U. S. NAVAL PROVING GROUND

DAHLGREN, VA.

REPORT NO. 2-43

THE EFFECT OF NOSE SHAPE ON THE BALLISTIC PERFORMANCE OF 15-lb. 3" AP SOLID SHOT AGAINST HOMOGENEOUS ARMOR PLATE.

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P R E F A C E

AUTHORIZATION

This study was authorized as part of N.P.G. Research Project APL-6, in Bureau of Ordnance letter NP9/A9 (Re3) dated 9 January, 1943.

OBJECT

This report describes part of a cooperative program with Frankford Arsenal on 3" solid armor-piercing shot. It deals with the effect of nose shape on ballistic performance.

SUMMARY

Ballistic limit determination are reported for the Army M-79 3" 15-lb. AP solid shot and for eight other experimental 15-lb. solid shot with various nose shapes machined on the M-79 body. The noses ranged from a pointed ogive of four-caliber radius to a blunt ogive of hemispherical form. The homogeneous plate used ranged from 0"73 to 4"17 in thickness, and the obliquity from 0° to 45°.

The blunt nosed forms were found to require the lowest striking velocities for complete penetration of the plate whenever they were able to effect a punching type of penetration. They shattered against plates too thick to punch.

On thick plate at low obliquities, sharper projectiles gave the best performance, but at higher obliquities they were subject to bending stresses which shattered them.

At high obliquities, angular nose outlines were more effective than rounded outlines. For .73" plate at 45° obliquity, the range of limit velocity was as much as 17 per cent for the different nose shapes.

Recommendations are made for further firing of projectiles with completely flat noses and for experimental variations in composition and heat-treatment of other blunt nosed forms.

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CONTENTS

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LIST OF FIGURES

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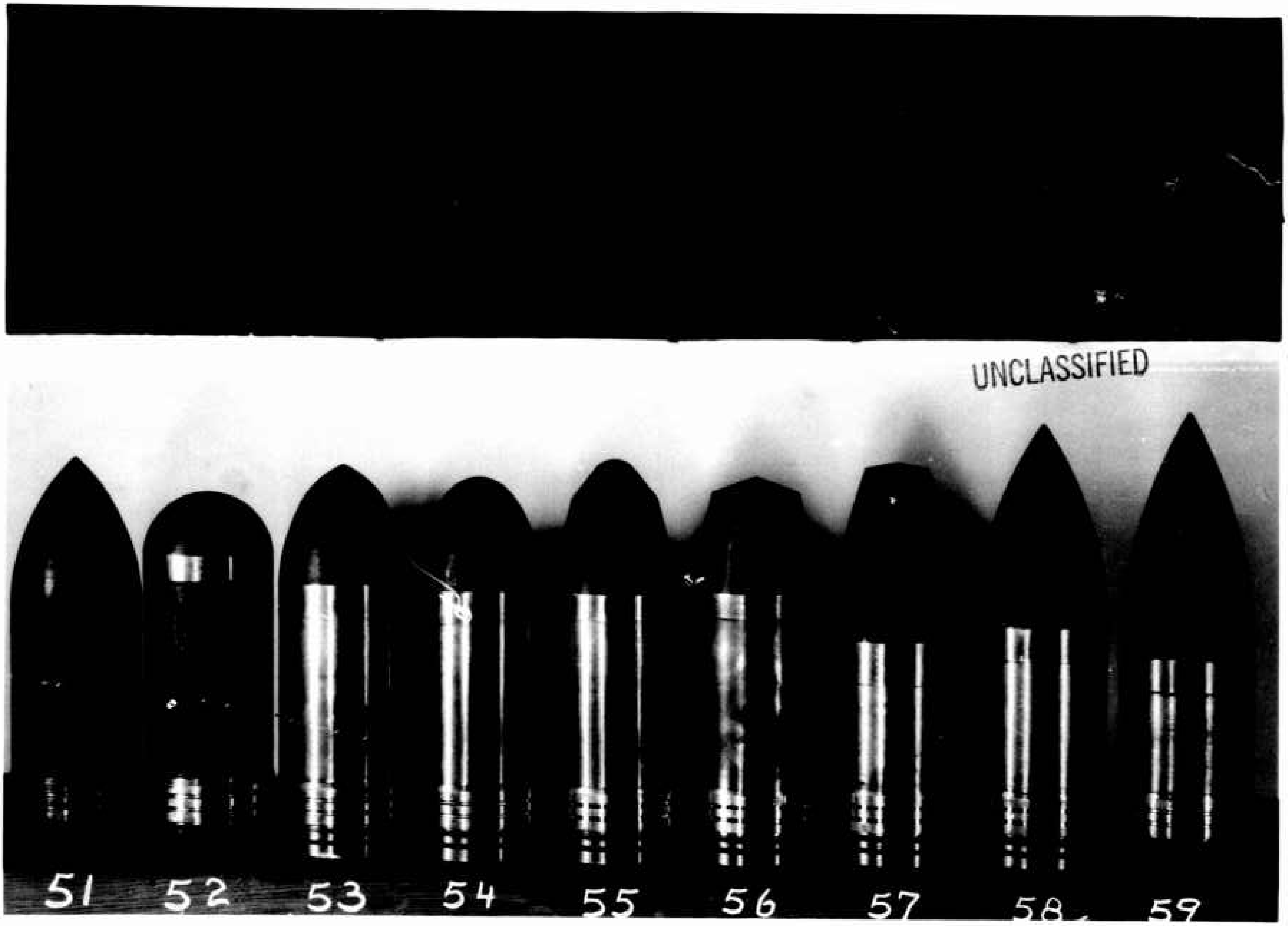

