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Igniter Documentation and Recommendations

Background Info

Liquid propellant rocket engines require a high energy ignition source. An inadequate source of ignition can lead a hard start, or the engine failing to ignite entirely. A hard start occurs when two combustion wavefronts exist in the combustion chamber due to pooling of the propellant mixture. In the best-case scenario, a hard start means rapid expulsion of gas from the engine resulting in a flameout. The worst-case scenario is catastrophic engine failure.

The common ways to ignite rocket engines are as follows:

- Pyrotechnic ignition – a glorified firework shoved up in thru the nozzle. An electric "match" lights it and then it lights the propellants coming out of the pintle. When the engine lights, it blows the whole thing out of the engine.
- Hypergolic ignition – Substances that spontaneously ignite when mixed together. This is a very reliable way to create ignition, but the substances used in this are very dangerous most of the time. Because of this, we decided not to pursue this route.
- Augmented Spark Torch Igniter – Uses a spark plug to combust fuel and oxygen in a small combustion chamber behind the rocket engine. This blows into the rocket engine through the back usually, like a torch

Augmented spark torch igniters are ideal in a lot of ways. For one thing, they are a reliable source of ignition, and if properly designed, are very repeatable (I.E won't cause hard starts). Also, for engine testing, it means you can have multiple burns in a quick succession without having to manually "reset" the igniter.

A good source for info on augmented spark torch igniters:

http://www.watzlavick.com/robert/rocket/

The engine that was designed for PSAS has a pilot hole in the back of it for an augmented spark torch igniter. This was the initial plan for igniting this engine, but as the 2.2kN engine is so small, it became clear that in order to mount the pintle with the correct pressure taps, it was going to be extremely difficult to fit the igniter. Furthermore, our capstone was on an extreme time crunch, and it would greatly simplify the test stand's plumbing, and would be quicker/easier to design in general.

Discussing this with the engine capstone team, they said that the igniter hole in the back of the engine was put in place so that we would have the option of using an internal AST Igniter, but it was not required in order to light the engine. Because of this, we decided to go for an external ignition system (see fig. 1).

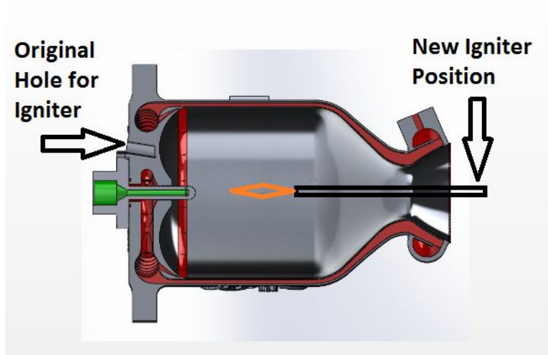


Fig. 1: New proposed igniter position

Using an external ignition system on the rocket has a lot of benefits. Besides the mention about not having enough room in the back, benefits include:

- Simulating the ignition of the engine in the rocket – For weight savings, the engine that will be used in the final rocket will almost certainly have an external ignition. By using an external ignition source for the tests, we can see how well an ignition system works before using it on the rocket itself.
- If “catastrophic engine failure” happens, the igniter will be out of the way of the engine (instead of bolted to the back of it). This means that it has a much better chance of surviving.
- It gives us options for the ignition (we can use pyrotechnic or AST).
- If we use a torch ignition system, the fuel and oxidizer no longer need to be at 450+ psi, as it no longer remains in the combustion chamber after ignition.
- It can be much less complex than an internal ignition.

The largest difficulty of having an external ignition is resetting the igniter for subsequent engine tests.

Igniter Arm Design

To hold the igniter that we decide to use in place, we designed a hinged arm that would mount to the frame of the test stand. A solid metal hinged arm could protect any fuel/oxygen hoses from potential flame, and it would be easy to reset the igniter to the correct location. Our design would be spring-loaded, so that if it fails, the arm’s natural position is away from the engine. It would be held in place by an electromagnet, which is strong enough to hold against the force of the unburnt fuel and oxidizer spraying against it, but weak enough so that when the engine ignites, the arm will swing out of harm’s way. A mockup of this arm is shown in fig. 2.

