WATERLOO ROCKETRY TEAM

Silver Brant Hybrid Engine Test Report
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Prepared for
Intercollegiate Rocket Engineering Competition
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Public Consumption

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Summary

This report outlines projects currently being worked on for The Intercollegiate Rocket Engineering Competition by the Waterloo Rocketry Team in Waterloo, Ontario, Canada.

Currently the team is actively working to improve last year's NOx/HTPB hybrid engine for a 10,000' rocket called the Silver Brant. The name comes from the all-aluminum construction that was selected and the popular Canadian-designed Black Brandt sounding rocket that has been used all over the world since the 1960's.

During the test, the engine ran nicely for a while. The following issue were observed:

- Thrust too low (100lbf rather than 300lbf)
- Combustion chamber burned through at the end of test
- DAQ cut out 3 seconds into the test

The following things went well with the test:

- We have a serviceable technique for casting star-grain hybrids
- Although the CC burned-through, we know why and it will be fixed for next test
- Our pyro-initiated valves did work although they need to be modified

Data recovered from the test can be seen below in Figure A:

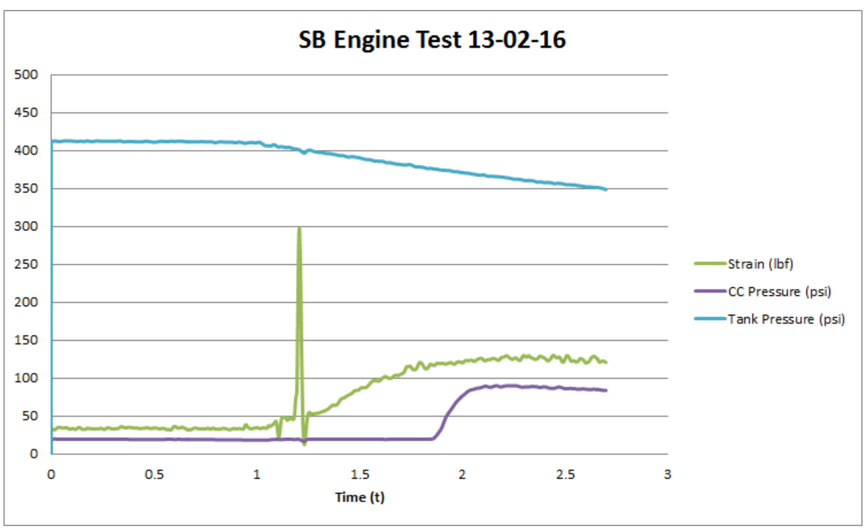

Figure A Pressure/Thrust data from test

Methods used for Hex-Star fuel grain casting are also outlined in **Appendix A: Fuel Grain Casting**.

Contents

List of Figures:

1.0 Background

1.1 Waterloo Rocketry Team

The Waterloo Rocketry Team is an engineering student team at the University of Waterloo in Waterloo, Ontario [1]. It is committed to giving students the resources to learn aerospace engineering in a competitive hands-on environment through the Intercollegiate Rocket Engineering Competition. The Waterloo Rocketry Team designs, builds, tests and competes with rockets designed to bring 10lb payloads to 10,000' and 25,000' respectively and then return them safely to ground-level. The Waterloo Rocketry Team strives to be the premier team at the Intercollegiate Rocket Engineering Competition through outstanding engineering, precision fabrication and innovative design. The team competes annually in the Intercollegiate Rocket Engineering Competition (IREC) in Green River, Utah. It is fairly new student design team with 2012 marking its second year of competing at IREC. [2]

1.2 Intercollegiate Rocket Engineering Competition

The Intercollegiate Rocket Engineering Competition (IREC) is an international design competition which sees universities and colleges compete to design, build and fly rockets as close as possible to target apogees (height above ground level). The competition is run by the Experimental Sounding Rocket Association (ESRA) and takes place annually in the dessert outside of Green River, UT. There are two categories. In the basic category, the target apogee (height above ground level) is 10,000’ while the advanced category is 25,000’. [2]

1.3 Test Objectives

The objective of the test was to evaluate the first iteration of the Silver Brant engine system. This system included a new combustion chamber, new injector design, new fuel grain design, and new nitrous valving system.

2.0 Apparatus

The test apparatus consisted of an updated version of our test mechanical and electrical systems. The DAQ/ Ignition controls are based off a NI USB-6221. The transfill tank is based off a HyperTek 4.5L fill tank. The transfill tank is filled from a standard K-bottle of Nitrous Oxide which has been inverted to decant the liquid phase of the nitrous. The combustion chamber stand has been adapted from a previous version with a full 21” iron shroud to protect against combustion chamber burn-through or rupture. The major difference in the valving plumbing is that mechanical pyro-initiated valves were used to control nitrous flow instead of electronic solenoid valves.

