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AERODYNAMICS AND FLIGHT STABILITY FOR A COURSE CORRECTED ARTILLERY ROUND

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Next generation artillery fuzes will contain components to minimize impact point dispersion. One concept under development, the Course Correcting Fuze (CCF), includes two drag brakes, and spin brakes to decrease projectile spin rate. These brakes provide both range and deflection command authority. Deployment is controlled through on-board processing of Global Positioning System (GPS) measurements. Events are scheduled by minimizing distance from the projected impact point and the target. Obviously, accurate aerodynamic coefficients are required to execute precise exterior ballistics calculations.

INTRODUCTION

The Army is reorganizing for the future, and cannon artillery is a part of each ground combat unit. Revolutionary cannon technologies like the Course Correcting Fuze (CCF) will make cannon artillery more precise, mobile, and lethal and will exponentially reduce the Army's logistics tail.

The CCF is controlled by a Guidance, Navigation, and Control (GN&C) system consisting of a GPS receiver, GPS antenna, system controller, and brake deployment devices. The system controller includes the processor and flight-control software to perform the required trajectory calculations and provide deployment of drag and/or spin-brakes as required. The CCF software reads input from a single GPS sensor and schedules aero-brake events for trajectory improvement. Events are scheduled by minimizing distance from the projected impact point and the target. This requires highly accurate aerodynamic coefficients to execute precise exterior ballistics calculations.

The exterior ballistics design challenges for CCF are defining forces and flow field changes caused by deployed brakes. Flow changes have a significant impact on total round dynamic stability and aerodynamic coefficients, and therefore on corrected round accuracy.

The design approach identified brake candidates analytically, and by scaled wind tunnel, static and spinning model testing in the Bofors transonic facility. Additionally, validation included both full scale spark range and full range artillery firings at the U.S. Army test facilities. Accurate CCF aerodynamic coefficients, plus vital Magnus data were produced in this way. These data were necessary for designing a dynamically stable 2-D corrector fuze for full range accuracy tests.

CCF CONCEPT OVERVIEW

Conventional methods for improving artillery accuracy are nearing the point of diminishing returns. On the other hand, the need to reduce collateral damage, minimize logistics burden and yet deliver highly accurate fires, dictates the need for much improved round accuracy. The Precision Guidance Kit (PGK) effort by the U.S. Army seeks to provide much improved accuracy. One concept, the BAE Systems CCF will be described. The CCF includes two drag brakes for range correction, and spin brakes to decrease projectile spin rate thus reducing the yaw of repose. Together these brakes provide both range and deflection command authority. Deployment of these brakes is controlled through on-board processing of GPS measurements. Figure 1 shows an overview of the CCF concept.

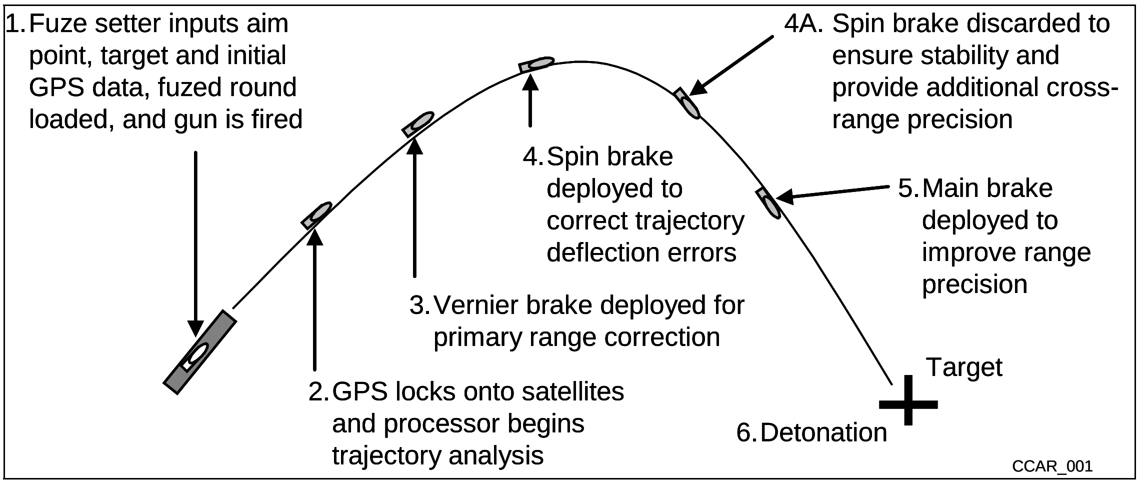

Figure 1. CCF Trajectory Correction Concept

As described, the GN&C for the CCF uses pyrotechnic actuators for spin and drag brake release. The system controller performs the required trajectory calculations and provides the electrical signals that fire the pyrotechnic actuators. On controller command, the actuators deploy the vernier and main drag brakes or activate the spin-brake mechanisms.

