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NOVEL EXAMINATION OF GUN BORE RESISTANCE – ANALYSIS AND EXPERIMENTAL VALIDATION

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Abstract

The resistance of a projectile to axial motion in a gun bore has been examined in the past [1] both experimentally and numerically. This resistance is an important aspect in accurately matching muzzle velocities in a computer simulation to experimental data. This resistance profile varies in magnitude as the projectile moves down the bore of a weapon. It initially increases as the rotating band or obturator is engraved and then decreases as travel continues. This profile is used in many computer codes in this form.

The Analysis and Evaluation Technology Division at ARDEC designed the 155mm XM1073E1 Instrumented Ballistic Test Projectile (IBTP) [2] as a strictly experimental vehicle to determine, among other things, bore resistance and blow-by of a plastic obturating band. This projectile was instrumented with pressure transducers and accelerometers with the data telemetered to a ground station. The difference between the force applied and acceleration was reduced from the data and the result plotted to determine a bore resistance profile.

The effect on internal ballistics of the experimentally derived engraving forces rather than simple assumed profiles (which are commonly used) has been started using the IBHVG2 [2] software. Additional work using a 1-dimensional modelling code, FNGUN [3], has been initiated to investigate further the correlation between experimental data and predictions.

BACKGROUND

In an attempt to better understand the interaction phenomena of projectiles inside a gun tube a procedure using the IBTP [1] Data was developed to obtain total resistance “pressure” opposing projectile travel. This so-called pressure is simply the resistive force expressed as a pressure using the bore area of the weapon. The desire for accurately predict muzzle velocity of cannon launched projectiles has necessitated an experimental method to determine total resistance in order to validate the numerical model and predict muzzle velocity with greater accuracy than ever before.

Figure 1 depicts the IBTP projectile. The five pressure sensors utilized in this design were PCB 109C11 piezoelectric gages rated for 80,000 PSI. The accelerometer block consisted of one ENDEVCO 7270A-20KG accelerometer in the axial direction and two 7270A-6KG accelerometers in the balloting direction, 90 degrees apart. The ARRT-124 telemetry system incorporated was a 9 channel analog system with 50 KHz bandwidth for input signals.

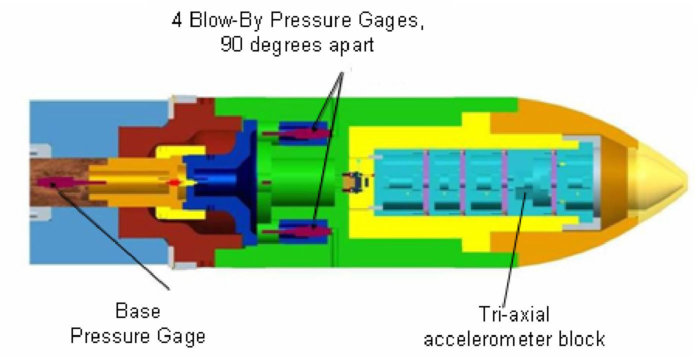


Figure 1: IBTP Projectile

Over the last three years, approximately 28 IBTP projectiles of slightly different configurations were fired at Yuma Proving Grounds. Six of them were fired in a configuration as depicted in figure 1. This configuration allowed direct measurement of projectile base pressure, blow-by pressures, simultaneously with projectile axial and two balloting accelerations. The IBTP serial number (S/N) TM17 incorporated all the improvements and lessons learned from the previous five firings and was fired in 2006

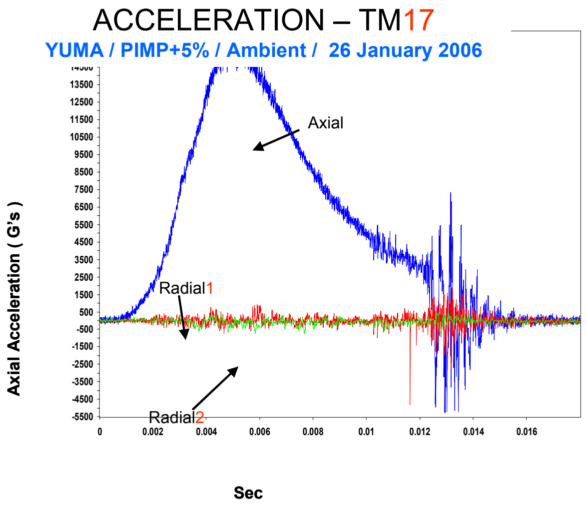


Figure 2. – Acceleration data for TM17.

