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Design of a 2kn Liquid-Fuel Rocket Engine Propellant Injector-Part 2

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ABSTRACT

This paper presents a preliminary design for a small propellant injector designed using SolidWorks. The propellant injector is designed for a pressure fed (blow-down) system, and is expected to operate at a chamber pressure of 1MPa, whilst providing a thrust of 2KN, the operating time is designed not to exceed 20s. A spray nozzle orientation type was selected for this design with a target combustion efficiency of 95% and nozzle efficiency of between 80-90%, all of these corresponded to a specific impulse (I_{sp}) of 216.16s, while the propellant injector was designed to utilize a combination of gaseous oxygen (GOX) and Kerosene ($C_{12}H_{26(liq)}$) as its propellant. The design is intended for a semi static test with steel (AISI 1035 SS) specified as the material for the design. The propellant injector weighed 3.96208kg. The Danfoss oil nozzle type OD was considered as the spray nozzle option for the injector design. The oil nozzle is to be used to atomize the fuel (kerosene) and oxidizer (oxygen) at high pressures; and because it was crucial to avoid scrubbing of the chamber wall by high-temperature oxidizing streams, a cooling bias due to maldistribution was proposed, and since the Danfoss nozzle had suitable atomization capacities the size and weight of pressure vessels would be minimized. It is also important to note that the injector implementation in liquid rocket engines; determines the percentage of the theoretical performance that the nozzle can achieve.

Keywords: Liquid fuel rocket engine, Propellant injector

I. INTRODUCTION

In a liquid rocket engine, the injector injects the correct amounts of propellants into the combustion chamber, atomizes, and combines the propellants (fuel and oxidizer) to achieve efficient and stable combustion that provides the required performance without jeopardizing hardware durability (Gill, et al., 1976) (Dieter, et al., 1992) (Anderson, et al., 2004).Injectors are typically a perforated disk located at the forward or top end of the combustion chamber, with diameters ranging from a few inches to over a yard. The injector also serves as a structural component, sealing the top of the combustion chamber against the high pressure and temperature inside the combustion chamber(Anderson, et al., 2004) (Dieter, et al., 1992) (Gill, et al., 1976).The injector's design, along with the injection pressure drop and propellant properties, determines the delivered performance (Isp), propellant mass distribution and spray drop size distribution for liquid propellants. The injector also determines the maximum achievable combustion efficiency, the heat transfer rates to the combustion chamber walls, and the maximum achievable thrust. Because well-designedinjectors canhaveawide range of combustionefficiency in different applications, thetype ofinjectorelementanditsspecific designisdependenton the:

- Chamberdiameter,
- Chamberpressure,
- Oxidizer-to-fuelmassratio,
- Propellantcombination
- Injectionpressuredrop,
- Stateofthepropellantsattheinjectorinlet,

- Performanceandliferequirements,and
- Experienceoftheenginemanufacturer.

All of these variables are normally determined before thedesign, analysis, and testing process (Anderson, et al., 2004) (Dieter, et al., 1992) (Rocketlab, 2003).The injector design has long been recognized as a critical component that often determines whether a combustion device succeeds or fails, an ideal injector design is one that fits the propulsion system's performance and life requirements, is free of combustion instabilities throughout its operating range, creates a safe environment surrounding the chamber walls, and can be manufactured cheaply and reliably (Ito, 2004)(Anderson, et al., 2004). The homogenous distribution of the correct mixture ratio and fine atomization of the liquid propellants results in high combustion efficiency. To ensure combustion efficiency near 100%, local mixing within the injection element spray pattern must occur at a microscopic level. A good injector design must also have goodcombustion stability (Turner, 2005). If the injector is easily triggered into destructive instability, high performance can become a secondary consideration (Anderson, et al., 2004) (Turner, 2005). Many of the injector key parameters for high performance also appear to reduce the stability margin, making it appear as though the design requirements for stability are at odds with those for performance (Dieter, et al., 1992) (Vigor, et al., 2004). The injection element type chosen, as well as the provision for damping any oscillatory phenomena, will play a big role in maintaining stable operation (Dieter, et al., 1992). One reason for the common use of 15-20% of chamber pressure as an appropriate level of injector pressure drop is injection flow resistance (Anderson, et al., 2004) (Dieter, et al., 1992) (Rocketlab, 2003).

TYPES OF INJECTORS

There are several types of injectors which engineers and designers alike have adopted, mostly their choice are often tailored to their individual mission requirement, experience and skill as well as ease of manufacture. This paper considered broadly only two types of injector which were suitable for a small a liquid-rocket engine and these include:

- **The Impinging stream injector:** In this type of injector the oxidizer and fuel are injected through a series of perforations, with the resulting streams intersecting, a disadvantage of this type of injector is that it requires extremely small holes for small engine flow rates, and the hydraulic characteristics and equations commonly used to predict injector parameters do not work well for small orifices, and drilling such small holes is extremely difficult (Rocketlab, 2003), examples of impinging stream injectors include:

1. Self-Impinging doublet type
2. Cross-Impinging doublet type
3. Cross-Impinging triplet type and many more

- **The Spray nozzle:** Conical, Solid Cone, Hollow Cone or other type of spray sheet can be obtained using this type of injector. When a liquid hydrocarbon fuel is forced through a spray nozzle, the resulting fuel droplets easily mix with gaseous oxygen, vaporizing and burning the combination. Spray nozzles are especially attractive since they are commercially available.

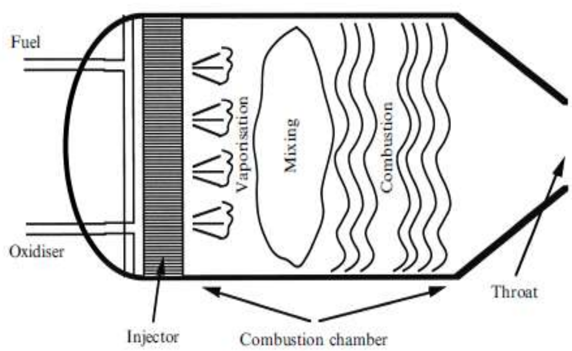

Figure 1: Injection and Combustion (Turner, 2005).

