Ballistic Range Determination of Nonlinear Dynamic Stability Parameters

by

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Introduction

The successful determination of nonlinear dynamic stability derivatives from ballistic range trajectories requires attention to many details of aeroballistics range technology. This includes knowledge of the facilities and the accuracy of the trajectory information, the trajectory data analysis process, the strong interdependence of the aerodynamic parameters, and the math modeling of the nonlinear aerodynamic coefficients. In the following material we will first review the elements of ballistic range testing, including facilities and model and sabot design. Second, we will consider the data acquisition equipment and calibration. Third, we will lay out the approach for obtaining aerodynamic parameters from trajectory data, including the information content required to obtain accurate nonlinear aerodynamic parameters, the importance of the interaction of the aerodynamic parameters, and the basic strategies and elements of the nonlinear parameter identification process. Fourth, a discussion of the elements that go into aerodynamic math modeling will be presented. Fifth, extensions of these ideas to full six-degrees-of-freedom data analysis with emphasis on dynamic stability parameters will be presented. Finally we will present an example of recent results and some concluding remarks.

Before getting to the heart of the matter, a brief history of aeroballistics ranges will set the timeline for the development of ballistic range aerodynamic methodology. Although the history of ballistics is as old as the history of guns and gun powder, not to mention the development of spears and bows and arrows, the modern era of aeroballistics range technology is often attributed to Alex Charters and began around 1940 when he was with the Army Ballistic Research Laboratory. Linear aerodynamic analysis for bodies with small mass and aerodynamic asymmetries started around 1953 with the work of Nicolaides (Ref. 1). Full nonlinear aerodynamic analysis of trajectory data using polynomial representations of the aerodynamics started with the work of Chapman and Kirk (Ref. 2) in 1970. Since that time many of the planetary probes were found to have dynamic stability parameters that were very nonlinear, particularly in angle of attack. Non-polynomial math modeling of these parameters started in the 1990's with the work of Arrow Tech Associates using a form function and the work of AerospaceComputing, Inc. using Gaussian functions.

Ballistic ranges have proven to be very versatile and are being used for flow field studies, such as shock shapes and boundary layer characteristics, aerodynamic data, which will be the focus of this paper, and impact testing. They have also been used to measure heat transfer at very high speeds as well as gas cap and wake radiation and ablation. For those interested in a more complete discussion of ballistic range technology, please see Ref. 3. Although this reference is fairly old, it still contains the essential information regarding various elements of ballistic range testing.

Ballistic range trajectory analysis is reasonably complex; as a result it is often poorly understood and underappreciated. For that reason this paper will review all aspects of ballistic range testing and trajectory analysis with an emphasis on nonlinear dynamic stability parameter determination.

Ballistic Ranges

Several aspects of ballistic range testing will be described briefly. These include range facilities, launchers and their important characteristics, and model and sabot design issues. Two different types of facilities will be used to illustrate these features: a short, pressure vessel facility, the Hypervelocity Free-Flight Aerodynamic Facility (HFFAF) at NASA Ames Research Center, and a long, one atmosphere facility, the Aeroballistic Research Facility (ARF) located at the US Air Force Research Laboratory at Eglin Air Force Base in Florida.

Range Facilities and Launchers

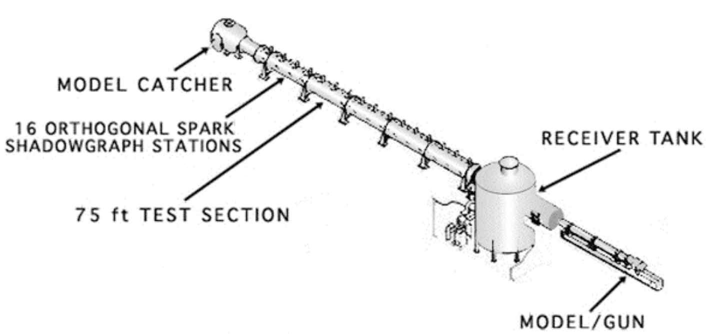
There are only a half a dozen or so active ballistic facilities that are capable of determining nonlinear dynamic stability coefficients. These are listed in Table I.

Table I. Ballistic Facilities

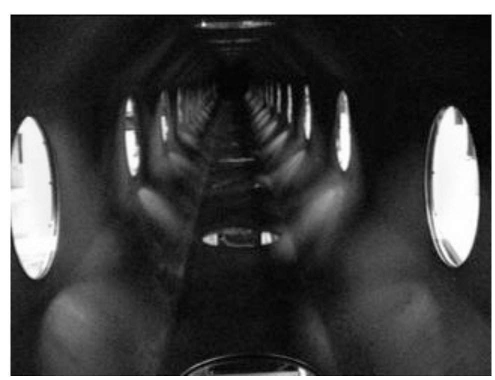
Facility	Location	Unique Characteristics
HFFAF	Ames Research Center	Pressurized, Hypervelocity
GDF	Ames Research Center	High Speed LED Cameras
ARF	Elgin Air Force Base	Long
Transonic Facility	Army Research Laboratory	Long, Large Guns
Aerodynamic Facility	Army Research Laboratory	Good Optics
DRDC	Valcartier, Canada	Long, Large Guns

These aeroballistic facilities are composed of several elements – the test section, launcher, blast chamber/dump tank and sabot stripper, and an impact/model catcher area. Each of these areas will be described briefly for the Hypervelocity Free Flight Aerodynamic Facility and the Aeroballistic Research Facility.

