Review on Combustion Analysis of Pulsejet Engine using Techniques of CFD and Analytical Modelling

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Abstract— This paper discusses the various works done by scholars in analysis of pulsejet engine. Various scholars have presented analytical studies by changing different design parameters and also using techniques of Computational Fluid Dynamics. Different designs of pulsejet engine are discussed i.e. valved and valveless are analysed by scholars.
Keywords: Pulsejet Engine, CFD

I. INTRODUCTION

A pulsejet engine is a type of jet engine in which combustion occurs in pulses. A pulsejet engine can be made with fewer no parts and is capable of running statically. Pulsejet engines are a lightweight form of jet propulsion, but usually have a poor compression ratio, and hence give a low specific impulse. One notable line of research of pulsejet engines includes the pulse detonation engine which involves repeated detonations in the engine, and which can potentially give high compression and good efficiency. The pulsejet is one of the simplest forms of propulsion known to man. They are known for having little to no moving parts, scalability, relatively low cost, ease of use, and extremely high noise. Pulsejets at the simplest level work by means of pulsed combustion and were invented in the early 1900s. Pulsejets generally operate either wavelessly, in which the combustion chamber is always open to the free stream, or valved in which the inlet is separated from the combustion chamber by some sort of mechanical valve.The modern valveless pulsejet was created in the early twentieth century by Marconet as well as Schmidt. This simple propulsion device consisted of an open inlet leading into a combustion chamber and exhausting out of the back by an often-flared exhaust tube. The main drawback of this simple design is that, during exhaling cycles, there is a significant loss of products out of the front of the jet. Studies have shown that as much as a third of the products of combustion leave through the front, causing a large amount of negative thrust.

II. LITERATURE REVIEW

O'Brien, John Grant[1] has presented review work on working of pulsejet engines. He stated that there is no specific and palpable law on which the working of a Pulse Jet is based on; therefore, all new innovations relating to the Pulse Jets are done on a trial and error basis. A considerable reason that the earlier Pulse Jets have not fulfilled their expected potential is that it is extremely complex and difficult to come up with a mathematical model, as such the entire theoretical study on the topic of Pulse Jet engines have not been completed till date. This being said, construction of a Pulse Jet engine is a comparatively simple task and so there exists numerous records of Pulse Jet engines being built. However, the lack of complete understanding at the present time hinders prediction and considerable modification/improvement of the engines performance.

Christian Talbot McCalley [2] has investigated smallest pulsejet engine. The purpose of the entire investigation and study of this project was to check if gasoline, propane, military grade JP-8 etc. can be used for UAV (unnamed aerial vehicle) and military purpose. After successful operation, all the data was acquired and the modifications were thoroughly studies and analyzed for optimum understanding. And it was understood that both the hobby scale pulse jets ran smooth upon using kerosene as fuel. One of the experiments that we must note was the work done by the Hiller aircraft Corporation on scaling down the valve less Pulse Jets. The smallest Pulse Jets they were able to operate was recorded to have a combustion chamber diameter of 19cm and its overall length was up to 36 cm. This jet relied on oxygen that were injected separately but at the same time. However, this setup was could not be operated in a consistent manner. Therefore, only the thrust data was recorded.

Michael Schoen[3] directed his research towards the miniaturization of valve less pulse jets in order to bridge the gap between hobby-scale and micro-scaled Pulse Jets. This work was done to understand the physical effect that the changes in Jet geometry have on the performance of the engine. It was observed that the tail pipe length is a direct function of inlet length. Furthermore, it was observed that allowing a diverging exit nozzle in the design of the jet allows for the jet to be shortened and operated in a more consistent manner. The highlight among the conclusions drawn from Schoen's work is that the combustion time is challenged by the period of fluid mechanic oscillations, at shorter lengths. Reducing the size of the jets gives way to a rise in its inherent operating frequency. Therefore, a highly reactive fuel must be employed in order for the combustion process to keep up with the acoustic property of the engine.