The overview and schematic of the test setup can be seen in Figures 1 and 2 below:

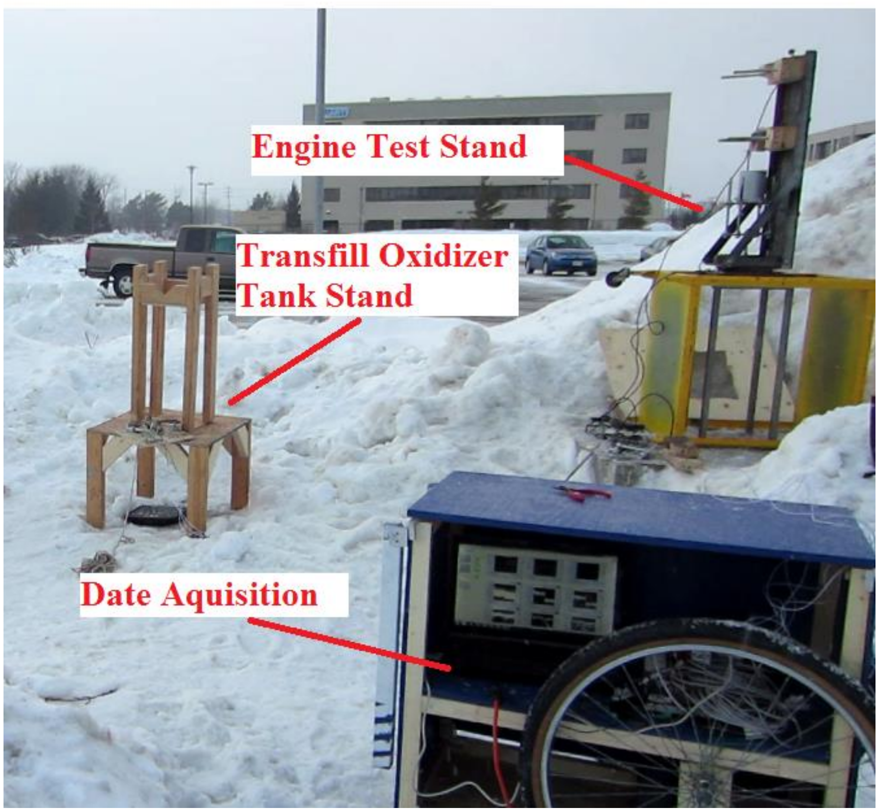

Figure 1: Test Area Overview

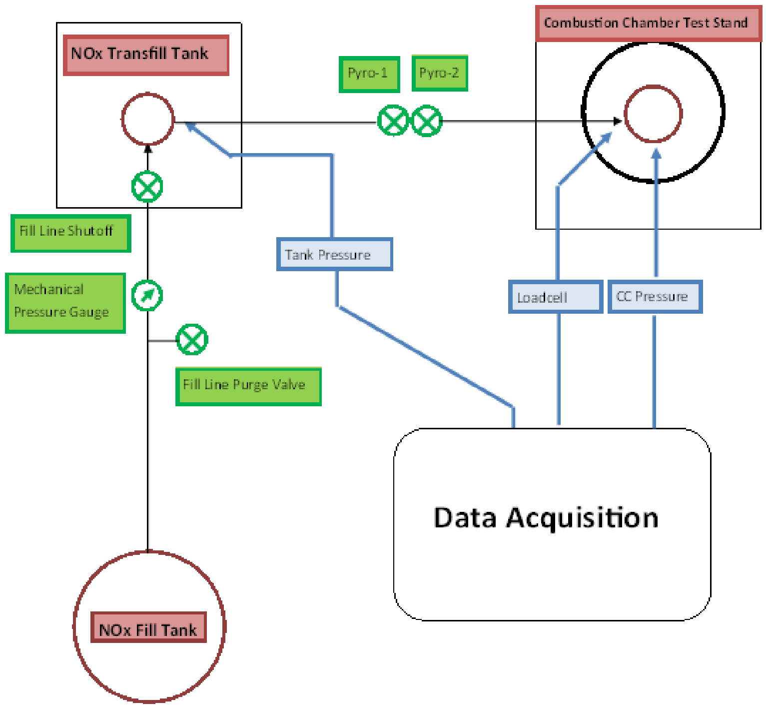

Figure 2: Test Setup Schematic

3.0 Results

3.1 Overview

The engine ran nicely for a while. Thrust results are still much lower than needed, returning about 100lbf thrust rather than the ~300lbf calculated, combustion chamber blew up, lab view cut out about 3 seconds into the test and 15 seconds into the test.

