Coupling of a Lumped Mass Interior Ballistics Code with the Finite Element Code ABAQUS

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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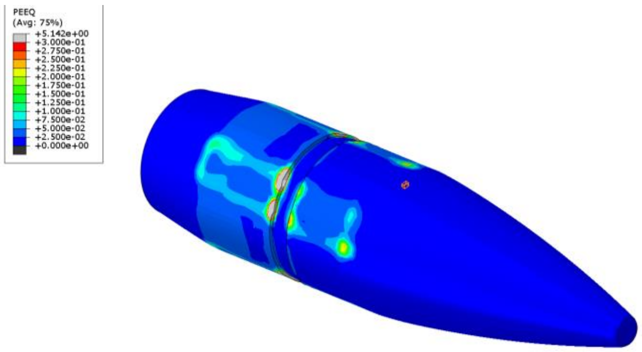
Why Finite Element Analysis?

- Finite Element analysis is a very useful tool in the evaluation of bullet structural integrity.



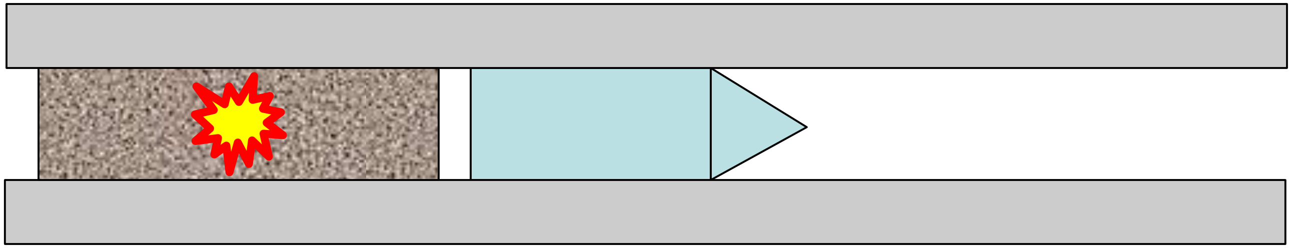
- Allows for visualization of stress and strain hot spots during the interior ballistics event.

- Allows fast geometric and material changes during concept development

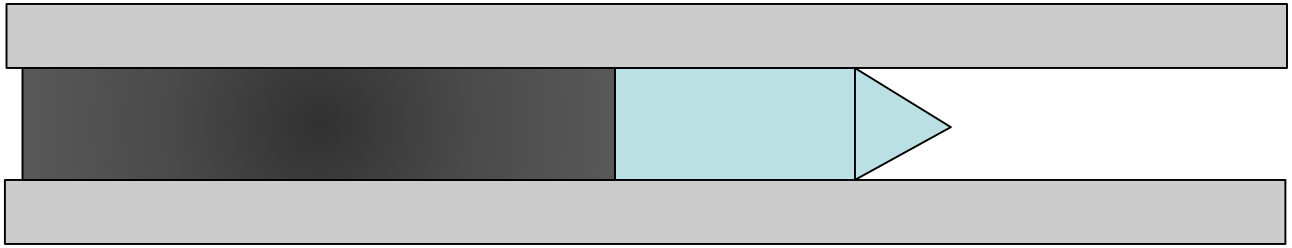
- Allows for visualization of events high speed cameras are incapable of capturing