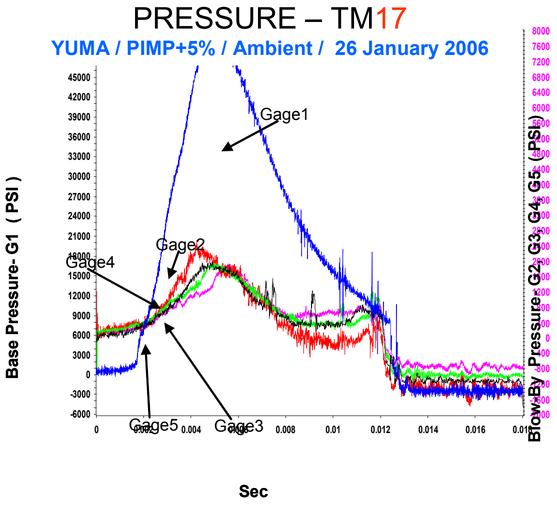


Figure 3. – Pressure data for TM17.

from a M284 cannon at PIMP+5% (permissible individual maximum pressure +5 %, with peak pressure equivalent to roughly 50,000 PSI breech pressure or approximately 15,700g's for the projectile). TM17 data was used to calculate pressure resistance.

Figure 2 displays the acceleration data and Figure 3 shows the pressure data taken from the test in which projectile number TM17 was fired.

Significant data distortions were present in the pressure data and these were greatest when recording pressures below 10,000 PSI. An investigation indicated these data anomalies were induced by the pressure sensor and the more significant ones were:

a). The negative pressure readings (figure 3) were caused by the gage inability to return to zero or by an initial condition of the gage when power was applied forcing the gage to sit at a positive value before the round is fired in which the negative pressure value shifts to the true zero.

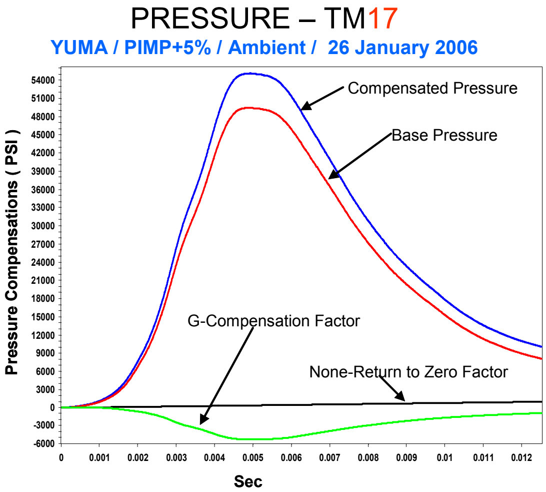


Figure 4. – Compensation factor for TM17.

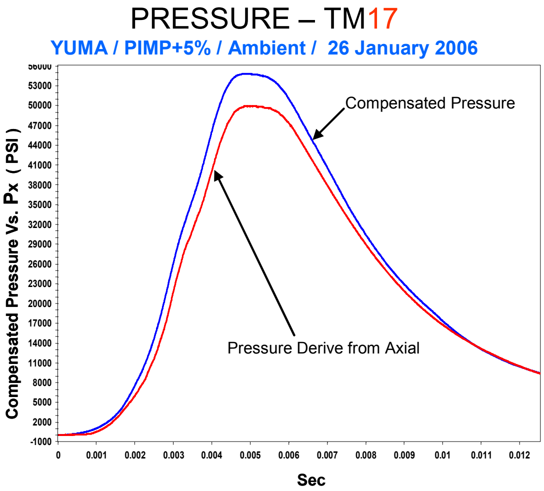


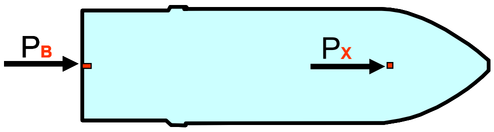
Figure 5 – compensated pressure data for TM17.

b). The G-compensation residuals (figure 3) caused by the blind gage built into the gage affected the reading.

