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CONTRACT NUMBER: DA-19-020-ORD-2422

TITLE:
BALLISTIC TEST PANELS
OF
EXPERIMENTAL AND STANDARD
PERSONNEL ARMOR MATERIALS

WAL FILE NUMBER: 710/1025-3

DECEMBER 18, 1953

WORK PERFORMED UNDER
TECHNICAL SUPERVISION
OF
WATERTOWN ARSENAL LABORATORY

BOSTON ORDNANCE DISTRICT
ARMY BASE
BOSTON 10, MASSACHUSETTS

OBJECT:

To evaluate the ballistic resistance of combinations of bonded nylon with 24S-T aluminum alloy and with Hadfield-manganese steel, when attacked with various types of fragment-simulating projectiles from 0° to 60° obliquities.

AUTHORS OF REPORT:

This work was performed by S. Sahagian in the Research Laboratories of the Victory Plastics Company, under the supervision of E. E. Mooney, Director.

SUMMARY:

Combinations of bonded nylon fabric with 24S-T aluminum alloy and with Hadfield-manganese steel were evaluated ballistically with caliber 0.22 T-37 (17 grain) fragment-simulating projectiles at 0°, 30°, 45° and 60° obliquities, and with caliber 0.15 (5.85 grain) and caliber 0.30 (44 grain) fragment-simulating projectiles at 0° obliquity only.

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TITLE

BALLISTIC TEST PANELS OF EXPERIMENTAL AND STANDARD PERSONNEL ARMOR MATERIALS

OBJECT

To evaluate the ballistic resistance of combinations of bonded nylon with 24S-T aluminum alloy and with Hadfield-manganese steel, when attacked with various types of fragment-simulating projectiles from 0° to 60° obliquities.

ABSTRACT

Combinations of bonded nylon fabric with 24S-T aluminum alloy and with Hadfield-manganese steel were evaluated ballistically with caliber 0.22 T-37 (17 grain) fragment-simulating projectiles at 0°, 30°, 45° and 60° obliquities, and with caliber 0.15 (5.85 grain) and caliber 0.30 (44 grain) fragment-simulating projectiles at 0° obliquity only.

These tests indicate that:

(1) At 0° to 20° obliquity, Hadfield-manganese steel plus bonded nylon is best, but at higher obliquities, 24S-T aluminum alloy plus bonded nylon is best.

(2) With 24S-T aluminum alloy and bonded nylon,

(a) For the T-37 projectile, at obliquities from 0° to 40° the best combination is approximately 50 percent 24S-T aluminum alloy and 50 percent bonded nylon. At obliquities above 40° the best combination is approximately 75 percent 24S-T aluminum alloy and 25 percent bonded nylon (by weight).

(b) For all three projectiles at 0° obliquity, better ballistic protection is offered when the aluminum/nylon weight ratio is approximately 2, rather than the combination in which the aluminum/nylon ratio is 3.

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- (3) With Hadfield-manganese steel and bonded nylon,
- (a) The combination of hard, heavy steel plates plus light bonded nylon is best against the lightest-weight (5.85 grain) projectile, at 0° obliquity.
 - (b) The combination of soft, light steel plates plus heavier bonded nylon is best against the other projectiles at 0° obliquity.
 - (c) At higher obliquities, the above two combinations have similar ballistic protection characteristics.
- (4) Only the T-37 projectile has been tested at 0° to 60° obliquities to date. Therefore, no conclusion can yet be drawn regarding the over-all superiority of any one combination of metal and bonded nylon against all three projectile weights at obliquities from 0° to 60°.

INTRODUCTION

This interim report summarizes the activities undertaken during the period March 20, 1953 to August 31, 1953, under Contract No. DA-19-020-ORD-2422: "Ballistic Test Panels of Personnel Armor Materials," issued by the United States of America through the Boston Ordnance District to Victory Plastics Company.

During the interim, Task Order No. 1 of the subject contract, comprised of the following items, was completed:

- (1) Ballistic tests on the following armor combinations at 0°, 30°, 45° and 60° obliquities, with caliber 0.22 T-37 (17 grain) fragment-simulating projectiles:
- (a) 3-ply bonded nylon.
 - (b) 5-ply bonded nylon.
 - (c) 9-ply bonded nylon.
 - (d) 0.072 in. 24S-T aluminum alloy and 5-ply bonded nylon.
 - (e) 0.072 in. 24S-T aluminum alloy and 9-ply bonded nylon.
 - (f) 0.102 in. 24S-T aluminum alloy and 3-ply bonded nylon.
 - (g) 0.102 in. 24S-T aluminum alloy and 5-ply bonded nylon.
 - (h) 0.028 in. Hadfield-manganese steel and 3-ply bonded nylon.
 - (i) 0.028 in. Hadfield-manganese steel and 5-ply bonded nylon.
 - (j) 0.045 in. Hadfield-manganese steel and 3-ply bonded nylon.

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(2) Ballistic tests on the armor combinations listed in (1) with caliber 0.15 (5.85 grain) fragment-simulating projectiles at 0° obliquity.

(3) Ballistic tests on the armor combinations listed in (1) with caliber 0.30 (44 grain) fragment-simulating projectiles at 0° obliquity.

MATERIALS AND TEST PROCEDURE

The nylon was 2 x 2 basket weave nylon duck, weighing 14.0 oz./sq.yd. with a thread count of 46 x 40 threads per inch, manufactured by the St. George Textile Corp., New York, N. Y., and finished by the Hellwig Dyeing Corp., Philadelphia, Pa. The panels of 3, 5 and 9 plies, were laminated for 15 minutes at 340° F. and 350 psi. The layers of nylon duck were laminated with Permacel 1500 (a phenol formaldehyde-polyvinyl butyrate thermosetting resin) as the bonding medium. The completed panels consisted of approximately 9 percent resin (based on percent by weight of fabric).

Aluminum Alloy Components.

The aluminum alloy components consisted of flat panels of 24S-T aluminum alloy, approximately 12 in. x 15 in., with thicknesses of 0.072 in. and 0.102 in.

Steel Components.

The steel components consisted of flat panels of Hadfield-manganese steel, manufactured by the Sharon Steel Corporation, Sharon, Pa., approximately 12 in. x 15 in., with thicknesses of 0.029 in. ± 0.002 in. and 0.045 in. ± 0.002 in. The hardness of the 0.029 in. thick steel panels was approximately Rockwell "B" 75, and of the 0.045 in. thick steel panels approximately Rockwell "C" 46.

Test Procedure.

The test panels were rigidly supported in an adjustable fixture which could be moved up and down, from side to side, and tilted from the vertical, to accommodate obliquity tests.

When nylon-metal combinations were fired, a $\frac{1}{4}$ in. space was maintained between the metal and nylon components, with the metallic component always facing the muzzle of the gun.

Ballistic tests were conducted by firing a sufficient number of rounds of the fragment-simulating projectiles (heat-treated to a hard-

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ness range of Rockwell "C" 29-31) at each target, to determine the ballistic limits of the components. Protection ballistic limits (V_{50}) were calculated from the results of the firing tests. A complete penetration under the protection ballistic limit criterion is defined as one in which the projectile or a fragment of the armor perforates a witness plate consisting of a sheet of 24S-T aluminum alloy 0.020 in. thick, placed 6 in. behind the armor. A V_{50} ballistic limit corresponds to the velocity level at which there is a 50 percent probability that complete penetration will occur.

All velocities were measured by means of a 1.6-megacycle Potter counter chronograph interval timer, triggered by the interruptions of the circuits as the projectiles pass over the photoelectric cells. The gun to target distance was kept constant at 9 ft. 8 in. The distance from gun to first screen was 2 ft. 8 in., first screen to second screen distance was 5 ft. 0 in., and second screen to target distance was 2 ft. 0 in. The velocities thus measured are referred to as "instrument velocities" and correspond to the velocity of the projectile midway between the two screens and at a distance of 4.5 ft. from the target. However, in this report all velocities have been corrected to striking velocities (velocity at point of impact) in accordance with Watertown Arsenal Report WAL 760/325.

The velocity-drop (Δu) expressions for the three fragment-simulating projectiles used in determining the striking velocities are as follows:

CALIBER (in.)	PROJECTILE WEIGHT (grains)	Δu
0.15	5.85	$.00858 \times u_i \times Z$
0.22	17	$.00620 \times u_i \times Z$
0.30	44	$.00455 \times u_i \times Z$

where Δu = Velocity drop,
 u_i = Instrument velocity,
 and Z = Base line = 4.5 ft.

Protection (V_{50}) ballistic limits were calculated using the following equation:

$$\text{BALLISTIC LIMIT } V_{50} = \frac{S_v + (N_p - N_c) K}{N_p + N_c}$$

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where S_v = The sum of all velocities between velocities for highest partial and lowest complete penetration,

N_p = Number of rounds resulting in partial penetrations between the highest partial penetration and the lowest complete penetration,

N_c = Number of rounds resulting in complete penetrations between the lowest complete penetration and the highest partial penetration,

and K = A constant, introduced to compensate for the differences between the number of partial and number of complete penetrations. A value of K equals one-half of the difference between the highest partial penetration and the lowest complete penetration.

DATA AND DISCUSSION

A summary of the ballistic results showing the V_{50} protection ballistic limits and kinetic energies absorbed by the various armor combinations at 0° obliquity, with caliber 0.15, 0.22 and 0.30 fragment-simulating projectiles are shown in Table 1. Figures 1 through 5 show graphically some of the more pertinent data presented in Table 1.

