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A Computational Approach to Optimizing Internal Ballistics of Star Grain Geometries in Neutral Burning Solid Rocket Motor

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Extended Abstract

The core of the design of solid rocket motors (SRMs) is in the optimization of its internal ballistics to achieve mission-specific performance objectives, such as desired thrust and burn time through efficient combustion. This paper introduces a computational tool designed to automate the optimization of star grain geometries in SRMs, focusing primarily on ballistic performance.

The process starts by employing the Quasi-steady 0D flow model (lumped model) [2] to compute the required grain exposed burning surface area by taking into consideration the SRM operating conditions and propellant properties [1]. Then the computational tool employs the unsteady 0D flow model [2] to simulate the internal ballistics and combustion behavior of solid rocket motors (SRMs). This simplified approach is chosen for its balance between computational efficiency and accuracy, enabling rapid iterations of design parameters. The model incorporates the effects of chamber volume on chamber pressure and, consequently, thrust [2]. The rocket motor free volume is estimated for each grain design based on its geometry to ensure accurate representation of ballistic characteristics.

Since the model requires a reliable method to calculate the grain's exposed burning surface area, the star grain burnback equations are employed and verified against results from the shape-independent level set method [2] [3]. The verification results showed an average match rate of 99.25%, indicating a high degree of consistency between the models. While the level set method has its limitations, it serves as a reliable standard for ensuring the accuracy of the derived equations. The tool further compares simulation results against user-specified performance requirements, providing feedback to guide optimization and ensure that key factors such as combustion efficiency, chamber pressure, and grain performance is met. Additionally, it calculates nozzle parameters for every grain and operating pressure combination, ensuring seamless integration between grain design and nozzle performance to achieve optimal motor behavior.

The optimization framework compares the average thrust of the near neutral primary burn phases (Zones 1 to 3 of the Star Geometry), in addition to minimizing both the overall grain weight and the duration of the sliver phase (Zone 4) [4]. By iteratively evaluating grain geometries against these criteria, the tool identifies designs that optimize thrust stability and burn efficiency across the entire combustion process. The current unoptimized model can evaluate 1 million designs in just 370 seconds and generate designs that meet the requirement with an accuracy of 98.6%, considering the effect of the star grain slivers on the required neutral profile.

To enhance accessibility, the tool is integrated into a graphical user interface (GUI) that streamlines the design process. The GUI allows users to input mission-specific parameters such as desired thrust, burn time, and motor caliber. It provides real-time feedback on the ballistic performance of candidate designs and facilitates the exploration of multiple design options without requiring extensive technical expertise. This approach significantly reduces the reliance on trial-and-error methods and accelerates the iterative design cycle.

In summary, this paper describes a methodology of automating the internal ballistics optimization of star grain geometries in SRMs, offering a streamlined, efficient, and accurate approach to designing motors that meet specific mission requirements. By focusing on the optimization of key performance metrics, the proposed tool provides a valuable resource for SRM designers, to accelerate development and improve the overall design process.

References

[1] E. Fleeman, "Missile Design and System Engineering," in *Missile design and system engineering*, Washington, DC:

American Institute of Aeronautics and Astronautics, Inc., 2012, pp. 197–203.

[2] A. Pons Lorente, “Study of Grain Burnback and Performance of Solid Rocket Motors,” Ph.D. dissertation, Dept. Heat Engine, Universitat Politècnica de Catalunya, 2013.

[3] W. Sullwald, “Grain Regression Analysis,” M.Sc Dessertation, Dept. of Mathematical Sciences, University of Stellenbosch, South Africa, 2014.

[4] A. Lefebvre, “Neutral star Copy.pdf.” Polytechnique Montreal, Canada, 2000.