The CCF flight control software reads input from a single GPS sensor and schedules three discreet events. These events, and the maneuver authority they provide, are: 1) Vernier-brake deployment time for range correction, 2) Spin-brake deployment time for cross-range correction, and 3) the main-brake deployment time.

TRAJECTORY CALCULATIONS AND ACCURACY IMPROVEMENT

The CCF flight control software contains a modified point mass model with the yaw of repose calculated using tricyclic theory [1]. The usual trajectory calculation has been recast as a subroutine and modified to describe multiple aerodynamic configurations, and to use GPS measurements.

There are three CCF brakes, and so there are six possible aerodynamic configurations. A distinct coefficient table is read at the onset of the calculation for each configuration. Deployment times are passed to the trajectory routine, and changes to the impact point are tracked. The distance between the desired impact point and the range of possible impact points is minimized.

The GPS data is overwritten onto the calculated state vector, and the calculation is allowed to proceed until impact from the last GPS data point. So while the optimization procedure described above is proceeding, GPS data is being introduced into the calculation to constantly improve the impact point prediction. The optimization process is repeated each time a GPS point becomes available.

EXTERIOR BALLISTICS DESIGN CHALLENGES

The exterior ballistics design challenges for CCF are defining forces and flow field changes caused by deployed brakes. Flow changes have a significant impact on total round dynamic stability and aerodynamic coefficients, and therefore on corrected round accuracy. While providing highly accurate coefficients to allow the GN&C system to effectively splice each trajectory segment, the projectile must maintain dynamic stability. To meet this challenge, the BAE Systems CCF aerodynamics team has used both static and spinning wind tunnel tests at Bofors and full scale verification tests in the ARL Transonic Range and Yuma Proving Ground.

Wind Tunnel Testing

Extensive testing has been done at the Bofors Transonic Wind Tunnel to identify the best CCF brake candidates and to develop aerodynamic coefficients. The Bofors tunnel is an open jet tunnel capable of Mach numbers between 0.1 and 3.66. The aerodynamic coefficients were measured on a spinning model driven by an electric motor placed inside the model, between the model and a 5-component balance. Spin rates up to 55,000 rpm were used. Figure 2 shows the model on the 5-component balance outside the transonic test section.

An accurate model was made in 1/4.5 scale matching the real full scale hardware of the M/549A1 projectile with a CCF. However, the wind tunnel spin brake fins had to be made about 4.5 times thicker than the real hardware due to fabrication reasons.

Several spin brake configurations have been tested in both wind tunnel and spark range. Configurations F5b and F6a are presented here as examples. Both configurations have four panels with zero cant angle. F6a has a 9 % smaller tip-to-tip span than the F5b. Figure 3 shows a sketch of the body, and figure 4 shows the spin brakes.

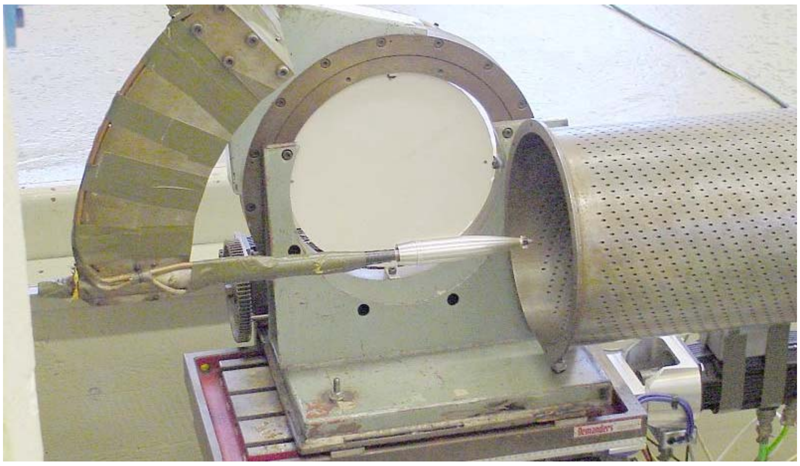

Figure 2. The model on the 5-component balance (outside of test section)

