Torch Ignition

Preliminary Design Review

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Introduction to the Torch Igniter Assembly

Overview of TIA, what system reqs in place?

- Purpose of ignition is to light LOX/CH_4 mixture in combustion chamber
- Ignition Assembly should be separate from combustion chamber of engine to avoid localized ignition of liquid propellant
  - This could damage chamber walls, causing failure
- Timing of ignition and propellant introduction into combustion chamber extremely important
  - Excess of either propellants can cause “hard start”

[1]

RPL

Types of Ignition

Pyrotechnic Ignition - Premixed solid oxidizer and fuel combination. No need for fuel lines. Most pyrotechnic igniters are single-use.

Catalyzed Ignition - Combustion achieved catalytically. Research is ongoing in this field of ignition.

Plasma Torch Ignition - Creates a high temperature plasma flow using large amounts of electrical energy. Use of one of the propellants possible.

Acoustic Ignition - Creation of standing waves to energize and heat the gaseous mixture of our propellants and induce combustion.

Augmented Spark Ignition - Utilizes on-board propellants and a spark to initiate and build the necessary power release level to ignite the main propellant in a timely manner.

[2]

Why Augmented Spark Torch Ignition?

Our Augmented Spark Torch Ignition method allows for the use of our propellants, rather than additional and distinct reactants.

Augmented Spark Ignition has shown to be extremely reliable and reusable, and allows us to initiate multiple engine restarts during flight with no excess reactants.

This form of ignition has been used by NASA since the late 1970s

[3]

Design Aspects

- Design based off previous NASA designs of LH_2/LO_2 and LCH_4/LO_2.
    - Three segments: upper flange, combustion chamber, injection tube.
    - Use of swirl inducing fuel inlets for film cooling of combustion chamber and cooling jacket for cooling of injection tube.
- Coaxially fitted within injector, both coaxially along TCA.

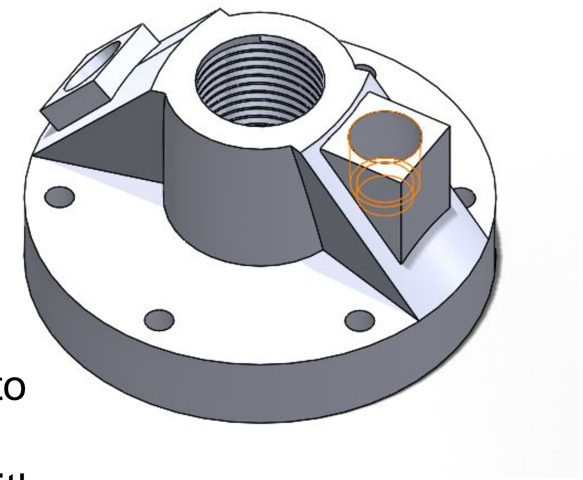
General Specifications

Dimensions

- 2 inch outer diameter.
- ~3 inch body length.
- ~0.5 $inch^3$ chamber volume.
- 0.95 inch chamber diameter.
- 0.70 inch chamber length.
- 6.12 W power draw for spark plug.

Upper Flange

- This part is used to house the spark plug and inject the LOX/CH_4 propellants
  - Where the magic happens
- In our design of the flange, there are 3 points of fuel injection:
  - Two impinging flows from the top surface, angled to combine the propellants just below the spark plug
    - The LCH_4 flow will be split to fill a reservoir with tangential ports to the combustion chamber that will be used for swirl cooling
  - One just below the combustion chamber to offer cooling to the flame tube (not on this part)
- Portion of combustion chamber resides in this part
  - Fastened to rest of chamber using six bolts and sealed with teflon O-ring



Spark Plug

Sits at the top of the assembly, inside the flange.

- Provides required activation energy to initiate combustion in the chamber.
- Simple, cheap, reliable, high degree of control.

NGK 2322 BUE surface gap plug selected.

- Analogous spark plug used in NASA LH2/LO2 igniter.
- Surface gap type prevents any interfering structure normally present in automotive spark plugs.

