MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF

IMPACT FUZE PERFORMANCE IN SNOW (U)
(Initial Evaluation of a New Test Technique),

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Introduction: Snow greatly reduces the effectiveness of impact-fuzed projectiles. In order to obtain maximum effectiveness in a winter battlefield environment, design of new fuzes and evaluation of current equipment requires detailed knowledge of the snow penetration event. Fuze performance data under various impact conditions can be obtained by both direct and reverse ballistic test procedures (1). In the direct test the fuzed projectile is subjected to realistic launch accelerations, but the test presents problems in accurately locating the point of impact and requires telemetry to obtain data from on-board transducers. The reverse ballistic technique, where the target is fired into a stationary projectile, has the advantage of allowing instrumentation in the projectile to be directly wired to recording equipment. However, this technique is difficult to utilize with snow since this material cannot sustain the high acceleration loads involved.

The centrifugal launch method that was used to conduct the tests discussed here is unique in that it provides advantages normally found in both techniques, i.e. sensors in the projectile can be directly wired to recording equipment, and the target is not subjected to the acceleration loads experienced in the reverse ballistic technique. The point of impact can also be closely controlled using the centrifugal launch technique.
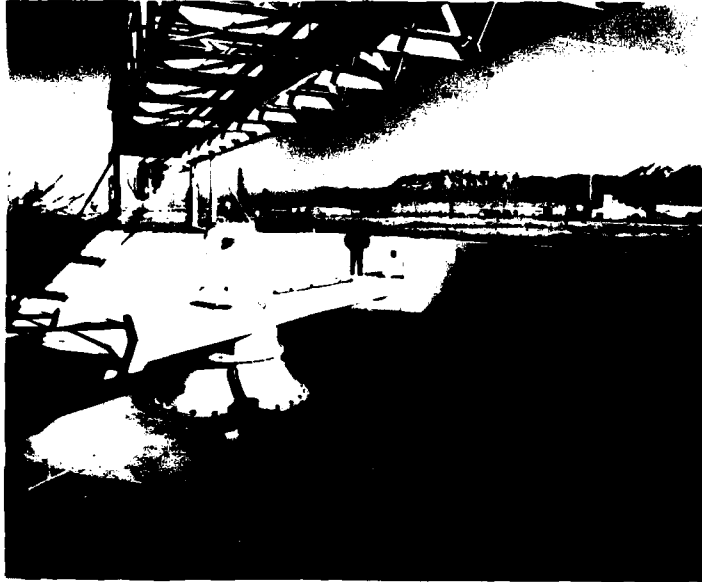
The information obtained from these tests consisted of measurements of the deceleration of a projectile when it impacts against a snow target. The deceleration data were smoothed using a low pass digital filter and integrated to obtain depth of penetration. This
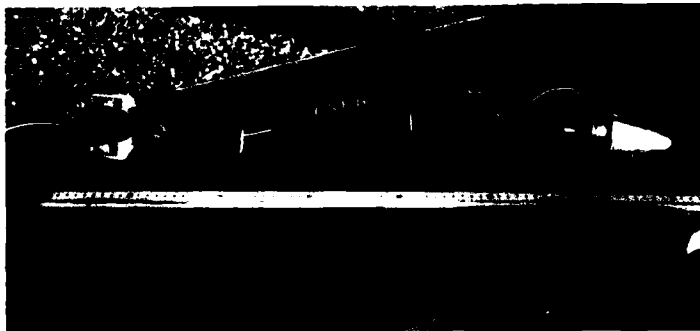
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1. View of the 10.7-m centrifuge located at
   Sandia Laboratories, Albuquerque, N.M.

2. Close-up view of instrumented M524 fuze
   and M374 81-mm projectile.

information was then compared with a modified hydrodynamic drag
equation (2) that has been used to describe fuze impact into both
snow and mud. Kovacs (3) and Davis (4) also used similar equations
to analyze fuze performance.

Test Procedure: The centrifuge facility utilized for these tests
(Fig. 1) is located at the Sandia Laboratories in Albuquerque,

3.   Preparation of the snow target.

N.M. Otts (5) presented a description of the centrifuge and an example of its use as an impact testing machine. It has a 10.7-m radius and is capable of subjecting a test item to tangential velocities up to 164 m/s.

