DoubleSShot

Work Package #4

Boilerplate Static Test Motor

Rev. 2011/01/14

Work Package #4 (WP#4)

Work Statement

The tasks involved in this WP deal with design and fabrication of the Boilerplate static test motor. The Boilerplate motor is a full *DoubleSShot* scale rocket motor that will be test fired to validate the basic design of the proposed *DoubleSShot* (DSS) flight motor. Due to uncertainties with scaling up a sugar-based motor to such a size, and in particular a dual-burn motor, the Boilerplate motor will incorporate design features that are rugged and reasonably tolerant to operating under conditions beyond the design parameters. In particular, with respect to chamber pressure and thermal loading, ruggedness will be achieved by use of a robust steel motor casing. Since weight is not a driving factor in design, the motor components can be simplified to allow for easier machining and lower cost.

This motor is slated to become, by far, the largest sugar-based motor ever fired (over twice the propellant capacity of the NEAR SC-100 motor).

The primary choice of grain configuration will be a single “unigrain” with a “star” core. The secondary choice is conventional BATES. The significant advantage of star over BATES is the potential for greatly reduced thermal loading of the aft chamber, since the propellant would serve as a casing insulator over most of the first burn duration. For a dual-phase motor, this advantage can make a critical difference. Since the usage of a star configuration with sugar propellant involves many unknowns, lacking a significant experience base, the plan is to initially fire the Boilerplate motor with a star grain. If the result proves to be unsatisfactory, a follow-up firing with a BATES grain would be performed.

Technical Requirements that are applicable to this WP are provided at the following link:
http://sugarshot.org/downloads/dss_technical_requirements_wp4.pdf

Tasks

1. Design of motor assembly and detail parts.
2. Fabrication of nozzle
3. Fabrication of Mid-bulkhead
4. Fabrication of Forward Bulkhead
5. Preparation of motor casings
6. Fabrication of casting tubes
7. Delay plug
8. Pyrogen and igniter system
9. Assembly, test fitting of components, and proof-loading

Task Descriptions

Task 1. Design the Boilerplate rocket motor of similar size to the proposed *DoubleSShot* flight motor. To be done using SRM.XLS or similar software for performance based sizing, in conjunction with established methods of sugar motor construction techniques, to the extent possible. The motor should be dual-burn operation with a delay period between burnout of the first phase and ignition of the second phase. The design parameters are provided below and in Appendix A. All components and assemblies should be drawn in CAD, preferably SolidWorks.
Detail parts include the following:

a. Nozzle assembly – may be one piece or multiple pieces, with the following design conditions:

   i. Convergent half-angle should be 30º maximum, divergent angle 12 º

   ii. throat length = ½ × throat diameter, maximum

   iii. expansion ratio 10, minimum

   iv. Material may be steel, or aluminum with suitable thermal protection

   v. A layer of SSA-1 (or similar) ablator representative of that intended to be used for the flight motor should line the convergent portion. The intent is to assess the performance of the liner.

   vi. Retention of nozzle to casing should provide for an ultimate capability of 2× over MEOP (Max expected operating pressure)

   vii. Dual o-rings should be used for sealing. Material should be buna-n (nitrile)

b. Mid-bulkhead assembly – Mid-bulkhead joins forward and aft motor casings. The following are the design constraints:

   i. Material may be steel, or aluminum with suitable thermal protection

   ii. A layer of SSA-1 (or similar) ablator representative of that intended to be used for the flight motor should line the flow channel

   iii. Flow channel diameter should be representative of that intended for the flight motor.

   iv. Retention of Mid-bulkhead to casings should provide for an ultimate capability of 2× over MEOP (Max expected operating pressure)

   v. Dual o-rings should be used for sealing both forward and aft motor casings. Material should be buna-n (nitrile)

vi. Provision to be made for a sensor to measure pressure in the aft chamber

vii. Forward end of Mid-bulkhead to be fitted with a burst diaphragm that is capable of withstanding a positive pressure differential in the forward chamber of 200 psi (1.38 MPa). The diaphragm to be made of frangible material that will not produce any fragments upon second phase startup.

c. Forward Bulkhead – closure for the forward casing.