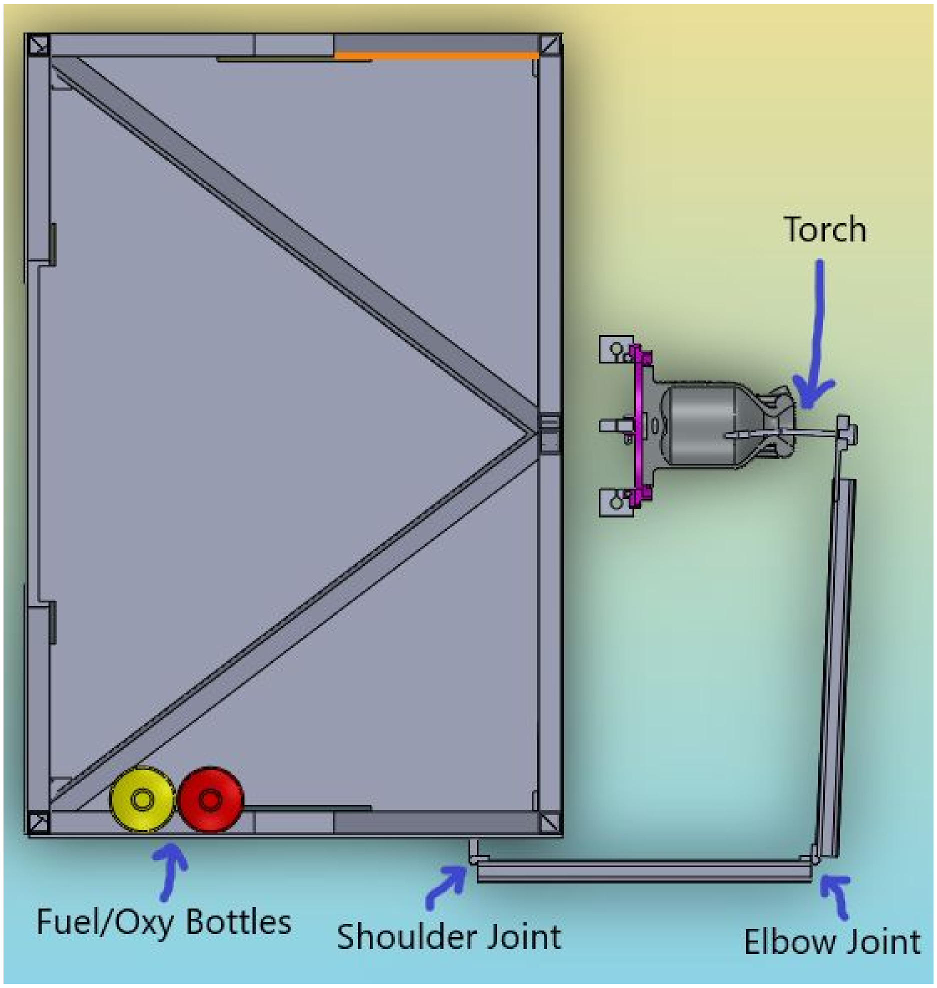
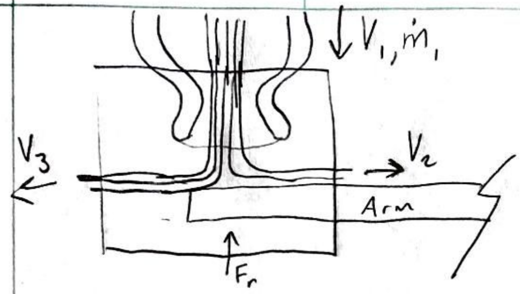


Figure 2: Cad Mockup of Igniter Arm. Electromagnet will be positioned on "forearm".

A CAD mockup of this armature can be found in the LFETS git folder, under "igniter".

