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NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

REPORT NO. 19-44

PENETRATION OF HOMOGENEOUS PLATE BY 3" 13.0 LB. FLAT NOSED PROJECTILES FITTED WITH WINDSHIELDS SECOND PARTIAL REPORT

29 July 1944

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SECOND PARTIAL REPORT

APPROVED:

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Previous Reports:

1. NPG Report No. 7-43 dated 19 April 1943.
2. NPG Report No. 12-44 dated 20 April 1944.

P R E F A C E

AUTHORIZATION

This study was authorized in the Bureau of Ordnance letter NP9/A9(Re3) dated 9 January 1943, as part of NPG Research Project APL-1.

OBJECT

The investigation described in this report was carried out for the purpose of comparing the performance of 3" flat-nosed and current armor piercing projectiles in the attack of homogeneous plate.

SUMMARY

In previous experimental tests of flat-nosed projectiles (references (1) and (2)) the projectiles used were monoblock and were not fitted with windshields. Since for the usual service applications windshields are essential, it was necessary to test the effect of a windshield on the penetration of homogeneous plate by flat-nosed projectiles. Accordingly such projectiles were manufactured by Crucible Steel Company and tested at the Naval Proving Ground. The ballistic limits (minimum velocity required for projectiles to pass completely through plate) obtained were compared with limits for 3-inch M79 and 3-inch Mk. 29-2 projectiles under the same test conditions.

The limit velocities for the flat-nosed projectiles were in general lower than were required by either 3-inch Mk. 29-2 projectiles fitted with caps and windshields or 3-inch monoblock M79 projectiles. The advantage of the present flat-nosed projectiles over other types of projectiles holds only for the attack of homogeneous plate (STS and Class B)

up to e/d (ratio of plate thickness to projectile caliber) of 0.65 at most. The advantage is particularly marked in the attack of divided armor and of thin plate (e/d of 0.5 or less) at high obliquities (45°-60°). When e/d is greater than 0.65 the projectiles are badly deformed or shattered on impact.

The results of the present tests together with previous results for flat-nosed projectiles are summarized in the following table. The limits are expressed as percentages of limits for undeformed 3" M79 projectiles under the same test conditions.

		Limit (% of M79 value)		
			With	Plain
			Windshield	Flat-Nosed
e/d	Obliquity	Mk. 29-2	(Flat-Nosed)	(Ref.(1)&(2))
0.16	0°	116	114	102
	30°,45°,60°	100-119	66-85	<69 (45°)
0.36	0°	104	90	---
	30°,45°,60°	113-122	80-93	---
0.49	0°	117	88	62
	30°,45°,60°	120-127	93-110	62-72
0.66	0°	125	97	62
	30°	124	102	93
	45°	133	126	101(40°)

From the above it is apparent that for e/d values up to 0.5 and obliquities up to 60° the penetration of homogeneous plate was accomplished by the flat-nosed projectiles at velocities on the average about 15% below those required by monoblock and capped AP projectiles.

Against a divided structure consisting of 0"5 and 1" STS separated six (6) feet apart, the limit velocity for the flat-nosed projectile was 67% of the Mk. 29-2 limit. The Mk. 29-2 projectile in all cases struck the second plate with about 45° yaw, whereas the flat-nosed projectile struck with 0° yaw. This difference in yaw together with the lower limit for the flat-nosed projectile accounts for the large observed difference in limit.

The limitation of the flat-nosed projectile in the attack of homogeneous armor lies in their failure to penetrate at high e/d because of shatter and their tendency to shatter against thinner plate at high striking velocities. Thus against 2".5 STS the projectiles shattered and failed to penetrate; and above e/d of 0.36 the noses of the flat-nosed projectiles were broken at high velocity (2000 ft./sec.) while they stood up at the limit velocities.

The results of the present investigation emphasize that in the attack of homogeneous plate up to e/d of 0.5 and at striking velocities below 2000 ft./sec. flat-nosed projectiles can successfully penetrate at velocities 10% to 25% below those required by any of the current types. Against divided structures the flat-nosed projectile appears to be particularly advantageous. In view of the above, the service application of the flat-nosed principle to rockets and bombs offers promise of success with a large increase in penetration efficiency.

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LIST OF FIGURES CONT'D

I. INTRODUCTION

In the past two years various experimental tests of flat-nosed projectiles have been carried out at 3-inch scale at the Naval Proving Ground (references (1) and (2)). These tests showed that under certain conditions a flat-nosed projectile could penetrate homogeneous plate at 50% of the velocity required by current projectile types. Particularly favorable results were observed against plates at high obliquity or against divided structures. The principal limitation of this type of projectile was found to be its inability to penetrate thick plate because of shatter. Thus its use was limited to the attack of structures with thicknesses not much greater than 1/2 caliber (e/d of 0.5). For this reason it was concluded that the principal possible application of the flat-nosed principal lay in bombs or perhaps special common projectiles for the attack of lightly armored targets. As none of the projectiles used in these tests were fitted with windshields and since the usual service applications would necessarily require a windshield it was desirable to obtain for test flat-nosed projectiles fitted with windshields. Crucible Steel Corporation was accordingly requested by the Bureau of Ordnance to manufacture 13.0 lb. flat-nosed projectiles fitted with windshields. The performance of these projectiles is discussed in the present report.

II. MATERIAL AND METHODS

Plate:

0".5 STS Carnegie-Illinois No. 23115-A
0".5 STS Carnegie-Illinois No. 612068
1".1 STS Carnegie-Illinois No. 174140
1".5 STS Carnegie-Illinois No. 40917
2".0 STS Carnegie-Illinois No. F1790
3".0 Class B Carnegie-Illinois No. 85187
3".2 Class B Carnegie-Illinois No. X9021

(All plates are accepted STS and Class B plates.)

NPG PHOTO NO. 1566 (APL).
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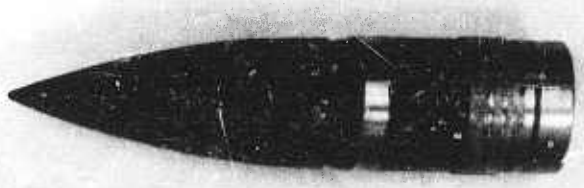
10 April 1944
FIGURE 1

3" M79 (Monoblock)



3" Mk29-2 (Assembled)

3" Mk29-2 (Disassembled)

3" Mk29 Flat-Nose (Assembled)

3" Mk29 Flat-Nose (Disassembled)

Projectiles:

Crucible Steel Co. 13.0-lb. 3" Mk. 29 Flat-nosed projectile (Buord Dwg. No. 124181) fitted with a steel windshield (0.21 lbs.)

Oldsmobile 13.0-lb. 3" Mk. 29-2 AP projectile (Buord Dwg. No. 330770) fitted with cap and steel windshield (0.43 lbs.) Lot 81.

Frankford Arsenal 15-lb. 3" M79 AP shot. This projectile is a monoblock type with neither cap nor windshield.

Methods of Measurement

All ballistic limits reported herein are expressed in terms of $F(e/d,\theta)$ values, where $F(e/d,\theta)$ is defined as follows:

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

M is the projectile mass in pounds, V_L is the limit velocity in feet per second (the minimum velocity required for a 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 in inches at the point of impact, and d is the projectile diameter in inches. All of the quantities entering into the defining expression above are measured directly except the limit velocity. The limit velocity for any test condition is calculated from the striking and residual velocities (references (1), (2) and (3)) or estimated from the depth of penetration. For most of the test conditions both complete and incomplete penetrations were obtained to give a bracket of the limit. The residual velocity for the complete penetration and the depth of penetration for the incomplete penetration are used to determine the value of the limit velocity within the bracket. As a measure of the amount of projectile deformation the diameter of the forward bourrelet of each projectile was measured before and after each round. Any gross deformations such as breakage were also noted.

III. RESULTS

The results given in detail in the Appendix are summarized below. F(e/d,θ) values for 3" Mk. 29-2 and 3" Mk. 29 (flat-nosed) are given in columns 4 and 5, respectively. In parenthesis after each tabulated F(e/d,θ) value are given the F(e/d,θ) values as percentages of the standard 3" M79 limits (undeformed projectiles) given by NPG Photo No. 1656 (APL) (reference (4)).

SUMMARY OF BALLISTIC RESULTS

			Observed F(e/d,θ)		
Gauge	e/d	Obl.	3" Mk. 29-2	3" Mk. 29 (Flat-Nosed)	Reference (2) Plain Flat-Nosed
0".49	0.16	0°	35,000±400 (116)	34,500±500 (114)	35,000±200 (102)*
		30°	29,200±300 (107)	23,200±400 (85)	---
		45°	30,500±500 (119)	20,600±600 (80)	<23,600 (69)*
		60°	30,500±300 (100)	19,900±300 (66)	---
1".08	0.36	0°	42,800±400 (104)	37,300±300 (90)	---
		30°	42,600±600 (115)	34,500±500 (93)	---
		45°	42,600±200 (122)	31,500±400 (90)	---
		60°	46,600±400 (113)	32,800±500 (80)	---
1".48	0.49	0°	51,700±400 (117)	38,800±400 (88)	28,500±200 (62)
		30°	49,000±600 (123)	39,700±300 (99)	30,100±300 (73)
		45°	47,800±500 (127)	41,400±500 (110)	32,600±200 (72)
		60°	52,800±800 (120)	41,000±400 (93)	31,000±500 (62)
1".98	0.66	0°	57,900±300 (125)	45,000±1000(97)	28,600±500 (62)
		30°	51,900±400 (124)	42,600±400 (102)	30,100±300 (93)
		45°	52,500±300 (133)	44,600±400 (126)	32,600±200 (101)**
2".43	0.81	0°	-----	>48,200 (>102)	41,000±1000(86)