Figure 1 shows the V_{50} ballistic limits of the Hadfield-manganese steel and nylon combinations when attacked by caliber 0.15, 0.22 and 0.30 projectiles at 0° obliquity. It can be seen that the 18.9 oz./sq.ft. steel and nylon combinations follow similar curves, e.g., the 18.9 oz./sq.ft. steel and 8.3 oz./sq.ft. nylon give higher V_{50} ballistic limits than the 18.9 oz./sq.ft. steel and 5.0 oz./sq.ft. nylon for each caliber projectile. This is to be expected, since they are of similar construction except that the latter has two less layers of nylon. However, the 29.4 oz./sq.ft. steel and 5.0 oz./sq.ft. nylon combination shows quite a deviation from the other two steel-nylon combinations. It can be seen that for the 5.85 grain projectile, approximately 400 ft./sec. more protection is offered than by the other combinations, but with the 44 grain projectile the protection offered drops to a point lower than the 18.9 oz./sq.ft. steel and 8.3 oz./sq.ft. nylon combination, although the total weight of the former is approximately 7.5 oz./sq.ft. more.

Figure 2 shows the V_{50} protection ballistic limits of the aluminum-nylon combinations when attacked by 5.85, 17 and 44 grain fragment-

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simulating projectiles at 0° obliquity. It can be seen from these curves that the 16.4 oz./sq.ft. aluminum and 15.3 oz./sq.ft. nylon (total weight: 31.7 oz./sq.ft.) combination offers approximately 80 ft./sec. more protection than the 23.7 oz./sq.ft. aluminum and 8.3 oz./sq.ft. nylon combination (total weight: 32.0 oz./sq.ft.), although both combinations have approximately the same total weight. Furthermore, the 16.6 oz./sq.ft. aluminum and 8.3 oz./sq.ft. nylon (total weight: 24.9 oz./sq.ft.) offers approximately the same protection as the 23.5 oz./sq.ft. aluminum and 5.0 oz./sq.ft. nylon combination (total weight: 28.5 oz./sq.ft.) although the former weighs approximately 3.5 oz./sq.ft. less than the latter.

A comparison is made in Figure 3 between aluminum-nylon and steel-nylon combinations having approximately the same total weights. The 18.9 oz./sq.ft. steel and 8.3 oz./sq.ft. nylon combination (total weight: 27.2 oz./sq.ft.) gave V_{50} protection ballistic limits approximately 150 ft./sec. higher than the 23.5 oz./sq.ft. aluminum and 5.0 oz./sq.ft. nylon combination (total weight: 28.5 oz./sq.ft.) for all three weights of projectiles. The combination of 18.9 oz./sq.ft. steel with 5.0 oz./sq.ft. nylon (total weight: 23.9 oz./sq.ft.) gave V_{50} protection ballistic limits approximately 75 ft./sec. higher than the combination of 16.6 oz./sq.ft. aluminum with 8.3 oz./sq.ft. nylon (total weight: 24.9 oz./sq.ft.) with the 5.85 and 44 grain projectiles, but offered comparable protection with the 17 grain projectile.

In Figure 4 a comparison is made between steel-nylon and aluminum-nylon combinations having total weights of approximately 32-35 oz./sq.ft. It can be seen that with the 5.85 grain projectile, the combination of 29.4 oz./sq.ft. steel with 5.0 oz./sq.ft. nylon offers superior protection. However, with the 44 grain projectile, the combination of 16.4 oz./sq.ft. aluminum with 15.3 oz./sq.ft. nylon offers the best protection. The combination of 23.7 oz./sq.ft. aluminum with 8.3 oz./sq.ft. nylon is inferior for all three weights of projectiles.

In order to obtain a better comparison of the armor combinations, the kinetic energy absorbed per unit weight of the armor combination versus the weight of projectile is plotted in Figure 5. By employing this method, differences in weights of the panels are eliminated, and direct comparison of the merits of each armor combination may be made. It should be noted at this point that the kinetic energy absorbed per unit panel weight tends to increase as the panel weight approaches zero; therefore a direct comparison cannot be fairly made between lighter weight and heavier weight panels. However, for the weight range of 20 to 40 oz./sq.ft., tests on identical constructions but different weights have shown that direct comparisons of the relative merits can be made. It is in the weight range below 10 to 15 oz./sq.ft. that comparisons between different weights are doubtful because the kinetic energy absorbed per unit panel weight tends to increase as the weight decreases. As shown in Figure 5 for the caliber 0.15 (5.85

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grain) fragment-simulating projectiles, the combination of 29.4 oz./sq.ft. steel with 5.0 oz./sq.ft. nylon is superior; for the caliber 0.22 T-37 (17 grain) and caliber 0.30 (44 grain) fragment-simulating projectiles, the 18.9 oz./sq.ft. steel with 8.3 oz./sq.ft. nylon combination offers superior protection.

A summary of the ballistic results showing the V_{50} protection ballistic limits, highest velocities resulting in partial penetrations, and lowest velocities resulting in complete penetrations of the various armor combinations with caliber 0.15 (5.85 grain) and caliber 0.30 (44 grain) fragment-simulating projectiles at 0° obliquity, and caliber 0.22 (17 grain) fragment-simulating projectiles at 0° , 30° , 45° and 60° obliquities are presented in Tables 2, 3 and 4, respectively.

Figures 6 through 12 show in graphical form some of the more pertinent data listed in Table 4.

Figure 6 shows the V_{50} protection ballistic limits of 3, 5 and 9 ply bonded nylon test panels at various obliquities.

Figure 7 shows the V_{50} protection ballistic limits of a few combinations of steel-nylon and aluminum-nylon test panels. It can be seen from these curves that 18.3 oz./sq.ft. steel with 5.0 oz./sq.ft. nylon (total weight: 23.3 oz./sq.ft.) when compared to 16.6 oz./sq.ft. aluminum with 8.2 oz./sq.ft. nylon (total weight: 24.8 oz./sq.ft.) gave comparable results at 0° obliquity, but markedly inferior results at higher obliquities. The 16.6 oz./sq.ft. aluminum with 8.2 oz./sq.ft. nylon (total weight: 24.8 oz./sq.ft.) when compared to 18.3 oz./sq.ft. steel with 8.4 oz./sq.ft. nylon (total weight: 26.7 oz./sq.ft.) showed comparable results at 30° , 45° and 60° obliquities, but inferior results at 0° obliquity.

Figure 8 shows combinations of 23.4 oz./sq.ft. aluminum with 4.9 oz./sq.ft. nylon (total weight: 28.3 oz./sq.ft.) and 18.3 oz./sq.ft. steel with 8.4 oz./sq.ft. nylon (total weight: 26.7 oz./sq.ft.) at various obliquities. From 0° to approximately 20° obliquity the steel plus bonded nylon is better than aluminum alloy plus bonded nylon, but above 20° obliquity the aluminum alloy plus bonded nylon is markedly superior.

Figure 9 shows a comparison of aluminum-nylon and steel-nylon panels having a weight range of approximately 32-35 oz./sq.ft. at various obliquities with caliber 0.22 (17 grain) fragment-simulating projectiles. It can be seen that the combination of 29.4 oz./sq.ft. steel with 5.0 oz./sq.ft. nylon (total weight: 34.4 oz./sq.ft.) offered superior ballistic protection at 0° , 30° and 45° obliquities, but at 60° obliquity the combination of 23.6 oz./sq.ft. aluminum with 8.4 oz./sq.ft. nylon (total weight: 32.0 oz./sq.ft.) offered the best ballistic protection.

Figures 10 and 11 show the V_{50} protection ballistic limits versus obliquities of aluminum-nylon and steel-nylon panels, respectively. It can be seen for the aluminum-nylon combinations, that in the obliquity range from 0° to approximately 40° , the combination 16.5

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oz./sq.ft. aluminum with 15.4 oz./sq.ft. nylon (total weight: 31.9 oz./sq.ft.) offers superior ballistic protection. At obliquities above approximately 40°, the combination of 23.6 oz./sq.ft. aluminum with 8.4 oz./sq.ft. nylon (total weight: 32.0 oz./sq.ft.) offers better ballistic protection. For the steel-nylon panels the combination 29.4 oz./sq.ft. steel with 5.0 oz./sq.ft. nylon offered superior ballistic protection from 0° to 60° obliquity.

It should be noted that these armor combinations do not have the same total weights. In order to obtain a better comparison of the merits of all armor combinations at various obliquities, the merit factor

$$\left[\frac{(BL V_{50})^2}{\text{PANEL WEIGHT (oz./sq.ft.)}} \right]$$

was plotted versus the obliquity. Here again it should be noted as in the case of the kinetic energies, that direct comparison of the merit factors may be made for the weight ranges of 20 to 40 oz./sq.ft. Below the weight range of 10 to 15 oz./sq.ft. the comparisons are doubtful because the merit factor tends to increase as the weight decreases. As shown in Figure 12, the combination of 23.4 oz./sq.ft. aluminum with 4.9 oz./sq.ft. nylon offers superior ballistic protection at 45° and 60° obliquities, but inferior protection at 0° and 30° obliquities. At 0° obliquity, Hadfield-manganese steel weighing 13.3 oz./sq.ft. in combination with bonded nylon offered superior ballistic protection; however, at higher obliquities inferior protection is offered.

CONCLUSIONS

(1) Ballistic tests at 0° obliquity should not be used as the sole basis for evaluation or selection of personnel armor materials. In some cases, combinations of armor materials which are best ballistically at 0° obliquity are markedly inferior at higher obliquities. Against the caliber 0.22 T-37 (17 grain) projectile, Figure 8 indicates that steel plus bonded nylon is better than aluminum alloy plus bonded nylon in the obliquity range of 0° to approximately 20°, and the aluminum alloy plus bonded nylon combination is considerably superior at higher obliquities.

(2) In the obliquity range from 0° to approximately 40°, superior performance results when the aluminum alloy and bonded nylon, each comprising 50 percent by weight of the total armor is attacked by the caliber 0.22 T-37 (17 grain) projectile. At obliquities above approximately 40°, better performance is obtained when the weight is divided 75 percent aluminum alloy and 25 percent bonded nylon (see the upper curves of Figure 10). On an over-all basis, there is little to be gained from one choice over the other.

