

Ballistic V₅₀ Evaluation of TIMET Ti108

by John Hogan

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by John Hogan Weapons and Materials Research Directorate, ARL

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					to determine if lower alloys in a plate's	
					to cracking while still meeting the minimum was provided by the Titanium Metals	
1 1				1	valuation were the 20-mm M602 armor	
). It was found that the Ti108 plate did not	
meet the minin	num ballistic requ	irements for the 20	-mm M602 AP-T	' threat, but d	id meet the requirement for the 30-mm	
	y 1 m/s. Future stu	udies or adjustment	s to the chemistry	y of the Ti108	3 can be conducted to optimize ballistic	
performance.						
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		mm APDS, armor	piercing discardir	ng sabot, 20-n	nm M602 AP-T, armor piercing with tracer	
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1. Introduction

 V_{50} evaluations are conducted to compare the ballistic performance of different titanium alloys. Conventional Ti-6Al-4V is commonly used in aerospace frames and engine components, but has difficulty passing ballistic shock testing on welds as cracking initiates in the welds and runs through parent body material. To see if a lower alloy content plate can provide a slightly lower strength with higher elongation and resistance to cracking, TIMET (Titanium Metals Corporation, Dallas, Texas) provided a 12-inch \times 27-inch \times 3.1-inch sample plate of an experimental alloy called Ti108 for V_{50} evaluation (Fig. 1, front view; Fig. 2, rear view). The plate chemistry and mechanical testing data were collected by TIMET and are provided in Tables 1 and 2, respectively.



Fig. 1 Ti108 strike face (front of plate)



Ti108 rear (back of plate) Fig. 2

Table 1	Chemistry	of Ti108,	heat no.	H16168

Ingot						Eleme	ent, wt%	6				
location	Al	С	Cr	Fe	Мо	Ν	Ni	0	Si	Sn	V	T_{β}, F^A
Тор	4.73	0.005	0.002	0.534	0.001	0.004	0.0042	0.177	0.014	< 0.005	2.99	1778
Top- middle	4.75	0.005	0.002	0.534	0.001	0.004	0.0041	0.179	0.014	< 0.005	2.99	1780
Middle	4.76	0.005	0.002	0.548	0.001	0.003	0.0043	0.184	0.016	0.005	3.01	1780
Bottom- middle	4.74	0.004	0.002	0.609	0.002	0.004	0.0049	0.171	0.016	< 0.005	3.05	1772
Bottom	4.75	0.004	0.002	0.592	0.002	0.004	0.0052	0.172	0.016	< 0.005	3.05	1773
Average:					0.001	0.004	0.0045	0.177	0.015	0.005	3.02	1777

Note: Ingot chemical analysis results 8000 lb 32-inch diameter triple vacuum arc remelting processed ingot ^A Calculated from binary equilibrium diagrams using the empirical formula T_{β} {°F, wt%} = 1607 + 39.3Al + 330O + 1145C + 1020N - 21.8V - 32.5Fe

Table 2	Tensile pro	perties: n	nechanical	test data fo	r Ti108, heat no	. H16168
---------	-------------	------------	------------	--------------	------------------	----------

Orientation		e yield ngth	Ultimate stren		Elongation	Reduction of area
_	ksi	MPa	ksi	MPa	%	%
L	111	765	125	862	13	23
Т	111	765	124	855	11	19

2. Experimental Procedure

A standard V_{50} was conducted on the TIMET Ti108 plate per Military Standard MIL-STD-662F.¹ The Ti108 plate was secured with clamps to a 50.8-mm-(2-inch) thick 90° stand (Fig. 3) to maintain a 0° obliquity. A 0.5-mm (0.020-inch) 2024AL witness plate was placed 152 mm (6.0 inches) behind and parallel to the rear of the Ti108 plate (Fig. 4). If the witness plate was impacted by the target or penetrator material causing light to pass through the sheet, the shot was considered a complete penetration (loss). If no light was seen through the sheet, even if damaged, this was considered a partial penetration (win). Projectile impact velocities and total yaw were measured with flash X-rays.² Impacts where the total yaw was greater than 3° were not used for the V₅₀ calculation.



Fig. 3 Titanium plate in target stand (front view)



Fig. 4 Titanium plate in target stand (side view)

The projectiles used for this evaluation were the 30-mm armor piercing discarding sabot (APDS) core (Fig. 5) and the 20-mm armor piercing with tracer (AP-T) M602 (Fig. 6).



Fig. 5 30-mm APDS core





The 30-mm APDS core was sabot-launched out of a 10-ft-long smooth bore lab gun, chambered for a 37-mm cartridge case, with a 1.090-inch-diameter bore. M2 165-mm propellant was used as the propelling charge and load weights were varied to vary the projectile impact velocity.

The M602 projectiles were pulled from M601 cartridges and were separately loaded into an 8-ft-long 20-mm diameter rifled lab gun chambered for a 25-mm case. MPM2 37-mm propellant was used as the propelling charge and load weights were varied to vary the projectile impact velocity.

Military Detail Specification MIL-DTL-46077G³ was used in determining a starting velocity in relation to the thickness of the target plate. Starting velocities of 1007 m/s (3303 ft/s) for the 30-mm APDS and 1050 m/s (3444 ft/s) for the M602 projectiles were selected and adjusted up or down depending on the result being a complete penetration (CP) or partial penetration (PP). Since a CP was determined on the initial shots of both projectiles, the impact velocities for subsequent shots were lowered until a PP was achieved. Once a PP was achieved, the process of increasing velocity after a PP and decreasing velocity after a CP continued until enough shots were taken so that a V_{50} could be calculated.

