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Numerical and Experimental Study of Thrust Force of Valve-less Pulse Jet

Ahmad Afsari, Ali Reza Tahavvor and Yousef Bazargan-Lari
Department of Mechanical Engineering, Shiraz Branch, Islamic Azad University, Shiraz, Iran

Corresponding Author: Yousef Bazargan-Lari, Department of Mechanical Engineering, Shiraz Branch, Islamic Azad University, Shiraz, 97 Daneshgah St., FarhangShahr. Blvd, Iran Tel: +98-711-6309101, 71879-55546

ABSTRACT

Pulse jets are characterized by simplicity, low cost of construction and high noise levels. Pulse jet fuel efficiency is a topic for hot debate, as efficiency is a relative term. The high noise levels usually make them impractical for other than military and other similarly restricted applications. However, pulse jets are used on a large scale as industrial drying systems and there has been a new surge to study and apply these engines to applications such as high-output heating, biomass conversion and alternative energy systems. In this study, testing is performed on the 450 cm pulse jet engine. Main objective of present study is finding and scaling laws and design characteristics of the pulse jets in order to optimization of the engines. The pulse jet used in this study is valve-less with propane fuel. Scaling capabilities of a valve less pulse jet are studied by varying inlet length, exit length, type of exit geometry and inlet area to combustor area ratio. Also, engine performance is defined by measuring chamber pressure, internal gas temperature, thrust and fuel flow rate. The scaling capability is characterized by the success of self-sustained combustion for each corresponding geometric configuration. Tailpipe length is found to be a function of valve less inlet length and may be further minimized by the addition of a diverging exit nozzle. Ranges of geometric configurations of this engine contain combustion chamber with 10.8, 5 cm inlet diameter, 12 cm exit diameter and 12 N thrust.

Key words: Pulse jet, valve-less, thrust force, diameter

INTRODUCTION

In 1949, Cornel Aeronautical Laboratory was working on a project for the US Navy, called Project Squid. This work focused on the operation of valve less pulse jets. In another work Bertin (1951) studied about Escopette pulse jet. This type of pulse jets uses air diode instead of valves like Marconnet pulse jet.

According to their research of the 1950s, the inlet had no preferred frequency; beside its high reliability and ease of using constant fuel pressure for feeding made it very attractive. The weakness of air diode is the flow back out which is the reason of reduction of the thrust.

Emmerich (1953) used pulse jets to produce tip-propulsion for rotors. Tests were performed at various altitudes and noise tests were conducted as well. They found that when the altitude was increased and density decreased, the jet became more and more difficult to start. All data was converted to ‘standard data’ for comparison purposes. As suspected, a decrease in thrust was noted as air density decreased.

Lockwood (1963) studied about U-tube pulse jets. This work studied several methods to achieve thrust for lightweight engines. They tested several exit geometries and combustion chamber designs and found that changing the combustion chamber shape has a dramatic effect on thrust and efficiency with TSFC levels less than 2.0 pph lb^{-1}. Also, Logan (1951) and Reynst (1961) studied about valve-less pulse jets and pulsating firing systems, respectively.

Defense Advanced Research Projects Agency (DARPA) is commenced the investigation about pulse jets. The main objective of these studies is research about scalability of small Unmanned Aerial Vehicle (UAV) propulsion. Review of literatures show that design parameters of pulse jets had not been fully investigated; therefore any equations about pulse jets have not been developed. So, the objective of present study is finding and scaling laws and design characteristics of the pulse jets in order to optimization of the engines.

GEOMETRY

This valve less pulse jet engine comprised an inlet tube, combustion chamber and exhaust nozzle. Two fuel ports were located at the combustor chamber and immediately downstream of the transition section, a stainless steel sheet with 6 mm thickness was chosen because it was available and easy to machine (Fig. 1).

FUEL INJECTION

Fuel was first injected upstream of the reed valves through 6MM stainless steel tubing inserted through the constant area inlet, as shown in Fig. 2. The fuel was added via two small holes drilled circumferentially about the tube. The fuel used in this experiment is gaseous propane.

