International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 **Vol-05, Issue-09, Dec 2019**

Mathematical modeling and analysis of a liquid rocket propellant (LH_2/LO_X) combustion chamber with variable mass flow and wall temperature

ABHAY KUMAR, M. Tech Scholar Mechanical Engg. Dept. SRK , Bhopal, India.

Dr. Manoj Chopra, Professor & HOD, RKDF Institute of Science & Technology, Bhopal, India.

Dr. S.S. PAWAR, Professor RKDF Institute of Science & Technology, Bhopal, India.

ABSTRACT - **The study of the subject on which the thesis is been written is for a cryogenic engine. Cryogenic is a branch of physics, which deals with the production and behaviour of materials at very low temperatures. Cryogenic being a vast branch of physic has many applications. The application with which or study is concerned cryogenic rocket engine. Further explanation for cryogenic will be elaborated in this study. Our primary reason for doing this study is to assess the pressure and optimise the exact inlet pressure to face up to the combustion chamber for a constant 50KN thrust of and gravitational impact on the cryogenic combustion chamber. This study has been done by employing a superb technique that is commonly used currently a day's known as CFD tools Fluent 14.5. For fluid flow system and chemical reaction model, Heat transfer and Mass transfer problem. Simulation results provide us acceptable contour results that describe the entire system in correct manner these results additionally validate the reference paper worth therefore our methodology is additionally validate that shows our case, giving boundary condition and geometrical parameters are correct. By CFD results we can conclude that micro-gravitational effect on cryogenic combustion chamber is negligible because velocity of such type of engine is very high as compare to increased velocity value due to lower gravity but increased value of pressure is definitely the positive results in this study. In current study we analyzed the CFD model of a cryogenic combustion chamber for various chamber pressures 40bar initially then changing the pressure by 50bar and 60 bar in Fluent software system. In current analysis we have a tendency to investigate the result of various microgravity through numerical investigation by victimisation gravity mechanism model in Fluent. Our main aim is to research the result of pressure variation on the chamber for a constant 50 KN thrust. Simulation results predict the flow development and turbulence model of a system. we have a tendency to see from the contour results of pressure, temperature and rate that once we increase the recess pressure from 40bar to 50bar and 60 bar the combustion chamber pressure is additionally will increase and contour rate also hyperbolic attributable to turbulence. During this whole method system is stable all the time this shows chamber is face up to or safe for constant 50KN thrust that is our main objective of the study.**

Keywords*: *Oxygen/Hydrogen, Combustion Device, Cryogenic Combustion, High Pressure, Diagnostic, Modelling, CFD, etc.

I. INTRODUCTION

Payload capacity can be increased with the propulsion system having higher specific impulse, in general liquid propellant engines results in longer burning time than conventional solid rocket engines which result in higher specific impulse. Liquid propellants can be classified based on the storable conditions, namely earth storable, cryogenic, space storable etc. Among these cryogenic propellants are widely used because of their high specific impulse compared to other type of propellants. Cryogenics are high energetic propellant combination, also the future space mission needs a propulsion system with the high thrust and reusable capacities, like Space Shuttle Main Engine (SSME), which can also leads to reduction in launch cost per kg of payload with the highly improved payload capacity. As above said space shuttle main engine uses Liquid oxygen and liquid hydrogen as a propellant combination with high specific impulse over the other cryogenic propellant combinations. Apart from the LOX/