3. Results and Analysis

Prior to the evaluation, the Ti108 plate's thickness was measured in all 4 corners, 1-inch in from the sides, and averaged. A Brinell hardness (HBW) measurement was also taken and the results are listed in Table 3.

Target Description	Average measured thickness (mm)	Average measured thickness (inches)	HBW
Ti108 = Ti-5Al-3V-0.6Fe-0.18C	35.9	3.1035	286

 Table 3
 Average measured thickness and HBW for Ti108 plate

The V_{50} results for the 30-mm APDS are given in Table 4 and the standard deviation in Table 5. The shot data sheets and plate photographs are provided in the Appendix.

LAT shot no.	Vs (m/s)	Result	Pitch (deg)	Yaw (deg)	Gamma (deg)	Powder grains	Remarks
15797	1100	CP	-0.39	-0.15	0.42	165	
15798	1013	PP	-1.46	0.13	1.47	145	
15799	1062	CP	-0.61	-1.01	1.18	155	
15800	1027	PP	-0.07	0.27	0.28	147	
15801	1037	CP	-0.49	0.40	0.63	150	
15802	1033	PP	0.57	-0.07	0.57	149	High partial
15803	1036	СР	-0.18	-0.67	0.69	150	Low complete

Table 4V50 results for 30-mm APDS projectile

4 shots	m/s
V ₅₀	1033
Spread	10
Gap	3
ZMR	
Std dev	5
Margin	1

The results from the 30-mm APDS threat show that the TIMET Ti108 exceeded the extrapolated minimum V_{50} requirement in MIL-DTL-46077G of 1032 m/s for a plate thickness of 3.1035 inches.

The V_{50} results for the 20-mm M602 AP-T projectile are given in Table 6 and the standard deviation in Table 7. The shot data sheets and plate photographs are provided in the Appendix.

LAT shot no.	Vs (m/s)	Result	Pitch (deg)	Yaw (deg)	Gamma (deg)	Powder grains	Remarks
15872	1044	СР	0.83	0.40	0.92	750	
15873	1006	СР	0.43	-1.50	1.56	700	
15874	965	PP	0.76	-0.03	0.76	650	
15875	977	PP	0.10	1.62	1.62	665	
15876	997	PP	-1.28	-1.47	1.95	685	High partial
15877	993	PP	-0.15	-2.93	2.93	690	
15878	1004	СР	-0.51	0.01	0.51	700	Low complete
15879		СР				690	No X-rays
15880		PP				683	No X-rays
15881	993	PP	2.12	-0.32	2.15	683	

Table 6V50 results for 20-mm M602 AP-T projectile

 Table 7
 Standard deviation for 20-mm M602 AP-T projectile

4 shots	m/s
V ₅₀	1000
Spread	13
Gap	7
ZMR	
Std dev	6
Margin	-19

The results from the 20-mm M602 AP-T threat show that the TIMET Ti108 did not meet the minimum V_{50} requirements in MIL-DTL-46077G of 1019 m/s for a plate thickness of 3.1035 inches.

4. Conclusions

The TIMET Ti108 did not meet the minimum V_{50} requirement per the threat given as outlined in this experiment under the MIL-DTL-46077G standard. The Ti108 did exceed the extrapolated requirement for the 30-mm APDS by 1 m/s, but performed under the requirement for the 20-mm AP-T by 19 m/s. Due to close proximity in velocity of meeting the minimum required V₅₀ standard, perhaps in the future additional studies or adjustments to the chemistry of the Ti108 can be conducted to optimize performance.

5. References

- 1. MIL-STD-662F. V₅₀ ballistic test for armor. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 1997 Dec 18.
- 2. Grabarek C, Herr E. X-ray multi-flash system for measurement of projectile performance at the target. Aberdeen Proving Ground (MD): Ballistic Research Laboratory (US); 1966. Report No.: BRL-TN-1634.
- MIL-DTL-46077G (w/ amendment 1). Armor plate, titanium alloy, weldable. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2017 Jan 26.

Appendix. Shot Sheets and Postimpact Photographs



A.1 30-mm APDS Shot Sheets and Photos

Fig. A-1 30-mm APDS overall front of plate (strike face)



Fig. A-2 30-mm APDS overall back of plate

Program:	L	AT	Shot #:	157	797	Date:	6/26/	/2017	Range:	G
Engineer:	Matt B	urkins	Projectile:	30mm	n APDS	Gun:		#2 10	1.090	
Test Di	rector:	Hugh	Walter	Gunner:	David H	andshoe	Muzzle t	o Target:	56"	
	Launch I	Package:		Case	Size:	37mm	Powde	r Type:	165mm	
	Length	Diam	Mass	Prime	r Type:	M38B2	Powder	Weight:	165 grams	
Penetrator			213.83	Expected	Velocity:	1007 m/s	Shot	Time:	919	
Sabot			14.52				Results			
Pusher			11.53		m/s	f/s	Residual	m/s	f/s	
Obturator			12.47	Velocity:	1100	3609	Velocity:			
Тс	tal (grams	5)	252.59							
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	-0.39	Yaw:	-0.15	Total Yaw:	0.42
Velocity:			х							
		•	•	Х-	Ray Times				· · ·	
ube Heads	1	2	3	4	5	6	7	8	9	10
Distance	16"	8"								
Preset	403.5	201.5								
Actual	404.1	202.2								
				Ta	arget Data					
Plate #			Material			Thick	Obliq.	Weight	Weight	BHN
Fiale #			Waterial			(in)	(deg)	Before	After	БЦИ
1		Ti Me	(H16168-5	Ti-108		3.1035"	0			286
2			Air			6"				
3			Witness			.020"				
4										
5										
6										
7										
8			1							
Plate #	Entrance	Hole (cm)	Center H	ole (cm)	Exit Ho	le (cm)		Bulge (cm	-	Pene
	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	3.3	3.7	2.2	2.4	66	7.5				
2										
3										
4										
5										
6										
7										
8										
8					Notes:	<u></u>	<u></u>	<u> </u>	<u> </u>	