* e/d of 0.20

** 40° obliquity

DEPENDENCE OF F(e/d,θ) ON OBLIQUITY

3" MK29-2, 13.0-LB. FLAT-NOSED, AND 15-LB. M79 PROJECTILES

0".5 STS

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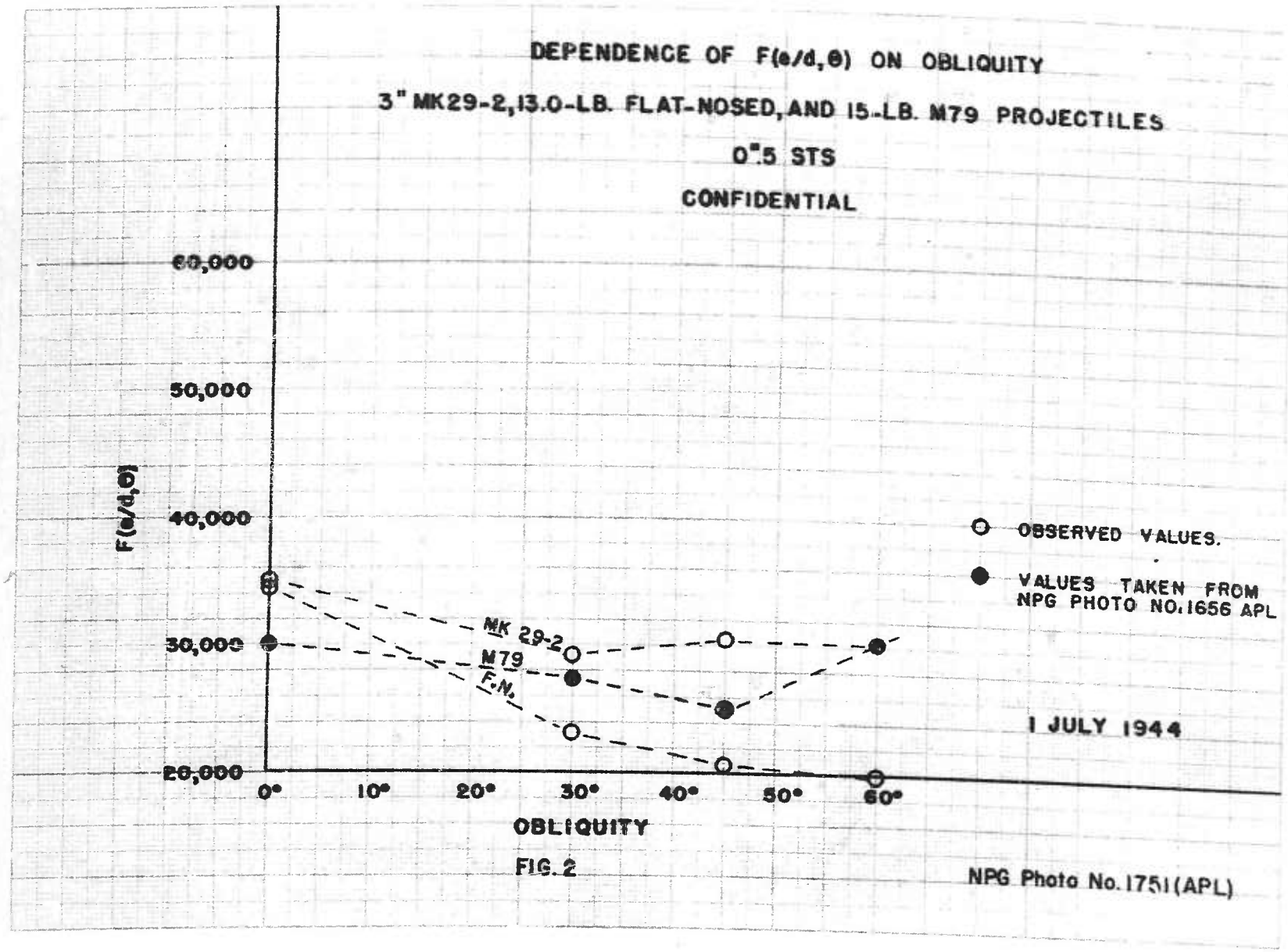

FIG. 2

NPG Photo No. 1751 (APL)

FIGURE 3

NPG PHOTO NO. 1658 (APL).
Condition of projectiles and windshields after impact of 3" Mk. 29-2 and 3" Mk. 29 (flat-nose) projectiles vs. 0.5 STS C.I.No. 23115A at 30° and 45° obliquity. Striking velocities of 300-600 ft./sec.
12 May 1944

- CONFIDENTIAL -

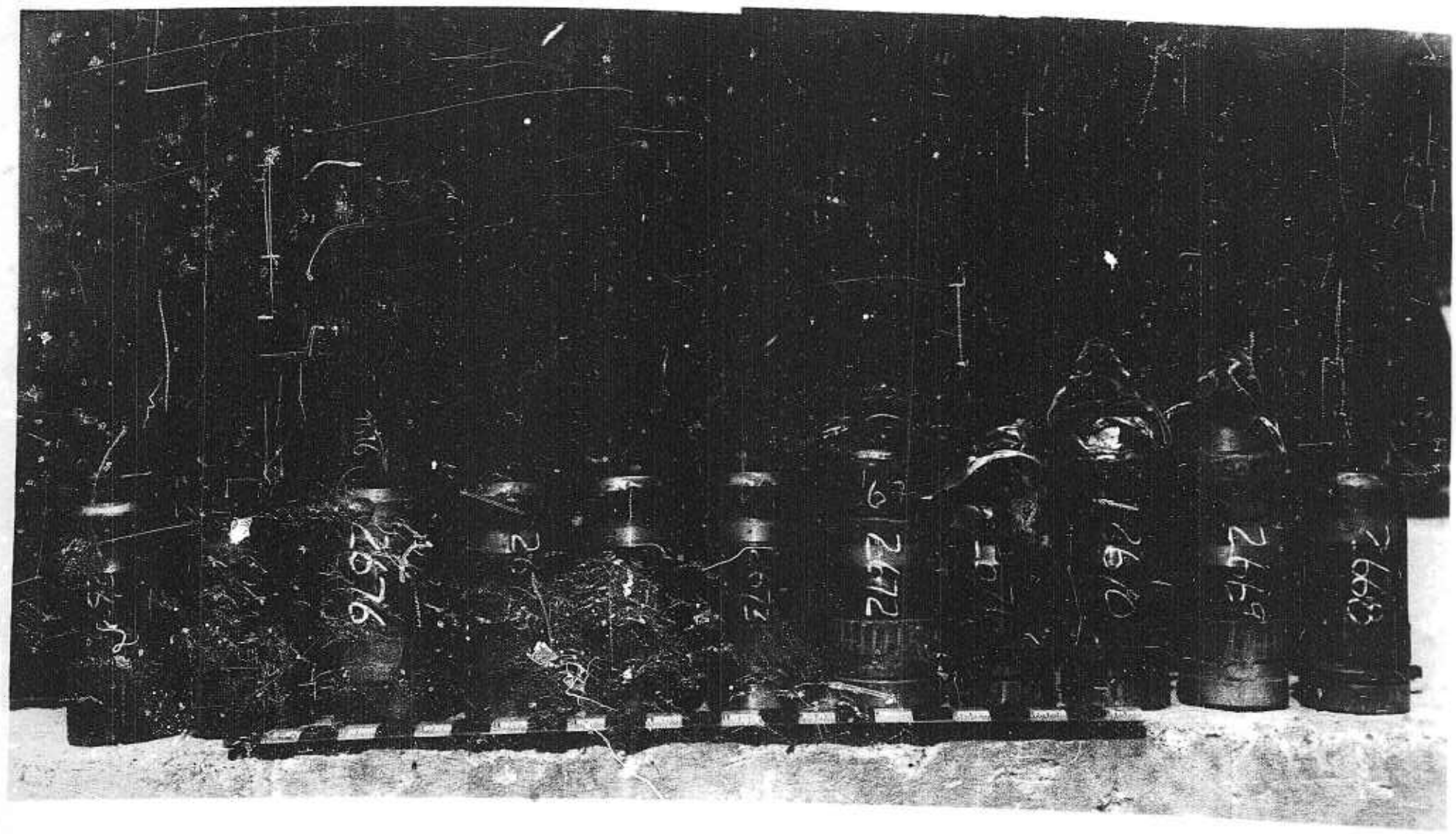

FIGURE 4

NPG PHOTO NO. 1640 (APL).
View of windshields and projectiles after striking 0°5 STS C.I.No. 23115-A at 60° obliquity and at velocities near the limit. Oldsmobile 3" Mk. 29-2 and Crucible 3" Mk. 29 (flat-nose) projectiles. Velocities for flat-nosed projectiles ranged from 400 to 500 f.s. and for Mk. 29-2 from 750-850 f.s.
10 May 1944 - CONFIDENTIAL -