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(3) Against missiles of various weights at 0° obliquity, aluminum alloy comprising over 75 percent by weight and very light bonded nylon weighing less than 25 percent of the total panel offers ballistic protection inferior to a similar construction in which the weights are distributed approximately 67 percent aluminum alloy and 33 percent bonded nylon. The lower two curves in Figure 2 show nearly equal ballistic protection offered by two such constructions; however, the combination of 67 percent aluminum alloy and 33 percent bonded nylon weighs approximately 3.5 oz./sq.ft. less than the combination of 75 percent aluminum alloy and 25 percent bonded nylon.

(4) A conclusion regarding superiority of a given panel combination should not be based on a limited number of test conditions (projectile caliber, obliquity or armor). Figures 1 to 4 illustrate that at 0° obliquity, many personnel armor combinations that are superior against small missiles weighing 5.85 grains, may prove inferior against heavier (44 grain) missiles.

(5) Where armor combinations of Hadfield-manganese steel and bonded nylon are involved, the heavier Hadfield-manganese steel (29.4 oz./sq.ft.) plus very light bonded nylon (5.0 oz./sq.ft.) having a total weight of 34.4 oz./sq.ft., offers superior ballistic protection against light-weight (5.85 grain) missiles, but inferior protection against heavier (44 grain) missiles at 0° obliquity (see Figure 5). The lighter Hadfield-manganese steel (18.9 oz./sq.ft.) plus bonded nylon (8.3 oz./sq.ft.) having a total weight of 27.2 oz./sq.ft. offers excellent over-all ballistic protection against 5.85, 17 and 44 grain missiles at 0° obliquity (see Figure 5), but shows markedly inferior protection relative to the aluminum-nylon combinations at higher obliquities when attacked by caliber 0.22 T-37 (17 grain) projectiles (see Figure 12).

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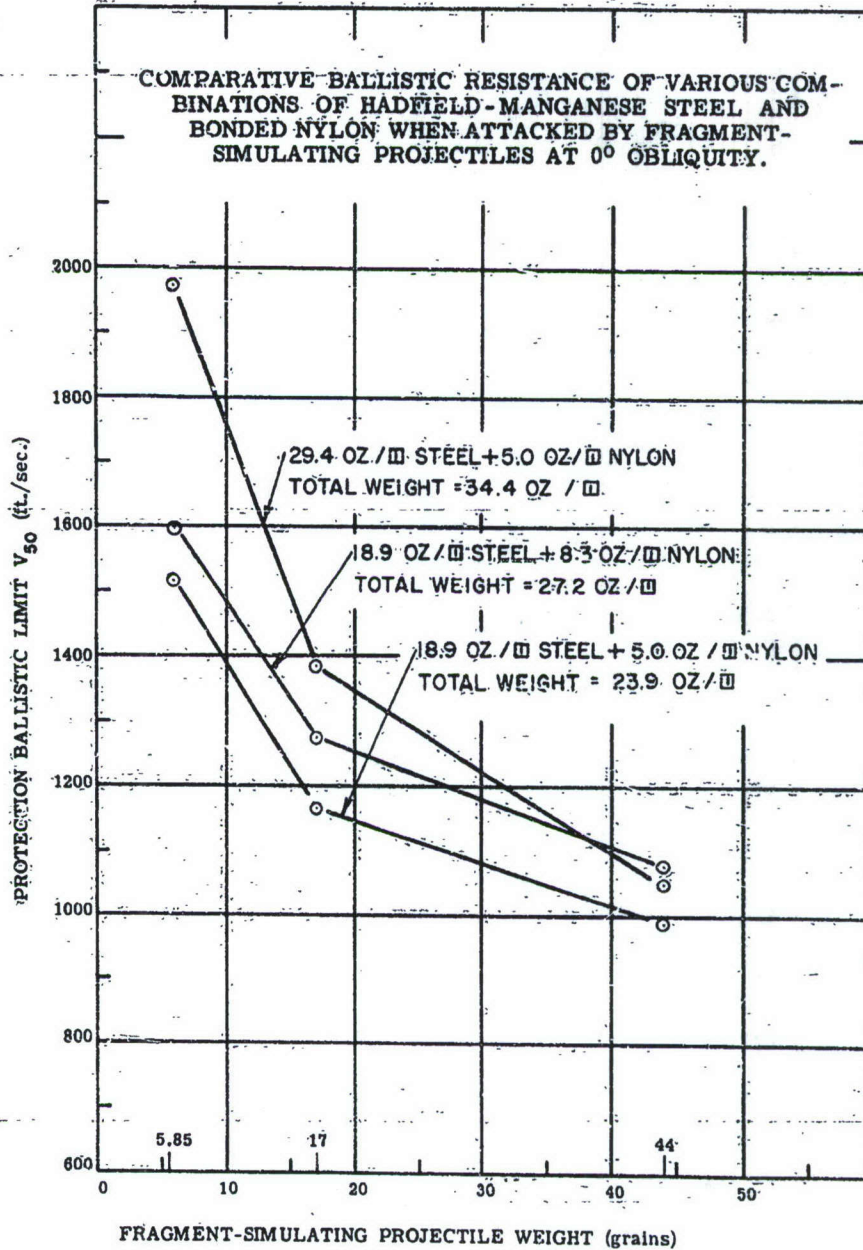


FIGURE 1.

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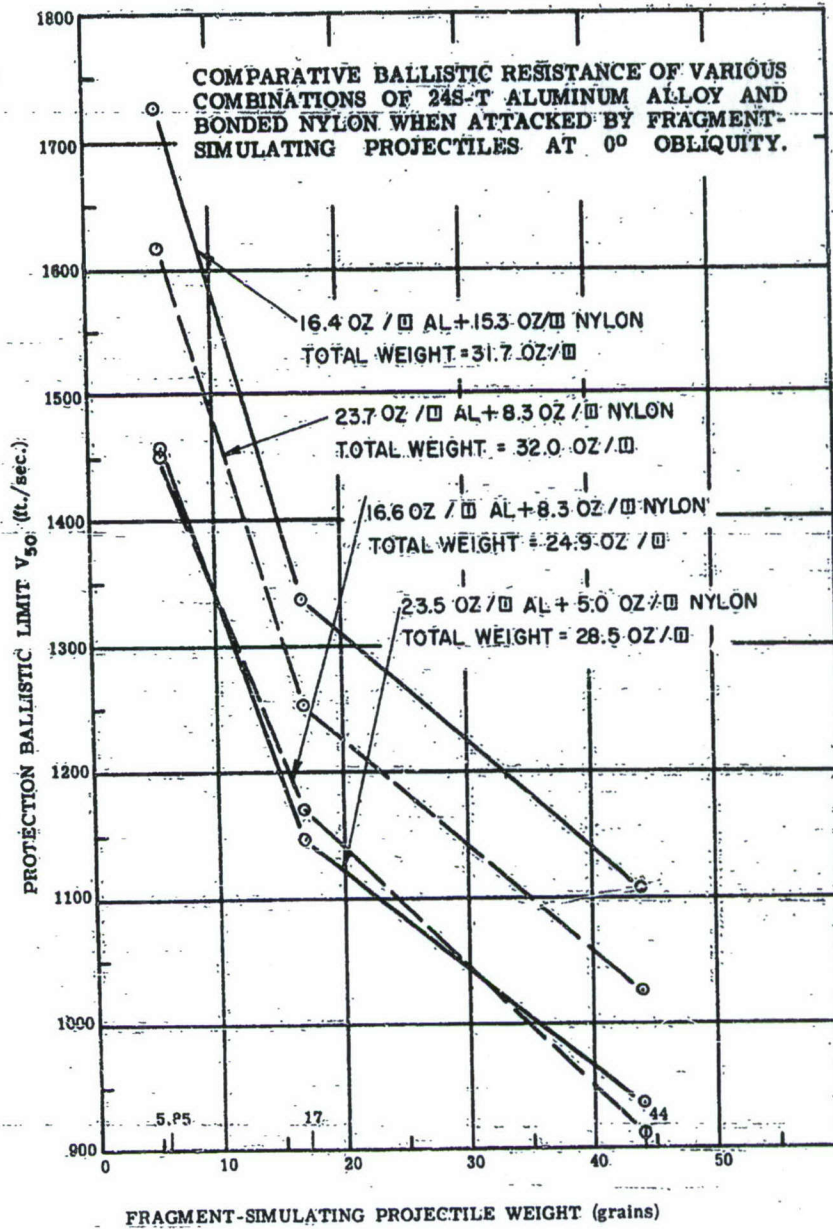


FIGURE 2.