An inert M374 81-mm projectile with an M524 fuze was used in these tests. The fuze was instrumented by replacing the striker and explosive train with a piezoresistive accelerometer mounted on an aluminum plug (Fig. 2). The instrumentation lead was run through the projectile body and out the tail section.

Targets made from both snow and nylon shavings (a candidate material to simulate snow) were used in these tests. The snow targets were prepared by sifting snow through a 6-mm-mesh screen into 610-mm-square by 150-mm-deep boxes constructed of 50-mm-thick Styrofoam (Fig. 3). These targets were then aged at least 24 hours to allow the snow to sinter. Snow densities of about 0.4 Mg/m^3 were obtained. The nylon targets were prepared by pouring 10-mm-long nylon shavings into the 150-mm-deep Styrofoam boxes. A piece of cheesecloth was placed over the surface of the shavings to keep them in place when the box was turned on its side for the test.

4. Snow target, with aluminum foil wind
   screen in place, positioned in stand
   prior to test event.

The target boxes were placed in a rigid stand located on a tangent to the arc made by the centrifuge arm and positioned to insure a near normal impact (Fig. 4). An aluminum foil wind screen was placed 150 mm in front of the snow targets to protect the snow surface from wind damage. Alternating layers of Styrofoam and plywood were placed behind the targets to stop the projectile.

The instrumented projectile was mounted on the centrifuge as shown in Fig. 5. When the centrifuge achieved the desired velocity, the projectile was released so that it impacted the target. The accelerometer output was amplified and recorded on an analog tape recorder. The frequency response of this system was flat to 5 kHz. Data were obtained for impact velocities ranging from 15 m/s (50 ft/s) to 91 m/s (300 ft/s).
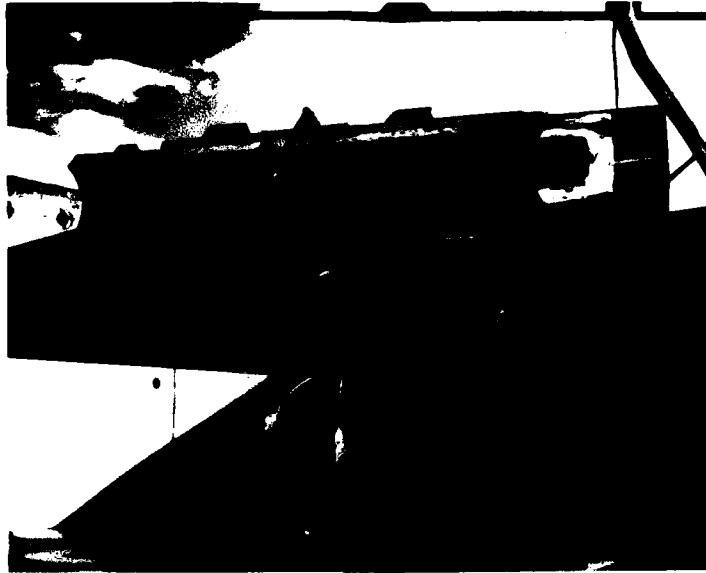
5. Close-up view of test projectile mounted on centrifuge arm. Note steel cable holding projectile to arm and explosive cable cutter used for projectile release.

Data Reduction: The test data were digitized for computer analysis using a sampling rate of 20 kHz which was high enough to avoid aliasing problems.* Input signals of known acceleration values were used to calibrate the system.

A typical acceleration vs. time signal for a snow impact at 30 m/s is shown in Fig. 6. Projectile impacts with the wind screen, the snow surface, and the barrier behind the snow target are identified in the figure. The travel times between these impacts were used to verify the impact identifications given in the figure.