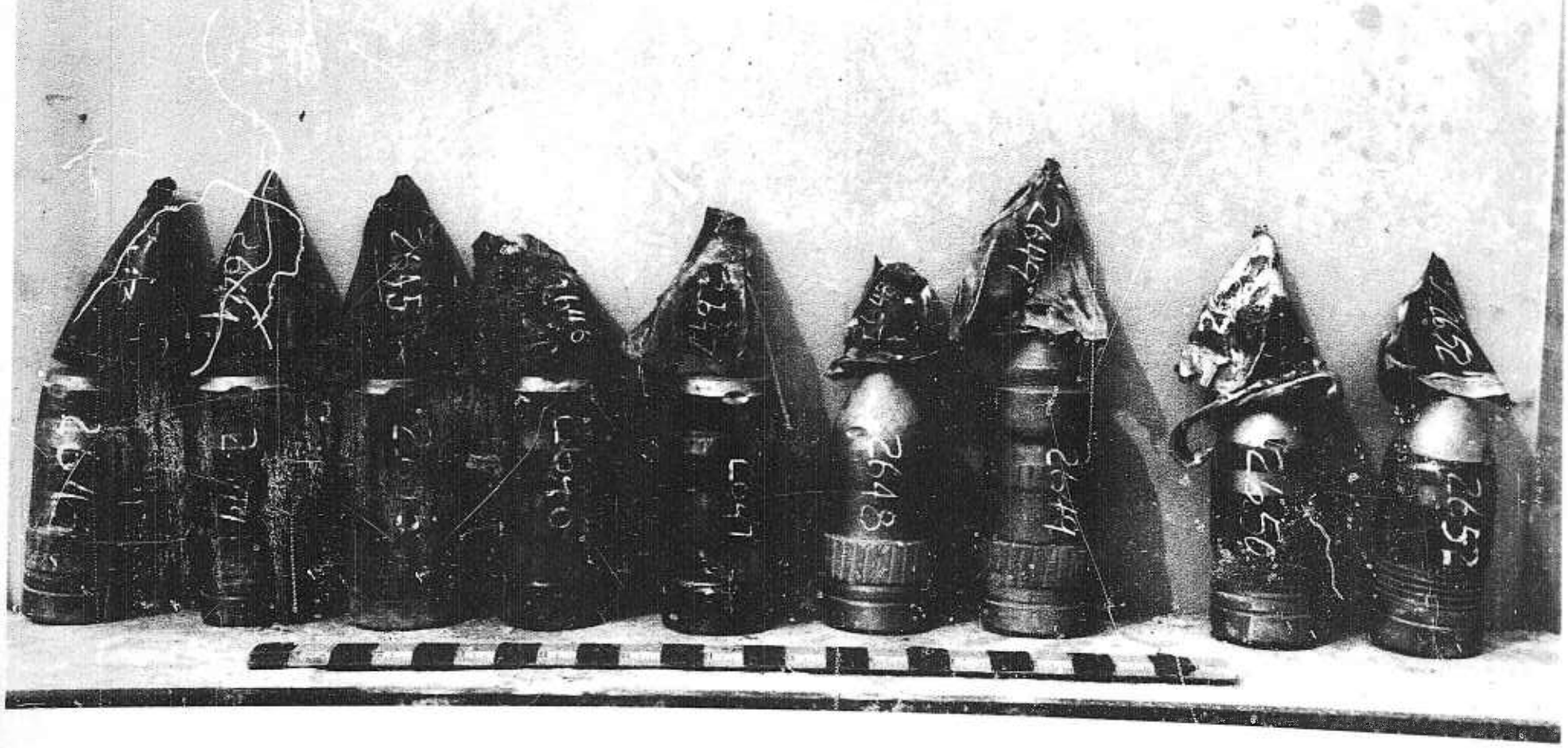

FIGURE 5

NPG PHOTO NO. 1650 (APL).
APL Plate No. 394 (OTS STS C.I.No. 23115-A) vs. 13.0 lb. 3" Olds. Mk. 29-2 AP projectiles and 12.90 lb. 3" C.S. Co. Mk. 29 flat-nose AP projectiles at 0°, 30° and 45° obliquity. FRONT VIEW. See NPG Photo No. 1651 (APL) for back view and data on impacts 2678-85 APL.

B.I.No.	"e"	"θ"	S.V.,f.s.	Proj.	%	Pene.	R.V.,f.s.	Proj.Cor.
2671 APL	0".493	45°00'	569	Olds.	87	Inc.1/4"	--	Cap off on tunnel.Proj. Whole.
2672	"	44°50'	616	"	94	CP	142	Cap off on plate.
2673	"	45°00'	460	C.S.Co.	70	"	--	Whole.
2674	"	44°50'	436	"	67	"	--	"
2675	"	45°00'	398	"	61	"	--	"
2676	0".492	45°00'	427	"	65	"	84	"
2677	0".493	45°10'	336	"	51	Inc.1"	--	"

May 17, 18, 19, 1944

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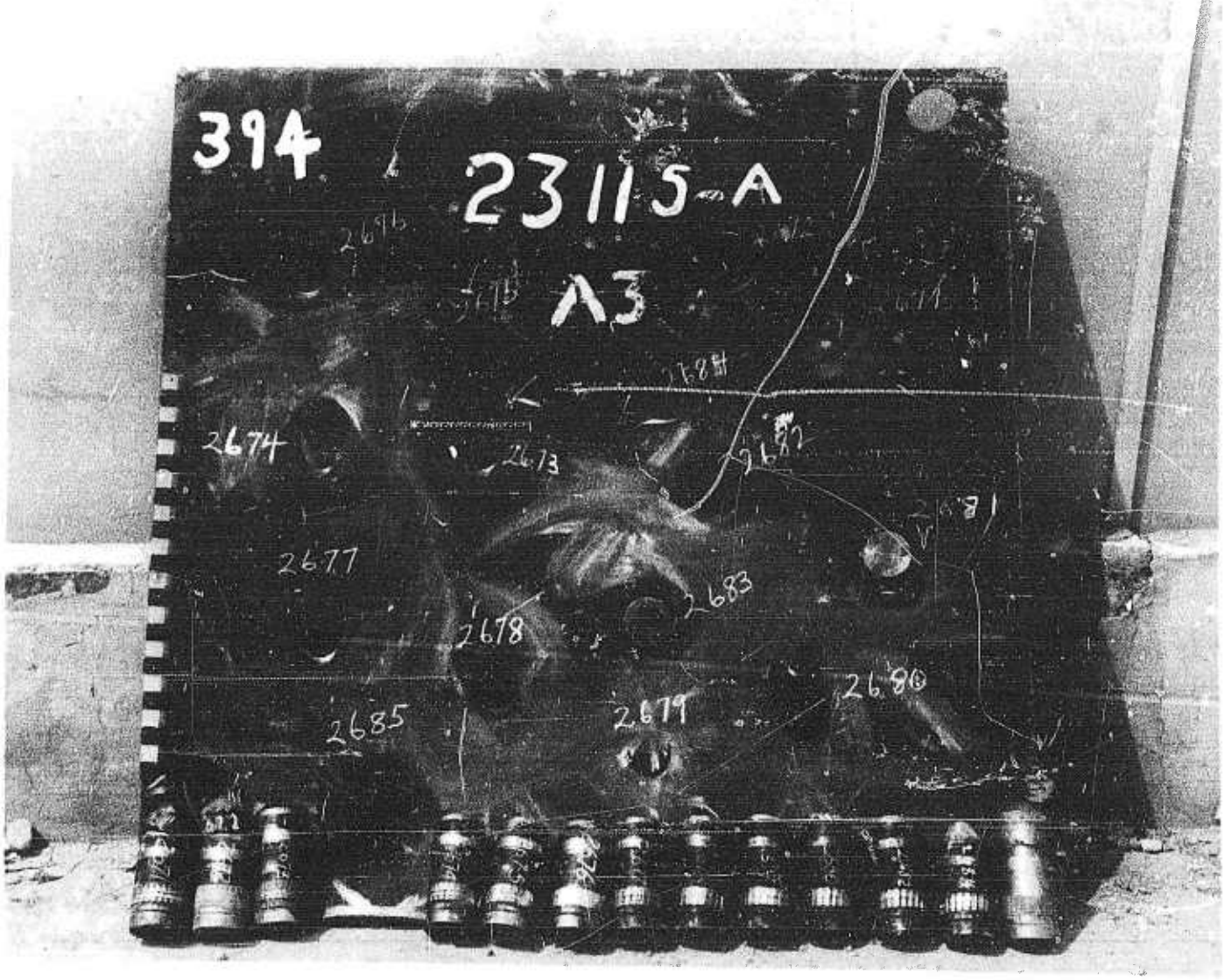

FIGURE 6

NPG PHOTO NO. 1651 (APL).
APL Plate No. 394 (0"5 ST3 C.I. No. 23115-A) BACK VIEW. See NPG Photo No. 1650 (APL) for front view and data on impacts 2671-77 APL.

B.I.No.	"e"	"Θ"	S.V., f.s.	%	Proj.	Pene.	R.V., f.s.	Proj. Cond.
2678 APL	0".493	30°00'	275	49	C.S.Co.	Inc.3/4"	--	Whole.
2679	0".494	29°50'	249	44	"	Inc.1/2"	--	"
2680	0".494	30°00'	330	58	"	Inc.1-1/2"	--	"
2681	0".494	30°00'	371	65	"	SIP 4-1/2"	--	"
2682	0".493	0°10'	393	77	"	Inc.1/2"	--	"
2683	0".493	0°30'	478	93	"	SIP 5-1/2"	--	"
2684	0".493	0°10'	476	93	Olds.	Inc. 2"	--	Mole.Cap off.
2685	0".493	0°30'	533	104	"	CP	253	" Cap on.