In both cases, correction factors have been determined to compensate the pressure for the effects of these distortions as shown in figures 4 and 5.

PRESSURE RESISTANCE CALCULATION

Two different methods have been used to determine resistance pressure. The experimental method using the axial acceleration and base pressure data from the IBTP TM17 firing as shown in figure 6 and a numerical model using all the parameters described in figure 7. After a comparison of the results, the numerical model was updated using the experimental data to fine tune critical propellant parameters and predict muzzle velocity with great accuracy.



Experimental Profile

$F = M \cdot \alpha$

$P_X = F / A$

$P_X = (W \cdot \alpha) / (A \cdot g_c)$ ....(1)

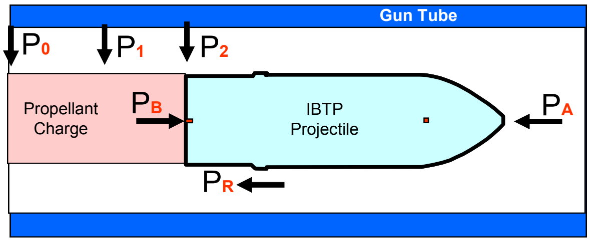
P_B	Projectile Base Pressure (PSI)
P_X	Pressure Derived from the Axial acceleration (G's)
P_R	Pressure Resistance (PSI)
M	Mass of the IBTP projectile (Lbs)
A	Projectile Cross Section (Square Inches)
α	Axial Acceleration (G's)

$W = M \cdot g_c$

g_c = gravitational Constant

g = Acceleration units

Figure 6. – Empirical Free Body Diagram



Numerical Model profile

P_0	Breech Pressure (PSI)
P_1	Mid-Chamber Pressure (PSI)
P_2	Fwd Chamber Pressure (PSI)
P_A	Pressure due to the Air in front of the Projectile (PSI)
P_B	Projectile Base Pressure (PSI)
P_R	Resistance Pressure (PSI)
P	Total Pressure (PSI)
W	Weight of Projectile (Lbs)
A	Bore Cross Section (Square inches)
g_c	Gravitational Constant
α	Projectile Axial Acceleration (G's)
P_R =	Total Friction + Blow-By + Engraving Forces

Figure 7.- Analytical Free Body Diagram.

EXPERIMENTAL PROCEDURE

Step1: Determine force from pressure and Newton's second law

Identify muzzle exit time for the acceleration from figure 2 and for the pressure from figure 4 and extract the acceleration and pressure up to this point. This is the setback portion of the axial event. Double integrate the axial acceleration to determine projectile travel distance and verify that muzzle exit corresponds to 200 inches of projectile travel. If not, make adjustments on the sampling frequency to match the travel distance.

Step 2: Smooth measured data

The operations required to determine resistance pressure can not be done with noisy data, because it usually results in negative values which have no physical meaning. To avoid this the data is smoothed by using filtering and curve fitting techniques as shown in figures 8 and 9.

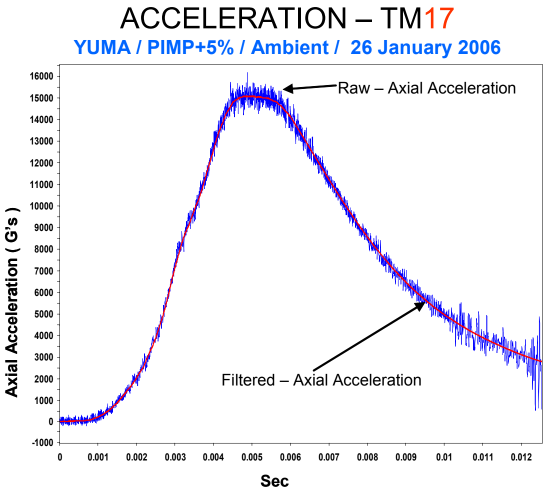


Figure 8. – Smoothed acceleration data for TM17.

