Ph.D. DISSERTATION DEFENSE

Candidate: Christopher Houthuysen
Degree: Doctor of Philosophy
School/Department: Charles V. Schaefer, Jr. School of Engineering and Science / Mechanical Engineering
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Title: A Methodology for Determining the Burn Rates of Complex Solid Gun Propellants through Closed Bomb Simulation

Chairperson: Dr. Nicholaus Parziale, Department of Mechanical Engineering, School of Engineering and Science

Committee Members: Dr. Hamid Hadim, Department of Mechanical Engineering, School of Engineering and Science
Dr. Jason Rabinovitch, Department of Mechanical Engineering, School of Engineering and Science
Dr. Tsan-Liang Su, Department of Civil, Environmental and Ocean Engineering, School of Engineering and Science
Dr. Donald Carlucci, Senior Research Scientist at DEVCOM-Armaments Center, and Department of Mechanical Engineering, School of Engineering and Science
Mr. Elbert Caravaca, Chief Scientist for the Propulsion Technology and Prototyping Division at DEVCOM-Armaments Center

ABSTRACT

The closed bomb vessel is a prominent means of characterizing the combustion behavior of solid gun propellants prior to gun launch. This sub-scale test allows the propellant to burn in a confined, constant volume environment, such that the resulting pressure-time trace can be collected via a pressure transducer. Historically, analytical and computational methods have been developed to determine the burn rates of gun propellants from these pressure-time traces, which is a closure relationship used to quantify the transfer of mass, momentum, and energy due to phase change. However, no procedure exists to determine the burn rates of gun propellants with spatially variable thermochemistry and/or ignition criteria on each surface. As a result of this discrepancy, intrinsic error is introduced in downstream interior ballistic calculations, which can lead to catastrophic failure of a given weapon system due to an over-pressurization event, or unsatisfactory performance metrics.

To address the aforementioned capability gap, a constrained, multivariate optimization algorithm has been developed for a well-stirred reactor model representation of the closed bomb. This model assumes grain surface decoupling such that grain surfaces can independently react in the simulation. Two peer-reviewed Joint Army Navy NASA Air Force (JANNAF) articles have been produced as a result of this work. The first paper documents the initial development and verification of a two-phase, reacting, compressible-granular flow solver developed in OpenFOAM, which is referred to as iBallistix. The second paper documents the initial development and verification of a closed bomb data reduction analysis using the aforementioned constrained, multivariate optimization algorithm. In both papers, idealized simulations were used as verification metrics.

In this work, the proposed closed bomb data reduction analysis as well as the legacy Excel-based Closed Bomb (XLCB) program are used to determine the burn rates of homogeneous, layered, and deterred propellants from experimental data. These burn rates are then used in the iBallistix solver to generate predicted pressure-time curves which are compared to the experimental pressure-time traces. As shown for the four test cases analyzed, the maximum mean error between the predicted and experimental pressure-time curves was 6.77% for the burn rates determined with the new data reduction analysis, and 23.81% for the burn rates determined with XLCB. This result clearly demonstrates that the burn rates are sensitive to proper characterization of the spatial thermochemical profile, and legacy approaches inaccurately characterize the combustion behavior of thermochemically complex solid propellants. Additionally, the results herein demonstrate that the well-stirred reactor approximation is adequate for determining the burn rates of complex solid gun propellants in closed vessels. Furthermore, burn rates determined with the proposed closed bomb data reduction analysis can be used in downstream interior ballistic models to improve the fidelity of the predicted results.