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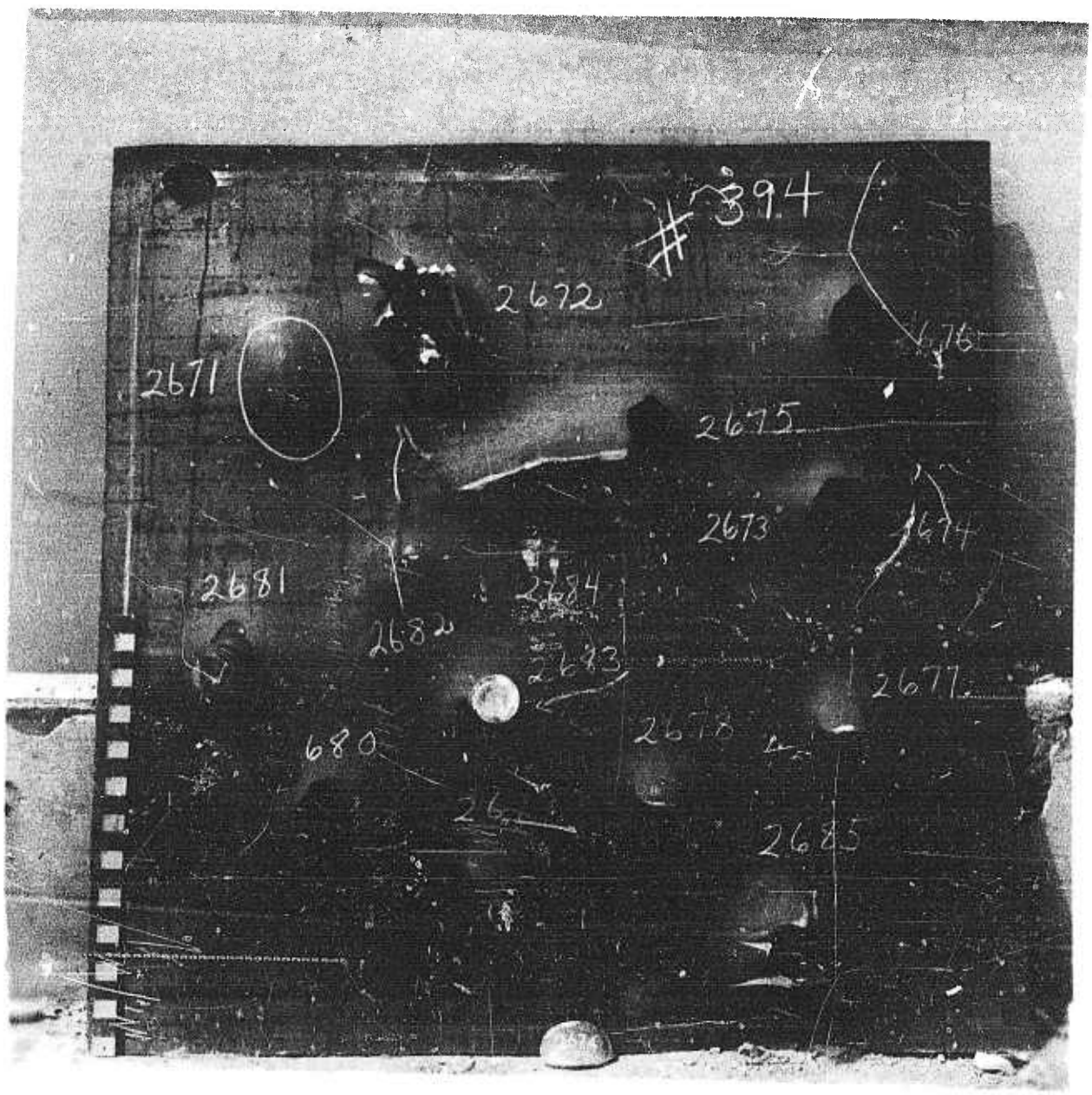

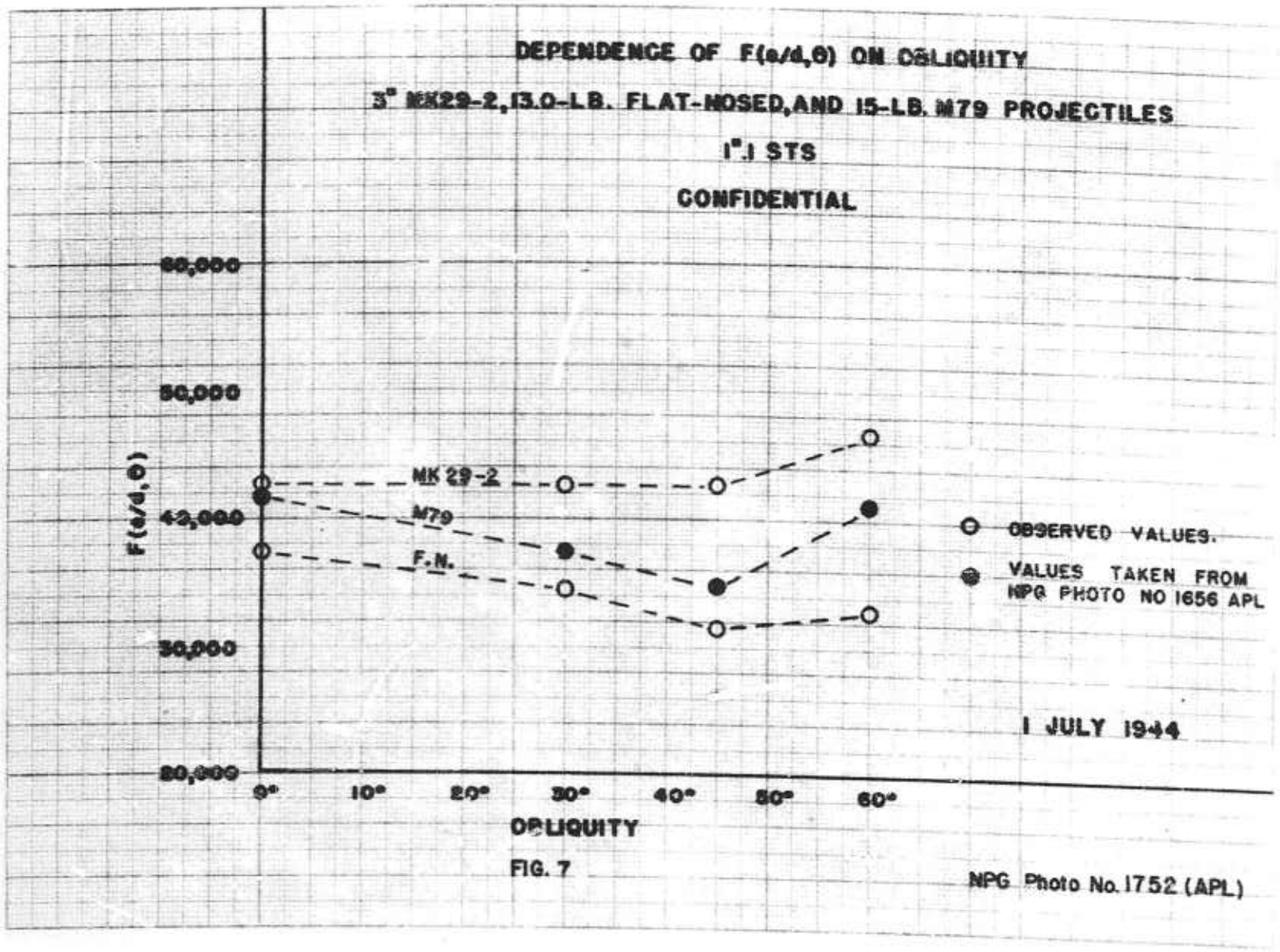

FIG. 7

NPG Photo No. 1752 (APL)

IV. DISCUSSION

In the evaluation of the performance of the 13.0 lb. flat-nosed projectiles comparisons with standard armor piercing and common projectiles were considered desirable. Since the flat-nosed projectiles were fitted with steel windshields, it was considered essential that one of the standard projectiles also have a steel windshield. Of the available projectiles the ones which best met this condition were service 3" Mk. 29-2 armor piercing projectiles, although these projectiles in addition to windshields are fitted with caps. The standard M79 projectile was used as a standard common projectile since its performance against homogeneous plate is well known (references (3) and (4)). In the following the relative ballistic performances of the 3" flat-nosed projectile, the 3" Mk. 29-2, and 3" M79 are discussed.

At e/d of 0.16 the ballistic limits of the flat-nosed projectiles are lower than the corresponding 3" Mk. 29-2 and M79 limits at all except normal obliquity. (Figure 2, NPG Photo No. 1751 (APL)). On normal impact the Mk. 29-2 and flat-nosed limits were about equal but were 15% above the M79 limit. Since the differences in nose shape can account for only 2-3% at this e/d (references (1),(2) and (5)), these relatively high limits at normal obliquity must be attributed to the additional energy required to compress the windshield. When the obliquity was increased to 30° and above the flat-nosed limits were decidedly lower than corresponding limits for the other projectiles. The rapid gain in efficiency of the flat-nosed projectile with initial increase in obliquity from normal is due to the deflection of the windshield out of the way with a lower loss of energy to the projectile than is required to compress the windshield at normal obliquity. For views of plate, projectiles and windshields see Figure 3 (NPG Photo No. 1658 (APL)), Figure 4 (NPG Photo No. 1640 (APL)), Figure 5 (NPG Photo No. 1650 (APL)) and Figure 6 (NPG Photo No. 1651 (APL)).