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*Aliasing, defined as the disguising of high frequency components of a signal as low frequencies, occurs when a sampling rate which is too low is used in the digitizing procedure (6, 7).
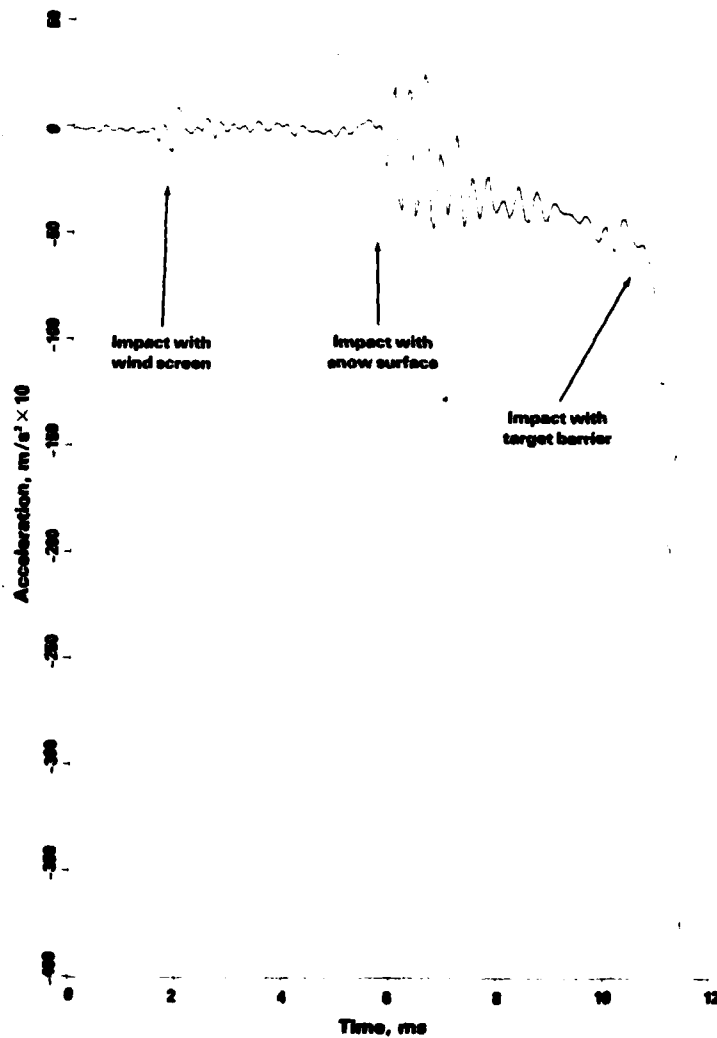
6. Acceleration vs. time data for 30-m/s impact of projectile into 0.39-Mg/m^3 density snow target.

This signal has been passed through a zero phase low pass digital filter with a cutoff frequency of 5 kHz, corresponding to the bandwidth of the analog recording equipment. The filter removes any high frequency noise produced by the digitizing process (7) without introducing any time shifts to the signal. This latter property of the filter is quite important. Computer

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programs to apply digital Butterworth filters to signals are
readily available (8). However, these filters will introduce a
frequency-dependent phase shift, which causes the output signal
to be delayed in time by an amount proportional to the frequency
of each component. To remove the phase shift, the filter was
first applied to the signal, obtaining a phase-shifted, filtered
output. The filter output was then reversed and the signal
passed through the filter again. This procedure has two effects:
a) the final output will not be phase (or time) shifted, since
the phase shift caused by the second pass will be the negative of
the phase shift caused by the first pass; and b) the final
amplitude response of the filter will be the square of the
amplitude response of a single filter operation. After filtering,
however, some high frequency noise superimposed on the snow
impact signal is still visible. This noise cannot be attributed
to the digitizing process and therefore must have some other
physical cause.

A possible source of this high frequency noise is resonant
vibration of the projectile. A test was conducted to ascertain
whether or not the resonant frequency of the projectile was of
the same order as the high frequency noise on the data traces by
suspending the projectile from a string attached to its tail and
then tapping it with a hammer. The output from the accelerometer
was digitized and is shown in Fig. 7. The amplitude vs. fre-
quency plot obtained from the Fourier transform of this signal is
shown in Fig. 8. The peak amplitude is around 1.5 kHz, with
significant amounts of power located at frequencies up to about
3.5 kHz, suggesting that resonant vibration of the projectile
could be the cause of the noise on the data traces. In most
cases, it was found that a low pass filter with a cutoff fre-
quency of around 1.5 kHz was sufficient to remove this high
frequency noise. For the higher impact velocities, however, the
low pass filtering procedure did not give usable results even if
a lower cutoff frequency was used.

