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Design And Cfd Analysis Of Valves- Pulse Jet Engine

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***Abstract* -** Pulse jets are considered one of the simplest aerospace propulsions systems to produce. The basic operation starts when a fuel, air mixture is introduced to the combustion chamber, an igniter combusts the air/fuel mixture which creates a rise in pressure. While the pulse jet may be inefficient, these engines can run on many different fuels. This has generated recent interest in this engine in search for alternatives to current propulsion systems. Some research has been run to increase efficiency by installing features such as flame holders in the engine for higher combustion efficiency, or by injecting water for increased compression.
The pulse jet is designed with a valved type and use propane as fuel. This project is aimed at comparing 3 valves, Ram intake, pyramid valve and solenoid valve. A Combustion Analysis of these three systems are analyzed using Ansys for the CFD simulation. pulse jets have been a staple of simple, low-cost jet propulsion. Due to its low efficiency, pulse jets were phased out with the introduction of modern rocket and turbojet engines, but the fascination of their simplicity has kept enthusiasts hooked on developing new designs and uses for recreation. Improvement of valved pulsejets and create a unique design. The purpose of this paper is to outline a design and execute an original one-way valve system for the intake of a pulse jet. Three different valves, Ram, Pyramid and solenoid are designed using solid works. The CFD analysis revealed that the highest temperature was achieved by Pyramidal Valve, followed by Ram Valve and the lowest temperature was achieved in the Solenoid Valve. Velocity wise, the Ram was the best, followed by Pyramidal and Solenoid Valves. However, pulse jet engine with pyramid valve has the highest mass fraction of carbon dioxide as a product.

***Keywords*:** Ram valve, pyramid valve, solenoid valve, CFD, Ansys

1. Introduction

Pulse jets are considered one of the simplest aerospace propulsions systems to produce. These engines consist of an intake, one way valve, combustion chamber, and exhaust. Given the shape of the pulse jet, the combusted gas expands and leaves the exhaust, a low-pressure region in the combustion chambers then formed by the inertia of the exhausted gas. This low pressure allows air to enter through a one-way valve which is mixed with fuel, and the cycle starts over again. While the exact origin of the pulse jet is unclear, in 1931, Robert Goddard patented his valved pulse jet in 1931 [2]. German Aerospace engineers during World War 2 used a pulse jet to propel a flying bomb. This bomb became the V1 bomb also known as the "buzz bomb", which was also the first cruise missile [1]. After World War 2, the United States and the USSR ran programs to further understand the feasibility of this engine but decided after a couple years to abandon these projects due to the short life of the intake valves, low efficiency, and high noise levels [3]. While the pulse jet may be inefficient, these engines can run on many different fuels. This has generated recent interest in this engine in search of alternatives to current propulsion systems. Some research has been conducted to increase ethe efficiency by installing features such as flame holders in the engine for higher combustion efficiency, or by injecting water for increased compression. The pulse jet we plan to build will be a valved type and will run on propane, built from rolled sheet metal cut on the plasma cutter, then welded to seal the combustion chamber and exhaust. The intake will be a mixture of CNC machined parts that are welded or fastened with bolts. To model this pulse jet, we will use solid works and solid works flow simulation to conduct the CFD. Elsadi et al. [4] perform an analysis on jet engine, several quantities at specific locations are needed. Sensors are instrumented on this engine at the compressor inlet, compressor outlet, turbine inlet, turbine exit, and exhaust to collect data on the temperature and pressure at each location. This data is then used to perform a performance analysis on the engine. In addition, there are sensors on this engine to monitor thrust, RPM, and fuel flow rate. Also, Elsadi et al. [5] studied a turbofan high pressure turbine was used as the test vehicle for this investigation. The main objective was to explore potential improvements in engine SFC (aerodynamic performance) by reducing the parasitic work while minimizing the impact on the factors that affect the durability of the turbine blades, feed pressure, temperature, and mass flow. Many studies have been done on the combustion process of pulse jet engine by increasing the combustion-air temperature from 80 to 130 degrees F for the same conditions of fuel flow and simulated ram pressure, the jet thrust was reduced about 6 to 10 percent, which is roughly equivalent to the percentage increase in absolute temperature of the combustion air [6]. Min et al. studied the effect of intake on the combustion of pulse jet engine, the increase of fuel flow, increases the degree of incomplete combustion of the fuel [7].

