NUMERICAL MODELING AND EXPERIMENTAL VERIFICATION OF A NOVEL BASE BLEED DESIGN

L. Svanberg[1], S. Strömberg[1], A. Totten[2], J. Vega[2], M. Hollis[2], R. St. Ours[2], D. Carlucci[2], B. Flyash[2]

1 BAE Systems Bofors AB, Karlskoga, SE email: Lars-Peter.Svanberg@baesystems.se
2 U.S. Armament, Research and Development Center, Picatinny Arsenal, Dover, N.J. 07871, USA email: dcarl@pica.army.mil

ABSTRACT

Understanding the behaviour of base bleed propellants in the bore of a gun is a rapidly developing field. The XM982 Excalibur projectile currently under development for the U.S. Army and the Kingdom of Sweden will contain a novel base bleed design. The design has been challenging due to the stringent weight requirements of the system. BAE Systems Bofors AB and the U.S. Army Armament, Research, Development and Engineering Center (ARDEC) have been collaborating to develop and analyze this novel base bleed device which was designed by BAE Systems Bofors AB.

The Analysis and Evaluation Technology Division at ARDEC and BAE Systems Bofors AB collaborated in the design of a specialized 155mm XM1073 Instrumented Ballistic Test Projectile (IBTP) [1] as an experimental vehicle to determine pressure differential between the interior of a base bleed cavity and the bore of the weapon. The projectile was instrumented with pressure transducers and with the data telemetered to a ground station. The pressure differential was tracked to assure base structural integrity both within the tube and immediately after gun launch.

The numerical modeling has been carried out at BAE Systems Bofors AB using the Matlab software. The data was taken from this model and used in finite element and CFD code run at both BAE Systems Bofors AB and ARDEC to assure adequate design margin exists in the base. The match of the experimental data to the model results was excellent.

DESIGN

Figure 1 depicts the IBTP projectile. High grade AMS-S-5000 4340 steel with specific chemical requirements to enhance the fracture toughness was used to manufacture the projectile body. The ogive and the base are made of 7075 T61 aluminum. These parts are designed to take the brunt of the force during ground impact and are considered replaceable.

The five pressure sensors are PCB 109C11 piezoelectric gages which are rated for 80,000 g's of axial shock and 552 MPa. As seen in figure 1, every gage is oriented specifically to take advantage of the axial shock capability. Each pressure sensor has an internal blind gage that is used to subtract the effects of acceleration from the pressure sensing element. If the gages were not parallel to the launch axis, extra noise and bias offsets would occur and ultimately interfere with the data.

Finally, all gages are kept as close to the environment as possible. The side wall gages are at 90 to each other, just centimeters ahead of the obturator. The telemetry electronics, designated as the ARRT-124 telemetry system, is an analog, 9 channel telemetry system with 3 channels used for an internal tri-axial accelerometer block.

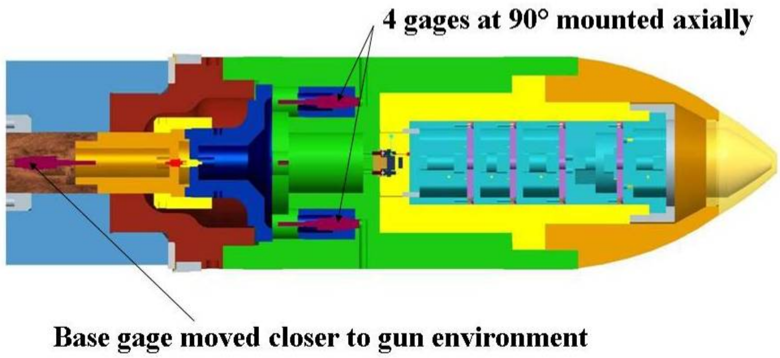

Figure 1: Instrumented Ballistic Test Projectile (IBTP).

