Empirical relationship for muzzle exit pressure in a 155 mm gun tube

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Abstract

The development of guided artillery projectiles has uncovered a need for the understanding of muzzle exit flows due to the common practice of designing deployable fins that open upon muzzle exit. Knowledge of this base pressure drop is also important for the electronics designer because so-called "set-forward" (the rapid "un-springing" of the projectile as it leaves the muzzle of the gun) has been identified as the cause of many component failures. An empirical relationship is developed for the base pressure drop in a 155 mm gun tube. This tube utilized a standard double-baffle muzzle brake. Several Instrumented Ballistic Test Projectiles (IBTP) were fired at various charge zones and the base pressure drops were compared and curve fits developed. A basic exponential decay curve with averaged coefficients was developed from the data. This empirical model can be utilized by researchers performing Computational Fluid Dynamics calculations as a check on results generated for the double baffle muzzle brake configuration.
Keywords: gun launch, gun hardening, muzzle exit, shot exit, electronics, MEMS, projectile dynamics, in-bore dynamics.

1 Muzzle exit behavior of projectiles

With today's focus on guided, smart projectiles, more and more designs are being developed that employ fins or other stabilization devices that are activated upon muzzle exit. This muzzle exit activation requires detailed knowledge of the pressure field to insure that these devices open uniformly and reliably.

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The set-forward effects or "un-springing" of the projectile as it leaves the muzzle of the weapon is a major reliability concern for gun launch electronics [1, 2] therefore an understanding of the time-dependent pressure field is critical.

In most instances the flow field at the muzzle of the weapon is a time-dependent jet flow complicated by one or more of the following: the presence of a muzzle brake; the two-phase nature of the propellant gas; the continued reaction of the burning propellant with its gaseous products and the atmosphere; compressibility effects and the presence of the moving projectile. The complicated nature of this problem usually forces the designer to move directly into a Computational Fluid Dynamics (CFD) model with some degree of simplification. One of the challenges that occur frequently in CFD is obtaining model confidence without hard data to validate against. The purpose of this paper is to provide useful data for the CFD researcher to validate against. Due to funding limitations data was only taken in a standard double baffle muzzle brake mounted on a U.S. M198 155 mm howitzer at different charge zones. It is hoped that this data will be useful in model validation.

2 Measurement technique

Data were obtained in 9 different firings at three different charge zones (i.e. three different propellant amounts) using an Instrumented Ballistic Test Projectile (IBTP). Table 1 specifies the pressures obtained in the firings while Figure 1 depicts the IBTP. The pressures were gathered from a pressure transducer mounted in the base of the projectile.

The data obtained in these tests are shown as Figure 2. We note that for space reasons these curves have been compressed to fit in a small area therefore the scales are not particularly legible. They are intended to provide the reader with a qualitative feel for the data. The interested reader is invited to contact the authors for full sized plots. In each case the pressure drop at muzzle exit is compared to filtered data resulting in the smooth curves. These curves were then used to determine the exponent β tabulated in Table 1.

3 Pressure drop model

The curve fit that best described the pressure drop across all firing conditions was an exponential decay of the form:

$$p_s(t) = p_e e^{-\beta t} \tag{1}$$

Here ps(t) is the base pressure acting on the projectile, p_e is the pressure acting on the base at the instant the aft end of the projectile clears the bore of the gun, t is the time in seconds from bore exit and β is an exponential decay factor established from the smoothed data. Table 1 shows the values of p_e and β obtained from the test as well as peak values of pressure (p_{max}) that occurred in the bore of the weapon measured with the pressure gage in the base of the IBTP.

A mean value of β was determined to be 5,577 with a standard deviation of 1,117. While this may seem to be fairly uncorrelated this model has actually helped the U.S. Army design gun launch electronics of very high reliability [4].

4 Uses of the model

There are, in general two uses for the model: CFD validation and structural modelling of projectiles. In the former case the relationship is used directly to compare base pressure measurements to the model results as the projectile leaves the muzzle of the weapon. In the latter case the pressure decay curve model is actually inserted at the proper time phasing in a finite element analysis to examine the response of the structure to the pressure drop. Alternatively the model can be modified as an acceleration time curve and used directly as a forcing function on a projectile.

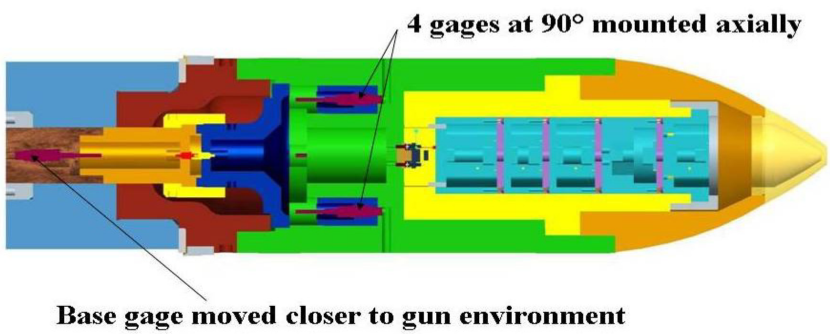

Figure 1: Instrumented Ballistic Test Projectile (IBTP).

Table 1: Firing data from IBTP tests.

	p_{max} (PSI)	p_e (PSI)	β
TM2	53096	9848	6500
TM3	54648	9989	6500
TM4	39707	8551	5000
TM5	42440	8751	5000
TM6	51059	9364	5500
TM7	46844	9354	7000
TM8	47729	9771	7000
TM9	29556	8457	6000
TM22	44000	6708	3500

5 Conclusions

A pressure decay model has been established for a double baffle muzzle brake configuration. This model has been shown to yield highly reliable projectile structures when used as either a CFD validation tool and as a structural model input. Future work will include pressure decay comparisons on tubes of various calibres using differing muzzle brake configurations.

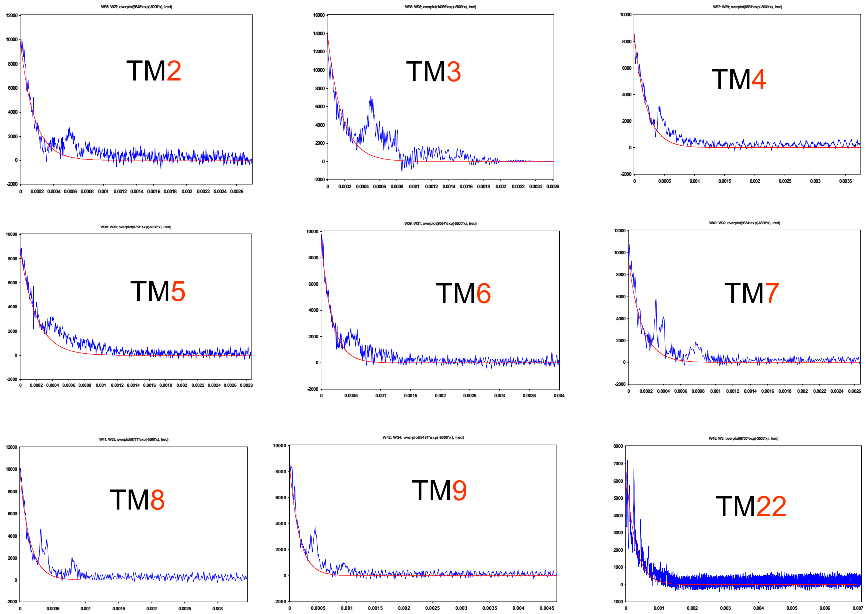

Figure 2: Qualitative plots of pressure drop at muzzle exit.

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