The objectives of this work are to design different valves, Ram intake valve, pyramid valve and solenoid valve for the pulse-jet engine and achieve CFD analysis to perform the combustion analysis, Engineering equation solver was used to calculate the conditions of the combustion which were given as inputs to run the CFD.

1.1 2. Design

The ram style intake is influenced by the geometry of a turbo-ramjet engine, similar to that of the SR-71 Blackbird. Instead of being used to slow the velocity of supersonic air, the cone is used for upstream fuel injection. Due to the nature of pulsejets, intake valves are subject to extreme heat. In an attempt to reduce heat and increase reliability, upstream fuel injection is used to cool intake valves and increase atomization of fuel to be combusted. The fuel was chosen for this engine is liquid propane due to its low temperature of -44°F and relatively wide stoichiometric operating range. A small 30° fan injector before each valve will provide sufficient cooling and fuel delivery. The injector design is based on a proven mechanical fuel system called a Hilborn injector. The design of a Ram valve at different views is shown in figure 1, however figure 2 shows the rough assembly with Ram valve.

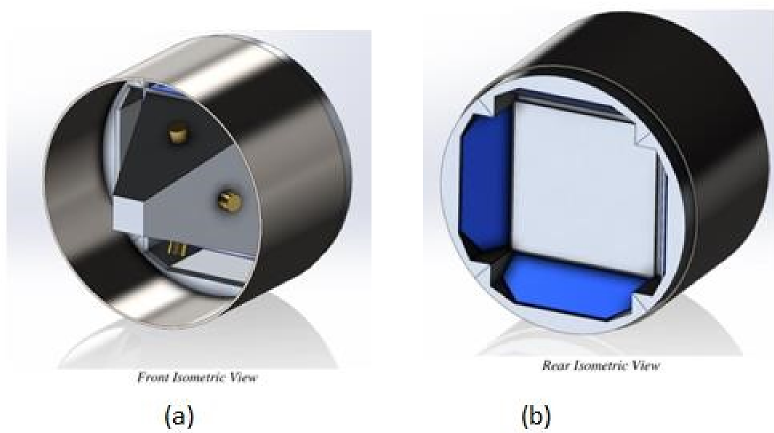


Fig. 1 Ram style valve: a- front isometric view, b- rear isometric view

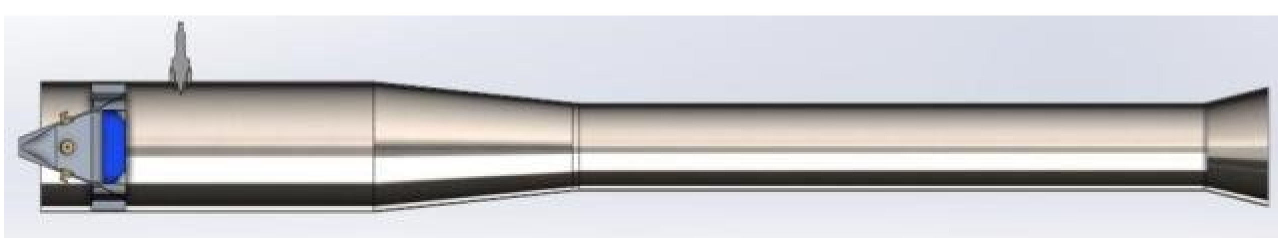


Fig. 2 Rough assembly with Ram style valve

Almost all existing valved pulse jets employ dynamics of the system to operate their closure/opening. The other design is considered a solenoid valve which would be controlled by a closed loop systems that would read physical states of the system and use them to match the frequency