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Ballistic V_{50} Evaluation of TIMET Ti108

by John Hogan

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by John Hogan

Weapons and Materials Research Directorate, ARL

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| 14. ABSTRACT A ballistic V ₅₀ evaluation of an experimental titanium alloy Ti108 was conducted to determine if lower alloys in a plate's content can provide slightly lower strengths with higher elongation and resistance to cracking while still meeting the minimum performance specifications outlined in MIL-DTL-46077G. A 3.1-inch-thick plate was provided by the Titanium Metals Corporation (Dallas, Texas) for the V ₅₀ evaluation. The projectiles used for the evaluation were the 20-mm M602 armor piercing with tracer (AP-T) and a 30-mm armor piercing discarding sabot (APDS). It was found that the Ti108 plate did not meet the minimum ballistic requirements for the 20-mm M602 AP-T threat, but did meet the requirement for the 30-mm APDS threat by 1 m/s. Future studies or adjustments to the chemistry of the Ti108 can be conducted to optimize ballistic performance. | | | | | |
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Contents

| | |
|---|-----------|
| List of Figures | iv |
| List of Tables | iv |
| Acknowledgments | v |
| 1. Introduction | 1 |
| 2. Experimental Procedure | 3 |
| 3. Results and Analysis | 6 |
| 4. Conclusions | 7 |
| 5. References | 8 |
| Appendix. Shot Sheets and Postimpact Photographs | 9 |
| List of Symbols, Abbreviations, and Acronyms | 37 |
| Distribution List | 38 |

List of Figures

| | | |
|----------|--|----|
| Fig. 1 | Ti108 strike face (front of plate) | 1 |
| Fig. 2 | Ti108 rear (back of plate) | 2 |
| Fig. 3 | Titanium plate in target stand (front view) | 3 |
| Fig. 4 | Titanium plate in target stand (side view)..... | 4 |
| Fig. 5 | 30-mm APDS core..... | 4 |
| Fig. 6 | 20-mm AP-T M602..... | 5 |
| Fig. A-1 | 30-mm APDS overall front of plate (strike face)..... | 10 |
| Fig. A-2 | 30-mm APDS overall back of plate | 10 |

List of Tables

| | | |
|---------|--|---|
| Table 1 | Chemistry of Ti108, heat no. H16168 | 2 |
| Table 2 | Tensile properties: mechanical test data for Ti108, heat no. H16168 .. | 2 |
| Table 3 | Average measured thickness and HBW for Ti108 plate..... | 6 |
| Table 4 | V ₅₀ results for 30-mm APDS projectile | 6 |
| Table 5 | Standard deviation for 30-mm APDS | 6 |
| Table 6 | V ₅₀ results for 20-mm M602 AP-T projectile..... | 7 |
| Table 7 | Standard deviation for 20-mm M602 AP-T projectile..... | 7 |

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1. Introduction

V₅₀ 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 × 27-inch × 3.1-inch sample plate of an experimental alloy called Ti108 for V₅₀ 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.

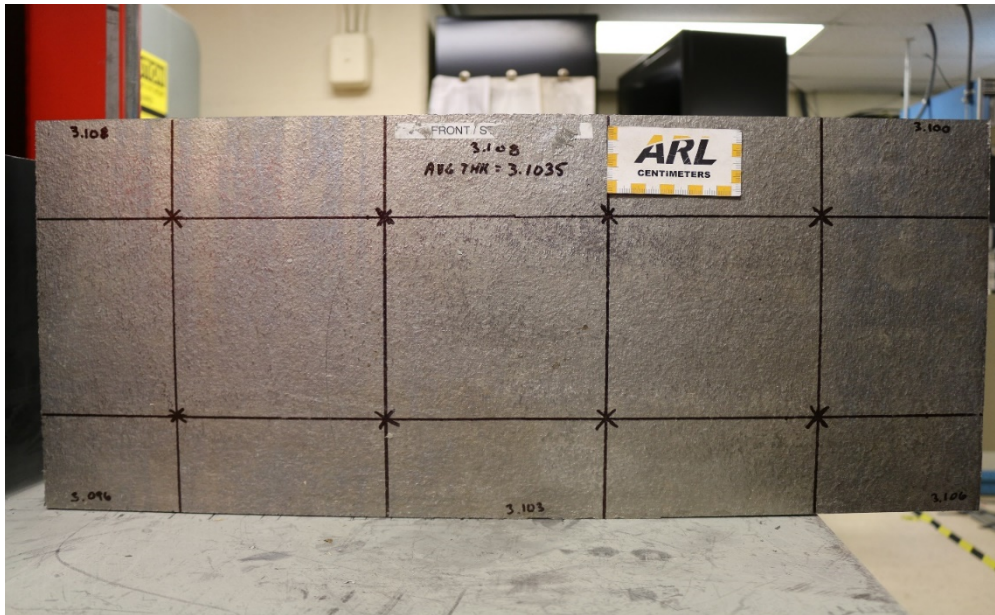


Fig. 1 Ti108 strike face (front of plate)