DOI : 10.35291/2454-9150.2019.0555

LH2 combination, LOX/ RP- 1 (Kerosene) semi- cryo combination is widely used in Russian launch vehicle engines of RD- 107, RD- 108and RD- 461 in the Soyuz launch vehicles, which offers slightly lower specific impulse than LOX/ LH2 combination with advantage of handling. The demand of increasing payloads and increasing size of satellite increases the need of more efficient rocket propulsion system. The cost of the payload can be decreased by implementing new reusable launching systems with the intentions to increase the efficiency of the launching system. For such condition high energetic cryogenic propellant combination provides suitable thrust to weight ratio with high specific impulse than current existed earth storable propellants. Reduction in launch cost per kg of payload with the highly improved payload capacity. As above said space shuttle main engine uses Liquid oxygen and liquid hydrogen as a propellant combination with high specific impulse over the other cryogenic propellant combinations. Apart from the LOX/ LH2 combination, LOX/ RP- 1 (Kerosene) semi- cryo combination is widely used in Russian launch vehicle engines of RD- 107, RD- 108and RD- 461 in the Soyuz launch vehicles, which offers slightly lower specific impulse than LOX/ LH2 combination with advantage of handling. The demand of increasing payloads and increasing size of satellite increases the need of more efficient rocket propulsion system. The cost of the payload can be decreased by implementing new reusable launching systems with the intentions to increase the efficiency of the launching system. For such condition high energetic cryogenic propellant combination provides suitable thrust to weight ratio with high specific impulse than current existed earth storable propellants. The propellant combination of liquid hydrogen and liquid oxygen has high specific impulse compared to other propellant combinations have been used in many rocket engines. The thermal analysis is a major issue in at the channel exit. Those parameters are important for the design of injectors and of the coolant pump. The design of a liquid rocket engine, because the prediction of peak heat-flux from the combustion gases to the engine wall is necessary to ensure the structural integrity of the combustion chamber. The need for thermal analysis is essentially important to extend the engine life by effective and efficient cooling system. Moreover, the analysis of the cooling channel flow is essential to predict not only the efficiency of the coolant, but also the coolant temperature and pressure. The design of thrust chamber consists of many parameters and detail calculations, using basic geometric parameters are adequate to understand the regenerative cooling effect of the system. For the built-up of gas dynamic profile of the combustion chamber, it is necessary to give some input data to the system such as thrust (at sea level), chamber pressure, ambient pressure and propellant components.

II. LITERATURE REVIEW

Senthilkumar et al. (2013)[1] The basic concept of a rocket engine relays on the release of the internal energy of the propellant molecules in the combustion chamber, the acceleration of the reaction product and finally the release of the hot gases at the highest possible velocity in the convergent/divergent nozzle. Liquid rocket engines burn propellants, which undergo chemical reactions to convert the stored chemical energy to thermal energy which results in the generation of thrust. Thrust chamber of cryogenic engine is modelled at a chamber pressure of 40 bar and thrust of 50KN to reduce the high temperature and pressure in the combustion chamber. CFD analysis is done to show the pressure and temperature variation in the thrust chamber modelled for 50KN thrust and chamber pressure of 40 bar. The design of rocket engine should be such that it should withstand the high pressure and high temperature of the combustion chamber. Ashwini, and Prabhakaran (2015) [2] This paper highlights about the rocket engine involving the use of cryogenic technology at a cryogenic temperature (123 K). This basically uses the liquid oxygen and liquid hydrogen as an oxidizer and fuel, which are very clean and non-pollutant fuels compared to other hydrocarbon fuels like Petrol, Diesel, Gasoline, LPG, CNG, etc., sometimes, liquid nitrogen is also used as fuel. The efficiency of the rocket engine is more than the jet engine. As per the Newton's third law of mechanics, the thrust produced in rocket engine is outwards whereas that produced in jet engine is inwards. Poschner and Pfitzner (2009) [3] M Poschner and M Pfitzner in this paper studied real gas as rocket propellant. Due to the high pressures and very low injection temperatures of the propellants in modern rocket combustors real gas effects play an important role in rocket combustion simulation. These have to be accurately modelled in combustion CFD simulations to enable an accurate prediction of the performance of the rocket combustion chamber. There research was based on theoretical model. They started with a simple experimental model and conducted simulation on cfx. The gases they used were liquid oxygen at 85 K and gaseous hydrogen at 257 K. They achieved a pressure of about 100 bar in combustion chamber at the time of combustion. Foe injecting gases they used co axial injector. Vivek Gautam (2007) [4] The study submitted by Vivek Gautam (2007) worked profoundly on rocket jet propulsion two phase co axial injector. His study marked a significant point on combustion and injection of propellant in combustion chamber. The previous studies that were conducted lack informative data. On such type of flows is either incomplete or ambiguous. Previous models available on the same study lacked operating conditions. Operating conditions were very narrow and limited. This part of this literature review is focused on the research performed on non-reacting two phase coaxial jets with cryogenic fluids such as liquid oxygen (LOX) and liquid nitrogen (LN2). These experiments were performed to analyze the flow, atomization and mixing characteristics of shear coaxial injectors typically used in cryogenic rocket engines. Vivek Gautam (2007) on studying Bellan (2000) [7] found that she performed an extensive review on subcritical and supercritical fluid atomization behaviour and modelling issues. She showed that fluid jet disintegration under supercritical conditions is fundamentally different from the much studied subcritical liquid atomization. Instead of the subcritical wave formation at the surface of the liquid resulting from the relative velocity between the liquid and gas, ensuing in the subsequent instability and the further breaking of the liquid sheet, under supercritical conditions the fluid disintegrates in a remarkably different fashion. The optical data shows wispy threads of fluid emanating from the jet boundary and dissolving into the surrounding fluid. The existing information on two phase flows and atomization behaviour is of qualitative nature for supercritical fluids and considerable experimental work is necessary to provide data appropriate for model validation. She also discussed and evaluated the accuracy of existing models based on specific aspects supercritical fluids, such as intrinsic transient behaviour, lack of a material surface, real gas equations of state, mixture non-idealistic, increased solubility, Soret and Dufour effects and high pressure transport properties. Another researcher Woodward (1994)[8] used X-ray radiography and instantaneous imaging technique to measure the potential core length of LOX stimulant (KI in aqueous solution) for a large range of Reynolds number, Weber number and density ratios. His measurements included two different approaches to measure the intact core length of LOX stimulant. The first technique was thresh-holding of jet images to reveal the core images corresponding specific liquid integrated thickness while the second technique was de convolution of time averaged images to obtain mean liquid volume fraction distributions. Although both the techniques had inherent unknown errors, they provided some very important measurements of cryogenic flow stimulants for the first time.

