UCIRP Propulsion Team Project Summary 2014-15

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Abstract

The objective of the UCI Rocket Project Propulsion Team was to design a liquid rocket engine that uses kerosene and liquid oxygen. The development of this engine will be used to create UCI's first liquid rocket engine and also to see how well our theoretical design calculations match with the actual rocket engine. The development of the engine was broken down to the major engine components of the nozzle, combustion chamber, ignition system and the injector plate. We will be designing this engine to conduct static test fires to measure total thrust output.

Introduction

The fundamental principle of Rocketry lies in the discovery of Sir Isaac Newton's third law of motion that states "for every action there is an equal and opposite reaction." Propellants, typically a mixture of fuel and oxidizer, are combined in a combustion chamber where they chemically react to form hot gases which are then accelerated and ejected at high velocity through a nozzle. The ejection of the hot gases imparts momentum to the engine which in turn is the thrust force that propels that rocket upward. The thrust force of a rocket motor is the reaction experienced by the motor structure due to ejection of the high velocity matter.

The goal of developing the liquid rocket engine will allow us to perform a static fire test to test the feasibility of our engine design. A static test fire is when a rocket engine is ignited for a short period of time to see if the engine is operating correctly and once it is deemed fully operational, the burn sequences are lengthened to measure thrust output. In years past, UCIRP has launched several solid engine rockets but because we are creating a new engine design, we plan on testing its performance before we attach it to an airframe. In doing, so we will also need to create a static fire test stand. The test stand will allow us to mount the rocket engine along with the propellant tanks so that we can measure vital performance data. The development of this rocket engine and its test stand will be a joint project with the Friends of Amateur Rocketry which will help provide a foundation for better liquid rocket engine development at UCI.