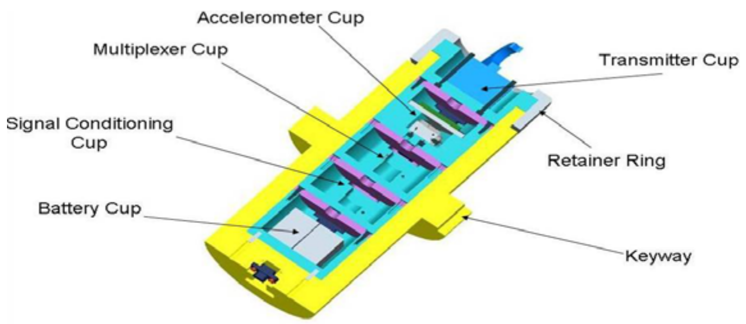

Figure 2: IBTP Telemetry unit.

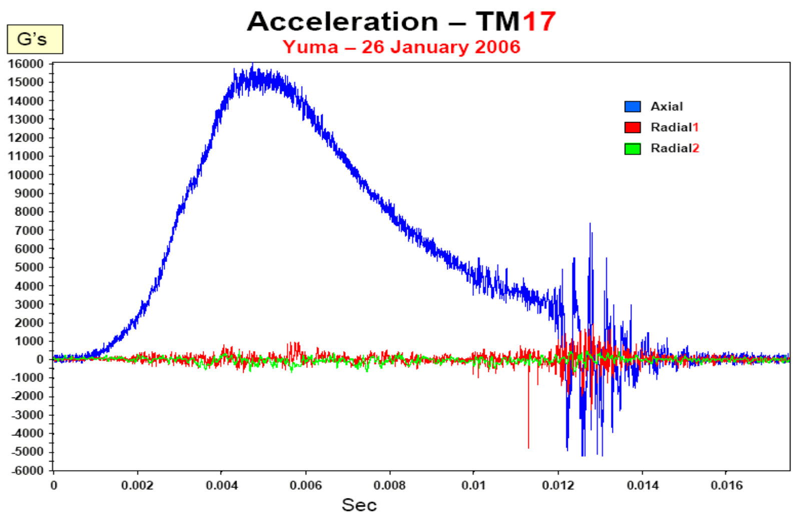

Figure 3: Acceleration-time curve for an IBTP firing.

The accelerometers consist of an Endevco 7270-20K for the axial sensor and 7270-6K for the transverse sensors. The system, as seen in figure 2, is fully modular. In the event that a subsystem does not function properly, it can be easily replaced. Since this system is continually evolving, it is unknown at this time how many cannon launchings and ground impacts the components can withstand.

INSTRUMENTED BALLISTIC TEST PROJECTILE

This past year, three IBTP's were fired at Yuma Proving Grounds. One IBTP (serial number TM17) was launched from a M109A5 cannon at PIMP+5% (permissible individual maximum pressure +5 %, equivalent to roughly 436 MPa breech pressure or approximately 15,700g's for the Excalibur projectile). The projectile had a slipping driving band obturator supplied by BAE Systems from Karlskoga, Sweden. Figure 3 displays the acceleration data and Figure 4 shows the pressure data taken from the same test. The side gages (gage numbers 2-5) only indicate

