The 23rd Conference of the Mechanical Engineering Network of Thailand
November 4 – 7, 2009, Chiang Mai

# Design, Construction and Experiment of Small Valve-less Pulsejet Engine

Sumpun Chaitep[1], Anucha Wongjansom[1]*, Nat Vorayos[1].and Saritporn Vittayapadung[2]

[1] Department of Mechanical Engineering, Chiang Mai University, Chiang Mai. 50200, Thailand
[2] Propulsion of Aerodynamics Research of Application Laboratory (PARA LAB) , Department of Mechanical Engineering, Chiang Mai University, Chiang Mai. 50200, Thailand
* Corresponding Author: Tel: (668) 40427125,
E-mail: a_and_u@hotmail.com

**Abstract**

This research was to design, construct and experiment the valve-less pulsejet engine in order to find the operation characteristics of the machine. The design of valve-less pulsejet is based upon the pulsating combustion supplied with inlet of fresh air mixed with fuel and dynamic outlet of hot gas for thrust production. Both inlet and outlet ports are axially flow, but eccentric installation to the line of thrust The experiment results was found that the designed valve-less pulsejet gives maximum thrust of 33.06 N at the combustion frequency of 280 Hz with fuel flow of 0.36 g/s. The operating frequency and thrust were increased depend upon a function of fuel flow rate. The frequency continues to increase until the maximum fuel flow was reached out at 0.41g/s at the frequency of 320Hz where the engine reaching a poor mixing conditions leading to a misfiring operation. The fuel used in these experiments was LPG.

## 1. Introduction

Design, construction and experiment of pulse combustion engine was initially funded by the Propulsion and Aerodynamics Research and Applications Laboratory (PARA Laboratory), at Chiang Mai University. The primary purpose was to explore the scalability of such engines, particularly for propulsion of small Unmanned Aerial Vehicle (UAV). The design parameters of pulsejets had not yet been fully investigated and equations had not been developed to such jets operational characteristic in a highly predictable manner. Deciphering the scaling laws and dominant design characteristics of the jets in order to have a tool for optimization of the engines was a primary objective of this work. A Valve-less pulse jet (or pulsejet) is one of the simplest jet propulsion devices ever designed, and is the simplest form of jet engine that does not require forward motion for sustaining its operation. Valve-less pulsejet are low in cost, light weight, powerful and easy to operate. They have all the advantages over conventional valve pulsejets, but without the troublesome reed valves that need frequent replacement. Also, small scale engines with moving parts are more prone to breakdown due to fatigue of the moving components [1], [2]. Pulsejets, especially valve-less pulsejets, are attractive as candidates for miniaturization due to their extremely simple design. A valve-less pulsejet can operate for its entire useful life with practically zero maintenance. They have been used to power model aircraft, experimental go-karts and even some unmanned military aircraft such as cruise missiles and target drones[2]The exothermic chemical reaction can be shortened by using hydrogen as fuel, which was necessary in this work[3]. It may even be necessary to premix and preheat the fuel and air to decrease the chemical kinetic time scale. It has also been suggested that increasing the combustion chamber size relative to the engine size will help with the very short residence times [3], [4]. In a review paper, Roy, et al. [4] reported the typical length for a pulse detonation engine is 0.3–3 m. It believes that 8 cm length pulsejet is the smallest operational pulsejet reported so far [5], [6], [7] and [8]. The fuel injection system, combustion chamber, and the inlet geometry must be carefully designed to create a fast mixing process and the necessary fluid dynamic and acoustic time scales to proper propagating pulsejet operation. In this research, original dimensional parameter from Lockwood-designed [Bruno Ogorelec, 2004] was chosen for the engine prototype development.

## 2. Methodology

### 2.1 Basic Principle

The valve-less pulsejet is really a misnomer. These engines have no mechanical valves, but they do have aerodynamic valves, which, for the most part, restrict the flow of gases to a single direction just as their mechanical counterparts. Indeed they have no mechanically moving parts at all and in that respect they are similar to a ramjet**.** With these engines, the intake and exhaust pipes usually face the same direction. This necessitates bending the engine into a "U" shape (the Lockwood-Hiller design is made this way) or placing a 180 degree bend in the intake tube. Example of the early experiment can be seen by Fig. 1.

**Fig. 1.** An early version of the Lockwood-designed engine with add-on thrust augmenter cones [Bruno Ogorelec, 2004]

When the air/fuel mixture inside the engine ignites, hot gases will rush out both the intake tube and the exhaust tube, since the aerodynamic valves "leak". If both tubes were not facing in the same direction, less thrust would be generated because the reactions from the intake and exhaust gas flows would partially cancel each other .This idea was proposed by a French propulsion research group named SNECMA.