We did some fluid momentum calculations to see how much force is applied to the arm prior to combustion. The results are shown below:



Assumptions:

1.) All fuel will shoot against arm

2.) $\rho_{fuel} = \rho_{water}$ (pintle test data)

3.) No LOX will shoot against arm (reasonable assumption as it is spraying orthogonal to fuel)

4.) $V_2 = V_3$ (all x axis momentum vectors will cancel each other i.e. fuel will spray all directions evenly when it hits arm.)

$$\dot{m}_1 = 0.5262 \text{ kg/s}$$

$$V_1 = 13.6 \text{ m/s}$$

$$\Sigma F = 0 = F_r + \int_{cs} u \rho V \cdot \hat{n}\, dA$$

$$-F_r = V_1 \rho (-V_1) A_1 + V_1 \cancelto{0}{\cos(90)} \rho V_1 A_2$$

$$\rho V_1 A_1 = \dot{m}_1$$

$$F_r = \dot{m}_1 V_1 = (0.5262 \text{ kg/s})(13.6 \text{ m/s})$$

$$F_r = 7.16 \text{ kg}\cdot\text{m/s}^2 = \boxed{7.16 \text{ N}}$$

$$\text{or } \boxed{1.61 \text{ lbF}}$$

For a factor of safety of 2, we should design to withstand 3 lbf.

These calculations show that there will be about 7.16N or 1.61lbF on the arm prior to combustion. To provide a factor of safety of 2, we should design for about 3lbF pushing at the end of the 18” forearm.

The electromagnet that was purchased was advertised as a 55lb magnet but testing of the holding force of the magnet on the actual arm showed that the magnet let go at about 15-20lbF. This means the electromagnet should be placed at least 4” away from the fulcrum point to provide enough holding force for the arm.

The elbow joint of the arm has already been assembled in a way that minimizes play in the hinge joint. It resides in the LFETS cabinet of the rocket room. See Fig. 3:

