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PENETRATION OF 60-GRAIN AND 240-GRAIN BOMB FRAGMENTS INTO WALLBOARD

TECHNICAL REPORT AFATL-TR-70-51

JUNE 1970

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AIR FORCE ARMAMENT LABORATORY
AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE
EGLIN AIR FORCE BASE, FLORIDA

PENETRATION OF 60-GRAIN AND 240-GRAIN BOMB FRAGMENTS INTO WALLBOARD

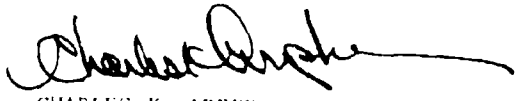
Richard P. Warnis

FOREWORD

Presently, the Degradation Effects Program (DEP) and others are using regression equations relating the striking velocity for cylinders as a function of their penetration into wallboard. This effort grew out of the question of whether actual bomb fragments would have a similar regression equation. This final phase of the study, which is concerned with testing 60-grain and 240-grain bomb fragments, was conducted during the period 1 January - 1 March 1970. The results from firing 15-grain bomb fragments into wallboard are available in AFATL-TR-70-48.

The DLRD range crew composed of Jack Byrne, TSgt Charles Sauls, Clyde Wallace, Sgt Ron Stearns, Sgt Terrell Costello, Sgt Dennis Houtari, Sgt Earl Farabaugh, and Sgt William Carson provided the necessary technical support and instrumention.

This technical report has been reviewed and is approved.



CHARLES K. ARPKE, Lt Col, USAF
Chief, Technology Division

ABSTRACT

The primary objective of this program was to define a function between the striking velocity for 60-grain and 240-grain random shaped bomb fragments and their depth into the wallboard trade named Nu-Wood. The 60-grain fragments were fired from a 20mm Mann barrel and the 240-grain fragments from a 30mm Mann barrel into bundled Nu-Wood. The 60-grain fragments were lightly filed to fit into a $3.77 \leq w \leq 4.01$ gram weight range and the 240-grain fragments into a $15.08 \leq w \leq 16.02$ gram weight range. The striking velocities for the 60-grain fragments were in the 600 ft/sec to 5000 ft/sec range and the 240-grain fragments in the 300 ft/sec to 3500 ft/sec range. The graph of fragment striking velocity as a function of depth into Nu-Wood showed a wide range of depths for approximately 2000 ft/sec and above striking velocities. A lower dispersion in penetration depths exists for velocities up to 2000 ft/sec. A least squares curve would not be valuable since the penetration spread is too wide at given velocities. Fragment penetration into Nu-Wood from firing cylinders does not give a realistic picture of 60-grain and 240-grain actual bomb fragmentation spread. The depth of penetration is not a primary function of the initial presented areas of impacting 240-grain fragments for 500 ft/sec to 3000 ft/sec velocities. When a factor of two or more exists between impacting presented areas for 60-grain bomb fragments, then the presented area seems to influence penetration.

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INTRODUCTION

Actual 60-grain and 240-grain bomb fragment firings into Nu-Wood were conducted at Range 22, Eglin AFB, during the months of January through March 1970.

The primary objective was to define a function between striking velocity and depth into Nu-Wood. Secondary objectives were:

a. To find if the penetration into Nu-Wood is a function of the presented area of the impacting fragment.

b. To observe the breakup characteristics of 60-grain and 240-grain bomb fragments in Nu-Wood.

c. To determine the extent of deflection of the fragments relative to projected paths in air and Nu-Wood.

SECTION II

TEST SET-UP

The general test set-up for the firings is shown in Figure 1. Figure 2 shows the co-ordinates X_1Y_1, X_2Y_2, and X_3Y_3 on the three- dimensional view of the Nu-Wood. The lower left hand corner of the Nu-Wood serves as the origin.

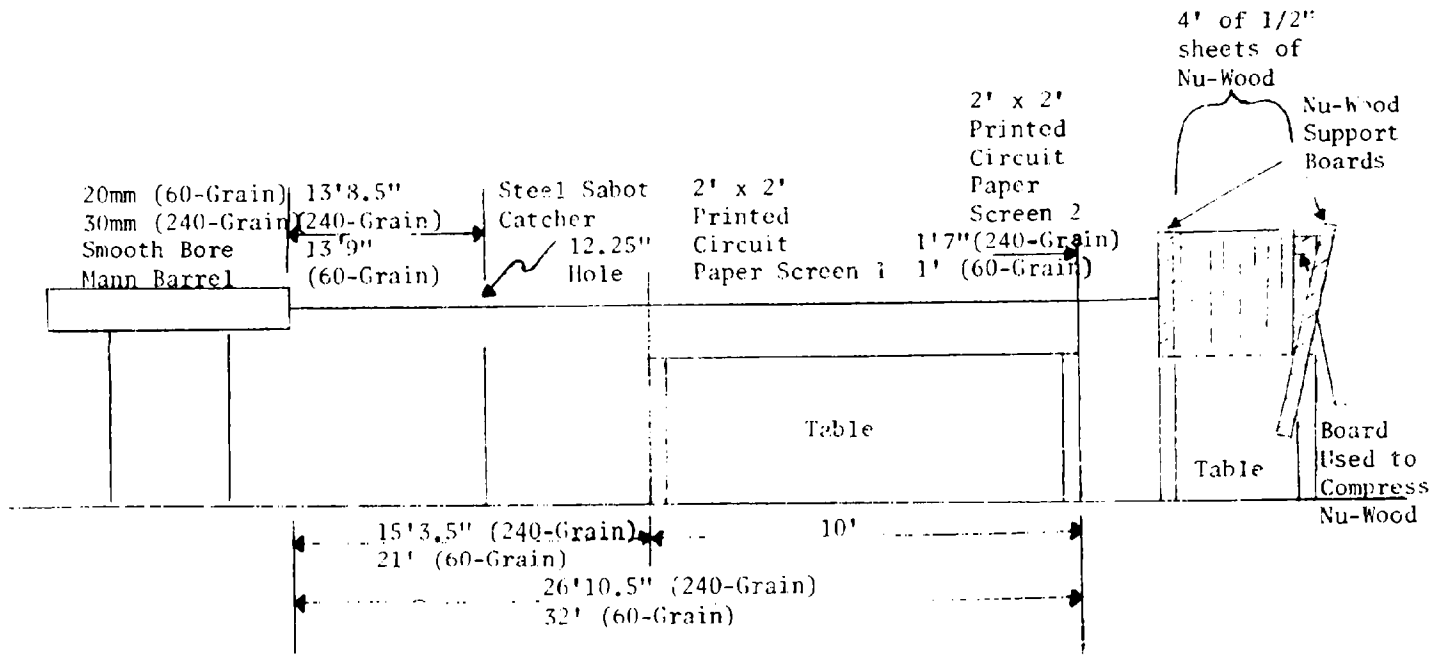

Figure 1. Test Set-Up

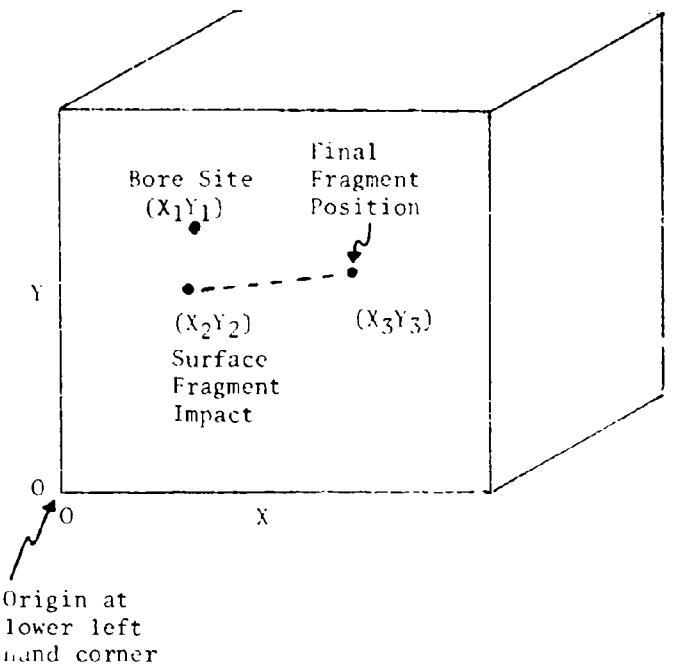

Figure 2. X and Y Co-ordinates on the Nu-Wood

SECTION III

PRIMARY OBJECTIVE

Figures 3 and 4 show the striking velocity as a function of penetration for 60-grain and 240-grain fragments. These striking velocities were obtained by correcting the fragment measured velocity for air drag. The air drag correction times the measured velocity was 0.9514 for 60-grain fragments and 0.9661 for 240-grain fragments. These were obtained from: [1]

$$V_S = \overline{V} \left[\frac{e^{\frac{-\alpha(S-x)}{m^{1/3}}} - e^{\frac{-\alpha S}{m^{1/3}}}}{e^{\frac{\alpha x}{m^{1/3}}}} \right]$$

V_S = Striking velocity (feet/sec).