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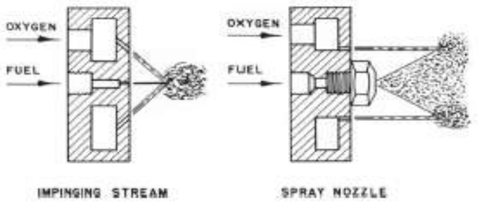

Figure 2: Fuel Injector for Small Rocket Engines (Rocketlab, 2003)

II. LITERATURE

INJECTOR DESIGN

Injector design, likemanyengineeringtasks,entails a number of trade-offs. There are potentially multiple approaches that could be used to design a suitable injector for any new engine application; however the most appropriate design starting point takes into account the application, engine size, propellant mix, and design priorities; although the initial approach calls for thorough optimization of all features but this quickly underscores the importance of the truly critical design parameters such as light weight, high performance, cheap cost and reliability amongst others(Dieter, et al., 1992) (Anderson, et al., 2004) (Bazarov, 2004).Because theinjector operating conditions are complex, there are many different types of injectors and injector assemblies.Injector design will combine prior experience and innovation in terms of the recognized difficulties such as the type of propellants and injection condition which will most strongly influence selection of the injection element(Bazarov, 2004) (Dieter, et al., 1992). A good injector or injector design must fulfill the following requirements amongst others:

1. Provide high combustion efficiency
2. Protect the chamber walls against excessive loading
3. Suppress combustion instability in the chamber
4. Suppress flow instabilities

To meet these requirements, injectors should provide pre-specified liquid-sheet thickness, spray-cone angle in the range of 36-120deg, and dynamic characteristics. In addition, the fabrication procedure should be simplified to achieve reliable designs (Bazarov, 2004).

CLASSIFICATIONOFINJECTORS

Liquidpropellantinjectorscanbe classifiedonthefollowingbasis:

1. **Applications**: Low-thrust engines, gas generators etc
2. **Propellants**: Earth-storable, hypergolic etc
3. **Pressure Drop**: High and Low pressure drop across injectors
4. **Design Features**: Dimensions and configurations
5. **Propellant Mixing**: External and internal mixing

PROPELLANTS

Chemicals used to create thrust are referred to as propellants, and refers only to chemicals that are stored inside a vehicle prior to use and does not include atmospheric gas or other material that may be collected during operation (Thirupathi, et al., 2015) (George, et al., 2001) (Dieter, et al., 1992). Examples of propellants and their systems include:

- **Bipropellants:** are two separate liquid propellants oxidizer and fuel usually stored separately and mixed in the combustion chamber.
- **Monopropellant:** is a single substance containing oxidizing agent and combustible matter, they are stable at atmospheric conditions, but decompose when heated or catalyzed.
- **Cold Gas Propellant:** are stored at very high pressure.
- **Cryogenic Propellant:** are liquefied gases at low temperature.
- **Gelled Propellant:** are liquid with gelling additive behaving like jelly or thick paint.

This paper considered a bipropellant mixture, which uses kerosene (hydrocarbon) and liquid oxygen (oxidizer). It is worth noting that the term “liquid propellant” encompasses all of the different liquids that are employed, and maybe one of the following:

1. Oxidizer (liquid oxygen, nitric acid, etc.)
2. Fuel (gasoline, alcohol, liquid hydrogen, etc.)
3. Chemical compound or mixture of oxidizer and fuelingredients, capable of self-decomposition
4. Any of the above, but with a gelling agent

CRITICAL COMBUSTION PROCESSES

The critical combustion processes describes primary physical mechanisms through which the injector is designed so as to establish control and solve development problems (Ito, 2004):

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A. Injector Manifold Distribution

Thestartingpointforanyinjectordesignisproper distributionofthefuelandoxidizeracrosstheinjectorface (Ito, 2004)(Dieter, et al., 1992) (Anderson, et al., 2004). The performance of the injector will be maximized if the mixture ratio is distributed uniformly across the injector core parts, on the other hand a homogenous mixture ratio at the combustion chamber wall may also result in excessive heat flow, causing thermal failure or necessitating an excessive regenerative cooling pressure drop(Ito, 2004) (Dieter, et al., 1992) (Anderson, et al., 2004).Where excessive heat flux or pressure drop due to regenerative cooling exist, it is critical to apply either a fuel film cooling or a barrier mixture ratio bias to reduce wall heat flux without lowering chamber pressure. The distribution of injector manifolds is a major requirement but not sufficient criterion for design success (Ito, 2004) (Dieter, et al., 1992).

B. Propellant Droplet Vaporization

A liquid rocket combustion chamber's physiochemical processes are extremely complicated, involving a range of complexity such as jet atomization, spray generation, droplet transport, multiphase flow mixing and chemical reactions to name a few (Ito, 2004). These processes have multiple major interactions that span a wide variety of time and length ranges, and because the transport characteristics of individual droplets have a significant influence in modeling the local flow behavior in a spray field, studying injector designs and combustion is a critical step in solving the problem(Ito, 2004) (Yang, et al., 2004) (Sutton, et al., 2000).

C. Bipropellant Mixing

To achieve a high Specific Impulse performance, uniform mixing is required and as such it is important to minimize mixing between the core and barrier combustion zones so as to improve engine performance while reducing combustion chamber and nozzle heat flux (Ito, 2004). It is also worth noting that low-molecular-weight propellants like hydrogen have a high diffusivity and easily combine. High-molecular-weight propellants, such as heavy hydrocarbons mix very slowly. Heavy hydrocarbons also have the disadvantage of forming an insulating layer of cooler fuel vapor around the droplet, which can prevent further droplet vaporization (Ito, 2004) (Anderson, et al., 2004) (Yang, et al., 2004).