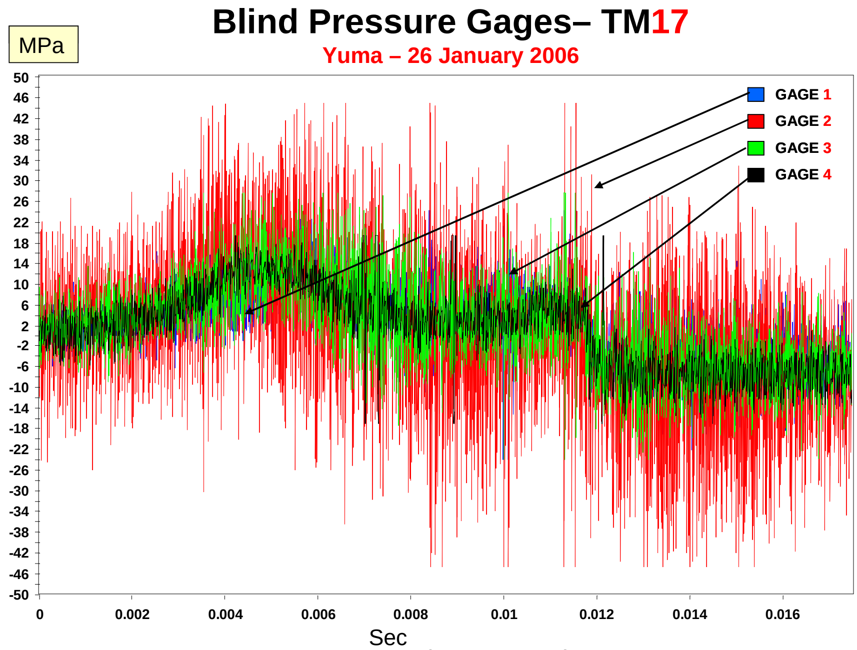

Figure 4: Measured pressure data for an IBTP firing

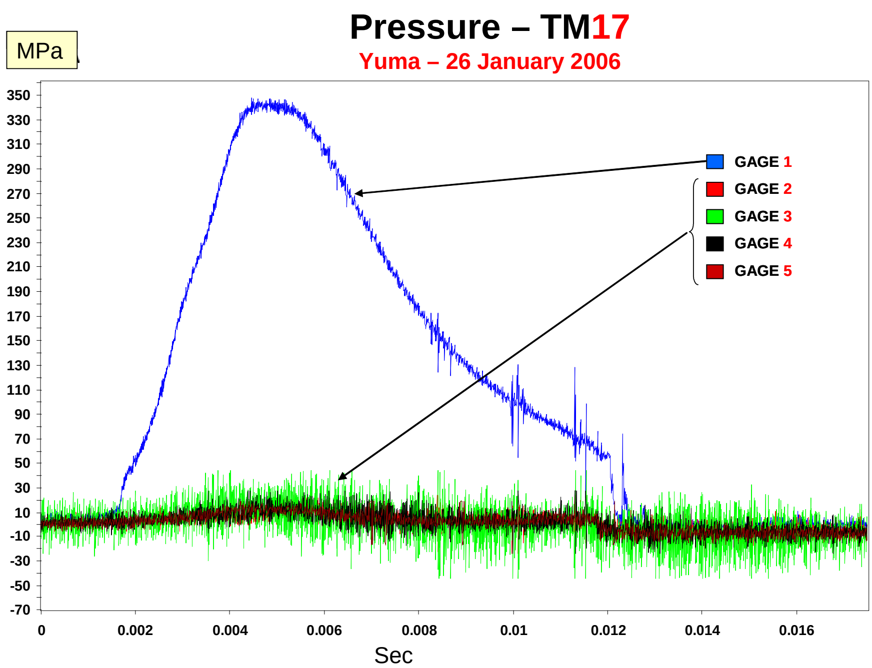

Figure 5: Blind pressure gage data for IBTP firing.

minimal blow by from the obturator, as seen in figure 5. Further data reduction is underway to determine the pressure distribution around the circumference of the projectile that would act to buckle a thin wall. A slight pressure bias is seen at muzzle exit that returns to zero within seconds, this is an anomaly that appears to be a combination of the gage signal conditioning and the ARRT-124 signal conditioning.

INSTRUMENTED PRESSURE BASE

The IBTP can be reconfigured to accommodate novel rocket motor or base bleed testing, figure 6 depicts this reconfiguration. The base is instrumented with pressure gages and hence designated the instrumented pressure base or IPB. Since the ARRT-124 system has 5 free channels, 5 pressure gages can be used in the base.

