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Author: Mr. Connor MacRobbie
University of Waterloo, Canada, cjmacrob@uwaterloo.ca

Dr. Jean-Pierre Hickey
University of Waterloo, Canada, jean-pierre.hickey@uwaterloo.ca
Mr. Haroon B. Oqab
Columbiad Launch Services Inc., Canada, haroon@columbiad.ca
Mr. George B. Dietrich
Space Canada Corporation, Canada, george@spacecanada.org
Dr. John Wen
University of Waterloo, Canada, john.wen@uwaterloo.ca
Mr. Anqi Wang
University of Waterloo, Canada, anqi.wang2@uwaterloo.ca

FRAMEWORK FOR THE DESIGN OF SOLID PROPELLANTS VIA FUNCTIONALLY GRADED, ADDITIVELY MANUFACTURED NANOENERGETIC MATERIALS

Abstract

The emergence of additively manufactured energetic materials is enabling novel design considerations for functionally-graded solid and hybrid propulsion systems. Although multi-layer solid propellants have been developed, the recent advent of a controllable manufacturing processes allows for a high-level of customization of the propellants that can be constructed to meet specific performance characteristics.

Currently, the propellant grain geometry and the addition of specific additives are the primary design parameters that are tuned to match the desired performance characteristics of a given engine. Despite many attempts at optimizing internal ballistics of solid motors, the time varying thrust characteristics are inevitable due to the highly-nonlinear effects in the regression rates, ablative losses, and combustion chamber pressure variability. The current design space is also constrained by the limitations in the manufacturability of geometrically complex fuel grains.

Recent advances in the development of a printed graphene oxide-based binder containing nanothermite fuels provides new opportunities to develop a high-level of control of the reactive properties in solid and hybrid engines. As the particle loading of the direct ink printed energetic material can be tuned, a functional grading in the printed product can be achieved in the layer-by-layer deposition of the nanoenergetic-laden ink. The combustion properties of the reduced graphene oxide (rGO)/Al/Bi_2O_3 nanothermite aerogel can be characterized over a wide range of nanothermite particle loading, from about 80% to 95% (per unit mass). As expected, the wide range of particle loading results in highly-variable regression rates and heat release that can be leveraged for the tailored design of these engines.

This novel direct ink printed process opens a new parameter space for the design of solid propellants. The present contribution reports on an analytical framework to match the engine performance curves to the functionally-graded combustion characteristics of an additively-manufactured solid or hybrid engine. The work will integrate the experimental results on (rGO)/Al/Bi_2O_3 nanothermite aerogel combustion characteristics but focus primarily on the optimization, via an inverse formulation, of the design of a functionally-graded, cylindrical grain solid propellant. As the additive manufacturing process permits a high-level of customization based on the particle loading, a wide design space can be explored for the

simplest geometric fuel grain. The present optimization framework can explored to develop new solid propellant engines to meet complex performance characteristics of future missions.