D. Injector Spray Atomization

Spray atomization from the injector face or the site of jet impingement is another key combustion process factor. The importance of spatial atomization distribution in injector design stems from the fact that the breakup distance divided by injector velocity accounts for a large portion of the combustion dead time (Ito, 2004) (Sirignano, et al., 2004). The combustion stability analyst requires this time lag to predict the low frequency feed system or chug stability margin that a pressure fed thruster may be required to operate at the end of its tank pressurization blow down cycle, or the intermediate operating point that all pump fed engines must endure during the start transient before bootstrapping up to full throttle (Ito, 2004) (Anderson, et al., 2004). In a LO_2/hydrocarbon injector, an accurate prediction of the differential breakup distances between the oxidizer and fuel spray fans from the injector face is also critical to successful injector design and thermal analysis, especially for injection elements aligned adjacent to the combustion chamber wall (Ito, 2004) (Sirignano, et al., 2004) (Dieter, et al., 1992).

Injector Design Equations

Different hydraulic flow pressure relationships, atomization, starting characteristics resistance to self-induced vibrations and combustion efficiency reflect the variances in injector arrangement.The hydraulic injector characteristics can be evaluated accurately and can be designed for orifices with the desired injection pressures, injection velocities, flows, and mixture ratio(George, et al., 2001) (Dieter, et al., 1992). For a given thrust F and a given Specific ImpulseI_{SP}, the total propellant mass flow$\dot{m}$is givenby:

$$\dot{m} = F/I_{SP} \dots\dots (1)$$

The relations between the mixture ratio, the oxidizer, and the fuel flow rates are givenby:

$$r = \dot{m}_o/\dot{m}_f \dots\dots (2)$$

$$\dot{m}_o + \dot{m}_f = \dot{m} \dots\dots (3)$$

$$\dot{m}_o = r\,\dot{m}/(r+1) \dots\dots (4)$$

$$\dot{m}_f = \dot{m}/(r+1) \dots\dots (5)$$

The relationship for the flowofanincompressiblefluidthroughhydraulic orifice is given by:

$$Q = C_d A\sqrt{\frac{2\Delta P}{\rho}}Q_o = C_d A_o\sqrt{\frac{2\Delta P}{\rho_o}}Q_f = C_d A_f\sqrt{\frac{2\Delta P}{\rho_f}} \dots (6)$$

$$\dot{m} = Q\rho = C_d A\sqrt{2\rho\Delta P} \dots\dots (7)$$

Where
Q = volumetric flowrate,

C_d= dimensionless discharge coefficient,
ρ = propellantmassdensity,
A = cross-sectionalareaoftheorifice,and
ΔP = pressuredrop.

These are broad relationships that can be applied to any part of the propellant feed system, the injector, or the entire liquid flow system. Figure (3) depicts a typical change in injection orifice flow and pressure drop, it can be seen that the hole with the lowest pressure drop or the highest flow usually have a circular entry. Small variations in chamfers, hole entry radius or burrs at the hole's edge can produce considerable variations in the discharge coefficient and jet flow patterns, which can affect the quality and distortion of atomized small droplets, the local mixture ratio and local heat transfer rates (George, et al., 2001) (Anderson, et al., 2004). Local chamber or injector burnout can be caused by an incorrectly constructed hole and the injection orifice dictate the mixture ratio and propellant flow rates for each given pressure drop (George, et al., 2001), equation (2) through to (7) gives the mixture ratio as:

$$r = \frac{\dot{m}_o}{\dot{m}_f} = \left[\frac{(C_d)_o}{(C_d)_f}\right]\left(\frac{A_o}{A_f}\right)\sqrt{\left(\frac{\rho_o}{\rho_f}\right)\left(\frac{\Delta P_o}{\Delta P_f}\right)} \dots\dots (8)$$

Even if the overall flow is somewhat different, the quantities in equation (8) must be chosen so that the correct design mixture ratio is achieved (George, et al., 2001) (Dieter, et al., 1992). Orifices with consistent discharge coefficient throughout a wide range of Reynolds number and whose invariant ratios $(C_d)_o/(C_d)_f$ should be used. Cold tests with stimulant liquids rather than reactive propellant liquids are used to assess the injector's quality. Water is frequently used to confirm pressure drops through the fuel or oxidizer side at various flows, allowing the pressure drops with propellants and discharge coefficients to be determined.The local cold flow mixture ratio distribution over the chamber cross section is determined using non-mixable inert liquids (George, et al., 2001) (Dieter, et al., 1992) (Gill, et al., 1976). The simulant liquid should have a density and viscosity that is similar to that of the actual propellant and all new injectors must be hot fired and tested with actual propellants before commissioning (George, et al., 2001) (Dieter, et al., 1992).

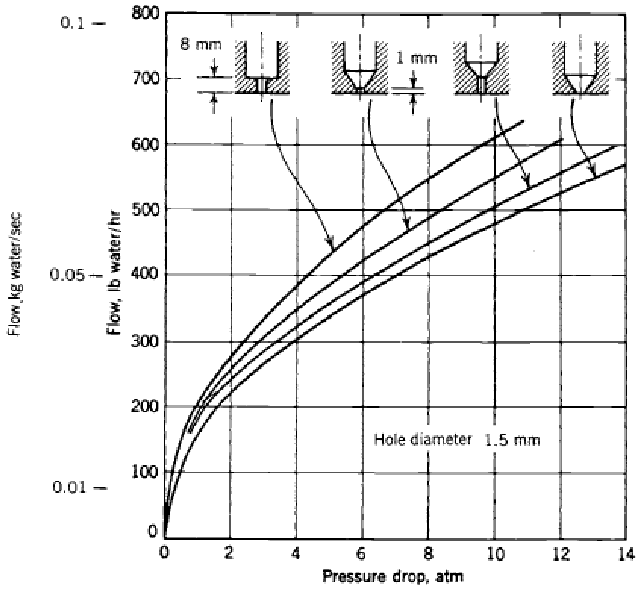

Figure 3: Hydraulic characteristics of four types of injection orifice (George, et al., 2001)