The Hypervelocity Free Flight Aerodynamic Facility (HFFAF): This facility, located at NASA Ames Research Center, is the only active ballistic range capable of aerodynamic testing at pressures other than sea level atmospheric pressure and in gases other than air (Ref. 3). A sketch of this facility is shown in Fig. 1a. It is composed of a 23-meter long octagonal cross section test section (approximately 3.3 meters across) with 16 orthogonal spark shadowgraph stations, a receiver tank (blast tank), a model catcher, and a launcher. A photograph of the inside of the test section is shown in Fig. 1b. The test section, model catcher, and blast tank comprise a vacuum tank that can be evacuated to 1 mm Hg and is suitable for testing in gases other than air.



a) Sketch of facility



b) Interior of the test section

Figure 1. The Hypervelocity Free Flight Aerodynamic Facility

Three types of launchers are available for use in this facility: powder gas, pressurized gas, and 2-stage light gas guns. These and their characteristics are listed in Table II.

Table II. HFFAF Launcher Types and Characteristics

Launcher Type	Barrel Diameters	Velocities
Powder Gas	12.5 to 57 mm	0.2 to 1.5 km/sec
Pressurized Gas	25 mm	0.1 to 0.3 km/sec
2-Stage Light Gas	12.5 to 37 mm	1 to 8 km/sec

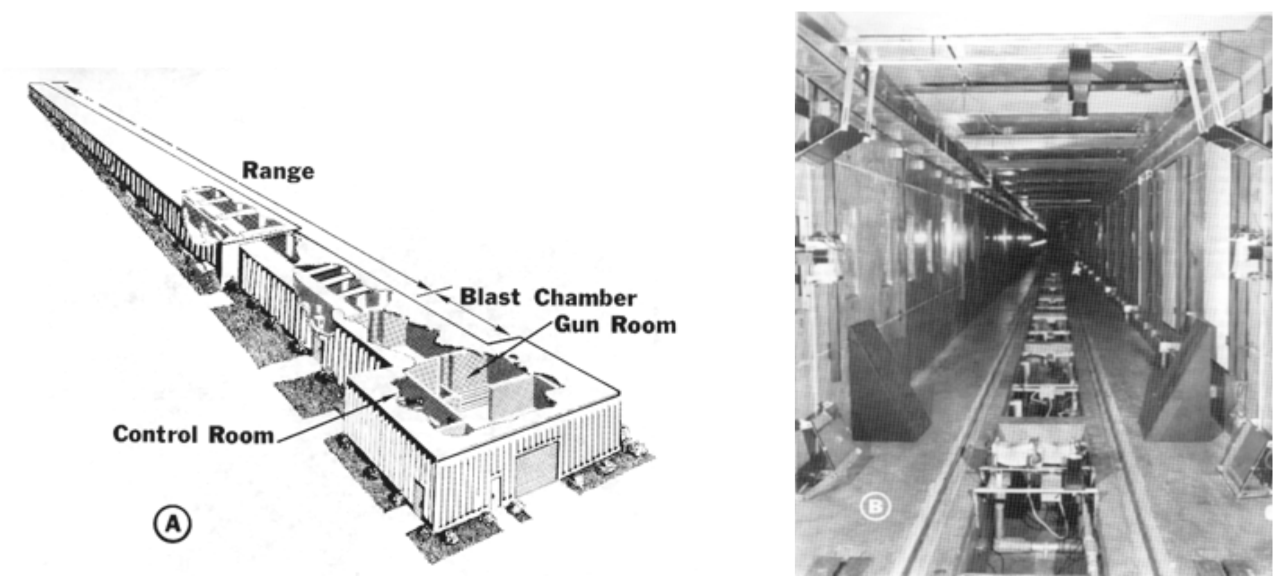
The Aerodynamic Research Facility (ARF): This facility located at Eglin Air Force Base is one of several one atmosphere ballistic facilities that can perform nonlinear aerodynamic testing. A sketch of this facility is shown in Fig. 2a and a photograph of the interior is shown in Fig 2b. This range has the same basic elements as the HFFAF. The test section is 200 meters in length and 5 to 8 meters square in cross section. It is capable of testing only at atmospheric pressure, and it has 50 orthogonal conical light shadowgraph stations. Additional details for this facility can be found in Refs. 4 and 5.

The types of launchers available at the ARF are powder gas guns and a 2-stage light gas gun. Their characteristics are given in Table III.

Table III. ARF Launcher Types and Characteristics

Launcher Type	Barrel Diameters	Velocities
Powder Gas	12.5 to 57 mm	0.2 to 1.5 km/sec
2-Stage Light Gas	12.5 to 37 mm	1 to 8 km/sec

Ballistic Range Characteristics: Ballistic ranges have some important characteristics that make them invaluable for aerodynamic testing, particularly for dynamic stability parameters. First there are no sting effects and minimal wall effects. The absence of a sting could prove critical when investigating the dynamic stability coefficients of blunt bodies. It is well recognized (Ref. 6) that, for blunt bodies, the



a) Sketch of the facility **b) Photograph of the interior**

Figure 2. The Aeroballistic Research Facility at Eglin Air Force Base