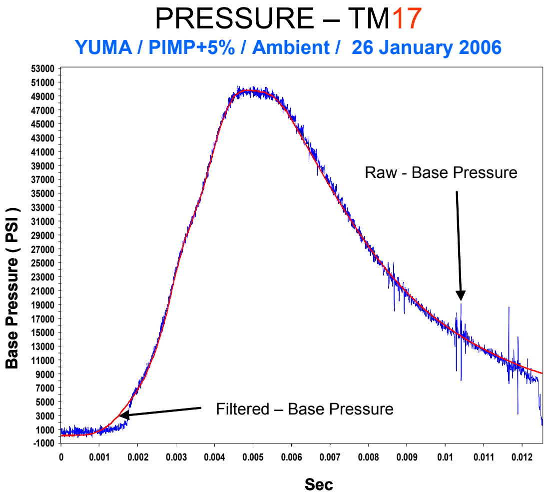


Figure 9. – Smoothed pressure data for TM17.

Step 3: Compensate pressure data

Compensate the pressure data as previously described.

Step 4: Subtract the force required to generate the acceleration from the force generated by the base pressure

Determine the pressure required to yield the axial acceleration and subtract it from the compensated pressure (the actual pressure acting on the base of the projectile). This is the resistance pressure in the time domain.

Step 5: Plot the resistance curve

Perform an XY Plot with the resistance from step 4 up to the travel distance calculated in step 1. The result is the resistance pressure vs. travel as shown as the lower trace in figure 10.

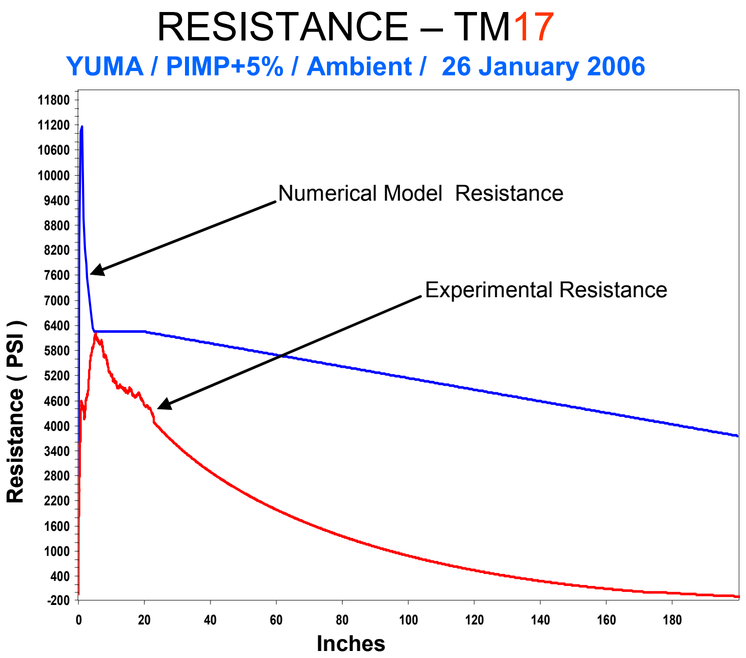


Figure 10. - Resistance Profile for TM17.

ANALYSIS CODE

A lumped parameter interior ballistics model, IBHVG2 [2], was used to generate analytical interior ballistic predictions. After generating an empirical resistance profile for the projectile in the tube, the model was exercised to determine if the new resistance profile would yield an acceleration profile for the projectile which would show a reasonable correlation to the empirical data.

The model employs basic physics and thermo-chemistry to drive the projectile down a launch tube. Both the energy balance and the equation of motion utilize the resistance profile. In the energy balance, the energy available to accelerate the projectile is reduced by losses. One of the losses is the energy lost due to engraving the projectile, the energy lost to friction with the bore and the energy lost to gas blow-by. All these losses were lumped together in the resistance profile. The resistance profile itself is a set of data points with a resistive pressure at an axial position down the tube. The model interpolates values between the data points. In the equation of motion, the base pressure is reduced by the resistive pressure prior to the acceleration being calculated.