[1,6]

Tapped Combustion Chamber

“The hole into which the torch ignitor tube is inserted must have the raised lip shown in figure 9 for proper operation; this provides a small manifold for the cooling hydrogen” (Repas, 1994).

The tap feeds into the raised lip connecting the combustion chamber and the igniter tube, allowing fuel to flow into the reservoir around the flame tube of the combustion chamber.

Contains interfacing structures for chamber pressure transducers.

The combustion chamber is sized properly for complete combustion of the propellants.

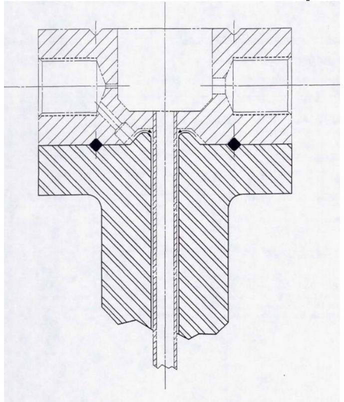
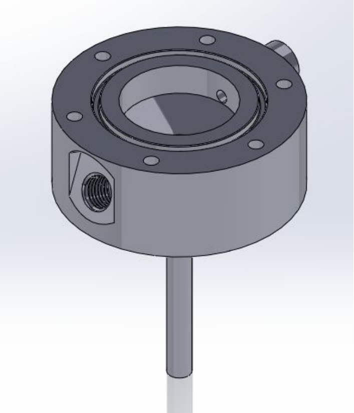


FIGURE 9

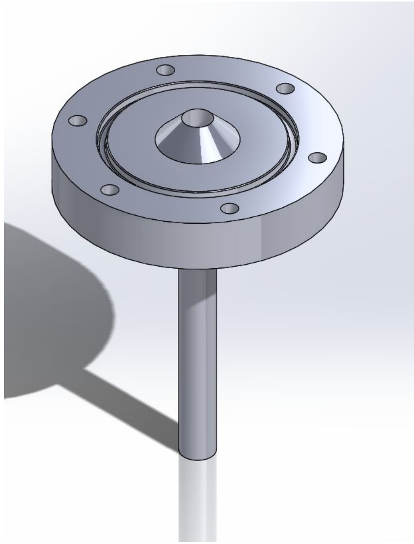


Ignition Tube

This component’s sits at the base of the igniter assembly and has multiple functions.

- Create a cooling jacket which surrounds and cools the main igniter tube using cryogenic methane.
- Provide an interface and seal between igniter assembly and thrust chamber.
- Inject surplus fuel into main ignition stream to further facilitate uniform ignition of TCA.

To make this design more flush with the injector and TCA of the main engine, this component may be coaxially built-in to the top of the injector, allowing the other components to be attached via simpler methods



Why - methalox

- Intermediary between the density of hydrocarbons and the performance of hydrogen
- Safer than hydrogen
  - Lower ignition temperature, more stable.
- Higher specific impulse
- Recent successful precedence in industry (SpaceX Raptor)
  - Can be manufactured on Mars

[5]

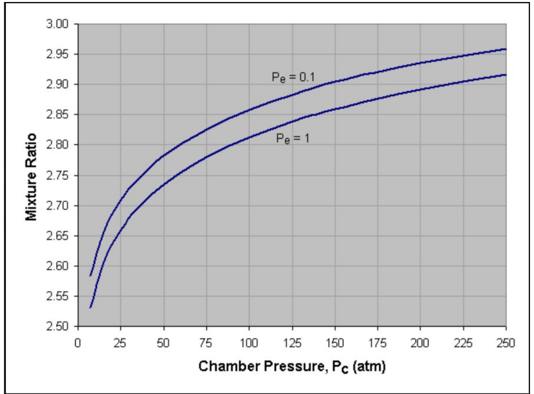
*As outlined by TCA team

Why- 294 psi Chamber Pressure

294 psi, or ~20 atm, is an extremely safe level of pressure for the materials we chose to use. For reference, the tensile strength of human skin is 2900.75 psi.

