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AEROBALLISTICS RANGE TESTS OF A 40 MM PROJECTILE

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Aeroballistic range tests were conducted on a high velocity 40 mm practice ammunition from a MK19 launcher mounted on a solid mount. The aerodynamic properties as well as the aerodynamic jump, the gun dispersion, and statistical properties on the mass, muzzle velocities and aerodynamic coefficients were determined. Ten projectiles were fired at a muzzle velocity of roughly 240.0 m/s.

INTRODUCTION

CASW (Company Area Suppression Weapon) is a high-priority procurement project for the Canadian Forces. This concerns a 40 mm grenade launcher with a fast firing automatic grenade launcher (AGL). Various rounds can be fired, such as; ground and air burst munitions, featuring forward-throwing concepts as well as rearward-throwing ones. High-explosive dual-purpose grenades (HEDP) as well as various practice rounds also exist. Some AGL systems feature elaborate fire-control systems, including day/night imagers, laser rangefinders, GPS, etc

DRDC Valcartier was tasked for comparing different contenders, from the point of view of fire control system, aerodynamic characteristics, flight dynamics, system analysis, hit probability and lethality on various engagement scenarios, which included but were not limited to, direct attack against vertical targets, top attacks in ground hit or airburst modes against fixed targets or troop formations. The latter two could be engaged in direct or indirect fire modes. The AGL also has the capability of firing in single or burst mode options. Prior to comparing various contenders or grenade types, it was necessary to identify the essential system parameters of the 40 mm AGL that would influence the hit probability of the various targets. To accomplish this, a realistic error budget had to be defined for every 40 mm gun-ammunition combination. Even though many sensitivity analyses were conducted on the basis of partial and unconfirmed information, it was believed necessary to obtain some reliable information on some of these parameters, that a comprehensive trial with a known system would be beneficial to obtain an order of magnitude on these errors.

To obtain some realistic data, it was decided to conduct a series of tests in the DRDC Valcartier aeroballistic range on a 40 mm practice ammunition launched from a MK19 AGL. Ten projectiles conditioned at 21° C were fired at roughly 240 m/s. The specific data that was coveted from these trials for the Monte Carlo simulations were; the standard deviation in the drag coefficient, the mass, the muzzle velocity as well as the ammunition dispersion, also referred to as aerodynamic jump or projectile jump.

PROJECTILE CONFIGURATION

The projectile consisted of a 40 mm practice ammunition as shown in Fig. 1. The reference diameter is 39.93 mm. The projectile is basically a bluff body with an l/d of 2.09 cal followed by a boom (tracer) of 0.27 cal. The projectile was tested without the tracer propellant. The mean physical properties of 15 measured projectiles are provided in Table 1 as well as the standard deviations.

EXPERIMENTAL FACILITIES and DATA ANALYSIS

DRDC Aeroballistic Range

The DRDC-Valcartier Aeroballistic Range [1] is an insulated steel-clad concrete structure used to study the exterior ballistics of various free-flight configurations. The range complex consists of a gun bay, control room and the instrumented range. Projectiles of caliber ranging from 5.56 to 155 mm, including tracer types, may be launched. The 230-meter instrumented length of the range has a 6.1-m square cross section with a possibility of 54 instrumented sites along the range. These sites house fully instrumented orthogonal shadowgraph stations that yield photographs of the shadow of the projectile as it flies down the range.

The gun muzzle (Fig. 2) was situated at a downrange coordinate 2.871 m in the aeroballistic range coordinate system. The gun was mounted on a solid mount as shown. Due to the low muzzle velocities, the movable butt was utilized to capture the projectiles before the end of the range. It was placed after shadowgraph station No. 39, at approximately 130.0 m. This allowed a possibility of 110.0 m to measure data.

Data Analysis

The first part of the data analysis process is to calculate the trajectories of the projectiles in the aeroballistic range facility coordinate system. The developed films are scanned and read with the CADRA system [2]. CADRA has tools that identify images of the model’s shadow and fiducal system in each shadowgraph, measure the positions of these images, and transform these measurements to three dimensional trajectory coordinates.

Extraction of the aerodynamic coefficients and stability derivatives is the primary goal in analyzing the trajectories measured in the DRDC aeroballistic range. This is done by means of the Aeroballistic Range Data Analysis System (ARFDAS, [3]). The data analysis consists of linear theory, 6 DOF single- and multiple-fit data reduction techniques with the Maximum Likelihood Method to match the theoretical trajectory with the experimentally measured trajectory. The MLM is an iterative procedure that adjusts the aerodynamic coefficients to maximize a likelihood function. The application of this likelihood function eliminates the inherent assumption in least square theory that the magnitude of the measurement noise must be consistent between parameters (irrespective of units). In general, the aerodynamic coefficients are nonlinear functions of angle of attack, Mach number and roll angle.