The poorer quality of the data at higher impact velocities
is due to two factors. First, as the impact velocity increases,
the amplitude of the resonant vibrations increases, thereby
decreasing the signal to noise ratio. This effect is analogous
to increasing the force of the hammer blow in the experiment
discussed above. Second, the data are degraded because the
impacting time interval decreases significantly. For a given
impact velocity, V_o, the number of significant data points N
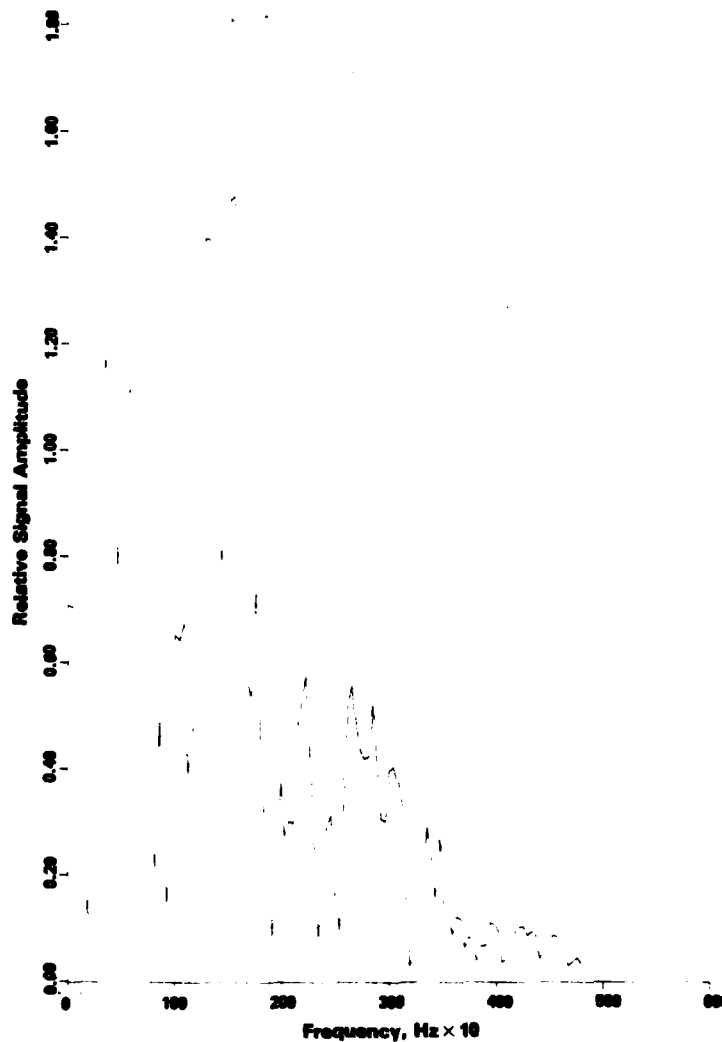obtained during an impact with a target of thickness d is limited
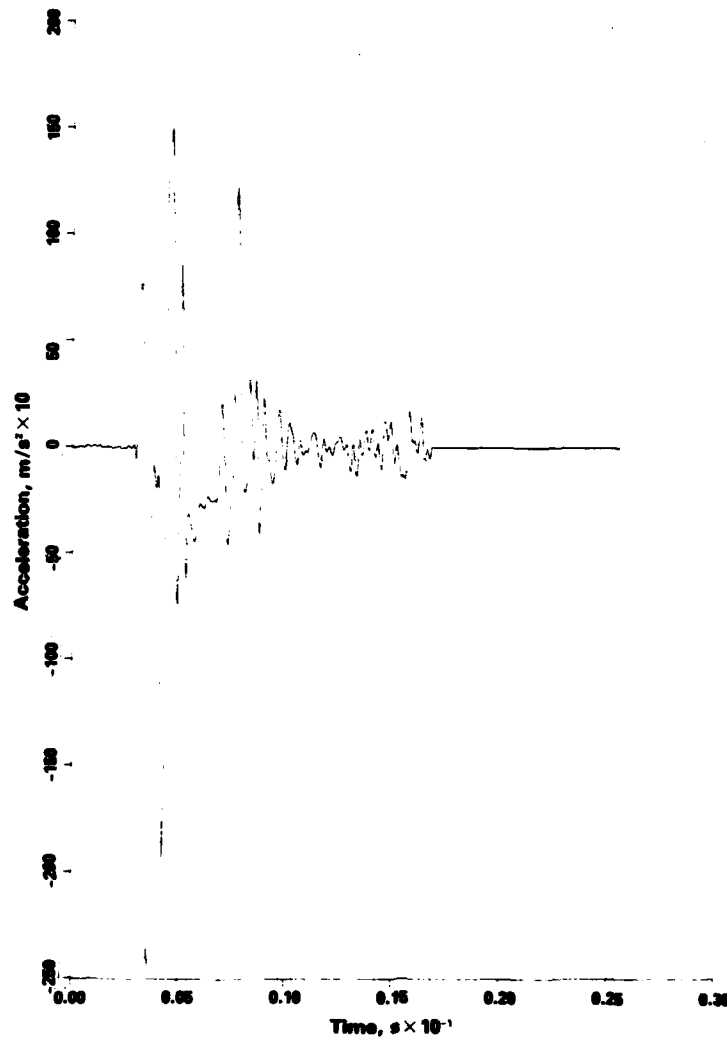
7. Acceleration vs. time response of test projectile
supported by a string after hammer impact.