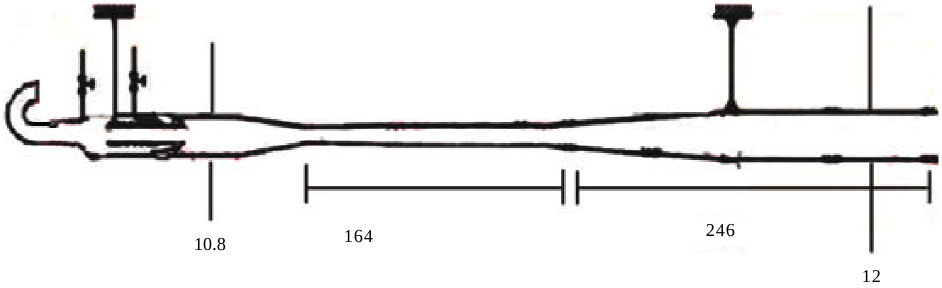

Fig. 1: Geometry (all dimensions are in cm)

Fig. 2: Experimental model of pulse jet

STARTING OF THE JET

Starting the pulse jet began with two things, the need to supply the first intake of air and a way to ignite mixture of fuel and air (Foa, 1960). In the valve less configuration, the fuel used was gaseous propane and directly injected in to the combustion chamber behind the inlet.

After the mixture entered the chamber, it was ignited by a spark. After the initial combustion events occur, the engine continued to run on its own. A warm jet was found to be easier to start than a cold jet; this is most likely due to the effect of heat transfer at the walls (Foa, 1960). After the jet is running, the ignition can be turned off and the forced air can be stopped.

PRESSURE, TEMPERATURE AND VELOCITY

Pressure data is used to determine the operational frequency of the jet, also to find the peak pressure and the amplitude of pressure waves. A pressure distribution is shown in Fig. 3. Pressure inside the combustion chamber immediately before ignition is generally equivalent to atmospheric free-stream conditions, after ignition pressure arise in combustion chamber, then pressure drops due to an over expansion and convert to velocity in nozzle exit.

Figure 4 shows the temperature trends for the intake, combustion chamber and exhaust for the propane fuel. High heat transfer coefficient because of high speed flow of air in intake tube (Fig. 5) result that we observe the intake temperature is lower than the combustion chamber temperature and exhaust temperature.