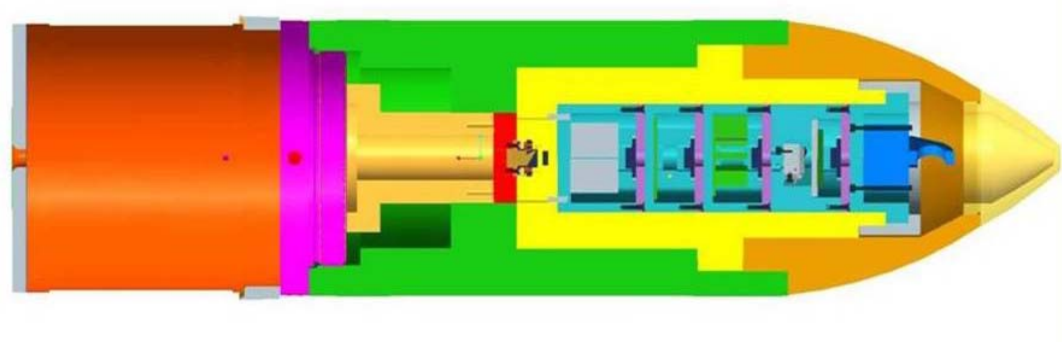

Figure 6: Cross section of an IBTP.

PURPOSE OF THE ANALYSIS CODE

During the design of the base-bleed for the XM 982 Excalibur projectile there was a need to get a better understanding of the environment that the base and base-bleed propellant is exposed to during gun launch in a projectile with slipping obturator. In order to quickly analyze the different combinations of guns, charges and temperatures required of the projectile design, a fast analysis tool is needed. A CFD-code with high resolution in time and space would be too time-consuming. The alternative is to create a simplified model of the physics involved and then validate it with suitable testing.

SHORT DESCRIPTION OF THE ANALYSIS CODE

The Matlab software was chosen as the development tool for the pressure differential calculations.

The model consists of a force balance over the back plane of the base of the projectile. On one side is the in-bore environment and on the other side the base bleed void which is dependent on the outside environment, base-bleed propellant behaviour, base-bleed void, hood extraction resistance and the nozzle that is the communication interface. The gas is treated according to the ideal gas-law and the base-bleed propellant burning is described according to Vielle’s burn law.

$$r = \beta * \left(P^{\alpha} + P_0\right) \tag{1}$$

The unknown parameters in equation (1) are α and β.

The charge and discharge of the base-bleed void is according to Saint-Venant-Wantzel with a nozzle dependent loss factor μ (contraction factor). For a pressure ratio less than critical:

$$\frac{dm}{dt} = \mu * A\left(\frac{P_{pl}}{P}\right)^{\frac{1}{\kappa}} * \rho * \sqrt{\left(\frac{2*\kappa}{(\kappa-1)} * \left(\frac{P}{\rho} - \frac{P_{pl}}{\rho * \left(\frac{P_{pl}}{P}\right)^{\frac{1}{\kappa}}}\right)\right)} \tag{2}$$

For a pressure ratio larger than critical:

$$\psi = \sqrt{\kappa} * \left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{2*(\kappa-1)}} \tag{3}$$

$$\frac{dm}{dt} = \mu * A * \psi * \sqrt{P * \rho} \tag{4}$$

The unknown parameter these expressions is μ. To determine α and β two types of bomb tests have been performed. One was a closed vessel test per STANAG 4115 and the other was a vented bomb test (EMBLA bomb test). Both of these tests yield α and β but by different methods. Results are shown in figure 7.

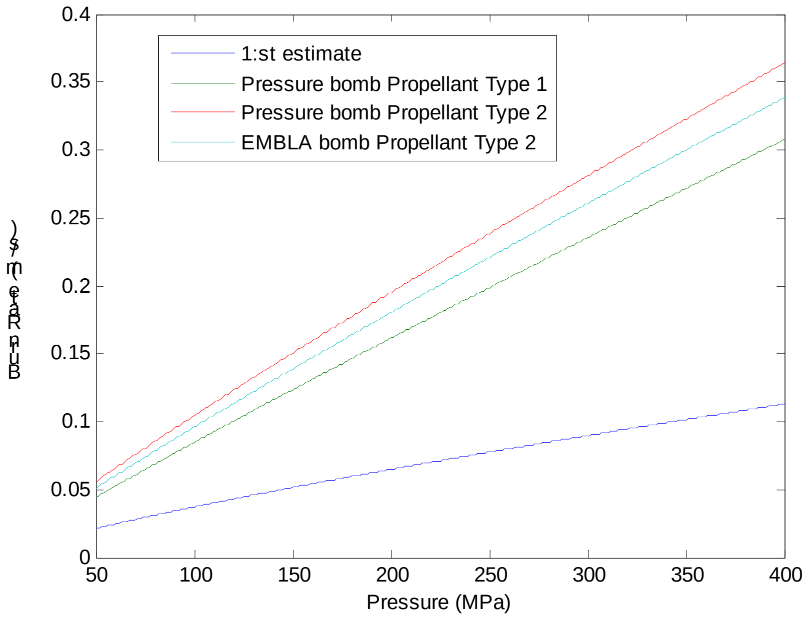

Figure 7: Burn rate vs. pressure.