This pressure corresponds with a mixture ratio of ~2.60, as well as ~5 lbs of thrust we desire.

[4]



Why 5 lbs Thrust?

Setting our thrust value at 5 lbs is most favorable for our design and manufacturing needs.

In terms of design, 5 lbs provides ample force to propel our combustion though the igniter tube and into the main Thrust Chamber Assembly.

At a lower thrust, the sizing of our combustion chamber, and overall igniter assembly, was simply too small for our purposes.

Timing

The timing mechanism is integral to the proper function of this device.

Timescale resolution on the order of milliseconds and operation complete in under 1 second.

General overview of operational sequence:

- Cooling jacket fuel line open.
- Combustion chamber fuel lines open.
- Spark plug fire and ignition of igniter chamber.
- Combustion chamber fuel lines close, chamber pressure drops to extinction.
- Cooling jacket fuel line closes.

These sequences are on the order of milliseconds [1,2]

Materials Choice: Inconel 718

According to George A. Repas, the igniter tube is the most vulnerable part of the assembly. Initially, NASA used Nickel for the tube; however, nickel could be easily bent.

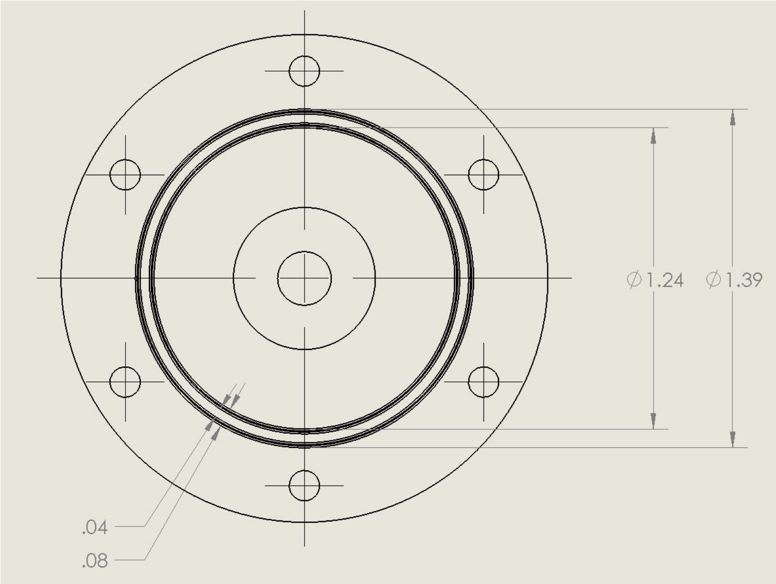
Haynes 188 alloy was substituted in as it was a stronger material, and lasted about 4 times as long. (~400 firings versus ~100 firings)

Haynes 188 has excellent oxidation resistance, cryogenic temperatures do not significantly affect its ductility, but its strength levels are increased measurably. **[3]**

However, for consistency, we **will use Inconel 718**, as with the rest of our engine. Inconel 718 is also a readily 3D-printed material, which is optimal for the manufacture of the Igniter flange, and very similar in its strengths to that of Haynes 188.

PAI O-ring type 1-026 used **[8]**

Metal O-Rings (Teflon coated) should be used between parts of the assembly as outlined here:



Tolerances +/- .003

Method of Manufacture

Additive Manufacturing: Our Igniter Flange part will absolutely need to be additively manufactured due to its complex geometry.

CNC Milling could be used on the Igniter Chamber and Igniter Tube, as they are relatively simple geometries.

According to Repas, assembly of the torch ignition tube to the combustion chamber must be done with E.B. welding or with a very high temperature furnace braze. [1] Because of this, we have decided that the igniter tube would best be assembled if it were a part of the injector assembly.