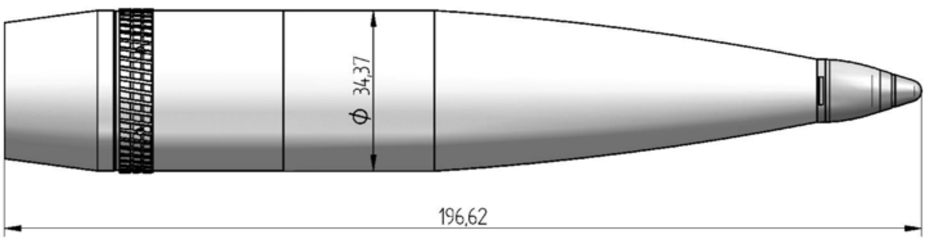

Figure 3. Wind tunnel M549A1 body-alone configuration

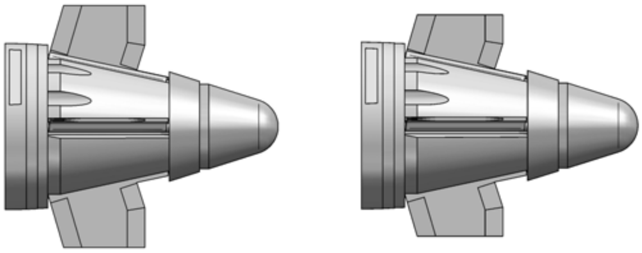

Figure 4. Wind tunnel fuzes with deployed spin brakes: F5b (left) and F6a (right).

ARL Spark Range Tests

The ARL Transonic Range is capable of testing large caliber rounds and has been used to identify key performance needs for both M795 and M549A1 projectiles. Tests were conducted at Mach 1.1 and 1.2 to observe critical Magnus effects. Tests are being done in the high subsonic area, Mach 0.95. Along with standard drag, normal force and pitching moment data, critical data for pitch damping, roll damping, and Magnus moment derivatives were obtained to supplement aerodynamic data from the wind tunnel and full range radar tests. In this way, BAE Systems has gained valuable insight into managing adverse Magnus effects present on all spinning projectile configurations with nose mounted fins.

Tests were conducted using simulant fuze hardware with deployed fixed fins corresponding exactly to the actual hardware used on a functional CCF. These fuzes are shown in figure 5.

Figure 5. Spark Range Fuzes

Shadowgraphs and projectile motion plots provided necessary flow field and projectile damping and stability data [2]. Typical damped motion plots and shadowgraphs for spin brake tests are shown in figures 6 and 7.