Interior Ballistics Overview

Ignition Phase



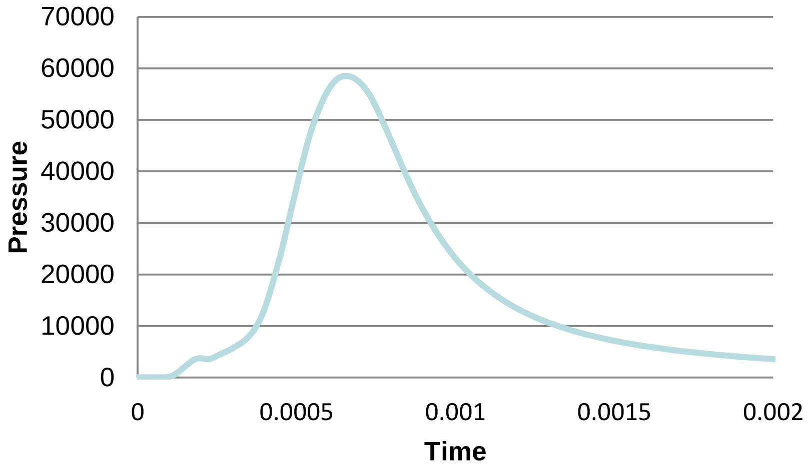
Combustion Phase

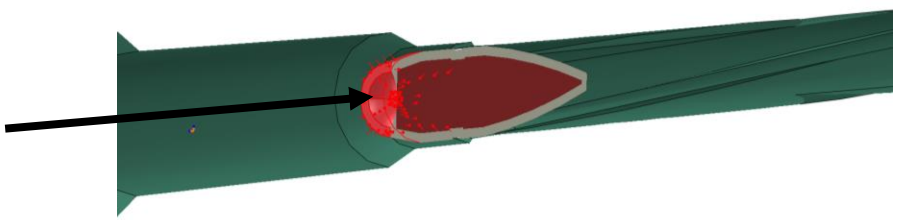


Expansion Phase

Current Method of Setting up Launch Models

- Typically use a “One Way” Pressure-Time curve to drive the bullet
  - Pressure-Time curves are usually obtained from test data
  - Typically applied as a pressure on the base of the projectile





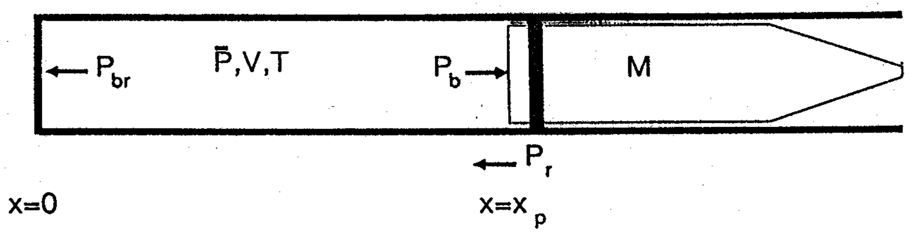
Problems with the current method

- There is a good reason we refer to it as a "One Way" P-T curve.
  - The pressure time curve is dead set to the tabulated values. At any time t in the analysis the pressure must be the value specified.
  - In real life many factors such as geometry changes, material changes, over/undersized bullets, and bore obstruction can change the bore resistance curve.
  - Changes in the bore resistance curve affect the rate of chamber volume expansion as a function of time.
  - From basic chemistry PV=nRT, if the chamber volume is different between two bullets at a given time then so is the pressure.
- BLUF – One way PT curves cannot react to any changes in the bullet or barrel, they are only valid for the exact scenario where the test data was obtained.

Lumped Mass Interior Ballistic Codes

- Lumped mass interior ballistic codes use some assumptions and computational iterations to calculate a PT curve.
  - Lumped mass assumes all propellant ignites uniformly at the same time.
  - Also assumes some form of pressure gradient from the chamber to the base of the projectile.
  - Lumped mass codes require a pre-determined bore resistance curve.
  - Also requires a large number of propellant parameters.
  - Some current and past codes includes ARL's Interior Ballistic High Speed Gun 3 (IBHVG3)[1] code, and the older Bear-Frankle[2] code.

Lumped Mass Driving Equations



[3]

SUMMARY OF GOVERNING EQUATIONS

ENERGY EQUATION:

$Q = U + W + Losses$

$$\rightarrow\ T = \frac{\sum_i \frac{F_i C_i z_i}{\gamma_i - 1} - A\int_0^{x_p} P_b\, dx - Losses}{\sum_i \frac{F_i C_i z_i}{(\gamma_i - 1)\ T_{f_i}}}$$