In order to be conservative in the analysis the most conservative burn rate was used in the hood extraction code to describe the gas generation inside the base bleed void.

The hood extraction resistance was determined by performing pull tests on bases that were exposed to pressure levels that occur in different charges and guns.

Determination of μ is a more demanding task. The method that has been used was gun tests using IBTP's.

The normal value should be on the order of 0.9 to 1 if the nozzle is correctly sized. Unfortunately this was not supported by test results. In order to obtain a valid measurement, an inert IBTP was designed. The main reason for using an inert base was to be able to fully instrument it.

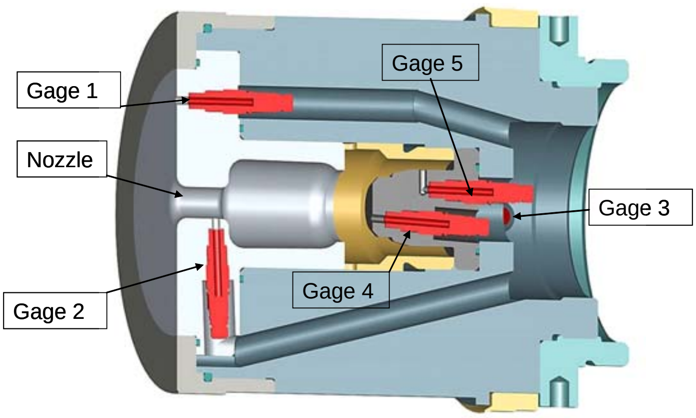

Figure 8: Location of pressure gages in the inert instrumented base.

To obtain pressure differences between the projectile back plane and the base void as well as calculate the contraction factor, the hood has been removed in this design. This is depicted in figure 8. In this design of the base the nozzle diameter was set to 12 mm.

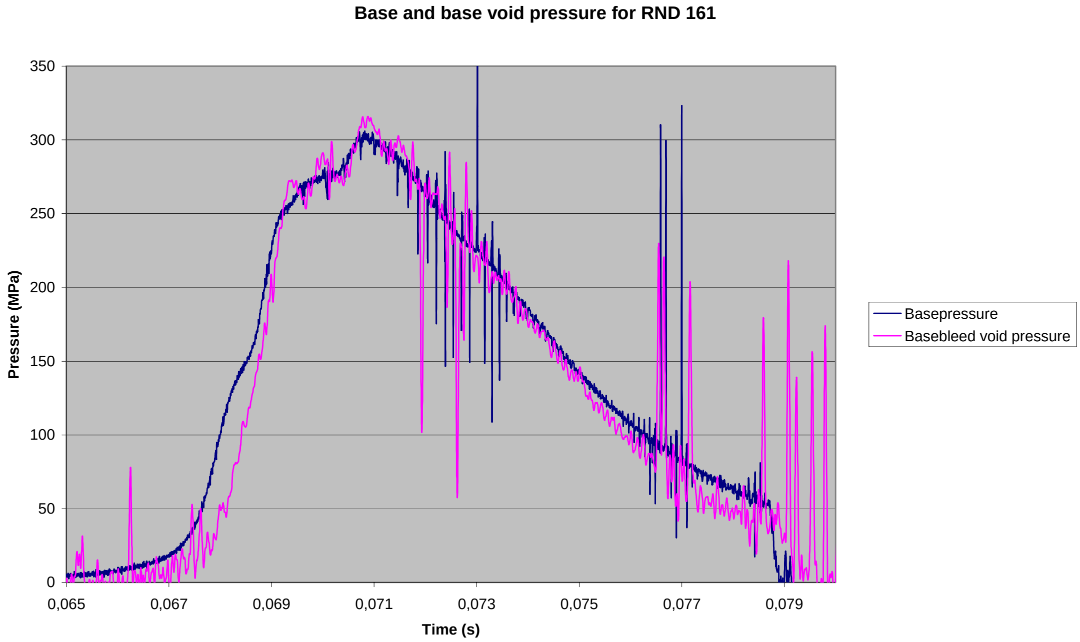

Figure 9: Pressure at gage 1 (base pressure) and gage 5 (base bleed void pressure).