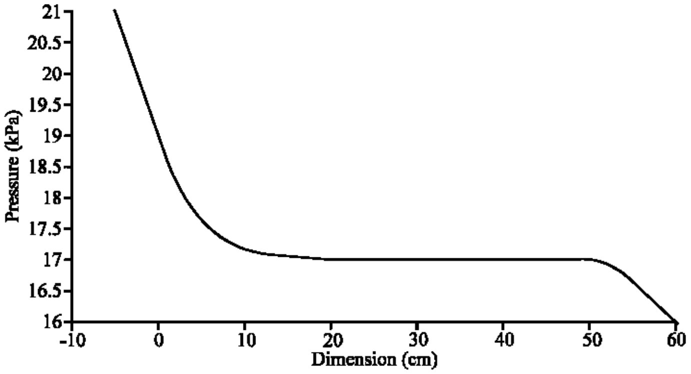

Fig. 3: Pressure distribution along the pulse jet

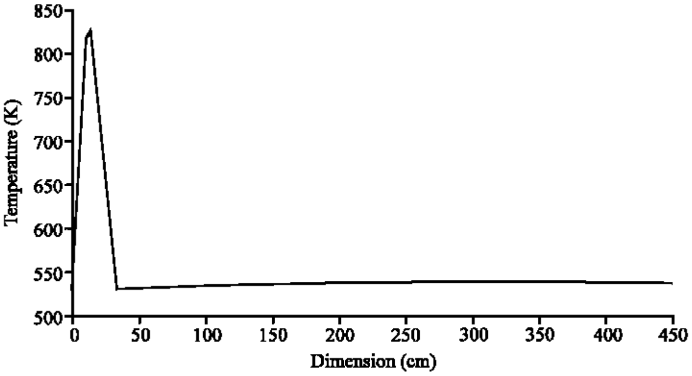

Fig. 4: Temperature distribution along the pulse jet

Fig. 5: Intake tube

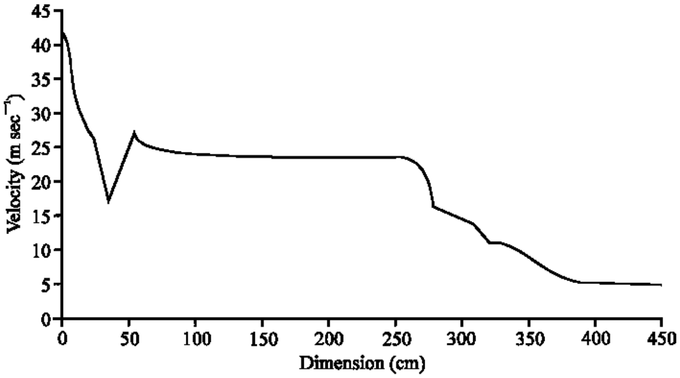

Fig 6: Velocity distribution along the pulse jet

Table 1: Influence of mesh count on thrust

Mesh type	Cooper	Cooper	Cooper
Elements	Hex/wedge	Hex/wedge	Hex/wedge
Interval count	10	20	30
Thrust (N)	10.39	10.45	10.46

In intake, we see maximum value of velocity because of effect of vacuum after ignition (Fig. 6). Also, grid study is done and its results are reported in Table 1. This table shows that grid sizes have less influence on results, therefore grid independent solution is achieved and second grid with interval count 20 is used as a main grid.

PRESSURE MEASUREMENTS

Obtaining time-resolved combustion chamber pressure was a goal from the start of the project. It was known from work with the 450 cm jet that monitoring pressure throughout the jet's

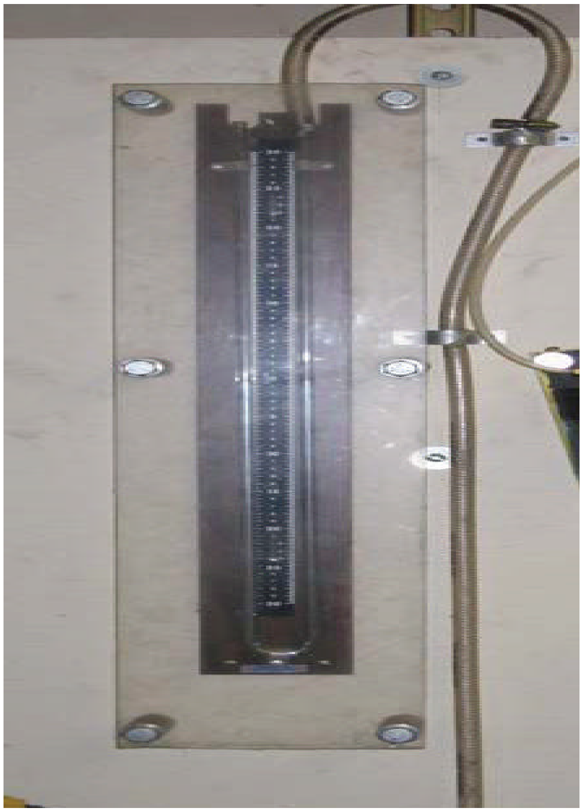

Fig. 7: Mercury manometer

operation was the best way to obtain operating frequency and validate CFD models. In addition, measuring the peak pressure rises in the combustion chamber proved useful in determining the pulse jet's efficiency.

Mercury manometer: To measure the average combustion chamber pressure, a Fisher Scientific mercury U-tube manometer was used, shown in Fig. 7. Its scale reads to 50 cm of mercury. It was connected to the combustion chamber pressure port by several meters of 1/4" plastic tubing.

