Volume: CAAA-2018 **Issue:** onference **Month of publication:** April 2018

DOI:

Design and Analysis of Fuel Injector Nozzle for Rocket Engines

M. Rajadurai[1], Nishanth. P[2], Mohan Kumar. M[3]
[1]*Asst Prof, Dept of Aeronautical Engineering, Mahendra Engg College, Namakkal.*
[2, 3]*Student, Dept of Aeronautical Engineering, Mahendra engg College, Namakkal.*

Abstract: The performance of the rocket is determined by atomization, mixing and combustion process. Injectors are used to control this process. Suitable method should be followed, so that the performance should be increased. The injector implementation in rockets determines the performance of the nozzle that can be achieved. A poor injector performance causes unburnt propellant to leave the engine, giving unpleasant and poor efficiency. Injectors can be as simple as a number of small diameter holes arranged in carefully constructed patterns through which the fuel and oxidizer travel. The performance of an injector can be improved by either using a superior propellant combustion, increasing the mass flow rate, positioning the angle of the hole or by reducing the size & increasing the number of orifices on the injector plate. In here the position is varied for different angles for doublet and triplet injectors to improve the performance of the rocket.

I. INTRODUCTION

A. Rocket engines

A rocket is a missile, spacecraft, aircraft or other vehicle that obtains thrust from a rocket engine. Rocket engine exhaust is formed entirely from propellant carried within the rocket before use. In fact, rockets work more efficiently in space than in an atmosphere. Multistage rockets are capable of attaining escape velocity from Earth and therefore can achieve unlimited maximum altitude.

Compared with air breathing engines, rockets are lightweight and powerful and capable of generating large accelerations. . To control their flight, rockets rely on momentum, airfoils, auxiliary reaction engines, gimbaled thrust, momentum wheels, deflection of the exhaust stream, propellant flow, spin, and/or gravity.

The stored propellant can be a simple pressurized gas or a single liquid fuel that disassociates in the presence of a catalyst (monopropellants), two liquids that spontaneously react on contact (hypergolic propellants), two liquids that must be ignited to react, a solid combination of fuel with oxidizer (solid fuel),or solid fuel with liquid oxidizer (hybrid propellant system).

B. Major Types of Rockets propulsion

1) Solid-fuel rockets (or solid-propellant rockets or motors) are chemical rockets which use propellant in a solid state.
2) Liquid-propellant rockets use one or more liquid propellants fed from tanks.
3) Chemical rockets are powered by exothermic chemical reactions of the propellant.
4) Thermal rockets use an inert propellant, heated by a power source such as electric or nuclear power.
5) Hybrid rockets use a solid propellant in the combustion chamber, to which a second liquid or gas oxidizer or propellant is added to permit combustion.

C. Types of Liquid Propellant Rockets

Liquid rockets have been built as monopropellant rockets using a single type of propellant, bipropellant rockets using two types of propellant, or more exotic tripropellant rockets using three types of propellant. Bipropellant liquid rockets generally use a liquid fuel, such as liquid hydrogen or a hydrocarbon fuel such as

RP-1, and a liquid oxidizer, such as liquid oxygen. The engine may be a cryogenic rocket engine, where the fuel and oxidizer, such as hydrogen and oxygen, are gases which have been liquefied at very low temperatures.

Liquid-propellant rockets can be throttled (thrust varied) in real-time, and have control of mixture ratio (ratio at which oxidizer and fuel are mixed); they can also be shut down, and, with a suitable ignition system or self-igniting propellant, restarted. Liquid propellants are also sometimes used in hybrid rockets, in which a liquid oxidizer is combined with a solid fuel.

D. Limitations of Liquid Rocket Propellants

1) Use of liquid propellants can be associated with a number of issues:
2) Because the propellant is a very large proportion of the mass of the vehicle, the center of mass shifts significantly rearward as the propellant is used.
3) Liquid propellants are subject to slosh, which has frequently led to loss of control of the vehicle. This can be controlled with slosh baffles in the tanks as well as judicious control laws in the guidance system.

