“1/4 scale” Ballistic Evaluation Rocket Motor (BEM)

Technical Specifications

Rev.2006/02/02

General information

This document specifies the chief requirements for the design and construction of the "1/4 scale" ballistic evaluation motor (BEM) and associated static test requirements. This BEM comprises a key developmental element of the *Sugar Shot to Space* (*SStS*) project. This document is intended to specify only those requirements of the BEM needed to ensure that it is sufficiently representative of the proposed flight vehicle motor, while maintaining a good deal of flexibility in the detail design and construction of the motor.

The basic concept of the proposed flight vehicle motor is unconventional in the sense that the operation is "dual phase" in nature. The motor consists of two distinct combustion chambers with separate propellant grain charges. The charges fire sequentially, separated in time by a certain delay period, thus the term "dual phase". The two chambers are joined by a "mid bulkhead" which incorporates a pyrotechnic "delay plug", which is fully consumed during the delay period. The purpose of having two separate propellant charges with a delay between operation of each is to allow the rocket vehicle to coast between firings. This greatly increases the potential peak altitude in comparison to a single "phase", or conventional, motor.

The goals of the "1/4 scale" static evaluation motor test program are as follows:

- to prove the "dual phase" concept using a largely similar, but scaled-down, design corresponding to that of the proposed flight motor
- to obtain actual performance data for comparison to predicted, and thus aid in the design of the flight vehicle motor.
- to obtain motor-specific operating characteristics of the KNSB propellant

A listing of abbreviations and acronyms used is the document is provided in Appendix A. General configuration of the "dual phase" motor concept, including terminology used, is shown in Appendix B. Appendix C details the method of sizing the closure attachments.

Basic specifications

Motor casing

1.1 Casing ID to be no less than 2.5” (64 mm), and no greater than 3.5” (89 mm).

1.2 Material to be steel or other similarly heat-resistant material. If aluminum alloy is used, a suitable thermal liner to be used, and minimum ID requirement will apply with liner installed.

1.3 If casing tubing has a welded seam, such seam to be visually inspected (to such an extent as is practical) to ensure there is no loss of material thickness along the length of the seam. The finished motor to be hydrostatically tested to 1.5 x MEOP.

1.4 Design SF=1.7 minimum, and burst SF= 2 minimum, based on MEOP, determined using *casing.xls*.

Closure attachments

2.1 Any suitable means may be used to secure the closures. Examples are threaded means, radial pattern of machine screws, or snap-rings.

2.2 If threads are used, minimum number of threads in engagement is 4.

2.3 If machine screws are used, the casing holes to have an e/D = 2 minimum

2.4 If snap rings used, groove to be no more than ½ the depth of the casing wall.

2.5 Closure attachments to be sized to fail at no less than 2 x MEOP and no more than 3 x MEOP (see appendix C.)

Nozzle

3.1 Material to be steel or other similarly heat-resistant material. If aluminum alloy is used, a suitable graphite or similarly heat-resistant material to be used as a throat insert.

3.2 Sealing to be provided by one or more silicone o-rings lubricated with silicone grease.

3.3 Throat diameter to provide for initial Kn = 350 and maximum Kn = 435.

3.4 Throat inlet to be well-rounded to minimize flow losses.

3.5 Convergence half-angle to be 30º at the throat inlet; divergence half-angle to be constant 12º.

3.6 Expansion Ratio to be 12:1. This is achieved by nozzle exit diameter to throat diameter ratio of 3.46.

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

3.8 A nozzle o-ring shield fabricated from ABS to be installed between nozzle seat and grain segment. Mastic putty to be applied to the nozzle-side surface of the shield prior to installation in the motor.

Forward Bulkhead

4.1 Material to be steel, aluminum alloy or other similarly heat-resistant material.

4.2 Pressure tight sealing to be provided by one or more silicone o-rings lubricated with silicone grease

5.1 Provision for a pressure tap to be incorporated (for measurement of second phase chamber pressure)

Mid Bulkhead

5.2 Material to be steel or other similarly heat-resistant material.

5.3 Pressure tight sealing to be provided by one or more silicone o-rings lubricated with silicone grease

5.4 Provision for a pressure tap to be incorporated (measurement of first phase chamber pressure)

5.5 Bulkhead to have a central port with a minimum diameter of 1.5 x nozzle throat diameter.

5.6 Central port to be tapered or similarly provisioned for positive retention of the Delay Plug under first-phase motor pressure loading. Entrance to be suitably rounded to facilitate combustion gas flow during second phase operation.

5.7 Delay plug to be fabricated of RNX-73 formulation with a thickness to provide a nominal delay period of 10 seconds minimum; 12 seconds maximum.

5.8 Delay plug to have a flame-resistant coating or layer on the top surface to prevent second-phase grain ignition upon burn-through of the plug.

5.9 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 is tentatively to be KNSB. A minor modification to the standard formulation may be required, such as the addition of an opacifier, pending the outcome of a separate propellant study.

6.2 Grain configuration to be BATES consisting of a total of 6 segments per phase.

6.3 Each propellant segment to have Lo/Do=1.73 and Do/do=3.54 (excluding liner).

6.4 Liner (inhibitor) to consist of 4 plies minimum of 0/90 glass cloth in polyester matrix. Alternatively, dense cardboard tubing of 0.050 in. (1.3 mm) minimum thickness may be used.

6.5 Spacing between segments to be 0.1 in. (2.5 mm) minimum; 0.25 in. (6.5 mm) maximum.

6.6 Each segment to be painted on both ends with Ignition Primer.

6.7 Segments may be cast directly into inhibitor liner. Liner interior must be coated prior to casting with melted sorbitol or epoxy adhesive.