I INTRODUCTION.

In connection with a general study of projectile composition, form and heat treatment, approved as NPG Research Project APL-6, in Bureau of Ordnance letter NP9/A9(Re3) dated 9 January, 1943, it was considered desirable to investigate as a first case the effect of nose shape on the performance of uncapped, solid projectiles. The Frankford Arsenal, in a letter dated April 1, 1942, proposed to supply a series of such projectiles for test at the Naval Proving Ground. The present report describes the result of firing of projectiles with nose shapes determined in conferences between Frankford Arsenal and Proving Ground representatives, and supplied by Frankford Arsenal. The firing was carried out in the Armor and Projectile Laboratory Range at the Naval Proving Ground.

II MATERIALS AND METHODS.

PROJECTILES:

Eight experimental nose designs (Figure 1) were prepared at Frankford Arsenal. Three were simple ogives, of 1/2 cal., 3 cal., and 4 cal. radius respectively; two were ogives with two or more radii; and three had complex contours resembling capped AP projectiles.

These eight nose designs were machined on Army M-79 3" AP projectile bodies, the length of the cylindrical portion being varied to keep the total weight at approximately 15 pounds. The characteristics of the experimental designs, together with those of the M-79 projectile, are summarized in the following table:

Drawing No. B-LM	Description	Length of nose bourrelet to tip	Angle of nose at tip
51	Standard Army M-79 shot with 1.67 cal. ogive	3".57	91°
52	Hemispherical Nose; 0.5 cal. ogive	1".50	180°
53	Blunt double ogive, resembling 3" Navy Type A-1 projectile nose	2".96	138°
54	Blunt triple ogive, resembling 3" Navy Type A projectile nose	2".76	180°

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Drawing No. B-LM	Description	Length of nose bourrelet to tip	Angle of nose at tip
55	Contour resembling 3" Navy Type A-1 cap	3".06	180°
56	Contour resembling 37 mm. Army M51B2 cap	2".62	139°
57	Contour resembling 8" Navy Mk. 11 cap	4".05	158°
58	Single 3 cal. ogive	4".94	67°
59	Single 4 cal. ogive	5".78	58°

Drawings of the projectiles are given in reference (1).

All the projectiles were machined from bar stock of WD-4150 and given the current standard heat-treatment of M-79 AP shot at Frankford Arsenal, details of which are also reported in reference (1).

METHOD OF COMPARISON OF PROJECTILE PERFORMANCE.