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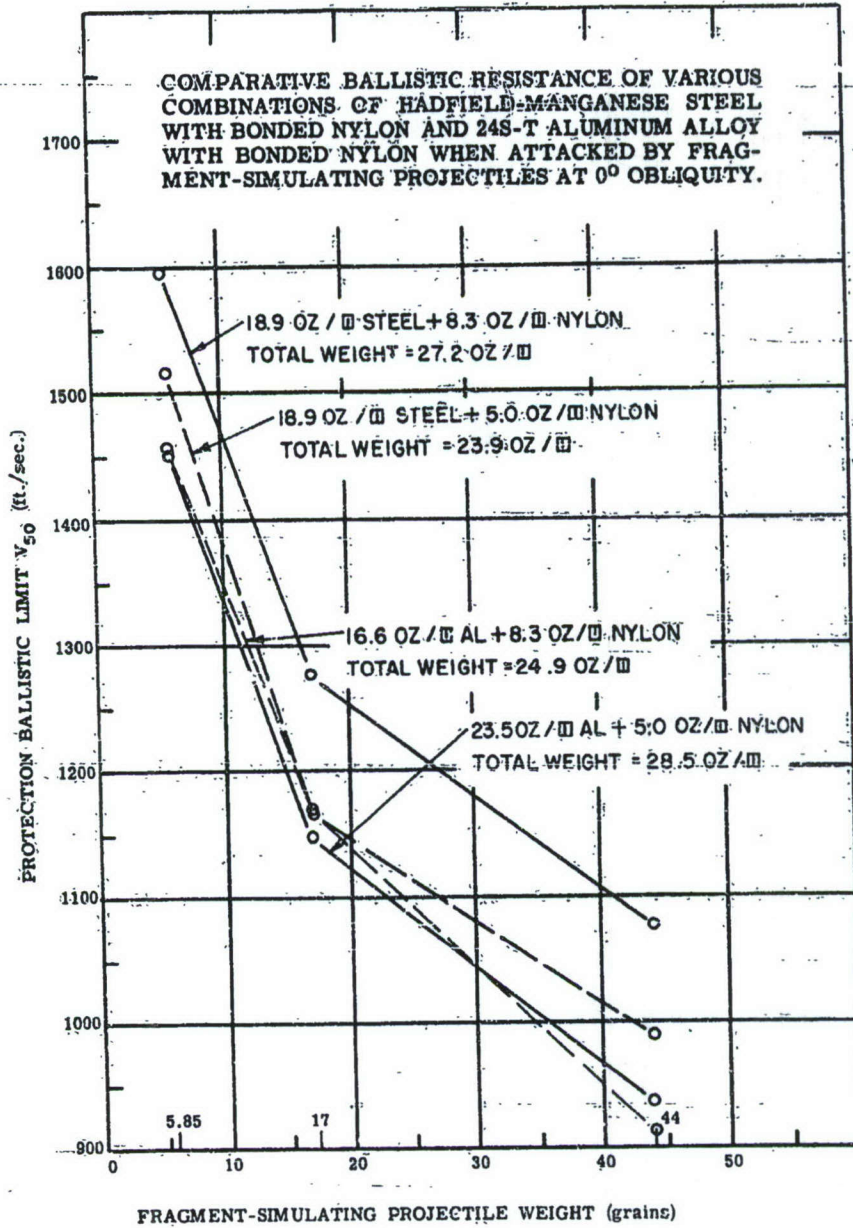


FIGURE 3.

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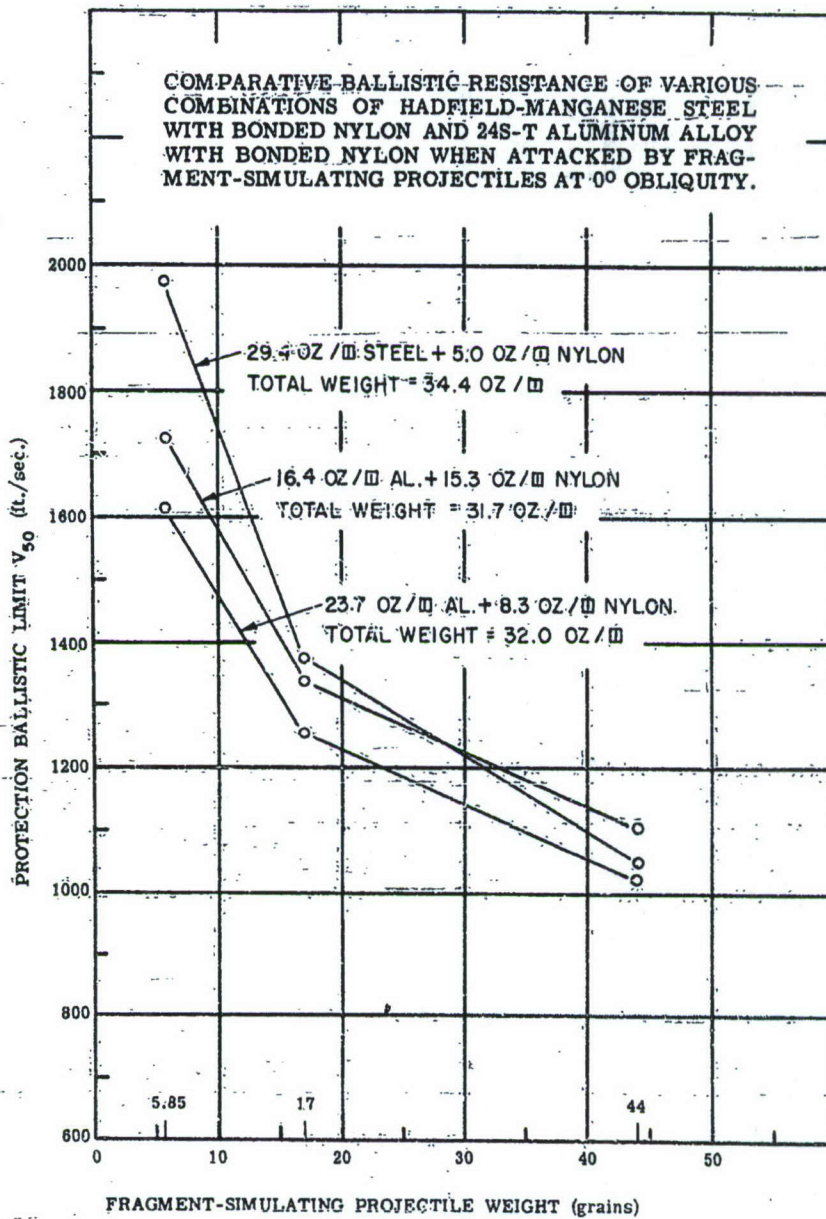


FIGURE 4.

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KINETIC ENERGY ABSORBED BY COMBINATIONS OF HADFIELD-MANGANESE STEEL WITH BONDED NYLON AND 24S-T ALUMINUM ALLOY WITH BONDED NYLON WHEN ATTACKED BY FRAGMENT-SIMULATING PROJECTILES AT 0° OBLIQUITY.

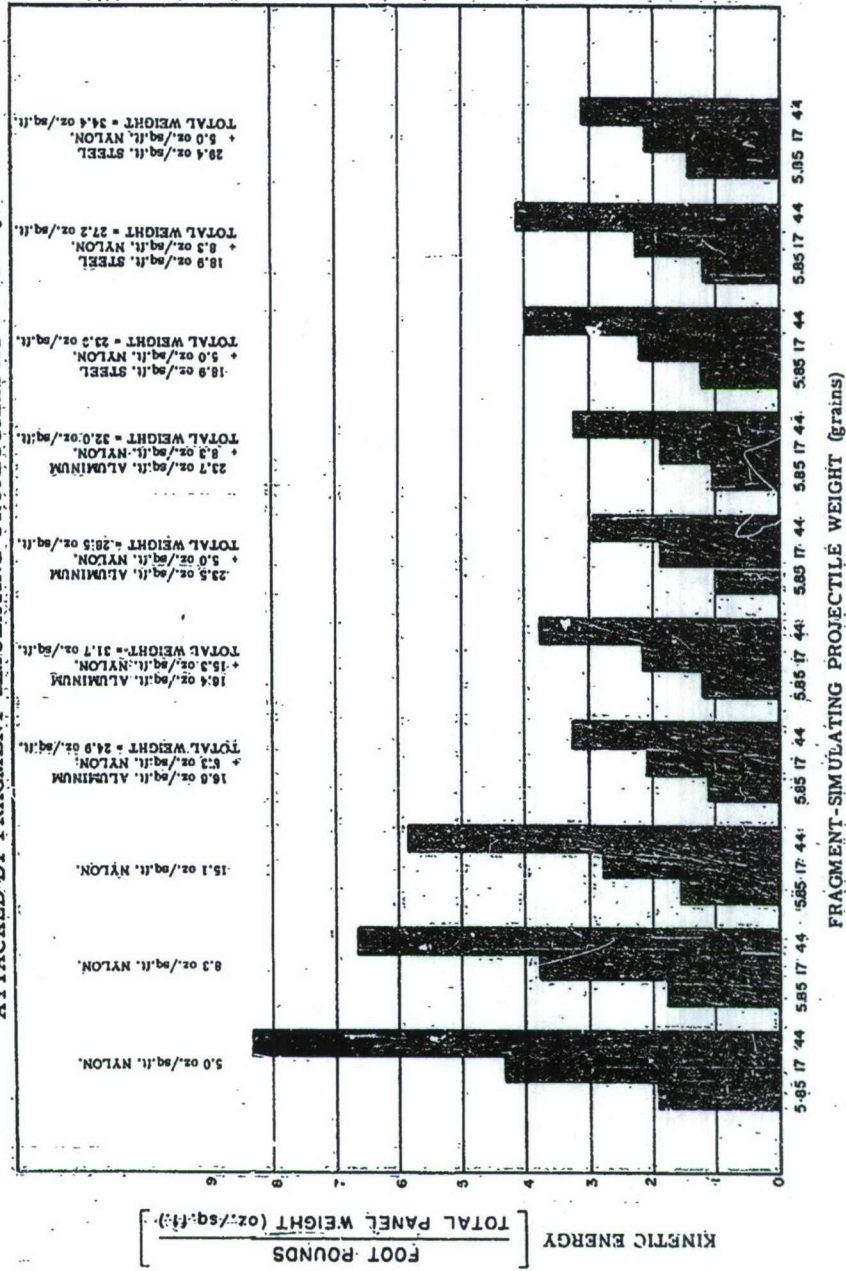


FIGURE 5.