At e/d of 0.36 the flat-nosed limits were below the M79 and Mk. 29-2 limits at obliquities from normal to 60°. (Figure 7 NPG Photo No. 1752 (APL)). From normal to 45° the flat-nosed limits were approximately constant at 10% below the M79 limits and at 60° the limit was 80% of the M79 limit. The flat-

DEPENDENCE OF F(e/d,θ) ON OBLIQUITY

3" MK29-2, 13.0-LB. FLAT-NOSED, AND 15-LB. M79 PROJECTILES

1".5 STS

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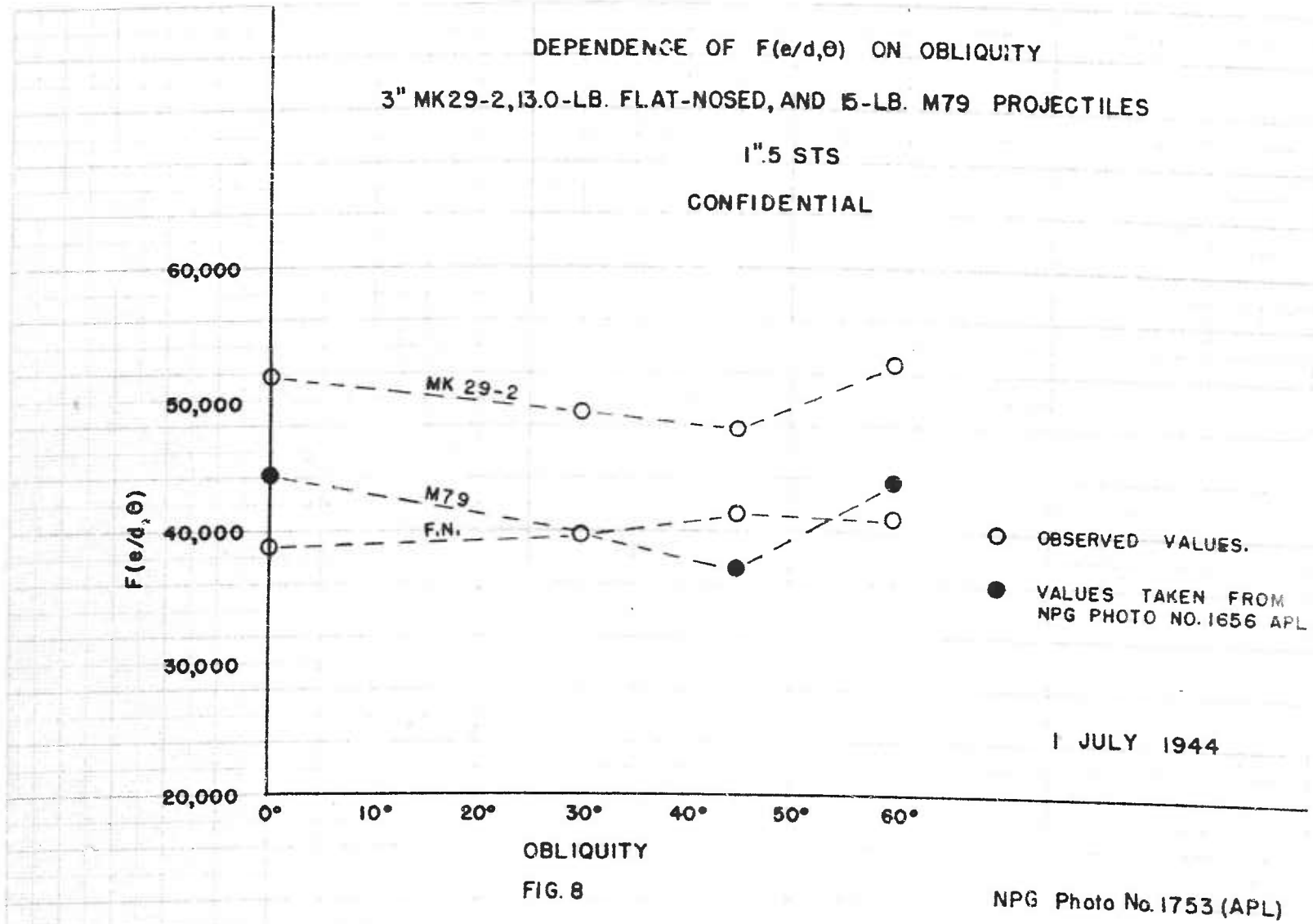

FIG. 8

NPG Photo No. 1753 (APL)

DEPENDENCE OF F(e/d,θ) ON OBLIQUITY

3" MK29-2, 13.0-LB. FLAT-NOSED, AND 15-LB. M79 PROJECTILES

2".0 STS

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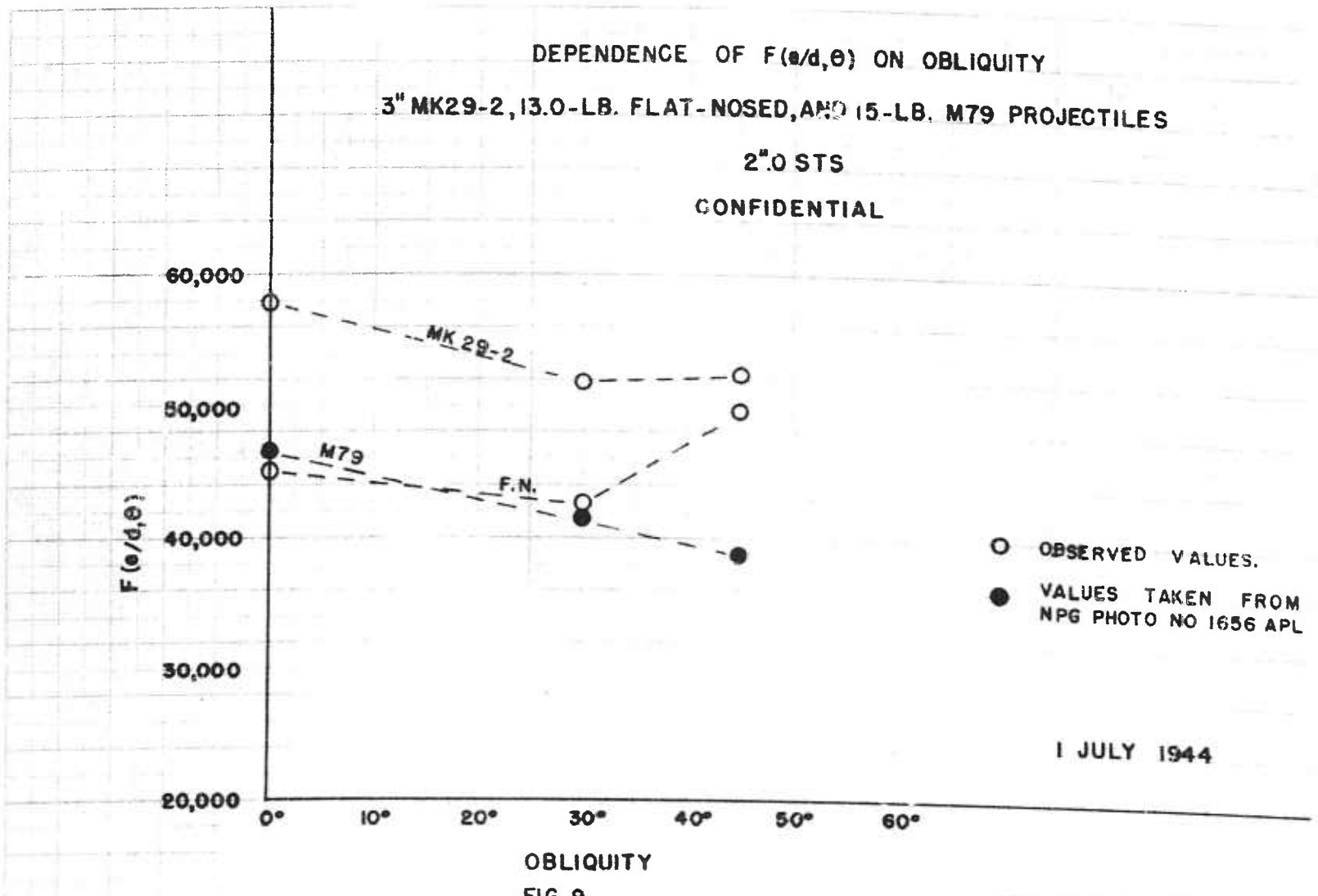

1 JULY 1944

FIG. 9

NPG Photo No. 1754 (APL)

FIGURE 10.

NPG PHOTO NO. 1510 (APL).
APL Plate No. 316 (Carn.-Ill. 2"5 Class B No. 59533) vs. C.S.Co. 13-lb. flat-nosed projectiles at 0° obliquity. FRONT VIEW. See NPG Photo No. 1511 (APL) for back view and NPG Photos Nos. 1208-09, 1232-33 (APL) for previous impacts.

B.I.No.	"e"	"θ"	S.V., f.s.	Pene.	%	Proj.Cond.
2386 APL	2"430	0°30'	1498	Inc.	109	Shattered.

