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Impact Verification of Space Suit Design for Space Station

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Moffett Field, California 94035

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Final Technical Report

for
for the period
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May 1987

Background

Previous work on single sheet structures determined the ballistic limit of 6061 T6 Aluminum of nominal 70 mil thickness. Using the Fish-Summers penetration equation with a material constant of 0.57 and the currently accepted debris particle distriution yielded a probability of penetration given a hit (Pkh) that was considered too low. If the debris particle size distribution curve remains constant what alternatives are left for increasing the Pkh of the proposed space suit? If we maintain the basic structure as a single sheet material then the choice would be to increase the thickness from 70 mils to over 200 mils thickness. For the torso portion of the suit this might be acceptable, but the increased inertial mass in the arms and legs areas of the suit would not be as acceptable. If we use a double sheet structure for those mobile parts, then the overall mass, although increased, could be much less than the equivalent single sheet requirement.

The principal behind the multi-sheet approach is that the first sheet acts as a bumper, initiating shock waves in the impacting particle to break it up into much smaller particles. these smaller particle tend to disperse upon emerging from the bumper sheet over a larger area dependent upon the distance between the bumper sheet and the rear sheet. The smaller particles that impact the rear sheet have a reduced penetrating capability and if sufficiently dispersed they will be defeated at the rear sheet.

The volume between the bumper and rear sheets may be empty or filled with a low density foam. The use of a foam filler would further reduce the penetration effectiveness of the particle cloud that strikes the rear sheet.

Earlier reports (2,3) have treated this problem extensively and the current test series will be used to validate this approach using materials consistant with current proposed suit design.

Experimental

The material selection for the test series was 6061 T6 Aluminum of thickness and separation consistant with practical design. The light-gas-gun used was the Vertical Gun Range Test Facility at NASA-Ames Research Center. The detection apparatus at this facility was regularly sensing particles in flight down to 1/16 inch diameter (1.59 mm) so this was used as the projectile size for the test series.

An initial round was fired into a single sheet target of 1/8 inch (3.2 mm) thickness. As expected, the target was easilly penetrated with a 1/16 inch (1.59 mm) diameter projectile at around 5.5 km/sec. The hole was approximately 5 mm diameter and the front and back views of this round are shown in figure 1a-1b. For the next test rounds, the overall thickness of 1/8 inch (3.2mm) was split into two sheets of 1/16 inch (1.59 mm) each and the sheets were separated by varying distances, from 3/8 inch down to 1/8 inch (9.5 mm to 3.2 mm). The height of the intersheet separation will be termed - "h". The Total Thickness of the two sheets we'll call "TT" and the projectile diameter "d". This is because the ratios of the height to projectile diameter, h/d, and the total thickness to projectile diameter ratio, TT/d, are both important factors in determining the ballistic limit of double sheet structures.

The front bumper in all of the tests in this series was maintained at 1/16 inch and was penetrated in each case. Figure 2 show this typical bumper sheet after impact. The hole was approximately 5 mm diameter.

The first double sheet test round used a separation distance, h, of 3/8 inch (3.2 mm). This yields an h/d of 6, and a TT/d of 2. Figure 3a & 3b shows the front and back of the rear sheet after impact. The impact velocity was 5.5 km/sec. We see that the cloud of debris impacted the rear sheet over a large area, resulting in many small craters and some dimpling of the rear sheet but with no penetration. Compare this with the rear sheet from the next round, Figures 4a & 4b, which had a urethane foam filler not present in the prior round. This round was at 4.86 km/sec. Much of the slower moving debris was trapped and never reached the rear sheet and the dimpling on the back of the sheet was smaller also. The typical damage to the foam filler is seen in figures 5a & 5b which shows the front and back of the foam filler from this round.

In the next tests the sheet separation ratio was reduced to h/d =

4, with TT/d ratio maintained at 2. Figures 6a & 6b and 7a & 7b show the front and back views of these air and foam filler rounds respectively.

Successive rounds with h/d's of 3 and 2 and air filler are shown in figures 8a & 8b and 9a & 9b respectively. At an h/d of 2 (fig 9) and an impact velocity of 5.67 km/sec we still have not reached the ballistic limit of the structure. There is some spallation from the back of the rear sheet as is seen but the structure has not yet been penetrated.