Program:		٩T	Shot #:	157	709	Date:	6/26/	2017	Range:	G
Engineer:		Surkins	Projectile:			Gun:	0/20/		1.090	G
Test Di		1	Walter	Gunner:	1	andshoe	Muzzlot	o Target:	56"	
TCST DI		Package:	vvaitei		Size:	37mm		r Type:	165mm	
	Length	Diam	Mass		r Type:	M38B2		Weight:	145 grams	
Penetrator	Lengen	Diam	213.27		Velocity:			Time:	1022	
Sabot			14.48				Results			
Pusher			11.48		m/s	f/s	Residual	m/s	f/s	
Obturator			12.7	Velocity:	1013	3324	Velocity:		, -	
	otal (grams	;)	252.1							
Phantom	m/s	, f/s	Complete:	Partial:	Pitch:	-1.46	Yaw:	0.13	Total Yaw:	1.47
Velocity:				х						
					Ray Times					
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	16"	8"								
Preset	403.5	201.5								
Actual	404.1	202.2								
				Ta	arget Data					
Plate #			Material			Thick	Obliq.	Weight	Weight	BHN
Flate #						(in)	(deg)	Before	After	DIIN
1		Ti Mex	(H16168-5	Ti-108		3.1035"	0			286
2			Air			6"				
3			Witness			.020"				
4										
5										
6										
7										
8					<u> </u>	<u> </u>		, ,		
Plate #		Hole (cm)	Center H	· ,		le (cm)		Bulge (cm)		Pene
4	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	3.4	3.8					1	6.9	7.2	
2										
3										
4										
5										
7 8										
ŏ					Notes:					
					140163.					





		۸ - ד	Chat #	4	700	Data	c lac	/2017	Demon	
Program:		AT	Shot #:	157		Date:	6/26/		Range:	G
Engineer: Test Di		Burkins	Projectile:			Gun:	Muzzlot		1.090	
lest Di			Walter	Gunner:		andshoe		o Target:	140.5"	
		Package:			Size:	37mm M38B2		er Type:	165mm 155 grams	
Devetueteu	Length	Diam	Mass 213.88		r Type: Velocity:			Weight: Time:	1115 1115	
Penetrator			14.24	Expected	verocity:	1020 11/2	Results	inne:	1115	
Sabot Pusher			14.24		m/s	f/s	Residual	m/s	f/s	
Obturator			12.48	Velocity:	1062	3485	Velocity:	111/5	1/ 5	
	otal (grams	:)	252.28		1002	5405	ve. oo.ey.			
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	-0.61	Yaw:	-1.01	Total Yaw:	1.18
Velocity:	1117.5	1/3	X		Then.	-0.01	14 .	-1.01		1.10
			~	X-	Ray Times				<u> </u>	
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	16"	8"		· ·					-	
Preset	387.5	193.5								
Actual	308.1	194.2								
				Ta	arget Data				ļļ	
N			Matarial		0	Thick	Obliq.	Weight	Weight	
Plate #			Material			(in)	(deg)	Before	After	BHN
1		Ti Mex	(H16168-5	Ti-108		3.1035"	0			286
2			Air			6"				
3			Witness			.020"				
4										
5										
6										
7										
8			1		1					
Plate #		Hole (cm)	Center H			le (cm)		Bulge (cm		Pene
	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	3.6	3.7	2.3	2.7	6.8	7.4				
2										
3										
4										_
5										
6										
7										
8										
					Notes:					



Program:		AT	Shot #:	158	200	Date:	6/26/	2017	Range:	6
Engineer:		Burkins	Projectile:		n APDS	Gun:	0/20/		1.090	G
Test Di		1	Walter	Gunner:	1	andshoe	Muzzlot	o Target:	1.090	
Test Di		Package:	warter		Size:	37mm		r Type:	140.5 165mm	
	Length	Diam	Mass		r Type:	M38B2		Weight:	147 grams	
Penetrator	Length	Diam	213.84		Velocity:			Time:	1336	
Sabot			14.52	Expected	veroerty.	1023 11/3	Results	inne.	1330	
Pusher			11.47		m/s	f/s	Residual	m/s	f/s	
Obturator			12.48	Velocity:	1027	3368	Velocity:	, o	., 0	
	otal (grams	;)	252.63							
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	-0.07	Yaw:	0.27	Total Yaw:	0.28
Velocity:	, •	., -		X						
,					Ray Times	l				
ube Heads	1	2	3	4	5	6	7	8	9	10
Distance	16"	8"								
Preset	396.5	198.5								
Actual	397.2	199.2								
				Ta	arget Data					
Plate #			Material			Thick	Obliq.	Weight	Weight	DUN
Plate #			Waterial			(in)	(deg)	Before	After	BHN
1		Ti Mex	(H16168-5	Ti-108		3.1035"	0			286
2			Air			6"				
3			Witness			.020"				
4										
5										
6										
7										
8			1		1					
Plate #	Entrance	Hole (cm)	Center H	ole (cm)	Exit Ho	le (cm)		Bulge (cm)		Pene
	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	3.2	3.2					1.1	6.6	7.2	
2										
3										
4										
5										
6										
7										
8										
					Notes:					