Adam Kiker[4] directed his focus towards developing micro-scale pulse jets. He managed to design and operate a record 8cm long pulse jet fuelled by hydrogen. It was observed that the frequency of the jet measures as one over the length. It was also observed that tripling the inlet length had the same effect as increasing the overall length by 50%. Furthermore, it was recorded that although the exhaust diameter did not have any considerable impact on the operating frequency, it did however affect the peak pressure rise in the combustion chamber that is as the exhaust diameter decreased the peak pressure increased. Kiker also recorded that with increase in fuel flow rate, the operating frequency and peak pressure also rise. This experiment was also able to obtain instantaneous thrust data which should not be overlooked even though the method of measuring used was somewhat questionable.

Rob Ordon[5] focused on the hobby-scale pulse jet. It had a length of 50cm and worked on either ethanol or propane. One of the highlights of this project was that Ordon had managed to make use of both valved and valve less pulse jets. This work was a significant contribution in further understanding the characteristics of the hobby-scale pulse jets and allowed Schoen and Kiker to complete the respective projects. The contribution of this project also led to the design of an analytical model which could predict the operating frequency of any valve less Pulse Jet. This model paved the way to finding the parameters that govern the design of Pulse Jets.

Daniel Paxson[6] from the NASA Glenn research center conducted another noteworthy study which used a hobby-scale pulse jet similar to that of Ordon's (50cm). This Jet however ran on gasoline and was used as a model for unsteady combustion to test thrust augmenters for use in the pulsed detonation engines. Paxson focused on the relationship between the exhaust diameter, pressure of the combustion chamber, and average thrust produced.

U. Sreekanth, Subba Rao B [7] has conducted work to understand the working of the pulse jet and employs a numerical approach in doing so. The fluid mechanics and acoustic properties are analyzed in a numerical manner in order to better understand the complete physics involved in the operation of the pulse jet. The study was directed to improve the already existent model design for valve less pulse jets, obtain the basic data on thrust of the model pulse jets, and also examine how the intake and exhaust lengths affect the thrust produced by the Jets.

Hussain SadigHussain[8] conducted a thorough research of the thermodynamic characteristics of conventional pulse jet engines and then a conceptual design and calculations of a pulse jet engine generating 100 lbs. of thrust is formulated, keeping the geometrical aspects (specific fuel consumption, thrust and frequency limitations) in frame. The objective was to estimate the dimensions of each part of the pulse jet in the simplest possible fashion. Important aspects such as inlet diffuser and exhaust nozzles effects that are significant in real applications have not been considered in this research. The primary domain of this research was to study the conventional engine and later design an elementary pulse jet engine with 100 lbs. thrust. While the study focuses on the investigation of geometrical aspects of the engine, continuous work on fuel ignition was required. Further detailed study of the pulse jet engine demanded the design to be built with suitable material and testing in lab to compare the actual thrust with the theoretical, studying the effects of changing dimensions on engine performance, Combustion chamber volume and shape, valve system type .

Liu Min[9] directed his experimental research that resulted in providing the practical fundament in order to improve the performance of small jet engines. The research was carried out on an air breathing engine experimental bench that includes the fuel supply system, test collection system, ignition valve type pulse jet engine. In order to measure the characteristics of the engine including wall temperature, the concentration of the combustion products, the gas temperature and the pulse pressure, infrared thermal imaging system along with flue gas analyzer were used. The whole experiment was carried out in experimental education center of aeronautics and astronautics of Nanjing University of science and technology. Although this experimental platform is best suited for a research on small jet engine like pulse jet engine. Liu Min performed his experimental research by focusing more on comprehensive small jet engine test bed. The whole experiment resulted in the change in fuel flow of the pulse pressure, wall temp and combustion products. It was also noted that with the increase of fuel flow, the pulse combustion gets intensified [9].