Ignition

7.1 Ignition of both motor phases to be electrically initiated.

7.2 Second phase igniter to be fired 15 seconds minimum; 18 seconds maximum, after first-phase motor startup.

7.3 Both motor phases to be ignited by use of a short-burn duration pyrogen device.

Static testing

8.1 Motor chamber pressure for both phases to be measured and recorded

8.2 Motor thrust during both phase operations to be measured and recorded

8.3 First phase casing outside wall temperature to be measured and recorded at 6 locations (minimum). Second phase casing wall temperature to be measured and recorded at 4 locations (minimum).

General

8.1 Preliminary design to be sketched or alternatively drawn in CAD with basic dimensions shown.

8.2 Preliminary design to be reviewed by the Motor Team Lead prior to acceptance as final design.

8.3 Final design of the complete motor assembly and component parts to be drawn in CAD (any standard software may be used).

8.4 Proposed test apparatus to be reviewed by Motor Team Lead prior to acceptance.

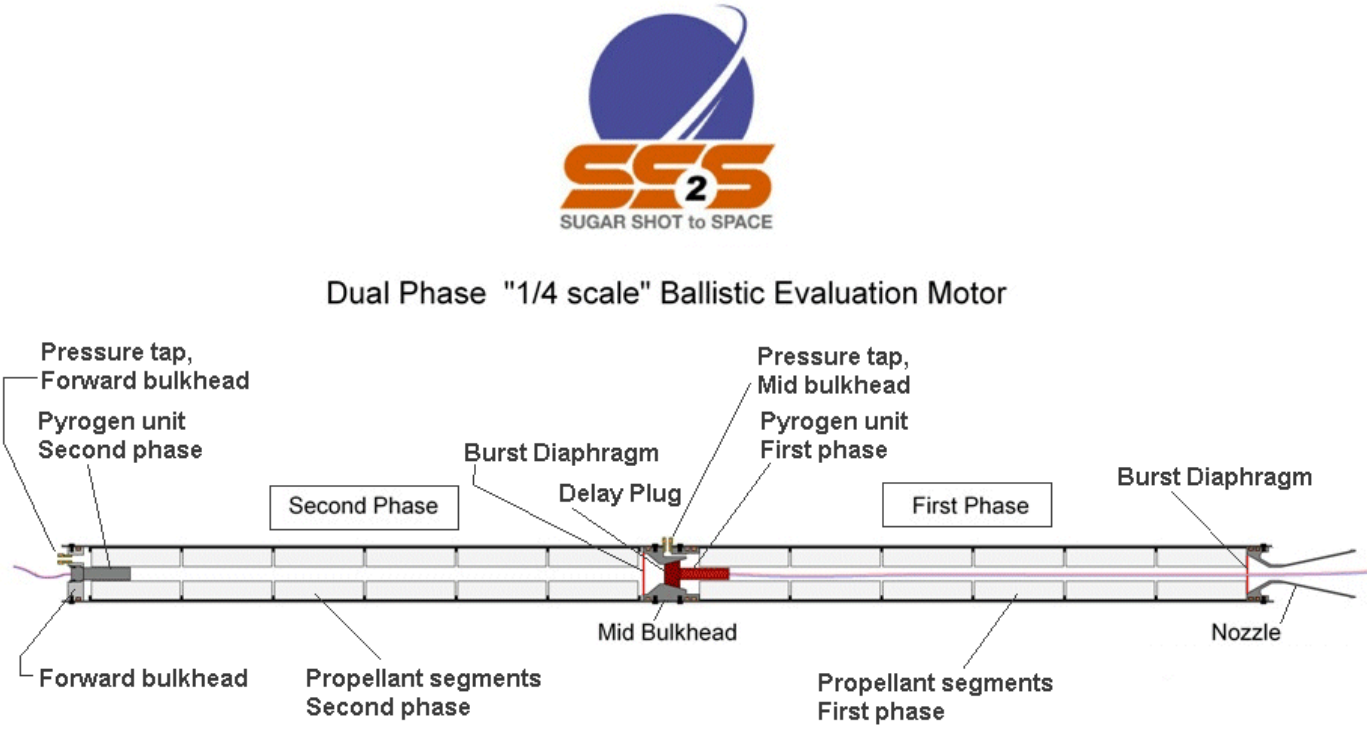
Appendix A

Abbreviations/acronyms

BATES	Ballistic Test Evaluation
Closure	Generic term for nozzle, mid bulkhead or forward bulkhead
do	Propellant grain segment initial core diameter
Do	Propellant grain segment outer diameter
e/D	Edge distance ratio: e=distance from hole center to casing edge; D=hole diameter
ID	Inside Diameter
Kn	Klemmung (ratio of grain burning area to nozzle throat cross-sectional area)
KNSB	Potassium Nitrate/Sorbitol propellant, of ratio 65/35, prepared by “standard” method.
Lo	Propellant grain segment initial length
MEOP	Maximum Expected Operating Pressure. MEOP=1100 psi (7.6 Mpa).
RNX-73	Propellant formulation based on Potassium Nitrate/Epoxy/Iron Oxide
SF	Safety Factor
TBD	To be determined

Appendix B

General configuration of Dual Phase motor



Appendix C Closure Strength Substantiation

1) Threaded attachments: TBD

2) Snap rings: Conventional snap-ring and groove analysis, or *snap-ring.xls*

3) Radial pattern of machine screws: Conventional bolt-ring analysis, or *bolt-ring.xls*

Bearing allowables are available from MIL-HDBK-5 for many materials such as low-carbon steel and aluminum alloys.