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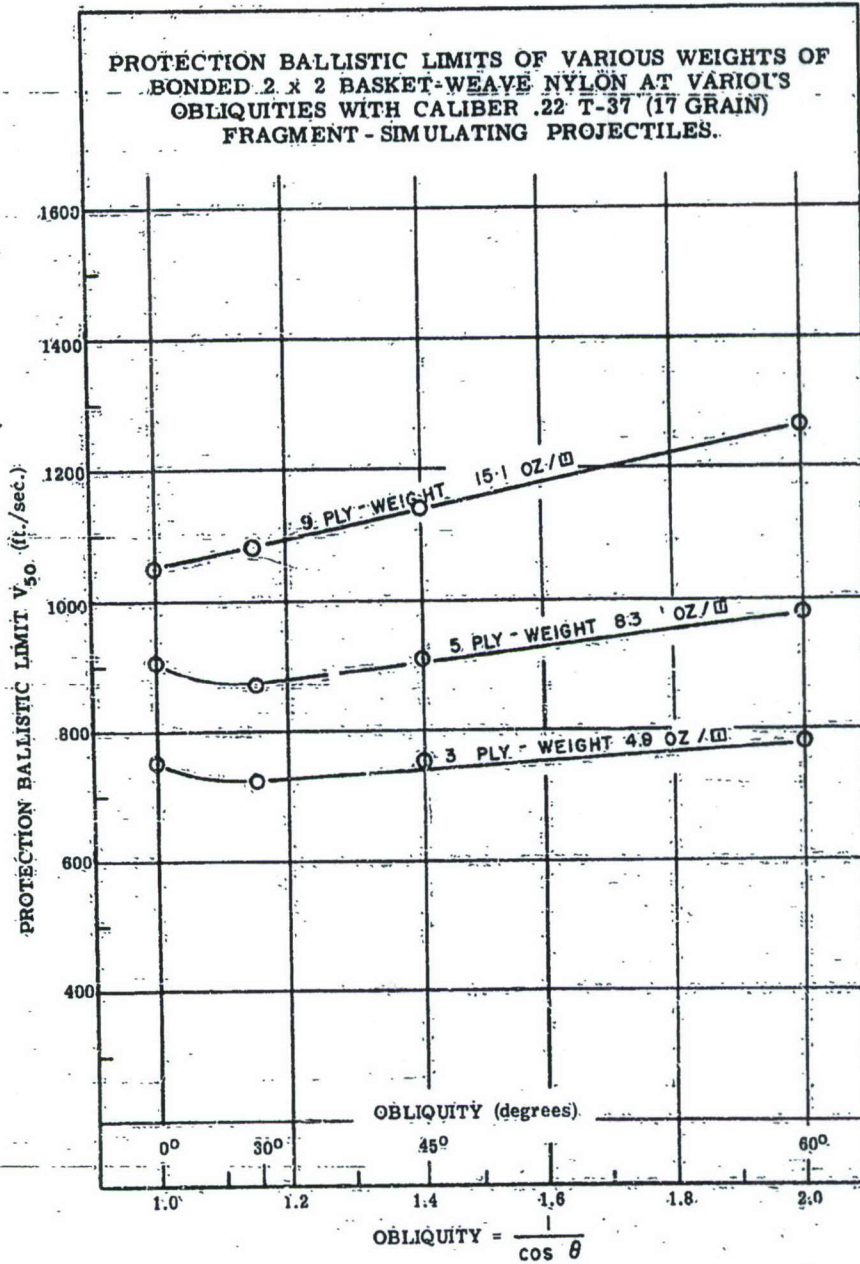


FIGURE 6.

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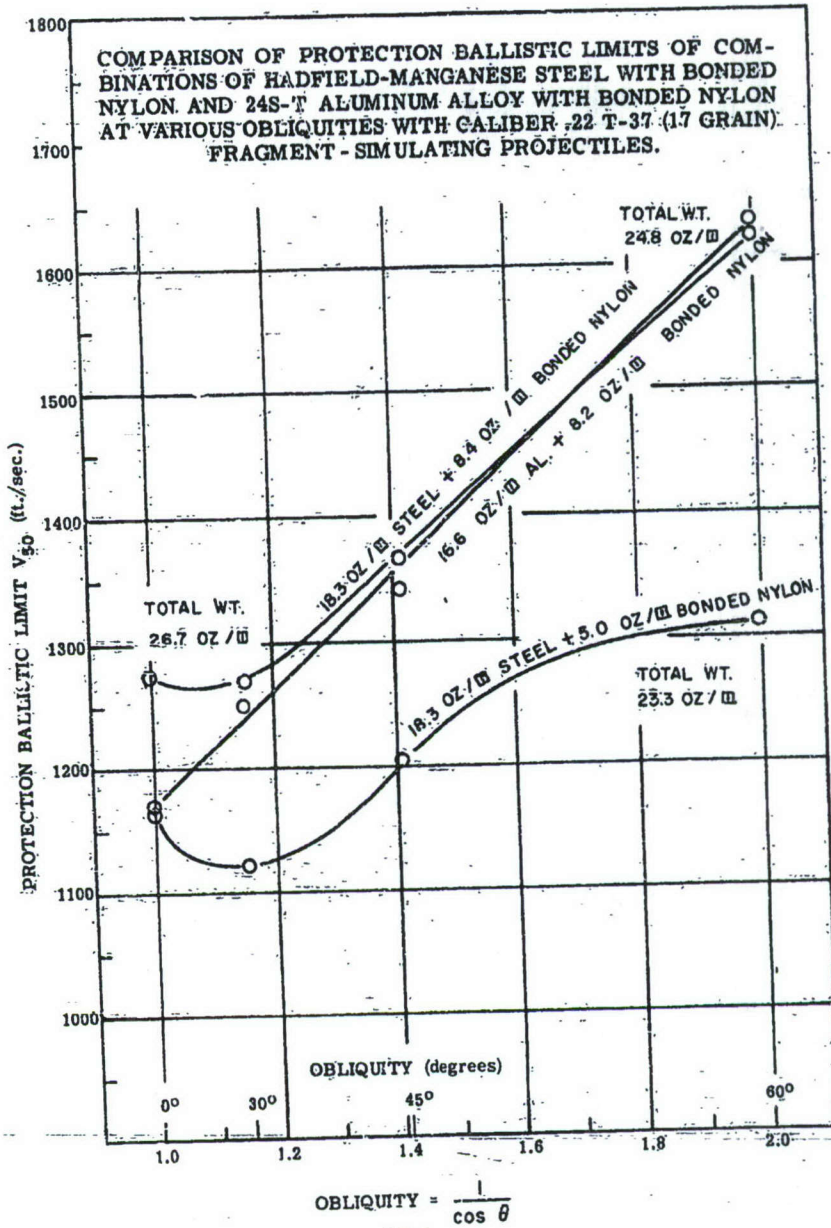


FIGURE 7.

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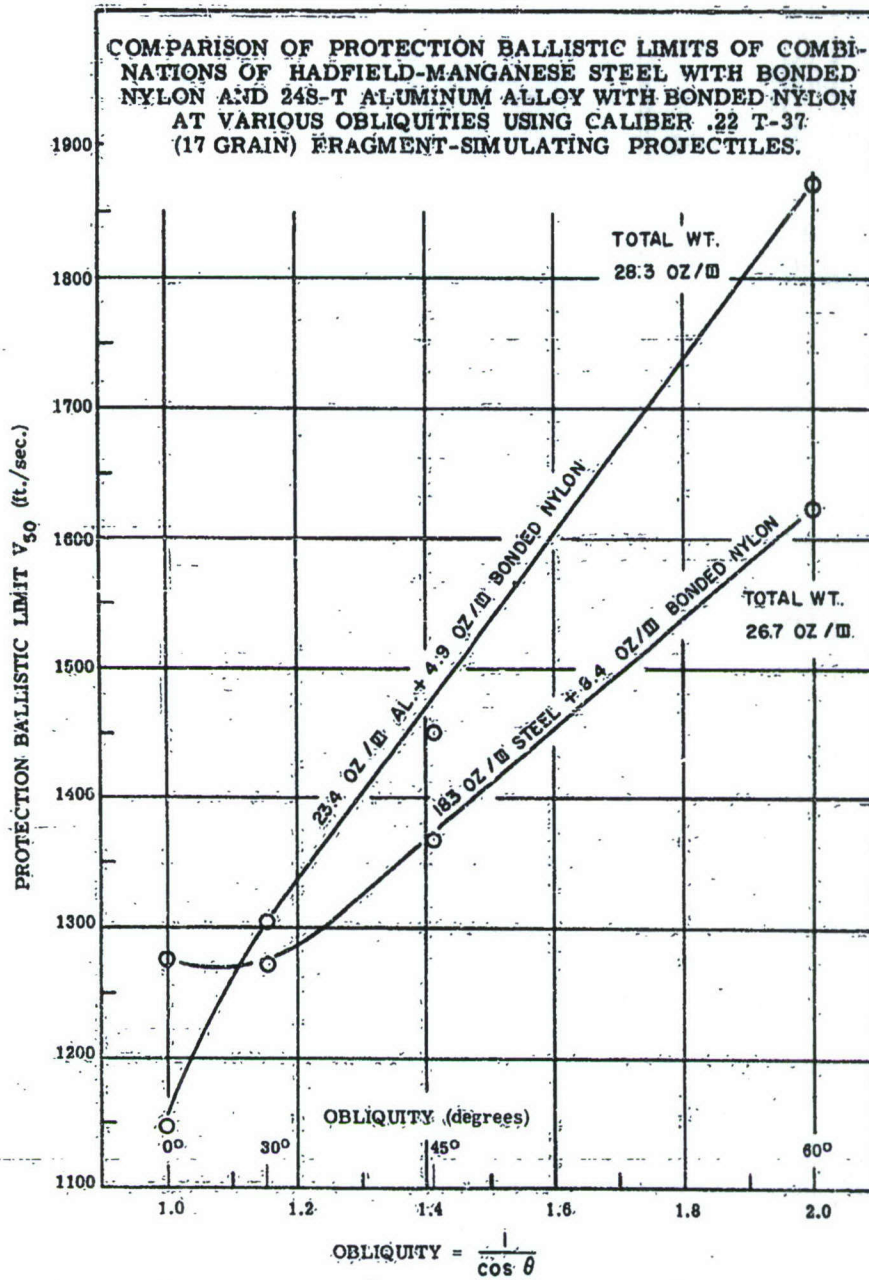


FIGURE 8.