March 6, 1944

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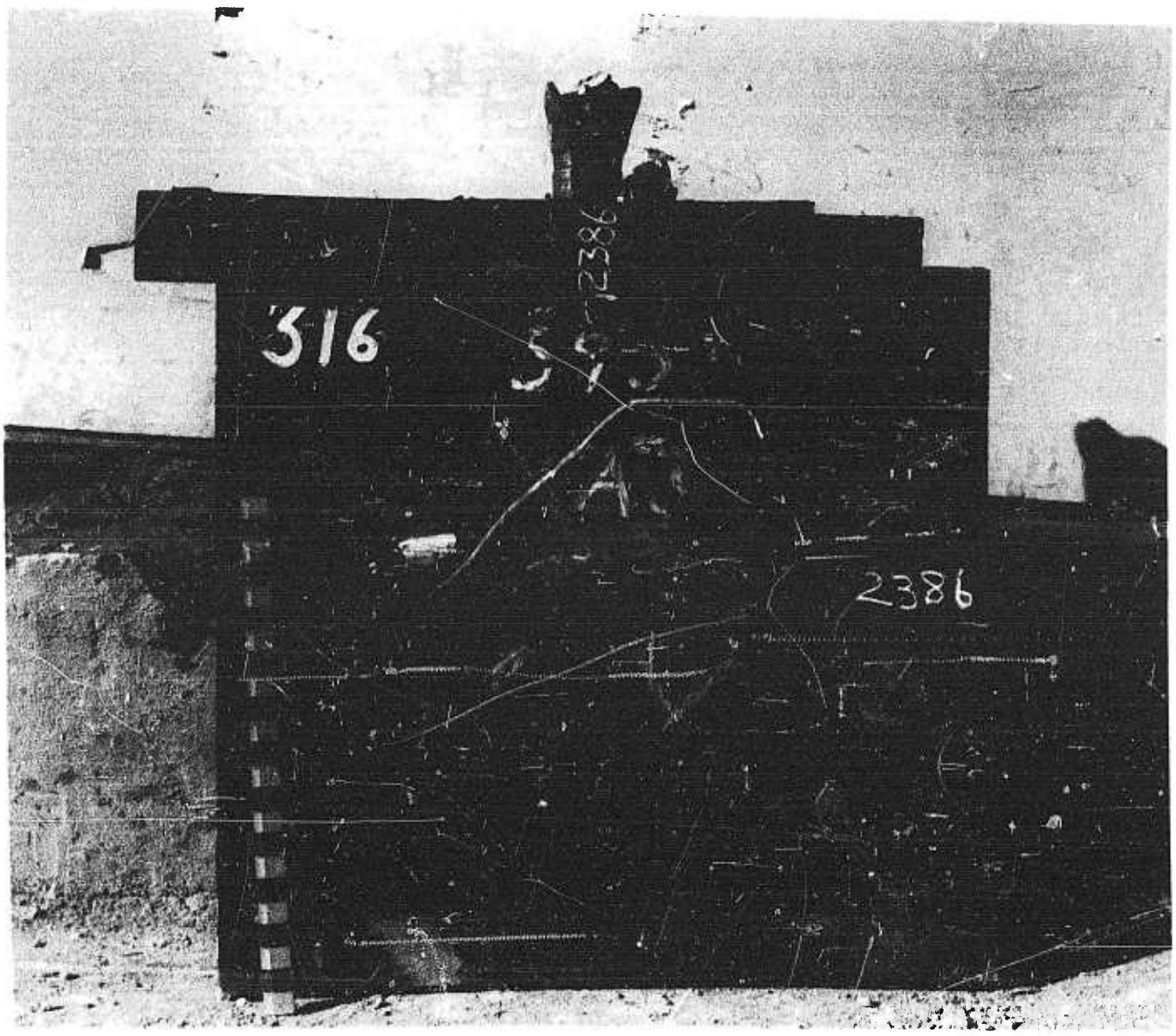
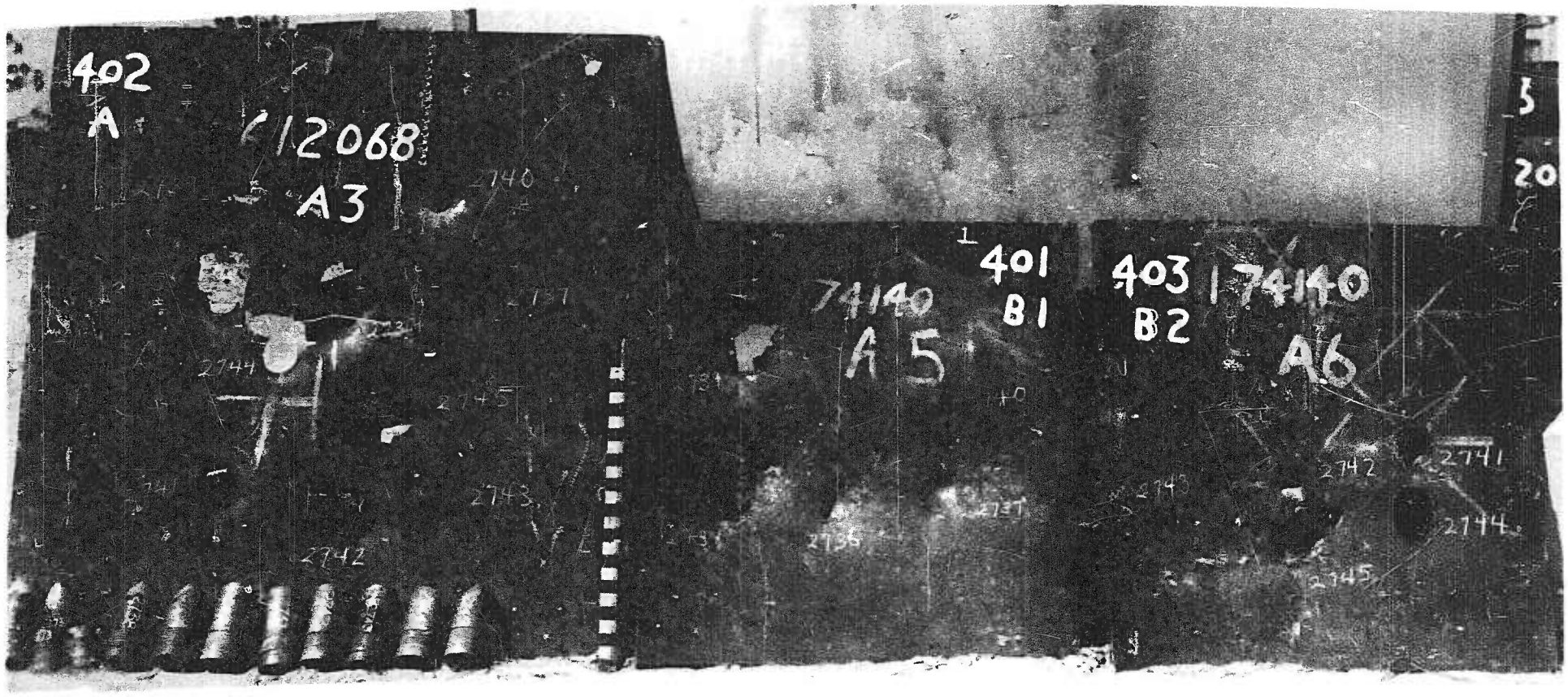


FIGURE 11

NPG PHOTO NO. 1726 (APL).
APL Plate Nos. 401, 402 and 403 (C.I. 1/2" and 1" STS Nos. 612068 and 174140, respectively) divided structure consisting of 1/2" and 1" STS spaced 6 feet apart vs. 13.0 lb. 3" Mk. 29-2 and flat nose projectiles at 30° obliquity. FRONT VIEW. See NPG Photo No. 1727 (APL) for back view and data on impacts 2741-45 APL.

B.I.No.	"e"	"G"	S.V.,f.s.	Pene.	R.V.,f.s.	Proj.Cond.	%	Proj.
			(Plates 402 and 401 A and B-1)					
2736 APL	1".078	29°50'	1265	Inc.1-1/2"	--	Eff. base.	107	Mk.29-2
	0".488			CP	--	Slapped.		
2737	1".078	29°50'	1342	Inc. 1"	--	Ineff.Broken	113	"
	0".488			CP	--	in 4 pieces.		
2738	1".078	29 40'	1477	Inc. 4"	--	Eff. Whole.	125	"
	0".488			CP	--	Slightly scarred.		
2739	1".077	29°30'	1524	CP	--	Eff.Slightly scarred.	129	"
2740	1".077	29°30'	1267	CP	--	Nose chipped.	108	Flat Nose
	0".488			CP	--			

June 16,19, 1944 -CONFIDENTIAL-



nosed limits decreased continuously relative to the M79 limits from about 85% at normal obliquity to 70% at 60°. Thus at this e/d over the full range of obliquities used the flat-nosed projectiles had limits from 10-30% below those of the standard projectiles.

At e/d of 0.49 the flat-nosed limits were consistently below the Mk. 29-2 limits but they fluctuated about the M79 values (Figure 8 NPG Photo No. 1753 (APL)). The flat-nosed limits increased from 75% at normal obliquity to 80-85% at 45°-60° obliquity with respect to the Mk. 29-2 limits. As compared with the M79 projectiles the flat-nosed projectiles had about a 10% advantage at 0° and 60° obliquity with a 10% disadvantage at 45° obliquity. The flat-nosed and M79 performances are essentially the same over the full range of obliquity at this e/d but both have a decided margin over the Mk. 29-2 projectile.

At e/d of 0.66 the flat-nosed projectile has lower limits than the Mk. 29-2 up to 45° but limits equal to or greater than the M79 projectiles (Figure 9, NPG Photo No. 1754 (APL)). The flat-nosed limits increased from 75% at normal obliquity to 95% at 45° of the corresponding Mk. 29-2 values. The M79 and flat-nosed limits are approximately equal at 0° and 30° obliquities but at 45° the flat-nosed limit is 25% above the M79 limit. The high limits for the flat-nosed projectiles result from large projectile deformation.

At e/d of 0.81 and 0° obliquity the flat-nosed projectile was broken up with little penetration at a velocity slightly above the M79 limit. A view of the projectile and plate is given in Figure 10 (NPG Photo No. 1510 (APL)).

Against a divided armor structure consisting of 1/2" and 1" STS spaced 6 feet apart, all at 30° obliquity, the limit velocity for the flat-nosed projectile was 67% of the Mk. 29-2 limit. This large difference in limits was a result not only of the difference in mechanism of armor penetration but also of the difference in yaw in the two cases. On every impact the Mk. 29-2 after penetration of the first plate (1/2") acquired a yaw of about 45° before striking the second plate. On the other hand the flat-nosed projectiles struck both plates at 0° yaw. One Mk. 29-2 projectile was broken up on impact with the second plate. (Figure 11, NPG Photo No. 1726 (APL)).

The limits for the present flat-nosed projectiles are not as low as those reported for plain, unwindshielded flat-nosed projectiles in references (1) and (2) up to e/d of 0.5 (Summarized in Results) but at the same time the limit velocities in general are 10%-25% lower than are required by the best conventional projectiles. The lower limits for the earlier tests are accounted for by the lack of windshields and by the full-caliber flat nose (the diameters of the noses of the present projectiles were 0.92 caliber). However, the general behavior of the present projectiles as to type of plate failure and the remarkably low limits against thin plate at high obliquity and against divided structures are characteristic of all flat-nosed projectiles previously tested.