		AT	Shot #:	158	201	Deter	c /ac	/2017	Demos	6
Program:		Burkins			APDS	Date:	6/26/		Range: 1.090	G
Engineer: Test Di		1	Projectile:	Gunner:	-	Gun: andshoe	Muzzlot	#2 10	1.090	
Test Di		Package:	Walter		Size:	37mm		er Type:	140.5 165mm	
	Length	Diam	Mass		r Type:	M38B2		Weight:	150 grams	
Penetrator	Length	Diam	212.82		Velocity:			Time:	1431	
Sabot			14.52	Expected	verocity.	1043 11/3	Results	inne.	1431	
Pusher			11.42		m/s	f/s	Residual	m/s	f/s	
Obturator			12.46	Velocity:	1037	3401	Velocity:	11,3	175	
	tal (grams	;)	251.5		1007	0.01	,			
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	-0.49	Yaw:	0.4	Total Yaw:	0.63
Velocity:	, 0	., 0	X	. artian		0110			iotai iuni	0.00
,				Х-	Ray Times	l				
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	16"	8"								
Preset	388.5	194.5								
Actual	389.1	195.2								
				Ta	arget Data					
Plate #			Material			Thick	Obliq.	Weight	Weight	BHN
Plate #			Waterial			(in)	(deg)	Before	After	BHIN
1		Ti Mex	(H16168-5	Ti-108		3.1035"	0			286
2			Air			6"				
3			Witness			.020"				
4										
5										
6										
7										
8								ļ		
Plate #		Hole (cm)	Center H	, ,		le (cm)		Bulge (cm		Pene
	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	3	4.1			4.5	6.4				
2										
3										
4										
5										
6										
7										
8										
					Notes:					



AN			L I	-110		SHEE				
Program:	L	AT	Shot #:	158	802	Date:	6/27/	2017	Range:	G
Engineer:	Matt B	lurkins	Projectile:	30mm	n APDS	Gun:			1.090	
Test Dir	rector:	Hugh	Walter	Gunner:	ļ	andshoe		o Target:	140.5"	
	Launch I	Package:	1	Case	Size:	37mm		r Type:	165mm	
	Length	Diam	Mass		r Type:	M38B2		Weight:	149 grams	
Penetrator			213.44	Expected	Velocity:	1030 m/s	Shot	Time:	635	
Sabot			14.55		1	1	Results			
Pusher			11.46	Velocity:	m/s	f/s	Residual	m/s	f/s	
Obturator			12.54	, ei o o i ej i	1033	3390	Velocity:			
То	tal (grams	5)	252.18							
Phantom	m/s	f/s	Complete:	Partial:	Pitch:	0.57	Yaw:	-0.07	Total Yaw:	0.57
Velocity:				Х						
				Х-	Ray Times	-				
ube Heads	1	2	3	4	5	6	7	8	9	10
Distance	16"	8"								
Preset	394.5	197.5								
Actual	395.1	198.2								
				Ta	arget Data					
Plate #			Material			Thick	Obliq.	Weight	Weight	BHN
						(in)	(deg)	Before	After	
1		Ti Me	(H16168-5	Ti-108		3.1035"	0			286
2			Air			6"				
3	-		Witness			.020"				
4										
5	-									
6										
7										
8			1							
Plate #		Hole (cm)	Center H			le (cm)		Bulge (cm)		Pene
	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	3.4	3.1					1.5	6.8	7	
2										
3										
4										
5										
6										
7										
8										
					Notes:					