Engine Design Layout

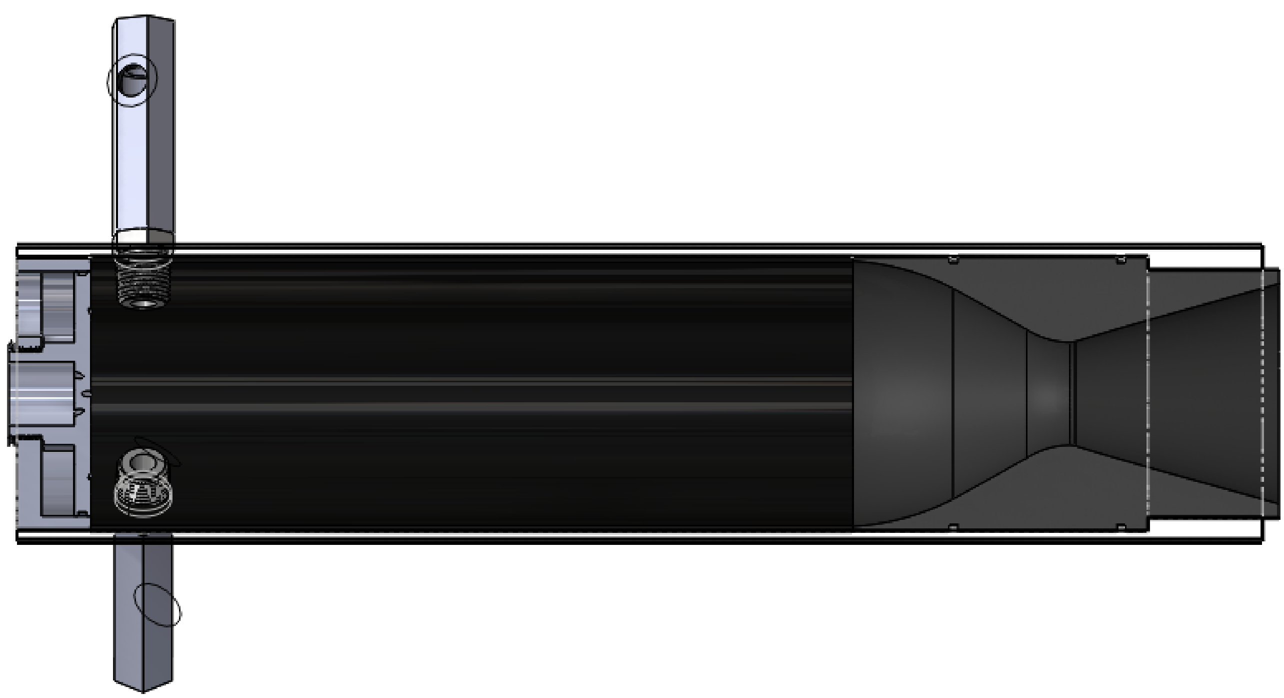

Figure 1: Proposed JP4-LOX Engine Layout

Engine Design Details

Nozzle

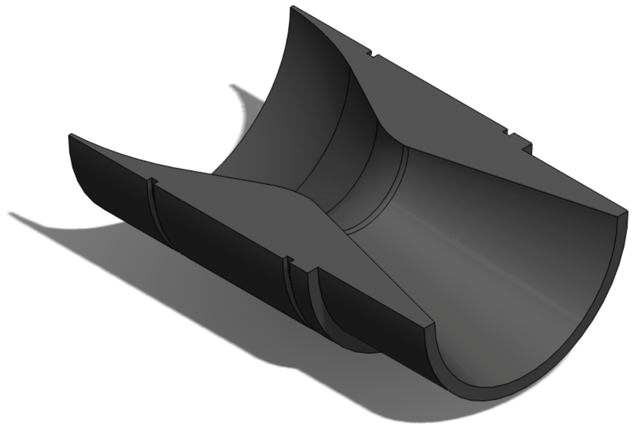

Figure 2: Extruded Graphite Nozzle

In our efforts to design UCI's first liquid rocket engine, we chose to design our rocket engine around the nozzle. The function of the nozzle is to convert the chemical-thermal energy generated in the combustion chamber into kinetic energy. The nozzle converts the slow moving, high pressure, high temperature gas in the combustion chamber into high velocity gas of lower pressure and temperature. By rapidly expanding the gases, the nozzle produces the thrust needed to launch the rocket. Last year we designed and optimized the nozzle and had it professionally manufactured. The graphite nozzle is currently designed to operate at temperatures in excess of 2500K and produce supersonic exhaust flow. The nozzle is intended to provide the basis for design the other engine components.

Design & Fabrication Status: Both Completed

Combustion Chamber

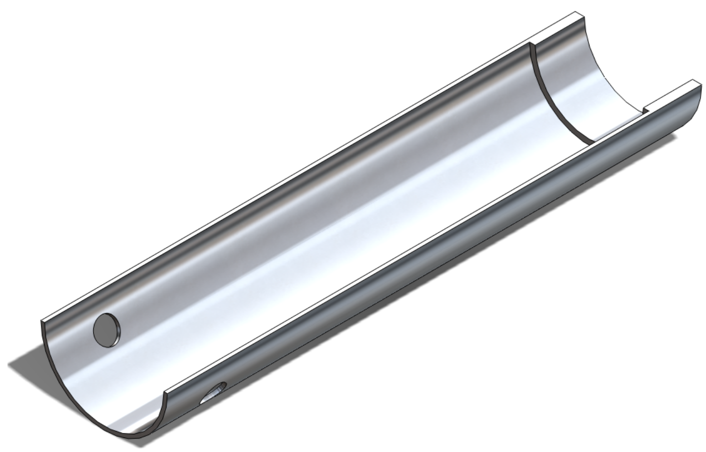

Figure 3: 6061-T6 Combustion Chamber

The chamber is designed for a pressure fed engine that will rely on Kerosene and Liquid Oxygen (LOX). It will consist of an aluminum 6061 cylinder of 0.125 in thickness (at its thinnest) that will house the nozzle on one end of the cylinder. The length of the chamber is 18 inches; the dimension was calculated based on the characteristic length equation. There were two major design considerations that were taken into account for the design of this chamber, which were thermal stress and the hoop stress (2) that the wall will experience. We designed in order to keep the Wall stresses under the yield stress of aluminum and to keep the temperature at the wall less than the melting temperature of aluminum. The team will still need to run simulation on software such as SolidWorks and Abaqus to see if our design parameters check out with the current calculations.