The model was exercised with the new resistance profile from the empirical analysis replacing the previously estimated resistance profile. The previous resistance profile was a scaled representation of the way a metallic rotating band is represented historically.

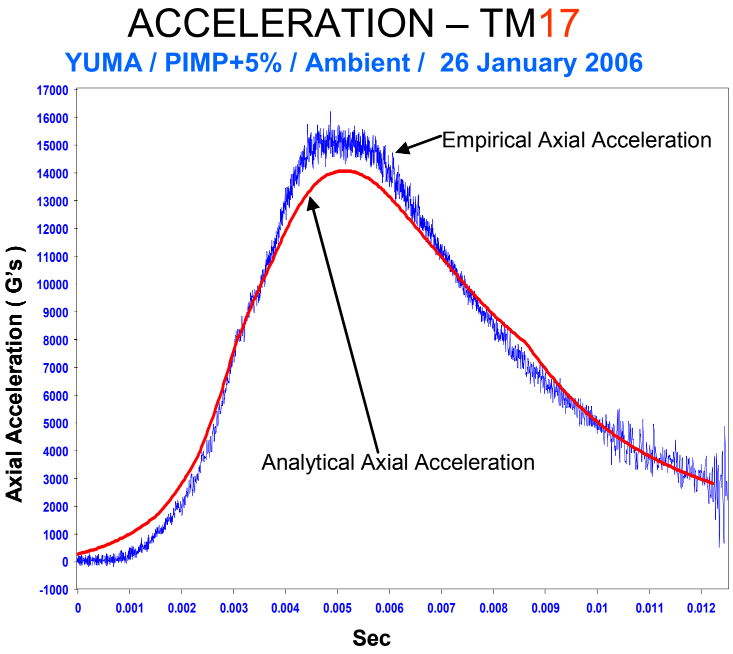


Figure 11. – Comparison of measured and calculated axial acceleration for TM17

The metallic band resistance pressure is greatest at approximately 75% of its insertion through the forcing cone of the tube. It then reduces through the rest of its engraving process and remains at a relatively low level during the rest of the ballistic cycle. The empirical resistance profile does not track with the physical representation of the rotating band obturator. It increases through the first 6 inches of travel, approximately, and then decreases through the rest of its in-bore flight. Utilizing this resistance profile, the model was recalibrated to adjust the closed bomb burn rate by modifying the burn rate coefficient to achieve the appropriate peak breech pressure.

SUMMARY

A data input file was generated using the specifics from the test round under study. The model was adjusted to match the peak pressure. A reasonably correlation was generated between the analytical model and empirical data. Limitations of using a lump parameter model are believed to be the prime source of error between the two. The pressure gradient within the chamber and tube is calculated by a Lagrangian approximation with no explicit hydrodynamics.

FUTURE EFFORTS

Currently efforts are underway to characterize KULITE pressure sensors with piezoresistive sensing elements and features such as 10 MHz resonant frequency and acceleration sensitivity of 5×10^{-8} % of full scale acceleration. A perceived advantage is that piezoresistive gages do not require charge amplifiers so the return to zero may not be present. Additionally, this gage is not G-compensated and the acceleration error is around 40 G's for a 15 kG shot therefore it is free of the G-compensation residuals issue

As refinements in the analysis of test data are realized, the modeling effort will be updated. Additionally, a 1-dimensional modeling effort will be initiated to attempt to get a more refined correlation between the test derived data and the model. Utilizing a hydrodynamic model should minimize the discrepancy between the acceleration plots.

REFERENCES

[1] M. Hollis, B. Flyash, A. Bahia, J. Potucek, D. Carlucci, *Empirical Measurements of Cannon Launch Pressures on a Finned 155-mm Artillery Projectile*, 21st International Symposium on Ballistics, 19-23 April 2004.

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[3] J. Hodson, C. C. Guyott, *FNGUN User Manual*, Report Ref. FNC/8950R, Frazer-Nash Consultancy Ltd, October 1994