by the bandwidth of the recording instrument B and is given by

$$N = \frac{d}{V_o} B. \tag{1}$$

For this experiment B = 5 kHz and d = 0.15 m. For a relatively

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8. Amplitude vs. frequency curve obtained
    using hammer input data in Fig. 7

low impact velocity of 30 m/s, N is 25, but for a high velocity
of 90 m/s the number of data points is reduced to only 8. It is
difficult to accurately define the deceleration of the projectile
with only 8 data points available for the event. With noise
superimposed on the signal, accurate measurement of the decelera-
tion with this limited number of data points becomes impossible.
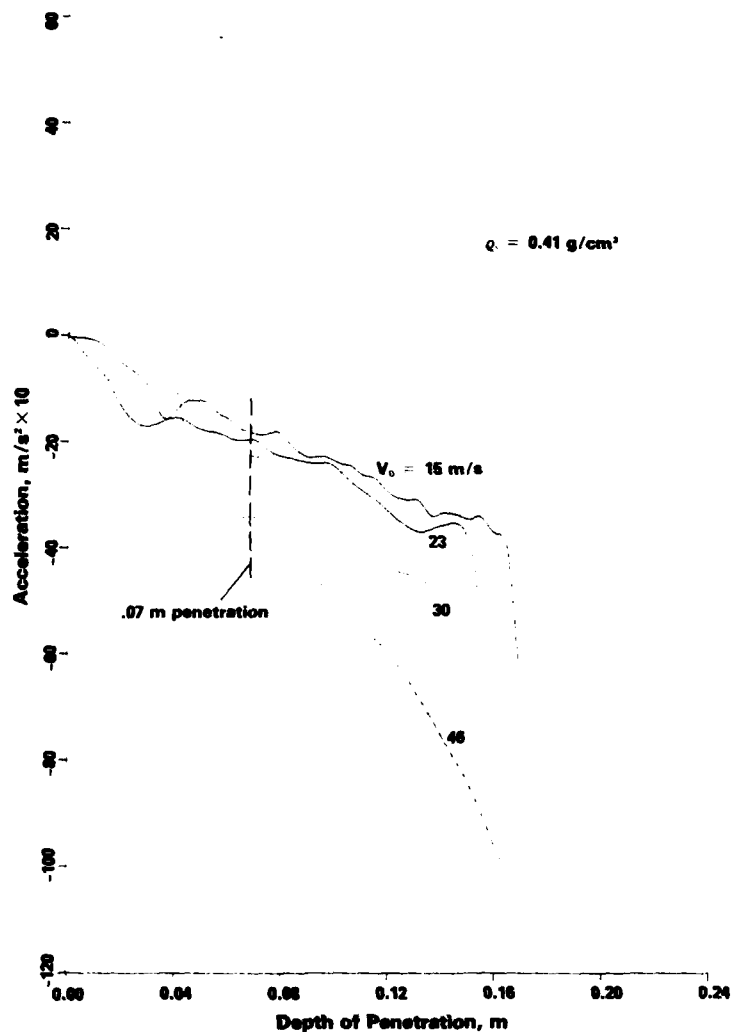
9. Acceleration vs. depth-of-penetration curves
   for snow at various impact velocities.

