



ProtoSShot-M Mark I Rocket Motor

Technical Specifications

Rev.2007/06/11

General information

This document specifies the chief requirements for the design and fabrication of the *ProtoSShot-M Mark I* rocket motor and associated static test requirements. This motor is being designed and manufactured in support of the *MiniSShot* project.

The basic concept of the *ProtoSShot-M Mark I* motor is similar to the earlier ¼ Scale BEM. The operation is “dual burn” in nature. The motor consists of two separate combustion chambers containing separate propellant charges. The charges fire sequentially, separated in time by a certain delay period, thus the term “dual-burn”. The two chambers are joined by a “mid bulkhead” which incorporates a pyrotechnic “delay plug”. This plug initially isolates the two chambers. During the first burn, the plug starts to combust and is fully consumed prior to completion of the delay period. The purpose of having two separate propellant charges with a delay between operation of each is to allow a rocket vehicle to coast between firings. This greatly increases the peak altitude in comparison to a single-burn, or conventional motor.

The primary goal of the *ProtoSShot-M Mark I* project is to provide a prototype motor that will form the basis of design of the flight vehicle motor for the *MiniSShot* project of the *SugarShot to Space* Program. If the manufacturing and static testing of the *ProtoSShot-M Mark I* motor is successful, the motor may be used (with any modifications as needed to meet *MiniSShot* requirements) as the *MiniSShot* flight motor.

The design concept of the *ProtoSShot-M Mark I* motor is shown in Figure 1 in comparison to the ¼ Scale BEM. The main differences relate to the size (scale) of the motor, and the intent of minimizing mass of the *ProtoSShot-M Mark I*, which is a requirement of the *MiniSShot* motor.

A listing of abbreviations and acronyms used in the document is provided in Appendix A. Illustrations of the *ProtoSShot-M Mark I* motor concepts, including terminology used, are shown in Appendix B. Table 1 provides thermal properties of selected metals, for reference.

Basic specifications

Motor casing

- 1.1 Casing diameter to be approximately 1/3 scale of the *eXtremeSShot* (full-scale) motor (275 mm).
- 1.2 Material to be fiberglass/epoxy composite tubing similar to the Ameron tubing being used for the SS-TEM and full scale-motor.
- 1.3 A suitable thermal liner to be used to protect casing inner surface.
- 1.4 The finished motor to be hydrostatically tested to $1.2 \times \text{MEOP}$. Only the 1st burn portion need be tested if the 2nd burn portion can be passed by similarity in design and fabrication.
- 1.5 Design SF= $1.5 \times \text{MEOP}$ minimum, based on burst pressure, determined from hydrostatic test specimen.

Closure attachments

- 2.1 Suitable machine screws to be used to secure the closures.
- 2.2 Radial pattern of machine screws to be determined using the *boltring.xls* spreadsheet developed for the SS-TEM.
- 2.3 Minimum $e/D = 4$.
- 2.4 Closure attachments to be sized to fail at no less than $1.8 \times \text{MEOP}$ and no more than $3 \times \text{MEOP}$.

Nozzle

- 3.1 Nozzle shall consist of a three-part assembly: Ring, Shell and Insert as shown in Figure 2. The mating flanges of the Ring and Shell components to be thermally isolated by a suitable heat resistant gasket.
- 3.2 Material for the Ring and Shell to be heat-resistant, low thermal conductivity material (ex. cast iron). For the Shell, mild steel is the preferred material. For the Ring, 300 series stainless steel is the preferred material. Fine grain graphite or similarly heat-resistant material to be used as a throat insert.
- 3.3 Screws used to secure nozzle Ring to Shell to be 300 series stainless steel, titanium alloy, or similar low thermal conductivity material.
- 3.4 Nozzle Ring to be isolated from direct exposure to combustion chamber heat by use of suitable thermal insulation.

- 3.5 Pressure sealing to be provided by one or more o-rings lubricated with silicone grease. O-rings to be protected from direct exposure of combustion gases by mastic putty or equivalent.
- 3.6 Throat diameter to be sized to provide for an MEOP of 1000 psi.
- 3.7 Throat inlet to be well-rounded to minimize flow losses.
- 3.8 Convergence half-angle to be 30° at the throat inlet; divergence half-angle to be constant 12°.
- 3.9 Expansion Ratio to be 12:1.
- 3.10 Nozzle to be fitted with a burst diaphragm. Burst pressure to 20% MEOP maximum, 10% MEOP minimum. Material fracture shall not produce any fragments.

