FREE FLIGHT AND INSTRUMENTED FLIGHT TECHNIQUES TO EXTRACT AERODYNAMIC STABILITY DERIVATIVES

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1. Introduction

Thirty five years ago Whyte, Jeung, and Bradley (*1*) wrote, "In free flight studies, the main task is to determine from observations of a missile's motion the values of the aerodynamic coefficients appearing in the differential equations describing that motion." That task is no different today. What have changed in the interim and continue to change are both the ability to make observations of aerial motions and the methodologies employed to determine aerodynamic coefficients. Advances in computers and computational methods have enabled the development of iterative parameter optimization techniques for non-linear coefficient estimation. At the same time, the commercial sector microelectronics revolution continues to introduce ever smaller and more capable sensors, processors, transmitters, and other components useful for obtaining on-board airframe state measurements.

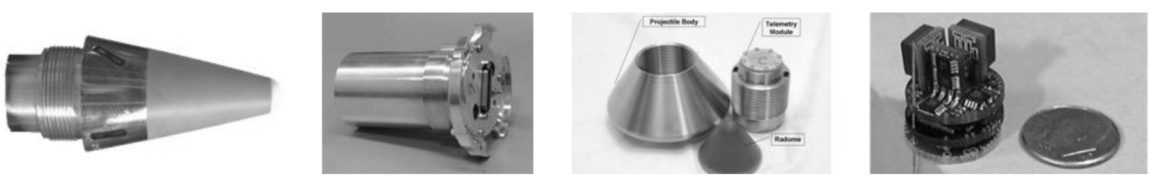
The Army Research Laboratory (ARL) and its predecessor the Ballistics Research Laboratory (BRL) has developed and employed custom telemetry (TM) systems in the measurement of in-flight projectile states for the past 40 years. These data complement the wind tunnel and enclosed range data traditionally employed for aerodynamic characterization. In an early effort employing TM data, yawsonde measurements were combined with ground radar velocity measurements and processed with Arrow Tech Associates' aerodynamic prediction codes to determine stability characteristics and to obtain certain aerodynamic force and moment coefficients (*2*). Next, ARL and Arrow Tech successfully applied these techniques to a 2.75-inch rocket to determine drag, static moment, and roll moment coefficients (*3,4*). By this time, the on-board instrumentation included a large array of sensors that, combined with novel data measurement techniques, allowed the body forces and body rates to be calculated accurately from launch through impact (*5*). Recently, ARL has partnered with Arrow Tech Associates to develop a custom software program to use the TM data, along with other information available, to calculate the aerodynamic coefficients of a projectile from measured flight data (*6*). This software code, Extending Telemetry Reduction to Aerodynamic Coefficients and Trajectory Reconstruction (EXTRACTR), imports the sensor data, meteorological (MET) data, radar data, and projectile physical properties to process, through an iterative algorithm, a solution for the aerodynamic coefficients which would have caused the measured flight response. The code attempts to fit the measured translational and rotational sensor data to the six-degree-of-freedom (6-DOF) equations of motion with the use of the maximum likelihood method and least squares and reaches an acceptable solution for a given aerodynamic coefficient (usually within three or four iterations).

In this paper, the projectile data acquisition and subsequent EXTRACTR results for several flight experiments of medium and large caliber projectiles and a scaled Apollo space capsule simulator will be described.

2. Obtaining in-flight state data

Ground-based instrumentation (e.g. pressure gauges, radars, yaw cards, and photographic equipment) commonly used at proving grounds and test facilities to measure and observe ballistic phenomena, have limited capabilities in characterizing what is happening on-board the projectile. Cards and photos provide only a small number of discrete data points along a trajectory. Radars can provide position, velocity, and spin measurements but do not give accurate projectile orientation information. On-board, recorder- or telemetry-based, measurement systems are used to obtain continuous in-bore and in-flight aeroballistic data resulting from the complex projectile dynamics of launch and flight.

One such system, the Aeroballistic Diagnostic Fuze (DFuze) is a patented instrumentation system (US#6349652), developed at the Advanced Munitions Concepts Branch (AMCB), Weapons Materials Research Directorate (WMRD), U.S. Army Research Laboratory (ARL). This system is a technological advancement of the yawsonde developed in the early 1970's by Clay (*7*) and Mermagen and Clay (*8*). It is packaged in a North Atlantic Treaty Organization (NATO) compatible artillery fuze and contains g-qualified miniature sensors, microelectronics, on-board data acquisition, a power supply, and telemetry components necessary to obtain and transmit the desired measurements. The DFuze will be described as an exemplar of on-board measurement systems in section 3.1. However, custom designs of measurement systems employing these components are routinely made at ARL to instrument all manner of projectiles with systems packaged in different shapes, installed at different locations, equipped with different sensors, etc to satisfy particular requirements and to meet particular test objectives. Figure 1 shows the NATO standard DFuze, two other TM system examples, and an on-board recorder system for a small caliber projectile.



a) DFuze b) Mid-body TM c) Apollo model TM d) Sensors & recorder

Figure 1. Projectile state measurement systems

3. EXTRACTR Demonstration Experiment

In December 2003, a firing program was conducted by ARL and Arrow Tech to demonstrate and further develop the EXTRACTR software. A controlled experiment was designed to obtain an in-flight data set using the DFuze instrumentation system for a projectile with well known aerodynamics. These data were used to 1) validate the EXTRACTR parameter identification analysis for matching the 6-DOF motion to the