$\overline{V}$ = Average measured velocity between the screens. The first screen is at x_o=0, the second at x=10 feet (ft/sec).

S = Distance from the first screen to the target (11 feet for 60-grain fragments and 11.58 feet for 240-grain fragments).

α = 0.0327 (constant for an air drag coefficient C_d = 0.640, and density of air, ρ = 0.310 grains/in^3.)

M = Mass of fragment in grains.

Valid data points and data points estimated from powder charges are plotted on Figure 3. The fragment weight range of $3.77 \leq w \leq 4.01$ grams for 60-grain fragments and $15.68 \leq w \leq 16.02$ grams for 240-grain fragments is not a function of depth into Nu-Wood. Figures 3 and 4 illustrate the wide spread in depths of penetration.

A means of classification of the fragments into shape categories was found from close examination of the fragments and solving for D in:

$$LWD = \frac{w}{\rho}$$

LWD = Length Width Depth where L>W>D (in.).

w = Weight of fragment (lbs.)

ρ = 0.284 $\frac{lbs}{in^3}$ as the general density of steel.

The categories are:

L-F = Long flat
L-C = Long chunky
F = Flat
F-C = Flat chunky
C = Chunky
L = Long

The calculated D values can fit appropriate groups for D (Inches):

60-Grain

Long Flat	Flat	Flat Chunky	Long Chunky	Chunky	Long
<0.450	0.450	0.550	0.650	0.750	≥1.500
	<0.550	<0.650	<0.750	<1.500	

240-Grain

Long Flat	Flat	Flat Chunky	Long Chunky	Chunky	Long
<0.800	0.800	0.850	1.100	1.250	≥1.500
	<0.850	<1.100	<1.250	<1.500	

Tables I and II and Figures 3 and 4 show the classification of the fragments. Figures 5 and 6 illustrate the majority of the fragments fired. After firing, many fragments were lost from impacting the sabot catcher, the printed circuit paper holders, or the Nu-Wood holders.

Figures 3 and 4 have regression plots of a penetration equation obtained by firing steel cylinders into wallboard trade named Nu-Wood and Flintkote. These cylinders had characteristic velocities from 305 ft/sec to 12,788 ft/sec, masses from 0.25 grain to 241.50 grains, and 0° to 70° obliquity from the projectile path to the perpendicular to the Nu-Wood surface. The finalized regression equation used for the plot is:[2]

$$V_S = \frac{112681(X)^{0.8091}(KM^{2/3})^{0.9078}}{M^{0.9368}}$$

V_S = Striking velocity of steel cylindrical fragments (ft/sec).
X = Depth of penetration measured perpendicular to the Nu-Wood surface (in.)
K = 0.0088
M = Mass of fragment (grains)

[2] This will be termed the Thor regression equation. The Thor regression plot for cylinders does not fit closely to the distribution of 60-grain and 240-grain bomb fragment data points. This can be attributed to the shape difference between pre-formed cylinders and actual bomb fragments. Also, the Thor regression equation has too large a range in its variables of mass, velocity, and obliquity.

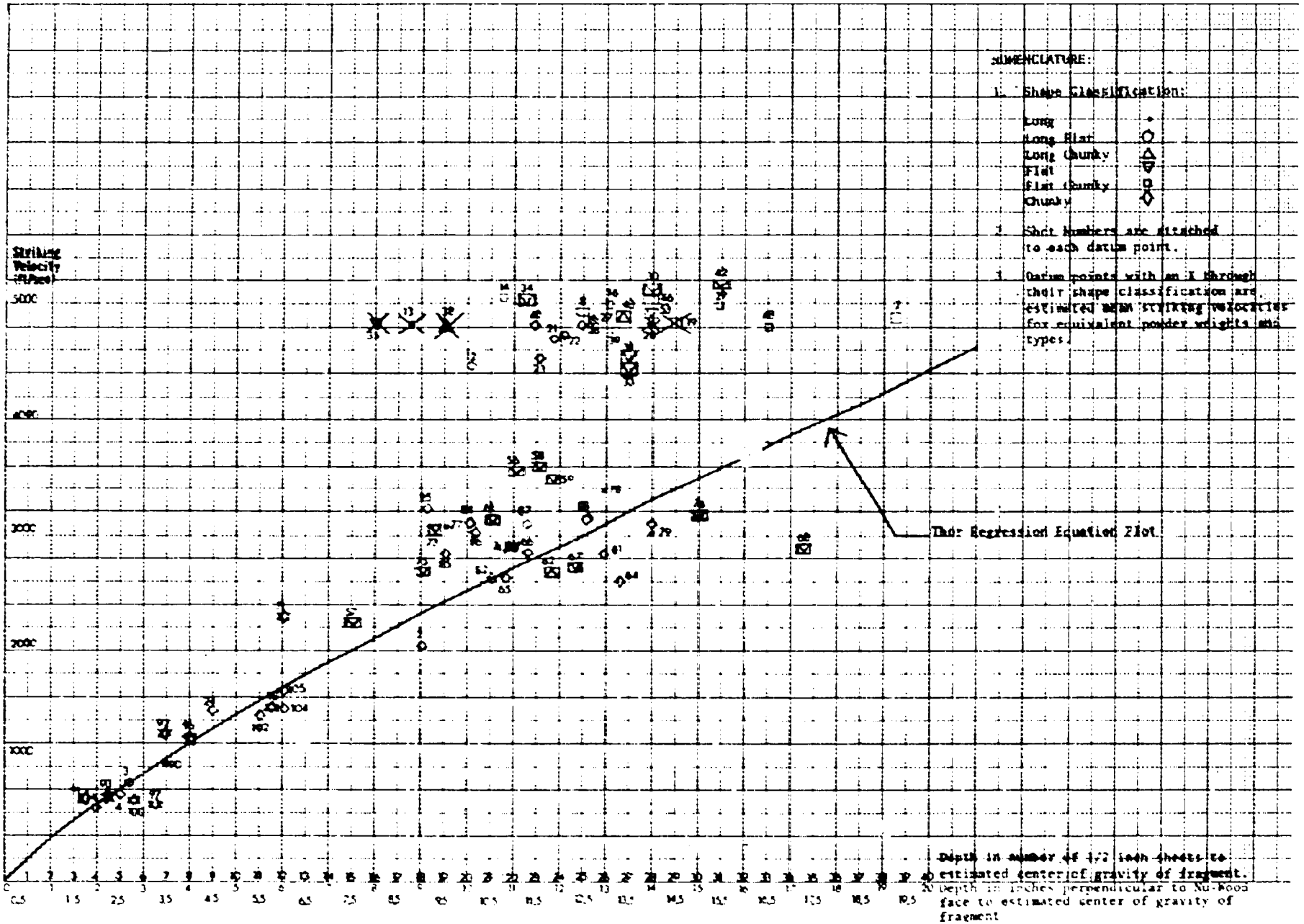

Figure 3. Striking Velocity Versus Penetration into Nu-Wood for 60-Grain Bomb Fragments