Design & Fabrication Status: Both Completed

Ignition System

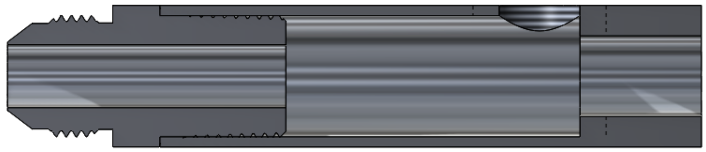

Figure 4: Ignition Chamber with AN-8 Fitting

In order for our engine to produce thrust, the liquid propellants fed into the chamber need to be supplied energy to initiate the hydrocarbon combustion reaction. The ignition system is responsible for taking liquid kerosene and oxygen and converting it into hot and fast moving water vapor and carbon dioxide. The ignition should occur within .1 seconds after propellants are injected into combustion chamber to avoid a hard start according to Jacob's Rocketry website. A hard start can occur if the ignition is late and there is too much propellant injected into the combustion which would lead to over-pressurization of the combustion chamber. A hard start could also lead to a lower impulse which would make our rocket inefficient. For our current design, we will be using three D5-P Apogee Quest Motors, solid propellant grains, to ensure ignition of our engine's propellant streams.

Design & Fabrication Status: Design Completed & Fabrication Pending

Injector Plate

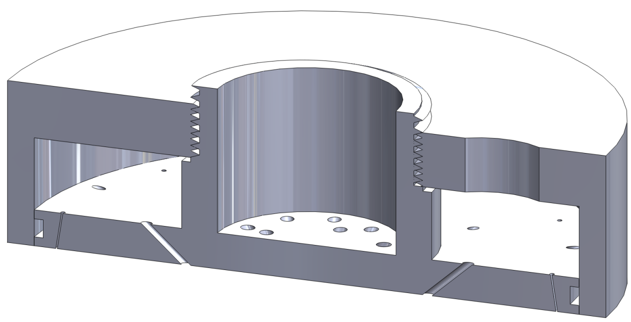

Figure 5: 6061-T6 Injector Plate

The injector, at this point in time, will be a bi-propellant injector with a solid propellant igniter. The injector will inject streams of each propellant in to the combustion. Fuel and oxidizer streams will meet (impinge) at several concentric points where they will then atomize each other, resulting in a fine mist. From there, the mist will be ignited by the solid propellant grain and then expelled out of the nozzle of the rocket. The injector will need to be able to sustain a calculated mass flow rate which will give the rocket the desired performance output. A steady propellant injection system will also help minimize any over designing necessary in the combustion chamber due to combustion instabilities which could cause hot combustion zones risking the integrity of the entire rocket engine.

Design & Fabrication Status: Design Completed & Fabrication Pending

Testing

Combustion Chamber

When designing the combustion chamber, we used a combination of structural mechanics and thermodynamics to help determine the limits of the material performance. Using the proposed design requirements, we created a MATLAB program to optimize the combustion chamber geometry by accounting for basic yield theory and heat transfer. Once we gathered preliminary data from the program, we used the SolidWorks FEA simulation package to verify the accuracy of our initial design.

Injector Plate

The injector plate underwent the most extensive design optimization and testing. Similar to the combustion chamber, we created a MATLAB program that used basic incompressible pipe flow theory to determine the overall head loss within our injector design permutations. Our injectors were designed to experience a 25% head loss but that will eventually need to be verified via cold flow testing. Even though we could not immediately fabricate an aluminum injector plate, we 3D-printed an ABS injector to initially check for design flaws. When the aluminum injector plate is completed, we intend to match the design pressure and expect to measure the head losses in the orifices.

Figure 6: ABS-Injector Cold Flow Test

Figure 6 clearly shows that our first injector design experienced major flow leakage on the outer walls and provided valuable insight into how to improve our design. This design relied on four individual plates however, as shown in Engine Details section, our finalized injector design only requires two plates. With our injector design finalized, we are currently waiting for the fabrication of the plate and expect to verify the actual head loss of the injector and compare it to our theoretical values.