Ballistic Limit Determinations

From previous studies into the penetration resistance of double sheet structures by Robert Nysmith (2,3) we mentioned earlier that the ballistic limit was a function of the sheet separation distance, h, the total thickness, TT, and their ratios with the impacting projectile diameter, d. Nysmith determined that the ballistic limit of double sheet structures depended on those ratios in the following manner:

B.L. = 0.059 X (h/d)**(2.0) X (TT/d)**(2.5)

This equation was felt to be conservative and that the exponent for the h/d ratio might be much higher. Figure 10 is reproduced from Nysmith's report (3). The exponent of 2.0 for the h/d ratio was determined for the upper straight line portions of these curves and for most of the curves this was for an h/d ratio greater than 5.

What this says is that the greater the sheet spacing, the more

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effective the structure is in defeating the projectile. To illustrate this graphically consider the drawing in figure 11. Upon impact with the bumper sheet, shock waves are set up in both the target and the projectile as a consequence of the overpressures developed. These shock waves radiate from the impact point spherically. Due to the finite thickness of the bumper sheet it is penetrated and the shattered projectile and bumper sheet material exits from the back of the bumper sheet in a conical pattern. The dashed lines in figure 11 show the intersection planes of the cone of debris with different h/d ratios. As the h/d ratio increases the cone intersects a larger diameter area of the rear sheet and the energy and momentum of the particles in the debris cone is borne by a larger area of the rear sheet. Consequently, for higher h/d ratios the ballistic limit of the structure increases. As the two sheets are brought together the ballistic limit defaults to that of a single sheet of material.

For two 1/16 inch (1.59 mm) thick sheets this defaults to 1/8 inch (3.2 mm). From earlier work on single sheet penetration we can use the Fish-Summers equation:

tp = 0.57 X pp**(0.1667) X mp**(0.352) X Vp**(0.875)

Which yields for 1/8 inch thick 6061 T6 Aluminum, a ballistic limit of 3.37 km/sec. If we separate the 1/8 inch sheet into two 1/16 inch sheets to 1/2 inch overall, an h of 3/8 inch, yielding an h/d of 6 and a TT/d of 2 for an impacting 1/16 inch diameter projectile, we can put these values into Nysmith's equation to ballistic limit of the single sheet structure. Larger separations would show even greater increases but would soon become impractical to incorporate into the suit structure.

To relate this to the situation of the space suit in orbit, let's take the proposed single sheet suit thickness of 0.070 inch (1.8 mm). If we place a single bumper sheet of say, 0.040 inch (1 mm) thickness at an overall separation of 1/2 inch (12.7 mm) and select a projectile diameter of 0.59 inch (1.5 mm) then determine the h/d and TT/d ratios we have:

$$h/d = 6.6, \quad TT/d = 1.87$$

By using Nysmith's equation we see the ballistic limit equals 12.2 km/sec for this configeration. Since this is above the nominal 10 km/sec orbital debris encounter velocity, we can be assured of defeating 1.5 mm diameter and under particles.

Although the inclusion of a foam filler between the sheets was not considered here in making these evaluations, we can see from the test series that a lightweight urethane foam filler does aid in the projectile defeat. Therefore the inclusion of a foam filler for insulation purposes could be of benefit in further increasing the Ballistic Limit over that stated above.

It is felt that the equations used here are conservative, and that the ballistic limit could even be higher than tose cited.