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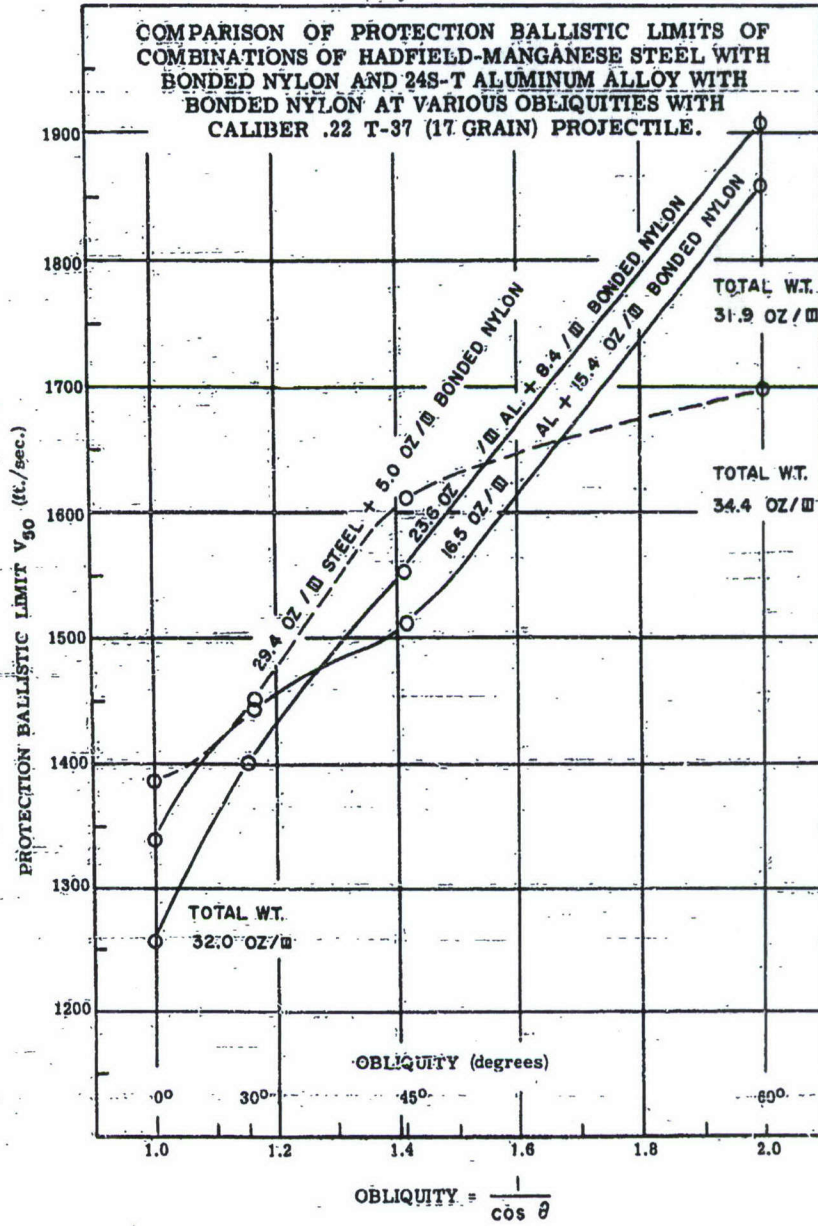


FIGURE 9.

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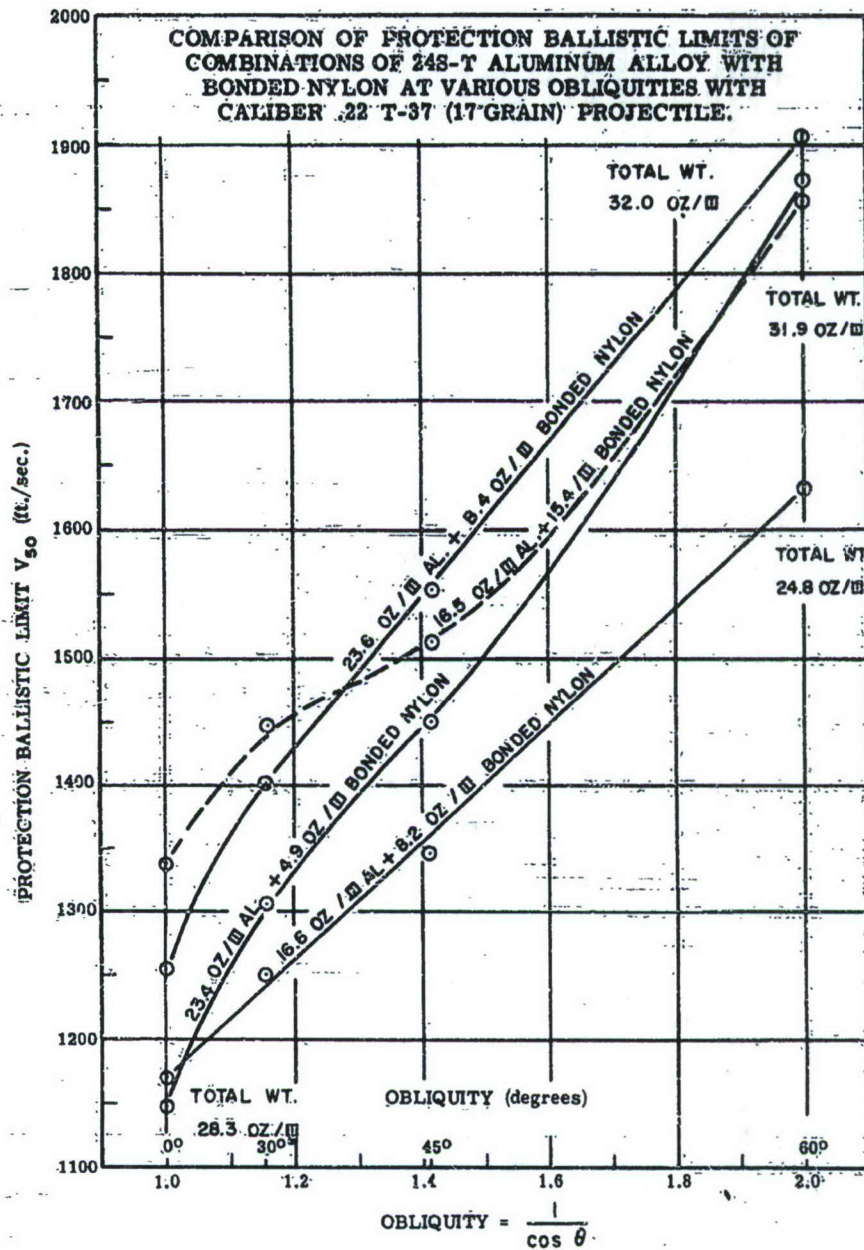


FIGURE 10.

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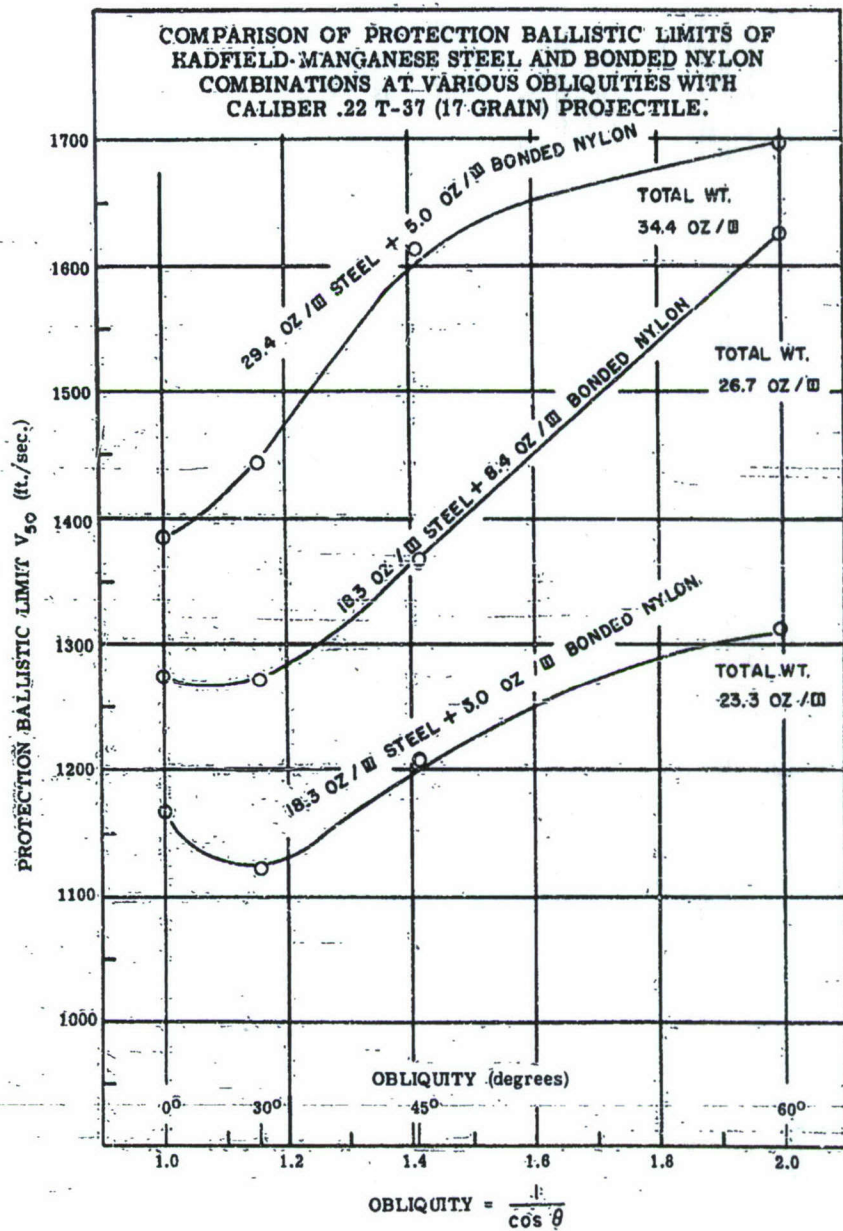


FIGURE 11.