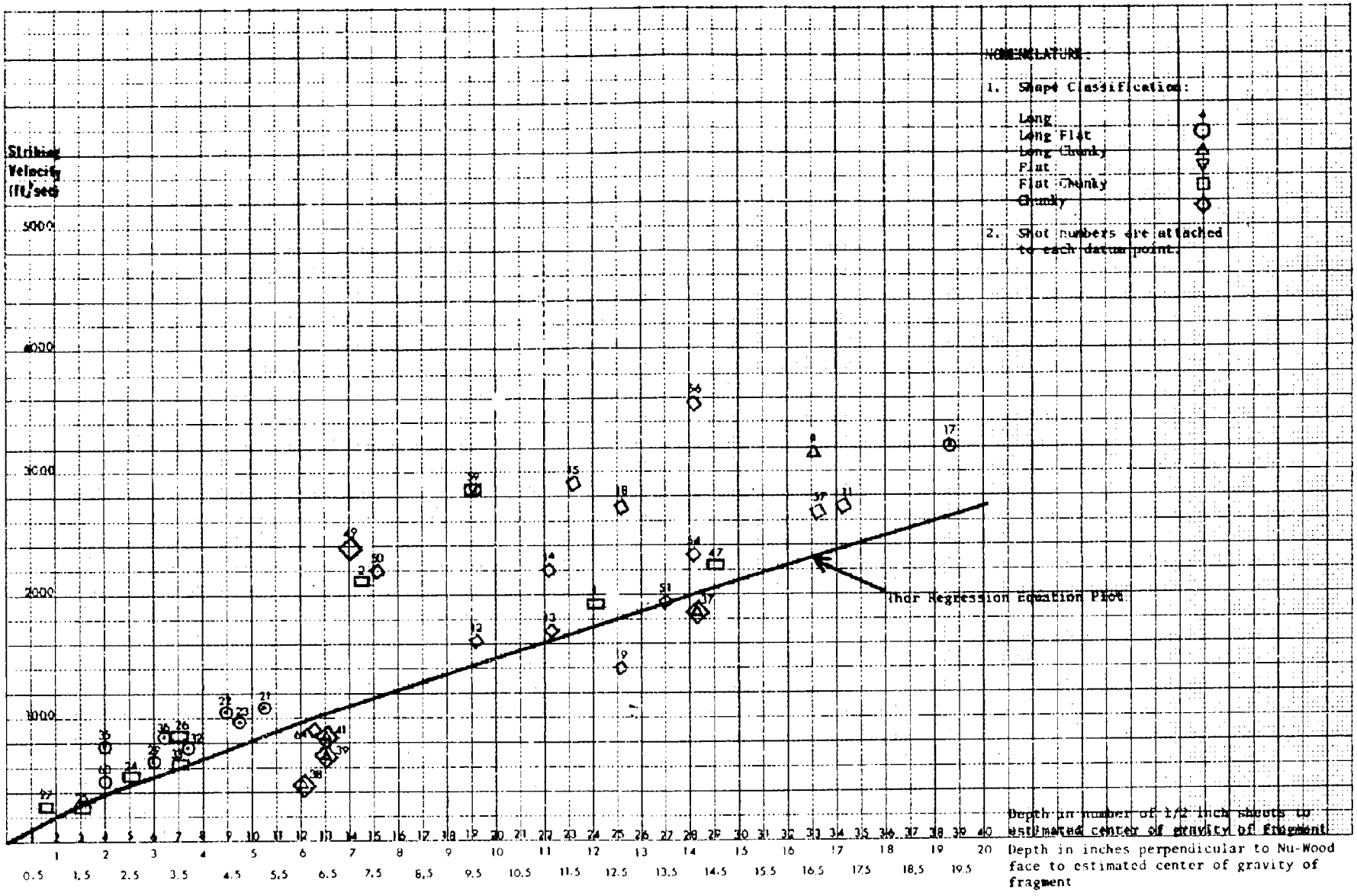

Figure 4. Striking Velocity Versus Penetration into Nu-Wood for 240-Grain Bomb Fragments