   i. Material may be steel, or aluminum with suitable thermal protection

   ii. Retention of Forward Bulkhead should provide for an ultimate capability of 2× over MEOP (Max expected operating pressure)

   iii. Dual o-rings should be used for sealing. Material should be buna-n (nitrile)

   iv. Provision to be made for a transducer to measure pressure in the forward chamber

   v. Provision to be made for a removable igniter

   vi. Provision to be made for mounting a pyrogen ignition unit.

   vii. Provision to be made for a fitting to transmit thrust loading to the test stand load cell

d. Motor casings – A forward and aft motor casing are required. These should have an inside diameter within 10% of the proposed flight motor, which has a nominal ID of 6.41 in. (163mm). The following are requirements for the casings:

   i. Material may be steel or aluminum. If aluminum, the interior needs to be thermally protected with a suitable liner

   ii. Burst pressure should be at least 2½× MEOP based on room temperature strength of casing material

e. Casting tubes – required for both forward and aft chambers. The casting tubes for the aft chamber experience a much greater thermal loading, due to exposure to both the first and second phase burns. The following are design requirements

   i. Aft chamber tubes to be fabricated of SSA-1 ablator or similar

   ii. Aft chamber tubes to have wall thickness of 0.200” (5.1mm).

   iii. Forward chamber tubes to be made of suitable heat resistant material

   iv. Casting tubes to have a lap joint at each end to allow for all tubes for each chamber to be assembled as a single monolithic grain assembly once propellant has been cast in each. Lap joint to be structurally bonded and pressure tight

v. Casting tube OD to allow for sufficient clearance when fitted in chamber to allow for rapid pressure equalization around grain assembly at motor startup.

vi. For the Star grain configuration, the number of casting tubes can be based on practical considerations, since the tubes and propellant will be joined to form a monolithic “unigrain”. The quantity of casting tubes should be six per chamber for the BATES grain configuration.

f. Delay plug – to be integral with the Mid-bulkhead and capable of serving as a structural closure during the first phase burn, yet providing minimal flow restriction during second phase burn. For MSS, this was accomplished by “burning away” entirely, being fabricated of a pyrotechnic formulation (*RNX-73* epoxy based propellant). The following design requirements apply:

  i. To be representative of the Delay Plug to be use for the flight motor to as close an extent as practical

  ii. To be capable of withstanding MEOP during entire first phase burn

  iii. To be fully consumed or otherwise capable of being fractured immediately upon second phase startup.

  iv. No sizeable fragments capable of restricting the nozzle throat to be produced upon second phase startup

  v. To provide for a delay of 16 seconds between end of first burn and startup of second burn

g. Pyrogen and igniter system – Both first and second phases are to use Pyrogen ignition to ensure rapid but “soft” startup. The Pyrogen units are to be ignited using a conventional “electric match”. The following are the design constraints:

  i. Aft chamber Pyrogen to be fully consumable with no fragments being capable of restricting the nozzle throat

  ii. Forward chamber Pyrogen may consist of a canister holding Pyrogen propellant. Canister should be mounted on the Forward Bulkhead in a secure manner

  iii. Design should be such that majority of flame is directed through the grain core with minimal impingement on any non-propellant surface of the motor

iv. Burn time should be as short as possible yet ensure rapid startup of all exposed propellant surfaces

v. Pyrogen grain should be sugar-based

Task 2. This task involves fabrication of the nozzle assembly. The person responsible for this task will either fabricate the nozzle or arrange to have the work done. Drawings will be supplied that will provide all dimensioning, materials, and other pertinent information. Drawings will be provided in either English or Metric units, as requested. A solid CAD model will also be available that can be used for CNC machining. Stock material can be supplied to the task owner if desired. Application of ablator may be performed as a separate task.

Task 3. This task involves fabrication of the mid-bulkhead assembly. The person responsible for this task will either fabricate the mid-bulkhead or arrange to have the work done. Drawings will be supplied that will provide all dimensioning, materials, and other pertinent information. Drawings will be provided in either English or Metric units, as requested. A solid CAD model will also be available that can be used for CNC machining. Stock material may be supplied to the task owner if desired. Application of ablator and installation of burst diaphragm may be performed as a separate task.