The 6DOF data reduction system can also simultaneously fit multiple data sets (up to five) to a common set of aerodynamics. Using this multiple-fit approach, a more complete range of angle of attack and roll orientation combinations is available for analysis than would be available from a single flight. This increases the probability that the determined aerodynamic coefficients define the model's aerodynamics over the entire range of test conditions.

The aerodynamic data presented in this paper were obtained using the fixed-plane 6DOF analysis with the single-fit data correlation techniques. The equations of motion have been derived in a fixed-plane coordinate system with Coriolis effects included. The formal derivation of the fixed-plane model is given in [4].

AERODYNAMIC PROPERTIES

A typical total angle of attack history is shown in Fig. 3. The projectile wobbles basically at a limit cycle of 3.0 deg over the range tested. This suggests a nonlinear Magnus moment coefficient.

The analyses of the 10 shots were conducted with the single fit data reduction technique and the statistical results of the aerodynamic coefficients of the ten shots can be found in Table. 2. Some multiple fits data reductions were also conducted to fix some aerodynamic coefficients but these are not presented here. The mean muzzle velocity was determined to be 234.1 with a standard deviation of 3.2 m/s. The low muzzle velocity and high variability is due to the fact that the projectiles had to be de-crimped and the HI-LO cartridge system seal was broken.

Since the angles of attack were low, it was not possible to discern the type of Magnus instability, precession or nutation. This is also the reason for the high standard deviation on the normal force coefficient slope. The pitch damping coefficient was held constant at -0.1.

In this Mach regime where total axial force is dominated by base flow, the round to round drag variability is probably due to subtle differences in the engraved rotating band resulting in base flow variations. This also may explain the variation in dynamic stability since Magnus moment nonlinearities are very sensitive to small variations in base flow. The roll damping coefficient was determined from the change in frequencies since the roll pins could not be read with consistency.

AERODYNAMIC JUMP DETERMINATION

The ammunition dispersion or projectile jump can be formulated as follows [5]:

$$\theta_{aero} = \frac{\left(C_{N\alpha} - C_X\right) d\, I_y}{C_{M\alpha}\, V_{muz}\, m d^2}\, q_0$$

This linear formulation states that if the initial yaw rate (q_0) of the projectile is known, the projectile jump is easily determined. Usually, the initial yaw rate is very difficult to obtain, however, there is direct relationship between the initial yaw rate and first maximum angle of attack [5]. The first maximum angle of attack from the muzzle is much easier to obtain in trials, like the use of yaw cards.

The aeroballistic range software allows the possibility of extrapolation back to the muzzle of the gun from the first station where data was taken. An example of this is provided in Fig. 4. From this, the first maximum yaw can be easily be acquired. This process was done for every shot with the unique muzzle velocity, aerodynamic coefficients and physical properties for each particular shot. The first maximum yaws of every shot are provided in Table 3, with the mean and standard deviation.

The direct relationship between the initial yaw rate and first maximum yaw can be graphically represented, as in Fig. 5 for this particular projectile with the solid black line. This line is not much influenced by small variations in muzzle velocities. The average first maximum yaw from the 10 shots fired was 2.3° and this yields an initial yaw rate of about 12.0 rad/s. The jump formula above can also be represented graphically and this is provided in Fig. 6. From this relationship, the dispersion due to aerodynamic jump is 0.40 mils.

The gun dispersion for the present setup was determined to be 0.64 mils in the vertical direction and 0.58 mils in the lateral direction.

CONCLUSIONS

Some basic parameters to be able to conduct system analysis studies were determined from an aeroballistic range trial, most importantly, the aerodynamic jump. This aeroballistic range trial also demonstrated the procedure to utilize to obtain the gun dispersion of the MK49 in various firing conditions [6].

REFERENCES

1. Dupuis, A. and Drouin, G., "The DREV Aeroballistic Range and Data Analysis System", AIAA Paper No. 88-2017, AIAA 15th Aerodynamic Testing Conference, San Diego, California, May 18-20, 1988.
2. “CADRA System”, AerospaceComputing, Inc., 2000.
3. "ARFDAS", Version 4.30, Arrow Tech Associates Inc, August 2003.
4. Hathaway, W. H. and Whyte, R., "Aeroballistic Research Facility Free-Flight Data Analysis using the Maximum Likelihood Function", AFATL-TR-79-98, December 1979.
5. PRODAS (Projectile Design/Analysis System, Version 3.1.29), Technical and User Manual, Arrow Tech Associates, Burlington, Vermont, USA.
6. Dupuis, A., “System Modeling Toll and Accuracy Trials for a 40 mm AGL”, DRDC Valcartier TM 2005-275, December 2005.