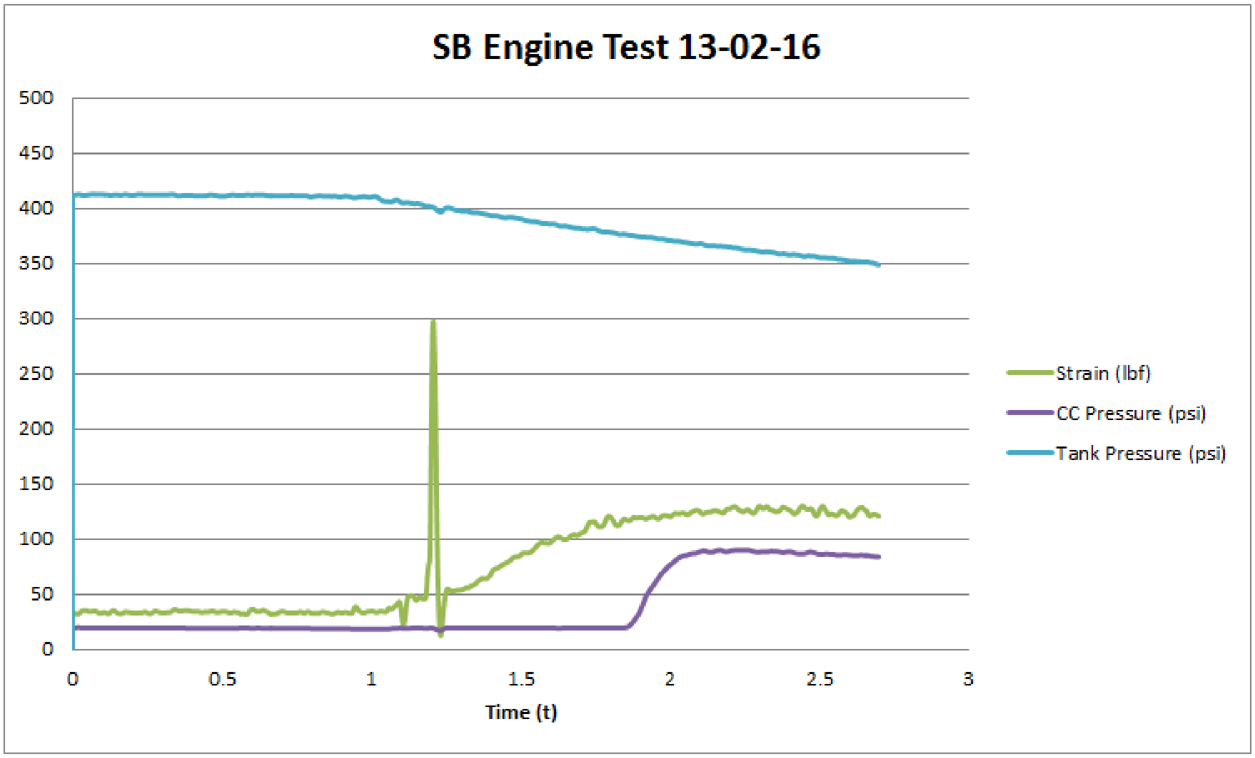

Figure 3: Data recovered from test

What went well:

- ABS grain sleeve casting shows promise, we are able to make serviceable star-grains
- The showerhead injector design seems pretty nice, definitely an improvement.
- The DAQ is still working for the most part and without many setup problems that have been problematic in the past
- We had fun and got to test an engine

Problem/Comments

1. Combustion chamber blew up
    1. Seems to be due to ABS liner precombustion chamber burning through. Will line precombustion chamber with ablative HTPB
    2. The 50% HTPB/50% Al fuel grain regressed far too quickly. New grain only has 10% Al

2. Low thrust
    1. Could be partially due to valve not opening fully but I think the nozzle is not optimized for the flow we are seeing, look at the video we dont seem to be getting mach conditions, chamber pressure is also very low (~100psi, not the 300psi the nozzle is designed for)
3. Lab view cut out 3 seconds into test
    1. Likely a problem with the DAQ, doublecheck connections for next test and run from grid-power rather than generator
4. DAQ sensors were not properly calibrated, pressure sensors were floating to about 20psi before the test
    1. This is intentional due to how the sensors were calibrated, we should switch to higher pressure sources for calibration though -Thomas
5. The pyro latches didn't actuate completely due to geometric problems with the latch locations
6. Setup time was still pretty long