Limitations & Lessons Learned

ITAR Regulations

At the beginning of the year, our preliminary engine design relied on using Kerosene and Hydrogen Peroxide however after speaking with Marci Copeland (Export Control Officer), we quickly learned that 85% Hydrogen Peroxide is a military controlled substance. Additionally, the potassium permanganate catalyst that we had proposed to use also was controlled therefore we decided to redesign our engine after talking with Marci. This was a major turning point in the development of our and engine and ended up providing us with valuable knowledge regarding ITAR controlled materials and substances.

Manufacturing Availability

After we learned about controlled Military substances, our next major limitation this year dealt with the availability of machine time. Between FABWORKS and the Mechanical Shop in ET, we had limited opportunities to fabricate our parts, namely the injector plate and combustion chamber. It was expected that we would have immediate access to the fabrication labs however because of class conflicts and lack of machine setups, we were unable to fabricate the injector and combustion chamber ourselves.

Bill of Materials

Presented below is our most current total of our bill of materials for the 2014-15 school year.

Part	Dimensions	Quantity	Manufacturer	Part ID	Cost
6061-T6 Al Circular Pipe	18.00” × 4.5” × 0.337”	1	Metals Depot	T3480	$77.18
Carbon Fiber	–	–	–	–	–
Epoxy	–	–	–	–	–
Flared Tube Fittings	AN8	5	McMaster-Carr	2227K13	$35.75
Flared Tube Fitting Plugs	AN8	3	McMaster-Carr	2227K53	$11.67
Neoprene O-Rings	$D_o \times D_i = 0.625" \times 0.5"$	100	McMaster-Carr	94115K014	$2.85
7/8” 6061 Aluminum Hexagonal Bar	L = 1 ft 6”	1	Discount Steel	ASTM B221-08	$10.61
D5-P Quest Motor	18mm	4	Apogee Rockets	5760	$24.00
Neoprene O-Rings (Pack of 15)	ID = 4” OD = 4.25”	1	Mcmaster	94115K514	$10.88
Neoprene O-Rings (Pack of 15)	ID = 1.5” OD = 1.625”	1	Mcmaster	94115K029	$13.48
4.25” 6061-T6 Aluminum Round Bar	L = 8”	1	Discount Steel	ASTM B221-08	$53.05
Ultra Temp 391 Ceramic Tape	$A = 2.1458\,ft^2$	1	Cotronics	391W-1	-
Neoprene O-Rings (Pack of 10)	W = 3/32”	1	Mcmaster	AS568A-155	$9.78
Jet Fuel (JP-4)	$\$3.84/gal$	2.01168 L	Local Airport	$9130-00-256-8613$	$2.04
Liquid Oxygen (LOX)	–	3.39507 L	–	–	–
Total Cost					**$251.29**

Conclusion

Currently, our nozzle and combustion chamber have been fabricated and the injector plate and ignition chambers are in the process of being fabricated. When the parts are fully fabricated, the ablative liner for the combustion chamber will be the only remaining part for a complete engine. Throughout the year we had the opportunity to not only redesign a liquid rocket engine but we also got to carry out in depth design optimization and analysis. In doing so, we have created the foundation for future liquid rocket engine development at UCI and hope this well continue on for years to come.

Future Plans

Listed below are the Propulsion Team’s future course of action:

- Finish fabrication of injector plate and ignition chambers
- Finish lay-up of ablative liner for combustion chamber
- Purchase JP4 and LOX, transport to F.A.R facility
- Carry out Static Fire Test
- Record nozzle erosion and thrust output of engine
- Begin engine design improvement with new data from static fire
- Begin integration of engine into airframe; begin working on mandrel for Carbon Fiber Ablative Engine

References

[1] Anderson, John D. *Modern Compressible Flow: With Historical Perspective*. Boston: McGraw-Hill, 2003. Print.

[2] Munson, Bruce Roy, T. H. Okiishi, Wade W. Huebsch, and Alric P. Rothmayer. *Fundamentals of Fluid Mechanics*. Hoboken, NJ: John Wiley & Sons, 2013. Print.

[3] Sutton, George Paul, and Oscar Biblarz. *Rocket Propulsion Elements*. Hoboken, NJ: Wiley, 2010. Print.