alter Gun ass F 213.59 Exp 14.43 11.37 Velo 252.17 omplete: Par X	Case Size Primer Typ ected Velo city:	PDS David Ha ze: /pe:	Date: Gun: andshoe 37mm M38B2 1040 m/s f/s 3399 -0.18 -0.18 6 -0.18 -0.1	6/27/ Muzzle tr Powder Shot Tr Results Residual Velocity: Yaw: 7 7 7 0 0 0 0 0 0	#2 10' o Target: r Type: Weight:	Range: 1.090 140.5" 165mm 150 grams 719 f/s Total Yaw; 9	0.69 10 BHN 286
Alterial Alter Alter Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial Alterial	Anner: Da Case Size Primer Typ ected Velo boity: 1 boity: 1 tial: Pi X-Ray 4 4 Targe	David Ha re: ype: locity: m/s 1036 Pitch: y Times 5	andshoe 37mm M38B2 1040 m/s f/s 3399 -0.18 6 Thick (in) 3.1035" 6"	Powde Powder Shot Residual Velocity: Yaw: 7 7 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	o Target: r Type: Weight: Time: m/s -0.67 8 8 8 	140.5" 165mm 150 grams 719 f/s Total Yaw; 9 9 Weight	10 BHN
ass F ass F 213.59 Exp 11.37 25 12.5 25 252.17 25 complete: Par 3 4 3 4 4 4 11.37 12.5 252.17 25 5 7 3 4 4 1 4 1 16168-5 Ti-10 Air 1	Case Size Primer Typ ected Velo city:	ze: ype: locity: m/s 1036 20itch: 5 5	37mm M38B2 1040 m/s f/s 3399 -0.18 6 -0.18 5 	Powde Powder Shot Residual Velocity: Yaw: 7 7 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	r Type: Weight: Time: m/s -0.67 8 8 Weight	165mm 150 grams 719 f/s Total Yaw; 9 9 Weight	10 BHN
213.59 Exp 14.43 Velo 11.37 Velo 252.17 Omplete: Par X 3 3 4 Aterial 16168-5 Ti-10 Air	Primer Typected Velo poity: 7 1 tial: Pi X-Ray 4 Targe	ype: locity: m/s 1036 Pitch: 5 5	M38B2 1040 m/s f/s 3399 -0.18 6 6 Thick (in) 3.1035" 6"	Powder Shot Results Residual Velocity: Yaw: 7 7 7 0 0 0 0 bliq. (deg)	Weight: Time: m/s -0.67 8 8 Weight	150 grams 719 f/s Total Yaw 9 9 Weight	10 BHN
213.59 Exp 14.43 Velo 11.37 Velo 252.17 Omplete: Par X 3 3 4 Aterial 16168-5 Ti-10 Air	ected Velo pocity: 1 tial: Pi X-Ray 4 Targe	locity: m/s 1036 Pitch: y Times 5	1040 m/s f/s 3399 -0.18 6 Thick (in) 3.1035" 6"	Shot Results Residual Velocity: Yaw: 7 7 7 0 0 0 0 bliq. (deg)	Time: m/s -0.67 8 Weight	719 f/s Total Yaw 9 Weight	10 BHN
14.43 [11.37] 12.5 Velo 252.17 Par 252.17 Normal Par X Normal	tial: Pi X-Ray 4 Targe	m/s 1036 Pitch: y Times 5	f/s 3399 -0.18 6 7 Thick (in) 3.1035" 6"	Results Residual Velocity: Yaw: 7 7 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	m/s -0.67 8 	f/s Total Yaw; 9 Weight	10 BHN
12.5 Velocities 12.5 252.17 complete: Par X 252.17 3 252.17 3 252.17 3 252.17 4 252.17 3 252.17 3 252.17 4 252.17 3 252.17 3 252.17 4 252.17 3 252.17 3 252.17 4 252.17 3 252.17 4 252.17 4 252.17 4 252.17 4 252.17 5 252.17 4 252.17 5 252.17 5 252.17 6 252.17 7 252.17 7 252.17 7 252.17 7 252.17 7 252.17 7 252.17 7 252.17 7 252.17 7 252.17 7 252.17 7 252.17 7 252.17 7 252.17 7 <td< td=""><td>tial: Pi X-Ray 4 Targe</td><td>1036 Pitch: y Times 5</td><td>3399 -0.18 6 </td><td>Velocity: Yaw: 7 Obliq. (deg)</td><td>-0.67 8 Weight</td><td>9 Weight</td><td>10 BHN</td></td<>	tial: Pi X-Ray 4 Targe	1036 Pitch: y Times 5	3399 -0.18 6 	Velocity: Yaw: 7 Obliq. (deg)	-0.67 8 Weight	9 Weight	10 BHN
12.5 252.17 complete: Par X 3 4 4 4 4 4 16168-5 Ti-10 Air	tial: Pi X-Ray 4 Targe	1036 Pitch: y Times 5	3399 -0.18 6 	Yaw: 7 Obliq. (deg)	-0.67 8 Weight	9 Weight	10 BHN
Air	X-Ray 4 Targe	y Times	6 Thick (in) 3.1035" 6"	7 Obliq. (deg)	8 Weight	9 Weight	10 BHN
X 3 Aaterial 16168-5 Ti-10 Air	X-Ray 4 Targe	y Times	6 Thick (in) 3.1035" 6"	7 Obliq. (deg)	8 Weight	9 Weight	10 BHN
X 3 Aaterial 16168-5 Ti-10 Air	4 Targe	5	Thick (in) 3.1035" 6"	Obliq. (deg)	Weight	Weight	BHN
Aaterial 16168-5 Ti-10 Air	4 Targe	5	Thick (in) 3.1035" 6"	Obliq. (deg)	Weight	Weight	BHN
Aaterial 16168-5 Ti-10 Air	4 Targe	5	Thick (in) 3.1035" 6"	Obliq. (deg)	Weight	Weight	BHN
16168-5 Ti-10 Air		et Data	(in) 3.1035" 6"	(deg)	0		
16168-5 Ti-10 Air		et Data	(in) 3.1035" 6"	(deg)	0		
16168-5 Ti-10 Air		et Data	(in) 3.1035" 6"	(deg)	0		
16168-5 Ti-10 Air		et Data	(in) 3.1035" 6"	(deg)	0		
16168-5 Ti-10 Air	8		(in) 3.1035" 6"	(deg)	0		
16168-5 Ti-10 Air	18		3.1035" 6"		Before	After	
Air			6"	0			286
Vitness			.020"				
Center Hole (c	-	Exit Hol	le (cm)		Bulge (cm)		Pene
Length Wi		ength	Width	Height	Length	Width	(cm)
	:	3.9	3.8				
			Image: Product Congulation 3.9 Image: Product Congulation Image: Product Co				







A.2 20-mm M602 AP-T Shot Sheets and Photos

Ah			E	-110	SHOT	SHEE	Т		A	KL
Program:	L	AT	Shot #:	158	872	Date:	12/4/	2017	Range:	G
Engineer:	John	Hogan	Projectile:	M	502	Gun:	#	#ED5 8' 20	mm (Rifled))
Test Di	rector:	Hugh	Walter	Gunner:	David H	andshoe	Muzzle t	o Target:	61.2	25"
	Launch F	Package:		Case	Size:	25mm	Powde	r Type:	37mm	
	Length	Diam	Mass	Prime	r Type:	M36A2	Powder	Weight:	750 grains	
Penetrator			110.56	Expected V	elocity m/s:	1050	Shot	Time:	1125	
Sabot										
Pusher							Results			
Obturator				Valasituu	m/s	f/s	Residual	m/s	f/s	
Тс	tal (grams	5)	110.56	Velocity:	1044	3426	Velocity:			
Phantom	m/s	f/s	Complete:	Partial:						
Velocity:			х		Pitch:	0.83	Yaw:	0.4	Total Yaw:	0.92
				X	Ray Times				······································	
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	15	8								
Preset	362.8	193.5								
Actual	363.2	194.3								
				Ta	arget Data					
Plate #			Material			Thick	Obliq.	Weight	Weight	BHN
Plate #			Waterial			(in)	(deg)	Before	After	DUIN
1		Ti Mex	(H16168-5	Ti-108		3.1035"	0			
2			Air			6"				
3			AL Witness			.020"				
4										
5										
6										
7										
8										
Plate #	Entrance	Hole (cm)	Center H	ole (cm)	Exit Ho	le (cm)		Bulge (cm)	Pene
Fiale #	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	1.9	1.8	1.3	1.5	3.1	3.5				
2										
3										
4										
5										
6										
7										
8										
					Notes:					