After filtering to remove the noise, the deceleration data
were integrated to obtain curves of depth of penetration as a
function of time. The penetration vs. time data and the original
deceleration vs. time data were then used to construct decelera-
tion vs. penetration curves at velocities from 19 to 46 m/s
(Fig. 9).

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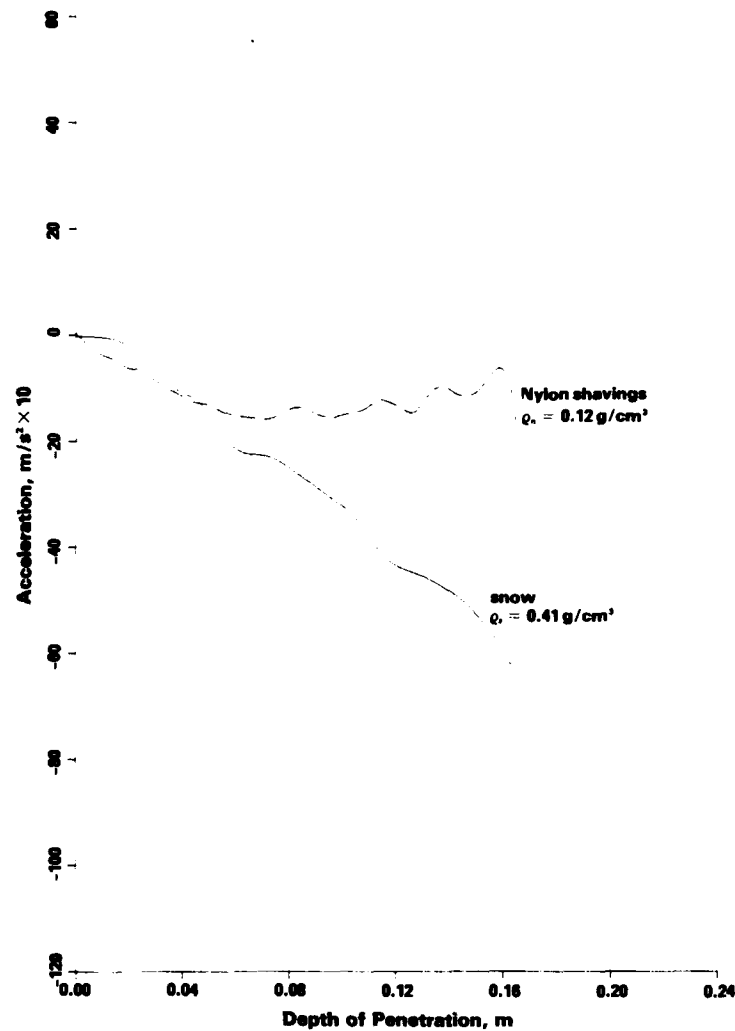
10. Projectile impacts into snow and nylon
    shaving targets at 30 m/s (solid line:
    snow; dashed line: nylon shavings).

Analysis of Results: As shown in Fig. 9 approximately the first
0.07 m of the deceleration vs. penetration curves was influenced
by the resonant vibration of the projectile. The vibration level
was relatively high during that part of the penetration event and
was not adequately reduced by the filtering technique. After the

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0.07-m point, the data appear reasonable and show a linear increase in deceleration with increasing penetration. There also seems to be a linear trend to the increase with impact velocity.

Data from representative impacts into targets constructed from nylon shavings are compared with snow data in Fig. 10. The nylon material, which had a density of 0.12 Mg/m^3, has been used by the USAF to simulate snow for missile nose cone impact tests. Projectile penetration into the nylon sample is characterized by an initial increase in deceleration (which might possibly be attributed to the projectile resonance) followed by a period with roughly constant deceleration. As shown, this is different from the characteristic shape of the deceleration vs. penetration curve for snow. However, there is also a considerable difference in density between these two targets.