Task 4. This task involves fabrication of the forward bulkhead assembly. The person responsible for this task will either fabricate the forward bulkhead or arrange to have the work done. Drawings will be supplied that will provide all dimensioning, materials, and other pertinent information. Drawings will be provided in either English or Metric units, as requested. A solid CAD model will also be available that can be used for CNC machining. Stock material may be supplied to the task owner if desired.

Task 5. This task involves fabrication of the two motor casings. The person responsible for this task will either prepare the casings or arrange to have the work done. Drawings will be supplied that will provide all dimensioning, materials, and other pertinent information. Drawings will be provided in either English or Metric units, as requested. Stock material may be supplied to the task owner if desired.

Task 6. This task involves fabrication of the casting tubes. Drawings will be supplied that will provide all dimensioning, materials, and other pertinent information. Drawings will be provided in either English or Metric units, as requested. Stock materials may be supplied to the task owner if desired.

Task 7. This task involves fabrication of the Delay Plug. Drawings will be supplied that will provide all dimensioning, materials, and other pertinent information. Drawings will be provided in either English or Metric units, as requested. Stock materials may be supplied to the task owner if desired. As the Delay Plug is integral to the Mid-bulkhead, this task will be accomplished once the Mid-bulkhead has been fabricated.

Task 8. This task involves fabrication of the two Pyrogen units. Extra units may be required for functionality testing. Drawings will be supplied that will provide all dimensioning, materials, and other pertinent information. Drawings will be provided in either English or Metric units, as requested. Stock material may be supplied to the task owner if desired

Task 9. This task relates to the assembly, test fitting of components, and proof-loading of the Boilerplate motor. Once all the components have been fabricated, a trial assembly is required to verify that all components fit together in an acceptable manner. Minor modifications may be required due to dimensional tolerance related issues or parts not made exactly to blueprint. The assembled motor may require hydro-static proof testing to verify structural integrity under pressure, and to confirm that no leakage occurs at the joint. The Delay Plug will require hydro-static proof testing to verify its structural integrity. The Delay Plug is to be verified at the condition expected following burnout of the first phase, when it has been partly burnt away. At this condition, it should be capable of withstanding MEOP without sign of deformation.

Deliverables

Task 1 Deliverable The following are deliverables relating to the motor design.

1.1. Submit results of motor performance sizing to Project Manager for review and approval(e.g. SRM.XLS file or similar). This submission should be done prior to commencing the motor mechanical design.

1.2. Submit preliminary drawing/sketch of proposed motor design sizing to Project Manager for review and approval, including any supporting documentation. This submission should be done prior to commencing the motor manufacturing drawings.

1.3. Drawings of all motor components, using established *SS2S* drawing standards, suitable for manufacturing the parts.

Task 2 Deliverable

2.1. Completed Nozzle assembly or components. May or may not include application of ablator. Part(s) to be shipped to assembly site.

Task 3 Deliverable

3.1. Completed Mid-Bulkhead. May or may not include application of ablator and burst diaphragm. Part(s) to be shipped to assembly site.

Task 4 Deliverable

4.1. Completed Forward Bulkhead, to be shipped to assembly site.

Task 5 Deliverable

5.1. Completed motor casings, to be shipped to assembly site.

Task 6 Deliverable

6.1. Completed casting tubes plus spares (minimum 1 each for forward and aft chamber), to be shipped to propellant casting site.

Task 7 Deliverable

7.1. Delay Plug installed in the Mid-bulkhead.

Task 8 Deliverable

8.1. Completed Pyrogen assemblies or components for both 1st and 2nd phase ignition. Propellant grains may be supplied as a separate task.

Task 9 Deliverable

9.1. The following are the deliverables relating to Assembly, test fitting of components, and proof-loading:

9.1.1. Report on trial assembly of complete motor to be supplied to Project Manager, including any non-conformances encountered in the fit-up. Recommendations to correct problems. Arrange to have parts modified as required

9.1.2. Report on hydro-static pressure testing of motor, if required. Report should indicate any indications of permanent deformation and any indications of leakage.