of the combustions. Additionally, this valve system by its definition will be able to observe and record parameters of the system like. A solenoid with a spring return is connected to the valve. Solenoid is located outside the combustion chamber, in the air intake area. This allows the core of the solenoid to stay operational, as high temperatures decrease magnetic permeability. Solenoid is to be controlled by a relay controlled by the microcontroller. Inputs for the close loop command to be received by piezo sensor (vibration), pressure sensors and temperature sensors. The fluid domain in the engine with solenoidal valve is shown in fig. 3-a and the design of solenoidal valve is shown in fig3-b

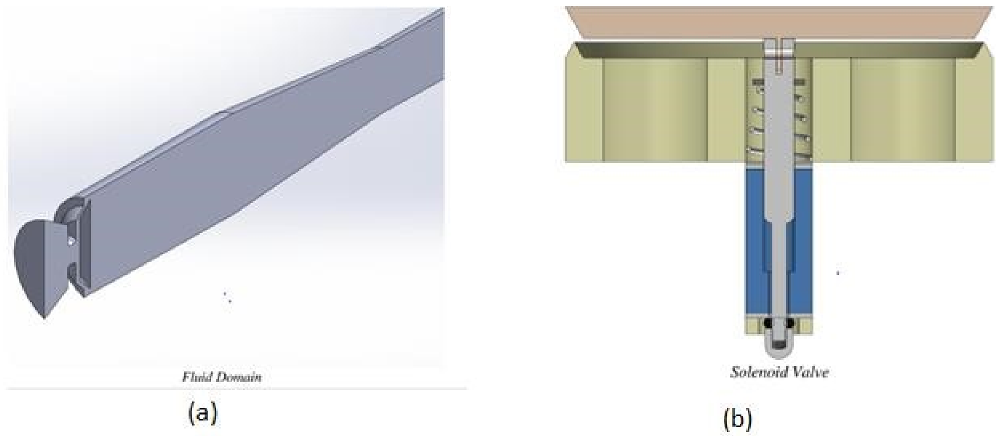


Fig. 3 the solenoidal valve: a- the fluid domain, b- the solenoidal valve

The third valve was analyzed is the pyramid valve. The potential for the pyramid valve is to allow for even mixture of air to fuel. This valve consists of 4 spring steel plates mounted to the rectangular valve frame. These spring steel plates will displace due to the low pressure when the exhausted gas exits the exhaust. Because there are 5 different seam areas within this valve, there is a lot of area spread out in this valve for air to enter the combustion chamber. Therefore, in theory, this will allow for an evenly mixed air-fuel mixture. In case of successful tests, all data will be recorded in addition with vibration studies. This data will be posted as a part of the pulse jet research and will aid in increasing the limited knowledge about pulse jets.

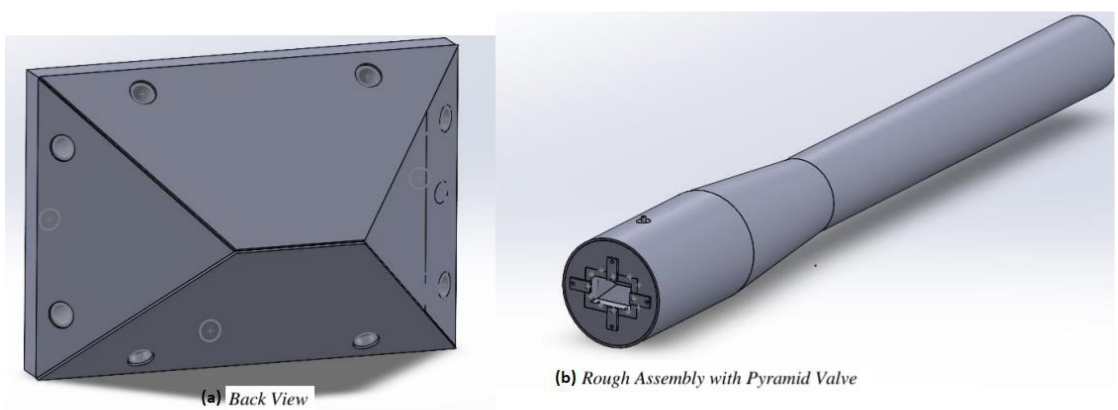


Fig. 4 the solenoidal valve: a- the back view of the valve, b- the assembly with pyramid valve