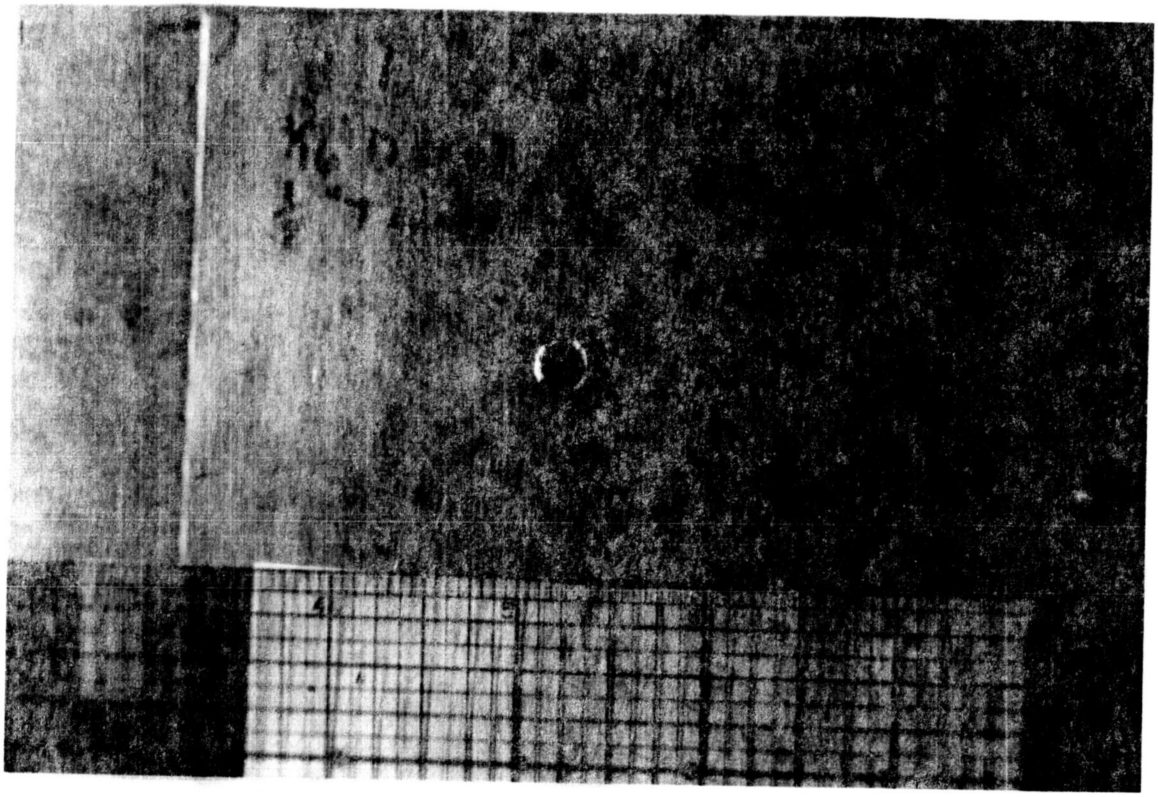
Bibliography:

1 - Ballistic Tests of Single Sheet Structures for Spacesuits
Fish, Dick, Eloret Institute, Sunnyvale, CA, Final Report, 1986

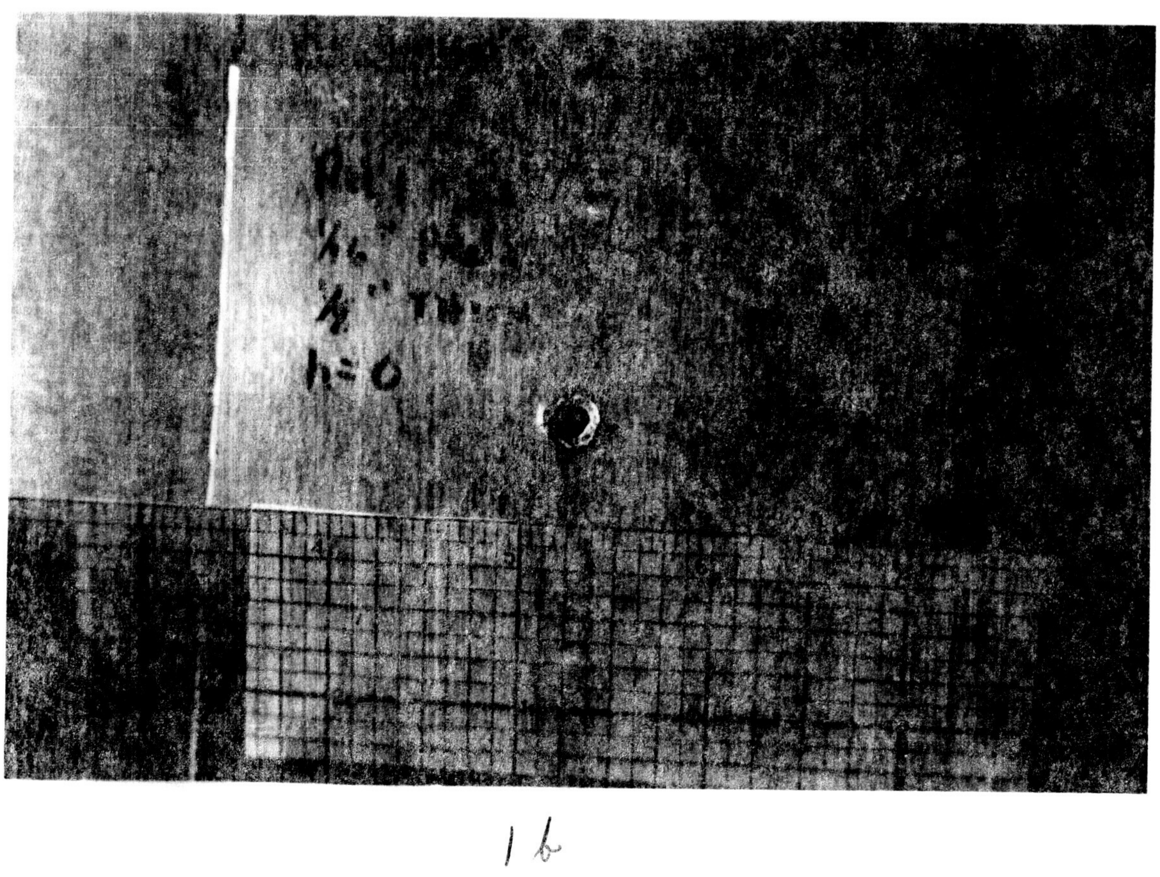
2 - Nysmith, C. Robert; and Summers, James L.: An Experimental Investigation of the Impact Resistance of Double-Sheet Structures at Velocities to 24,000 Feet Per Second. NASA TN D-1431

