Design of a Advanced Focused Wave Pulsejet Engine

Ponnuru Ramalinga Karteek, B.V.N. Praveen

Abstract— **A pulsejet engine is a kind of a jet engine in which combustion occurs in pulses. The valveless pulsejet engine represents an attractive alternative to the current aerospace propulsion systems. The main advantage of pulsejet engines are their construction simplicity as the engine is essentially a hollow tube with little or no moving parts. This results in a highly reliable system which is economical to construct and maintain. R & D of pulsejet engines has lead to the making of UAV's and other small scale aerospace applications. The main aim of this paper is to design a focused wave pulsejet engine lead to the making of UAV's and other small scale aerospace application. The main of this paper is to design a focused wave pulsejet engine.**

Index Terms **— Pulsejet engines, Deflagration, Focus wave, FEW, Elastic Modulus, Yield Strength, Thermal Expansion Coefficient.**

I. Introduction

A pulse jet engine is a type of jet engine in which combustion occurs in pulses. Pulsejet engines can be made with a few or typically no moving parts and are capable of running continuously. Pulse jet 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. Pulsejet engines can be classified into two types

- Valved Pulsejet Engines
- Valveless Pulsejet Engines

Valved pulsejet engines use a mechanical valve to control the flow of expanding exhaust, forcing the hot gas to go out of the back of the engine through the tailpipe only, and allow fresh air and more fuel to enter through the intake whereas a Valveless pulsejet engine has no moving parts and uses its unique constructional features to accomplish the process of combustion. The valveless pulsejet operates on the same principle as the valved pulsejet, but the valve is the engine's geometry. Fuel, as a gas or atomized liquid spray, is either mixed with the air in the intake or directly injected into the combustion chamber. Starting the engine usually requires forced air and an ignition source, such as a spark plug, for the fuel-air mix. With modern manufactured engine designs, almost any design can be made to be self-starting by providing the engine with fuel and an ignition spark, starting the engine with no compressed air. Once running, the engine only requires input of fuel to maintain a self-sustaining combustion cycle.

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II. PULSEJET ENGINE WORKING AND DESIGN

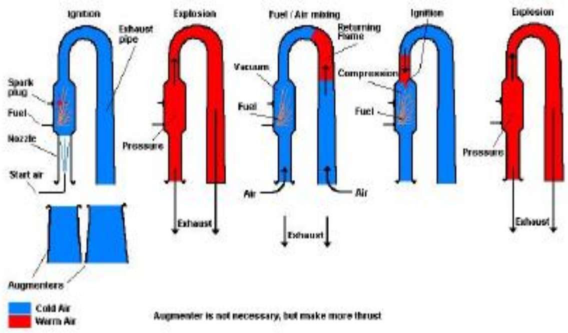

Fig. 1 Principle of a valveless pulse jet engine

The combustion cycle comprises five or six phases: Induction, Compression, (in some engines) Fuel Injection, Ignition, Combustion, and Exhaust. Starting with ignition within the combustion chamber, a high pressure is raised by the combustion of the fuel-air mixture. The pressurized gases obtained from combustion exit both through the exhaust and intake manifold. The inertial reaction of this gas flow causes the engine to provide thrust, this force being used to propel an airframe or a rotor blade. The inertia of the travelling exhaust gas causes a low pressure in the combustion chamber. This pressure is less than the inlet pressure (upstream of the one-way valve), and so the induction phase of the cycle begins.

In the simplest of pulsejet engines this intake is through a venturi which causes fuel to be drawn from a fuel supply. In more complex engines the fuel may be injected directly into the combustion chamber. When the induction phase is under way, fuel in atomized form is injected into the combustion chamber to fill the vacuum formed by the departing of the previous fireball; the atomized fuel tries to fill up the entire tube including the tailpipe. This causes atomized fuel at the rear of the combustion chamber to "flash" as it comes in contact with the hot gases of the preceding column of gas — this resulting flash "slams" the reed-valves shut or in the case of valveless designs, stops the flow of fuel until a vacuum is formed and the cycle repeats in the design phase.

Before, building up a pulsejet engine it is necessary to keep in mind the amount of thrust to be produced. So, taking the thrust as the epicentre, the design process is done. The main parts to be designed are as follows:

- Combustion Chamber
- Inlet and Exhaust

III. DESIGN OF A COMBUSTION CHAMBER

Since the pulsejet are unsteady flow jet engines - so due to lack of analytical techniques in predicting the thrust of the engines the dimensions of the combustion chamber cannot be predicted for any thrust output. So for any thrust output, the specification was given as an average. At, a particular point of time within the cycle the thrust output can be specified by an equation

$$F= \dot{m}_e v_e - \dot{m}_o v_o + (p_e - p_o)A_e \quad (1)$$

Where $_{e,}$ $_{o}$ are the mass flow rate of the gases either entering or existing the combustion chamber. takes into account the pressure difference between the exhaust fluid and ambient conditions, mass flow rate is defined as

$$m = \rho \cdot V \cdot A \quad (2)$$

In order to increase the mass flow rate from the combustion chamber the combustion chamber volume should be increased so the cross sectional area available for the flow will increase. Thus, the increase in volume provides an increase in effective mass for combustion. As per Newton's Second Law this larger mass provides a larger force.