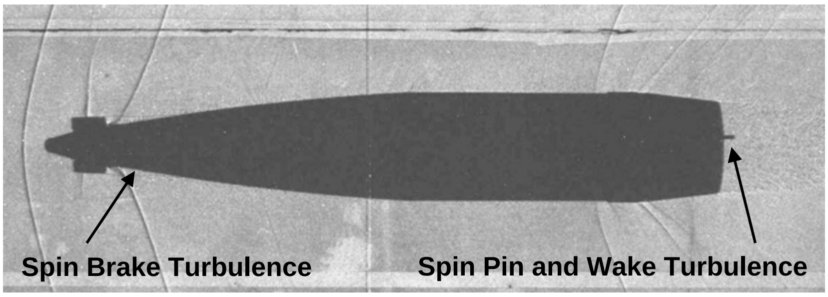

Figure 6. Spin Brake Shadowgraph

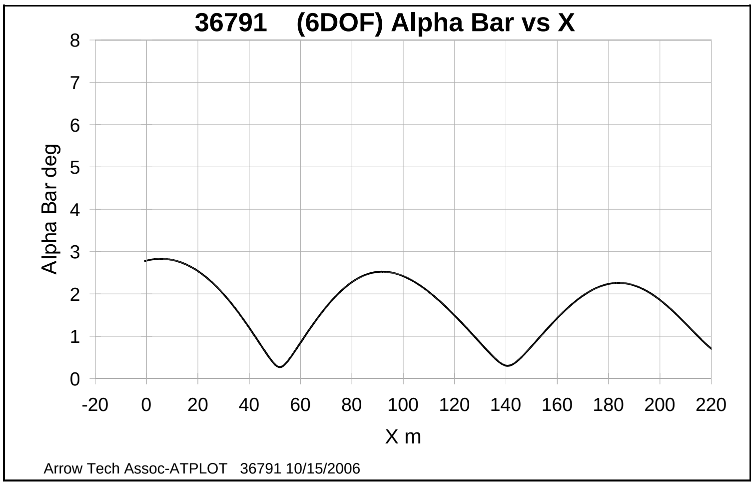

Figure 7. Spark Range, Damped Motion Plot

WIND TUNNEL AND SPARK RANGE COMPARISON

It is essential for the CCF concept to keep the projectile dynamically stable after deployment of the different brakes. From the beginning of the program, it was clear that the spin brake design was going to be the most challenging. Fins on a spinning body are usually a source of Magnus moments, and a thorough understanding of how to control the Magnus moment is important to CCF reliability. The BAE Systems approach was to use both wind tunnel testing with spinning model and spark range testing because it is more convenient to quickly test several spin brake configurations at all the relevant Mach numbers in the wind tunnel. The most promising candidates are then tested in the spark range to validate and calibrate the wind tunnel data and to obtain pitch damping that is a critical coefficient for the dynamic stability. Of course, all the other coefficients that are needed for the aerodynamic data base were also measured. Some results will be described here in order to show how wind tunnel and spark range data compare to each other. The configurations are labelled: B = Body Alone, BF5b = Body with F5b spin brake and BF6a = Body with F6a spin brake. Figure 8 and figure 9 (left) show Magnus moment, C_{np}. There is a slight difference in Mach between wind tunnel (1.15) and spark range (1.1), but the comparison effect is small. For the body alone, the agreement is very good between the two experimental methods. With spin brakes, the Magnus moment becomes more negative, especially for F5b that has the larger span. At small angles of attack, the agreement between wind tunnel and spark range is excellent. For higher angles, the data starts to deviate. This might be due to thicker fins for the wind tunnel model.

The roll damping moment, C_{lp}, was measured in the wind tunnel by spinning the model at a constant spin rate (figure 9 [right]). The rolling moment that is sensed by the balance can then be transformed to roll damping by dividing by the dimensionless spin rate. Figure 10 shows normal force and pitching moment coefficient derivatives for body alone and body with F6a spin brake. The absolute magnitudes from the wind tunnel vary slightly compared to the spark range data values, but the spin brake delta effect is clearly captured.

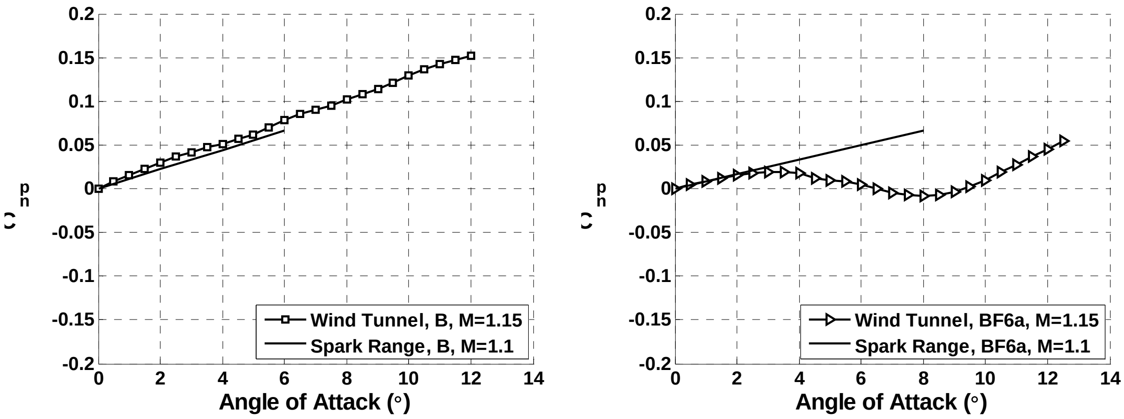

Figure 8. Magnus moment coefficient versus angle of attack. Wind tunnel data at 55,000 rpm.