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MERIT FACTOR OF COMBINATIONS OF HADFIELD-MANGANESE STEEL WITH BONDED NYLON AND 24S-T ALUMINUM ALLOY WITH BONDED NYLON AT VARIOUS OBLIQUITIES WITH CALIBER .22 T-37 (17 GRAIN) FRAGMENT-SIMULATING PROJECTILES.

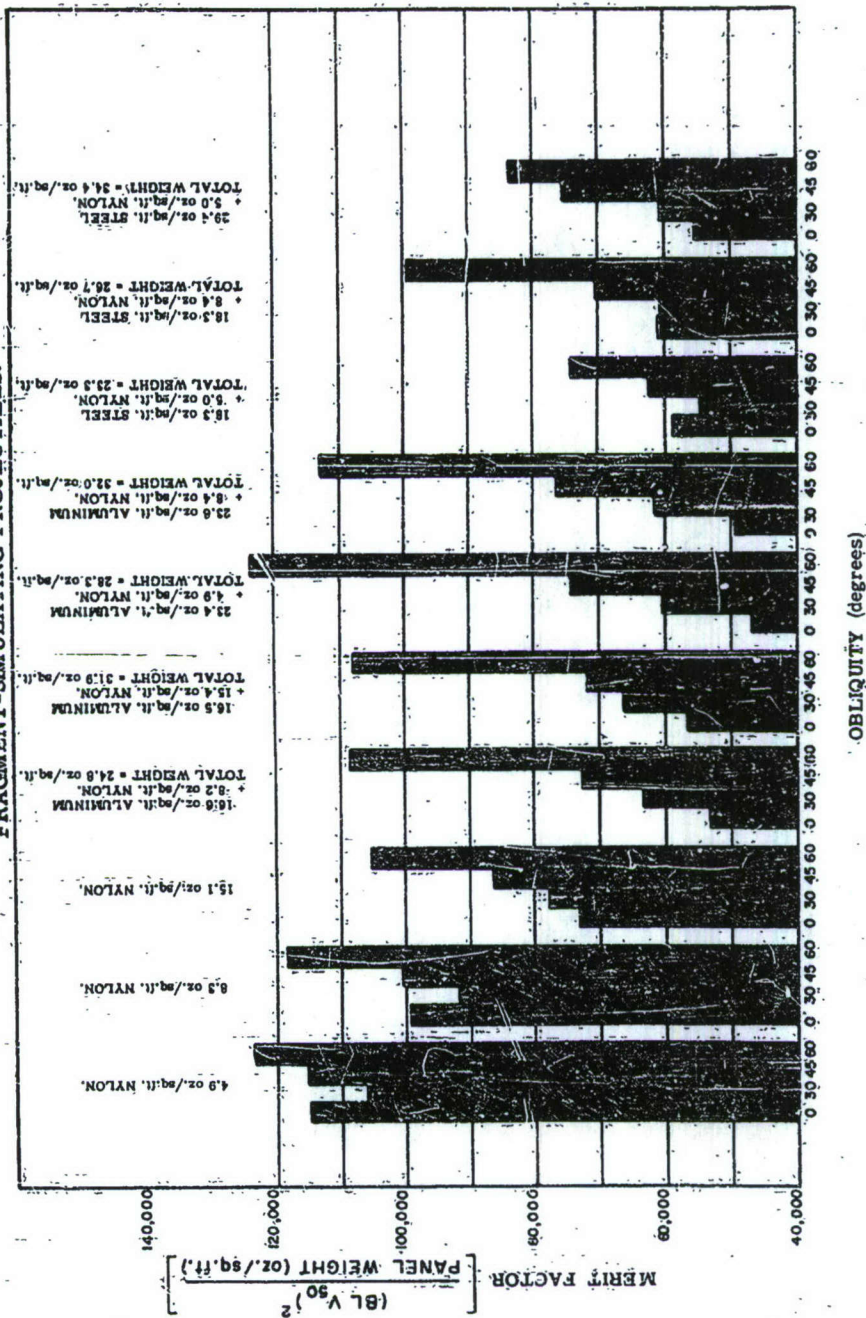


FIGURE 12.

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TABLE 1.

COMPARISON OF THE BALLISTIC RESISTANCES OF VARIOUS COMBINATIONS OF HADFIELD-MANGANESE STEEL WITH BONDED NYLON AND 24S-T ALUMINUM ALLOY WITH BONDED NYLON WHEN ATTACKED BY CALIBER 0.15, 0.22, AND 0.30 FRAGMENT-SIMULATING PROJECTILES AT 0° OBLIQUITY.

METALLIC COMPONENT	NUMBER OF PLYS OF NYLON	PANEL NUMBER	AVERAGE PANEL THICKNESS (In.)		PANEL WEIGHT (oz./sq.ft.)		TOTAL COMBINED WEIGHT (oz./sq.ft.)	PROTECTION BALLISTIC LIMITS V_{50} (ft./sec.) FOR			KINETIC ENERGY FOOT POUNDS			
			METAL	NYLON	METAL	NYLON		CAL .15 5.85 GRAIN	CAL .22 17 GRAIN	CAL .30 44 GRAIN	TOTAL PANEL WEIGHT (oz./sq.ft.)			
											CAL .15	CAL .22	CAL .30	
NONE	3	1544		0.087		5.0	5.0	860				1.912 *		
	3	1439		0.089		4.9	4.9		750				4.32 *	
	3	1590		0.087		5.0	5.0			655				8.36 *
	5	1545		0.112		8.3	8.3	1065				1.770 *		
	5	1440		0.113		8.3	8.3		907				3.73 *	
	5	1598		0.113		8.3	8.3			754				6.88 *
	9	1546		0.197		15.4	15.4	1363				1.565 *		
	9	1441		0.198		15.1	15.1		1050				2.75 *	
	9	1597		0.197		15.0	15.0			950				5.87 *
	5	1547		0.072	0.112	16.6	8.3	24.9	1451				1.095	
24S-T ALUMINUM ALLOY	5	1454		0.072	0.113	16.6	8.3	24.9		1170			2.07	
	5	1803		0.072	0.112	16.6	8.3	24.9			911			3.25
	9	1548		0.072	0.197	16.6	15.2	31.3	1727			1.215		
	9	1533		0.071	0.198	16.4	15.3	31.7		1338			2.13	
	9	1804		0.071	0.197	16.4	15.0	31.4			1106			3.79
	3	1550		0.102	0.087	23.5	5.0	28.5	1458			0.965		
	3	1458		0.100	0.087	23.1	5.0	28.1		1148			1.770	
	3	1805		0.103	0.087	23.7	5.0	28.7			936			2.97
	5	1585		0.103	0.112	23.7	8.3	32.0	1619			1.062		
	5	1503		0.103	0.113	23.7	8.4	32.1		1254			1.850	
5	1806		0.102	0.112	23.5	8.3	31.8			1025			3.25	
HADFIELD-MANGANESE STEEL	3	1589		0.029	0.067	18.9	5.0	23.9	1516			1.245		
	3	1512		0.028	0.067	18.3	4.9	23.2		1166			2.21	
	3	1607		0.029	0.067	18.9	5.0	23.9			989			3.99
	5	1590		0.029	0.112	18.9	8.3	27.2	1596			1.212		
	5	1516		0.028	0.113	18.3	8.4	26.7		1275			2.29	
	5	1608		0.029	0.112	18.9	8.3	27.2			1078			4.17
	3	1588		0.045	0.067	29.4	5.0	34.4	1974			1.470		
	3	1525		0.045	0.067	29.4	5.1	34.5		1385			2.10	
	3	1809		0.045	0.067	29.4	5.0	34.4			1050			3.12

* SEE PAGE 6 PARAGRAPH 4.

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TABLE 2.

BALLISTIC RESISTANCE OF VARIOUS COMBINATIONS OF HADFIELD-MANGANESE STEEL WITH BONDED NYLON AND 24S-T ALUMINUM ALLOY WITH BONDED NYLON WHEN ATTACKED BY CALIBER 0.15 (5.85 GRAIN) FRAGMENT-SIMULATING PROJECTILES AT 0° OBLIQUITY.

METALLIC COMPONENT	NUMBER OF PLYS OF NYLON	PANEL NUMBER	AVERAGE PANEL THICKNESS (in.)		PANEL WEIGHT (oz./sq.ft.)		TOTAL COMBINED WEIGHT (oz./sq.ft.)	PROTECTION BALLISTIC LIMIT (V ₅₀) (ft./sec.)	STRIKING VELOCITIES RESULTING IN	
			METAL	NYLON	METAL	NYLON			HIGHEST PARTIAL PENETRATION (ft./sec.)	LOWEST COMPLETE PENETRATION (ft./sec.)
NONE	3	1544		0.067		5.0	5.0	860	940	829
	5	1545		0.112		8.3	3.3	1065	1108	1035
	9	1546		0.197		15.4	15.4	1363	1414	1359
24S-T ALUMINUM ALLOY	5	1547	0.072	0.112	16.6	8.3	24.9	1451	1479	1402
	9	1548	0.072	0.197	16.6	15.2	31.8	1727	1843	1662
	3	1550	0.102	0.067	23.5	5.0	28.5	1458	1489	1428
	5	1585	0.103	0.112	23.7	8.3	32.0	1619	1697	1565
HADFIELD-MANGANESE STEEL	3	1589	0.029	0.067	18.9	5.0	23.9	1516	1539	1497
	5	1590	0.029	0.112	18.9	8.3	27.2	1596	1634	1565
	3	1588	0.045	0.067	29.4	5.0	34.4	1974	2000	1863

NOTES:

1. Fabric - 2 x 2 Basket Weave Nylon, 14.0 oz./sq.yd., 46 x 40 threads/in., manufactured by St. George Textiles and finished by Hellwig.
2. Resin - Permacel 1500 (a phenol-formaldehyde-polyvinyl butyral resin).
3. Resin Content - 9 percent, based on percent by weight of fabric.
4. All layers of coated nylon dried for 10 minutes at 220° F. prior to lamination.
5. Nylon panels laminated 15 minutes at 340° F., 350 psi.
6. Spacing of 1/4 in. between metallic and nylon components with metallic component always facing muzzle of gun.
7. Hardness of 0.029 in. Hadfield-manganese steel, Rockwell "B" 75.
8. Hardness of 0.045 in. Hadfield-manganese steel, Rockwell "C" 46.
9. All thickness measurements are averages of 10 readings.
10. Caliber 0.15 (5.85 grain) fragment-simulating projectiles used. Projectiles heat-treated to a hardness range of Rockwell "C" 29-31.