The fuels in gas form of LPG are injected in combustion chamber instantly. After ignitions occurs a high explosion with hot gases and high pressure rushes towards both pipe ends with sound speed and because air can stretched out and by momentum of gas molecules, occurs a low pressure - vacuum in combustion chamber and pipes at lower than ambient air pressure outside. This lower pressure than atmospheric pressure causes the air rushes in to the inlet pipes enters the combustion chamber with atmospheric pressure which mixes with fuel for next explosion. Meanwhile the expanding gases rushed from the exhaust pipe create a thrust power in the opposition direction. With such construction one can get a thrust, which can move a vehicle forward. Dimension of inlet pipe and exhaust pipe must be crucial for automatic suction of A/F charge.

## 2 Design of valve-less pulsejet and Experiment setup

Valve-less pulsejet designed has dimension of combustion chamber head of 64 mm diameter and 543.4 mm total length detail shows in Fig.2, where as the fuel used in all results reported here was LPG, fuel was injected at a constant controlled rate directly into the combustion chamber. This greatly simplified the fuel injection process and eliminated the need for pulsed injection. The air inflow was still controlled by the oscillating pressure and acoustic waves [9], [10] and [11]. Types of inlets were tested with a rearward-facing inlet configuration as shown in Fig.3. The spark igniter can be seen at the front of the pulsejet and the fuel line is direct to the igniter. Fig. 4 shows a schematic of the experimental apparatus for a rearward-facing inlet configuration. The spark igniter is used only to start up, after that the pulse combustion is sustained by its flame front propagation in the combustion chamber.

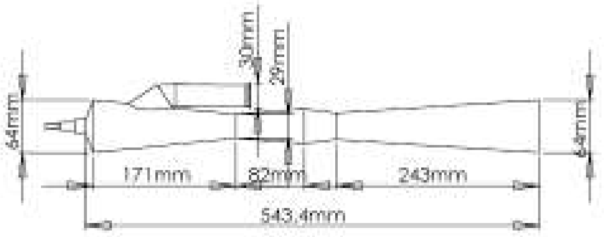


**Fig. 2** Dimension of Valve-less pulsejet

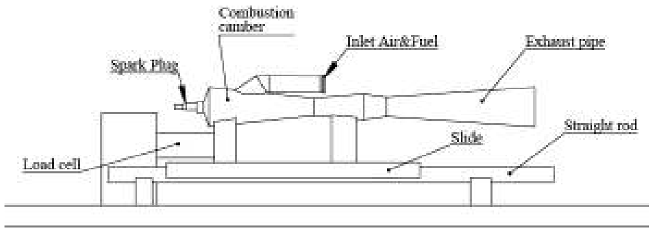


**Fig.3** The schematic for the experimental apparatus with rearward-facing inlet.


**Fig.4** Position of Fuel line and Air start line at the inlet.

Thrust measurement with respect to time was measured using a sound recording. The load cell was exposed to shear loads in the directions of positive and negative thrust.

## 3. Results and Discussion

### 3.1 Operating frequency

One of the earliest descriptions of the pulsejet is that it behaves like a 1/4 wave tube, or organ pipe [9]. Thus the fundamental operating frequency of the pulsejet is inversely proportional to the total pulsejet length, *L*. However from purely acoustic considerations, it is not clear how the operation frequency for the valve-less pulsejet varies with the inlet length [10], [11]. In experiment, 4 data of operating frequency obtain to 260Hz, 270Hz, 280Hz and 320Hz was collected. Show in Fig.5 is an example of data recorded at 280Hz

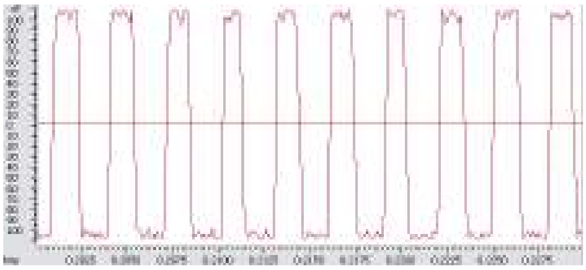

Fig.5 operating frequency at 280Hz

Fig. 6 shows a summary of experiments conducted comparing the jet's behavior at various Thrust and frequency**.** it is assumed that the jet operates most efficiently at the point of highest Thrust, between 280 and 290 Hz .At 320 Hz is critical point because it is last point of sustentation higher 320Hz pulse jet cannot be run by itself. The observations revealed that at initial condition pressure of supplied fuel of 4 bar with fuel flow rate of 0.33 g/s give higher thrust but unsustainable combustion. The explosion depends on frequency of spark plug show in Fig. 7.

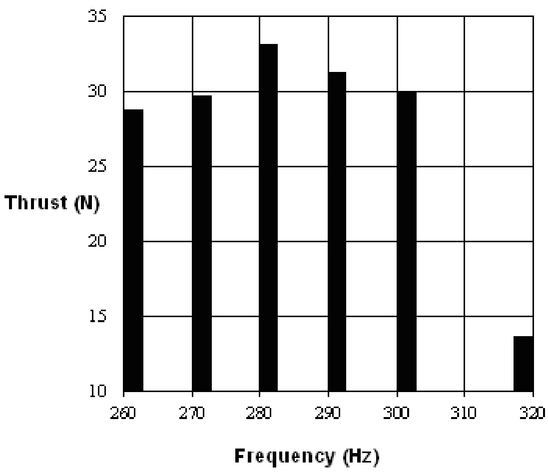


Fig.6 frequency vs. Thrust rearward-facing configuration.