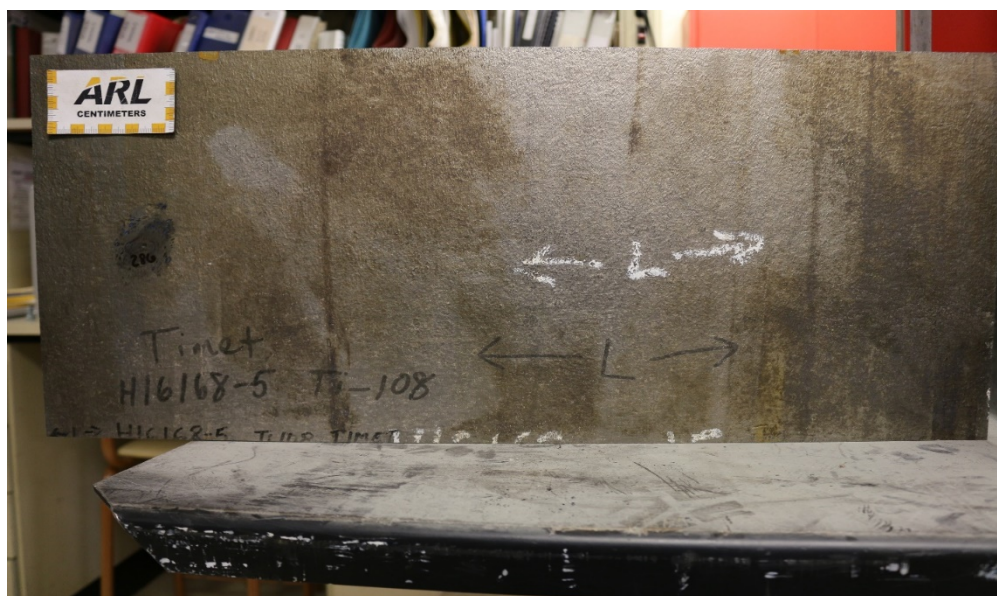


Fig. 2 Ti108 rear (back of plate)

Table 1 Chemistry of Ti108, heat no. H16168

| Ingot location | Element, wt% | | | | | | | | | | | |
|----------------|--------------|-------|-------|-------|-------|-------|--------|-------|-------|--------|------|---------------------------------|
| | Al | C | Cr | Fe | Mo | N | Ni | O | Si | Sn | V | T _β , F ^A |
| Top | 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: | 4.74 | 0.005 | 0.002 | 0.563 | 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

$T_{\beta} \{^{\circ}\text{F, wt}\%\} = 1607 + 39.3\text{Al} + 330\text{O} + 1145\text{C} + 1020\text{N} - 21.8\text{V} - 32.5\text{Fe}$

Table 2 Tensile properties: mechanical test data for Ti108, heat no. H16168

| Orientation | Tensile yield strength | | Ultimate tensile strength | | Elongation | Reduction of area |
|-------------|------------------------|-----|---------------------------|-----|------------|-------------------|
| | ksi | MPa | ksi | MPa | % | % |
| L | 111 | 765 | 125 | 862 | 13 | 23 |
| T | 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 V_{50} 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).