1.2 3. Computational Fluid Dynamics

Multiple CFD studies are completed for determining physical characteristics of the combustion and other fluids that exist in the operating volume of the diffuser and the pulse jet pipe. The environment selected for computing is Ansys and its module CFD Fluent. The chronology of simulation evolutions is as follows: simulation of a chosen pipe geometry with a “test” intake geometry at temperature of 420 Rankine and mass flow rate boundary conditions of typical value for smaller scale pulse jets [8]; Case of each intake and valve geometry. For all geometries an adaptive meshing was used in order to enable the tetrahedral meshing and allow for more precise meshing of smaller geometry. Due to usage of pressure based

CFD calculation method, relaxation factors are used by the program. The default relaxation factors for pressure and kinetic energies seemed to be aggressive and were lowered. Momentum and density factors were change by trial and error to achieve better convergence. The propane was used as a fuel, the chemical Equation:

$$C3H8 + 5(O2 + 3.75N2) \rightarrow 3CO2 + 4H2O + 18.8N2$$

Figure 5 shows the contour of the velocity for different intake pulse jet engine, it is observed that the highest velocity (1100 ft/s) when the intake is Ram jet valve comparing to the velocity (1030 ft/s) at the exit of solenoid valve pulse jet engine. However, the lowest velocity (700 ft/s) when the pyramid valve was used. Therefore, the thrust is the highest when Ram valve intake was used in the jet engine, and this is because of the intake valve geometry. Note that all geometries have injectors located in the mixing front of the C3H8 and Air. Ignition before thorough mixing created multiple separate flame fronts that got mixed towards the end. The second thing that can be noted about the injectors comes from the Pyramidal Valve case as shown in figure 7. In this case the injector penetrates halfway through the diameter of the combustion chamber which causes the C3H8 to flow backwards as it contacts the wall. This behavior of a fluid creates so called slanted “pillow” which pushes complete mixture towards the exhaust. In this case turbulence is created but it has more of a negative character, as it carries propane into a low air pocket sending the mixture perpendicular to the incoming air. Very easy problem to fix, yet so small it creates a big difference.