**Fig.7** Explosion at 4 bar pressure fuel supplied.

**Fig.8** Inside pulse jet run in sustentation at 280Hz, as view from the end of exhaust pipe

### 3.2 Fuel Consumption

Fuel consumption from experiments show in Fig.9. At the highest thrust, which is at 280Hz give fuel flow is 0.36 g/s. At critical points, i.e., higher pulse frequency, the pulse combustion cannot be sustained by itself once the spark igniter is cut-off. However, the narrow throttle ability is most likely the result of poor mixing of air-fuel conditions.

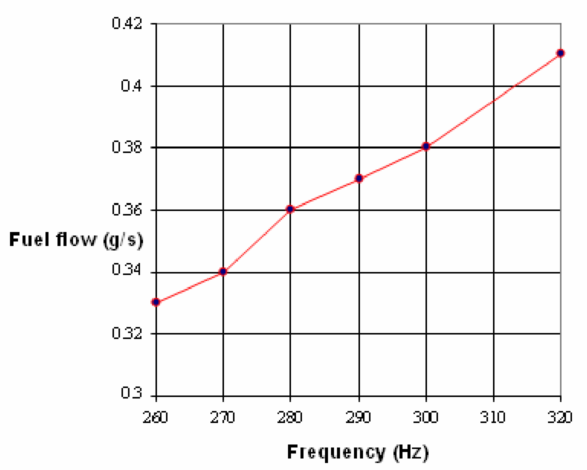


Fig.9 Frequency versus Fuel flow.

## 4. Conclusion

Valve-less pulsejet in this design gives the maximum thrust of 33.06N at frequency 280Hz and fuel flow of 0.36 g/s. The operating frequency and thrust rise are a function of fuel flow. At low fuel flow, causes both lower frequency and pressure. However, the frequency rises with increasing fuel flow. With the design of rearward-facing inlet, the combustion frequency continues to increase until the maximum fuel flow is reached out at 0.41g/s fuel supply at the frequency of 320Hz is poor mixing conditions. Higher frequencies at a certain critical values are unsustentation.

## 5. Acknowledgments

The authors gratefully acknowledge the contribution of Propulsion and Aerodynamic research and application (PARA) laboratory, Department of Mechanical Engineering, Chiang Mai, Thailand. Thanks to the research fund supported from the Gas Turbine Development project and the Flying Robot project , Institute for Science &Technology Research & Development, Chiang Mai University

## 6. References

[1] A. Majumdar and C. Tien, Microscale Thermophys. Eng. 2 (1998), pp. 67–69.

[2] S. Eidelman, W. Grossman and I. Lottati, J. Propulsion Power 7 (1991) (6), pp.857–865. ).

[3] C.M. Spadaccini, A. Mehra, J. Lee, X. Zhang, S. Lukachko and I.A. Waitz, Eng.Gas Turbines Power 125 (2003), pp. 709–719.

[4] G.A. Boyarko, C. Sung and S.J. Schneider 42th AIAA Aerospace Sciences Meeting, Reno (2004) (AIAA-2004-0303).

[5] G.D. Roy, S.M. Frolov, A.A. Borisov and D.W. Netzer, Prog. Energy Combust. Sci. 6 (2004),pp. 545–672.

[6] S. Eidelman, W. Grossman and I. Lottati, J. Propulsion Power 7 (1991) (6), pp. 857–865.

[7] W. Fan, C. Yan, X. Huang, Q. Zhang and L. Zheng, Combust. Flame 133 (2003), pp. 441–450.

[8] T.R.A. Bussing, G. Pappas, AIAA-94-0263, January 1994.

[9] A.C. Fernandez-Pello, A.P. Pisano, K. Fu, D.C. Walther, A.J. Knobloch, F.C. Martinez, M.Senesky, D.G.Jones, C. Stoldt and J. Heppner International Workshop on Power MEMS (Power MEMS 2002),Ibaraki, Japan (2002).

[10] H.T. Aichlmayr, D.B. Kittelson and M.R. Zachariah, Chem. Eng. Sci. 57 (2002), p. 4161

[11] H.T. Aichlmayr, D.B. Kittelson and M.R. Zachariah, Chem. Eng. Sci. 57 (2002), p. 4173.

[12] K. Kailasanath, AIAA-2002-0470, January 2002.

[13] In: H. Tsien, Editor, Jet Propulsion, Guggenheim Aero. Lab.(1946).

[14] T. Geng, F. Zheng, A.P. Kiker, A.V. Kuznetsov and W.L. RobertsExperimental and numerical investigation of an 8-cm valveless pulsejet, April 2006

[15] In: H. Tsien, Editor, Jet Propulsion, Guggenheim Aero. Lab.(1946).