II. DESIGN AND MODELING

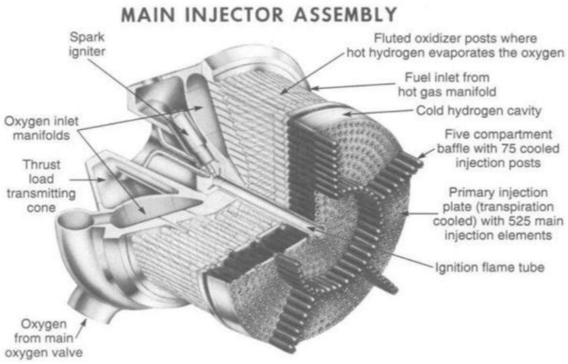
A. Design Of Fuel Injector

The propellants stored in low-medium pressure tanks are delivered to high pressure combustion chambers using a network of pipes and turbo pump assemblies.

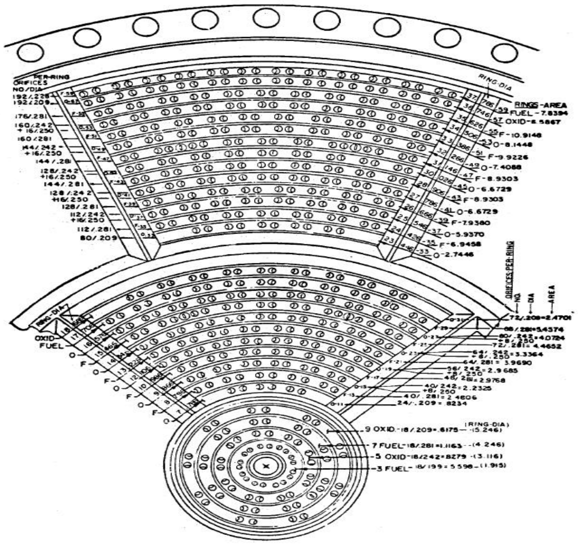
These turbo pumps have blades which rotate at very high speeds. They draw the propellants from the tanks, increase the pressure as they pass through the rotating blades, avoid cavitations (formation of vapours in liquids due to decrease in pressure), and then deliver the required mass flow rate to the injector bulkhead.

The injector is located just above the main combustion chamber. It is here, in the injector, where the mixing occurs.

The function of the injector is similar to those of a carburetor of an internal combustion engine. The injector has to introduce and meter the flow of the liquid propellants to the combustion chamber, cause the liquids to be broken up into small droplets (a process called atomisation), and distribute and mix the propellants in such a manner that a correctly proportioned mixture of fuel and oxidiser will result, with uniform propellant mass flow and composition over the chamber cross section.



2.1 Injector assembly



2.2 Injector Construction

The Main Types Of Injectors:

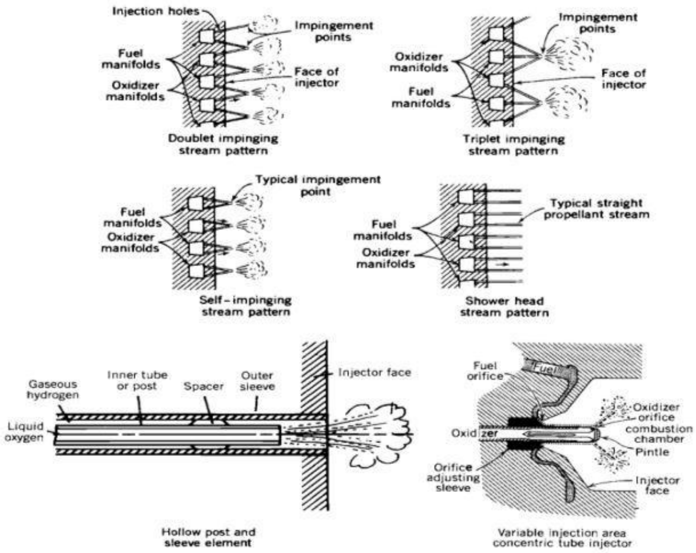
1) Shower head
2) Self-impinging doublet
3) Cross-impinging triplet
4) Centripetal or swirling
5) Shower head
6) Self-impinging doublet
7) Cross-impinging triplet
8) Centripetal or swirling

B. *F-1 Engine Fuel Injector*

The Rocket dyne-developed F-1 engine is the most powerful single-nozzle liquid-fuelled rocket engine ever flown. The M-1 rocket engine was designed to have more thrust, however, but it was only tested at the component level. The F-1 burned RP-1 (rocket grade kerosene) as the fuel and used liquid oxygen (LOX) as the oxidizer. A turbo pump was used to inject fuel and oxygen into the combustion chamber.