EQUATION OF STATE:

$$P(V - mb) = nRT = mR'T$$

MASS BURNING RATE EQUATIONS:

$$\dot{m} = \rho r s; \quad r = f(P) \quad [e.g., B\, P^n]$$

$$s = f(x_b \text{ or } z)$$

EQUATIONS OF PROJECTILE MOTION:

$$a = \left(\frac{P_b - P_r}{m}\right) A$$

$$v = \int_0^t a\, dt$$

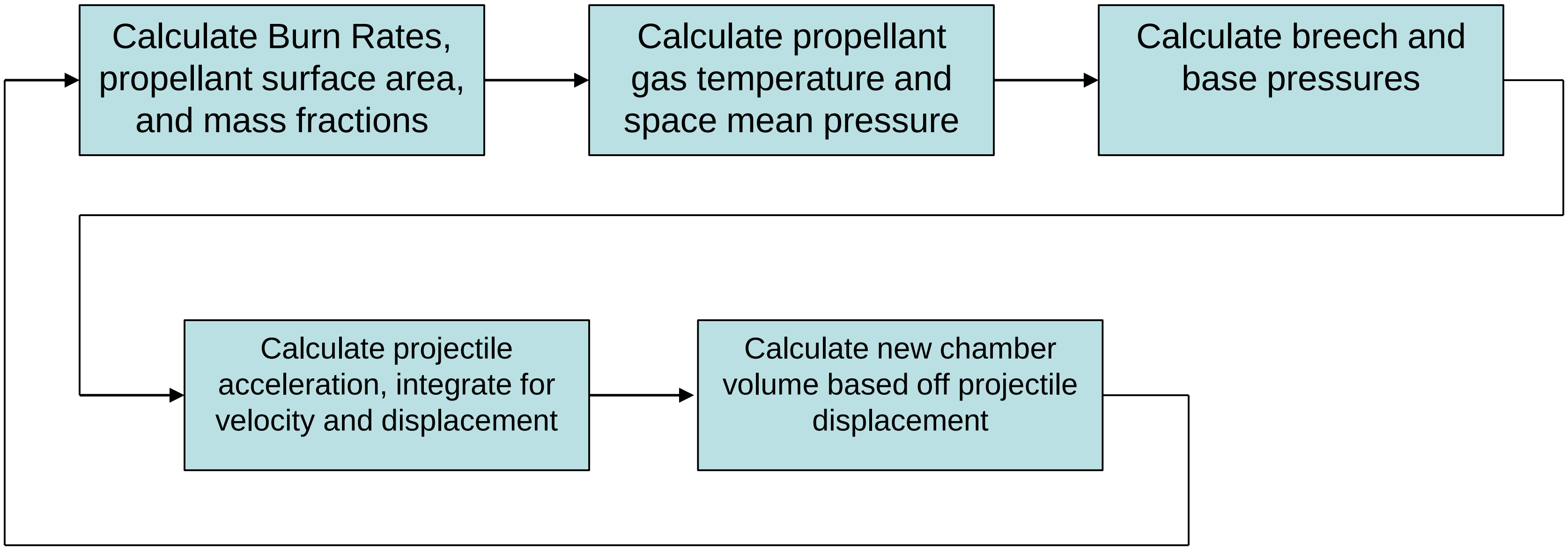
$$x = \int_0^t v\, dt$$

PRESSURE GRADIENT (LaGrange)