It's very difficult to work Inconel 718, and thus quite expensive to manufacture using traditional methods. Inconel 718 requires longer times to cut than traditional metals due to being a high-temperature metal alloy.

Traditional Inconel 718 Manufacture

We will need to use a specialized ceramic inserts and methods for Inconel 718 milling. According to [9], maximum insert life is ~50 minutes, thus we will need multiple ceramic inserts

Welding Inconel

The interface between the igniter combustion chamber and igniter tube that could end up built into the engine injector may need to be welded to avoid having bolts/screws on the inside of the injector.

More research needs to be done to decide if the inconel will be welded or if a brazen weld can be used.

Traditional Manufacturing of Inconel 718 Costs

KY2100 Carbide Inserts are Specific for Inconel 718 Machining:	~$25 (multiple) [10]
KC5510 Ceramic Finishing Insert:	~$20 (multiple) [11]
Machining Inconel 718 Requires Slower Speeds (Exact times unknown)	
Hourly Cost of Machining:	~$120 - $300 [12,13]
End Cost:	~$700 - $2500 [13]

Interfaces

Injector Assembly - Our Torch Igniter will fit centered coaxially within the injector. We ensure the plates between the two assemblies are smooth and tightly bolted together.

Propellant Plumbing Assembly - The igniter will share propellant flow from the plumbing assembly, and thus plumbing must exist between the igniter and the propellant tanks.

Control Systems: Proper control of valves, spark plug function and relative timing with internal and external mechanisms.

Risk Assessment

Non-steady state design, operation for durations >2 seconds may induce structural failure.

Improper function can result in an engine damage, hard-start and/or catastrophic failure. [2]

Too much pressure (too long of a start up time before spark).

Risk Abatement

Avionics team will have full control over fuel flow to the igniter. Safety checks, and very specific timing will be executed via computer; allowing for safe and effective ignition.

Utilizing Pressure transducer data acquisition, we’ll obtain thorough information through testing. This will allow us to determine optimal operational/design parameters.

We will maintain a safe chamber pressure of 20 atmospheres (~294 psi) for <2 seconds for our ignition combustion. This is achieved through avionics’ System Control over our propellant flow.

Material Cost Analysis

Additively Manufactured Igniter Assembly

$192/kg

Minimum Material cost estimate:

0.6033 kg * $192/kg = $115.83 * 1.4 (FOS)

= $162.17

[7]

Additively Manufactured Igniter Flange

Density: $8220 kg/m^3$
Exact Volume: $1.26\ in^3$ = **$2.065E\text{-}5\ m^3$**
Exact Mass: $(2.065E\text{-}5\ m^3)*(8220 kg/m^3)$ = **0.180 kg**
Minimum Material Cost: ($192/kg) * (0.180kg)
=**$32.59**

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Mass properties of Assem1
    Configuration: Default
    Coordinate system: -- default --

Mass = 1.33 pounds

Volume = 4.51 cubic inches

Surface area = 48.91 square inches

Center of mass: ( inches )
    X = 1.08
    Y = 3.19
    Z = 1.77

Principal axes of inertia and principal moments of inertia: ( pounds * squa
Taken at the center of mass.
     Ix = ( 0.04,  1.00, -0.08)      Px = 0.68
     Iy = (-0.34,  0.09,  0.94)      Py = 0.73
     Iz = ( 0.94, -0.01,  0.34)      Pz = 0.76

Moments of inertia: ( pounds * square inches )
Taken at the center of mass and aligned with the output coordinate syste
    Lxx = 0.76          Lxy = 0.00          Lxz = -0.01
    Lyx = 0.00          Lyy = 0.68          Lyz = 0.00
    Lzx = -0.01         Lzy = 0.00          Lzz = 0.73

Moments of inertia: ( pounds * square inches )
Taken at the output coordinate system.
    Ixx = 18.52         Ixy = 4.61          Ixz = 2.54
    Iyx = 4.61          Iyy = 6.41          Iyz = 7.52
    Izx = 2.54          Izy = 7.52          Izz = 15.89
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