By applying a correction factor of the square root of the density ratio of the simulant liquid and the propellant, the true mixture ratio can be determined from cold flow test data, measured hole areas and discharge coefficients (Thirupathi, et al., 2015) (George, et al., 2001). The mixture ratio can be given as $\Delta P_f = \Delta P_o$ and $\rho_f = \rho_o$ when water at the same pressure is alternatively supplied into both the fuel and oxidizer lines. As a result, multiplying the mixture ratio determined in the water test by the square root of the propellant combinationdensity ratio and the square root of the pressure drop ratio yields the actual propellant mixture ratio. The method of propellant atomization, which includes simultaneous vaporization, partial combustion and mixing, is difficult to understand and injector performance must be assessed, through

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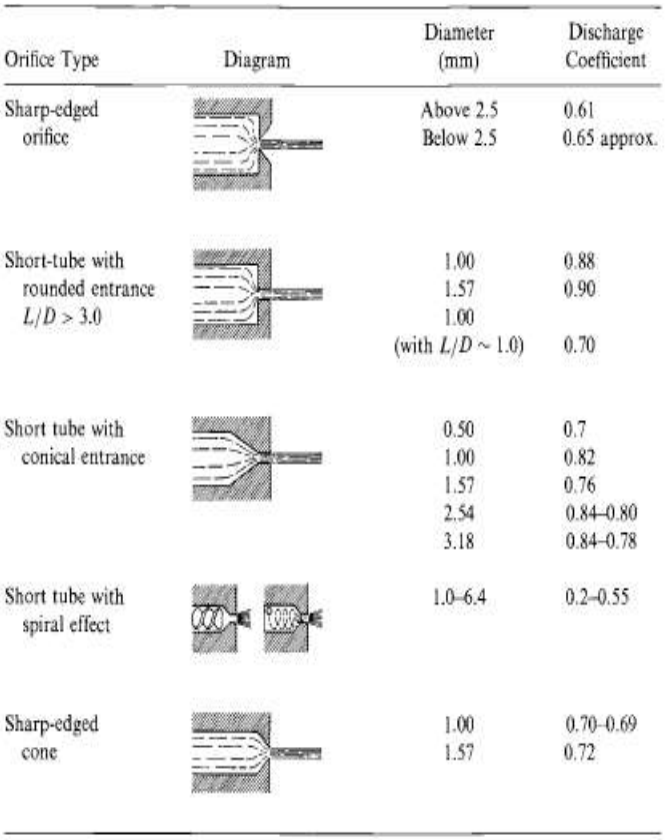
experimentation in a burning rocket thrust chamber. The injection velocity is calculated as follows:

$$V = Q/A = C_d\sqrt{2\Delta P/\rho} \dots\dots (9)$$

Figure 4displays the discharge coefficients for several types of injection orifices. When the discharge coefficient equals 1, the velocity is at its maximum for a given injection pressure drop. Smooth and well rounded injection hole entrances, as well as clean bores produce high discharge coefficient values.



Orifice Type	Diagram	Diameter (mm)	Discharge Coefficient
Sharp-edged orifice		Above 2.5 Below 2.5	0.61 0.65 approx.
Short-tube with rounded entrance $L/D > 3.0$		1.00 1.57 1.00 (with $L/D \sim 1.0$)	0.88 0.90 0.70
Short tube with conical entrance		0.50 1.00 1.57 2.54 3.18	0.7 0.82 0.76 0.84–0.80 0.84–0.78
Short tube with spiral effect		1.0–6.4	0.2–0.55
Sharp-edged cone		1.00 1.57	0.70–0.69 0.72

Figure 4: Injector Design Coefficients (George, et al., 2001)

III. CALCULATIONS

Design Parameters:

Table 1: Design Parameters

Design Parameters			Units
Thrust	F	2000	N
Specific Impulse	Isp	216.60	s
Gravity	g	9.81	m/s^2
Relative Molecular Mass Oxygen	RMMO	563.18	gmol
Relative Molecular Mass Kerosene	RMMK	170.33	gmol
Mixture Ratio	R	3.31	-
Density of Oxygen	ρ(Oxygen)	1142	Kg/m^3
Density of Kerosene	ρ(Kerosene)	810	Kg/m^3
Time of flight	t	20	s

Kerosene and Oxygen were the choice for propellants.
The combustion equation for Kerosene and Oxygen is given as:

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$$C_{12}H_{26} + 17.6O_2 \rightarrow 12CO_2 + 13H_2O$$

Thrust; F = 2000N
Specific Impulse; I_{sp} = 216.60s
In terms of weight flow-rate

$$\dot{w}_p = \frac{F}{I_{SP}} = \frac{2000}{216.60}$$

$$\dot{w}_p = 9.23 kg/s$$

Where mixture ratio is given as;

$$r = \frac{\dot{w}_o}{\dot{w}_f} = \frac{RMM_o}{RMM_f}$$

Density of Kerosene; ρ_k = 810 kg/m^3
Relative molecular mass of kerosene; RMM_K = 170.34g/mol

Density of Oxygen; ρ_o = 1142 kg/m^3
Relative molecular mass of oxygen; RMM_o = 563.20g/mol
Thus:

$$r = \frac{563.20}{170.34} = 3.31$$

$$\dot{w}_f = 2.14 kg/s$$
$$\dot{w}_o = 7.09 kg/s$$

Where time of flight; t = 20s
Mass of the fuel and Oxidizer are given as:

$$M_f = \frac{\dot{w}_f \times t}{g} = 4.37 kg$$

$$M_o = \frac{\dot{w}_o \times t}{g} = 14.46 kg$$

Converting to volume using the equation;

$$V = \frac{M}{\rho}$$

Thus; the volume of the fuel and oxidizer is given as:

$$V_f = \frac{M_f}{\rho_f} = 0.0053 m^3$$
$$V_o = \frac{M_o}{\rho_o} = 0.0126 m^3$$