The comparison of the performance of the different experimental projectiles in this report is based on the calculated $F(e/d,\theta)$ values under each test condition. $F(e/d,\theta)$ is defined as follows:

$$F(e/d,\theta) = 41.57 \frac{M^{1/2} V \cos\theta}{e^{1/2} d}$$

where M is the projectile mass in pounds, V is the limit velocity in feet per second (the minimum velocity required for the projectile to pass completely through the plate) θ, the obliquity, is the angle between the normal to the plate and the line of flight, e is the plate thickness at point of impact in inches, and d is the projectile diameter in inches. The $F(e/d,\theta)$ value calculated for each projectile under each test condition is then compared with standard Navy $F(e/d,\theta)$ values as given by the 1931 empirical formula

$$F(e/d,\theta) = 6(e/d - 0.45)(\theta^2 + 2000) + 40{,}000$$

where e and d are in the same units and θ is in degrees. The calculated value of F is expressed in the tables in the Appendix as a percentage of this empirical F. For complete penetrations the limit velocity is calculated from residual velocity measurements and for incomplete penetrations from the depth

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of penetration In the event that a good estimate of the limit cannot be made, the value of $F(e/d,\theta)$ is calculated by using in place of the limit velocity the highest striking velocity giving incomplete penetration, and the result is marked with a plus sign to indicate that the true value is higher.

TEST CONDITIONS:

Guns: 3"/50 cal. Mk. 19 No. 5523.
3"/23 cal. Mk. 13 No. 2044.

Plate: 0"73 STS Carnegie-Illinois No. 83880 at 0° and 45° obliquity (T.S. = 122,000 psi.)

1"94 STS Carnegie-Illinois No. 87547 at 0°, 30° and 45° obliquity (T.S. = 131,000 psi.)

4-1/16" Class B Carnegie-Illinois No. DD37 at 0° obliquity (T.S. = 108,000 psi.)

III RESULTS:

In Table I the projectile performance is given in terms of the percentage of the M-79 (no.51) projectile limit under the same test conditions. The detailed results given in the Appendix are summarized below.

TABLE I

Projectile performance in terms of percentage of M79. The lowest percentage indicates the best projectile performance.

No.	Projectile Nose Shape	Plate Thickness and Obliquity 0"73 0°	1"95 0°	4" 0°	1"95 30°	1"95 40°	0"73 45°
51	M79 - 1.67 cal. ogive	100	100	100	100	100	100
52	Hemisphere - .5 cal.ogive	93	93	(102)	103	100	113+
53	Type A-1 - Uncapped	97	103*	102	105	99	109
54	Type A - Uncapped	95	102*	103	102	100	112+
55	Type A-1 - Capped	98	100*	103	100	(104)	107
56	M51B2 - Capped	96	97	(100)	103	99	100
57	Mk. 11-1 - Capped	96	(98)	(102)	103	(103)	99
58	3-Cal. ogive	100	96	97	(101)	(102)	96
59	4-Cal. ogive	99	97	96	(98)	(103)	96

* Limit estimated from depth of penetration.
\+ Projectile rejected in excellent condition. The limit is greater than the figure given.
( ) Projectile rejected shattered at this value. Limit uncertain.

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vs. 3"
B.I.No.
"e"
Condition
760 APL 4.16
1-3/4"
761 1908 1-1/2" 15.05
4-3/4"
764 Corp. 445 15.45 ot yet recovered.
765 4.10
767 4.17 in plate.
769 4.16
-11 September,
119
760
761
762
763
764
765
766
767
768
769
792

IV DISCUSSION.

0° Obliquity. 0"73 and 1"95 STS and 4" Class B

The results have shown that against thin plate, on which the projectiles did not deform on impact, the blunter projectiles in general gave complete penetrations at lower striking velocities than the standard M-79 (No. 51); while against thick plate the blunt projectiles were inferior not only because of breakage but also because of higher limit values. Thus against 0"73 STS all of the projectiles except the 3-caliber (No. 58) and 4-caliber (No. 59) ogives gave lower limit values than the standard M-79 and the hemispherical-nose projectile (No. 52) gave the lowest limit of 7% below the M-79 value. Against the 1.95 plate Nos. 52, 56, 58 and 59 gave limits of from 3 to 7% below the M-79 limit value with the hemispherical-nose projectile (No. 52) again giving the lowest limit at 7% below the M-79 value. All of the other projectiles gave higher limits, while the No. 57 shattered on an incomplete penetration at 98% of the M-79 limit.