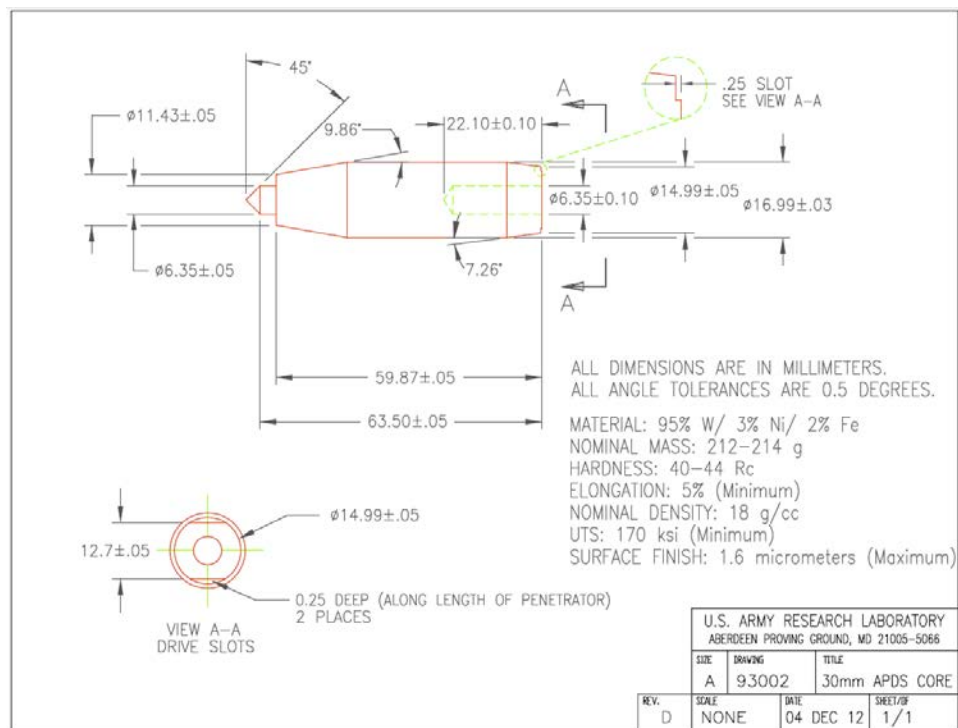


Fig. 5 30-mm APDS core

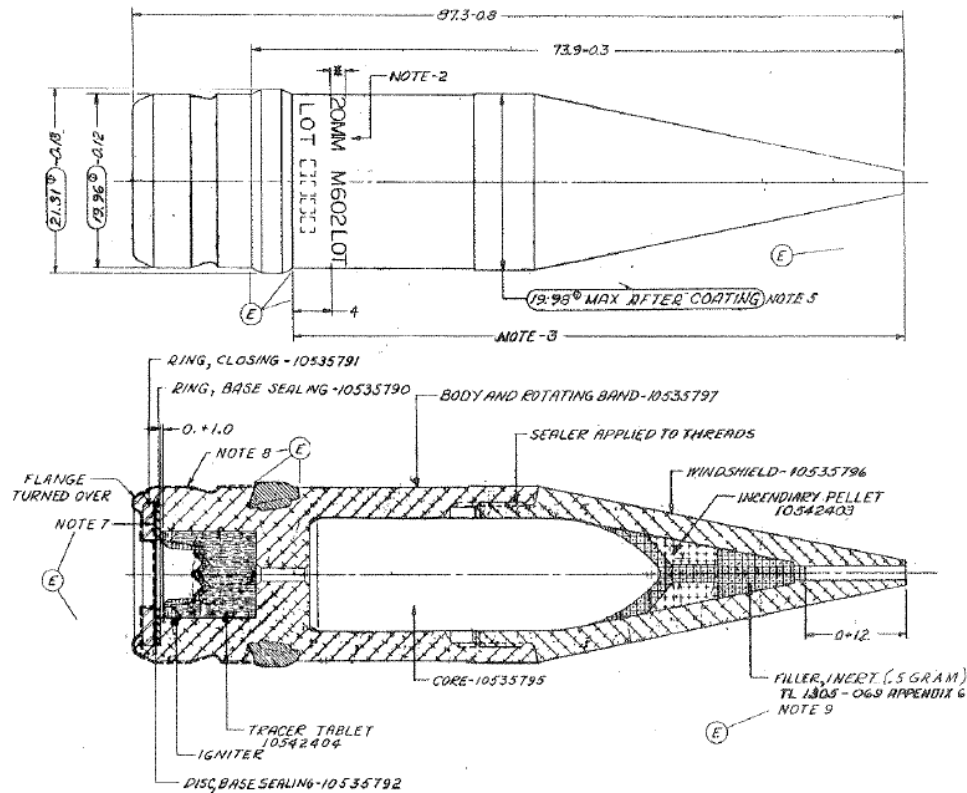


Fig. 6 20-mm AP-T M602

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.

Table 3 Average measured thickness and HBW for Ti108 plate

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

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.

Table 4 V_{50} results for 30-mm APDS projectile

| 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 | |
| 15803 | 1036 | CP | -0.18 | -0.67 | 0.69 | 150 | High partial Low complete |

Table 5 Standard deviation for 30-mm APDS

| 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.

Table 6 V_{50} results for 20-mm M602 AP-T projectile

| LAT shot no. | Vs (m/s) | Result | Pitch (deg) | Yaw (deg) | Gamma (deg) | Powder grains | Remarks |
|--------------|----------|--------|-------------|-----------|-------------|---------------|--------------|
| 15872 | 1044 | CP | 0.83 | 0.40 | 0.92 | 750 | |
| 15873 | 1006 | CP | 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 | CP | -0.51 | 0.01 | 0.51 | 700 | Low complete |
| 15879 | ... | CP | ... | ... | ... | 690 | No X-rays |
| 15880 | ... | PP | ... | ... | ... | 683 | No X-rays |
| 15881 | 993 | PP | 2.12 | -0.32 | 2.15 | 683 | |

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 V_{50} 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.
3. 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

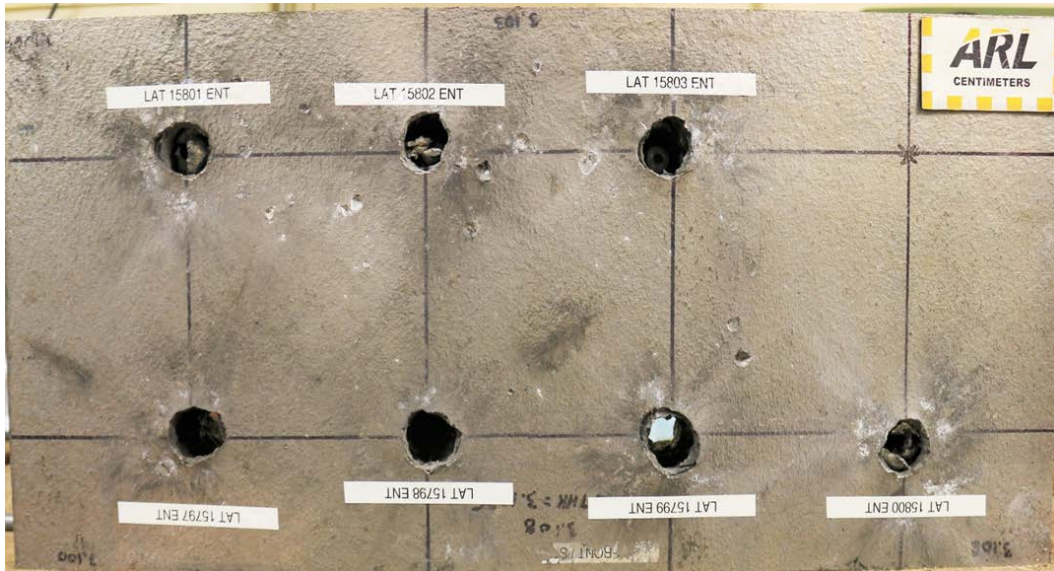


Fig. A-1 30-mm APDS overall front of plate (strike face)



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

| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|--------------------|----------------|------------|-------------------|---------------|--------------|-----------|---|
| Program: | LAT | | | Shot #: | 15797 | | Date: | 6/26/2017 | | Range: | G |
| Engineer: | Matt Burkins | | | Projectile: | 30mm APDS | | Gun: | #2 10' 1.090 | | | |
| Test Director: | Hugh Walter | | | Gunner: | David Handshoe | | Muzzle to Target: | 56" | | | |
| Launch Package: | | | | Case Size: | 37mm | | Powder Type: | 165mm | | | |
| | Length | Diam | Mass | Primer Type: | M38B2 | | Powder Weight: | 165 grams | | | |
| Penetrator | | | 213.83 | Expected Velocity: | 1007 m/s | | Shot Time: | 919 | | | |
| Sabot | | | 14.52 | Results | | | | | | | |
| Pusher | | | 11.53 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Obturator | | | 12.47 | | 1100 | 3609 | Velocity: | | | | |
| Total (grams) | | | 252.59 | | | | | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | Pitch: | -0.39 | Yaw: | -0.15 | Total Yaw | 0.42 | |
| Velocity: | | | X | | | | | | | | |
| X-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 | | | | | | | | | |
| Target Data | | | | | | | | | | | |
| Plate # | Material | | | | | Thick (in) | Obliq. (deg) | Weight Before | Weight After | BHN | |
| 1 | Ti Mex H16168-5 Ti-108 | | | | | 3.1035" | 0 | | | 286 | |
| 2 | Air | | | | | 6" | | | | | |
| 3 | Witness | | | | | .020" | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Plate # | Entrance Hole (cm) | | Center Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 3.3 | 3.7 | 2.2 | 2.4 | 6..6 | 7.5 | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
| | | | | | | | | | | | |



| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|--------------------|----------------|-------------------|--------------|----------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15798 | | Date: | 6/26/2017 | | Range: | G | |
| Engineer: | Matt Burkins | | Projectile: | 30mm APDS | | Gun: | #2 10' 1.090 | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 56" | | | | |
| Launch Package: | | | Case Size: | | 37mm | | Powder Type: | 165mm | | | |
| | Length | Diam | Mass | Primer Type: | | M38B2 | | Powder Weight: | 145 grams | | |
| Penetrator | | | 213.27 | Expected Velocity: | | 1007 m/s | | Shot Time: | 1022 | | |
| Sabot | | | 14.48 | Results | | | | | | | |
| Pusher | | | 11.48 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Obturator | | | 12.7 | | 1013 | 3324 | Velocity: | | | | |
| Total (grams) | | | 252.1 | | | | | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | Pitch: | -1.46 | Yaw: | 0.13 | Total Yaw | 1.47 | |
| Velocity: | | | | X | | | | | | | |
| X-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 | | | | | | | | | |
| Target Data | | | | | | | | | | | |
| Plate # | Material | | | | | Thick (in) | Obliq. (deg) | Weight Before | Weight After | BHN | |
| 1 | Ti Mex H16168-5 Ti-108 | | | | | 3.1035" | 0 | | | 286 | |
| 2 | Air | | | | | 6" | | | | | |
| 3 | Witness | | | | | .020" | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Plate # | Entrance Hole (cm) | | Center Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 3.4 | 3.8 | | | | | 1 | 6.9 | 7.2 | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
| | | | | | | | | | | | |