Table 1 – Statistical physical properties

Model #	d (mm)	Ix ($g\ cm^2$)	Iy, Iz ($g\ cm^2$)	m (g)	CG from nose (x/l)	l (mm)
$\bar{x}$	39.930	544.12	1192.15	240.82	0.6041	83.656
s	0.0065	1.57	8.76	0.93	0.0012	0.111
$s/\bar{x}$ (%)	0.016	0.29	0.74	0.39	0.200	0.133

Table 2 – Aerodynamic Coefficients - Single Fit Average Values at Mach 0.656

Aerodynamic coefficient	Mean (x)	STD DEV (s)	s/x (%)
C_{X0}	0.161	0.0051	3.17
$C_{N\alpha}$	1.792	0.3073	17.2
$C_{M\alpha}^{cg}$	1.512	0.0608	4.02
C_{lp}	-0.0187	0.0035	18.7
C_{Mq}	-0.1	-	-

Table 3 – First Max Yaws

SHOT NUMBER	1st Max Yaw (deg)
B01	2.87
B02	1.55
B03	2.85
B04	2.90
B05	1.74
B06	2.71
B07	2.46
B08	2.10
B09	2.73
B10	1.31
Mean	2.323
STD. DEV.	0.601

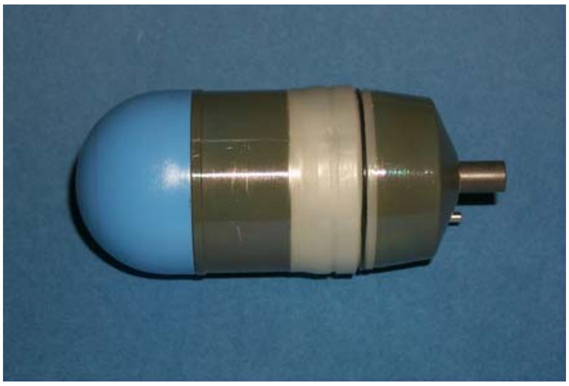

Figure 1. 40 mm projectile

Figure 2. Gun setup

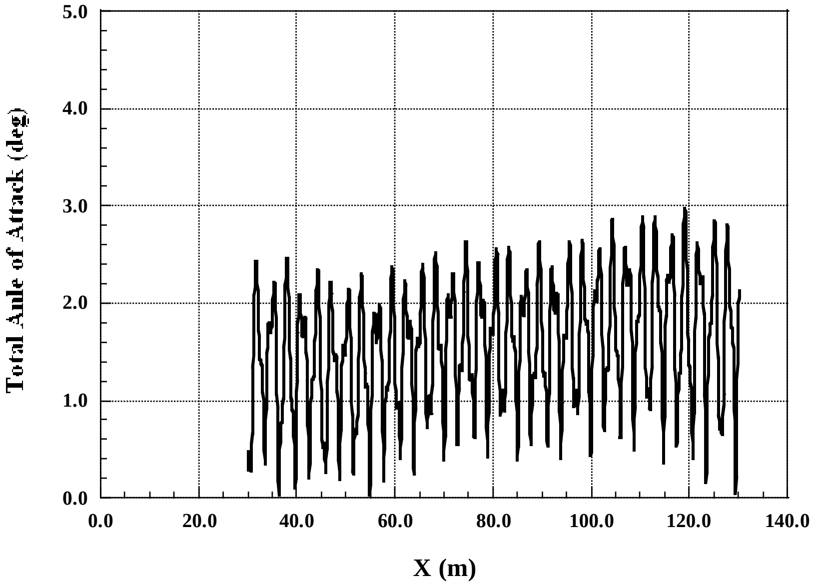

Figure 3. Typical angle of attack history

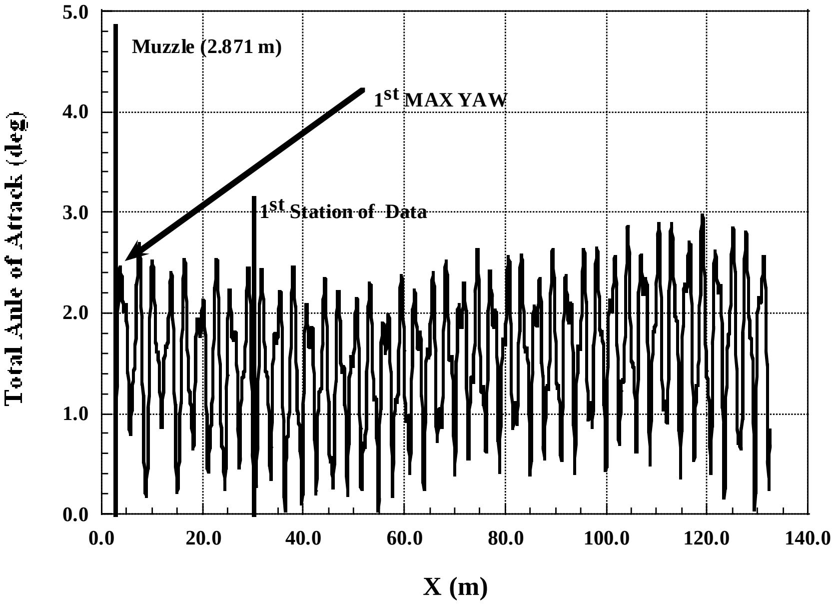

Figure 4. Angle of attack extrapolated to muzzle.

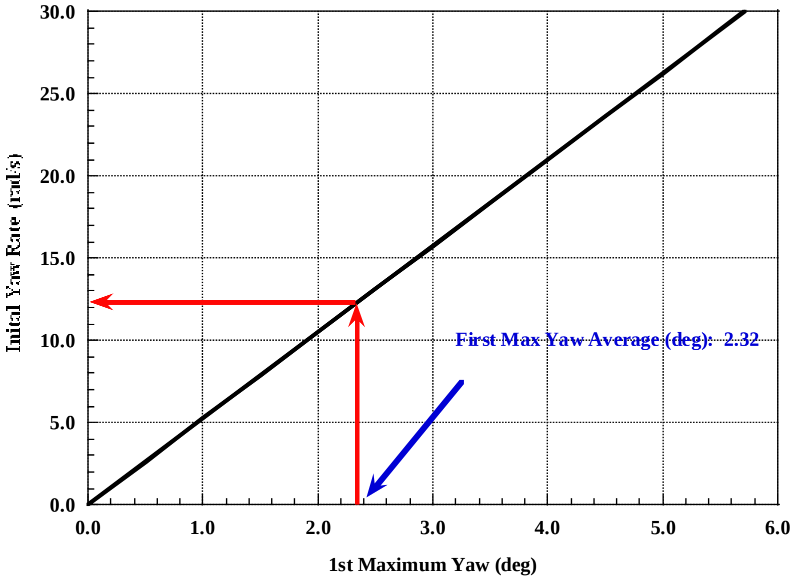

Figure 5. First max yaw - initial yaw rate relationship

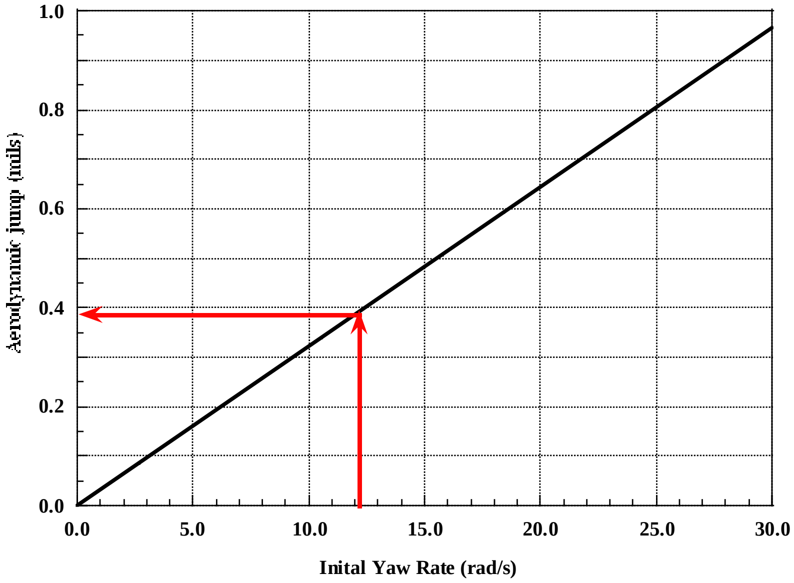

Figure 6. Aerodynamic dispersion – initial yaw rate relationship