Volumetric flow per sec:

$$\dot{V}_f = \frac{0.0053 m^3}{60s} = 0.0000899015 m^3/s$$

$$\dot{V}_o = \frac{0.0126 m^3}{60s} = 0.000211064 m^3/s$$

Converting to US gal/hr

$$\dot{V}_f = 0.0000899015 m^3/s = 85.49\ USgal/hr$$

$$\dot{V}_o = 0.000211064 m^3/s = 200.72\ USgal/hr$$

Table 2: Calculated Parameters

Calculated Parameters			
Parameters			
Total Impulse	I_t	40000.00	Ns
Mass Flow-rate of propellant	M_p	18.83	kg
Weight Flow-rate of propellant	W_p	9.23	Kg/s
Weight Flow-rate of Kerosene	W_k	2.14	Kg/s
Weight Flow-rate of Oxygen	W_o	7.09	Kg/s
Mass of Kerosene	M_k	4.37	Kg
Mass of Oxygen	M_o	14.46	kg
	m^3	**liter**	**US gal**
Volume of Kerosene	0.0054	5.3941	1.4250
Volume of Oxygen	0.0127	12.6638	3.3454
	Chamber	Throat	Exit
Temperature (k)	3611.49	3283.17	2853.08
Pressure (N/m^2)	1000000	564473.93	243087.46
Mach Number	0.22	1.00	2.16
Area (m^2)	0.0224	0.0050	0.0112
Diameter (m)	0.1688	0.0796	0.1192
Radius (m)	0.0844	0.0398	0.0596
Velocity (m/s)	-	1144.65	1739.72
Density (kg/m^3)	0.28	0.17	0.09
Specific Volume (m3/kg)	3.61	5.82	11.75

Table 3: Spray Nozzle Options Fuel (Kerosene)

No. of Nozzles	Flow rate (US gal/hr)	Availability	Error
1 Nozzle	85.490	None	-
2 Nozzles	42.745	None	-
3 Nozzles	28.496	29.88	1.384
4 Nozzles	21.372	23.31	1.938

Table 4: Spray Nozzle Options Oxidizer (Oxygen)

No. of Nozzles	Flow rate (US gal/hr)	Availability	Error
1 Nozzle	200.750	None	-
2 Nozzles	100.375	None	-
3 Nozzles	66.916	None	-
4 Nozzles	50.187	None	-
5 Nozzles	40.150	None	-
6 Nozzles	33.158	33.47	0.312

The Internal Injector Cup Diameter available for Oxidizer manifold (D_{ic})is equal to the External Injector Cup Diameter (D_{ec}) available for Spray Nozzles;

$$D_{ic} = D_{ec} = 154.4\text{mm}$$

$$\text{Radius of internal diameter} = \frac{D_{ic}}{2} = 77.2\text{mm}$$

$$\text{Surface Area for Injector Face; } SA_i = \frac{\pi D_i^2}{2} = 18725.8\text{mm}^2$$

The Danfoss oil nozzle type OD was considered as the spray nozzle option for the injector design. The oil nozzle was used to atomize the fuel (kerosene) and oxidizer (oxygen) at high pressures; the Danfoss oil nozzle is offered with different spray angles:

a. To CEN standard:

60°, 70°, 80°, 90° and 100° under four different atomizing indexes: I - II - III - IV.
b. Non-CEN-standardoilnozzles:
30°, 45°, 60° and 80° with three different spraypatterns: S,HandB

S=solid,
H=hollow,
B = semi-solid

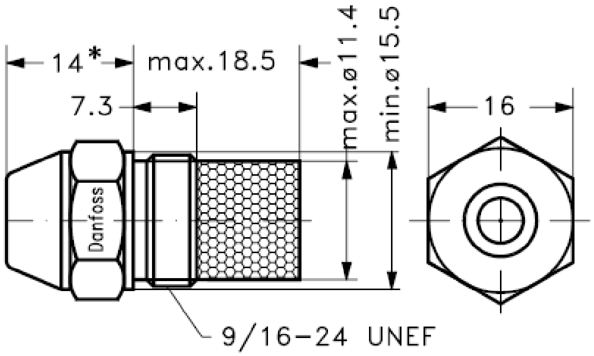

Figure 5: Dimensioned Sketch of the Danfoss Spray Nozzle

Test oil: Min Viscosity: 3.4mm^2/s
Min Density: 840 kg/m^3
Atomizing Pressure: 1000 kPa