III. OBJECTIVE

Due to their high specific impulse, Oxygen/Hydrogen systems are often used to increase launcher performance and will probably continue to be the preferred option for the next decades. In order to get insight into complex processes involved in the combustion of such propellants, research efforts have been conducted in both France and Germany including theoretical and experimental activities. This article deals with recent progress achieved by research teams from both countries in high pressure Oxygen/Hydrogen (O2/H2) combustion systems. In current study we will analyze the CFD model of a cryogenic combustion chamber for different chamber pressure 40bar initially and then changing the pressure by 50bar and 60 bar in Fluent software. We will also investigate the effect of different microgravity through numerical investigation by using gravity mechanism model in Fluent. Our main aim is to investigate the effect of pressure variation on the chamber for a constant 50 KN thrust. CFD analysis will be done to show the pressure, temperature and velocity variation in the thrust chamber modeled for 50KN thrust and chamber pressure of 40, 50 and 60 bar. The design of rocket engine should be such that it should withstand the high pressure and high temperature of the combustion chamber.

IV. RESULTS ANALYSIS

CASE – I => Pressure – 40 Bar, Temp- 3420 K, g= 9.81

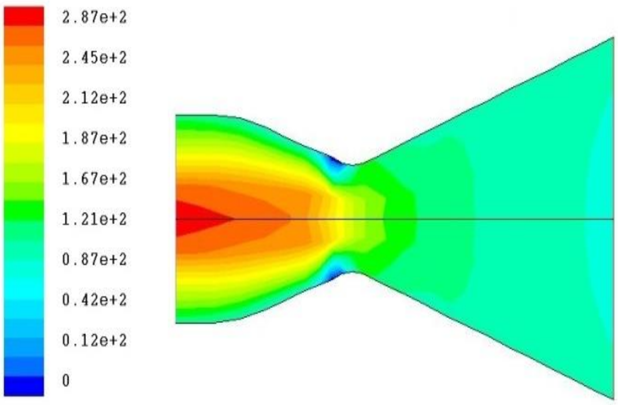

Figure 1 Pressure at 40 Bar Inlet Pressure @ g=9.81

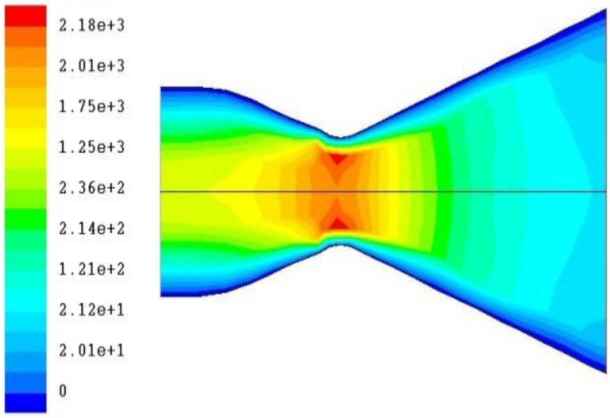

Figure 2 Velocity at 40 Bar Inlet Pressure @ g=9.81

CASE – II => Pressure – 50 Bar, Temp- 3420 K, g= 9.81

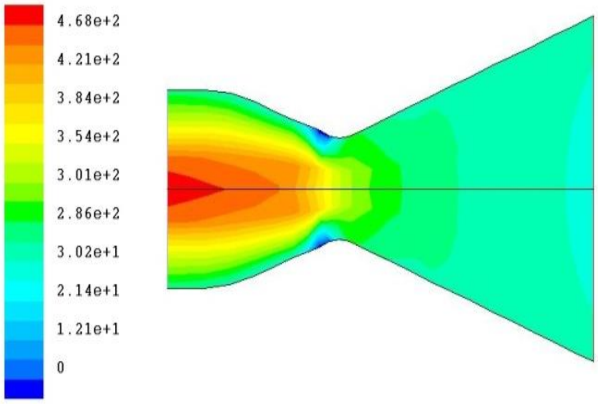

Figure 3 Pressure at 50 Bar Inlet Pressure @ g=9.81

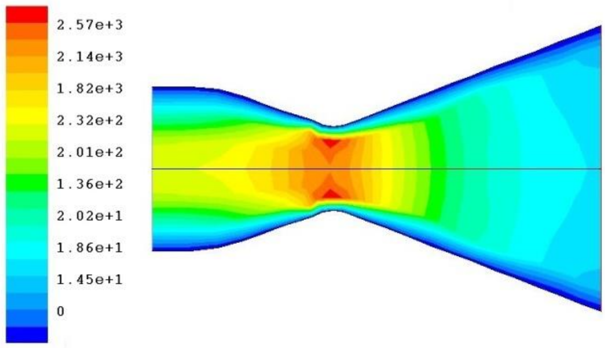

Figure 4 Velocity at 50 Bar Inlet Pressure @ g=9.81

CASE – III => Pressure – 60 Bar, Temp- 3420 K, g= 9.81

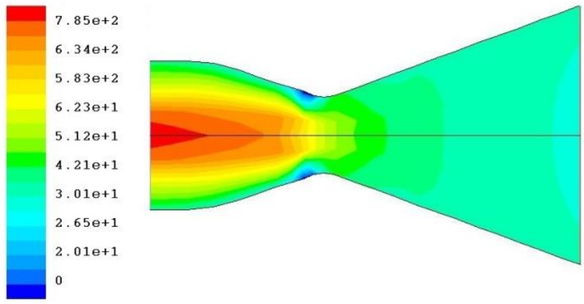

Figure 5 Pressure at 60 Bar Inlet Pressure @ g=9.81

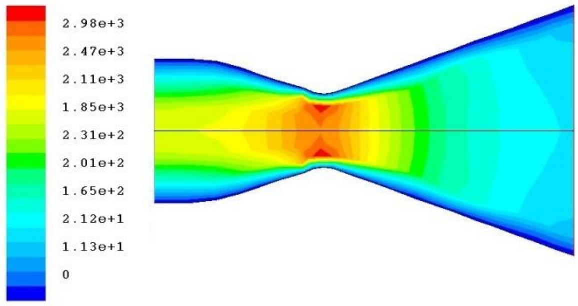

Figure 6 Velocity at 60 Bar Inlet Pressure @ g=9.81

CASE – IV => Pressure – 60 Bar, Temp- 3420 K, g_1= 0.75g

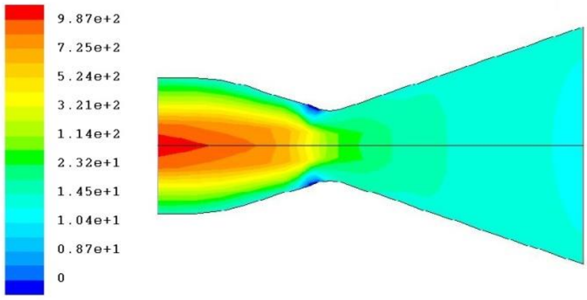

Figure 7 Pressure at 60 Bar Inlet Pressure @ g_1=0.75g

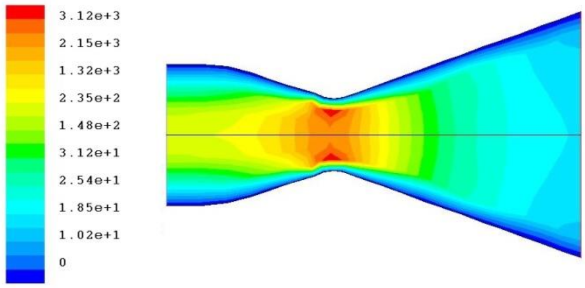

Figure 8 Velocity at 60 Bar Inlet Pressure @ g_1=0.75g

CASE – V => Pressure – 60 Bar, Temp- 3420 K, g_1= 0.5g

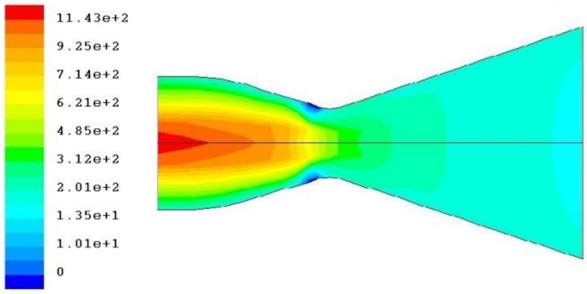

Figure 9 Pressure at 60 Bar Inlet Pressure @ g_1=0.5g

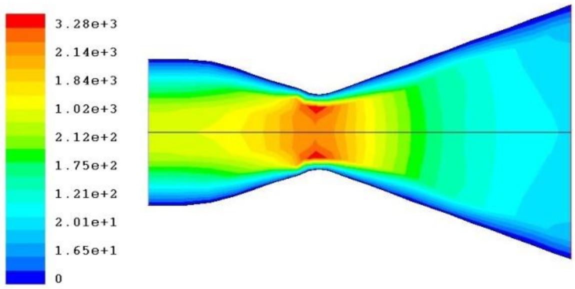

Figure 10 Velocity at 60 Bar Inlet Pressure @ g_1=0.5g