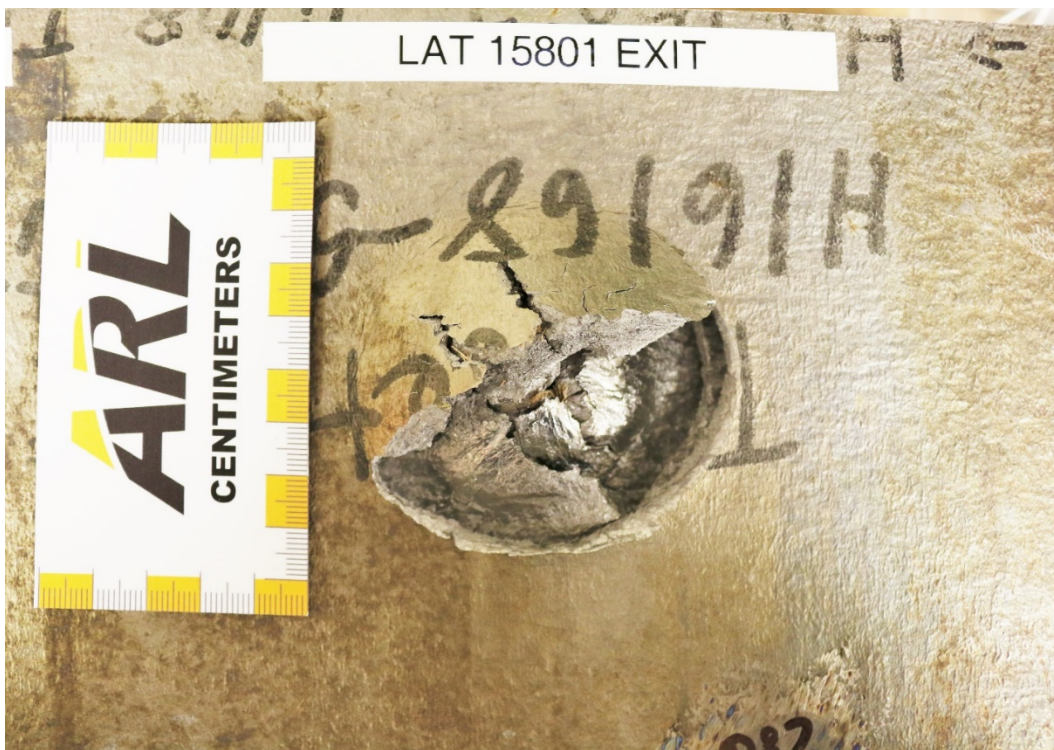
| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|--------------------|----------------|-------------------|--------------|----------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15799 | | Date: | 6/26/2017 | | Range: | G | |
| Engineer: | Matt Burkins | | Projectile: | 30mm APDS | | Gun: | #2 10' 1.090 | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 140.5" | | | | |
| Launch Package: | | | Case Size: | | 37mm | | Powder Type: | 165mm | | | |
| | Length | Diam | Mass | Primer Type: | | M38B2 | | Powder Weight: | 155 grams | | |
| Penetrator | | | 213.88 | Expected Velocity: | | 1050 m/s | | Shot Time: | 1115 | | |
| Sabot | | | 14.24 | Results | | | | | | | |
| Pusher | | | 11.41 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Obturator | | | 12.48 | | 1062 | 3485 | Velocity: | | | | |
| Total (grams) | | | 252.28 | | | | | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | Pitch: | -0.61 | Yaw: | -1.01 | Total Yaw | 1.18 | |
| Velocity: | | | X | | | | | | | | |
| X-Ray Times | | | | | | | | | | | |
| 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 | | | | | | | | | |
| Target Data | | | | | | | | | | | |
| Plate # | Material | | | | | Thick (in) | Obliq. (deg) | Weight Before | Weight After | BHN | |
| 1 | Ti Mex H16168-5 Ti-108 | | | | | 3.1035" | 0 | | | 286 | |
| 2 | Air | | | | | 6" | | | | | |
| 3 | Witness | | | | | .020" | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Plate # | Entrance Hole (cm) | | Center Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 3.6 | 3.7 | 2.3 | 2.7 | 6.8 | 7.4 | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
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| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|--------------------|----------------|-------------------|--------------|----------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15800 | | Date: | 6/26/2017 | | Range: | G | |
| Engineer: | Matt Burkins | | Projectile: | 30mm APDS | | Gun: | #2 10' 1.090 | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 140.5" | | | | |
| Launch Package: | | | Case Size: | | 37mm | | Powder Type: | 165mm | | | |
| | Length | Diam | Mass | Primer Type: | | M38B2 | | Powder Weight: | 147 grams | | |
| Penetrator | | | 213.84 | Expected Velocity: | | 1025 m/s | | Shot Time: | 1336 | | |
| Sabot | | | 14.52 | Results | | | | | | | |
| Pusher | | | 11.47 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Obturator | | | 12.48 | | 1027 | 3368 | Velocity: | | | | |
| Total (grams) | | | 252.63 | | | | | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | Pitch: | -0.07 | Yaw: | 0.27 | Total Yaw | 0.28 | |
| Velocity: | | | | X | | | | | | | |
| X-Ray Times | | | | | | | | | | | |
| Tube Heads | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Distance | 16" | 8" | | | | | | | | | |
| Preset | 396.5 | 198.5 | | | | | | | | | |
| Actual | 397.2 | 199.2 | | | | | | | | | |
| Target Data | | | | | | | | | | | |
| Plate # | Material | | | | | Thick (in) | Obliq. (deg) | Weight Before | Weight After | BHN | |
| 1 | Ti Mex H16168-5 Ti-108 | | | | | 3.1035" | 0 | | | 286 | |
| 2 | Air | | | | | 6" | | | | | |
| 3 | Witness | | | | | .020" | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Plate # | Entrance Hole (cm) | | Center Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 3.2 | 3.2 | | | | | 1.1 | 6.6 | 7.2 | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
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| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|--------------------|----------------|-------------------|--------------|----------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15801 | | Date: | 6/26/2017 | | Range: | G | |
| Engineer: | Matt Burkins | | Projectile: | 30mm APDS | | Gun: | #2 10' 1.090 | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 140.5" | | | | |
| Launch Package: | | | Case Size: | | 37mm | | Powder Type: | 165mm | | | |
| | Length | Diam | Mass | Primer Type: | | M38B2 | | Powder Weight: | 150 grams | | |
| Penetrator | | | 212.82 | Expected Velocity: | | 1045 m/s | | Shot Time: | 1431 | | |
| Sabot | | | 14.52 | Results | | | | | | | |
| Pusher | | | 11.42 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Obturator | | | 12.46 | | 1037 | 3401 | Velocity: | | | | |
| Total (grams) | | | 251.5 | | | | | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | Pitch: | -0.49 | Yaw: | 0.4 | Total Yaw | 0.63 | |
| Velocity: | | | X | | | | | | | | |
| X-Ray Times | | | | | | | | | | | |
| 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 | | | | | | | | | |
| Target Data | | | | | | | | | | | |
| Plate # | Material | | | | | Thick (in) | Obliq. (deg) | Weight Before | Weight After | BHN | |
| 1 | Ti Mex H16168-5 Ti-108 | | | | | 3.1035" | 0 | | | 286 | |
| 2 | Air | | | | | 6" | | | | | |
| 3 | Witness | | | | | .020" | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Plate # | Entrance Hole (cm) | | Center Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 3 | 4.1 | | | 4.5 | 6.4 | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
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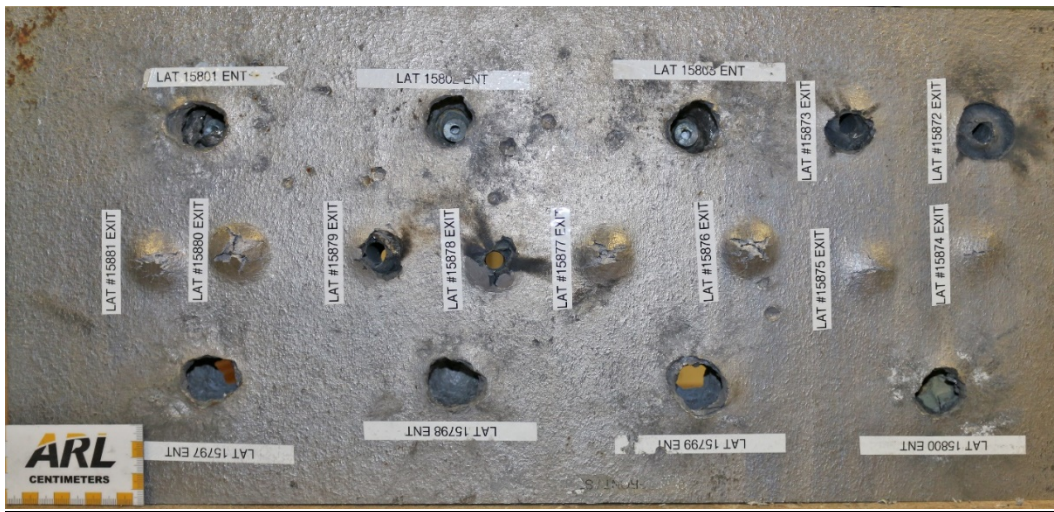
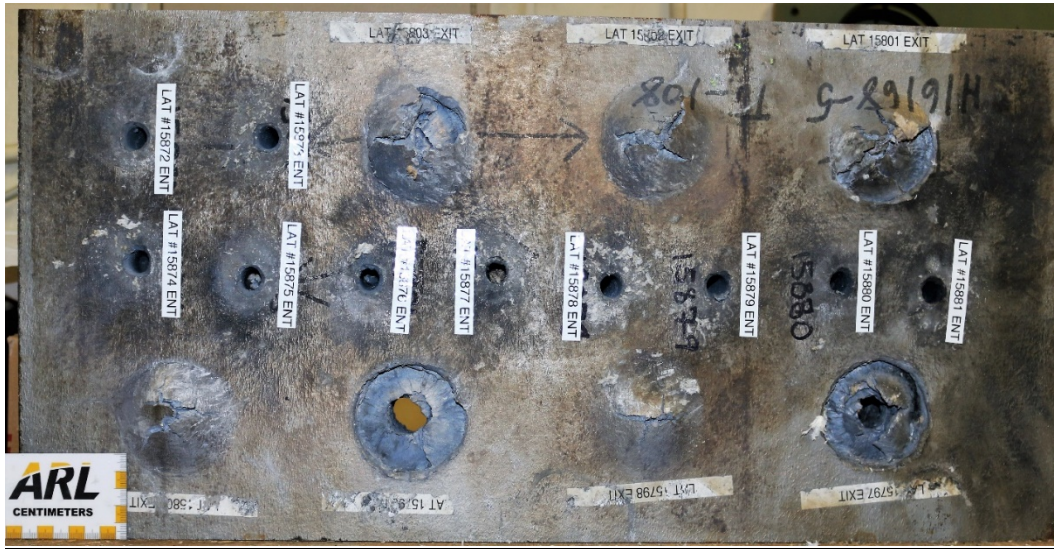
| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|--------------------|----------------|-------------------|--------------|----------------|--------------|-----------|-----------|
| Program: | LAT | | Shot #: | 15802 | | Date: | 6/27/2017 | | Range: | G | |
| Engineer: | Matt Burkins | | Projectile: | 30mm APDS | | Gun: | #2 10' 1.090 | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 140.5" | | | | |
| Launch Package: | | | Case Size: | | 37mm | | Powder Type: | 165mm | | | |
| | Length | Diam | Mass | Primer Type: | | M38B2 | | Powder Weight: | 149 grams | | |
| Penetrator | | | 213.44 | Expected Velocity: | | 1030 m/s | | Shot Time: | 635 | | |
| Sabot | | | 14.55 | Results | | | | | | | |
| Pusher | | | 11.46 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Obturator | | | 12.54 | | 1033 | 3390 | Velocity: | | | | |
| Total (grams) | | | 252.18 | | | | | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | Pitch: | 0.57 | | Yaw: | -0.07 | | Total Yaw |
| Velocity: | | | | X | | | | | | | |
| X-Ray Times | | | | | | | | | | | |
| Tube Heads | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Distance | 16" | 8" | | | | | | | | | |
| Preset | 394.5 | 197.5 | | | | | | | | | |
| Actual | 395.1 | 198.2 | | | | | | | | | |
| Target Data | | | | | | | | | | | |
| Plate # | Material | | | | | Thick (in) | Obliq. (deg) | Weight Before | Weight After | BHN | |
| 1 | Ti Mex H16168-5 Ti-108 | | | | | 3.1035" | 0 | | | 286 | |
| 2 | Air | | | | | 6" | | | | | |
| 3 | Witness | | | | | .020" | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Plate # | Entrance Hole (cm) | | Center Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 3.4 | 3.1 | | | | | 1.5 | 6.8 | 7 | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
| | | | | | | | | | | | |