K Sainath[10] directed his research on the pulse jet engine which have a few or no moving parts which are capable of running statically. They are light weight form of jet propulsion engines and comprises of small value compression ratio with low specific impulse. He further classified the engine into two parts viz., drafting and construction & the modification in the nozzle at the exhaust section so as to increase the thrust of the pulse jet engine. This modification of the nozzle is done in ANSYS software under Computation Fluid Dynamics (CFD). He further designed the prototype which involves in selection of material that is easy to work with. While putting it at test the compressor pressure was noted around 20-50 psi.

Divyesh B. Patel, Jayesh R. Parekh [11] has defined pulse jet engine (or pulsejet) as a type of jet engine in which combustion occurs in pulses. Pulsejet engines can be made with few or no moving parts, and are capable of running statically. Pulsejet engines are characterized by simplicity, low cost of construction but high vibrations and noise levels. Pulsejet fuel efficiency is a topic for hot debate, as efficiency is a relative term. While the thrust-to-weight ratio is excellent, thrust specific fuel consumption is generally very poor.

Putnam et al. [12], has observed that the pressure begins to rise in the combustor as the combustion reaction flame rapidly expands during the first half of the combustion cycle. Maximum pressure is reached when the flame has completely filled the chamber. The pressure then begins to fall as the combustion reaction flame wanes during the second half of the process and the gases exit through the inlet and exhaust pipes. The isochoric assumption is based on the observation that very little of the reaction products exit from the combustor during the pressure-rise portion of the cycle.

III. PULSEJET ENGINE OPERATION

Pulsejets operate on the Humphrey cycle as shown in Figure 1. The four step cycle starts at state 1 with isentropic compression followed by isochoric heat addition, isentropic expansion, and lastly, isobaric heat rejection as it returns to state 1.

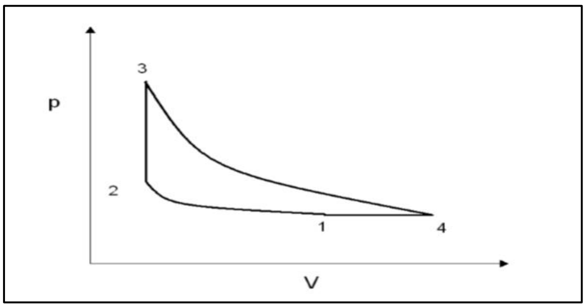

Fig. 1: p-V diagram for the Humphrey Cycle

The general design for a valveless pulsejet can be approximated by matching the frequency of a short length Helmholtz resonator for the inlet and combustion chamber to a long length Helmholtz resonator for the outlet and combustion chamber. This allows for the design of the pulsejet to come from the following two equations.

$$f_i = \frac{c_i}{2\pi}\sqrt{\frac{S_i}{VL_i}}$$

These symbols are representative of the following values where i describes the inlet properties and e describes the exhaust tube properties:

f Frequency
c Local Speed of Sound
S Cross-Sectional Area
L Length
V Combustion Chamber Volume

By setting the frequency of the inlet to the frequency of the exhaust tube the jet is "fully resonant" meaning that the inlet and the exhaust tube are resonant with each other and the jet will operate under self-sustaining combustion. The equation for the inlet frequency can be solved explicitly. The frequency for the exhaust tube, however, must be solved implicitly due to the presence of the frequency in the tangent coefficient as well as inside the tangent operator. When designing the jets for this project a simple Microsoft Excel solver was created to solve for the frequencies and match them based on input parameters of overall length, desired radius of the exhaust tube, and the ratio of the inlet volume to the combustion chamber volume. Once all of the parameters of the jet are pinned down a model can be created using CAD software.

IV. CONCLUSION

It is noticed that many works has been done on pulsejet engine but no single theory and lack of mathematical model has demanded further research in analysis of pulsejet engine. The use of computational fluid techniques can reduce time and cost required for analysis of pulsejet engine and has proved to be feasible platform for analysis.

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