$$P_b = \frac{\overline{P} + \frac{CP_r}{3M}}{1 + \frac{C}{3M}}$$

$$P_{br} = P_b + \frac{C(P_b - P_r)}{2M}$$

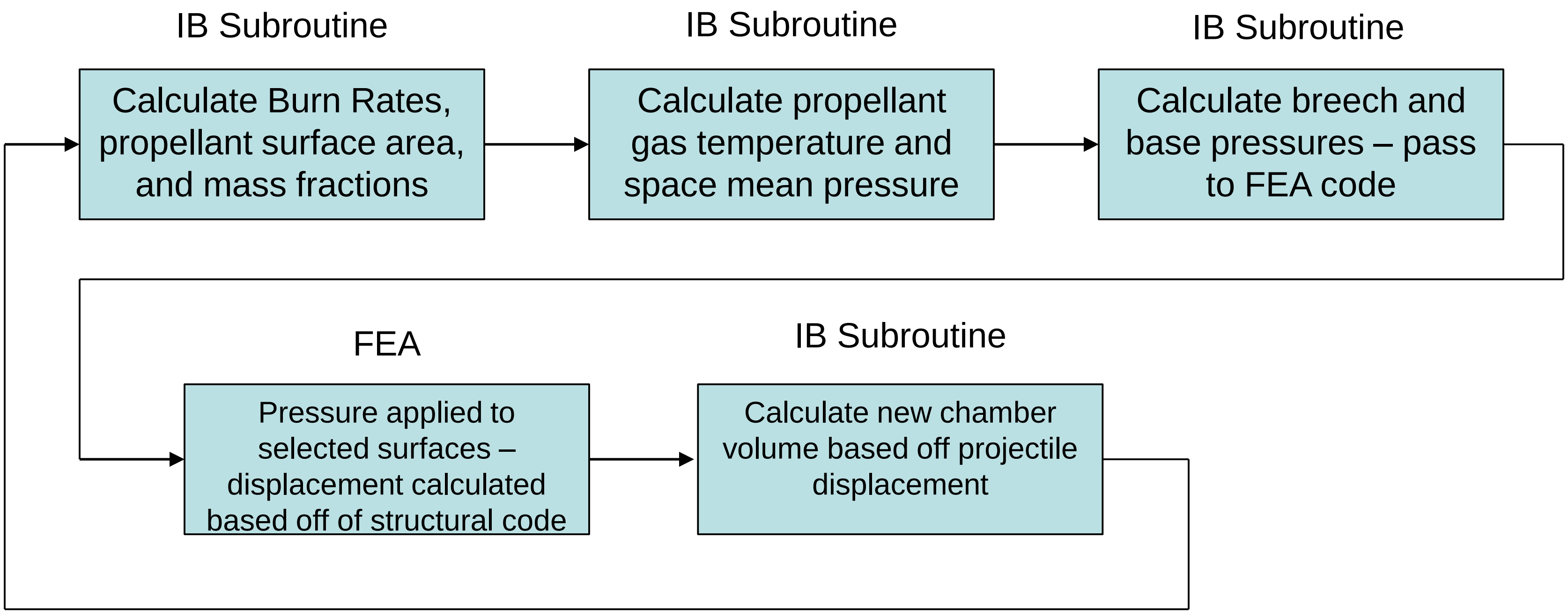
IB Computational Flow



Coupling of the two Codes

- The FEA and Lumped Mass codes are coupled together to take advantage of the both of their individual strengths.
  - Pressure is initially calculated in the lumped mass subroutine and passed into the FEA code as surface pressures.
    - Three different surfaces are specified – base, breech, and gradient.
  - The accelerations, velocities, and displacements are calculated as part of the FEA code (as well as stress, strain, and other structural parameters)
  - The bore resistance curve is now a function of material properties, the contact algorithms, and element deformations in the FEA code.
  - A plane is specified on both the chamber and the projectile in FEA, as the projectile moves the delta between the planes is calculated and fed back to the lumped mass subroutine.
  - The lumped mass subroutine then calculates the new chamber volume, then the new pressures are calculated and fed back to the FEA code.