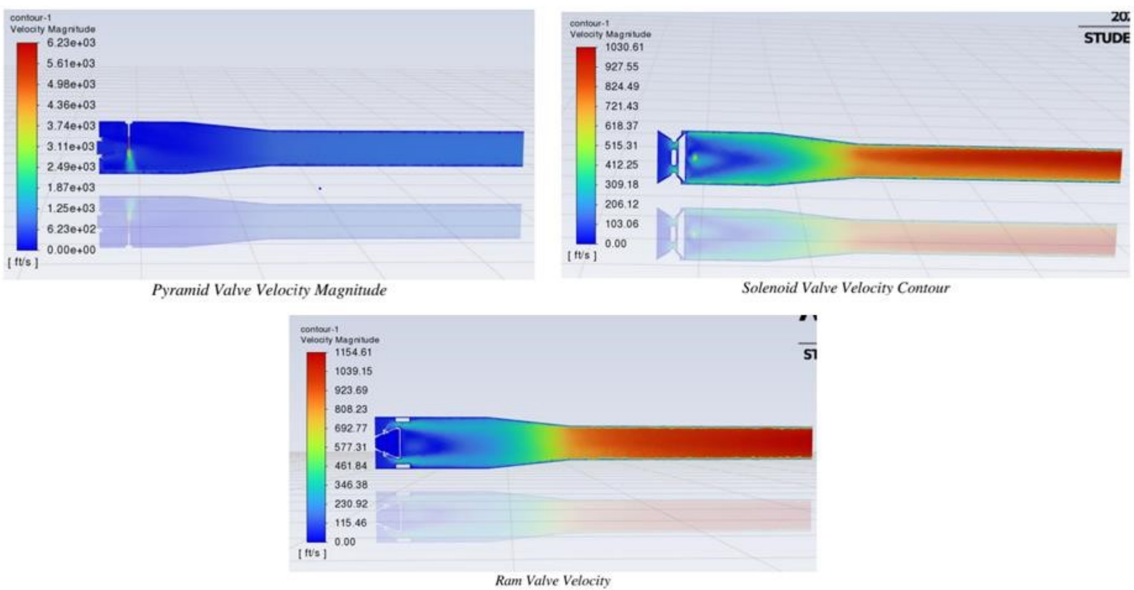
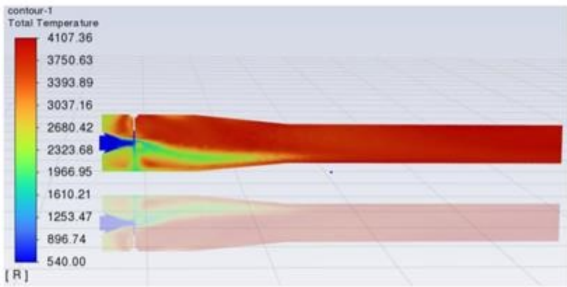
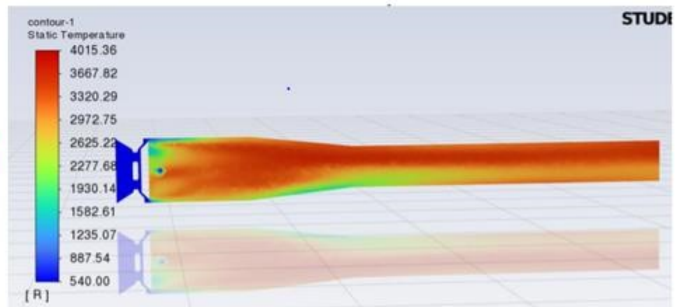


Fig. 5, The contour of the velocity for different intake valves of the pulse jet engine

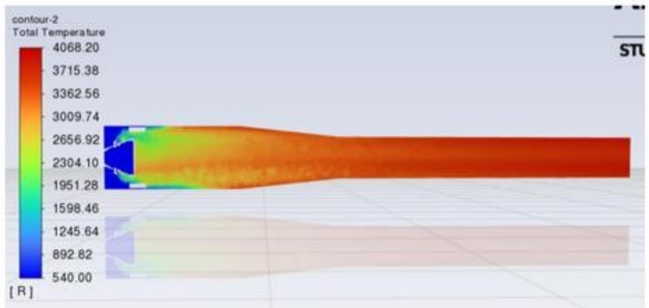
Figure 6 shows the contour of the temperature for different intake valves of pulse jet engine. It can be noticed that the highest temperature was achieved by Pyramidal Valve [4107R], followed by Ram Valve [4067R] and the lowest temperature was achieved in the Solenoid Valve.