9.1.3. Report on hydro-static pressure testing of “burnt” Delay Plug. Report should indicate any indications of permanent deformation and any indications of leakage

Risk management

If any task runs into technical or other issues that may affect completion of a deliverable within agreed upon time frame, this must be reported to Project Manager in a timely manner. An action or action plan will then be worked out between WP owner and Project Manager to resolve the issue or plan a course of action to mitigate the effect upon the project.

Progress reporting

A brief synopsis of progress made is to be supplied to the Project Manager on a regular basis (e.g bi-weekly) until such time as Work Package has reached mature stage. Submission of photos and/or videos relating progress are strongly encouraged, for inclusion in the project’s Weekly Activity Report

Funding

Funds for this Work Package will be supplied to cover all materials and other expenses, excluding labor. Significant expenditures (greater than $100) need prior approval of Project Manager. Expenses should be tracked for reimbursement upon completion of WP. Funds may alternatively be supplied in advance, to cover purchase of materials or other supplies. Labor and machine setup costs may be covered if parts are commercially fabricated at a discount cost. As SS2S is a volunteer, minimal budget program, donation of supplies needed for fulfilling this WP is encouraged, by both the WP owner and SS2S team.

Appendix A – Additional Boilerplate motor design parameters

Thrust profile	neutral (to the extent practicable)	
MEOP	1000 psi	6.9 MPa
Nozzle efficiency	0.85	
Area ratio, core to throat	2.0 minimum	
Grain Length to Diameter ratio	10:1 maximum	

Propellant KNSB with the following parameters:

Grain mass density, ideal	ρ_p	g/cm^3	1.841
Ratio of specific heats, 2-ph.	k	-	1.042
Ratio of specific heats, mixture	k	-	1.1361
Effective molecular wt.	M	kg/kmol	39.9
Combustion temperature	To	K	1600
Pressure exponent	n	-	0.22
Burn rate coefficient	a	$mm/s/Mpa^n$	5.13
Combustion efficiency	ηc	-	0.95

Proposed Star profile core geometry is shown in Figures 1 and 2. This core shape delivers a suitably neutral Kn through much of the burn. The Kn versus surface regression is shown in Table 1.

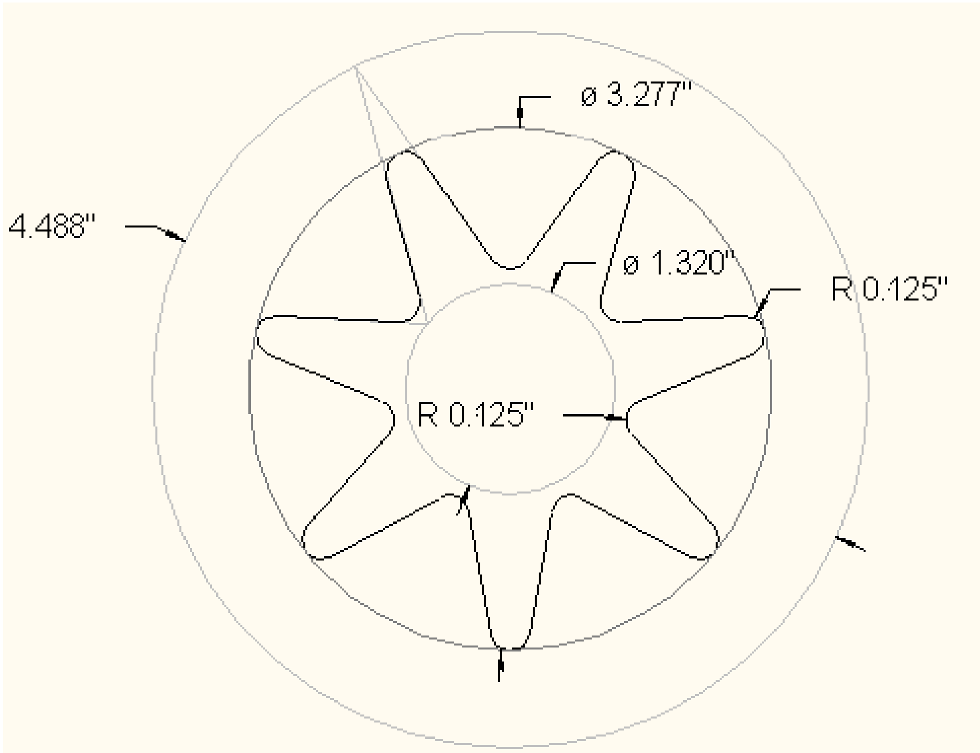

Figure 1 – star core cross-section (US units)