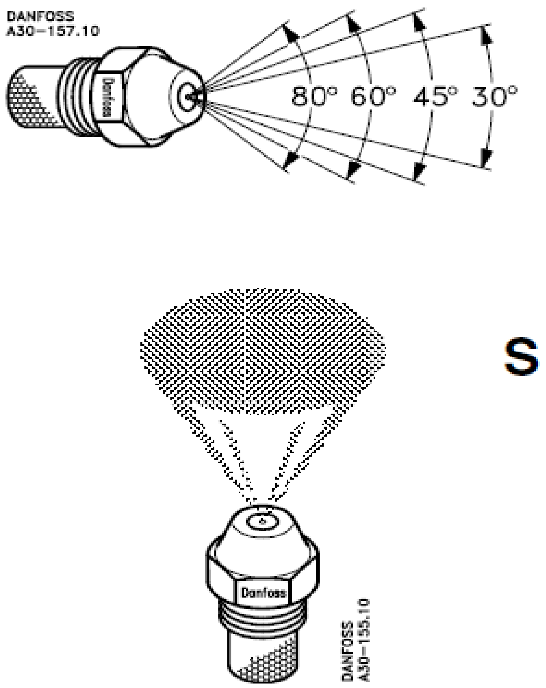

Figure 6: Danfoss Nozzle with solid spray pattern and spray angles

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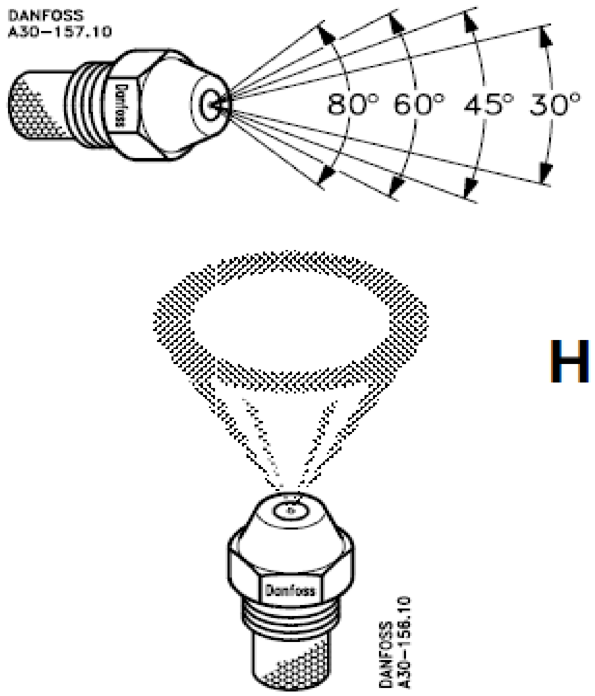

Figure 7: Danfoss Nozzle with hollow spray pattern and spray angles

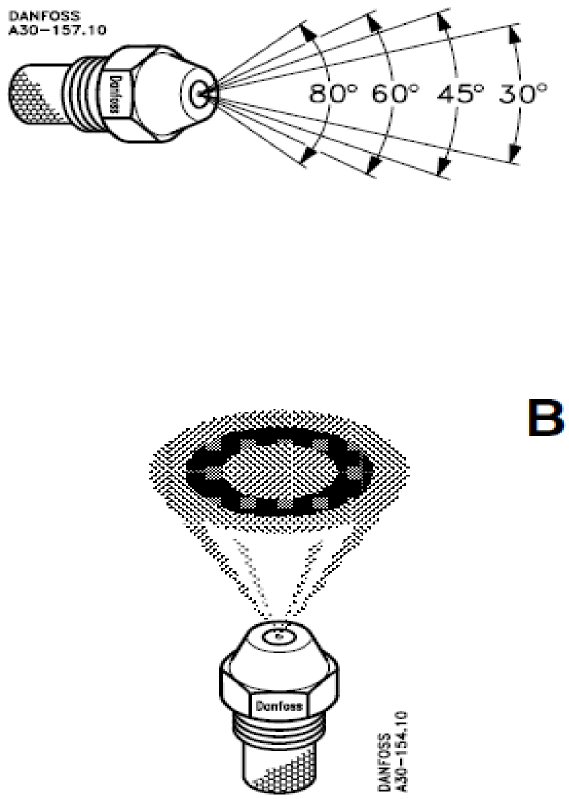

Figure 8: Danfoss spray nozzle with semi-solid spray pattern and spray angles

IV. DISCUSSION

Table 2: Calculated Parameters

Calculated Parameters

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Parameters			
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Weight Flow-rate of Oxygen	W_o	7.09	Kg/s
Mass of Kerosene	M_k	4.37	Kg
Mass of Oxygen	M_o	14.46	kg
	m^3	**liter**	**US gal**
Volume of Kerosene	0.0054	5.3941	1.4250
Volume of Oxygen	0.0127	12.6638	3.3454
	Chamber	Throat	Exit
Temperature (k)	3611.49	3283.17	2853.08
Pressure (N/m^2)	1000000	564473.93	243087.46
Mach Number	0.22	1.00	2.16
Area (m^2)	0.0224	0.0050	0.0112
Diameter (m)	0.1688	0.0796	0.1192
Radius (m)	0.0844	0.0398	0.0596
Velocity (m/s)	-	1144.65	1739.72
Density (kg/m^3)	0.28	0.17	0.09
Specific Volume (m3/kg)	3.61	5.82	11.75

Table 3 and Table 4specified the design and calculated parameters respectively, Table 3 and Table 4 specified the propellant flow-rate and spray nozzle availability; this information was then used alongside the design equations to calculate the number of spray nozzle required, measures were taken to minimize the error in the propellant flow rate as well as ensuring the injector weight were kept at a minimum. The diameter of the injector which is a key parameter of injector design was used to specify the fuel and oxidizer manifolds respectively. The thermodynamic properties of kerosene and oxygen were sourced from open data. The diameter of the combustion chamber as seen from Table 2 is a key parameter in the design of a typical propellant Injector which ultimately determined the diameter of the fuel and oxidizer manifolds; an iterative method was used to determine the number of spray nozzle required. The mixture ratio was the basis for determining the propellant flow-rate.The values of these key parameters were then used to develop a 3D-CAD representation of the injector and its accessories on SolidWorks.The proposed material specified for the injector was specified as AISI 1035 Steel (SS) with yield strength of 282.68 N/mm2 and a tensile strength of 585 N/mm2, the estimated mass of the injector and accessories wasgiven as 3.96208kg. Recall from the "Design of a 2KN liquid-fuel rocket engine combustion chamber – Part 1" (Bage, et al., 2022) the combustion chamberweighed 6.4329kg, thus the combined weight of the combustion chamber and the injector resulted to 10.39498kg, for a 2KN design specification, this translated to a combined Thrust-to-Weight ratio of 19.6 on the combustion chamber and injector assembly, by convention this is also a good starting point as most combustion chambers with their associated injectors tend to be the heaviest part of the rocket which also doubles as a dead weight upon exhausting the usable propellant.