The IBTP discussed above was fired on 16 December 2004 out of an M284 gun tube with muzzle brake, using a U.S. propelling charge.

The measurements showed the pressure decrease after muzzle exit to be twice as fast as had been predicted. This new knowledge was incorporated into the code. By comparing measurements with calculations a good understanding of nozzle behaviour was established. This comparison is shown in figure 10.

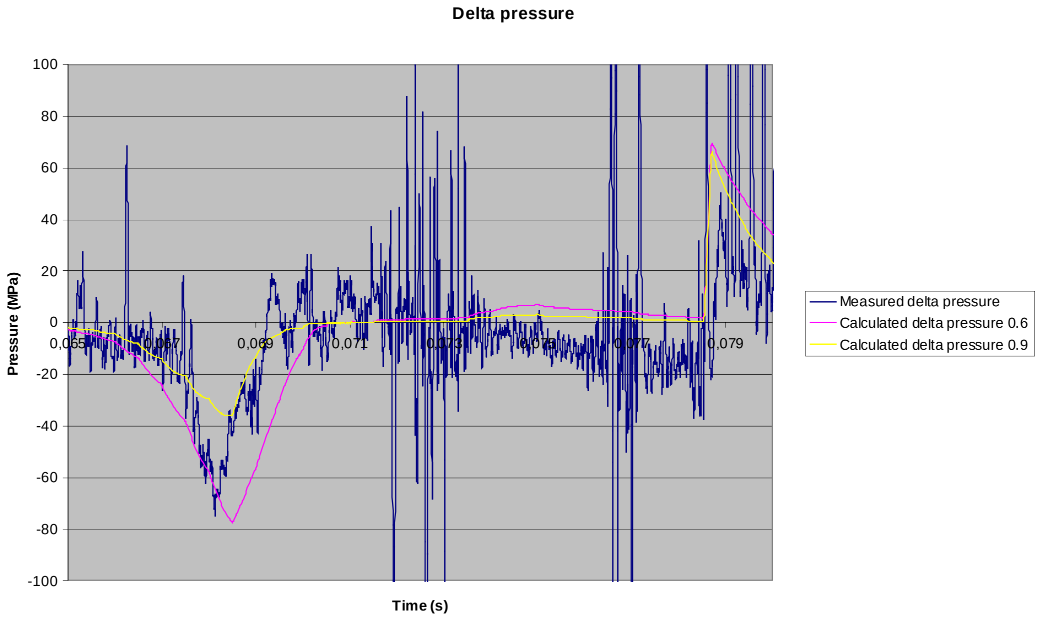

Figure 10: Pressure difference between gage 1 and gage 5 compared to calculations with a contraction factor of 0.6 (Magenta) and 0.9 (Yellow).

The result of this calculation is that for small nozzle diameters μ ranges from 0.6 to 0.7. This led to an increase of nozzle size and a change in μ based on the nozzle *l*/*d* ratio.

After validation with the inert base a test with an instrumented live base bleed was performed. The purpose of this test was to investigate if the propellant was working properly in bore and after muzzle exit.

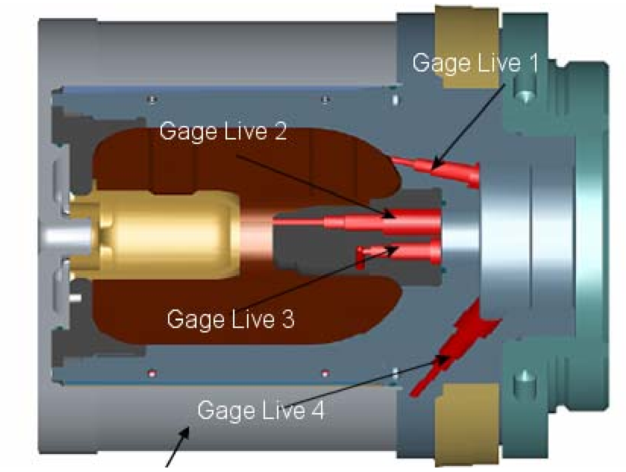

Figure 11: Instrumentation of the live instrumented base.

