Ballistic Analysis and Preliminary Design of Launch Vehicle Solid Boosters

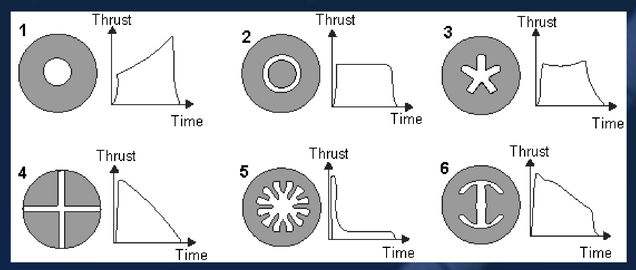
Author: John Ford **Institution: Embry-Riddle Aeronautical University** **Mentor: Jason Campbell** **ER-51**

Abstract

Internal Ballistic Analysis predicts motor performance through the time history of motor firing and concerns itself with the internal hot gas flowfield generated in the combustion chamber. Derived from 1-D ballistics prediction are thrust-time plots called traces used to determine motor performance. Different motor parameters such as propellant mass, burn time, and a pseudotrace, a trace which reflects optimum performance desired for the motor, was determined and provided by the EV department and sent to ER for ballistic analysis. Using known characteristics of previous systems, components, and materials, a preliminary design for the motor was set up. Ballistic analysis was performed through SPP, Solid Performance Program, in order to achieve a suitable design with a trace that closely matched the pseudotrace. Once a suitable trace was found the parameters of the modified motor were run through POST, Program to Optimize Simulated Trajectories, for a final launch vehicle performance. If through POST the design was determined optimum then the motor could be considered for future launch vehicle designs.

Introduction

The propellant for solid rocket motors consists of a mixed casting composed of fuel, oxidizer, and a polymer rubber binder. The grain has a hollow bore that allows the hot gas produced from the ignited propellant to travel down to the nozzle where it is converted from heat energy to kinetic energy through expansion to produce thrust. This can be expressed though the mass flow equations, $\dot{m}_{in} = \rho_p r_b A_b$ and $\dot{m}_{out} = \frac{p_c A_t}{c^*}$ and due to the conservation of mass, $\dot{m}_{in} = \dot{m}_{out}$. Since thrust and pressure is proportional to burn surface area, by creating a certain grain geometry that has varying surface area during burnback of the grain, thrust can be altered during firing. In the figure below, common grain geometries are shown with their respective thrust trace.



For space launch vehicles, a constant or neutral thrust is not practical due to certain constraints on structural integrity such as a period of maximum dynamic pressure called Max Q, thrust-to-weight ratios, and LOX Inlet Pressure. During Max Q, thrust must be reduced in order for the vehicle to remain structurally sound.

Methodology

- Understand and show working knowledge in SRM Performance and Design
- Get acquainted with SPP and POST programs
- Create a final preliminary design for consideration for future launch designs

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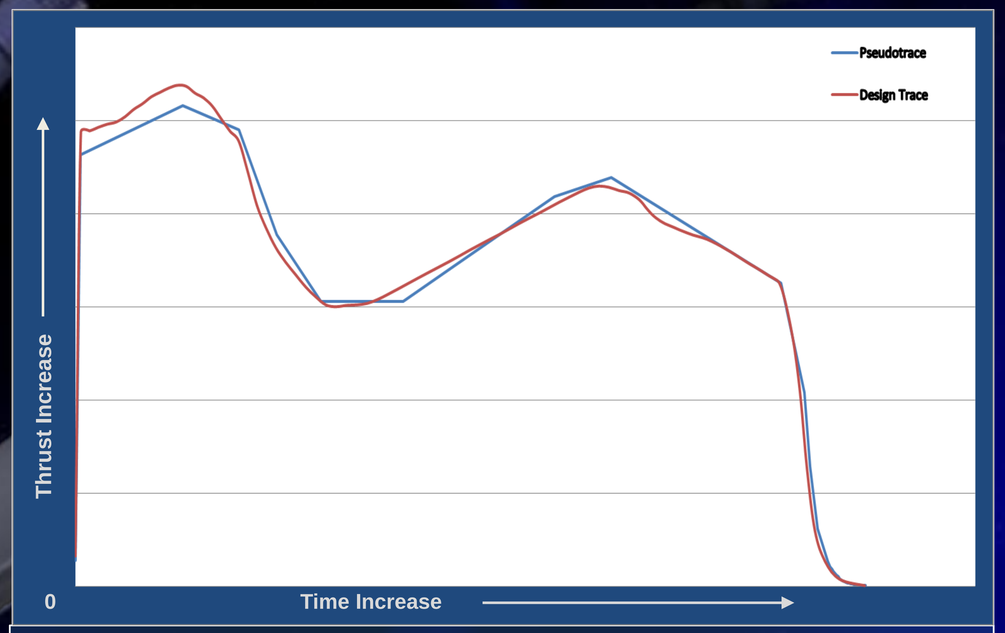
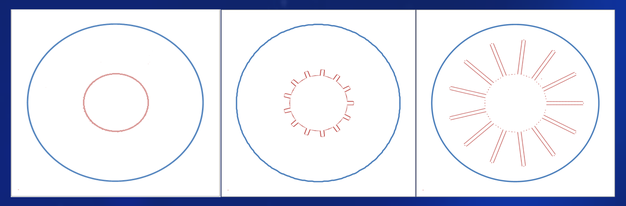


Design Methodology

The launch vehicle uses two five-segment SRMs with the center three segments of equal length, and fins in the two aft end segments. Below are some of the design parameters set up in SPP that were altered from the preliminary design:

- Number of fins and fin axial position
- Fin depth, length, and thickness
- Length of fin extensions
- Length and diameter of motor in order to match propellant mass
- Necessary adjustments for new motor length
- Inhibitors between each segment
- Web thickness changed to accommodate web burn time
- Impulse and Specific Impulse adjustment



In order for the preliminary design for the motors to be acceptable for further development, a check analysis for vehicle performance of this booster was necessary. POST was used to analyze the vehicle trajectory and performance using the resulting booster design. Booster performance was constrained by trajectory, max LOX inlet pressure (280-300 psi), maximum dynamic pressure (max=800 psf) and maximum acceleration (max = 4.0 g).

Results & Design Parameters

Number of Fins:	13	N/A	Specific Impulse	272 s	(Adjusted)
Propellant Length	1,712.2 in	N/A	Web Burn Time	109.95 s	99.99%
Propellant Mass	1,651,500 lbm	99.94%	LOX Inlet Pressure	299 psi	<300 psi
Total Impulse	450,000,000 lb*ft/s	99.97%	Max Dynamic Pressure	698 psf	<700 psf