 (Bomb Bay)	1	2450	23-5/8	133
P3 (Wing Stations)	6	2450	--	--

Therefore, Sandia only looked at those release conditions which provided each weapon with a minimum impact angle of 55°.

- Using the provided weapon data, the ice penetration equation from [1] presented in Section 1, and the impact angle, the velocities required to penetrate various thicknesses of ice were calculated for each weapon.
- From the impact velocities, angles, and a Sandia-defined angle of attack, the axial and lateral forces on each weapon were calculated. The axial forces were calculated by using the material properties of the appropriate ice thickness as listed in Table 1 with the cylindrical cavity expansion techniques developed in [3]. The lateral forces were calculated using the approximate technique Simplified Analytical Model of Penetration with Lateral Loading (SAMPLL) [15]. An angle of attack of 2° was used in all the lateral loading calculations in order to include the contribution of surface winds and slight aerodynamic instabilities of each weapon to the lateral loads.
- From the provided design drawings, the stresses and deformations expected during penetration for the varying impact velocities were calculated for each weapon. The calculated stresses were then compared to the yield strength of the case material to determine the limit of the ice thickness that each weapon can penetrate and be expected to structurally survive.

The results of these analyses for each weapon are presented in Table III with a discussion of the results presented below.

<u>MK-60 Series Mines</u>

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III. MODIFICATIONS REQUIRED TO ENABLE SEVERAL AIR-DELIVERED ANTI-SUBMARINE WEAPONS TO PENETRATE 10 FEET OF SEA ICE

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IV. CONCLUSIONS

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14. Longcope, D. B., and Foresstal, M. J., "Penetration of Targets Described by a Mohr-Coulomb Failure Criterion with a Tension Cutoff, "Journal of Applied Mechanics, Vol. 50, June 1983, pp. 327-333.

15. Young, C. W., and Young, E. R., "Simplified Analytical Model of Penetration with Lateral Loading, SAND 84-1635, Sandia National Laboratories, Albuquerque, NM, May 1985.

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Sandia National Laboratories

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October 5, 1983

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  For: M. M. Kleinerman, Rm. 20-223

Subject: Load/Time Histories for Mk-82, -83, and -84 Bomb Shapes Penetrating 10 Feet of Ice (U)

Gentlemen:

Under Sandia National Laboratories' contract with the Naval Air Systems Command to determine the ice penetration capability of several of the Navy's conventional mines, torpedoes, and destructors, we have calculated the axial and lateral loading environments for those weapons which will structurally survive 10 feet of ice penetration. Under this agreement, we are to provide this data to the appropriate Naval laboratories so that they can analyze

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CMDR Hickman NAVAIR x
Wash., DC 9/26/83
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Attn: AIR-54133
For: CMDR H. W. Hickman, Code AIR-35F

References:

[1] CNSI Letter dtd 9-26-83, M. M. Hightower, SNLA, to CMDR H. W. Hickman, NAVAIR, subj: "Progress Report for September on SNL's Ice Penetration Study" (U).

[2] Forrestal, M. J., "Forces on Conical-Nosed Penetrators Into Targets With Constant Shear Strength," (U), Mechanics of Materials 2, pp. 173-177, 1983.

[3] Hightower, M. M.; Norwood, F. R.; and Young, C. W., "Development of an Ice Penetration Model," (U), Report SAND82-0599, Sandia National Laboratories, Albuquerque, NM, December 1982.

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Sandia National Laboratories
Albuquerque, New Mexico 87185

December 12, 1983

#WB-1926
Commanding Officer
Naval Air Systems Command
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Stanley H. Keel
Department of the Navy
Washington, DC 20361

For: CMDR. H. W. Hickman, Code AIR-35F

Subject: Ice Penetration Study (U)

Gentlemen:

Under a Scope of Work Agreement between NAVAIR and Sandia National Laboratories, the ice penetration capability of several Naval weapons have been analyzed. Additionally, we have been asked to determine if the Mk-83 and -84 series weapons can be adapted to penetrate ice at low altitude deliveries. The major problems with a low altitude delivery of an ice penetrating system are: attaining the impact velocities required to penetrate ice and attaining the impact angles required to prevent weapon ricochet or broaching. These requirements suggest that the weapon modifications could be rather complicated. The results of our study are discussed in this letter.

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Mike Hightower
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Attachments: Figures 1-4;
Tables 1-3.

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APPENDIX C

Table 1.

NAVAIR P3 Aircraft Compatibility System Constraints

SYSTEM TYPE	SYSTEM CONSTRAINTS Weight (lbs)	Diameter (inches)	Length (inches)
1	1200	14	134
2	1600	21	133
3	2450	23-5/8	133
4	2450	--	---

to try and make these modifications fall within the constraints of either Systems 1 or 2. In this report, the modifications required for ice penetration and the expected loading environments for the following weapons will be addressed: Mk-65 Quickstrike, Mk-60 Captor, Mk-56 moored mine, and Mk-55 and Mk-52 bottom mines. The modifications required for ice penetration and the loading environments expected were presented in [2] for the Mk-82, -83, and -84 bomb shapes and in [3] for the Mk-46 and ALWT torpedoes.