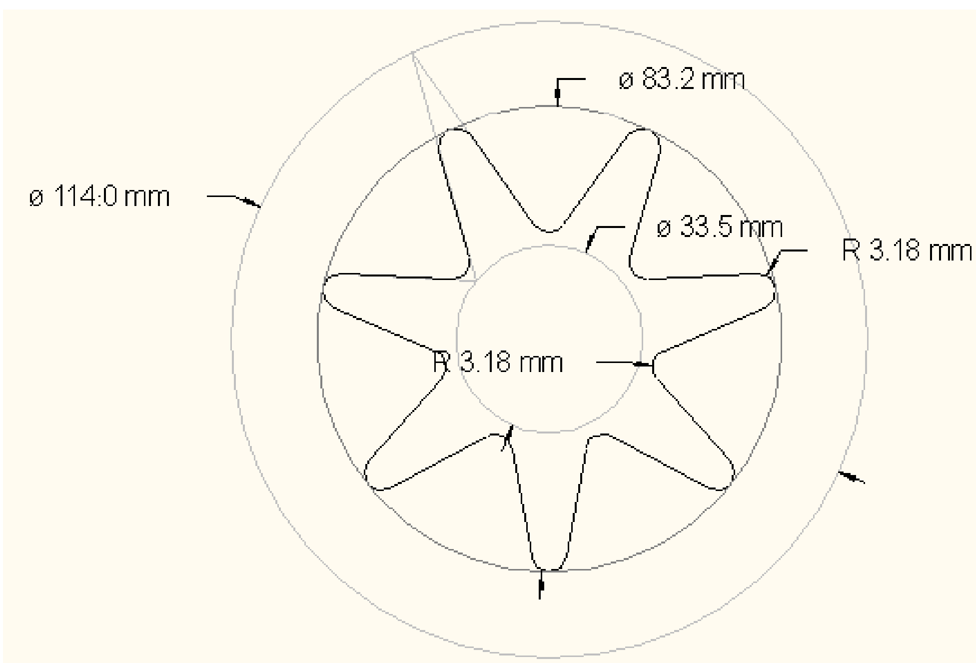

Figure 2 – star core cross-section (metric units)

Figure 3 shows a plot of the burning area of the star grain (Fig.1) for the following typical grain dimensions:

Dgrain = 5.6 in (142 mm)
Lgrain = 60 in (1524 mm)

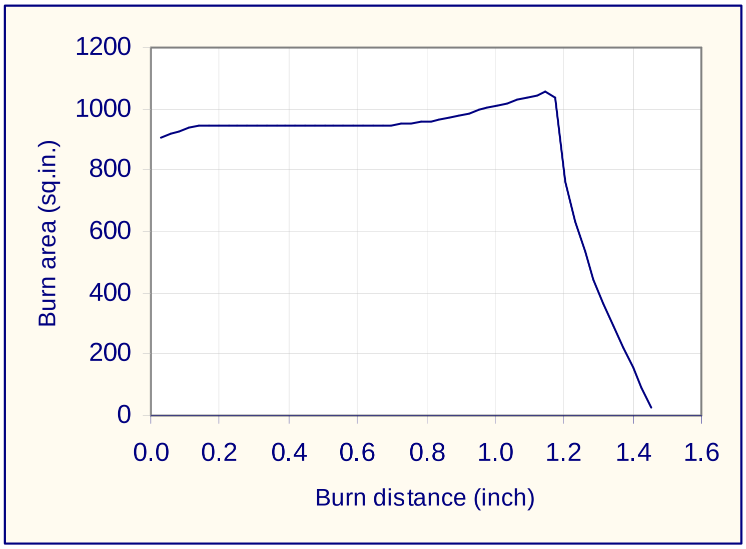

Figure 3 – Chart illustrating typical star regression