Pyramid Valve Temperature

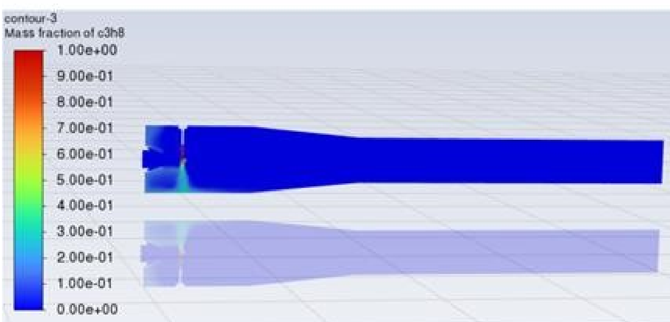


Solenoid Valve Temperature Contour

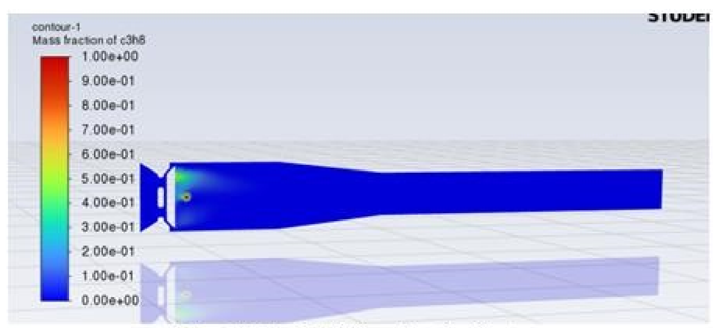


Ram Valve Total Temperature

Fig. 6, The contour of temperature for different intake valves of pulse jet engine



Pyramid Valve C3H8



Solenoid Valve C3H8 Mass Fraction Contour

Fig. 7 the injector of the fuel for pyramid and solenoid valves

One of the products of air-fuel reaction in the combustor is H2O, figure 8 revealed the contour of water for three different intake valves. It is noticed from that the geometry of fuel-air injector affects on H2O mass fraction at the exit of the pulse jet engine, pulse jet engine with Ram valve produces more mass fraction of H2O as a product then followed by pyramid and the lowest mass fraction of H2O was found in the pulse jet engine with solenoid valve. In general H2O as a product can affect on the environment and one of the reasons that cause climate change by creating contrail at very high altitude, therefore the design of intake valve should be taking into account. It was found that t the contrail cirrus outbreak is warming in the early morning and cooling during the day [9].