Against 4" Class B (Figure 2) the 3-caliber (No. 58) and 4-caliber (No. 59) ogives gave the lowest limits with values of 3 to 4% below those obtained with the M-79, all of the other contours either giving higher limits than the M-79 or shattering on impact. To summarize then, the blunter projectiles in general gave lower limits against 0"73 and 1"95 STS with the hemispherical-nose projectile (No. 52) giving the best performance with limits of 6% and 7% below the M-79 value, whereas against 4" plate the bluntest projectiles shattered on impact, those blunter than the M-79 that did not shatter gave higher limits than the M-79, while the sharper projectiles (3-caliber and 4-caliber ogives) gave the best performance 3 to 4% below the M-79 value.

The low limit values found for the blunt projectiles, particularly those with the hemispherical noses against 0"73 and 1"95 STS is probably a result of the fact that the plate failures in those cases were by punching, which is known to be a lower energy type of failure than the usual piercing mechanism. The reason that the bluntest projectiles failed against thick plate seems to be that because of their bluntness the initial stresses on the nose are greater than for more pointed projectiles. In the case of 4" Class B the stresses were sufficient to shatter the blunter of the projectiles submitted for this test.

30° Obliquity. 1"95 STS

Against 1"95 STS at 30°, the standard M-79, No. 51, and No. 55 gave the lowest limits of any of the projectiles tested. The total spread between the M-79 and poorest pro-

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NPG PHOTO [illegible] (APL) - APL Plate [illegible] 121 (C.I. 1194 STS plate 87547) vs. 3" F.A. exper. ogive [illegible] projectiles at 4[illegible] obl. FRONT VIEW.

F.I.No.	"e"	"[illegible]"	S.V.,f.s.	[illegible]	R.V.,f.s.	Proj.Type	Weight	Condition
776-APL	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	15.[illegible] lb.	Shattered.
777	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]16	[illegible]	[illegible]	Not yet rec.
778	[illegible]	[illegible]	[illegible]	"	[illegible]	[illegible]	[illegible].5	Slightly upset.
779	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]
780	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]3	Shattered.
781	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	15.[illegible]	Shattered.
782	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] nose.

14-1[illegible] [illegible] [illegible]

jectile (No. 53) was 6%. The 3-caliber and 4-caliber ogives shattered on incomplete penetration, 1% above and 2% below the M-79 limit, respectively.

<u>40° Obliquity. 1"95 STS</u>

Nos. 51 (the M-79), 52, 53, 54 and 56 all gave the same limits within 1% and the others all shattered on incomplete penetrations at two to four per cent above the M-79 limit (Figure 3). The blunter, more round nosed, projectiles gave the best performance under these conditions.

<u>45° Obliquity. 0"73 STS</u>

Against 0"73 STS at 45° the sharpest projectiles, - the 3-caliber ogive (No. 58) and 4-caliber ogive (No. 59) - gave the lowest limits of 4% below the M-79 limit values. Nos. 56 and 57 gave within 1% the same limit as the M-79. All of the other projectiles had limits or were rejected at velocities of from 5 to 9% above the M-79 limit.

V <u>CONCLUSIONS</u>.

At low values of e/d and low obliquities the best penetration of homogeneous armor is given by blunt-nosed projectiles. This result follows because of the punching action of such projectiles.

At high values of e/d (0.6 to 1.3) and low obliquities (0°) sharper-nosed projectiles give the best performance. Local stresses are built up on the flat portions of blunt-nosed projectiles under such conditions, which may be sufficient to shatter the projectiles. (The fact that the blunter projectiles gave higher limits in this case may be a result of greater deformation for them than for the more pointed projectiles).

At intermediate values of e/d (0.6) and high obliquities, (30° - 40°) long-nosed projectiles are subject to bending stresses which may shatter the nose before penetration. Under these conditions projectiles with rounded nose outlines will ricochet from the plate at velocities at which projectiles having a shoulder on the nose are enabled to "take hold" of the plate and to penetrate completely.

VI <u>RECOMMENDATIONS</u>.