Forward Bulkhead

- 4.1 Material to be aluminum alloy or other similar lightweight material.
- 4.2 Pressure tight sealing to be provided by one or more o-rings lubricated with silicone grease

Mid Bulkhead

- 5.1 Material to be steel or other similarly heat-resistant material. Aluminum may be used if its durability is clearly proven by static test.
- 5.2 Pressure tight sealing to be provided by one or more o-rings lubricated with silicone grease
- 5.3 Mid bulkhead to have a central port with a minimum diameter of no less than 75% chamber effective inner diameter (effective inner diameter takes into account insulation and grain inhibitor thicknesses).
- 5.4 Mid bulkhead flow surfaces to be lined with a suitable thermal insulation to minimize heat transfer to the bulkhead body.
- 5.5 Central port to be tapered or similarly provisioned for positive retention of the Delay Plug under 1st burn motor pressure loading..
- 5.6 Delay plug to be fabricated of RNX-73 formulation with a thickness to provide a nominal delay period of TBD seconds minimum; TBD seconds maximum.
- 5.7 Delay plug design to be proven by hydrostatic testing to 1.2 × MEOP minimum. A representative specimen may be used in lieu of actual plug. Tested plug to be of a thickness expected to be remaining after burnout of the 1st burn.

- 5.8 Mid-bulkhead to be fitted with a burst diaphragm. Burst pressure to 20% MEOP maximum, 10% MEOP minimum. Material fracture shall not produce any fragments.

Propellant Grain

- 6.1 Propellant to be KNSB.
- 6.2 Grain configuration to be BATES consisting of a total of 6 segments per chamber.
- 6.3 Propellant segments to have Lo/Do and Do/do ratios to provide for approximately neutral burn.
- 6.4 do/Dt to be 1.3 minimum.
- 6.5 Liner (inhibitor) to consist of dense cardboard tubing of 0.060 in. (1.5 mm) minimum thickness or similarly heat resistant, non-sagging, non-melting material.
- 6.6 Liners to be of length to provide for a minimum 3/8" (10 mm) spacing between adjacent propellant segment end faces. Ends of liners must be as squared as practical to ensure minimal combustion gas seepage and impingement upon casing thermal liner.
- 6.7 As a minimum, each segment to be painted on both ends with suitable Ignition Primer. Additional ignition aids such as combustible discs should be considered to help ensure rapid ignition of propellant end faces.
- 6.8 Segments may be cast directly into inhibitor liner. Liner interior must be coated prior to casting with melted sorbitol. A comprehensive "tap" test to be performed on all segments to ensure disbonding is no greater than 5% on any given segment, and no greater than 3% overall. Cyanoacrylate may be used, when practical, to repair disbonded areas.
- 6.9 Propellant density for any given segment must be 92% theoretical or greater.

Ignition

- 7.1 Ignition of both motor burns to be electrically initiated.
- 7.2 Both motor burns to be ignited by use of a short-burn duration pyrogen device.

Static testing

- 8.1 Motor thrust during both burn operations to be measured and recorded.

- 8.2 Thermal measurements should be taken of 1st burn casing and nozzle Ring. Recommended locations for casing measurements include the area just aft of the Mid Bulkhead, and the area where fins are to be attached.

General

- 9.1 Concerted effort shall be made to minimize mass of all components of the motor.
- 9.2 Preliminary design to be sketched or alternatively drawn in CAD with basic dimensions shown.
- 9.3 Preliminary design to be reviewed by the Project Manager prior to acceptance as final design.
- 9.4 Final design of the complete motor assembly and component parts to be drawn in CAD (any standard software may be used).
- 9.5 Proposed test apparatus and procedure to be reviewed by Project Manager prior to acceptance.

Appendix A

Abbreviations/acronyms

BATES	Ballistic Test and Evaluation System
Closure	Generic term for nozzle, mid bulkhead or forward bulkhead
do	Propellant grain segment initial core diameter
Do	Propellant grain segment outer diameter
Dt	Nozzle throat diameter
e/D	Edge distance ratio: e = distance from fastener hole center to casing edge; D = fastener hole diameter
ID	Inside Diameter
KNSB	Potassium Nitrate/Sorbitol propellant, of ratio 65/35, prepared by conventional "melt & cast" method.
Lo	Propellant grain segment initial length
MEOP	Maximum Expected Operating Pressure. MEOP=TBD psi (TBD Mpa).
RNX-73	Pyrotechnic composition based on Potassium Nitrate/Epoxy/Iron Oxide
SF	Safety Factor
TBD	To be determined