TABLE 3.

BALLISTIC RESISTANCE OF VARIOUS COMBINATIONS OF HADFIELD-MANGANESE STEEL WITH BONDED NYLON AND 24S-T ALUMINUM ALLOY WITH BONDED NYLON WHEN ATTACKED BY CALIBER 0.30 (44 GRAIN) FRAGMENT-SIMULATING PROJECTILES AT 0° OBLIQUITY.

METALLIC COMPONENT	NUMBER OF PLYS OF NYLON	PANEL NUMBER	AVERAGE PANEL THICKNESS (in.)		PANEL WEIGHT (oz./sq.ft.)		TOTAL COMBINED WEIGHT (oz./sq.ft.)	PROTECTION BALLISTIC LIMIT (V ₅₀) (ft./sec.)	STRIKING VELOCITIES RESULTING IN	
			METAL	NYLON	METAL	NYLON			HIGHEST PARTIAL PENETRATION (ft./sec.)	LOWEST COMPLETE PENETRATION (ft./sec.)
NONE	3	1599		0.067		5.0	5.0	655	717	645
	5	1598		0.113		8.3	8.3	754	777	728
	9	1597		0.197		15.0	15.0	950	976	906
24S-T ALUMINUM ALLOY	5	1603	0.072	0.112	16.6	8.3	24.9	911	921	906
	9	1604	0.071	0.197	16.4	15.0	31.4	1106	1118	1090
	3	1605	0.103	0.067	23.7	5.0	28.7	936	974	897
	5	1606	0.102	0.112	23.5	8.3	31.8	1025	1039	984
HADFIELD-MANGANESE STEEL	3	1607	0.029	0.067	18.9	5.0	23.9	989	1016	936
	5	1608	0.029	0.112	18.9	8.3	27.2	1078	1088	1043
	3	1609	0.045	0.067	29.4	5.0	34.4	1050	1088	1020

NOTES:

1. Fabric - 2 x 2 Basket Weave Nylon, 14.0 oz./sq.yd., 46 x 40 threads/in., manufactured by St. George Textiles and finished by Hellwig.
2. Resin - Permacel 1500 (a phenol-formaldehyde-polyvinyl butyral resin).
3. Resin Content - 9 percent, based on percent by weight of fabric.
4. All layers of coated nylon dried for 10 minutes at 220° F. prior to lamination.
5. Nylon panels laminated 15 minutes at 340° F., 350 psi.
6. Spacing of 1/4 in. between metallic and nylon components with metallic component always facing muzzle of gun.
7. Hardness of 0.029 in. Hadfield-manganese steel, Rockwell "B" 75.
8. Hardness of 0.045 in. Hadfield-manganese steel, Rockwell "C" 46.
9. All thickness measurements are averages of 10 readings.
10. Caliber 0.30 (44 grain) fragment-simulating projectiles used. Projectiles heat-treated to a hardness range of Rockwell "C" 29-31.

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TABLE 4.

BALLISTIC RESISTANCE OF VARIOUS COMBINATIONS OF HADFIELD-MANGANESE STEEL WITH BONDED NYLON AND 24S-T ALUMINUM ALLOY WITH BONDED NYLON WHEN ATTACKED BY CALIBER 0.22 T-37 (17-GRAIN) FRAGMENT-SIMULATING PROJECTILES AT VARIOUS OBLIQUITIES.

METALLIC COMPONENT	NUMBER OF PLYS OF NYLON	OBLIQUITY (degrees)	PANEL NUMBER	AVERAGE PANEL THICKNESS (in.)		PANEL WEIGHT (oz./sq.ft.)		TOTAL COMBINED WEIGHT (oz./sq.ft.)	PROTECTION BALLISTIC LIMIT (V ₈₀) (ft./sec.)	STRIKING VELOCITIES RESULTING IN:		MERIT FACTOR BL (V ₈₀) ² TOTAL PANEL WT (oz./sq.ft.)	
				METAL	NYLON	METAL	NYLON			HIGHEST PARTIAL PENETRATION (ft./sec.)	LOWEST COMPLETE PENETRATION (ft./sec.)		
NONE	3	0	1439		0.089		4.9	4.9	750	750	750	114,800 *	
	3	30	1442		0.087		4.9	4.9	721	708	734	105,900 *	
	3	45	1450		0.088		4.9	4.9	751	768	732	115,000 *	
	3	60	1451		0.088		4.9	4.9	779	780	778	123,800 *	
	5	0	1440		0.113		8.3	8.3	907	923	804	99,200 *	
	5	30	1443		0.112		8.3	8.3	871	890	847	91,400 *	
	5	45	1443		0.113		8.3	8.3	913	932	899	100,300 *	
	5	60	1448		0.110		8.1	8.1	878	884	874	118,200 *	
	9	0	1441		0.198		15.1	15.1	1050	1074	1033	73,000 *	
	9	30	1445		0.197		15.1	15.1	1081	1130	1055	77,900 *	
	9	45	1447		0.197		15.2	15.2	1241	1156	1125	88,200 *	
	9	60	1449		0.197				1264	1265	1262	105,100 *	
	24S-T ALUMINUM ALLOY	5	0	1454	0.072	0.113	16.6	8.3	24.9	1170	1161	1165	53,000
		5	30	1455	0.072	0.113	16.6	8.3	24.9	1252	1259	1246	63,100
		5	45	1456	0.072	0.113	16.6	8.2	24.8	1342	1362	1317	72,700
5		60	1457	0.072	0.113	16.6	8.1	24.7	1634	1638	1628	108,200	
9		0	1533	0.071	0.198	16.4	15.3	31.7	1338	1362	1317	56,500	
9		30	1534	0.071	0.198	16.4	15.4	31.8	1449	1486	1413	68,000	
9		45	1535	0.072	0.198	16.6	15.4	32.0	1514	1572	1413	71,800	
9		60	1536	0.072	0.198	16.6	15.5	32.1	1859	1893	1808	107,700	
3		0	1458	0.100	0.087	23.1	4.8	28.3	1304	1338	1259	48,800	
3		30	1459	0.102	0.088	23.5	4.9	28.4	1450	1473	1413	60,200	
3		45	1462	0.102	0.087	23.5	5.1	28.4	1872	1909	1851	74,200	
3		60	1499	0.101	0.088	23.3	8.4	32.1	1254	1252	1255	123,500	
5		0	1503	0.103	0.113	23.7	8.5	32.0	1401	1425	1377	49,200	
5		30	1506	0.102	0.113	23.5	8.4	31.7	1553	1599	1509	61,400	
5		45	1507	0.101	0.113	23.3	8.5	32.2	1906	1961	1857	76,300	
5	60	1510	0.103	0.113	23.7						112,800		
HADFIELD-MANGANESE STEEL	3	0	1512	0.028	0.087	18.3	4.9	23.2	1166	1187	1149	58,500	
	3	30	1513	0.028	0.087	18.3	5.0	23.3	1123	1156	1059	54,200	
	3	45	1514	0.028	0.087	18.3	5.0	23.3	1205	1224	1167	62,300	
	3	60	1515	0.028	0.087	18.3	5.0	23.3	1313	1362	1202	74,100	
	5	0	1516	0.028	0.113	18.3	8.4	26.7	1275	1283	1255	80,900	
	5	30	1517	0.028	0.113	18.3	8.4	26.7	1271	1296	1237	60,600	
	5	45	1523	0.028	0.113	18.3	8.3	26.6	1367	1393	1342	70,100	
	5	60	1524	0.028	0.113	18.3	8.3	26.6	1624	1659	1599	99,300	
	3	0	1525	0.045	0.087	29.4	5.1	34.5	1385	1425	1338	55,600	
	3	30	1527	0.045	0.087	29.4	5.0	34.4	1424	1486	1400	60,700	
	3	45	1528	0.045	0.087	29.4	5.0	34.4	1612	1688	1477	75,800	
	3	60	1529	0.045	0.087	29.4	5.0	34.4	1696	1744	1666	83,700	

* SEE PAGE 9, PARAGRAPH 2.

NOTES:

- Fabric - 2 x 2 Basket Weave Nylon, 14.0 oz./sq.yd., 46 x 40 threads/in., manufactured by St. George Textiles and finished by Hellwig.
- Resin - Permacel 1500 (a phenol formaldehyde-polyvinyl butyral resin).
- Resin Content - 9 percent, based on percent by weight of fabric.
- All layers of coated nylon dried for 10 minutes at 220° F. prior to lamination.
- Nylon panels laminated 15 minutes at 340° F., 350 psi.
- Spacing of 1/4 in. between metallic and nylon components w. h. metallic component always facing muzzle of gun.
- Hardness of 0.028 in. Hadfield-manganese steel, Rockwell "C" 75.
- Hardness of 0.045 in. Hadfield-manganese steel, Rockwell "C" 46.
- All thickness measurements are averages of 10 readings.
- Caliber 0.22 T-37 (17 grain) fragment-simulating projectiles used. Projectiles heat-treated to a hardness range of Rockwell "C" 29-31.

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