A hydrodynamic drag force equation,

$$F = \frac{1}{2} C_D \rho V_o^2 A, \tag{2}$$

where

F = drag force on projectile,

C_D = drag coefficient,

ρ = target density,

V_o = projectile velocity, and

A = projectile area,

has been used by several investigators as a basis for determining fuze performance against water, snow, or mud targets. Kornhauser (2) reported that eq. 2 produces conservative estimates of fuze performance, i.e. the calculated force is lower than the actual force. However, he did not have access to any test data against snow targets to verify his hypothesis. Kornhauser also stated that when calculating forces on point detonating devices the drag coefficient C_D should be 1. Equation 2 then reduces to the equation for the stagnation pressure for a body traveling in a fluid medium:

$$F/A = \frac{1}{2} \rho V_o^2 . \tag{3}$$
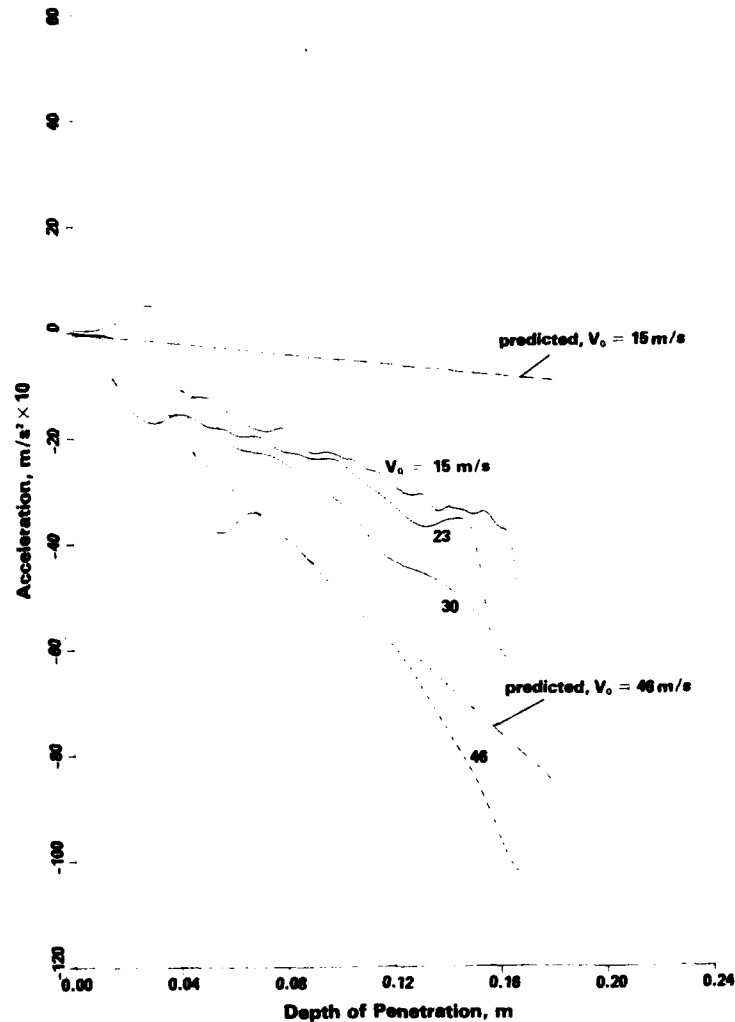
11. Comparison of predicted vs. measured snow
    impact data (solid line: measured values;
    dashed line: predicted values).

Data from impacts into snow are compared with predictions
made using eq. 3 in Fig. 11. For low velocities (15-30 m/s),
this equation predicts a lower value for deceleration than was
measured. At 46 m/s, there is close agreement between the
theoretical and the measured deceleration values. The experimental
data above this velocity are severely degraded by noise but were

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used to estimate deceleration values. These estimated values are less than predicted by eq. 3.

Conclusions: The centrifuge technique is an acceptable method of launching instrumented projectiles and has the capability of providing data without the use of telemetry.

For snow, the data presented show that the forces on a projectile increase as projectile impact velocity increases, and that this relationship is approximately linear.

Projectiles launched into targets prepared from nylon shavings undergo much less deceleration than those launched into snow targets.

Hydrodynamic theory appears to agree with snow test results at an impact velocity of 46 m/s but deviates from measured decelerations at other velocities.

Recommendations: A technique (such as deconvolution) should be developed to eliminate the resonant noise from the data signals so that tests can be conducted over a much greater velocity range.

Future tests should be conducted with higher bandwidth instrumentation to provide sufficient data for analysis at the higher impact velocities. It is estimated that a bandwidth of 40 kHz would be adequate for impact velocities up to 240 m/s.

Future testing should also include deeper targets so that a steady-state penetration condition could be achieved. This condition would also be facilitated by a simpler projectile shape (i.e., cylindrical) than that of the M374 projectile used here.

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