3 - Nysmith, C. Robert: Penetration Resistance of Double-Sheet Structures at Velocities to 8.8 km/sec. NASA TN D-4568

SINGLE SHEET IMPACT



1a



1b

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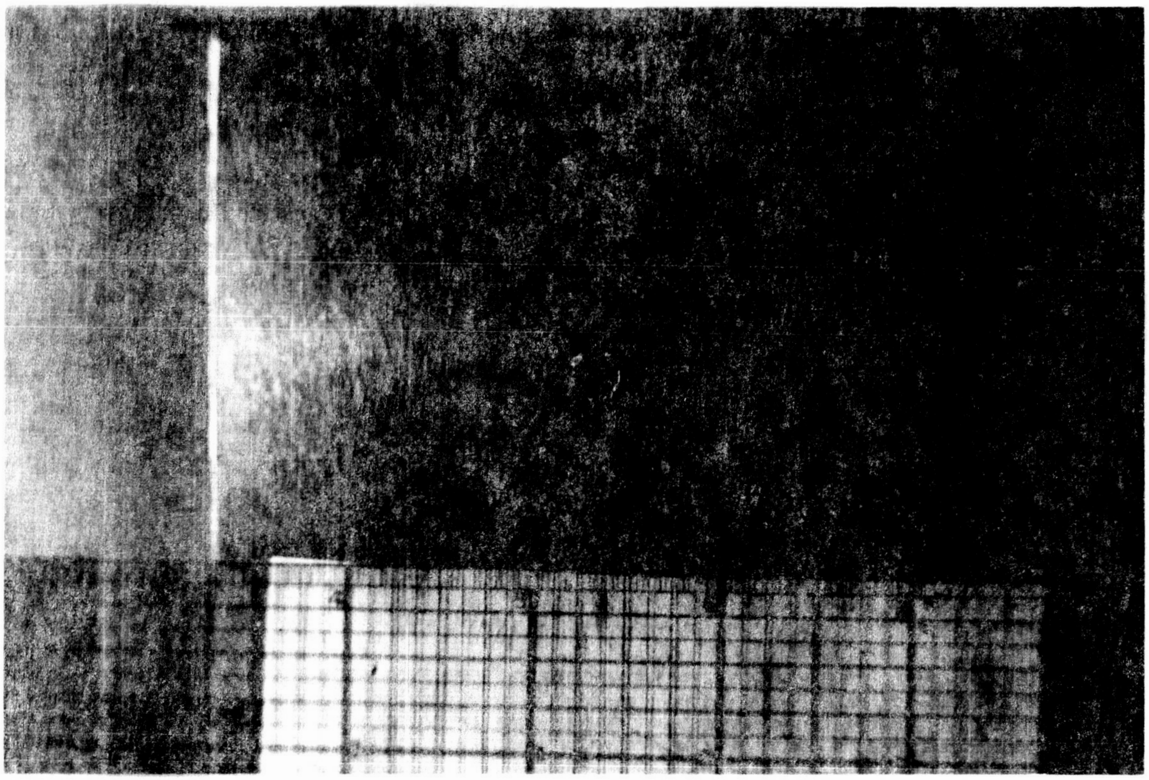
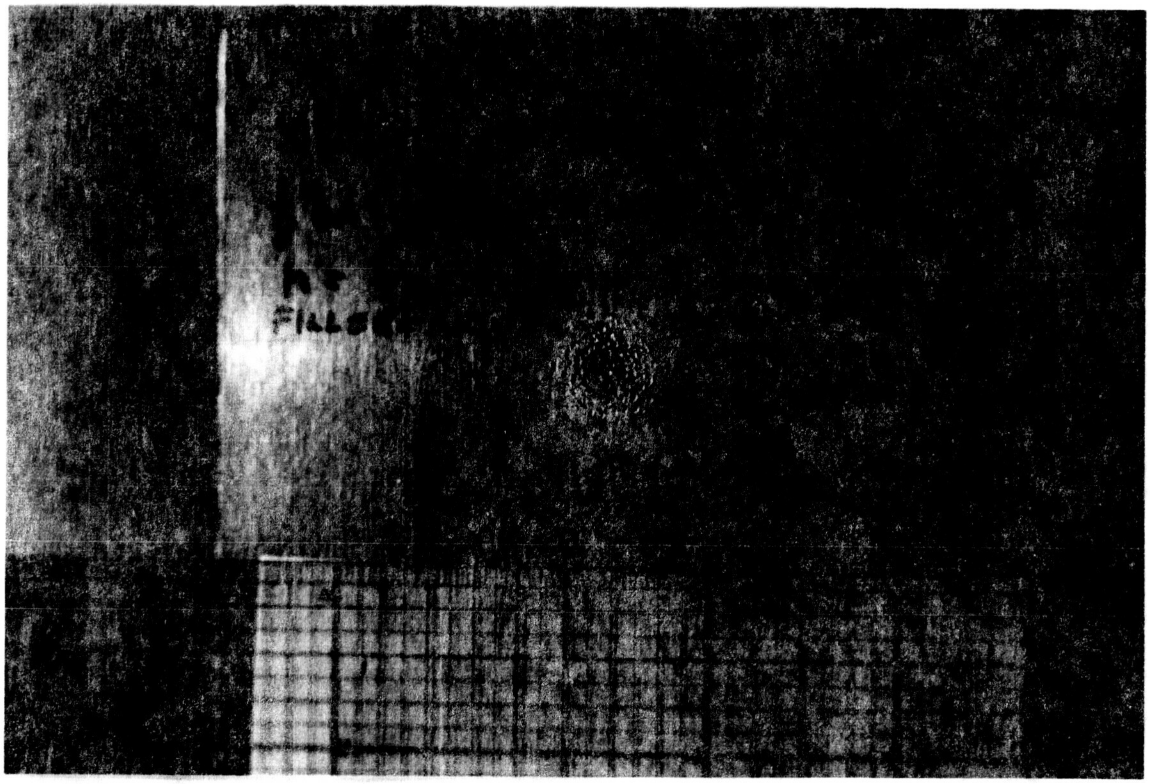
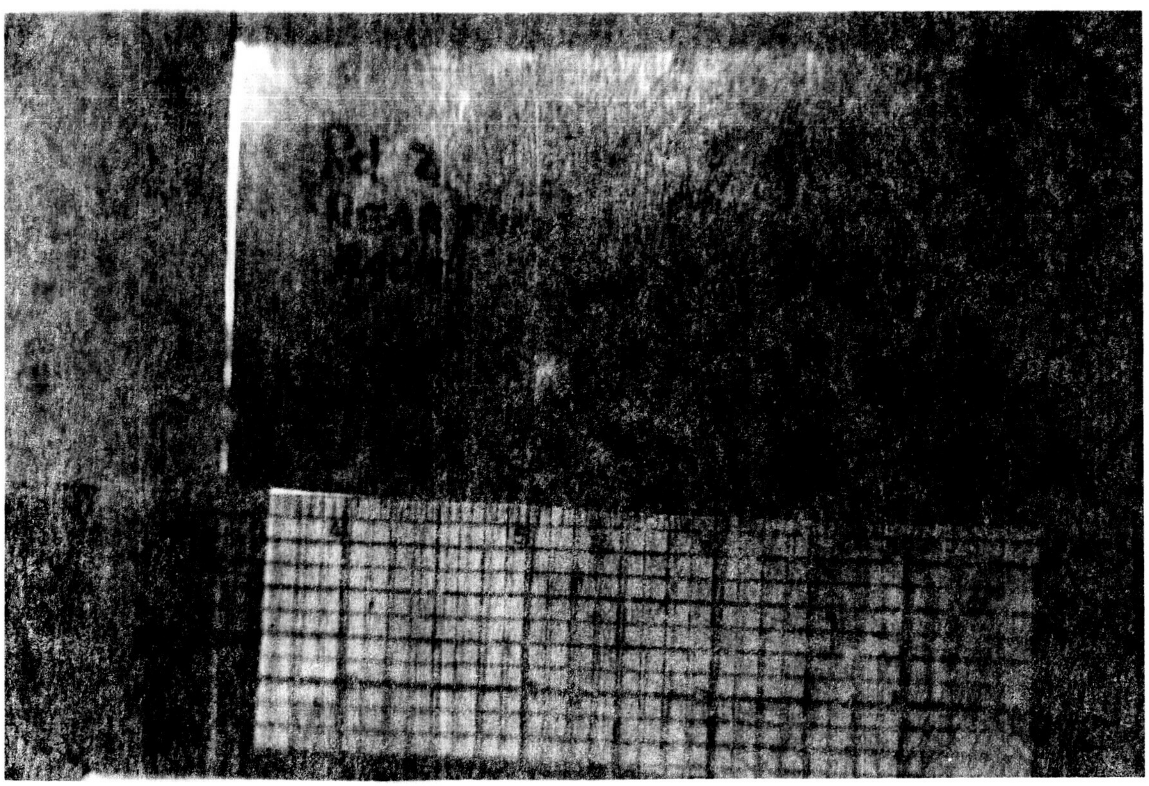