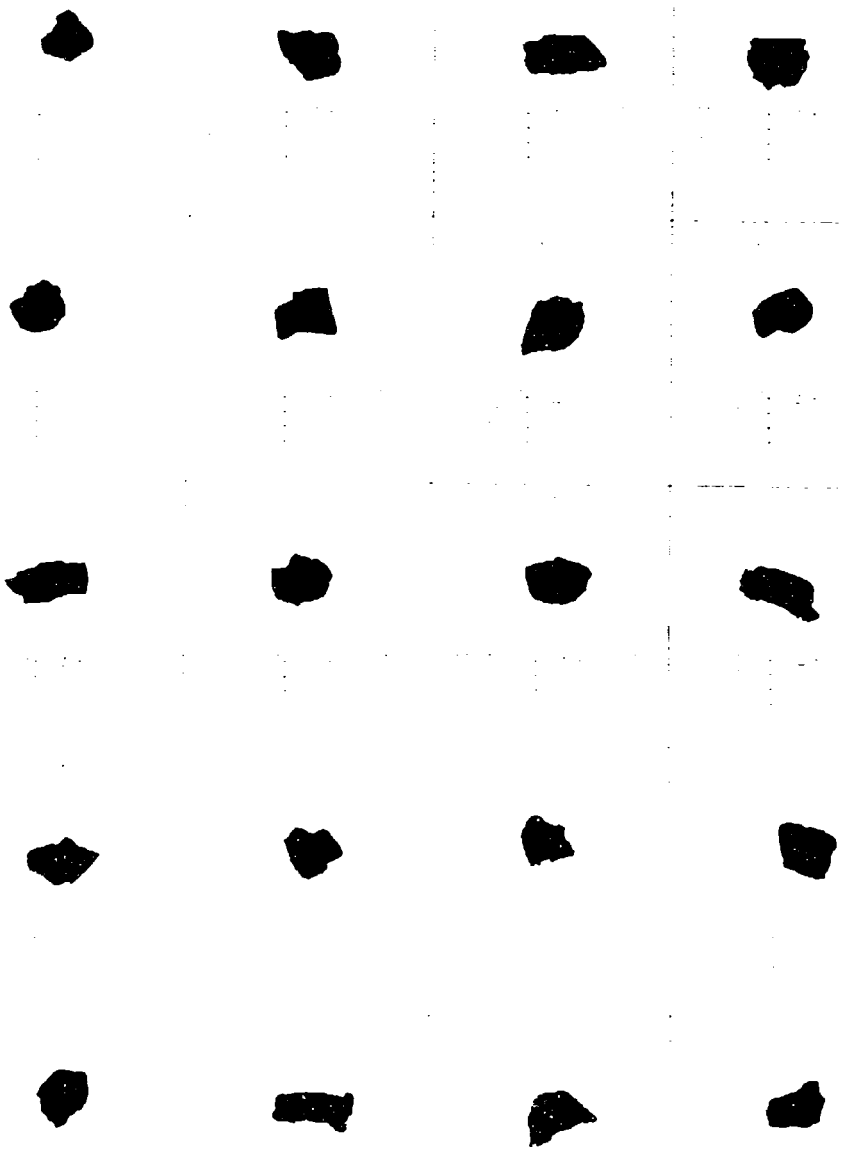

Figure 5. Illustration of the Majority of 60-Grain Bomb Fragments Before Firing

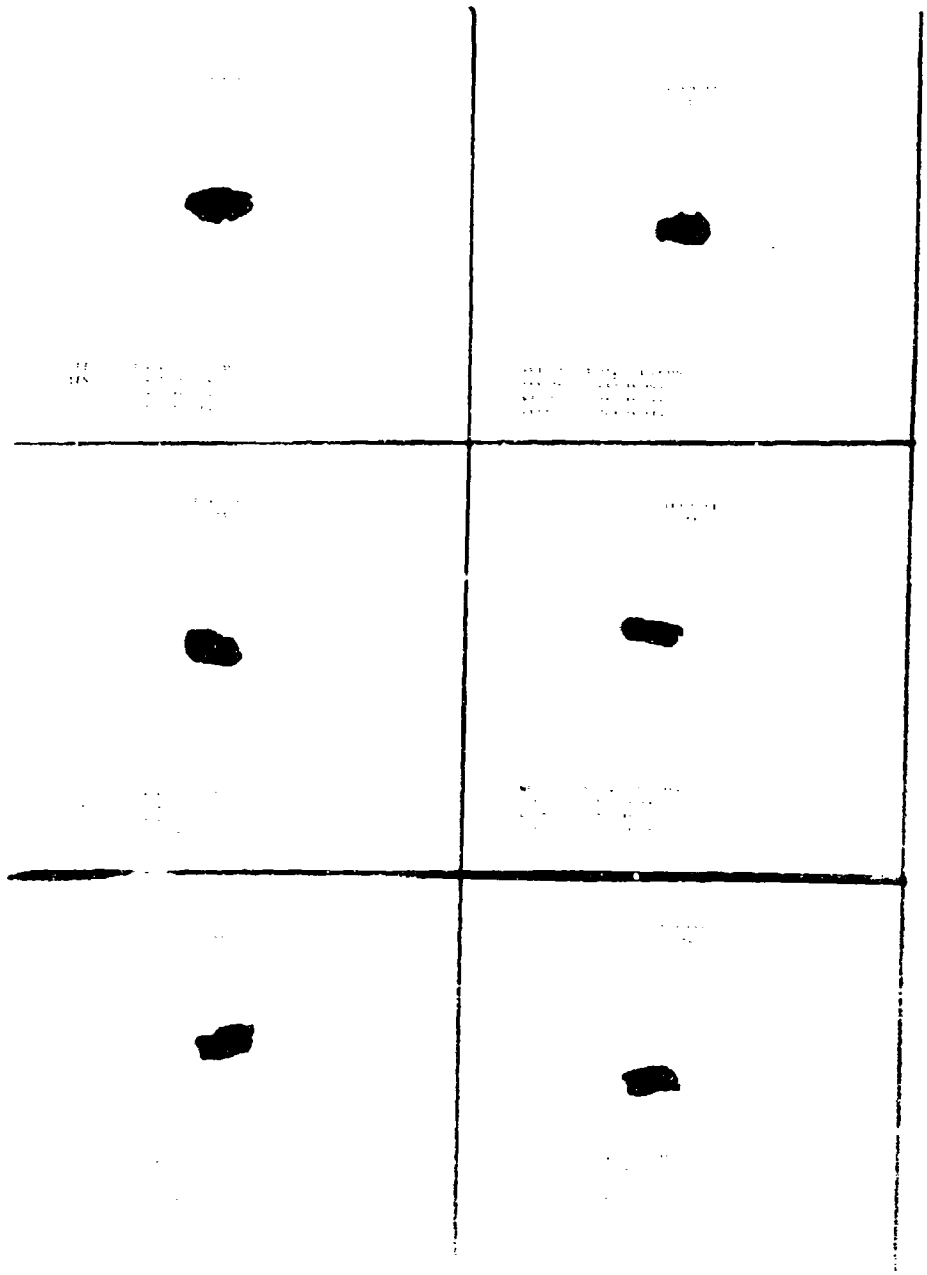

Figure 5. (Continued)

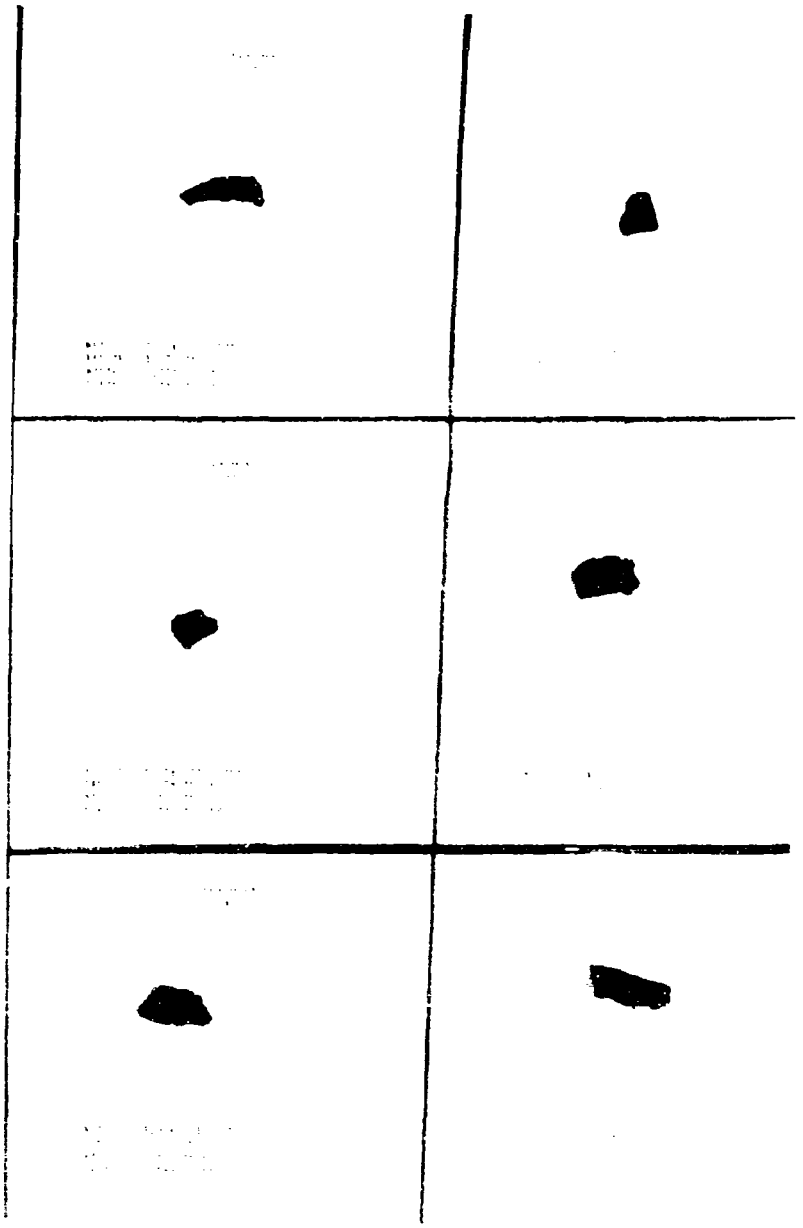

Figure 5. (Concluded)