Combined Code Computational Flow

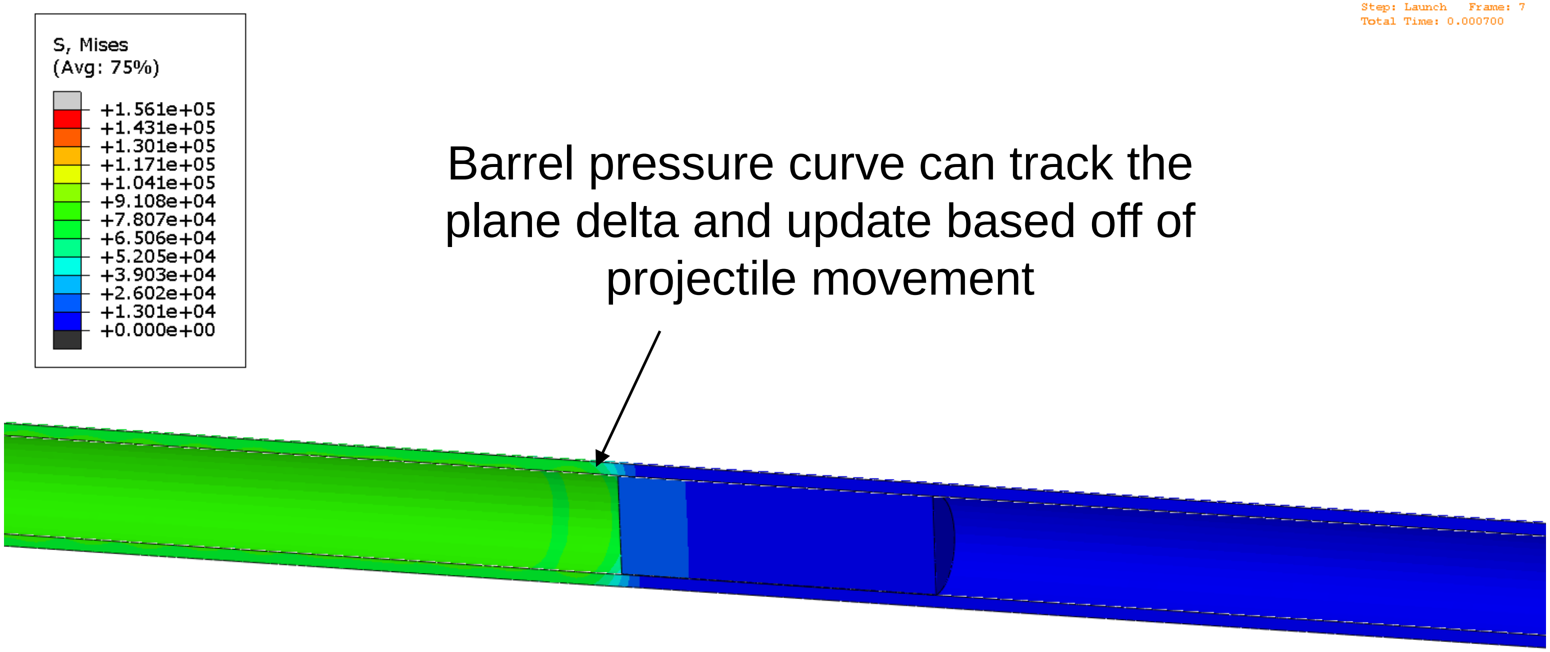


Features of ARDECIB

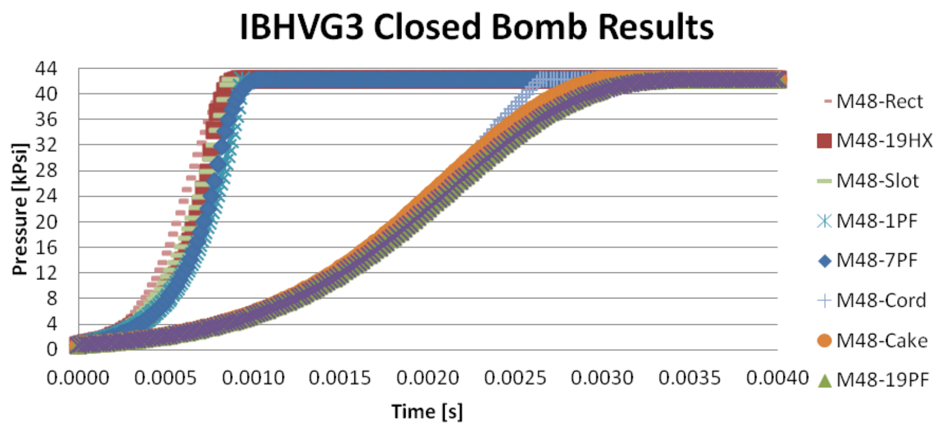
- Can currently handle up to 4 propellant layers.
- Has all major propellant shapes coded in.
- Has a GUI to run in the ABAQUS CAE program.
- Can have multiple gun barrels and projectiles within the same analysis.
- Currently working on
  - Hi-Low chamber – this is calculated using a separate computational fluid dynamic code.
  - Multiplex rounds – again a separate CFD code is being used.

