Flame Spreading in Granular Propellant: Comparison of Theory to Experiments

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Abstract

HYDRODYNAMIC aspects of the gun environment have been central to the theme of interior ballistics theory for over a century. Decoupled from a nontrivial description of propellant ignition and flamespread, the problem has been amenable to numerical solution for more than a decade. More recently, however, the occurrence of several catastrophic gun ammunition malfunctions has been linked to ignition-induced two-phase flow dynamics. A number of approaches have been pursued intensely to provide a solution to the combined two-phase flow, ignition and flamespread interior ballistics problem. A detailed review of four such modeling efforts has been provided by Kuo.[1] Work reported herein relates to efforts aimed at reconciling experimental data with numerical predictions obtained using a computer code developed by Gough.[2] Manipulation of poorly known input parameters or statements of constitutive physics was performed both to identify those parameters that most affect the calculated results and to draw useful inferences about the physical processes themselves. Considerable success has been demonstrated in attempts to simulate the performance of a Navy 5-in./54-caliber case gun; however, similar agreement with data obtained in an Army 155-mm howitzer was unattainable without substantial modifications to available input data. An attempt has been made to provide a physically motivated explanation for this difference in the level of agreement for the two configurations.

Contents

The Gough model, also known as the NOVA code, is a two-phase flow treatment of the gun interior ballistic cycle, formulated under an assumption of quasi-one-dimensional flow. Gas and particles are treated as interpenetrating media, with conservation equations derived using formal averaging techniques. Constitutive laws include a covolume equation of state for the gas and an incompressible solid phase. Compaction of an aggregate of particles is allowed, with intergranular stress represented as a function of propellant bed porosity. Interphase drag and heat transfer are represented by reference to empirical correlations for fixed and fluidized beds. Functioning of the igniter is included by providing as input an experimentally determined mass injection rate as a function of position and time. Grain temperature follows from the convective heat-transfer correlation and unsteady heat conduction in the solid, with ignition based on a surface temperature criterion. Propellant combustion is then assumed to follow a typical, pressure-dependent power law. Previous efforts to model a 76-mm gun had demonstrated the importance of charge configuration to the formation of pressure waves.[3] As a result, the code was modified to include a lumped parameter treatment of the mechanical response of any filler elements present. The reader is directed to the references for a more complete discussion of the code, including detailed descriptions of the numerical solution techniques.

Clearly, the adequacy of a one-dimensional representation is questionable, and the impact of limitations imposed by such

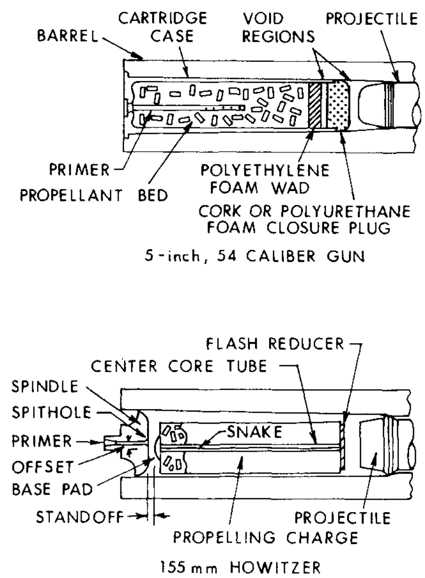

Fig. 1 Schematic representation of two test configurations.

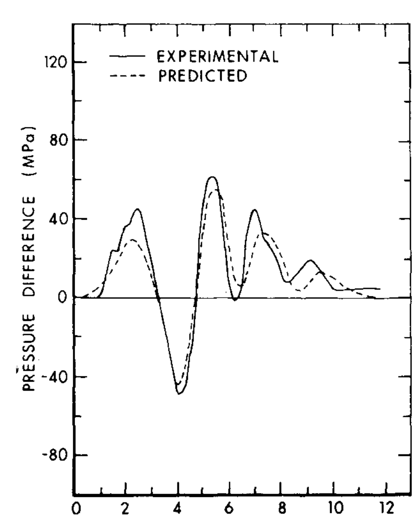

Fig. 2 Experimental and predicted pressure-difference profiles for the 5-in. gun.

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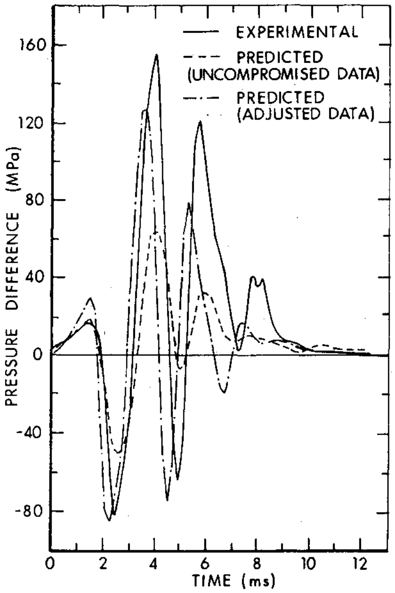

Fig. 3 Experimental and predicted pressure-difference profiles for the 155-mm howitzer.

a description must be viewed as one of the major concerns of this study. A comparative schematic representation of two configurations for which numerical simulations were attempted is presented in Fig. 1. No radial ullage is present in the Navy 5-in./54-caliber gun, although compactible packaging elements separate the propellant bed from the projectile base. Also present is a high-pressure bayonet primer, radial discharge from which belies the one-dimensional representation. The 155-mm howitzer configuration is complicated by a nonaxisymmetric distribution of radial ullage exterior to the propellant bag. A low-pressure center-core ignition system is present, although it is believed to have malfunctioned in the particular firing simulated.

In attempts to simulate the 5-in. gun environment, all input data except projectile engraving pressures were determined independently. Typical procedures for obtaining such data have been summarized previously.[4] An abundance of output information is available from each calculation for comparison to experiment; however, a single diagnostic procedure involving both spatial and temporal contributions has been selected for presentation here. If one differences pressure-time data taken at two longitudinal positions along the gun chamber (preferably the extreme ends), a graphic portrayal of the evolution of the pressure wave is obtained. Experimental results also have shown flame-front propagation to be virtually coincidental with the initial passage of this pressure wave in medium-caliber guns.[5] A comparison of predicted and experimental pressure-difference data (breech pressure minus chamber mouth pressure) for the 5-in. gun, presented in Fig. 2, exhibits excellent qualitative and satisfying quantitative agreement.

An attempt to model the 155-mm howitzer performance provided less satisfactory results. As shown in Fig. 3, only by arbitrary increases in the calculated interphase drag and measured propellant burning rates could reasonable agreement be obtained. A qualitative explanation for the required increase in the drag level can be attributed to the one-dimensionality of the code. The initial bed porosity is calculated based on a full-bore distribution of the propellant, whereas the actual charge is somewhat smaller in diameter. This procedure leads to an overestimate of initial porosity and a corresponding underestimate of interphase drag (at least prior to bag rupture). The necessity of also increasing the burning rate suggests that transient burning rate excursions or even grain fracture may be augmenting gas production rates in high-wave-dynamics environments.

References

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