CSSI

CANADIAN STUDENT SPACE INITIATIVE

Test Motor 1 Experiment Report

Test Fires 1–8

Aug 31 2018

Introduction

This report will be detailing the first 8 test fires of the hybrid rocket motor: Test Motor 1, which uses paraffin wax as fuel and gaseous oxygen as oxidizer. The test fires are intended to showcase the ability for CSSI to design and build a hybrid rocket motor that can generate thrust efficiently. The motor generates thrust by combusting paraffin wax at a very high rate within the steel pipe, which acts both as a combustion chamber and the fuel container. The hot exhaust gasses then exit through the compression-expansion nozzle, which accelerates it to supersonic speeds, generating thrust. Thrust is recorded in this experiment by mounting the engine on a sliding rail, where a force sensor is also secured onto. The sensing end of the force sensor is then placed against a non sliding, static wall. When the engine is conducting a test fire, all thrust force generated on the axis of the rail will push the force sensor against the static wall, allowing the thrust to be measured and recorded. Other variables that will be measured are the pressure of the oxygen output, which is very close to the chamber pressure, the burn time and the stability of the exhaust (using camera recording). This experiment also considered the safety of people near the motor when testing heavily and uses a protective, double layered box, with 5cm of sand in between walls to shield the motor when conducting tests. The top of the box uses 2 layers of ½’ polycarbonate sheets spaced by 5 cm to protect against objects flying out from the top.

Materials

- 1 Acrylic tube (½ inch diameter)
- 1 Computer running Logger Pro software
- 1 Vernier Labquest®
- 1 gaseous oxygen tank
- 1 gas pressure regulator
- ¾ diameter inch steel pipe
- Paraffin wax (as much as possible while letting enough oxygen through for combustion) See figure 1.
- Test stand (for size see figure 2)
    - 1 Sliding rail
    - 3 steel Tightening straps (1x 1 inch, 2x ¾ inch)
    - 1 small block of wood
    - 2 large blocks of wood (for bottom and and front)
    - 2 sheets of wood (2 on each side)
    - Sand (to enough to fill the gap between the 2 sheets of wood on each side)
    - Vernier dual range (10N; 50N) force sensor
    - Screws and steel corner brackets

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Figure 1: paraffin wax inside ¾ inner diameter steel tube

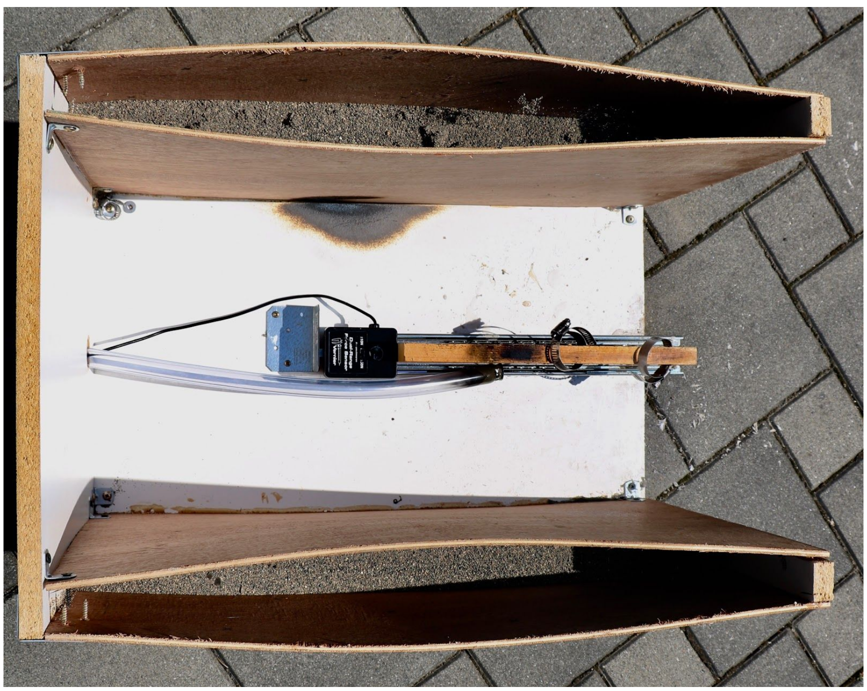

Figure 2: Test stand

Method:

1. Screw nozzle onto fuel casing
2. Connect oxidizer tube to fuel casing by screwing on brass fitting (the section from the brass fitting onwards will now be known as "the motor"
3. Position the motor through the 2 steel straps and on top of the piece of wood (see figure 3)

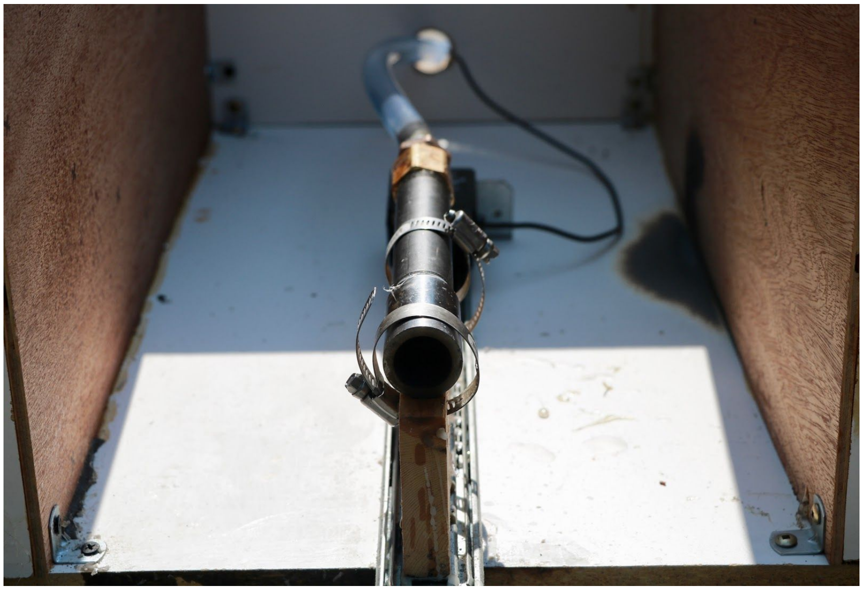

Figure 3: motor position in relations to the test stand

4. Tighten the both steel straps and make sure the motor is secured
5. Attach force sensor to Labquest 1 & connect Vernier Labquest® to a computer
6. Open logger pro on computer and "zero" the force sensor reading
7. Check that force sensor is working by pushing on the piece of wood below the motor and make sure force sensor reading returns to 0 (±0.1N) upon the cease in application of force
8. Insert igniter into the motor casing beyond the nozzle, make sure at least 10 cm deep

9. Put the transparent cover over the motor test stand
10. Put a camera/phone on the transparent cover and start recording a video of the motor (make sure to record the whole motor, brass connection point to nozzle, in case the motor fails at any point)
11. Put a camera 3-5 meters away and almost perpendicular to the test stand & start recording (this camera only needs to capture the flame and the nozzle exit)
12. Open the oxygen valve a little until a sound is whistling sound is heard
13. Ignite the igniter by putting in the safety pin at pressing the ignition button
14. After confirmed ignition, throttle up by increasing oxygen flow rate (turn regulator knob)
15. After burn is complete (all paraffin wax used up and flame out), cease oxygen flow
16. Stop the logger pro data collection and save it
17. Stop all video collections
18. Make sure the transparent cover is free of debris and remove the cover
19. Cool down motor (ex. with wet towel)
20. After it is cool enough, remove motor by loosening the both steel straps and unscrewing the brass fitting from the fuel casing

Results:

Blue hyperlinks lead to more information about each test	Total Impulse (N·s)	Effective Exhaust Velocity (m/s)	Specific Impulse (s)	Peak thrust (N)	Oxygen gas pressure (kPa)	Total firing time (s)	Mass of Fuel (g)
Rounded to nearest...	1s' place	10' place	1s' place	10ths' place	10s' place	10ths' place	1s' place
Test 1	-	-	-				32
Test 2	-	-	-				32
Test 3	-	-	-				34
Test 4	24	680	69	8.5		6.7	35
Test 5	18	1670	170				11
Test 6 (no data)	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Test 7	82	2480	253	22.0	n/a	5.3	33
Test 8	54	1800	186	11.0	200	6.5	30

Observations

- Rocket motor at full thrust can generate vibrations that are up to ±0.8N
- Combustion not extremely stable with flame fluctuating when the oxygen input is not
- Exhaust flame not always sticking to wall of expansion nozzle, caused by under expansion of gasses

Conclusions

The tests were successful, demonstrating the ability for the rocket to produce thrust and impulse of above 80 Newton-seconds (N·s) in test 7. Currently 80 N·s is the maximum total impulse allowed for people age 12-17 without any further certification (according to Natural Resources Canada[1]). The maximum thrust achieved was on test fire 7 (most powerful test) was 22N, slightly lower than most commercial model rocket motors with ≈80N·s of total impulse. Some failures were experienced during testing due to the materials used being pushed to tight tolerances. An example of this is the acrylic tube used to transport oxygen was rated for 310 kPa but during test 7, that pressure limit was exceeded due to high chamber pressure, causing the acrylic tube detach from the engine casing. This caused the oxygen pressure to be decreased for a safety margin in the next tests. A decrease in oxygen leads a slower rate of combustion, which results in a decrease of thrust (evident in test 8). The specific impulse (I_{sp}) and effective exhaust velocity (c) figures were extremely high for a small scale rocket motor, reaching above 250 seconds of I_{sp} in test 7. These high values were in part caused by a systematic error in which the oxygen mass was not measured, meaning that only the mass of the paraffin wax was considered in the calculations for I_{sp} and *c*. It is uncertain how the I_{sp} and *c* of Test Motor 1 compare to commercial motors[2] because of the error, although theoretically the boundary layer to the flame inside the combustion chamber should liquify and atomize, increasing surface area of combustion and increasing efficiency.

[1] Frequently Asked Questions on Explosives Regulations: Part 15 https://www.nrcan.gc.ca/explosives/acts-regulations/9843#p15

[2] Commercial motors with similar total impulse and average thrust, such as the Aerotech F-25 (specs here)

Evaluation of the Experiment

Although a very successful proof-of-concept, there are a few things that can be improved on. First, the oxygen mass could be measured with a scale. An accurate mass of oxygen used in a motor test would result in valid specific impulse (I_{sp}) and effective exhaust velocity (c) values. An average thrust column should also be added. This would help with calculating the rocket's acceleration and other parameters as we progress to later stages of rocket development.

The oxygen mass may not be measured for the remainder of tests with this motor due to the high costs associated with a scale that is accurate down to the gram and at the same time able to measure a maximum of more than 30 kg (oxygen tank is heavy). Also, the next test motor will utilize externally pressurized liquid oxygen, which would not require a scale to measure the mass (volume / density = mass).

There were 2 accident that occurred, both at connection points. In test 6, paraffin wax melted by the heat in the motor leaked out from multiple tiny gaps at the joint between the nozzle and the fuel casing (¾ inch steel tube). In test 7, the chamber pressure was too great for the acrylic tubing to withstand, causing it to expand and disconnect from the connector. Short term solutions were devised after tests 6 and 7, with teflon sealant being used to seal the joints and a reduction in chamber pressure (also causing a reduction thrust and I_{sp}) to reduce the expansion in the acrylic tubing. The problems in regards to structural failure at connection points were resolved, with the successes of test fire 8, where all connection points held throughout the test.