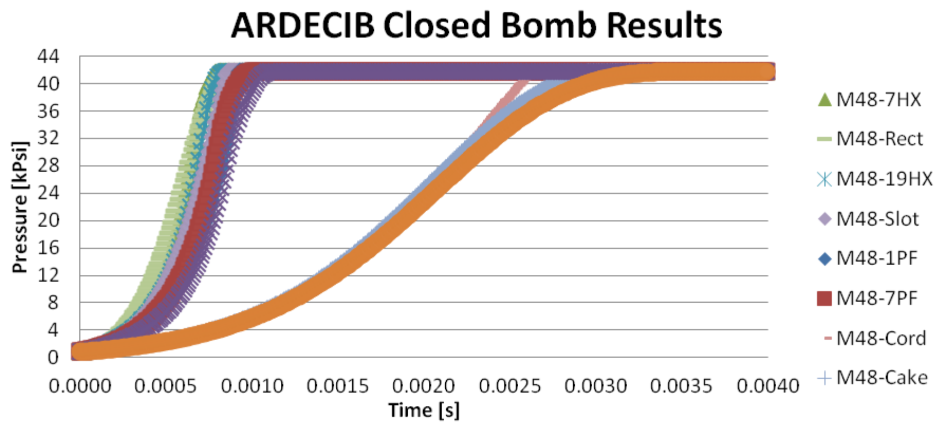
Other features

Barrel pressure curve can track the plane delta and update based off of projectile movement