Into the nozzle extension by a large, tapered manifold; this relatively cool gas formed a film which protected the nozzle extension from the hot (5,800 °F (3,200 °C)) exhaust gas.

The fuel pump delivered 15,471 US gallons (58,560 litres) of RP-1 per minute while the oxidizer pump delivered 24,811 US gal (93,920 l) of liquid oxygen per minute. Environmentally, the turbo pump was required to withstand temperatures ranging from input gas at 1,500 °F (820 °C) to liquid oxygen at −300 °F (−184 °C). Structurally, fuel was used to lubricate and cool the turbine bearings A gas-generator was used to drive a turbine which in turn drove separate fuel and oxygen pumps, each feeding the thrust chamber assembly. The turbine was driven at 5,500 RPM by the gas generator, producing 55,000 brake horsepower (41 MW).



2.3 Designs of injectors

C. *Design Parameters*

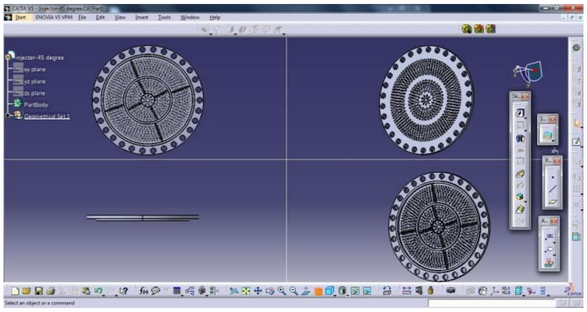
Three Stages

1. 14 Rings
2. 11 Rings
3. 4 Rings

Angle of Third stage = 20 degree

Fuel = Kerosene; Oxidizer = Liquid oxygen

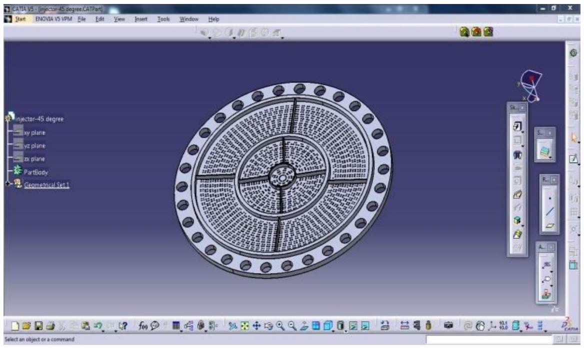
Based on the design parameters given above the fuel injector is designed using CATIA V5 and the model is shown in below. The injector is designed for five



2.4 3-d view of injector

Fuel = 17.07 m/s;
Oxidizer = 40.54 m/s
Total Holes = 2090 holes
Mixture Ratio = 2.27
Vacuum Specific Impulse = 269 s
Vacuum Thrust = 8,000,000 N

different angles. The angles are of 30°, 40°, 45°, 50° and 60°. The design images of these configurations are given in below.



2.5 50° injector design

III. NUMERICAL ANALYSIS OF FUEL INJECTOR

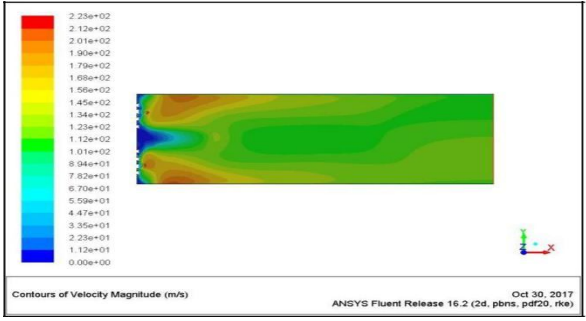
A. CFD

Computational fluid dynamics (CFD) is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows.

