2022 End of Year Report

My objective for the year was to launch a class I rocket glider (the Mk I Viper). In accordance with the FAA regulation, the total mass can't exceed 1.5 kg including 125 gm of propellant. The hybrid rocket engine uses hydrogen peroxide (HTP) as the oxidizer and poly-lactic acid (PLA) as the fuel. The PLA is infused with $KMnO_4$ thus making it catalytic with the HTP. Also, I've added a small amount (O/F = 25) of ethanol to the HTP which results in a faster ignition time as well as increased performance. However, after a few launch attempts, I realized I didn't have enough thrust to exit the rail guide at the required velocity for aerodynamic control. I needed more thrust.

For aerodynamic control, the design of the Mk I Viper requires ~ 4 m/sec when it leaves the rail guide. I had selected, based only on pressure and video diagnostics, a stainless steel injector (SS) with a 1.0 mm orifice which has an initial flow rate of ~ 13.2 ml/sec at 140 psig. For the oxidizer, I used 50 ml of ~ 85% hydrogen peroxide with 2 ml of denatured ethanol (HTPE), O/F = 25. For the fuel, I used a 12.5 cm PLA/$KMnO_4$ fuel core with a five star grain configuration. At the end of the fuel core was a 2.3 cm in diameter 4.5 cm long CPVC mixing chamber, and then a phenolic nozzle with a 5 mm throat diameter (L* = 95 cm). Propellant tank pressure was ~ 140 psig. After adding a load cell to the test stand and doing a static test, I measured the thrust to ramp up from ~ 15 N to ~ 20 N. Fifteen newtons at ignition was just not enough to get the rocket glider to 4 m/sec as it exited the rail guide.

As such, I spent the rest of the year working on scaling parameters to decrease ignition time and increase thrust. I've narrowed the scaling parameters down to three, initial surface flux (ISF), length to diameter ratio (L/D), and initial throat diameter (ITD). I wanted to keep the mixing chamber length to 4.5 cm because by fitting the CPVC pipe into two CPVC couplings, the couplings added structural strength to the mixing chamber. I varied the L* by varying the throat area. For example, in the test above, the ISF was 0.2 $gm/cm^2/sec$, the L/D was 9.8, the ITD was 5.0 mm, and the L* was 98 cm.

The ISF, L/D, ITD, L*, and the resident time in the fuel core all work together to decrease ignition time and increase thrust. The most thrust I could get using the SS injector with a 1.0 mm orifice was ~ 19 N. I tried to increase the thrust by increasing the throat diameter to 6 mm (L* = 58 cm) and then to 6.7 mm (L* = 47 cm). But, still only got to ~ 19 N. Apparently, the mass flow rate during the burn drives the average thrust. Also, when I increased the throat diameter, my ignition time increased. I needed a longer oxidizer resident time in the fuel core.

Based on a suggestion from edzieba*, I introduced a variable orifice at the end of the fuel grain to reduce the initial flow rate thus increasing the resident time of the HTPE oxidizer in the fuel core. The previous test used a SS washer as a fuel core retainer. The SS washer was 2 mm thick with a 14 mm inner diameter. Preliminary experiments revealed that the ideal flow restrictor has a 5.0 mm orifice and is 2 mm thick. The flow restrictor is made of PLA. As such, it becomes part of the combustion process. I believe the edzieba flow restrictor will become an essential part of the fuel core, especially when I go to higher thrust and larger throat diameters.

To increase the thrust, I went to a SS injector with a 1.5 mm orifice. With this injector, the initial flow rate is ~ 21 ml/sec at 140 psig. I used the scaling parameters (ISF, L/D, and ITD) to increase the thrust of the HTPE/PLA hybrid rocket engine. I designed and printed a higher flux fuel grain and inserted a variable PLA flow restrictor at the end of the fuel core. My average thrust went from ~19 N to ~23 N and overall performance was on par with previous test.

The tables below show the most important test. It also shows how much work is left to do to finalize the scaling parameters for the Mk I Viper.