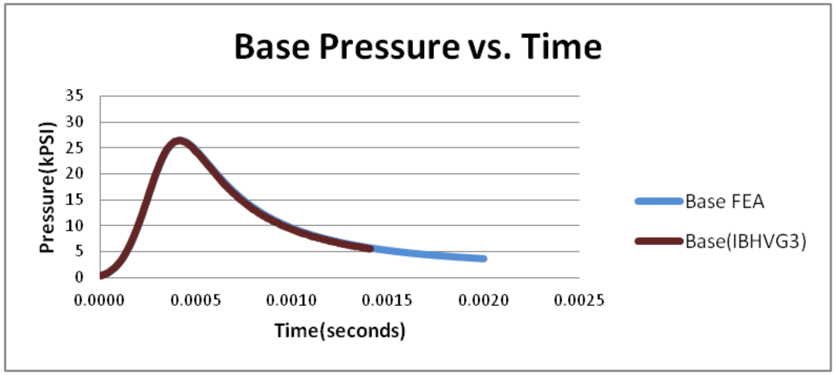


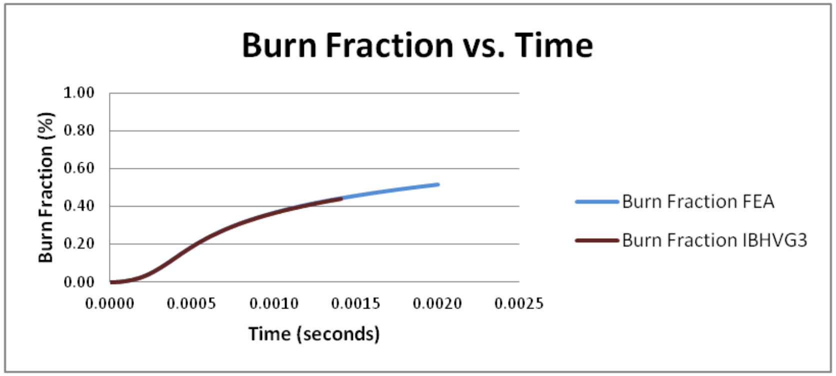
Code Calibration – Closed bomb Models



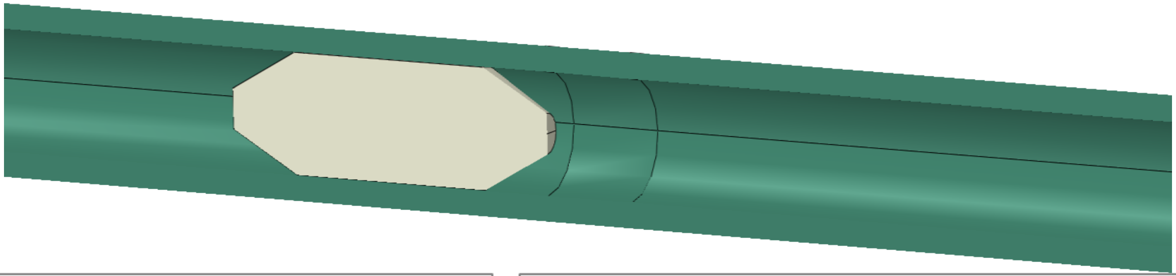


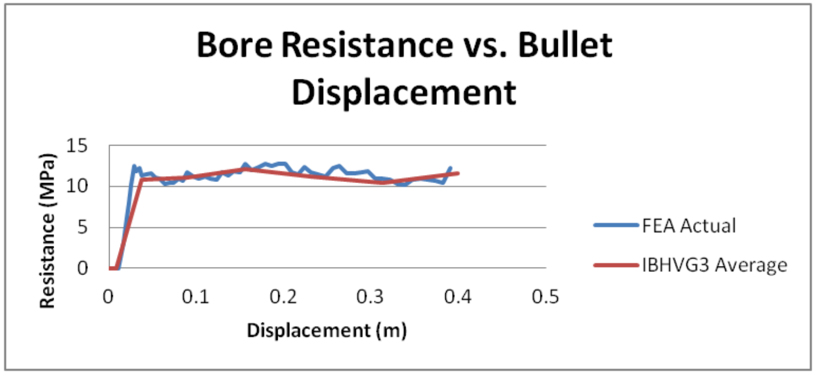
Code Calibration – Resistance Free Projectile

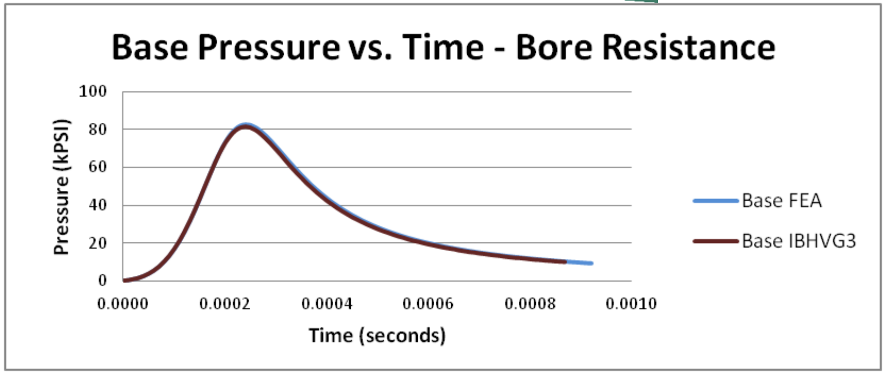


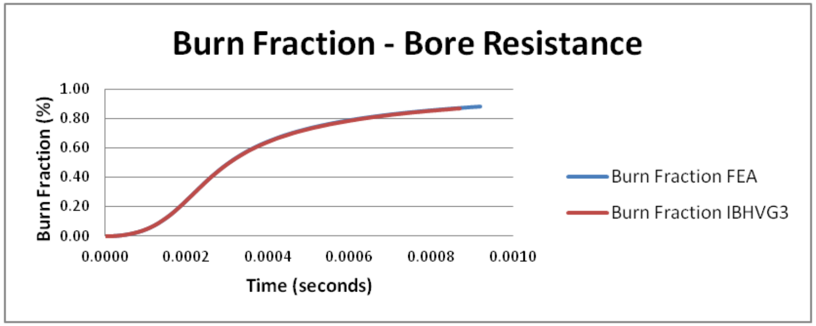


Code Calibration – With Bore Resistance









Questions?

References

- [1] Anderson R., Fickie K., “IBHVG2 – A Users Guide” BRL-TR-2829; US Army Ballistic Research Laboratory: Aberdeen Proving Ground, MD, July 1987
- [2] Baer P., Frankle J., “The Simulation of Interior Ballistics Performance of Guns by Digital Computer Program” BRL-TR-1183; US Army Ballistics Research Laboratory; Aberdeen Proving Ground, MD, December 1962
- [3] Horst A., “Intro to Gun Propulsion Physics” Internal Course at Army Research Lab; Aberdeen Proving Ground, MD, January 2010