4.0 Discussion/Recommendations of Solutions

1. We will make sure the ABS liner fits the CC properly and any gaps will have mated (male-female) connections so the aluminum is not exposed to heat. we will remove the precombustion chamber in the ABS section entirely since the injector bulkhead already has one
2. We need to get NOx temp up to 25 deg. C, the heating blanket was insufficient. We are looking at heating the NOx during transfill and while in the transfill tank. Ben/Adam will also work on better CC optimization and nozzle optimization.
3. Thomas is looking into the DAQ problems

4. We need to have a calibration procedure pre-test, lets set that up. We will use hydraulic pump for high pressure calibration (Thomas/David)
5. The geometry can be changed easily to fix the valve actuation problem, I want to seriously consider moving to burst-tube one-way igniter/valve system although it means we cannot shutoff flow, it would also mean that it reduces our launch failure modes (igniter/valve are now the same, allows remote fill/disconnect) and it would reduce a lot of weight and complexity of the rocket. In short, I think we can get closer to our target altitude by not using the spring valves and just using burst tube.
6. To reduce setup time, I'd like to move to making a slightly bigger box on our stand we can leave the "sled" and shroud attached semi-permanently, the long-term idea is we will be able to test more.

General comments:

- Estimate mass flow, simulate and make some new nozzles for next test
- Cast some more grains for next test
- Install labview on more computers
- We will source thermocouples for CC/tank temperature monitoring
- Source some silicone grease for better assembly

5.0 Appendix A: Fuel Grain Casting

This section will outline the process used for star-shaped fuel grain casting to increase reactive surface area and thus, initial thrust. Some problems were faced but overall it is a serviceable method.

5.1 Grain Overview:

- Hex-Star cross-section
- Core: 6061 2" Hex w/ foam glued (polyurethane) to it (see pics), end machined round to fit bottom plug
- Bottom plug: 3"diax2" steel round with 3/4" hole to centre core
- Length 24"
- Grain sleeve: 3" nom. ABS pipe
- Fuel: 50% HTPB/mdi and 50% Aluminum powder
- Plug, core all covered in vaseline for lubrication

The final grain geometry can be seen in Figure 4: below:

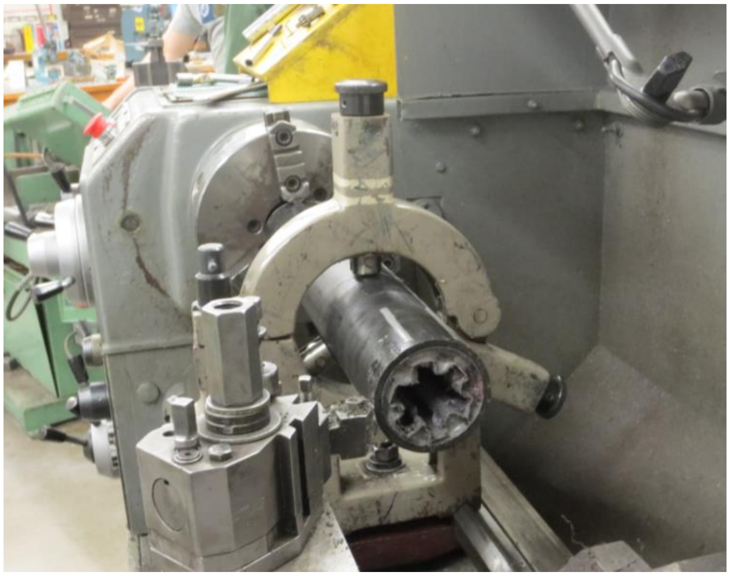

Figure 4: Final grain geometry

The laid-up core used to cast the grain can be seen in Figure 5 below:

Figure 5: Hex-core used for casting

5.2 Problems

- Glue was not fully cured, foam became boyant in fuel mixture causing grain geometry to be ruined at the bottom. This can be seen in figure 6 below:

- Had problems releasing from mold
    - Dissolved foam using acetone
    - Serviceable method for removal: apply torsion to hex bar by putting 1/2" steel rod through it.

- Could not get bottom plug out
- Grain not quite centered at top
- Some leakage of resin through bottom, seal better next time
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5.3 Fuel Grain Casting Recommendations

- Allow 24h curing time for core using polyurethane glue
- Install O-rings on circular portion of hex bar and bottom plug
- Tap two holes onto bottom plug which will allow bar to be attached for torsion and pulling when removing mold
- Make a similar top plug for centering and to hold foam down, and turn down hex bar at top to 3/4" as well for hole clearance
- Vaseline can probably be used only at bottom and top as foam is being dissolved via acetone anyway