2

TYPICAL FRONT SHEET DAMAGE



3a



3b

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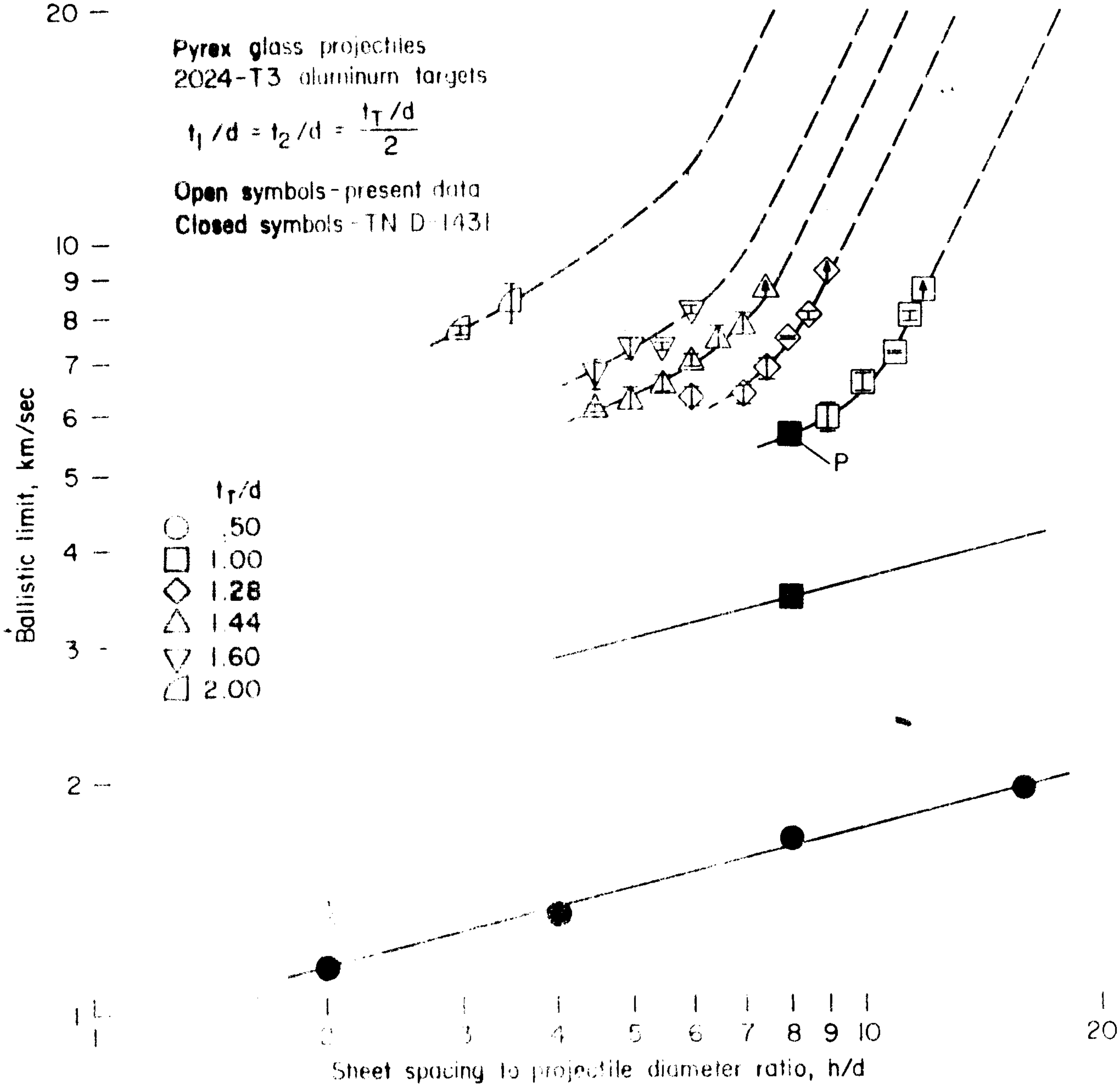