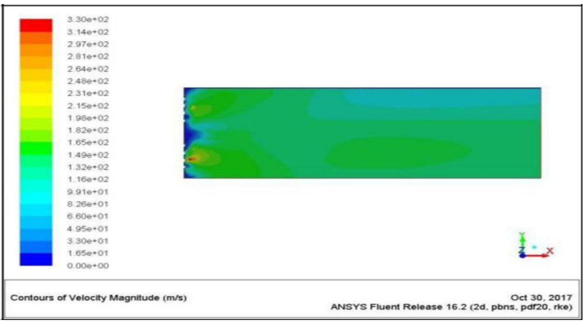
The three basic elements are

i. Pre-processor
ii. Solver and
iii. Post-Processor

B. Velocity Distribution



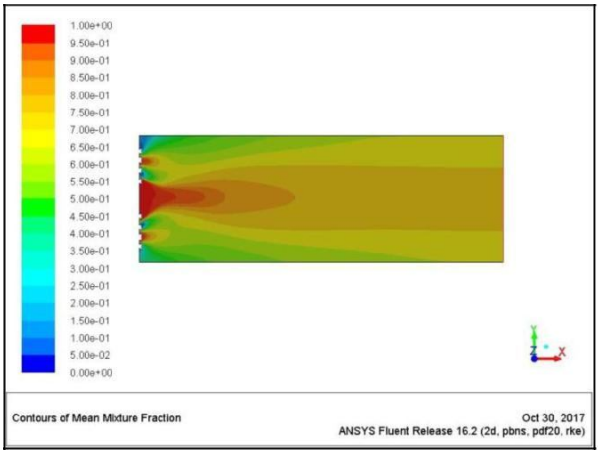
3.1 velocity at 45^0



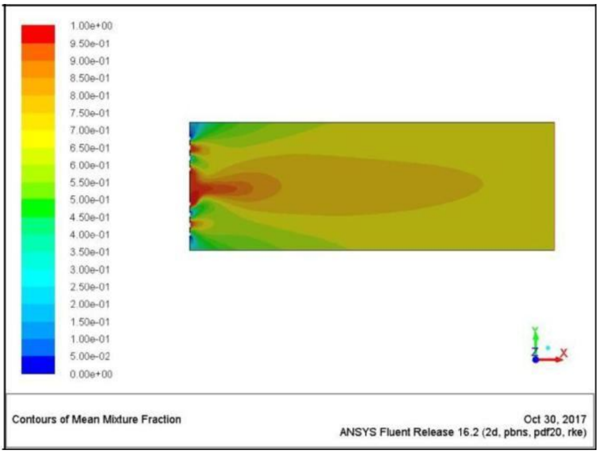
3.2 velocity at 50^0

We have the Velocity of 134 m/s at angle of 45^0. In figure 9, we have the Velocity of 157 m/s at angle of 50^0.By comparing all velocities with respect to various angles of attacks, we have maximum velocity of 157 m/s at angle of $50^{0.}$

C. *Mean mixture Fraction*



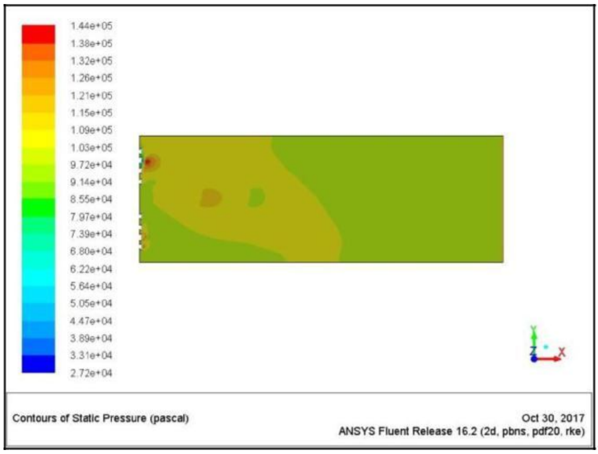
3.3 mean mixture fraction at 45^0



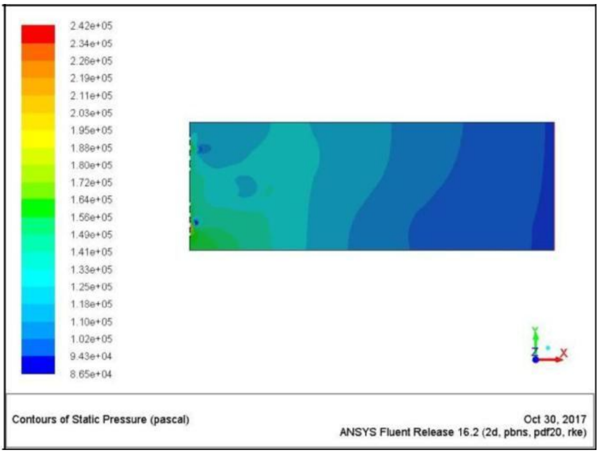
3.4 mean mixture fraction at 50^0

In all the cases the value of the mean mixture fraction was found to be as 0.85 in average. This indicates that 85% of the fuel has been burnt in here due to the combustion and remaining 15% has been escaped due to high velocity injection of the fuel and oxidizer.