Thermocouples: Type B high temperature thermocouples were used to attain temperature measurements of the intake, exhaust and combustion chamber temperatures. The intake and exhaust temperatures were measured one diameter upstream and one diameter downstream respectively shown in Fig. 8 and 9. The combustion chamber temperature was measured at the instrumentation port location 1/8 of a diameter away from the combustion chamber walls as seen in Fig. 10.

From measurements maximum pressure of various locations and thrust force are obtained. These results are presented in Table 2. According to this table pressure of intake tube and exhaust have not any considerable difference, but pressure of combustion chamber is high. These effects are produced thrust force equal to 12 N approximately as indicated in Table 2.

Fig. 8: Thermocouple locations at intake

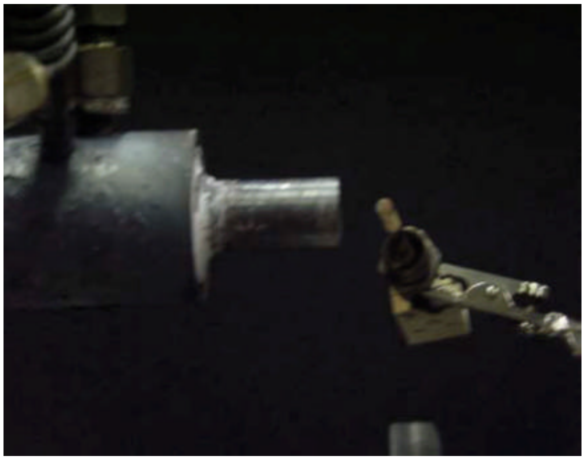

Fig. 9: Thermocouple locations at exhaust

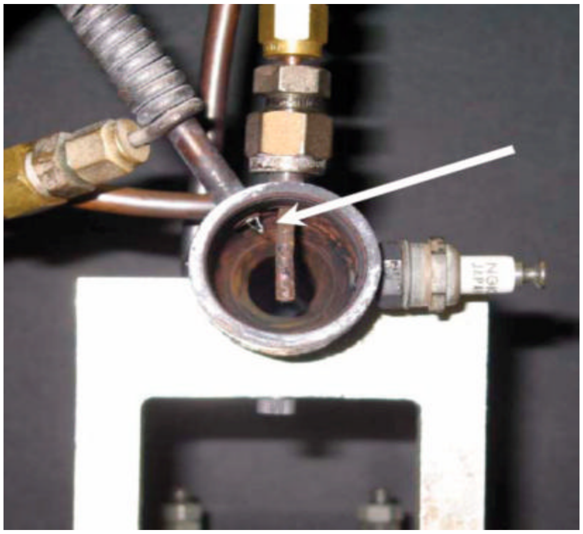

Fig. 10: Thermocouple location inside combustion chamber

Table 2: Pressure and thrust force values

Parameter	Intake tube	Combustion chamber	Exhaust
Pressure (kPa)	111	122	110
Thrust (N)	-	-	11.8

CONCLUSION

The effects of lengthening are similar on both valved and valve less jets. The valve less jet is less sensitive to changes in length than the valved jet. It is also noted that the valved jet operates closer to ¼ wave tube than the valve less. By increasing the exhaust length, the throttle ability increases as well. A maximum can be reached for certain inlets in the valve less configuration. Upper throttle ability limits plateau at specific exhaust lengths while the lower throttle ability limit continues to decrease.

The effect of changing the diameter of the inlet is that the frequency increases with increasing diameter. The change is linear and it can be modeled as a Helmholtz Resonator. The temperature effect of increasing inlet diameter is that the exhaust temperature rises (due to it being fuel rich) and the inlet temperature decreases (due to increased air intake).

The current configuration produces little thrust due to the experimental setup that includes opposing inlet/exits. The exhaust exit geometry is sensitive to shape. A flared tip is preferred and sometimes required for operation. The 50 cm class pulse jet can be modeled as the average of the inlet's Helmholtz frequency and the exhaust's 1/6 wave tube frequency.

Highest average combustion pressure occurs with 5/8" inlet, this is due to the flow not fully expanding at high fuel flow rates and combustion occurring in exhaust tube.

Combustion chamber peak pressures are significantly higher for valved jets.

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