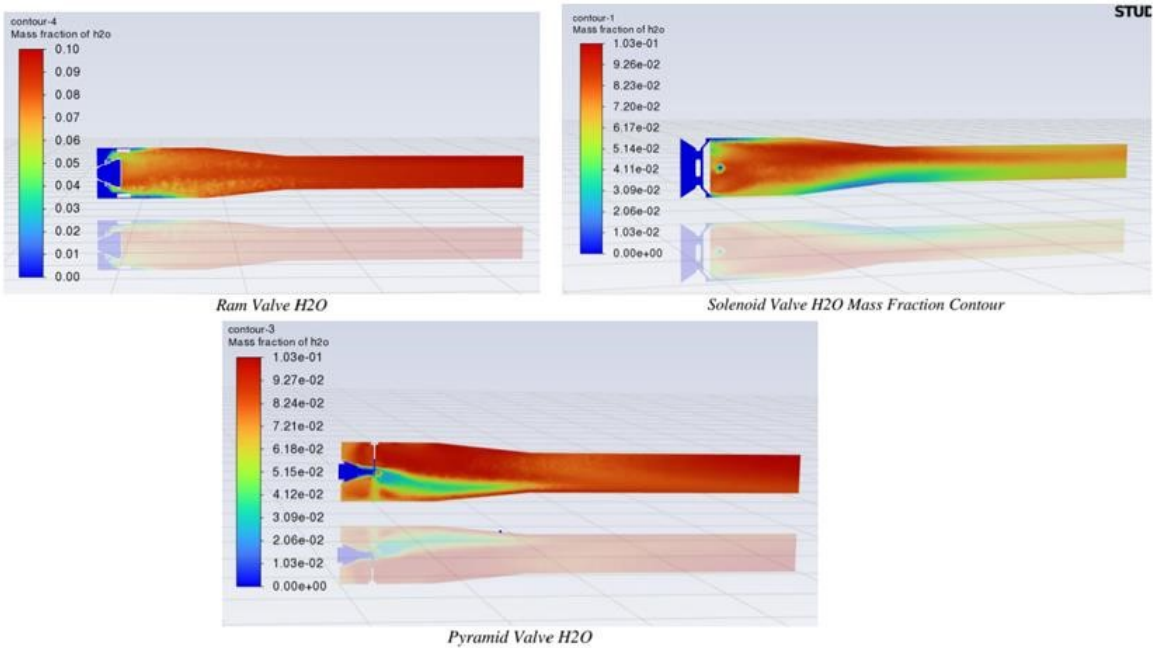


Fig. 8 The contour of water for different valves

Carbon dioxide is one of the exhausted gases as a product resulted from combustion, previous studies showed that carbon dioxide effects on the climate change [6]. Figure 9 shows the contour of carbon dioxide for the different intake valves of the pulse jet engine. The pulse jet engine with pyramid valve has the highest mass fraction of carbon dioxide (0.15), followed by the engine with solenoid valve (0.13), and the lowest mass fraction of carbon dioxide as a product was found for Ram valve engine (0.095).

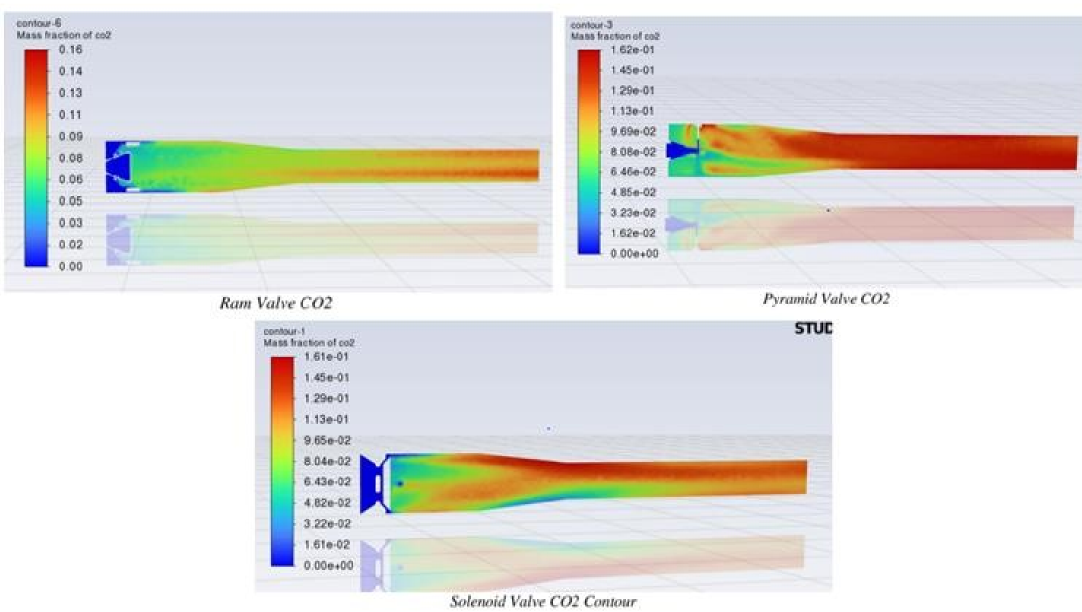


Fig. 9 The contour of carbon dioxide for different valves

4. Conclusion

Pulse jet engine with different intake valves were studied. CFD is used to analyze the ram, pyramid and solenoid valves. Propane was used as fuel for all the CFD analysis. The CFD calculations use stochiometric ratios for calculating the products. The flow rates are set constant and the same for all geometries which causes a complete reaction to be reached as the mixture has enough time to burn all the propane. It is concluded that the highest temperature was achieved by Pyramidal Valve [4107R], followed by Ram Valve [4067R] and the lowest temperature was achieved in the Solenoid Valve. Velocity wise, the Ram was the best, followed by Pyramidal and Solenoid Valves. For the products resulted from the chemical reaction in the combustor, pyramid valve has the highest mass fraction of carbon dioxide. pulse jet engine with Ram valve produces more mass fraction of H_2O as a product then followed by pyramid.

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