Developmental Design & Ballistics Analysis of a Solid-Solid Fuel Torch (SFT) Rocket Motor

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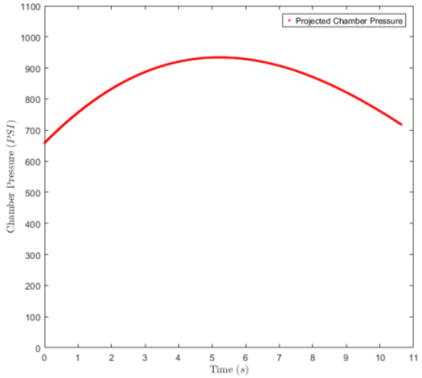
Key Performance Parameters (KPPs)

Design Constraints & Target Performance – Solid SFT	
11" Max Grain Dimensions:	8.000" OD, 34.0" Length (max)
Throat Diameter:	0.700 in
Average Chamber Pressure:	800 – 900 PSI
Target Burn Time:	Min & target 10.5 sec, max 12 sec
Propellant:	Aluminized HTPB Grain (13-20% Al), AP Oxidizer
Target Mass:	20.20 – 26.75 lbm

Motor Grain Design & Ballistics Analysis

From the targeted Key Performance Parameters (KPPs), various motor grain design configurations were traded for each motor throat material, which included center-perforated, end burner, conical, and bevel geometries with zero, one, or two inhibited motor grain faces. A lumped parameter regression model was used for this analysis.



Solid SFT Selected Grain Specifications	
Grain Size:	8.00" OD, 1.50" ID
Grain Length:	8.45"
Burn Rate:	0.32 in/s @ 1000 PSI
Burn Time:	10.64 s
Average Chamber Pressure:	850.9 PSI
Total Mass:	26.6 lbm (12.1 kg)

$$\dot{m}_{in} = \rho_F \dot{r}_b A_b \qquad \dot{m}_{out} = \frac{P_c A_t}{c^\star} \qquad I_{sp} = \frac{\int F dt}{\dot{m} g_0}$$

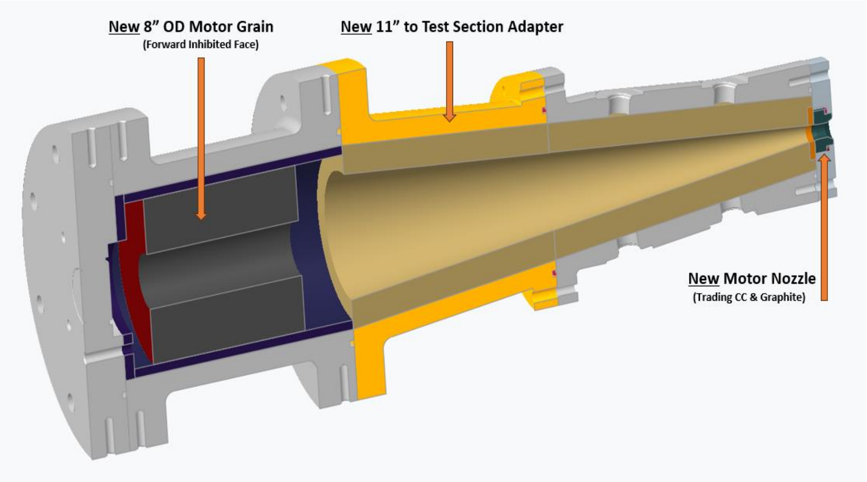
$$a = \frac{\dot{r}_{b,ref}}{P^n_{c,ref}} \qquad P_c = \left(\frac{a \rho_F A_b c^\star}{A_t}\right)^{\frac{1}{1-n}} \qquad F = C_F A_t P_c$$

Abstract

During the Space Shuttle program, NASA developed a Hybrid Solid Fuel Torch rocket motor test bed to conduct an extensive testing campaign on ablative insulation representative of a Solid Rocket Motor (SRM) environment. Following testing of this hybrid motor configuration, however, revealed unexpected slag plating and throat erosion, and further observations put into question if the hybrid motor was sufficient to replicate similar conditions representative of a Solid Rocket Motor environment suitable for insulation testing. With this, Solid-Solid Fuel Torch (Solid SFT) seeks to revitalize the program using existing 11" motor case hardware from the Hybrid Rocket Motor (HRM) program and test section hardware from the Hybrid Solid Fuel Torch (iSFT) testing to develop a fully solid test bed.

Following brief ballistics analysis, the original 5" motor grain size was deemed unsuitable due to not meeting the desired Key Performance Parameters (KPPs). As such, motor ballistics analysis was conducted using a Lumped Parameter Ballistics model with various motor configurations and geometries to select a new grain geometry that best fits the desired performance. Developmental design & analysis was also conducted to design a custom motor adapter and ablative nozzle to create a complete, integrated assembly for motor testing.

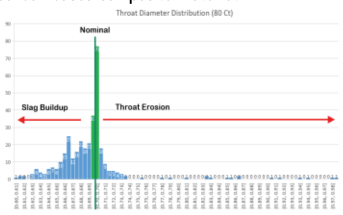
Solid SFT Rocket Motor - Integrated Assembly

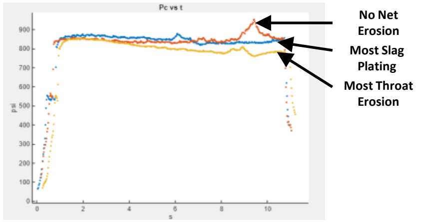


The complete Solid SFT rocket motor integrated assembly makes use of the existing 11" hybrid rocket motor case and Hybrid SFT test section hardware to form a cohesive solid rocket test motor.

Hybrid SFT Shortfalls

One of the significant shortfalls in the Hybrid Solid Fuel Torch (SFT) testing sequence was the presence of slag buildup and erosion for the Tungsten throat. Solid SFT seeks to address these concerns with an ablative nozzle material. Trade studies are being conducted to assess between a Graphite or Carbon-Carbon based composite material.



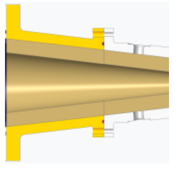


Motor Adapter Design

To make use of the 11" Hybrid motor case and original Hybrid SFT test section, an SAE 4340 Steel adapter was designed to connect the two sections.

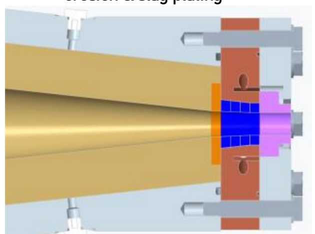
An O-ring groove was sized and added accordingly based on squeeze, gland fill, and other necessary sizing parameters from the Parker O-ring handbook.

Insulation can be separated into two distinct parts or installed as a single uniform piece as needed.



Nozzle Trade Analysis & Design

For previous Hybrid SFT testing, a water-cooled Tungsten nozzle was used which experienced significant erosion & slag plating



As an alternative, an ablative nozzle is being designed, with trade studies occurring between Graphite and a Carbon-Carbon composite nozzle.