Appendix B

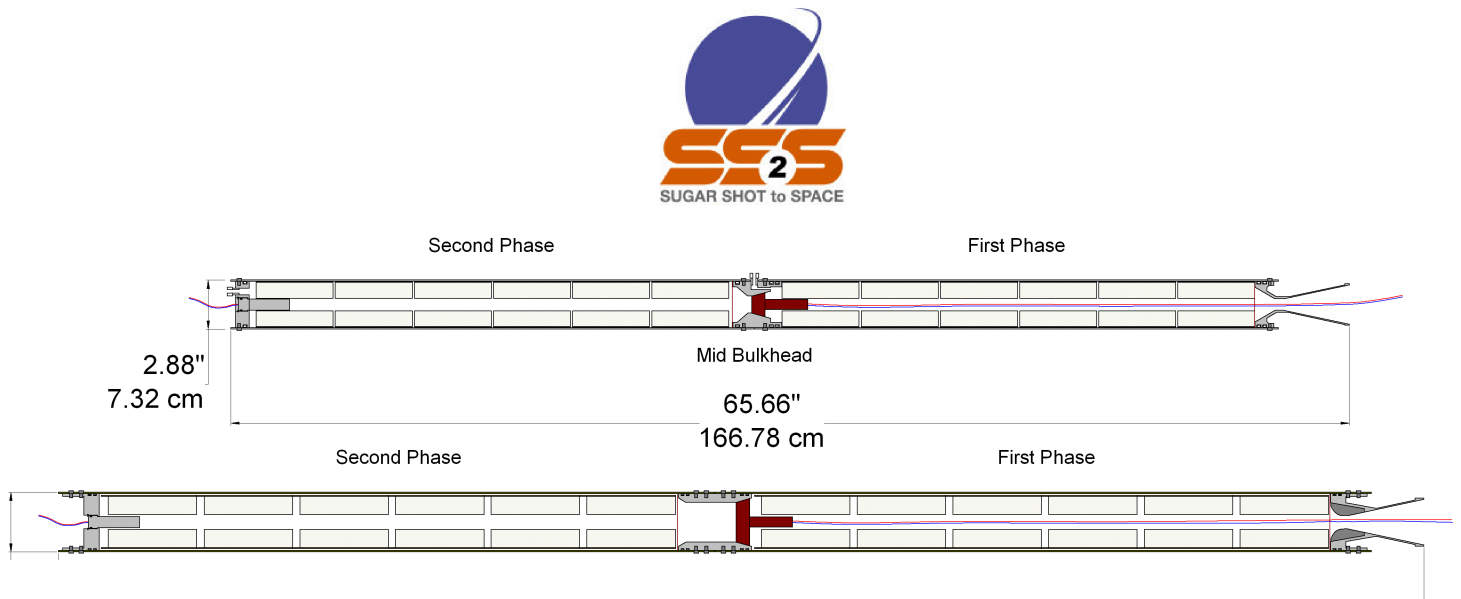


Figure 1 Comparison between 1/4 Scale BEM (top) and *ProtoSShot-M Mark I* rocket motor concept

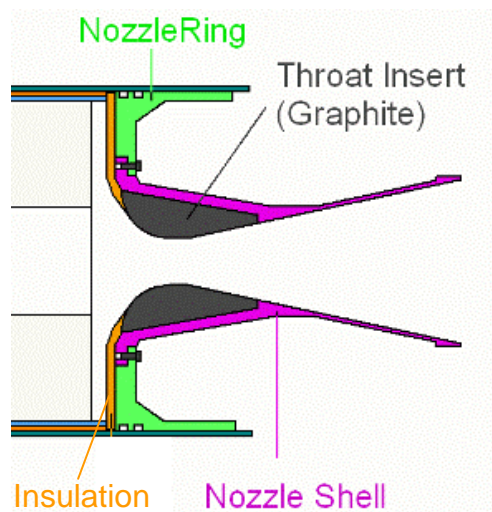


Figure 2 Three-piece nozzle design concept for the *ProtoSShot-M Mark I* rocket motor

Thermal Properties of Various Metals						
Property	Units	Aluminum 6061-T6	Mild steel AISI 1010	Alloy steel 4130	Stain.steel AISI 304	Titanium Ti-6Al-4V
Melting pt.	C.	582	1527	1482	1400	1650
Density	g/cm ³	2.7	7.8	8.1	7.9	4.4
Conductivity	W/m-K	167	64	41	15	7

Table 1 Thermal properties of selected metal alloys.