Since blunt-nosed projectiles were found to give the lowest limits wherever they were able to penetrate without shattering, it is recommended that as the next step in the co-operative program a series of projectiles with the extreme case of a blunt nose, namely an entirely flat nose, be manufactured and tested. It appears desirable to have groups of different weights, for example 15 pounds and 7-1/2 pounds, in order to secure as much information as possible on the mechanism of punching. The effect of the addition of a windshield should also be studied.

Earlier tests of blunt and flat nosed projectiles against armor do not seem to have fully explored the possibilities of this type of projectile against such targets as tanks, submarines and lightly-armored vessels, and of flat nosed bombs against deck armor. Attention should be paid to the behavior against plate of such projectiles when equipped with windshields attached in various ways and when made with modifications of a simple square end. Attention should also be paid to the possibility of improving the performance of blunt nosed projectiles by determination of the optimum alloy composition and optimum heat treatment.

VII REFERENCES.

(1) Frankford Arsenal Report No. R-255 of 9 November, 1942.

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VIII APPENDIX.

Symbols.

% = ...	% of empirical $F(e/d,\theta)$ value.
37,000 ...	Limit $F(e/d,\theta)$ value based on residual velocity measurements.
37,000* ..	Limit estimated from depth of penetration.
37,000+ ..	Projectile rejected in excellent condition at the $F(e/d,\theta)$ value. The true limit $F(e/d,\theta)$ is thus greater than the figure given.
( )	Projectile rejected shattered at this value.
CP	Complete penetration.
Inc	Incomplete penetration.

Projectile Condition.

E	Excellent.
NB	Nose shattered. (Less than than half of projectile shattered).
X	Shattered. (More than half of projectile shattered).
NU	Nose upset.

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Ballistic Results

0"73 STS at 0° Obliquity.

APL Impact No.	Proj.	e in.	θ	m lbs.	V_S f.s.	Pene. in.	V_R f.s.	Observed F(e/d,θ)	%	Proj. Cond.
964	51	0.729	4°10'	15.00	593	CP	0	37,300	100	E
972	52	0.729	0°30'	15.20	585	CP	214	34,800	93	E
967	53	0.729	2°20'	15.45	609	CP	227	36,400	97	E
968	54	0.729	1°30'	15.10	606	CP	230	35,800	95	E
970	55	0.729	4°10'	15.30	583	CP	59	36,800	98	E
971	56	0.730	0°20'	15.30	572	CP	106	35,800	96	E
969	57	0.729	4°40'	15.05	601	CP	192	36,100	96	E
965	58	0.729	0°30'	15.35	611	CP	159	37,700	100	E
966	59	0.729	0°40'	15.20	607	CP	164	37,200	99	E

0"73 STS at 45° Obliquity.

APL Impact No.	Proj.	e in.	θ	m lbs.	V_S f.s.	Pene. in.	V_R f.s.	Observed F(e/d,θ)	%	Proj. Cond.
801	51	0.73	45°00'	14.90	774	CP	340	31,200	89	E
802	51	0.73	45°00'	14.90	739	CP	239	31,200	89	E
809	52	0.73	44°50'	15.20	792	(Inc)	-	35,600+	102+	E
807	53	0.73	45°00'	15.45	749	CP	0	33,900	97	E
808	54	0.73	45°00'	15.10	790	(Inc)	-	35,300+	101+	E
806	55	0.73	45°00'	15.30	752	CP	122	33,500	96	E
810	56	0.73	45°00'	15.25	777	CP	360	31,300	90	E
805	57	0.73	45°00'	15.05	762	CP	328	31,000	89	E
803	58	0.73	45°00'	15.35	764	CP	405	29,700	85	E
804	59	0.73	45°00'	15.15	765	CP	400	29,700	85	E

1"95 STS at 0° Obliquity.