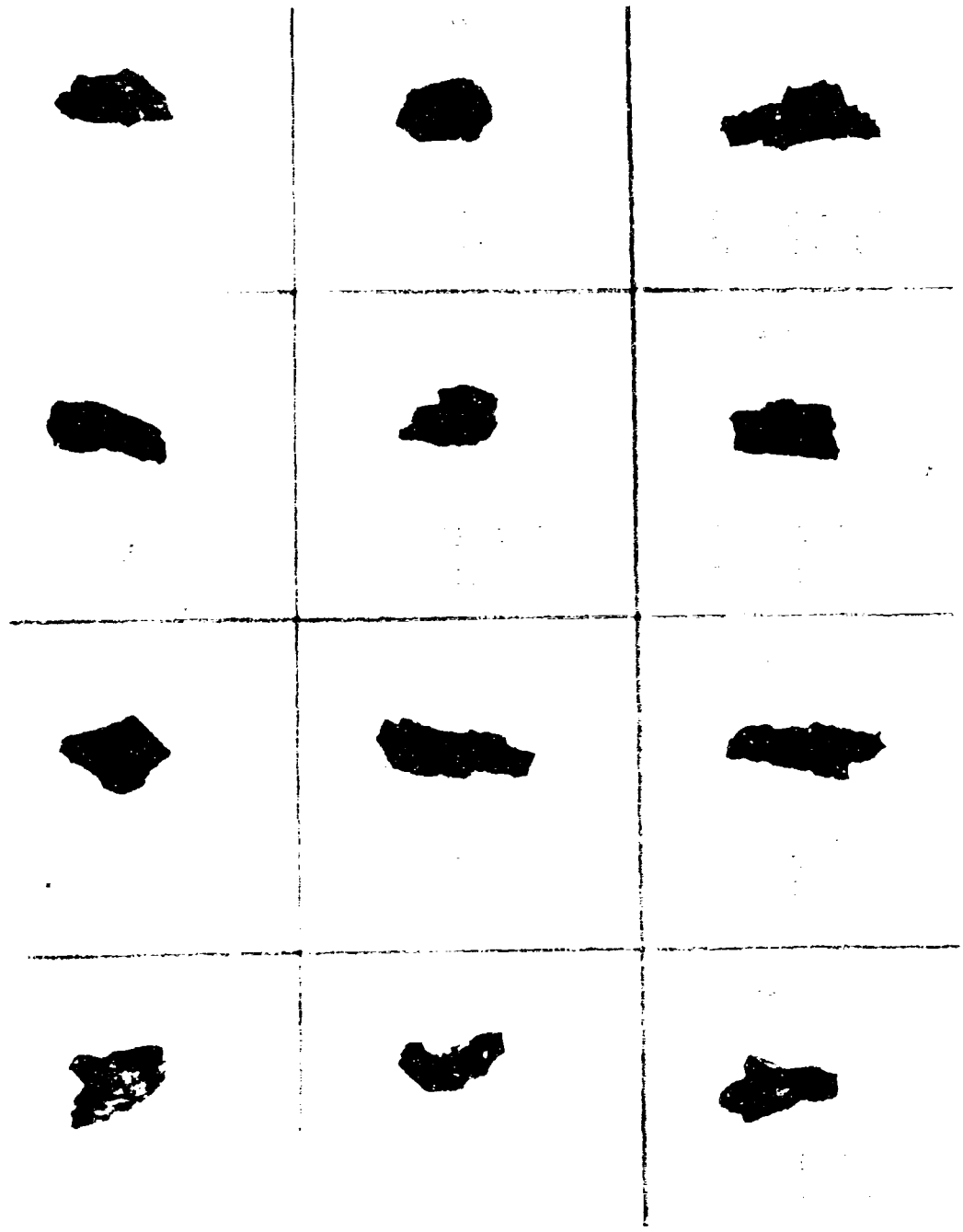

Figure 6. Illustration of the Majority of 240-Grain Bomb Fragments Before Firing

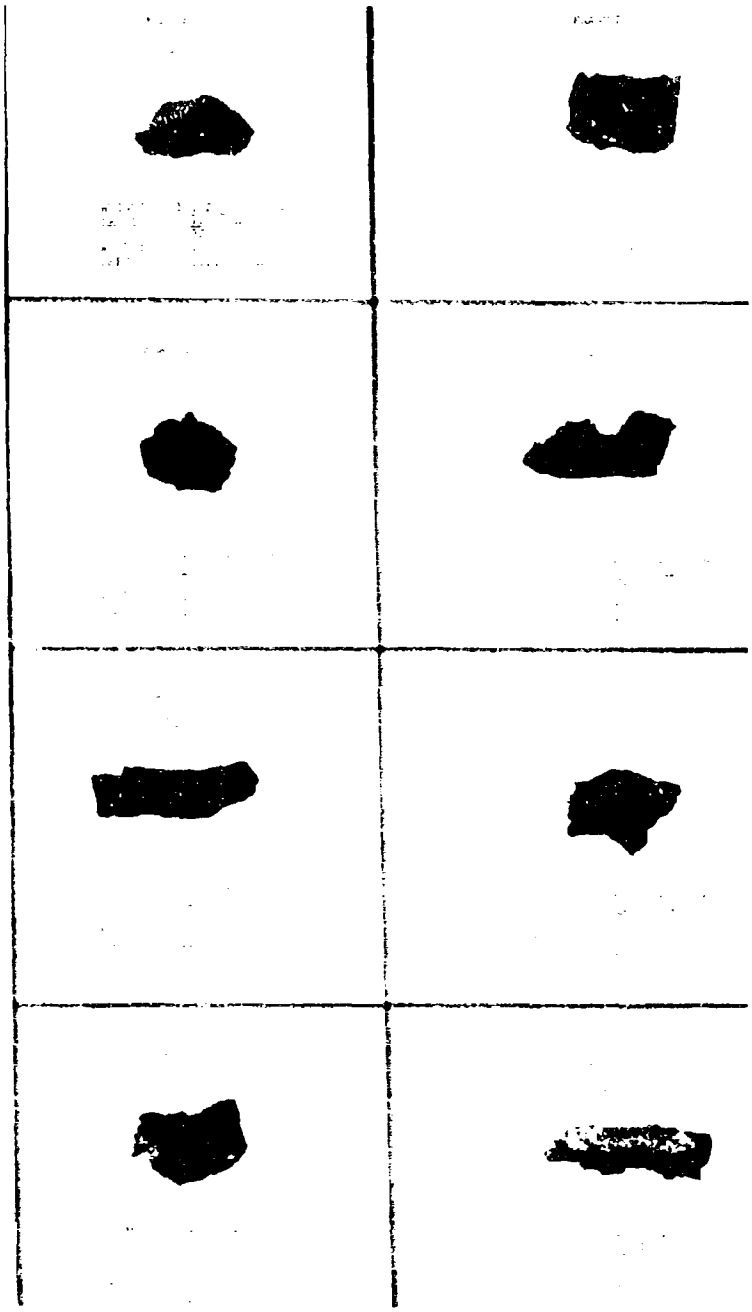

Figure 6. (Concluded)

TABLE 1. 60-GRAIN BOMB FRAGMENT SHAPE CLASSIFICATION, POWDER CHARGE, MEASURED VELOCITY, STRIKING VELOCITY, AND PENETRATION INTO NU-WOOD DATA.

SHOT NO.	FRAGMENT NO.	SHAPE CLASSIFICATION	POWDER WEIGHT (GRAINS), TYPE	MEASURED VELOCITY (FT/SEC)	STRIKING VELOCITY (0.9514 x MEASURED VELOCITY) (ft/sec)	NU-WOOD FRAGMENT PENETRATION DEPTH PERPENDICULAR TO NU-WOOD SURFACE TO ESTIMATED CENTER OF GRAVITY OF FRAGMENT (INCHES)	COMMENTS
1	1	Chunky	200-IMR4895	679	646	2.00	Good Shot
2	1	Chunky	225-IMR4895	2147	2043	9.00	Good Shot
3	1	Chunky	205-IMR4895	891	848	2.75	Good Shot
4 /	1	Chunky	210-IMR4895	814	774	2.50	Good Shot
5	1	Chunky	200-WC857	371	353	N/A	Fragment made impact hole, then bounced out to be found on floor 6 ft. from Nu-Wood.
6	1	Chunky	250-WC857	450	428	N/A	No recovery. Fragment went under cable holding Nu-Wood.
7	2	Flat Chunk	625-IMR4895	5131	4882	19.25	Good Shot
8	2	Flat Chunk	625-IMR4895	5171	4920	12.50	Strong X-axis deflection in Nu-Wood. From (7 1/2", 8 1/2") surface co-ordinate to (2 1/8", 3") where found.
9	2	Flat Chunk	625-IMR4895	2709 (5070)	(4824)	N/A	No recovery. Fragment struck sabot catcher.
10	3	Long Chunk	625-IMR4895	2856 (5070)	(4824)	N/A	No recovery. Fragment struck sabot catcher.
11	4	Flat Chunk	625-IMR4895	5079 (5070)	(4824)	N/A	Fragment broke up in flight into four small pieces.
12	5	Chunky	625-IMR4895	4697	4469	10.00	Fragment broke up in Nu-Wood. A .60 gram piece appeared to break off in 10th sheet and then diverged to be found in 14th sheet.
13	6	Flat Chunk	631.5-IMR4895	3167 (5070)	(4824)	8.75	A .10 gram weight loss. Cannot locate piece. Still consider as datum point.
14	6	Flat Chunk	634.5-IMR4895	5299	5041	10.75	Good Shot
15	6	Flat Chunk	634.5-IMR4895	3212 (5070)	(4824)	N/A	No recovery. Fragment struck sabot catcher.
16	11	Flat Chunk	634.5-IMR4895	5244	4989	13.12	A .12 gram weight loss. Could not locate piece. Can be considered as a datum point.
17	11	Flat Chunk	634.5-IMR4895	3876 (5070)	(4824)	N/A	No recovery.
18	16	Flat Chunk	634.5-IMR4895	3042 (5070)	(4824)	N/A	No recovery. Appeared fragment broke up in flight.
19	17	Flat Chunk	634.5-IMR4895	3667 (5070)	(4824)	14.50	Sabot velocity.