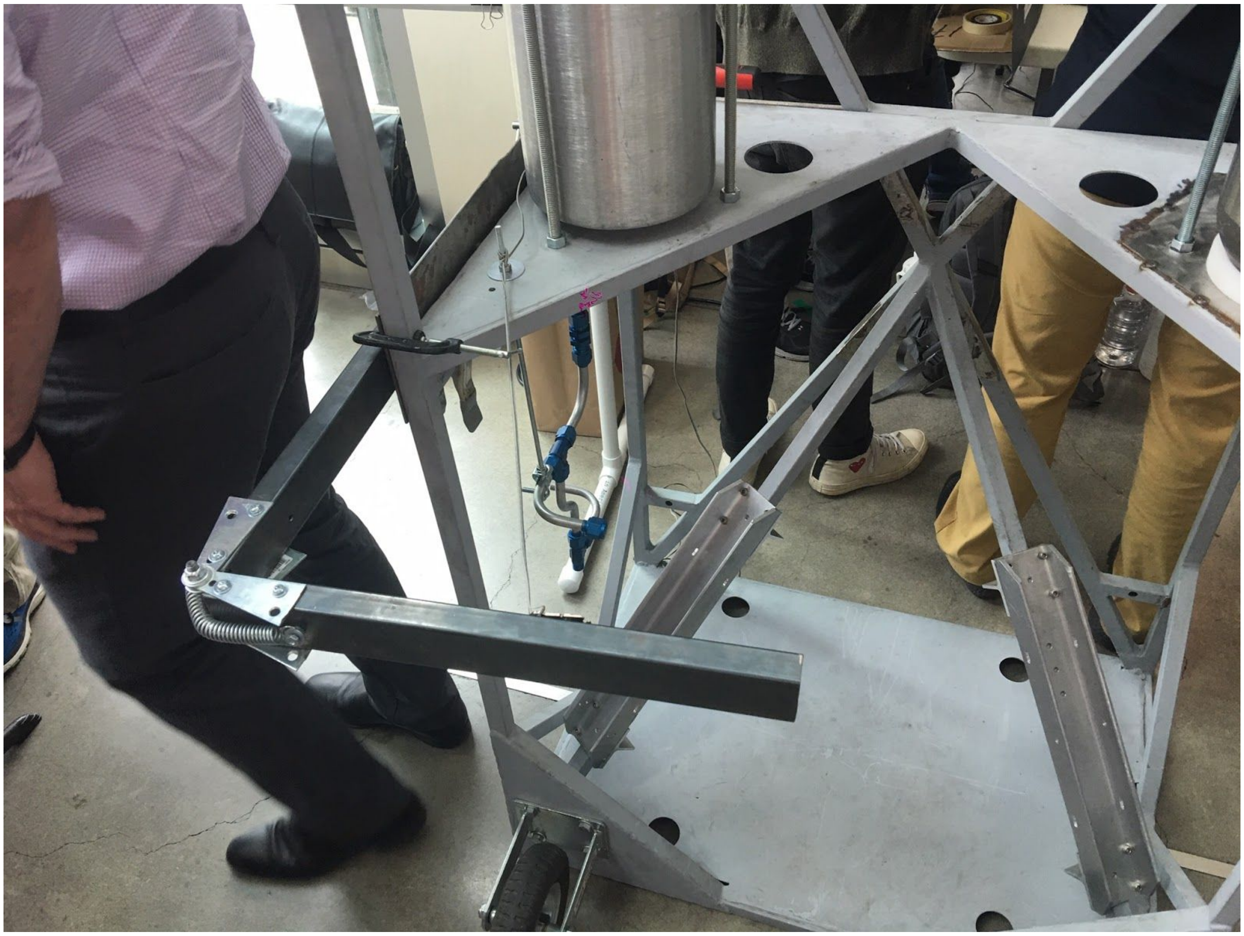


Fig. 3: First Iteration of arm construction. Position on stand should be reversed 180 degrees, so that it will be directly outside of the engine.

Ignition Source

The igniter arm could be used with various ignition sources. The latest design iteration for an ignition source consists of a modified brazing torch placed on the end of the arm, used a bit like an augmented spark torch igniter. This design is subject to change based on the results of further tests (ex. hot flow pintle test).

The brazing torch will be grounded and an insulated wire will be brought out to the end of the nozzle of the torch. A model airplane ignition attached to a servo PWM generator will be used to generate a near-continuous spark at the tip of the torch to ignite it.

The fuel and oxygen supply will be mounted to the stand, regulated, and then attached through 2 solenoid “GEMS” valves. The fuel and oxygen lines will then be attached to flex line ran through the arm and out to the torch body.

Almost all of the parts have been acquired for this ignition system, apart from the material for the torch body or any experimental torch tips that we would like to try. However, it has not been assembled yet.

A concern of this design is that the torch flame may get “blown out” prior to ignition. Another concern is that the pintle may get overheated. Because of this, the design should be validated at first by itself, and then in a **hot flow pintle test**. This test consists of firing the pintle injector without the engine. A slow motion camera should be pointed at the pintle during this test so that the ignition flame front can be observed. The ignition of the propellant of this test should have a single flame front, and should consistently ignite the propellants in each test.

As a backup strategy, pyrotechnic ignition may be a good option, although this has not been explored as much. In a pinch, a decent pyrotechnic ignition option might be a road flare or sparkler with an electric match on it. Any pyrotechnic ignition could be easily adapted to fit the end of the arm.

Recommendations:

My recommendations regarding the igniter are dependant on a few things. First of all, I think **there is value in completing the design of an internal spark torch igniter**. The benefits of the predictable, repeatable ignition source make it worthwhile for future engine testing, and a well designed internal spark torch igniter can be used throughout multiple engine iterations.

With this being said, **I would recommend that the design and construction of an internal spark torch igniter should be its own capstone project**. Although the design of a spark torch igniter has already been started by Adam Harris, there is enough iterative design work and testing involved that it should keep a capstone team busy for a year, and if they finish early, they could explore pyrotechnic ignition as a backup strategy.

If PSAS decides to go this route, PSAS’ next iteration of engine should have more care taken for the interface of the igniter to the back of the engine. I believe it would be easier to design the igniter first, and then design the engine considering the position and mounting of the igniter.

However, **if an engine is to be tested prior to an internal spark torch igniter capstone, the armature/external ignition system should be developed/used**. Although this ignition system is much more crude, it is simpler and less time consuming to design, and a large portion has already been designed. As previously stated, the biggest issue with the external ignition arm design is the fact that it needs to be reset for each successive engine test. This is the largest design obstacle to overcome.

An option for resetting an external ignitor that I was thinking about is a winch system to pull the arm back into place.