Tables I, II, and III below show the SS injector with a 1.0 mm orifice and Tables IV, V, and VI cover the SS injector with a 1.5 mm orifice. Where V_{dot} is the initial flow rate at 140 psig, L is the length of the fuel core, ISF is the initial surface flux at valve opening, d_{eq} is the equivalent grain diameter, and L/D is the length to diameter ratio. Optimizing the rocket engine using a 1.0 mm orifice gives ~ 19 N of thrust and optimizing the rocket engine with a 1.5 orifice gives ~ 23 N of thrust.

Table I

Noz Orifice (mm)	V_{dot} (ml/sec) @140 psig	L (cm)	ISF ($gm/cm^2/sec$)	d_{eq} (cm)	L/D
1.0	13.23	10	0.16	1.27	7.9

d_t (cm)	t_{ig} (sec)	L* (cm)	c* (m/s)	c^*_{eff}	O/F	Ref
0.55						
0.6	n/a	59.2	n/a	n/a	n/a	08/30/22
0.65						

Table II

Noz Orifice (mm)	V_{dot} (ml/sec) @140 psig	L (cm)	ISF ($gm/cm^2/sec$)	d_{eq} (cm)	L/D
1.0	13.23	12	0.14	1.27	9.4

d_t (cm)	t_{ig} (sec)	L* (cm)	c* (m/s)	c^*_{eff}	O/F	Ref
0.55						
0.6	1.4	58.3	1181	0.73	5.3	09/23/22
0.65						

Table III

Noz Orifice (mm)	V_{dot} (ml/sec) @140 psig	L (cm)	ISF ($gm/cm^2/sec$)	d_{eq} (cm)	L/D
1.0	13.23	12.5	0.13	1.27	9.8

d_t (cm)	t_{ig} (sec)	L* (cm)	c* (m/s)	c^*_{eff}	O/F	Ref
0.55						
0.6						
0.65	2.0	58.3	1560	0.98	5.2	09/27/22

Table IV

Noz Orifice (mm)	V_{dot} (ml/sec) @140 psig	L (cm)	ISF (gm/cm^2/sec)	d_{eq} (cm)	L/D
1.5	20.84	12.5	0.24	1.52	8.2

d_t (cm)	t_{ig} (sec)	L* (cm)	c* (m/s)	c^*_{eff}	O/F	Ref
0.55						
0.6	1.3	59.2	1508	0.94	4.1	08/18/22
0.6	3.5	59.2	961	0.6	10.4	09/07/22
0.6	n/a	59.2	n/a	n/a	n/a	09/09/22
0.65						

Table V

Noz Orifice (mm)	V_{dot} (ml/sec) @140 psig	L (cm)	ISF (gm/cm^2/sec)	d_{eq} (cm)	L/D
1.5	20.84	14	0.21	1.52	9.2

d_t (cm)	t_{ig} (sec)	L* (cm)	c* (m/s)	c^*_{eff}	O/F	Ref
0.55						
0.6						
0.65	0.83	54.2	1423	0.89	3.1	12/01/22

Table VI

Noz Orifice (mm)	V_{dot} (ml/sec) @140 psig	L (cm)	ISF (gm/cm^2/sec)	d_{eq} (cm)	L/D
1.5	20.84	15	0.23	1.52	8.2

d_t (cm)	t_{ig} (sec)	L* (cm)	c* (m/s)	c^*_{eff}	O/F	Ref
0.55						
0.6						
0.65	1.1	54.2	1584	0.99	3.3	10/26/22
0.65	1.4	54.2	1571	0.98	2.8	10/31/22

Finally this year, I've upgraded my rocket engine test. I now have 4000 psi reinforced concrete walls. I've mounted a steel test frame on one of the walls and now can test higher thrust engines (at least until the neighbors start complaining). I've run several test on it with load cell and pressure diagnostics and I'm getting more consistent data. As such, 2023 looks like it's going to be a fun year!

* edzieba, Reply #28, NASASpaceflight.com Forums>>General Discussion>>Advanced Concepts>> HTP/PLA/KMnO4 Hybrid Rocket Engine, 11/05/2021