20	17	Flat Chunk	634.5-IMR4895	N/A	N/A	N/A	No recovery. Fragment hit sabot catcher.
21	8	Chunky	634.5-IMR4895	4928	4688	11.88	Good shot.
22	8	Chunky	634.5-IMR4895	4948	4708	1.00	Good shot.
23	8	Chunky	634.5-IMR4895	4739	4509	11.62	Good shot.
24	8	Chunky	600-WC857	1550	1475	4.50	Good shot.
25	8	Chunky	675-WC857	3392	3227	9.12	Good shot.
26	8	Chunky	625-IMR4895	5061	4815	12.50	Good shot.
27	8	Chunky	625-IMR4895	2692 (5070)	(4824)	12.50	Sabot velocity.
28	8	Chunky	625-IMR4895	3515 (5070)	(4824)	14.00	Break up occuring. Sheet 7 got .30 gram piece, sheet 26 got .43 gram piece and main fragment weighing 3.33 grams.
29	10	Flat Chunk	634.5-IMR4895	5236	4982	15.50	Good shot.
30	19	Flat, Flat Chunk	634.5-IMR4895	5374	5113	14.00	Good shot.
31	19	Flat, Flat Chunk	634.5-IMR4895	4769	4537	13.50	A .05 gram break-off. Could not locate piece. Still considered as a datum point.
32	22	Long Chunk	634.5-IMR4895	3274 (5070)	(4824)	N/A	No recovery.
33	19	Flat, Flat Chunk	634.5-IMR4895	4733	4503	13.50	Good Shot.
34	19	Flat, Flat Chunk	634.5-IMR4895	5280	5023	11.25	A .10 gram weight loss. Could not locate piece. Still considered as datum point.
35	7	Flat	634.5-IMR4895	3093 (5070)	(4824)	8.00	A .15 gram weight loss. The .10 gram piece found in 6th sheet. Could not find .05 gram piece.
36	7	Flat	634.5-IMR4895	2906 (5070)	(4824)	N/A	No Recovery. Fragment hit Nu-Wood holder.
37	23	Long Chunk	634.5-IMR4895	2982 (5070)	(4824)	N/A	Fragment appeared to break up and strike Nu-Wood holder.
38	18	Long Chunk	634.5-IMR4895	3276 (5070)	(4824)	9.50	Sabot velocity.
39	15	Flat Chunk	625-IMR4895	5008	4765	13.25	Bad shot. A .20 gram weight loss. Piece found in 10th sheet.
40	20	Chunky	625-IMR4895	3565 (5070)	(4824)	11.50	Sabot velocity.
41	20	Chunky	625-IMR4895	3752 (5070)	(4824)	N/A	No recovery. Fragment went into table holding Nu-Wood.
42	19	Flat, Flat Chunk	625-IMR4895	5420	5156	15.50	A .05 gram weight loss. Still a good datum point.
43	13	Flat Chunk, Long Chunk	625-IMR4895	3235 (5070)	(4824)	13.00	A .30 gram weight loss. Could not find piece.
44	18	Long Chunk	625-IMR4895	2939 (5070)	(4824)	N/A	No recovery. Fragment hit sabot catcher.
45	9	Long Chunk	625-IMR4895	3762 (5070)	(4824)	N/A	No recovery. Fragment hit sabot catcher.
46	16	Flat Chunk	625-IMR4895	5314	5056	14.00	A .60 gram weight loss. Could not find piece.

TABLE I. (CONCLUDED)

SHOT NO.	FRAGMENT NO.	SHAPE CLASSIFICATION	POWDER WEIGHT (GRAINS), TYPE	MEASURED VELOCITY (FT/SEC)	STRIKING VELOCITY (0.9514 x MEASURED VELOCITY) (ft/sec)	NU-WOOD FRAGMENT PENETRATION DEPTH PERPENDICULAR TO NU-WOOD SURFACE TO ESTIMATED CENTER OF GRAVITY OF FRAGMENT (INCHES)	COMMENTS
47	26	Flat, Flat Chunk	625-IMR4895	3488 (5070)	(4824)	N/A	No recovery. Fragment hit sabot catcher.
48	14	Flat Chunk	625-IMR4895	5035	4790	16.50	A .10 gram weight loss. Still a good datum point.
49	14	Flat Chunk	625-IMR4895	4604	4685	N/A	Fragment broke up in flight.
50	12	Long Chunk	625-IMR4895	5226 (5070)	(4824)	N/A	No recovery.
51	25	Flat Chunk, Long Chunk	625-IMR4895	3405 (5070)	(4824)	N/A	No recovery.
52	24	Flat Chunk, Long Chunk	625-IMR4895	3592 (5070)	(4824)	N/A	No recovery.
53	19	Flat, Flat Chunk	625-IMR4895	3727 (5070)	(4824)	14.00	Velocity too high.
54	9	Long Chunk	625-IMR4895	3015 (5070)	(4824)	N/A	No recovery. Fragment hit sabot catcher.
55	27	Flat, Flat Chunk	625-IMR4895	2573 (5070)	(4824)	N/A	No recovery. Fragment hit sabot catcher.
56	19	Flat, Flat Chunk	400-IMR4350	3541	3558	11.00	Good shot.
57	19	Flat, Flat Chunk	430-IMR4350	3561	3581	7.50	Good shot.
58	19	Flat, Flat Chunk	420-IMR4350	3561	3582	11.50	Good shot.
59	19	Flat, Flat Chunk	450-IMR4350	3659	3481	11.75	Good shot.
60	19	Flat, Flat Chunk	410-IMR4350	3309	3148	N/A	Fragment hit another hole in Nu-Wood.
61	19	Flat, Flat Chunk	400-IMR4350	3294	3134	10.50	Good shot.
62	29	Flat Chunk, Long Chunk	390-IMR4350	2813	2675	11.75	Good shot.
63	29	Flat Chunk, Long Chunk	390-IMR4350	1081 (2737)	(2613)	N/A	No recovery. Fragment hit sabot catcher.
64	30	Chunky	390-IMR4350	2737	2603	15.25	Good shot.
65	30	Chunky	400-IMR4350	2797	2660	10.75	Good shot.
66	30	Chunky	400-IMR4350	2895	2835	13.25	Good shot.
67	36	Flat, Flat Chunk	400-IMR4350	2883	2741	12.25	Good shot.
68	36	Flat, Flat Chunk	400-IMR4350	3029	2882	17.25	Good shot.
69	40	Long Flat, Long Chunk	400-IMR4350	N/A (2963)	(2818)	N/A	No recovery. Fragment hit sabot catcher.
70	31	Long Chunk	400-IMR4350	2782	2647	8.00	Bad shot. A 1.16 gram weight loss. Could not find piece.
71	39	Flat, Long Chunk	400-IMR4350	2406	2289	6.00	Good shot. Different can of powder used.
72	39	Flat, Long Chunk	400-IMR4350	2462	2342	N/A	No recovery. Fragment hit Nu-Wood holder.
73	36	Flat, Flat Chunk	420-IMR4350	3184	3030	9.25	Good shot.
74	36	Flat, Flat Chunk	420-IMR4350	3063	2914	11.00	Good shot.

75	56	Flat, Flat Chunk	420-IMR7828	2807	2671	9.00	Good shot.
76	56	Flat, Flat Chunk	420-IMR4350	3331	3179	15.00	Good shot.
77	54	Long	420-IMR4350	2282 (3188)	(3033)	9.50	Sabot velocity.
78	54	Long	420-IMR4350	3336	3364	15.00	Good shot.
79	54	Long	400-IMR4350	3158	3004	14.00	Good shot.
80	"	Long	400-IMR4350	N/A (3140)	(2987)	N/A	No recovery.
81	53	Chunky	400-IMR4350	3008	2862	13.00	Good shot.
82	53	Chunky	400-IMR4350	2782	2647	10.50	Good shot.
83	58	Chunky	400-IMR4350	3185	3034	14.00	Good shot.
84	58	Chunky	400-IMR4350	3279	3111	10.06	Good shot.
85	58	Chunky	400-IMR4350	2989	2843	9.56	Good shot.
86	57	Chunky	400-IMR4350	3290	3130	10.00	A .05 gram weight loss. Still can be considered a datum point.
87	58	Chunky	400-IMR4350	3278	3119	11.35	Good shot.
88	58	Chunky	400-IMR4350	3293	3133	12.50	Good shot.
89	56	Flat, Flat Chunk	375-IMR4350	302	278	N/A	No recovery. Fragment hit Au-Wood holder.
90	54	Long	225-IMR4350	1079	26	1.50	Good shot.
91	59	Flat, Long Chunk	225-IMR4350	736	310	2.00	Good shot.
92	59	Flat, Long Chunk	225-IMR4350	1369	1302	3.50	Good shot.
93	59	Flat, Long Chunk	225-IMR4350	736	767	2.25	Good shot.
94	59	Flat, Long Chunk	225-IMR4350	1352	1267	N/A	Bad shot. Fragment dropped out of 3rd sheet.
95	59	Flat, Long Chunk	225-IMR4350	705	669	N/A	Went through (or pushed a hole in) 5 sheets and bounced out to be found 10 ft. in front of target.
96	59	Flat, Long Chunk	225-IMR4350	1312	1218	4.00	Good shot.
97	59	Flat, Long Chunk	225-IMR4350	719	675	5.25	Good shot.
98	59	Flat, Long Chunk	225-IMR4350	1618	1537	5.75	Good shot.
99	59	Flat, Long Chunk	225-IMR4350	736	710	N/A	Forgot to get depth of penetration.
100	59	Flat, Long Chunk	225-IMR4350	739	705	2.50	Good shot.
101	59	Flat, Long Chunk	225-IMR4350	1054	1001	N/A	Bad shot.
102	58	Chunky	225-IMR4350	1525	1451	5.50	Good shot.
103	58	Chunky	225-IMR4350	492	468	N/A	Bad shot. Bounced out and hit floor.
104	57	Chunky	225-IMR4350	1612	1531	6.00	Good shot.
105	55 (?)	Chunky	225-IMR4350	1744	1659	6.00	Good shot except for possible mistaken identity of fragment.