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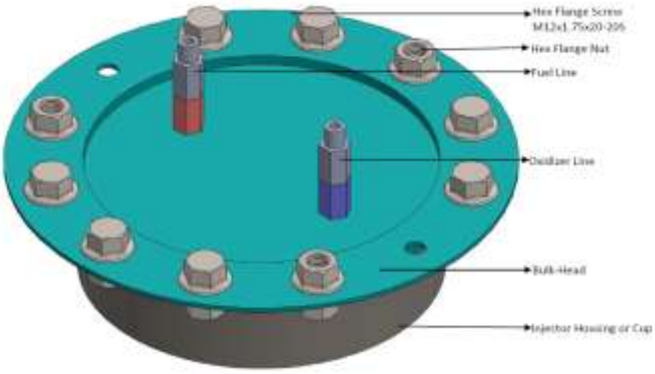

Figure 9: Injector assembly showing bulkhead

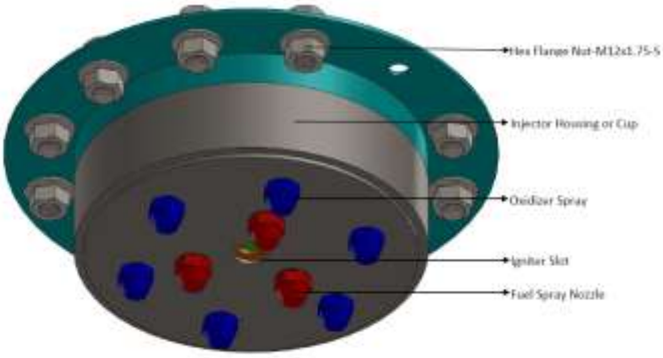

Figure 10: Injector assembly showing Injector Cup and Spray Nozzles

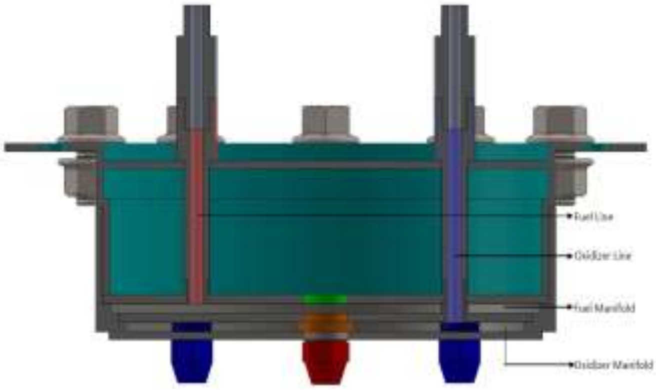

Figure 11: Injector assembly showing fuel and oxidizer manifolds

Mass properties of 2KN Injector Assembly 2021
Configuration: Default
Coordinate system: -- default --
Mass = 3962.08 grams
Volume = 575846.08 m^3
Surface area = 409582.56mm^2
Center of mass: (mm)
X = -3.79
Y = 719.91
Z = 12.56
Principal axes of inertia and principal moments of inertia: (g *mm^2)
Taken at the center of mass
Ix = (1.00, -0.00, 0.00) Px = 13690196.50
Iy = (0.00, 0.00, -1.00) Py = 13696135.45
Iz = (0.00, 1.00, 0.00) Pz = 22815286.88
Moments of inertia: (g* mm^2)
Taken at the center of mass and aligned with the output coordinate system.
Lxx = 13690196.51 Lxy = -222.07 Lxz = 0.01
Lyx = -222.07 Lyy = 22815286.88 Lyz = 0.00

Lzx = 0.01 Lzy = 0.00 Lzz = 13696135.45
Moments of inertia: ($g*mm^2$)
Taken at the output coordinate system
Ixx = 2067739705.83 Ixy = -10798538.79 Ixz = -188343.84
Iyx = -10798538.79 Iyy = 23496769.04 Iyz = 35815761.05
Izx = -188343.84 Izy = 35815761.05 Izz= 2067177732.52

V. RECOMMENDATION

The oxidizer vaporizes faster than fuel in most liquid propellant combinations; it is recommended that a suitable injector design comprises of an estimate of the effective mass distribution and a judgment of design adequacy in this regard (Dieter, et al., 1992) (Ito, 2004). In terms of performance and chamber compatibility, the distribution of mixture ratios is also very significant.Withcombustionchambersmadeofmetals(copper, nickel, steel), it is crucial to avoid scrubbing of the chamber wall by high-temperature oxidizing streams, although most injection patterns are designed to avoid this possibility, andgenerallyto provide an excess of fuel in these areas. To spread a protective evaporating layer on the wall surface, formal film cooling or boundary layer cooling systems should use fuel streams that directly impinge on the wall at a shallow angle. Other systems employ barrier zone elements in the region close to the wall that are either fuel rich or completely fuel free, all these methods involve a performance penalty (Dieter, et al., 1992) (Bird, et al., 2012).

VI. CONCLUSION

The effect of mixture ratio maldistribution on performance penalty can be quantified using a mass weighted stream tube analysis. It can also account for both planned cooling bias and unintended performance losses due to maldistribution. It would seem prudent to perform a simple cold flow hydraulic distribution testing of the injector manifold design before committing the injector design to a specific injector pattern bearing in mind the cost of injector redesign and retesting which may be necessitated by either chamber thermal failure or disappointingly low injector performance due to injection maldistribution.

BIBLIOGRAPHY

[1]. **Chemical Process Principles, Part -I, Materials and Energy Balances** [Book] / auth. Hougen Olaf A, Watson Kenneth M and Ragatz Roland A. - Calcutta : Asia Publishing House, 1976.

[2]. **Design and Analysis of a fuel Injector of a Liquid Rocket Engine** [Journal] / auth. Thirupathi M., Madhavi N. and Naidu K. Simhachalam // International Journal of Engineering and Advanced Technology. - [s.l.] : Blue Eyes Intelligence Engineering & Sciences Publication Pvt. Ltd., June 2015. - 5 : Vol. 4. - pp. 223-229. - 2249-8958.