APL Impact No.	Proj.	e in.	θ	m lbs.	V_S f.s.	Pene. in.	V_R f.s.	Observed F(e/d,θ)	%	Proj. Cond.
892	51	1.943	1°00'	14.90	1255	CP	259	47,300	112	E
894	52	1.944	3°40'	15.15	1209	CP	371	44,000	104	E
899	53	1.940	1°10'	15.45	1242	4-3/4"	-	48,700*	115*	E
898	54	1.940	0°10'	15.15	1228	3-1/2"	-	48,300*	114*	E
897	55	1.940	0°10'	15.30	1215	8-1/8"	-	47,400*	119*	E
895	56	1.943	1°00'	15.30	1203	CP	198	46,100	109	E
896	57	1.941	3°10'	15.00	1213	Inc.	-	(46,800)	(110)	X
900	58	1.943	1°20'	15.35	1219	CP	341	45,800	108	E
901	59	1.945	2°50'	15.30	1190	CP	142	46,000	109	E

1"95 STS at 30° Obliquity.

APL Impact No.	Proj.	e in.	θ	m lbs.	V_S f.s.	Pene. in.	V_R f.s.	Observed F(e/d,θ)	%	Proj. Cond.
785	51	1.95	30°00'	15.00	1360	CP	419			E
786	51	1.95	30°00'	15.00	1352	CP	400			E
787	51	1.95	30°05'	15.00	1296	3-3/4"		43,700	101	E
793	52	1.95	30°00'	15.25	1351	CP	78	45,300	104	E
795	53	1.95	30°00'	15.45	1360	CP	143	46,000	106	E
794	54	1.95	30°05'	15.20	1357	CP	249	44,800	103	E
790	55	1.95	30°05'	15.35	1344	CP	334	43,900	101	E
792	56	1.95	30°00'	15.25	1350	SIP	-	45,300	104	E
791	57	1.95	30°20'	15.10	1356	CP	-	45,200	104	E
789	58	1.95	30°00'	15.35	1311	Inc	-	(44,300)	(102)	NP
788	59	1.95	29°50'	15.30	1279	Inc	-	(43,100)	(99)	NP

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1"95 STS at 40° obliquity.

APL Impact No.	Proj.	e in.	θ	m lbs.	V_S f.s.	Pene. in.	V_R f.s.	F(e/d,θ)	%	Proj. Cond
774	51	1.95	40°10'	14.95	1617	-	-			X
775	51	1.95	40°10'	15.00	1676	CP	370			NU
773	51	1.95	40°15'	15.00	1740	CP	852	48,800	110	NU
777	52	1.95	40°00'	15.30	1679	CP	616	48,700	110	NU
773	53	1.95	40°00'	15.50	(1690)	CP	729	48,200	109	NU
784	54	1.95	39°55'	15.20	1699	CP	739	48,700	110	NU
783	55	1.95	39°50'	15.30	1688	Inc	--	(50,500)	(114)	X
782	56	1.95	40°00'	15.35	1667	CP	690	48,100	109	NB
781	57	1.95	40°00'	15.10	1686	Inc	--	(50,000)	(113)	X
779	58	1.95	40°00'	15.40	1666	Inc	--	(49,800)	(112)	X
780	59	1.95	39°50'	15.30	1677	Inc	--	(50,200)	(113)	NB

4" Class B at 0° obliquity

APL Impact No.	Proj.	e in.	θ	m lbs.	V_S f.s.	Pene. in.	V_R f.s.	F(e/d,θ)	%	Proj. Cond
738	51	4.03	0°10'	14.90	2043	CP	817			E
739	51	4.04	0°20'	14.95	2165	CP	1075	49,400	97	E
757	52	4.07	0°10'	15.30	1883	Inc	--	(50,700)	(100)	X
764	53	4.16	0°10'	15.45	1949	CP	445	50,800	99	E
763	54	4.16	0°10'	15.20	1891	4-3/4"	--			E
767	54	4.17	0°10'	15.20	1998	Inc	--	(53,100)	(104)	X
762	55	4.15	0°10'	15.25	1895	6-5/8"	--			E
768	55	4.17	0°00'	15.30	1925	CP	--	51,000	100	E
760	56	4.16	0°00'	15.25	1861	1-3/4"	--	(49,500)	(97)	X
761	57	4.15	0°00'	15.05	1908	1-1/2"	--	(50,700)	(99)	X
766	58	4.17	0°20'	15.40	1889	CP	593	48,100	(94)	E
758	59	4.08	0°10'	15.30	1903	CP	722			E
759	59	4.08	0°40'	15.25	1776	CP	263	47,200	(93)	E

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