Nomenclature: 1. N/A: Not applicable
2. Velocities in parenthesis are the mean estimates for equivalent powder weights and types. These are quite reliable and are plotted in Figure 3.

TABLE II. 240-GRAIN BOMB FRAGMENT SHAPE CLASSIFICATION, POWDER CHARGE MEASURED VELOCITY, STRIKING VELOCITY, AND PENETRATION INTO NU-WOOD DATA.

SHOT NO.	FRAGMENT NO.	SHAPE CLASSIFICATION	POWDER WEIGHT (GRAINS) TYPE	MEASURED VELOCITY (FT/SEC)	STRIKING VELOCITY (0.9514 x MEASURED VELOCITY) (ft/sec)	NU-WOOD FRAGMENT PENETRATION DEPTH PERPENDICULAR TO NU-WOOD SURFACE TO ESTIMATED CENTER OF GRAVITY OF FRAGMENT (INCHES)	COMMENTS
1	19	Flat Chunk	500-IMR4350	2044	1975	12.00	Good shot.
2	19	Flat Chunk	600-IMR4350	2255	2179	7.25	Good shot.
3	19	Flat Chunk	850-IMR4350	1964	1897	N/A	Sabot velocity. Fragment struck Nu-Wood holder frame.
4	17	Long Chunk	850-IMR4350	3313	3230	16.50	Fragment broke up into two halves at final fragment location.
5	18	Long Chunk	800-IMR4350	N/A	N/A	9.00	No velocity recorded. Bad shot.
6	18	Long Chunk	800-IMR4350	2264	2187	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity.
7	5	Flat, Flat Chunk	800-IMR4350	2494	2409	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity.
8	8	Long Chunk	800-IMR4350	2355	2275	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity.
9	6	Long Chunk	800-IMR4350	N/A	N/A	N/A	Fragment hit catcher. Bad shot. No time recorded.
10	10	Long Flat	800-IMR4350	471	455	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity.
11	2	Chunky	800-IMR4350	2855	2758	17.00	Good shot.
12	2	Chunky	825-IMR4350	1749	1690	9.50	Good shot.
13	2	Chunky	825-IMR4350	1834	1772	11.00	Good shot.
14	2	Chunky	700-IMR4895	2339	2260	11.00	Good shot.
15	2	Chunky	800-IMR4895	3042	2939	11.50	Good shot.
16	14	Long, Long Flat	800-IMR4895	2992	2891	N/A	Bad shot. Fragment hit sabot catcher.
17	13	Long, Long Flat	800-IMR4895	3370	3256	19.25	Good shot.
18	7	Chunky	800-IMR4895	2856	2759	12.50	Good shot.
19	7	Chunky	300-IMR4895	1518	1466	12.50	Good shot.
20	16	Flat Chunk	250-IMR4895	489	472	N/A	Bad shot. Fragment hit sabot catcher.
21	15	Long, Long Flat	250-IMR4895	1181	1141	5.25	Good shot.
22	12	Long, Long Flat	240-IMR4895	1141	1102	4.50	Good shot.
23	12	Long, Long Flat	230-IMR4895	1054	1018	4.75	Good shot.
24	11	Flat Chunk	225-IMR4895	599	579	2.50	Good shot.
25	11	Flat Chunk	228-IMR4895	345	333	1.50	Good shot.
26	11	Flat Chunk	250-IMR4895	917	886	3.50	Good shot.
27	16	Flat Chunk	250-IMR4895	345	334	.75	Good shot.

28	16	Flat Chunk	250-IMR4895	517	506	N/A	Bad shot. Fragment hit catcher.
29	20	Long, Long Flat	230-IMR4895	714	690	5.00	Good shot.
30	20	Long, Long Flat	230-IMR4895	1050	1004	7.00	Bad shot. Sa-Wood not packed.
31	20	Long, Long Flat	240-IMR4895	446	431	N/A	Bad shot. Hit sabot catcher.
32	16	Long, Long Flat	245-IMR4895	1047	1012	5.75	Good shot.
33	15	Flat Chunk	245-IMR4895	721	697	5.50	Good shot.
34	15	Long, Long Flat	500-IMR4895	367	355	N/A	Bad shot. Hit sabot catcher.
35	15	Long, Long Flat	500-IMR4895	861	832	2.00	Good shot.
36	15	Long, Long Flat	500-IMR4895	920	889	5.25	Good shot.
37	4	Chunky, Long Chunk	600-IMR4895	1930	1871	14.00	Good shot.
38	4	Chunky, Long Chunk	600-IMR4895	517	501	6.00	Depth and velocity seem quite unrelated. This is probably due to fragment's shape character.
39	4	Chunky, Long Chunk	600-IMR4895	780	754	6.50	Good shot. Again, fragment's shape is causing great depth.
40	4	Chunky, Long Chunk	800-IMR4895	N/A		N/A	Bad shot. No velocity and fragment hit sabot catcher.
41	7	Chunky	800-IMR4350	867	838	6.50	Good shot.
42	2	Chunky	800-IMR4350	1907	1842	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity recorded.
43	9	Flat Chunk	800-IMR4350	2317	2238	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity recorded.
44	1	Long Chunk	800-IMR4350	2472	2388	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity recorded.
45	13	Long, Long Flat	800-IMR4350	2094	2023	N/A	Bad shot. Fragment hit printed circuit paper holder.
46	13	Long, Long Flat	800-IMR4350	N/A	N/A	N/A	Bad shot. No velocity and fragment hit sabot catcher.
47	11	Flat Chunk	800-IMR4350	2380	2299	14.50	Good shot.
48	11	Flat Chunk	800-IMR4350	2107	2383	N/A	Bad shot. Fragment hit sabot catcher. Sabot velocity.
49	23	Chunky	800-IMR4350	2439	2414	7.00	Good shot.
50	21	Chunky	800-IMR4350	2352	2272	7.50	Good shot.
51	27	Chunky	1000-IMR4350	2067	1997	13.50	Good shot.
52	26	Chunky	1000-IMR4350	2827	2731	N/A	Bad shot. Fragment hit catcher.
53	27	Chunky	1000-IMR4350	2910	2811	N/A	Bad shot. Fragment hit catcher.
54	22	Chunky	1000-IMR4350	2443	2360	14.00	Good shot.
55	24	Chunky	1000-IMR4350	N/A		N/A	Bad shot. No velocity and fragment hit sabot catcher.
56	22	Chunk	1000-IMR4350	3727	3601	14.00	Good shot.

TABLE II. (CONCLUDED)

SHOT NO.	ENGAGE NO.	SHAPE CLASSIFICATION	POWDER WEIGHT (GRAINS), TYPE	MEASURED VELOCITY (FT/SEC)	STRIKING VELOCITY (0.9514 x MEASURED VELOCITY) (ft/sec)	NU-WOOD FRAGMENT PENETRATION DEPTH PERPENDICULAR TO NU-WOOD SURFACE TO ESTIMATED CENTER OF GRAVITY OF FRAGMENT (INCHES)	COMMENTS
57	22	Chunky	1000-IMR4350	2826	2730	16.50	Good shot.
58	22	Chunky	1000-IMR4350	2966	2865	N/A	Bad shot. Fragment hit catcher. Sabot velocity.
59	25	Flat, Flat Chunk	1030-IMR4350	3008	2906	9.50	Good shot.
60	5	Long Flat	250-IMR4350	564	545	2.00	Good shot.
61	5	Long Flat	300-IMR4350	1218	1177	8.75	Bad shot. A 1-gram weight loss. Did not locate piece.
62	21	Chunky	280-IMR4350	995	961	N/A	Bad shot. Hit too close to another hole.
63	21	Chunky	280-IMR4350	881	851	N/A	Bad shot. Fragment hit sabot catcher.
64	28	Chunky	280-IMR4350	927	896	6.50	Good shot.

Nomenclature: 1. N/A: Not applicable
2. There are no estimated velocities from equivalent powder weights and types for these firings.

SECTION IV

SECONDARY OBJECTIVES

When a difference factor of two or greater exists in impact presented area between two 60-grain fragments at the same velocity, then the presented area seems to be an independent variable in penetration. Table III helps to support this conclusion.