In the first tests of flat-nosed projectiles at the Naval Proving Ground (Reference (1)) it was noted that projectile deformation in all cases increased with increase of striking velocity. The same effects were also noted in the present tests. From the Appendix the following cases are cited. Against 1".75 STS at normal obliquity the increase in diameter of bourrelet at 900 ft./sec. was 0".020 and at 1150 ft./sec. it was 0".048. Against 2".0 STS at 30° the increase in diameter at the bourrelet rose from 0".051 at 1350 ft./ sec. to 0".096 at 1500 ft./sec.

Several rounds were fired at 1800-2000 ft./sec. to observe projectile deformation at high striking velocities. On this test some of the projectile noses were broken. At striking velocities of 1800-2000 ft./ sec. against 1"STS the projectiles were broken at 0° and 45° but penetrated at 60° without appreciable deformation; against 1".5 STS they were broken at 0° and 60° but not at 45°; and against 2".0 plate they were broken at 0° and 45°.

From a consideration of the low limits observed for flat-nosed projectiles against plates at e/d up to 0.5 and of the tendency to break up at higher velocities (for the present projectiles 1800-2000 f.s. and above) it is evident that the flat-nosed principle is ideally suited to service armor piercing rockets and bombs. For these projectiles have relatively low striking velocities and are designed for the penetrating of lightly armored targets (e/d of 0.5 and below). Since the setback forces are low, light windshields can be used and thus keep their detrimental effects on penetration at a minimum. The application

of the flat-nosed form to common projectiles may be limited by the tendency to shatter at high velocity although the targets that can be successfully attacked are similar to those met by bombs and rockets. In the present war the Japanese Navy is known to have been using a type of flat-nosed common projectile of 8-inch caliber with which they have had a measure of success. (References (6) and (7)).

V. CONCLUSIONS

1. 3-inch 13.0 lb. flat-nosed projectiles fitted with windshields penetrate homogeneous plate at considerably lower velocities than do standard service projectiles over a wide range of test conditions including divided armor.

2. Although flat-nosed projectiles may penetrate in an intact condition at low velocity, they may shatter under the same test conditions at high velocity.

VI. REFERENCES

1. Penetration of Homogeneous Armor by 4-inch Flat-Nosed Projectiles. U.S. Naval Proving Ground Report No. 7-43 dated 19 April 1943.

2. Penetration of Homogeneous Plate by 3-inch Flat-Nosed Projectiles - Partial Report AD-310 001 U.S. Naval Proving Ground Report No. 12-44 dated 20 April 1944.

3. Penetration of Homogeneous Plate of One Tensile Strength (110,000 psi.) by 3" M79 AP Projectiles - Partial Report. U.S. Naval Proving Ground Report No. 8-44 dated 18 April 1944. AD-309[illegible]

4. Penetration of Homogeneous Plate of One Tensile Strength (125,000 psi.) by 3" M79 AP Projectiles - Second Partial Report U.S. Naval Proving Ground Report No. 20-44 (In Preparation).

5. The Effect of Nose Shape on the Ballistic Performance of 15-lb. 3" AP Solid Shot Against Homogeneous Armor. U.S. Naval Proving Ground Report No. 2-43 dated 26 February 1943.

6. Examination of a Japanese 8-inch Common Projectile. U.S. Naval Proving Ground Report No. 4-43 dated 12 March 1943.

7. U.S.S. SALT LAKE CITY (CA 25) Gunfire Damage, Bering Sea 26 March 1943, U.S. Navy Bureau of Ships Report No. 42 dated 15 May 1944.

VII. APPENDIX

BALLISTIC DATA

Symbols

V_S(f.s.).... Striking velocity in feet per second.

V_S (%)..... Striking velocity in per cent of standard value calculated from the Navy 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 the obliquity in degrees. The percentages in parenthesis after each experimental $F(e/d,\theta)$ value are with respect to this empirical formula.

Pene (in.)... Depth of penetration in inches measured from the front surface normal to the plane of the plate.

CP..... Complete penetration. Projectile completely through and clear of the plate.

Inc..... Incomplete penetration - none of the projectile completely through and clear of the plate.

SIP..... Projectile stuck in plate. A special case of incomplete penetration.

V_R (f.s.).... Residual velocity in feet per second of projectile after penetrating the plate.

Δd.....	Increase in diameter in inches of the forward bourrelet of the projectile as a result of the impact.
W.....	Projectile whole. The projectile may be deformed but because it is stuck in the plate measurements cannot be taken of the deformation.
D.....	Projectile deformed.
E.....	Projectile undeformed.
B(2).....	Projectile broken on a secondary impact.

3" Mk. 29-2 Projectile

APL Impact No.	e in.	θ	M lbs.	V_S f.s.	V_S %	Pene. in.	V_R f.s.	Projectile Condition Δd (in)	
				0".5 STS Carnegie-Illinois No. 23115-A					
				0° Obliquity					
2684	0".493	0°10'	13.00	476	93	Inc. 2"	--	0.000	E
2385	0".493	0°30'	13.00	533	104	CP	253	0.000	E
				F(e/d,θ) = 35,000±400 (96%) (Cap not removed by impact)					
				30° Obliquity					
2670	0".491	29°50'	13.00	459	81	Inc.	--	0.000	E
2669	0".491	30°00'	13.00	490	87	CP	139	0.000	E
				F(e/d,θ) = 29,200±300 (83%) (Cap not removed by impact)					
				45° Obliquity					
2672	0".493	44°50'	13.00	616	94	CP	142	0.000	E
2671	0".493	45°00'	13.00	569	86	Inc.1/4"	--	0.000	E
				F(e/d,θ) = 30,500±500 (92%) (Cap removed by impact)					
				60° Obliquity					
2651	0".488	59°50'	13.00	755	90	Inc.	--	0.000	E
2652	0".491	59°50'	13.00	829	98	Inc.3/4"	--	0.000	E
2649	0".488	59°50'	13.00	842	100	CP	--	0.000	E
2648	0".488	59°50'	13.00	887	105	CP	--	0.000	E
				F(e/d,θ) = 30,300±300 (100%) (Cap removed by impact)					

3" Mk. 29-2 Projectile

APL Impact No.	e in.	θ	M lbs.	V_S f.s.	V_S %	Pene. in.	V_R f.s.	Projectile Condition Δd (in)	
1" STS Carnegie Illinois No. 174140									
0° Obliquity									
2703	1".062	1°00'	13.00	913	114	CP			
2704	1".065	1°10'	13.00	871	108	SIP 5-1/2"	--	0.000 --	B W
F(e/d,θ) = 42,800±400 (110%)									
30° Obliquity									
2664	1".078	30°00'	13.00	1063	116	CP	72	0.000	B
2665	1".078	30°10'	13.00	1019	109	SIP 6"	--	--	W
F(e/d,θ) = 42,600±600 (111%)									
45° Obliquity									
2697	1".064	45°10'	13.00	1234	112	SIP-5-1/2"	--	--	B
2698	1".063	45°10'	13.00	1249	113	CP	--	0.000	B
F(e/d,θ) = 42,600±200 (113%)									
60° Obliquity									
2640	1".078	59°50'	13.00	1907	125	Inc. near limit	--	.004	D
2641	1".078	59°50'	13.00	1969	129	CP	--	.002	D
2642	1".078	60°00'	13.00	1850 (est)	121	Inc.1-1/2"	--	.001	D
F(e/d,θ) = 46,600±400 (126%)									

3" Mk. 29-2 Projectiles

APL Impact No.	e in.	θ	M lbs.	V_S f.s.	V_S %	Pene. in.	V_R f.s.	Projectile Condition Δd (in)	
				1"5 STS No.(40917)					
				0° Obliquity					
2617	1".481	1°00'	13.00	1207	123	SIP 5"	--	---	W
2618	1".478	1°00'	13.00	1243	127	SIP 6-1/4"	--	---	W
2619	1".472	1°00'	13.00	1245	127	Inc.	--	0.000	E
2620	1".463	0°10'	13.00	1303	134	CP	455	0.000	E
				F(e/d,θ) = 51,700±400 (127%)					
				30° Obliquity					
2621	1".475	30°10'	13.00	1329	117	Inc. 2"	--	0.000	E
2623	1".471	30°00'	13.00	1393	123	CP	224	0.000	E
2622	1".475	30°10'	13.00	1402	123	CP	243	0.000	E
				F(e/d,θ) = 49,000±600 (120%)					
				45° Obliquity					
2627	1".489	45°10'	13.00	1505	106	Inc. 3/4"	--	---	B(2)
2628	1".486	45°10'	13.00	1573	111	Inc. 3/4"	--	---	B(2)
2630	1".492	45°10'	13.00	1615	114	Inc.1-1/4"	--	0.000	E
2629	1".483	45°00'	13.00	1663	118	CP	--	0.000	E
				F(e/d,θ) = 47,800±500 (116%)					
				60° Obliquity					
2633	1".487	59°50'	13.00	2324	115	Inc.1-3/8"	--	---	B(2)
2634	1".486	60°00'	13.00	2514	125	Inc.1-5/8"	--	---	B(2)
2635	1".481	60°00'	13.00	2603	129	CP	--	Not Recovered	
				F(e/d,θ) = 52,800±800 (127%)					

5" Mk. 29-2 Projectiles

APL Impact No.	e in.	θ	M lbs.	V_S f.s.	V_S %	Pene. in.	V_R f.s.	Projectile Condition Δd (in.)	
2" STS C.I. No. (F1790)									
0° Obliquity									
2712	1".982	0°20'	13.00	1543	130	Inc. 3-1/2"	--	.003	D
2714	1".971	0°20'	13.00	1657	140	CP	362	.004	D
2713	1".982	1°20'	13.00	1589	134	SIP 5-3/4"	--	---	W
2711	1".982	1°40'	13.00	1522	128.0	SIP 3-1/4"	--	---	W
				$F(e/d,\theta) = 57,900 \pm 300$ (136%)					
30° Obliquity									
2731	1".964	30°00'	13.00	1637	117	Inc. 4-1/2"	--	0.006	D
2730	1".963	30°20'	13.00	1684	120	CP	210	0.006	D
2729	1".970	30°00'	13.00	1720	122	CP	298	0.004	D
				$F(e/d,\theta) = 51,900 \pm 400$ (119%)					
45° Obliquity									
2726	1".976	45°00'	13.00	2067	116	SIP 8"	--	---	W
2725	1".980	45°00'	13.00	2155	121	CP	--	0.005	D
2724	1".980	45°00'	13.00	2192	123	CP	--	0.007	D
2723	1".980	45°00'	13.00	2306	129	CP	--	Not Recovered	
				$F(e/d,\theta) = 52,500 \pm 300$ (116%)					