[3]. **Design and Dynamics of Jet and Swirl Injectors** [Book Section] / auth. Bazarov Vladimir // Liquid Rocket Thrust Chambers: Aspect of Modelling, Analysis, and Design / book auth. Yang Vigor and Puri Puneesh. - Lexington : American Institute of Aeronautics and Astronautics, Inc., 2004. - Vol. 200. - 1-56347-223-6.

[4]. **Design of a 2KN Liquid-Fuel Rocket Engine Combustion Chamber-Part 1** [Journal] / auth. Bage Ali A, Abdulrahman Abdulazeez and Sholiyi Dr. Olusegun S. - Epe, Lagos : International Journal of Advances in Engineering and Management, 2022. - 1 : Vol. 4. - 2395-5252.

[5]. **Distortion and Disintegration of Liquid Streams** [Book Section] / auth. Sirignano William A. and Mehring Carsten // Liquid Rocket Thrust Chambes: Aspects of Modeling, Analysis, and Design / ed. Yang Vigor [et al.]. - Reston : American Institute of Aeronautics and Astronautics, Inc., 2004. - Vol. 200. - 1-56347-223-6.

[6]. **How to Design, Build and Test Small Liquid-Fuel Rocket Engines** [Book] / auth. Rocketlab. - China Lake, California : Leroy J. Krzycki, 2003. - ISBN 9600-1980-4.

[7]. **How to Design, Build and Test Small Liquid-Fuel Rocket Engines** [Book] / auth. Rocketlab. - China Lake, Carlifornia : Rocketlab, 1971.

[8]. **Introduction to Chemical Engineering Thermodynamics** [Book] / auth. Smith J. M., Van Ness H. C. and Abbott M. M.. - New York : McGraw-Hill, 2001. - ISBN 0-07-240296-2.

[9]. **Liquid Bipropellant Injectors** [Book Section] / auth. Anderson William E., Long Matthew R. and Heister Stephen D. // Liquid Rocket Thrust Chambers: Aspect of Modelling, Analysis, and Design / book auth. Yang Vigor [et al.]. - West Lafayette, Indiana : American Institute of Aeronautics and astronautics, 2004.

[10]. **Liquid Rocket Engine Injectors** [Report] / auth. Gill G. S. and Nurick W. H.. - Springfield, Virginia : National Aeronautics and Space Administration, 1976. - NASA SP-8089.
[11]. **Liquid Rocket Thrust Chambers: Aspects of Modelling, Analysis, and Design** [Book] / auth. Vigor Yang [et al.]. - Reston, Virginia : American Institute of Aeronautics and Astronautics, Inc, 2004. - ISBN 1-56347-223-6.
[12]. **Liquid-Propellant Droplet Vaporization and Combustion** [Book Section] / auth. Yang Vigor [et al.] // Liquid Rocket Thrust Chambers: Aspect of Modelling, Analysis and Design / ed. Yang Vigor [et al.]. - Reston : American Institute of Aeronautics and Astronautics, Inc., 2004. - 1-56347-223-6.
[13]. **Modern Engineering For Design Of Liquid-Propellant Rocket Engines** [Book] / auth. Dieter Huzel K and David Huang H. - Washington, DC : American Institute of Aeronautics and Astronautics, Inc, 1992. - ISBN 1-56347-013-6.
[14]. **Optimum Stage-Weight Distribution of Multistage Rockets** [Book] / auth. John Coleman J.. - Los Angeles 45, Carliformia : Space Technology Laboratories, Inc, 1960. - STL/TN-60-0000-09036.
[15]. **Physical Chemistry** [Book] / auth. Rakshit P C. - India : Sarat Book Distributers, 2001.
[16]. **Propellant Feed Valves for Starting and Control of Rocket Motors** / auth. Schoenheit W.. - Farnborough, Hants : Royal Aircraft Establishment, 1951. - U.D.C No: 621.455-441:621-33.
[17]. **Propellant Injection Systems and Processes** [Book Section] / auth. Ito Jackson I // Liquid Rocket Thrust Chambers: Aspects of Modelling, Analysis and Design / ed. Yang Vigor [et al.]. - Reston : American Institute of Aeronautics and Astronautics, Inc., 2004. - Vol. 200. - 1-56347-223-6.
[18]. **Rocket and Spacecraft Propulsion Principles, Practice and New Developments** [Book] / auth. Turner Martin J.L.. - Chichester, UK : Springer-Praxis, 2005. - ISBN 3-540-22190-5.
[19]. **Rocket Propulsion Elements** [Book] / auth. George Sutton P. and Oscar Biblarz. - New York / Chicester / Weinheim / Brisbane / Singapore / Toronto : John Wiley & Sons, INC, 2001. - ISBN 0-471-32642-9.
[20]. **Rocket Propulsion Elements** [Book] / auth. Sutton G. P and Biblarz O. - New York : John Wiley & sons, Inc., 2000.
[21]. **Rockets; A Teacher's Guide with Activities in Science, Mathematics, and Technology** [Book] / auth. Deborah Shearer A., Gregory Vogt L. and Ed D.. - Houston, Texas : National Aeronautics and Space Administration. - EG-1999-06-108-HQ.
[22]. **Summary of Rocket Nozzle Relationships** / auth. Bianchi D.. - Rome,Italy : Sapienza Universita Di Roma.
[23]. **The Design and Building of a Level 3 Rocket** [Report] / auth. Vic Bekarian [et al.]. - California, San Diego : University of Carlifornia, 2013.
[24]. **Thunder Over The Horizon; From V2 Rockets to Ballistic Missiles** [Book] / auth. Clayton Chun K. S.. - United States of America : Praeger Security International, 2006. - ISBN: 0-275-98577-6.
[25]. **Transport Phenomena** [Book] / auth. Bird Byron R., Stewart Warren E. and Lightfoot Edwin N.. - Singapore : John Wiley & Sons, 2012. - ISBN: 978-81-265-0808-2.