The presented area upon impact of 240-grain fragments does not seem to be a significant variable in depth of penetration. This conclusion results from studying Table IV.

The 60-grain fragment break-offs were generally located along the fragment path. This is contrary to the 15-grain study where the break-offs were at the final mother fragment position. The 240-grain fragments had few breakoffs and not enough study was given about their origin.

For the same velocity and mass the penetration could be related to a function of many variables:

Penetration = F (Fragment shape, fragment surface, fragment tumbling before and after impact, fragment impacting presented area, compression of Nu-Wood, etc.)

An examination of bore sight, fragment entrance, and finalized position in Nu-Wood co-ordinates reveals no appreciable air deflection and Nu-Wood deflection of fragments. Air deflection could be attributed to the sabot aiming the fragment after exit from the Mann barrel. Since the Nu-Wood deflection is slight, no transformations are made on the perpendicular to Nu-Wood surface penetration data. All the penetration data in Figures 3 and 4 need not be corrected for the slight angular deflections in Nu-Wood.

Some other interesting facts found from testing are:

a. The recovered fragments had Nu-Wood clinging to them.

b. As the fragment goes deeper into the Nu-Wood it tends to make a large and less clean or sharp hole. This could be attributed to Nu-Wood building up on the fragment as it penetrates.

c. The Lexan sabot will be dented on its base from the fragment's initial momentum impulse.

d. For better air flight stability a sabot fitting a fragment is better than a sabot with a hole too large.

TABLE III. PRESENTED AREAS OF IMPACTING 60-GRAIN BOMB FRAGMENTS

SHOT NO.	FRAGMENT NO.	SHAPE CLASS	X(DEPTH OF PENETRATION PERPENDICULAR TO NU-WOOD SURFACE TO ESTIMATED CENTER OF GRAVITY OF FRAGMENT) (INCHES)	A(PRESENTED AREA OF FRAGMENT) (INCHES^2)	V(STRIKING VELOCITY) (FT/SEC)
91	39	Flat, Long Chunky	2.00	.2050	710
93	39	Flat, Long Chunky	2.25	.1175	757
4	1	Chunky	2.50	.1450	774
3	1	Chunky	2.75	.1275	848
1	1	Chunky	2.00	.1250	646
97	39	Flat, Long Chunky	3.25	.0225	675
92	39	Flat, Long Chunky	3.50	.1675	1302
96	39	Flat, Long Chunky	4.00	.0475	1248
24	8	Chunky	4.50	.1700	1475
102	38	Chunky	5.50	.1013	1451
105	35	Chunky	6.00	.1825	1659
104	37	Chunky	6.00	.1250	1534
71	39	Flat, Long Chunky	6.00	.2075	2289
57	19	Flat, Flat Chunky	7.50	.0763	2237
75	36	Flat, Flat Chunky	9.00	.2388	2671
82	33	Chunky	10.50	.1650	2647
65	30	Chunky	10.75	.1150	2657
62	29	Flat Chunky, Long Chunky	11.75	.1175	2678
64	30	Chunky	13.25	.0800	2613
85	38	Chunky	9.50	.1413	2844
66	30	Chunky	11.25	.1300	2845
81	33	Chunky	13.00	.0863	2862
68	36	Flat, Flat Chunky	17.25	.0450	2882
73	36	Flat, Flat Chunky	9.25	.0975	3039
83	38	Chunky	14.00	.1300	3034
79	34	Long	14.00	.0713	3004
86	37	Chunky	10.00	.1475	3130
84	38	Chunky	19.00	.1600	3111
61	19	Flat, Flat Chunky	10.50	.0925	3134
87	38	Chunky	11.25	.1150	3119
88	38	Chunky	12.50	.1463	3133
76	36	Flat, Flat Chunky	15.00	.1188	3179
56	19	Flat, Flat Chunky	11.00	.1250	3559
58	19	Flat, Flat Chunky	11.50	.1100	3582
23	8	Chunky	11.62	.2019	4509
31	19	Flat, Flat Chunky	13.50	.1450	4537
33	19	Flat, Flat Chunky	13.50	.1838	4503
21	8	Chunky	11.88	.1925	4688
22	8	Chunky	12.00	.2200	4708
26	8	Chunky	12.50	.0888	4815
48	14	Flat Chunky	16.50	.1238	4790
8	2	Flat Chunky	12.50	.2238	4920
16	11	Flat Chunky	13.12	.1125	4989
29	10	Flat Chunky	14.50	.0800	4982
14	6	Flat Chunky	10.75	.1494	5041
34	19	Flat, Flat Chunky	11.25	.2288	5023

TABLE IV. PRESENTED AREAS OF IMPACTING 240-GRAIN BOMB FRAGMENTS

SHOT NO.	FRAGMENT NO.	SHAPE CLASS	X(DEPTH OF PENETRATION PERPENDICULAR TO NU-WOOD SURFACE TO ESTIMATED CENTER OF GRAVITY OF FRAGMENT) (INCHES)	A(PRESENTED AREA OF FRAGMENT) ($INCHES^2$)	V(STRIKING VELOCITY) (FT/SEC)
1	19	Flat Chunky	12.00	.1650	1975
51	27	Chunky	13.50	.3875	1997
2	19	Flat Chunky	7.25	.6850	2179
14	2	Chunky	11.00	.1400	2260
60	3	Long Flat	2.00	.1125	545
38	4	Chunky, Long Chunky	6.00	.1913	501
26	11	Flat Chunky	3.50	.2638	886
41	7	Chunky	6.50	.4013	838
64	28	Chunky	6.50	.3050	896
22	12	Long, Long Flat	4.50	.5000	1102
21	13	Long, Long Flat	5.25	.0900	1141
49	21	Chunky	7.00	.0650	2414
54	22	Chunky	14.00	.2888	2360
59	23	Flat, Flat Chunky	9.50	.0663	2906
15	2	Chunky	11.50	.3463	2939
12	2	Chunky	9.50	.3275	1690
13	2	Chunky	11.00	.5250	1772
37	4	Chunky, Long Chunky	14.00	.2888	1874
14	2	Chunky	11.00	.1400	2260
47	11	Flat Chunky	14.50	.1300	2299
18	7	Chunky	12.50	.4525	2759
11	2	Chunky	17.00	.4150	2758

SECTION V

CONCLUSIONS

The fundamental conclusions are:

a. The existing Thor equation predictions for cylinders do not fit actual 60-grain and 240-grain bomb fragment data.

b. Depth of penetration into Nu-Wood is not a reliable method to predict velocities for 60-grain and 240-grain bomb fragments.

c. The depth of penetration is not a primary function of impact presented area for 60-grain and 240-grain bomb fragments. The 60-grain fragments seem more sensitive to impact presented area than the 240-grain fragments.

REFERENCES

1. Section II of USAF TH 61A1-3-7 titled, "JMEM/AS Joint Service Test Procedures for High Explosive Bomb and Bomblets."

2. Malick, Donald, The Calibration of Wallboard for the Determination of Partical Speed, Ballistic Analysis Laboratory, TR-61, May 1966, Page 16.

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13 ABSTRACT

The primary objective of this program was to define a function between the striking velocity for 60-grain and 240-grain random shaped bomb fragments and their depth into the wallboard trade named Nu-Wood. The 60-grain fragments were fired from a 20mm Mann barrel and the 240-grain fragments from a 30mm Mann barrel into bundled Nu-Wood. The 60-grain fragments were lightly filed to fit into a 3.77 $\leq \omega \leq$ 4.01 gram weight range and the 240-grain fragments into a 15.08 $\leq \omega \leq$ 16.02 gram weight range. The striking velocities for the 60-grain fragments were in the 600 ft/sec to 5000 ft/sec range and the 240-grain fragments in the 300 ft/sec to 3500 ft/sec range. The graph of fragment striking velocity as a function of depth into Nu-Wood showed a wide range of depths for approximately 2000 ft/sec and above striking velocities. A lower dispersion in penetration depths exists for velocities up to 2000 ft/sec. A least squares curve would not be valuable since the penetration spread is too wide at given velocities. Fragment penetration into Nu-Wood from firing cylinders does not give a realistic picture of 60-grain and 240-grain actual bomb fragmentation spread. The depth of penetration is not a primary function of the initial presented areas of impacting 240-grain fragments for 500 ft/sec to 3000 ft/sec velocities. When a factor of two or more exists between impacting presented areas for 60-grain bomb fragments, then the presented area seems to influence penetration.

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