The loading information calculated for each of the weapons which could be modified within the constraints listed in Table 1 include:

Axial acceleration/time
Lateral acceleration/time
Lateral forces/time

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References:

[1] CNSI Letter dtd 9-26-83, M. M. Hightower, SNLA, to CMDR H. W. Hickman, NAVAIR, subj: "Progress Report for September on SNL's Ice Penetration Study" (U)

[2] CNSI Letter dtd 10-5-83, M. M. Hightower, SNLA, to M. M. Kleinerman, NSWC, and F. Smith, NWC, subj: "Load/Time Histories for Mk-82, -83, and -84 Bomb Shapes Penetrating 10 Feet of Ice" (U)

[3] CNSI Letter dtd 10-14-83, M. M. Hightower, SNLA, to CMDR H. W. Hickman, NAVAIR, subj: "Ice Penetration Study" (U)

[4] Forrestal, M. J., "Forces on Conical-Nosed Penetrators Into Targets With Constant Shear Strength," (U), Mechanics of Materials 2, pp. 173-177, 1983.

[5] Hightower, M. M.; Norwood, F. R.; and Young, C. W., "Development of an Ice Penetration Model," (U) Report SAND82-0599, Sandia National Laboratories, Albuquerque, NM, December 1982.

[6] Letter dtd 3-7-77, C. W. Young, SNLA, to M. M. Kleinerman, NSWC, subj: "Mk-82 and Mk-65 Quickstrike Penetration Tests at White Sands Missile Range" (U)

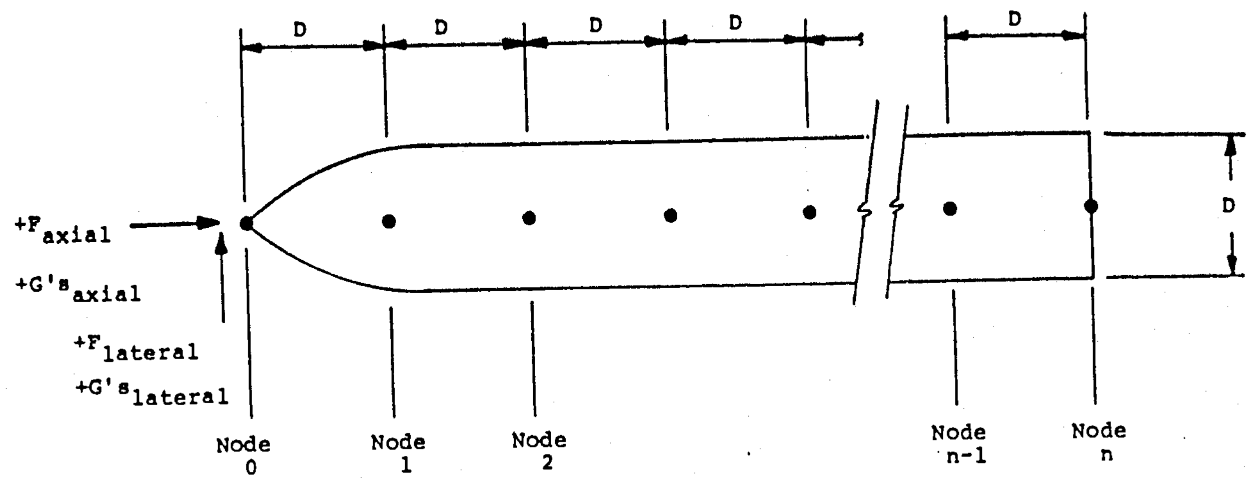

Figure 1. Location of nodes for the lateral loading plots.

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APPENDIX D

Table 1.

NAVAIR P3 Aircraft Compatibility System Constraints

SYSTEM TYPE	SYSTEM CONSTRAINTS Weight (lbs)	Diameter (inches)	Length (inches)
1	1200	14	134
2	1600	21	133
3	2450	23-5/8	133
4	2450	--	---

This preliminary report considers only possible modifications to the Mk-46 and ALWT torpedoes.

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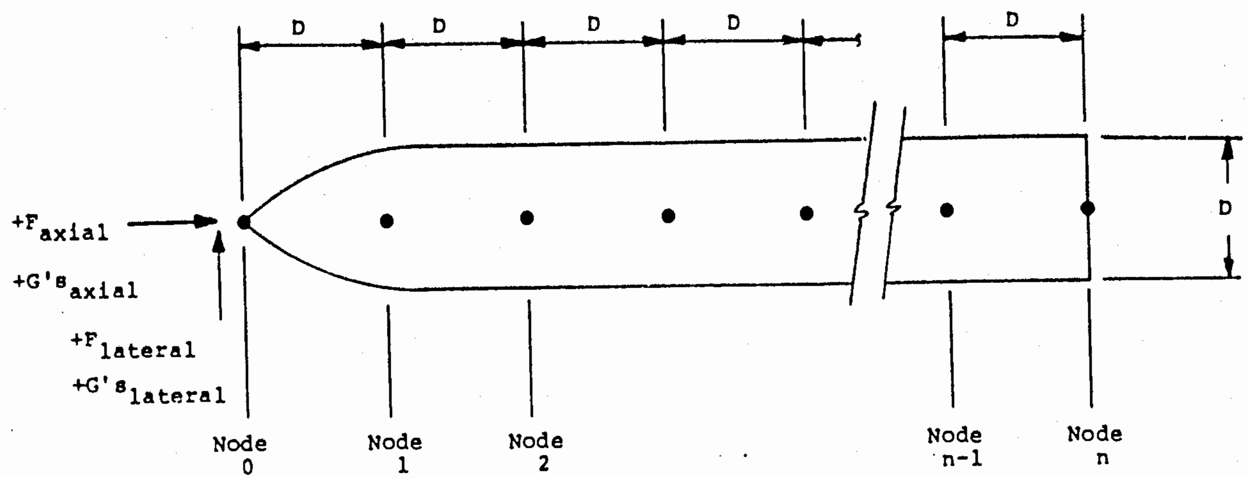

Figure 1. Location of nodes for the lateral loading plots.

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