CASE – VI => Pressure – 60 Bar, Temp- 3420 K, g_1= 0.25g

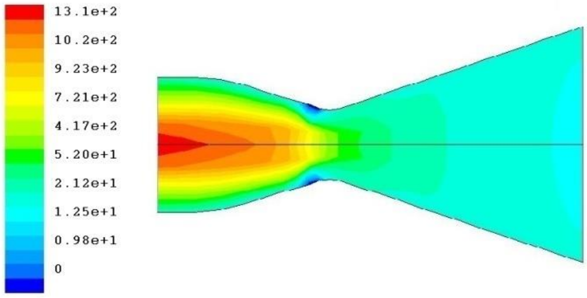

Figure 11 Pressure at 60 Bar Inlet Pressure @ g_1=0.25g

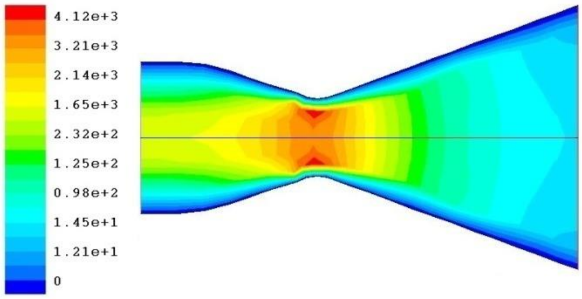

Figure 12 Velocity at 60 Bar Inlet Pressure @ g_1=0.25g

V. CONCLUSION

In current study we will analyze the CFD model of a cryogenic combustion chamber for different chamber pressure 40bar initially and then changing the pressure by 50bar and 60 bar in Fluent software. In current research we investigate the effect of different microgravity through numerical investigation by using gravity mechanism model in Fluent. Our main aim is to investigate the effect of pressure variation on the chamber for a constant 50 KN thrust.

DOI : 10.35291/2454-9150.2019.0555

Simulation results predict the flow phenomenon and turbulence model of a system. We see from the contour results of pressure, temperature and velocity that when we increase the inlet pressure from 40bar to 50bar and 60 bar the combustion chamber pressure is also increases and streamline velocity also increased due to turbulence. In this whole process system is stable all the time this shows chamber is withstand or safe for constant 50KN thrust which is our main objective of the study.