FIG. 10

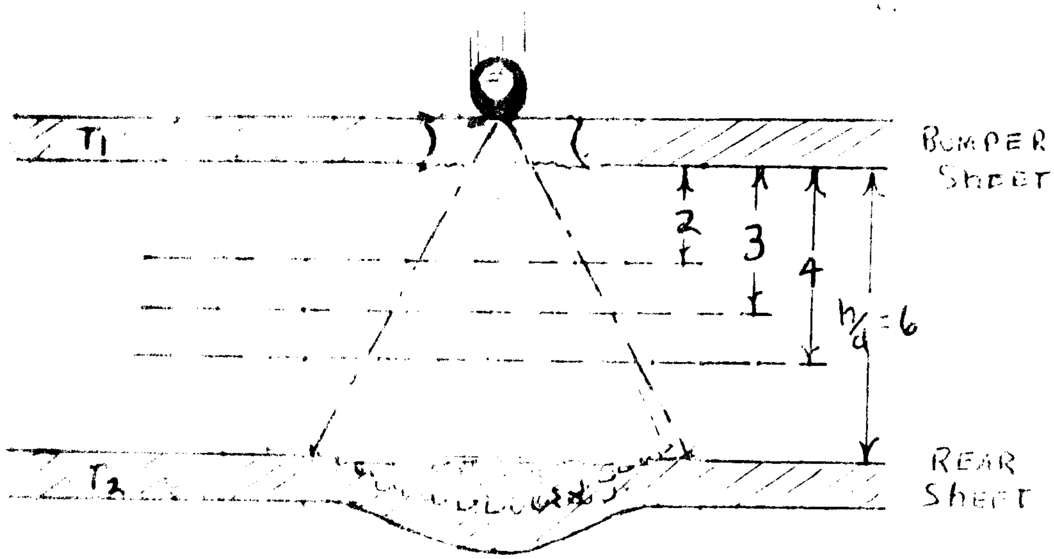

FIGURE 11

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16. Abstract

The ballistic limits of single sheet [ref.1] and double sheet structures made of 6061 T6 Aluminum of 1.8 mm and larger nominal thickness were investigated for projectiles of 1.5 mm diameter fired in the Vertical Gun Range Test Facility at NASA Ames Research Center. The hole diameters and sheet deformation behavior were studied for various ratios of sheet spacing to projectile diameter. The results indicate that for projectiles of less than 1.5 mm diameter the ballistic limit exceeds the nominal 10 km/sec orbital debris encounter velocity, if a single-sheet suit of 1.8mm thickness is behind a single bumper sheet of 1mm thickness spaced 12.5mm apart.

[1] Ballistic Tests of Single Sheet Structures for Space Suits, in "Impact Verification of Space Suit Design for Space Station," Technical Progress Report, 5/85 - 12/86, prepared by Eloret Institute for NASA Ames; NCC2-347.

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