							10/1			
Program:		AT	Shot #:		873	Date:	12/4/		Range:	G
Engineer:		Hogan	Projectile:		502	Gun:			mm (Rifled)	
Test Di		. <u> </u>	Walter	Gunner:		andshoe		o Target:	61.2	25"
	Launch F	1			Size:	25mm		r Type:	37mm	
	Length	Diam	Mass		r Type:	M36A2		Weight:	700 grains	
Penetrator			110.32	Expected V	elocity m/s:	1000	Shot	Time:	1340	
Sabot		ļ								
Pusher						£ / -	Results		£/-	
Obturator		- \	110.22	Velocity:	m/s	f/s	Residual Velocity:	m/s	f/s	
	otal (grams	1	110.32	Dantial	1006	3300	verocity.			
Phantom Velocity:	m/s	f/s	Complete:	Partial:	Ditah	0.42	Verm	1 Г	Tatal Varu	1 5 6
verocity.			X	v	Pitch:	0.43	Yaw:	-1.5	Total Yaw:	1.56
Fube Heads	1	2	2	4 4	-Ray Times	c	7	0	9	10
	1 15	2	3	4	5	6	7	8	9	10
Distance	381.0	8 203.2								
Preset										
Actual	382.2	204.2		T.	arget Data					
				10	arget Data	Thick	Obliq.	Weight	Weight	
Plate #			Material			(in)	(deg)	Before	After	BHN
1		Ti Mex	(H16168-5	Ti-108		3.1035"	0			
2			Air			6"				
3			AL Witness			.020"				
4										
5										
6										
7										
8										
Diata #	Entrance	Hole (cm)	Center H	ole (cm)	Exit Ho	le (cm)		Bulge (cm)		Pene
Plate #	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	1.9	1.7	1.3	1.1	3.2	2.4				
2										
3										
4										
5										
6										
7										
8										
					Notes:					

Program:	L	AT	Shot #:	158	874	Date:	12/5/	2017	Range:	G
Engineer:	John	Hogan	Projectile:	M	502	Gun:			mm (Rifled)	
Test Di		-	Walter	Gunner:		andshoe		o Target:	61.2	
	Launch	Package:		Case	Size:	25mm	Powde	r Type:	37mm	
	Length	Diam	Mass	Prime	r Type:	M36A2		Weight:	650 grains	
Penetrator			110.55	Expected V	elocity m/s:	950	Shot	Time:	626	
Sabot										
Pusher							Results			
Obturator				Valasitu	m/s	f/s	Residual	m/s	f/s	
Тс	otal (grams	5)	110.55	Velocity:	965	3165	Velocity:			
Phantom	m/s	f/s	Complete:	Partial:						
Velocity:				х	Pitch:	0.76	Yaw:	-0.03	Total Yaw:	0.76
				Х-	Ray Times					
Fube Heads	1	2	3	4	5	6	7	8	9	10
Distance	15	8								
Preset	401.0	213.9								
Actual	402.2	214.2								
	I			Ta	arget Data				,	
Plate #			Material			Thick	Obliq.	Weight	Weight	BHN
		T N A		T: 400		(in)	(deg)	Before	After	
1			(H16168-5	11-108		3.1035"	0			
2			Air			6" .020"				
3			AL Witness			.020				
4 5										
6										
7										
8										
0	Entrance	Hole (cm)	Center H	ole (cm)	Exit Ho	le (cm)		Bulge (cm)		Pene
Plate #	Length	Width	Length	Width	Length	Width	Height	Length	, Width	(cm)
1	1.9	1.8	- 01		- 0-		0.3	3.6	4.2	
2										
3										
4										
5										
6										
7										
8										
					Notes:					

Program:	L	AT	Shot #:	158	875	Date:	12/5/2017		Range:	G
Engineer:	John	Hogan Projectile:		M602		Gun:	#	#ED5 8' 20	mm (Rifled)	1
Test Di	irector: Hugh Walter			Gunner:	David H	andshoe	Muzzle to Target: 61.			25"
	Launch F			Case	Size:	25mm	Powde	r Type:	37mm	
	Length	Diam	Mass	Prime	r Type:	M36A2	Powder	Weight:	665 grains	
Penetrator			110.39	Expected V	elocity m/s:	985	Shot	Time:	720	
Sabot										
Pusher							Results			
Obturator				Velocity:	m/s	f/s	Residual	m/s	f/s	
Тс	otal (grams	5)	110.39	verocity.	977	3206	Velocity:			
Phantom	m/s	f/s	Complete:	Partial:						
Velocity:				х	Pitch:	0.1	Yaw:	1.62	Total Yaw:	1.62
				X	Ray Times					
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	15	8								
Preset	386.8	206.3								
Actual	387.2	207.2								
	1			Ta	arget Data					
Plate #	te # Materia		Material			Thick	Obliq.	Weight	Weight	BHN
		Ti Mo		T: 100		(in) 3.1035"	(deg) 0	Before	After	
1		Ti Mex H16168-5 Ti-108 3.1035" 0 Air 6" 6"								
2			All AL Witness			.020"				
4			AL WITHESS			.020				
5										
6										
7										
8										
	Entrance	Hole (cm)	Center H	ole (cm) Fxit Hc		le (cm)	Bulge (cm)			Pene
Plate #	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	2	1.8					0.5	4	4.3	
2										
3										
4										
5										
6										
7										
8										
					Notes:					