In figure 12 it is shown that the pressure inside the base bleed had a long duration at high pressure after muzzle exit which would not be the case if the propellant was burning according to the assumed burn law or if its geometry remained intact.

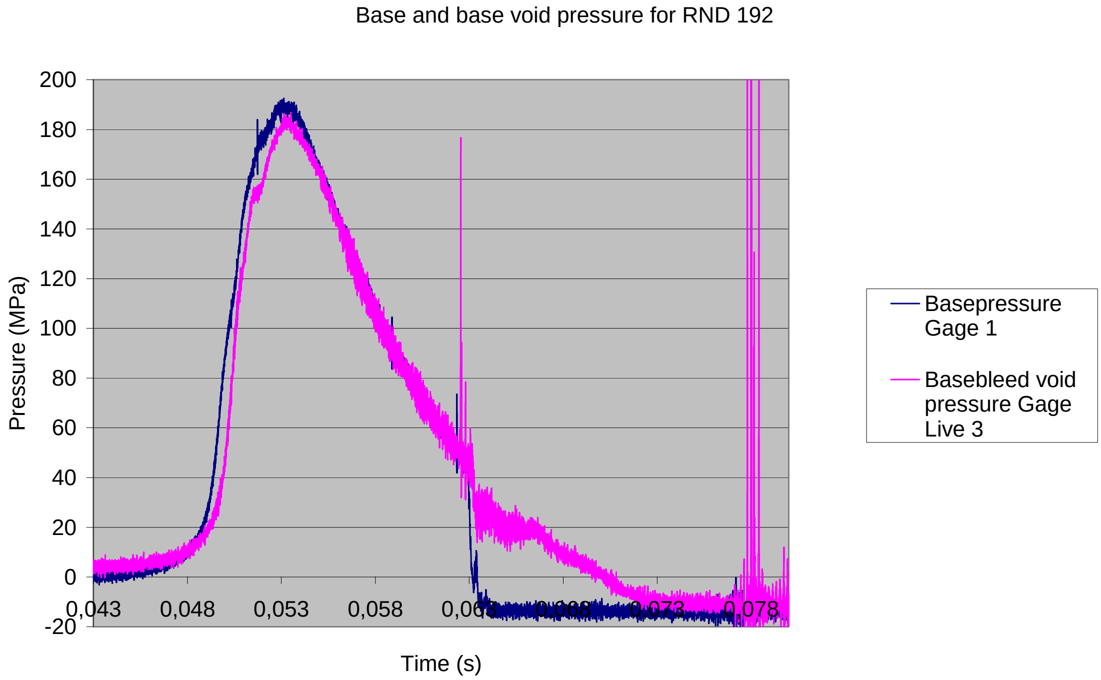

Figure 12: Measurements on the live IBTP with ruptured base bleed propellant.

HOW THE ANALYSIS CODE WAS USED

The code was used as a tool to identify design changes, evaluating compatibility with different gun and charge systems.

SUMMARY OF PERFORMED WORK

The Instrumented Ballistic Test Projectile (IBTP) was developed as a tool to establish understanding of blow-by, in-bore friction and muzzle exit effects. A physics based model was developed to predict pressure changes in a base bleed projectile design during gun launch. A smart application of testing using both standard tests as well as the IBTP tuned the physics based model to allow rapid and accurate design iterations to be performed. The ARDEC-BAE Systems Bofors AB team performed outstanding work in a highly collaborative environment.

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.

[2] Minnicino, Michael A., *BANDSLIP R1.2 Theory and User's Guide*, ARL-TR-3598, Aberdeen Proving Ground, MD, September 2005.