| <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="text-align: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> </div> | | | | | | | | | | | |
|---|------------------------|-------|------------------|--------------------|----------------|-------------------|--------------|----------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15803 | | Date: | 6/27/2017 | | Range: | G | |
| Engineer: | Matt Burkins | | Projectile: | 30mm APDS | | Gun: | #2 10' 1.090 | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 140.5" | | | | |
| Launch Package: | | | Case Size: | | 37mm | | Powder Type: | 165mm | | | |
| | Length | Diam | Mass | Primer Type: | | M38B2 | | Powder Weight: | 150 grams | | |
| Penetrator | | | 213.59 | Expected Velocity: | | 1040 m/s | | Shot Time: | 719 | | |
| Sabot | | | 14.43 | Results | | | | | | | |
| Pusher | | | 11.37 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Obturator | | | 12.5 | | 1036 | 3399 | Velocity: | | | | |
| Total (grams) | | | 252.17 | | | | | | | | |
| Phantom Velocity: | m/s | f/s | Complete: | Partial: | Pitch: | -0.18 | Yaw: | -0.67 | Total Yaw | 0.69 | |
| | | | X | | | | | | | | |
| X-Ray Times | | | | | | | | | | | |
| Tube Heads | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Distance | 16" | 8" | | | | | | | | | |
| Preset | 390.5 | 195.5 | | | | | | | | | |
| Actual | 391.1 | 196.2 | | | | | | | | | |
| Target Data | | | | | | | | | | | |
| Plate # | Material | | | | | Thick (in) | Obliq. (deg) | Weight Before | Weight After | BHN | |
| 1 | Ti Mex H16168-5 Ti-108 | | | | | 3.1035" | 0 | | | 286 | |
| 2 | Air | | | | | 6" | | | | | |
| 3 | Witness | | | | | .020" | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Plate # | Entrance Hole (cm) | | Center Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 3.4 | 3.2 | | | 3.9 | 3.8 | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
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| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
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A.2 20-mm M602 AP-T Shot Sheets and Photos



| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|------------------------|----------------|-------------------|-----------------------|---------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15872 | | Date: | 12/4/2017 | | Range: | G | |
| Engineer: | John Hogan | | Projectile: | M602 | | Gun: | #ED5 8" 20mm (Rifled) | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 61.25" | | | | |
| Launch Package: | | | Case Size: | | 25mm | Powder Type: | 37mm | | | | |
| | Length | Diam | Mass | Primer Type: | | M36A2 | Powder Weight: | 750 grains | | | |
| Penetrator | | | 110.56 | Expected Velocity m/s: | | 1050 | Shot Time: | 1125 | | | |
| Sabot | | | | | | | | | | | |
| Pusher | | | | Results | | | | | | | |
| Obturator | | | | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Total (grams) | | | 110.56 | | 1044 | 3426 | Velocity: | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | | | | | | | |
| Velocity: | | | X | | 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 | | | | | | | | | |
| Target 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 Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 1.9 | 1.8 | 1.3 | 1.5 | 3.1 | 3.5 | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
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| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
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| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|------------------------|----------------|-------------------|-----------------------|---------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15873 | | Date: | 12/4/2017 | | Range: | G | |
| Engineer: | John Hogan | | Projectile: | M602 | | Gun: | #ED5 8" 20mm (Rifled) | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 61.25" | | | | |
| Launch Package: | | | Case Size: | | 25mm | Powder Type: | 37mm | | | | |
| | Length | Diam | Mass | Primer Type: | | M36A2 | Powder Weight: | 700 grains | | | |
| Penetrator | | | 110.32 | Expected Velocity m/s: | | 1000 | Shot Time: | 1340 | | | |
| Sabot | | | | | | | | | | | |
| Pusher | | | | Results | | | | | | | |
| Obturator | | | | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Total (grams) | | | 110.32 | | 1006 | 3300 | Velocity: | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | | | | | | | |
| Velocity: | | | X | | Pitch: | 0.43 | Yaw: | -1.5 | Total Yaw | 1.56 | |
| X-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 | 204.2 | | | | | | | | | |
| Target 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 Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 1.9 | 1.7 | 1.3 | 1.1 | 3.2 | 2.4 | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
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| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|------------------------|----------------|-------------------|-----------------------|---------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15874 | | Date: | 12/5/2017 | | Range: | G | |
| Engineer: | John Hogan | | Projectile: | M602 | | Gun: | #ED5 8" 20mm (Rifled) | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 61.25" | | | | |
| Launch Package: | | | Case Size: | | 25mm | Powder Type: | 37mm | | | | |
| | Length | Diam | Mass | Primer Type: | | M36A2 | Powder Weight: | 650 grains | | | |
| Penetrator | | | 110.55 | Expected Velocity m/s: | | 950 | Shot Time: | 626 | | | |
| Sabot | | | | | | | | | | | |
| Pusher | | | | | | | | | | | |
| Obturator | | | | Results | | | | | | | |
| Total (grams) | | | 110.55 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| | | | | 965 | 3165 | Velocity: | | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | | | | | | | |
| Velocity: | | | X | Pitch: | 0.76 | Yaw: | -0.03 | Total Yaw | 0.76 | | |
| X-Ray Times | | | | | | | | | | | |
| Tube Heads | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Distance | 15 | 8 | | | | | | | | | |
| Preset | 401.0 | 213.9 | | | | | | | | | |
| Actual | 402.2 | 214.2 | | | | | | | | | |
| Target 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 Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 1.9 | 1.8 | | | | | 0.3 | 3.6 | 4.2 | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
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| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
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| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|------------------------|----------------|-------------------|-----------------------|---------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15875 | | Date: | 12/5/2017 | | Range: | G | |
| Engineer: | John Hogan | | Projectile: | M602 | | Gun: | #ED5 8" 20mm (Rifled) | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 61.25" | | | | |
| Launch Package: | | | Case Size: | | 25mm | Powder Type: | | 37mm | | | |
| | Length | Diam | Mass | Primer Type: | | M36A2 | Powder Weight: | | 665 grains | | |
| Penetrator | | | 110.39 | Expected Velocity m/s: | | 985 | Shot Time: | | 720 | | |
| Sabot | | | | | | | | | | | |
| Pusher | | | | | | | | | | | |
| Obturator | | | | Results | | | | | | | |
| Total (grams) | | | 110.39 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| | | | | 977 | 3206 | Velocity: | | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | | | | | | | |
| Velocity: | | | | X | 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 | | | | | | | | | |
| Target 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 Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 2 | 1.8 | | | | | 0.5 | 4 | 4.3 | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
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| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
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| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|------------------------|----------------|-------------------|-----------------------|---------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15876 | | Date: | 12/5/2017 | | Range: | G | |
| Engineer: | John Hogan | | Projectile: | M602 | | Gun: | #ED5 8' 20mm (Rifled) | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 61.25" | | | | |
| Launch Package: | | | Case Size: | | 25mm | Powder Type: | 37mm | | | | |
| | Length | Diam | Mass | Primer Type: | | M36A2 | Powder Weight: | 685 grains | | | |
| Penetrator | | | 110.31 | Expected Velocity m/s: | | 990 | Shot Time: | 920 | | | |
| Sabot | | | | | | | | | | | |
| Pusher | | | | Results | | | | | | | |
| Obturator | | | | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Total (grams) | | | 110.31 | Velocity: | 997 | 3270 | Velocity: | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | | | | | | | |
| Velocity: | | | | X | Pitch: | -1.28 | Yaw: | -1.47 | Total Yaw | 1.95 | |
| X-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 | | | | | | | | | |
| Target 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 Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 1.8 | 1.9 | | | | | 1.1 | 4 | 4.1 | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |
| Notes: | | | | | | | | | | | |
| | | | | | | | | | | | |

| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|------------------------|----------------|-------------------|-----------------------|---------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15877 | | Date: | 12/5/2017 | | Range: | G | |
| Engineer: | John Hogan | | Projectile: | M602 | | Gun: | #ED5 8" 20mm (Rifled) | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 61.25" | | | | |
| Launch Package | | | Case Size: | | 25mm | Powder Type: | | 37mm | | | |
| | Length | Diam | Mass | Primer Type: | | M36A2 | Powder Weight: | | 690 grains | | |
| Penetrator | | | 110.18 | Expected Velocity m/s: | | 1000 | Shot Time: | | 1037 | | |
| Sabot | | | | | | | | | | | |
| Pusher | | | | Results | | | | | | | |
| Obturator | | | | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Total (grams) | | | 110.18 | | 993 | 3257 | Velocity: | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | | | | | | | |
| Velocity: | | | | X | Pitch: | -0.15 | Yaw: | -2.93 | Total Yaw | 2.93 | |
| X-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 | | | | | | | | | |
| Target 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 Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 1.8 | 1.8 | | | | | 1 | 4.2 | 4 | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |

Notes:

| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|------------------------|----------------|------------|-------------------|-----------------------|--------------|-----------|---|
| Program: | LAT | | | Shot #: | 15878 | | Date: | 12/5/2017 | | Range: | G |
| Engineer: | John Hogan | | | Projectile: | M602 | | Gun: | #ED5 8' 20mm (Rifled) | | | |
| Test Director: | Hugh Walter | | | Gunner: | David Handshoe | | Muzzle to Target: | 61.25" | | | |
| Launch Package | | | | Case Size: | 25mm | | Powder Type: | 37mm | | | |
| | Length | Diam | Mass | Primer Type: | M36A2 | | Powder Weight: | 700 grains | | | |
| Penetrator | | | 110.67 | Expected Velocity m/s: | 1005 | | Shot Time: | 1122 | | | |
| Sabot | | | | | | | | | | | |
| Pusher | | | | | | | | | | | |
| Obturator | | | | Results | | | | | | | |
| Total (grams) | | | 110.67 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| | | | | | 1004 | 3293 | Velocity: | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | | | | | | | |
| Velocity: | | | X | | Pitch: | -0.51 | Yaw: | 0.01 | Total Yaw | 0.51 | |
| X-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 | | | | | | | | | |
| Target 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 Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 1.8 | 1.6 | | | 1.5 | 2.1 | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |

Notes:

| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|------------------------|----------------|-------------------|-----------------------|---------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15879 | | Date: | 12/5/2017 | | Range: | G | |
| Engineer: | John Hogan | | Projectile: | M602 | | Gun: | #ED5 8' 20mm (Rifled) | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 61.25" | | | | |
| Launch Package | | | Case Size: | | 25mm | Powder Type: | | 37mm | | | |
| | Length | Diam | Mass | Primer Type: | | M36A2 | Powder Weight: | | 690 grains | | |
| Penetrator | | | 110.36 | Expected Velocity m/s: | | 995 | Shot Time: | | 1259 | | |
| Sabot | | | | | | | | | | | |
| Pusher | | | | Results | | | | | | | |
| Obturator | | | | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Total (grams) | | | 110.36 | | | | Velocity: | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | | | | | | | |
| Velocity: | | | X | | Pitch: | | Yaw: | Total Yaw: | | | |
| X-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 | | | | | | | | | |
| Target 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 Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 1.6 | 1.7 | | | 1.4 | 2.3 | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |

Notes:

No X-rays trigger wire was fraged.

| <div style="display: flex; justify-content: space-between; align-items: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> | | | | | | | | | | | |
|--|------------------------|-------|------------------|------------------------|----------------|-------------------|-----------------------|---------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15880 | | Date: | 12/5/2017 | | Range: | G | |
| Engineer: | John Hogan | | Projectile: | M602 | | Gun: | #ED5 8" 20mm (Rifled) | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 61.25" | | | | |
| Launch Package | | | | Case Size: | 25mm | | Powder Type: | 37mm | | | |
| | Length | Diam | Mass | Primer Type: | M36A2 | | Powder Weight: | 683 grains | | | |
| Penetrator | | | 110.59 | Expected Velocity m/s: | 990 | | Shot Time: | 1340 | | | |
| Sabot | | | | | | | | | | | |
| Pusher | | | | | | | | | | | |
| Obturator | | | | Results | | | | | | | |
| Total (grams) | | | 110.59 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| Phantom | m/s | f/s | Complete: | Partial: | | | | | | | |
| Velocity: | | | | X | Pitch: | | Yaw: | Total Yaw: | | | |
| X-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 | | | | | | | | | |
| Target 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 Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 1.6 | 1.8 | | | | | 1 | 4 | 4.2 | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| 7 | | | | | | | | | | | |
| 8 | | | | | | | | | | | |

Notes:

No X-rays frags in trigger screen holder.

| <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="text-align: center;"> <h2 style="margin: 0;">EF-110 SHOT SHEET</h2> </div> </div> | | | | | | | | | | | |
|---|------------------------|-------|------------------|------------------------|----------------|-------------------|-----------------------|---------------|--------------|-----------|--|
| Program: | LAT | | Shot #: | 15881 | | Date: | 12/6/2017 | | Range: | G | |
| Engineer: | John Hogan | | Projectile: | M602 | | Gun: | #ED5 8' 20mm (Rifled) | | | | |
| Test Director: | Hugh Walter | | Gunner: | David Handshoe | | Muzzle to Target: | 61.25" | | | | |
| Launch Package | | | | Case Size: | 25mm | | Powder Type: | 37mm | | | |
| | Length | Diam | Mass | Primer Type: | M36A2 | | Powder Weight: | 683 grains | | | |
| Penetrator | | | 110.4 | Expected Velocity m/s: | 990 | | Shot Time: | 723 | | | |
| Sabot | | | | | | | | | | | |
| Pusher | | | | | | | | | | | |
| Obturator | | | | Results | | | | | | | |
| Total (grams) | | | 110.4 | Velocity: | m/s | f/s | Residual | m/s | f/s | | |
| | | | | | 993 | 3257 | Velocity: | | | | |
| Phantom | m/s | f/s | Complete: | Partial: | | | | | | | |
| Velocity: | | | | X | Pitch: | 2.12 | Yaw: | -0.32 | Total Yaw | 2.15 | |
| X-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 | | | | | | | | | |
| Target 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 Hole (cm) | | Exit Hole (cm) | | Bulge (cm) | | | Pene (cm) | |
| | Length | Width | Length | Width | Length | Width | Height | Length | Width | | |
| 1 | 1.8 | 1.7 | | | | | 0.9 | 3.6 | 4.1 | | |
| 2 | | | | | | | | | | | |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
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| Notes: | | | | | | | | | | | |
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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 |
| CP | complete penetration |
| HBW | Brinell hardness |
| LAT | light armor technologies |
| PP | partial penetration |
| TIMET | Titanium Metals Corporation |
| ZMR | zone of mixed results |

1 DEFENSE TECHNICAL
(PDF) INFORMATION CTR
DTIC OCA

2 DIR ARL
(PDF) IMAL HRA
RECORDS MGMT
RDRL DCL
TECH LIB

1 GOVT PRINTG OFC
(PDF) A MALHOTRA

1 ARL
(PDF) RDRL WMP E
J HOGAN