Program:		AT	Shot #:	15	876	Date:	12/5/2017		Range:	G
Engineer:		Hogan	Projectile:	M602		Gun:			mm (Rifled)	
0			Gunner:				o Target:	61.2		
Test Bi	Launch F		Warter		Size:	25mm		r Type:	37mm	
	Length	Diam	Mass		r Type:	M36A2		Weight:	685 grains	
Penetrator	Lengen	Diam	110.31		elocity m/s:	990		Time:	920	
Sabot			110.01		,		0.101		520	
Pusher		ļ					Results			
Obturator					m/s	f/s	Residual	m/s	f/s	
	otal (grams	5)	110.31	Velocity:	997	3270	Velocity:	, -		
Phantom	m/s	f/s	Complete:	Partial:						
Velocity:	,			х	Pitch:	-1.28	Yaw:	-1.47	Total Yaw:	1.95
				Х-	Ray Times				,	
Fube Heads	1	2	3	4	5	6	7	8	9	10
Distance	15	8								
Preset	384.8	205.2								
Actual	385.2	206.2								
				Ta	arget Data					
Plate #			Material			Thick	Obliq.	Weight	Weight	BHN
Fiale #			Waterial			(in)	(deg)	Before	After	БПІ
1		Ti Me	KH16168-5	Ti-108		3.1035"	0			
2			Air			6"				
3			AL Witness			.020"				
4										
5										
6										
7										
8			1							
Plate #		Hole (cm)	Center H		Exit Ho	. ,	Bulge (cm			Pene
	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	1.8	1.9					1.1	4	4.1	
2										
3										
4										
5										
6 7										
/										
8										

ÂŔ	<u>L</u>		EI	-110	SHOT	SHEE	Γ		A	RL
Program:	L	AT	Shot #:	158	377	Date:	12/5/	/2017	Range:	G
Engineer:	John	Hogan	Projectile:	M602		Gun:	#	#ED5 8' 20	mm (Rifled)
Test Dir	Director: Hugh Walter			Gunner:	David H	andshoe	Muzzle t	o Target:	61.	25"
	Launch Package			Case	Size:	25mm	Powde	r Type:	37mm	
	Length	Diam	Mass	Prime	r Type:	M36A2	Powder	Weight:	690 grains	
Penetrator			110.18	Expected V	elocity m/s:	1000	Shot	Time:	1037	
Sabot										
Pusher		•					Results			
Obturator				Valacity	m/s	f/s	Residual	m/s	f/s	
То	tal (grams	5)	110.18	Velocity:	993	3257	Velocity:			
Phantom	m/s	f/s	Complete:	Partial:						
Velocity:				х	Pitch:	-0.15	Yaw:	-2.93	Total Yaw	2.93
				Х-	Ray Times					
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	15	8								
Preset	381.0	203.2								
Actual	382.2	204.3								
				Та	arget Data					
Plate #			Material			Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN
1		Ti Me	(H16168-5	Ti-108		3.1035"	0			
2			Air			6"				
3			AL Witness			.020"				
4										
5										
6										
7										
8										
	Entrance	Hole (cm)	Center H	ole (cm)	Exit Ho	le (cm)		Bulge (cm)	Pene
Plate #	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	1.8	1.8					1	4.2	4	
2										
3										
4										
5										
6										
7										
8										

Á Ŕ	<u>R</u> L		EI	-110	снот	SHEE	Г		Â	RL
Program:	L	AT	Shot #:	158	378	Date:	12/5/	/2017	Range:	G
Engineer:	John	Hogan	Projectile:	M602		Gun:	#ED5 8' 20		mm (Rifled)
Test Di	Director: Hugh Walter			Gunner:	David H	andshoe	Muzzle t	o Target:	61.	25"
	Launch	Package		Case	Size:	25mm	Powde	er Type:	37mm	
	Length	Diam	Mass	Prime	r Type:	M36A2	Powder	Weight:	700 grains	
Penetrator			110.67	Expected V	elocity m/s:	1005	Shot	Time:	1122	
Sabot										
Pusher		•					Results			
Obturator				Valacity	m/s	f/s	Residual	m/s	f/s	
Тс	otal (grams	5)	110.67	Velocity:	1004	3293	Velocity:			
Phantom	m/s	f/s	Complete:	Partial:						
Velocity:			х		Pitch:	-0.51	Yaw:	0.01	Total Yaw:	0.51
				Х-	Ray Times					
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	15	8								
Preset	379.1	202.2								
Actual	380.2	203.2								
				Та	arget Data		-			
Plate #			Material			Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN
1		Ti Mex	(H16168-5	Ti-108		3.1035"	0			
2			Air			6"				
3			AL Witness			.020"				
4										
5										
6										
7										
8										
Plate #	Entrance	Hole (cm)	Center H	ole (cm)	Exit Ho	le (cm)		Bulge (cm)	Pene
Fiale #	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	1.8	1.6			1.5	2.1				
2										
3										
4										
5										
6										
7										
8										