CONCLUSIONS AND PLANS

The approach of testing carefully selected configurations in the wind tunnel at relevant ranges in Mach, angles of attack and spin rates and then validating and calibrating the data at key Mach numbers with accurate full scale, spark range tests has proven to be very successful.

Ongoing Computational Fluid Dynamics (CFD) analysis for spinning rounds will be incorporated with experimental results to further understand Magnus effects and define performance improvements.

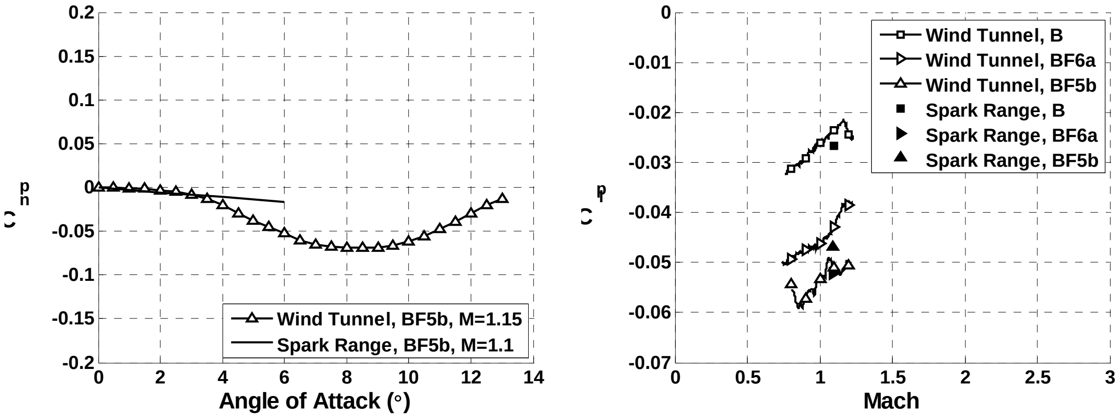

Figure 9. Magnus moment coefficient versus angle of attack (left) and roll damping coefficient versus Mach (right). Wind tunnel data at 55,000 rpm.

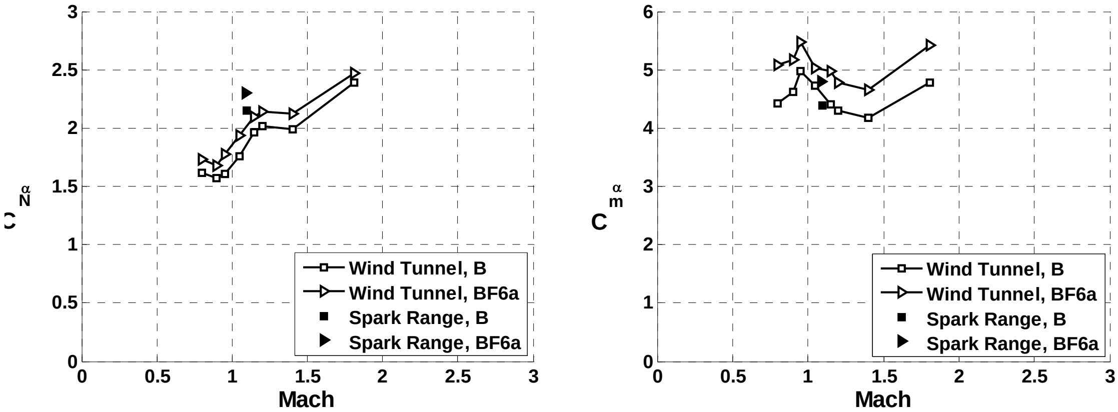

Figure 10. Normal force coefficient derivative (left) and pitching moment coefficient derivative (right) versus Mach for body alone and body with spin brake F6a. Wind tunnel data at 55,000 rpm.

REFERENCES

[1] Vaughn, H.R., “A Detailed Development of the Tricyclic Theory”, Sandia Lab Report SC-M-67-2933, (1968)

[2] Fischer, M.A., and Hathaway, W.H., “ARFDAS Users Manual”, AFATL-TR-88-48, Air Force Armament Laboratory, Eglin AFB, FL, (November 1988)