Flat-Nosed 3" Mk. 29

APL Impact No.	e in.	θ	M lbs.	V_S f.s.	V_S %	Pene. in.	V_R f.s.	Projectile Condition Δd (in.)	
			0".5 STS Carnegie-Illinois No. 23115-A						
				0° Obliquity					
2682	0".493	0°10'	12.90	393	77	Inc. 1/2"	--	---	W
2683	0".493	0°30'	12.90	478	93	SIP 5-1/2"	--	---	W
2760	0".491	3°00'	12.90	2010	390	CP	--	0.040	Nose chipped
						F(e/d,θ) = 34,500±500 (94%)			
				30° Obliquity					
2679	0".494	29°50'	12.89	249	44	Inc. 1/2"	--	0.000	E
2678	0".493	30°00'	12.99	275	49	Inc. 3/4"	--	0.000	E
2680	0".494	30°00'	12.90	330	51	Inc. 1-1/2"	--	0.000	E
2681	0".494	30°00'	12.84	371	65	SIP 4-1/2"	--	0.000	E
2668	0".491	30°30'	12.87	498	88	CP	244	---	E
								0.000	E
						F(e/d,θ) = 23,200±400 (66%)			
				45° Obliquity					
2674	0".493	44°50'	12.92	436	17	CP	--	0.000	E
2675	0".943	45°00'	12.92	398	61	CP	--	0.000	E
2676	0".492	45°00'	12.88	427	65	CP	84	0.000	E
2673	0".493	45°00'	12.91	460	70	CP	--	0.000	E
2677	0".493	45°10'	12.88	336	51	Inc. 1"	--	0.000	E
2761	0".49-	46°00'	12.95	2010	301	CP	--	0.002	Nose chipped
						F(e/d,θ) = 20,600±600 (62%)			

Flat-Nosed 3" Mk. 29

APL Impact No.	e in.	θ	M lbs.	V_S f.s.	V_S %	Pene. in.	V_R f.s.	Projectile Condition Δd (in.)
0".5 STS Carnegie-Illinois No. 2311[illegible]-A								
60° Obliquity								
2645	0".488	59°50'	12.88	441	53	Inc. 2"	--	0.003 D
2647	0".488	60°00'	12.94	635	72	CP	--	0.004 D
2646	0".488	60°10'	12.91	557	66	CP-O	--	0.001 D
2762	0".491	60°30'	13.00	2010	234	CP	--	0.000 Nose chipped.

$F(e/d,\theta) = 19,900 \pm 300$ (66%)

Flat-Nosed 3" Mk. 29

APL Impact No.	e in.	θ	M lbs.	V_S f.s.	V_S %	Pene. in.	V_R f.s.	Projectile Condition Δd (in.)	
				1" STS C.I. No. 174140					
				0° Obliquity					
2705	1".066	1°00'	12.88	764	95	SIP 5"	--	---	W
2706	1".066	1°00'	12.90	829	103	CP	--	0.000	E
2707	1".066	3°20'	12.92	1801	224	CP	--	Nose broken	B
				F(e/d,θ) = 37,300±300 (96%)					
				30° Obliquity					
2667	1".078	29°50'	12.92	841	92	CP	113	0.000	E
2666	1".078	30°10'	12.94	769	84	SIP 4-3/4"	--	---	W
				F(e/d,θ) = 34,500±500 (90%)					
				45° Obliquity					
2699	1".062	44°50'	12.93	973	89	CP	--	0.000	E
2700	1".062	44°50'	12.97	978	89	CP	--	.002	D
2702	1".069	44°50'	13.00	202	185	CP	--	Shattered	
2701	1".063	45°00'	12.92	905	82	SIP 5-3/4"	--	---	W
				F(e/d,θ) = 31,500±400(83%)					
				60° Obliquity					
2636	1".080	59°50'	13.00	1311	86	SIP 7"	--	---	W
2637	1".079	60°00'	13.00	1302	85	SIP 6"	--	---	W
2638	1".078	60°10'	13.00	1338	87	SIP 6"	--	---	W
2639	1".077	60°20'	13.00	1391	90	CP	--	0.000	E
2763	1".078	61°00'	12.98	2014	128	CP	--	0.007 Nose chipped.	
				F(e/d,θ) = 32,800±500 (89%)					

Flat-Nosed 3" Mk. 29

APL Impact No.	e in.	θ	M lbs.	V_S f.s.	V_S %	Pene. in.	V_R f.s.	Projectile Condition Δd (in)	
1"5 STS No. 40917									
0° Obliquity									
2613	1".487	0°10'	12.92	923	94	SIP 2-1/2"	--	0.020	D
2614	1".486	0°50'	12.88	935	95	SIP 5-3/4"	--	---	W
2615	1".479	1°00'	12.92	977	100	CP	121	0.029	D
2612	1".488	0°10'	12.86	1148	116	CP	--	0.045	D
2616	1".480	1°00'	13.05	1793	183	CP	--	Nose shattered	
				$F(e/d,\theta)$ = 38,800±400 (96%)					
30° Obliquity									
2626	1".463	30°00'	12.96	1097	97	SIP 3"	--	---	Nose chipped
2625	1".463	30°00'	12.91	1112	98	CP	--	0.009	Nose chipped
2624	1".470	29°40'	12.92	1126	100	CP	105	0.011	Nose chipped
				$F(e/d,\theta)$ = 39,700±300 (98%)					
45° Obliquity									
2331	1".492	45°00'	12.95	1404	99	Inc.	--	---	W
2333	1".477	44°10'	12.90	1425	102	CP	--	---	W
2332	1".475	44°20'	12.90	1548	111	CP	--	Nose broken	
2764	1".475	45°30'	12.96	2017	142	CP	--	---	W
				$F(e/d,\theta)$ = 41,400±500 (100%)					
60° Obliquity									
2632	1".491	60°00'	13.0	1972	97	SIP 2-1/2"	--	---	W
2631	1".489	60°10'	13.0	2072	102	CP	--	Nose shattered	
				$F(e/d,\theta)$ = 41,000±400 (98%)					

Flat-Nosed 3" Mk. 29

APL Impact No.	e in.	θ	M lbs.	V_S f.s.	V_S %	Pene. in.	V_R f.s.	Projectile Condition Δd (in)	
2" Carnegie-Illinois No. J1790									
0° Obliquity									
2708	1".971	0°20'	13.00	1226	103	SIP 2-1/2"	--	---	W
2710	1".982	0°20'	13.00	1864	157	CP	--	Nose shattered .105	D
2709	1".971	0°30'	13.00	1327	112	CP	--		
F(e/d,θ) = 45,000±1000 (106%)									
30° Obliquity									
2732	1".964	29°50'	13.00	1516	108	CP	--	0.096	D
2735	1".966	30°10'	13.00	1340	95	Inc.	--	0.051	D
2734	1".967	30°10'	13.00	1406	100	CP	--	0.062	D
2733	1".968	30°10'	13.05	1466	104	CP	--	0.087	D
F(e/d,θ) = 42,600±400 (98%)									
45° Obliquity									
2727	1".974	44°50'	13.05	1977	111	CP	--	Nose broken	
2728	1".972	45°00'	13.00	1935	109	Inc.3-1/2"	--	Shattered	
F(e/d,θ) = 49,600±400(110%)									

Flat-Nosed 3" Mk. 29

2".4 STS Carnegie-Illinois No. 59533

2386	2".43	0°30'	12.95	1498	109	Inc. 1"	--	Shattered	
F(e/d,θ) = >48,200 (>109%)									

Deck Structure

1/2" STS (C.I. No. 612068) and 1" STS (C.I. No. 174140)
Spaced 6 feet Apart

APL Impact No.	e (in)	θ	M lbs.	V_S f.s.	V_S %	Pene.	V_R f.s.	Projectile Condition Δd (in.)	
3" Mk. 29-2 AP Projectiles									
2737	0".488	29°50'	13.0	1342	113	CP	--	---	
	1".078	29°50'	--	--	--	Inc. 1"	--	Broken	
2738	0".488	29°40'	13.0	1477	125	CP	--	---	
	1".078	29°40'	--	--	--	Inc. 4"	--	0.000	E
2739	0".488	29°30'	13.0	1524	129	CP	--	---	
	1".078	29°30'	--	--	--	CP	--	0.000	E
2745	0".488	30°30'	13.0	2012	169	CP	--	---	
	1".073	30°30'	--	--	--	CP	--	0.000	E
F(e/d,θ) = 52,500±600 (127%)									
3" Mk. 29 (Flat-Nosed) Projectile									
2743	0".488	29°40'	12.92	973	82	CP	--	---	
	1".078	29°40'		--	--	Inc. 2-1/2"	--	0.002	D
2742	0".488	29°50'	12.92	1057	89	CP	--	---	
	1".076	29°50'		--	--	CP	327	0.002	D
2741	0".488	29°40'	12.95	1232	104	CP	--	---	
	1".078	29°40'		--	--	CP	574	0.007	D
2744	0".488	30°30'	12.95	2009	168	CP	--	---	
	1".073	30°30'		--	--	CP	--	Nose broken.	
F(e/d,θ) = 35,000±500 (85%)									

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