Á Ŕ	<u>R</u> L		EI	F-110	SHOT	SHEE	Γ		Â	RL
Program:	L	AT	Shot #:	158	379	Date:	12/5/	/2017	Range:	G
Engineer:	John	Hogan	Projectile:	M602		Gun:	#ED5 8' 20		mm (Rifled)
Test Di	Director: Hugh Walter			Gunner:	David H	andshoe	Muzzle t	o Target:	61.	25"
	Launch Package			Case	Size:	25mm	Powde	er Type:	37mm	
	Length	Diam	Mass	Prime	r Type:	M36A2	Powder	Weight:	690 grains	
Penetrator			110.36	Expected V	elocity m/s:	995	Shot	Time:	1259	
Sabot										
Pusher							Results			
Obturator				Velocity:	m/s	f/s	Residual	m/s	f/s	
Тс	otal (grams	5)	110.36	verocity.			Velocity:			
Phantom	m/s	f/s	Complete:	Partial:						
Velocity:			х		Pitch:		Yaw:		Total Yaw:	
				Х-	Ray Times		-			
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	15	8								
Preset	382.9	204.2								
Actual	383.2	205.2								
				Ta	arget Data					
Plate #			Material			Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN
1		Ti Me	(H16168-5	Ti-108		3.1035"	0			
2			Air			6"				
3			AL Witness			.020"				
4										
5										
6										
7										
8			-							
Plate #	Entrance	Hole (cm)	Center H	ole (cm)	Exit Ho	le (cm)		Bulge (cm)	Pene
i iate #	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	1.6	1.7			1.4	2.3				
2										
3										
4										
5										
6										
7										
8										

No X-rays trigger wire was fragged.

ÂŔ	Ż		EI	-110	SHOT	SHEE ⁻	Г		Â	RL
Program:	L	AT	Shot #:	158	380	Date:	12/5/	/2017	Range:	G
Engineer:	John	Hogan	Projectile:	M602		Gun:	#ED5 8' 20		mm (Rifled)
Test Di	t Director: Hugh Walter			Gunner:	David H	andshoe	Muzzle t	o Target:	61.	25"
	Launch Package			Case	Size:	25mm	Powde	er Type:	37mm	
	Length	Diam	Mass	Prime	r Type:	M36A2	Powder	Weight:	683 grains	
Penetrator			110.59	Expected V	elocity m/s:	990	Shot	Time:	1340	
Sabot										
Pusher							Results			
Obturator				Velocity:	m/s	f/s	Residual	m/s	f/s	
Тс	otal (grams	5)	110.59	verocity.			Velocity:			
Phantom	m/s	f/s	Complete:	Partial:						
Velocity:				х	Pitch:		Yaw:		Total Yaw:	:
				Х-	Ray Times			-		
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	15	8								
Preset	384.8	205.2								
Actual	385.2	206.3								
				Ta	arget Data			-	_	
Plate #			Material			Thick (in)	Obliq. (deg)	Weight Before	Weight After	BHN
1		Ti Mex	(H16168-5	Ti-108		3.1035"	0			
2			Air			6"				
3			AL Witness			.020"				
4										
5										
6										
7										
8										
Plate #	Entrance	Hole (cm)	Center H	ole (cm)	Exit Ho	le (cm)		Bulge (cm))	Pene
Fiale #	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	1.6	1.8					1	4	4.2	
2										
3										
4										
5										
6										
7										
8										

No X-rays frags in trigger screen holder.

ÂŔ	<u>R</u>		EI	F-110	снот	SHEE.	Г		A	RL
Program:	L	AT	Shot #:	158	381	Date:	12/6/	2017	Range:	G
Engineer:	John	Hogan	Projectile:	M602		Gun:	#	#ED5 8' 20	mm (Rifled)
Test Di	rector:	Hugh	Walter	Gunner:	David H	andshoe	Muzzle t	o Target:	61.	25"
	Launch	Package		Case	Size:	25mm	Powde	r Type:	37mm	
	Length	Diam	Mass	Prime	r Type:	M36A2	Powder	Weight:	683 grains	
Penetrator			110.4	Expected V	elocity m/s:	990	Shot	Time:	723	
Sabot										
Pusher							Results			
Obturator				Mala site u	m/s	f/s	Residual	m/s	f/s	
Тс	tal (grams	5)	110.4	Velocity:	993	3257	Velocity:			
Phantom	m/s	f/s	Complete:	Partial:						
Velocity:				х	Pitch:	2.12	Yaw:	-0.32	Total Yaw	2.15
				Х-	Ray Times					
Tube Heads	1	2	3	4	5	6	7	8	9	10
Distance	15	8								
Preset	384.8	205.2								
Actual	385.2	206.2								
				Та	arget Data					
Plate #			Material			Thick	Obliq.	Weight	Weight	BHN
Flate #						(in)	(deg)	Before	After	DIIN
1		Ti Me	(H16168-5	Ti-108		3.1035"	0			
2			Air			6"				
3			AL Witness			.020"				
4										
5										
6										
7										
8			I							
Plate #	Entrance	Hole (cm)	Center H	ole (cm)	Exit Ho	le (cm)		Bulge (cm))	Pene
Trate ii	Length	Width	Length	Width	Length	Width	Height	Length	Width	(cm)
1	1.8	1.7					0.9	3.6	4.1	
2										
3										
4										
5										
6										
7										
8										

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List of Symbols, Abbreviations, and Acronyms

APDS	armor piercing discarding sabot
AP-T	armor piercing with tracer
ARL	US Army Research Laboratory
СР	complete penetration
HBW	Brinell hardness
LAT	light armor technologies
PP	partial penetration
TIMET	Titanium Metals Corporation
ZMR	zone of mixed results

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