D. *Pressure Distribution*



3.5 Pressure Distribution at 45^0



3.6 Pressure Distribution at 50^0

we have the Pressure of 9.14×10^4 Pa at angle of 45^0. In figure 29, we have the Pressure of 9.43×10^4 Pa at angle of 50^0. whereas the pressure for the 50^0 model holds to have a average pressure of 9.43×10^4 Pa. So when we compare all the parameters the model of 50^0 injector is having a better performance in all aspects. So its been suggested to use this injector for the future use.

IV. RESULT AND DISCUSSION

The simulation results obtained for the Fuel Injector model is as given below.

Si.No	Angle	Velocity (m/s)	Mean mixture fraction	Temp (K)	Pressure (Pa)
3	45	134	0.85	826	9.14×10^4
4	50	157	0.85	845	9.43×10^4

Fuel injectors are place a major role in the combustion chamber, where a poor injector performance causes un burnt propellant to leave the engine, giving unpleasant and poor efficiency. Injectors can be as simple as a number of small diameter holes arranged in carefully constructed patterns through which the fuel and oxidizer travel. The injector has been designed for various angles to determine its improved performance. The injectors are placed to the angle of 30°, 40°, 45°, 50° and 60°, these models are analysed in Ansys fluent and the output parameters such as pressure, velocity and temperatures has been compared for these cases. Based on the output variables the result for the 50° fuel injector holds a better performance in terms of all variables. The model has been simplified and analysed for simulating the results in fast manner. Based on this configuration the actual combustion chamber can be designed and analyzed to verify and validate the results in future before the implementation process. So when we compare all the parameters the model of 50^0 injector is having a better performance in all aspects. So its been suggested to use this injector for the future use.

REFERENCES

[1] Mohan B, Yang W, Chou SK. Fuel injection strategies for performance improvement and emissions reduction in compression ignition engines—A review.http://dx.doi.org/ 10.1016/j.rser.2013.08.051.

[2] Suh HK, Lee CS. A review on atomization and exhaust emissions of a biodiesel- fueled compression ignition engine. Renewable Sustainable Energy Rev 2016;58:1601–20..http://dx.doi.org/10.1016/j.rser.2015.12.329

[3] Gill DW, Ofner H, Stoewe C, Wieser K, Winklhofer E, Kato M, et al. An investigation into the effect of fuel injection system improvements on the injection and combustion of dimethylether in a diesel cycle engine. SAE Tech Pap 2014–01-2658; 2014. doi:10.4271/2014-01 2658.Copyright.

[4] Kim D, Martz J, Violi A. Effects of fuel physical properties on direct injection spray and ignition behavior. Fuel 2016;180:481–96. http://dx.doi.org/10.1016/ j.fuel.2016.03.085

[5] Ferrari A, Mittica A. Response of different injector typologies to dwell time variations and a hydraulic analysis of closely-coupled and continuous rate shaping injection schedules. Appl Energy 2016;169:899–911. http://dx.doi. org/10.1016/j.apenergy.2016.01.120.

[6] Salvador FJ, Gimeno J, De la Morena J, Carreres M. Using one-dimensional modeling to analyze the influence of the use of biodiesels on the dynamic behavior of solenoid-operatedinjectors in common rail systems: results of the simulations and discussion. Energy Convers Manage 2012;54:122–32. http:// dx.doi.org/10.1016/j.enconman.2011.10.007

[7] Payri R, Salvador FJ, Gimeno J, De la Morena J. Influence of injector technology on injection and combustion development, Part 2: Combustion analysis. Appl Energy 2011;88:1130–9. http://dx.doi.org/10.1016/j.apenergy.2010.10.012

[8] Patel C, Lee S, Tiwari N, Agarwal AK, Lee CS, Park S. Spray characterization, combustion, noise and vibrations investigations of Jatropha biodiesel fuelled genset engine. Fuel 2016:185:410-20 http://dx.doi.org/10.1016/ j.fuel.2016.08.003