REFERENCES

[1] S. Senthilkumar , Dr. P. Maniiarasan ,Christy Oomman Jacob ,T. Vinitha Design And Analysis Of Thrust Chamber Of A Cryogenic Rocket Engine 2013

[2] A.m. Ashwini, M. Prabhakaran "Cryogenic technology in rocket engines" B.E. Final year, *Dept of Aeronautical Engineering*, Dr. Pauls Engineering College. 2015

[3] M. Poschner, M. Pfitzner "CFD-Simulation of supercritical LOX/GH2 combustion considering consistent real gas thermodynamics" Thermodynamics Institute, Faculty for Aerospace Engineering, *University of the Federal German Armed Forces* , Munich 2009

[4] Vivek Gautam "Flow And Atomization Characteristics Of Fluid From A Co Axial Rocket Injector" Graduate School of the *University of Maryland*, College Park,2007

[5] Oschwald, M., Smith, J. J., Branam, R., Hussong, J., Schik, A., Chehroudi, B. and Talley, D.: "Injection of Fluids into Supercritical Environments", *Combustion Science and Technology*, Vol. 178, 2000

[6] Bellan, J.: "Supercritical (and subcritical) Fluid Behavior and Modeling: Drops, Streams, Shear and Mixing Layers, Jets and Sprays", *Progress in Energy and Combustion Science*, Vol. 26, 2000

[7] Woodward, R.: "*Doctoral Dissertation*", Submitted to Department of Mechanical Engineering, Penn State University, 1994

[8] Glogowski, M., Bar-Gill, M., Puissant, C., Kaltz, T., Milicic, M., and Micci, M., "Shear Coaxial Injector Instability Mechanisms," *30th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, Indianapolis, IN, June 27-29, 1994, AIAA-94-2774

[9] Vingert, L., Gicquel, P., Lourme, D., and Menoret, L.: "Coaxial Injector Atomization", *Progress in Aeronautics and Astronautics*, Vol. 169, AIAA, 1994.

[10] Carreau, J. L., Porcheron, Prevost, L., E., Visage, D. Le and Roger, F., Gicquel, P. and Vingert, L.:" Atomization of a Liquid Oxygen Jet by a Coaxial Inert Gas Jet", *14th Conference on Liquid Atomization and Spray Systems*, Florence, 1997

[11] Mayer, W.: "Coaxial Atomization of a Round Liquid Jet in a High Speed Gas Stream: A Phenomenological Study, Characteristics on the Surface of Round Liquid Jet", *Experiments in Fluids* Vol. 16, 1994.

[12] Branam, R. and Mayer, W.: "Length Scales in Cryogenic Injection at Supercritical Pressure", *Experiments in Fluids* Vol. 33, 2002,

[13] Porcheron, E., Carreau, J. L., Prevost, L., Visage, D. Le, Roger, F.,: "Effect of Injection Gas Density on Coaxial Liquid Jet Atomization", *Atomization and Sprays*, Vol. 12, Issue 1, 2002

[14] Chehroudi, B., Cohn, R., and Talley, D. G.: "Cryogenic Shear Layers: Experiments and Initial Growth Rates of Round Cryogenic Jets at Subcritical and Supercritical Pressures", *International Journal of Heat and Fluid Flow*, Vol. 23, No. 5, 2002

[15] Candel, S., Juniper, M., Singla, G., Scouflaire, P. and Rolon, C.: "Structure and Dynamics of Cryogenic Flames at Supercritical Pressure", *Combustion Science and Technology*, 178, 2006

[13] Habiballah, M., Orain, M., Grisch, F., Vingert, L., Gicquel, P.: "Experimental Studies of High-pressure Cryogenic Flames on the Mascotte Facility", *Combustion Science and Technology*, 178, 2006

[17] Ivancic, B. and Mayer, W.: "Time and Length Scales of Combustion in Liquid Rocket Thrust Chambers", *Journal of Propulsion and Power*, Vol. 18, No. 2, March-April. 2002,

[18] Oefelein, J. C. and Yang, V.: "Modeling High Pressure Mixing and Combustion Processes in Liquid Rocket Engines", *Journal of Propulsion and Power*, Vol. 14, No. 5, September-October 1998

DOI : 10.35291/2454-9150.2019.0555