A statistical analysis was conducted using the available thrust and combustion chamber volume data.

Table 1: Combustion chamber volume and Thrust

Type	Volume of Combustion Chamber (m^3)	Thrust (kg)
Belfast University	9.72E-04	3.95
Enics M44D	6.93E-04	5
Enics M150	6.66E-03	15.3
Lockwood	8.82E-03	25
Chinese	2.81E-04	1.9
AWE Engine	3.44E-04	1.02
Lady Anne Boleyn	3.72E-04	1.3
Mikhail Twin Intake	7.72E-04	6.8

This data can be used to determine a relation between combustion chamber volumes to thrust output. A graphical result was obtained by taking thrust on the x axis and Combustion Chamber volume on the y axis. A relation between the combustion chamber volume and thrust output is formulated as

$$T= 2151V_{CC} + 1.45 \quad (3)$$

Where V_{cc} is volume of combustion chamber
T is thrust of the engine

Since the thrust values vary as a linear function of combustion chamber volume from the above equation a linear line trend Can be used. A safety factor is to be considered in order to allow for inheriting errors in the statistical analysis given the relatively small number of data points.

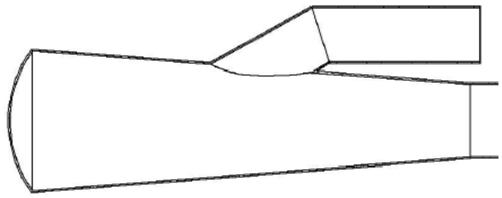

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Figure 2
Line diagram of combustion chamber

The end cap of the combustion chamber is an important part whose purpose is to reflect the pressure waves at the focal point. The design of the cap was developed according to the principle stated by M. C. Junger and D. Feit in sound structures and their interactions and has been further validated through similar applications. The following analysis was used in the design of the end cap for the combustion chamber. A plane surface was considered with pressure waves acting upon it. Taking this into account for the combustion chamber design; if and small element of the cap's curved surface is considered the surface can be considered as plane surface. A pressure field is expressed as

$$P_i(x,z)= p_i e^{(ik_i (x\sin^{\theta} - z\cos^{\theta})} \quad (4)$$

The analysis assumed the reflecting surface is identical in magnitude as there is no energy loss during deformation. The result of the analysis can be formulated as

$$P_i(x,z)= p_i e^{(ik_i (x\sin^{\theta} + z\cos^{\theta})} \quad (5)$$

The result is identical to the function used to specify the incidenting pressure field. Using this result, an approximately curved combustion chamber surface can be used to reflect all waves incident at an angle to the surface towards the exhaust.

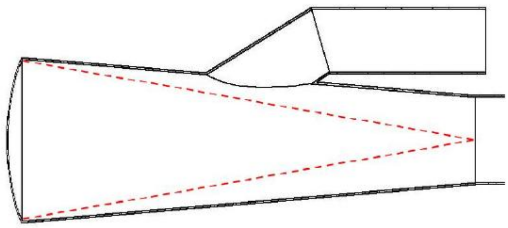

Figure 3 line diagram of focus point for the combustion chamber end cap

IV. DESIGN OF INLET AND EXHAUST

The design of inlet and exhaust parts of a pulsejet engine is of utmost importance because it is through these parts the self sustaining combustion and thrust output of the engine depends. To build up these parts a statistical analysis was conducted on existing working pulsejet designs to determine a relation between the sizes of exhaust and intake.

Table 2 Area Ratio Statistical Analysis

Name	Area Ratio (DEX/DIN)
K-PT-07X	1
Chinese	1.1
Twin Intake	1.8
Lady Anne	1.9
Advanced FEW	2.3
Elektra II	2.8
Other	2.4
Average	1.9

Another statistical study was also undertaken to determine the relationship between combustion chamber volume of various existing designs and the exhaust area. Exhaust area was chosen as the majority of the thrust was exhausted from the trust. The results of this analysis are compiled below:

Table 3 Combustion Chamber to exhaust area ratios

Name	Combustion Chamber Volume ($m^{3)}$	Exhaust Area ($m^{2)}$	Ratio VCC/AEX
Advanced FWE	3.44E-04	7.92E-04	0.434
Lady Anne Boleyn	3.72E-04	8.04E-04	0.462
Chinese	2.812E-04	5.07E-04	0.554
University of Belfast PJ	9.72E-04	1.13E-03	0.857
Twin Intake	7.72E-04	8.55E-04	9.02

From the above tables which were taken into consideration the average ratio of V_{cc} to AEX was found to be 0.64. Here, the combustion chamber volume was known and from the average ratio the exhaust area can be predicted. From the average ratio of DEX to DIN i.e; 1.9 the diameter of the intake is determined.

V.MATERIAL SELECTION

When selecting a material only two of the three parameters can be optimized. For example low weight and high reliability result in high costs. For this task the two most important factors are the cost needs to be kept to a minimum and reliability must be maximized, as failure during testing would be dangerous and have undesirable consequences for the successful building up of the engine. So, Stainless steels SS 304, SS 316 and Inconel were found to be giving satisfied results. So the materials can be chosen as per the will and wish. In the actual working of pulsejet engine due to the high velocity of the moving gases and the high temperatures involved the engine is subjected to high erosion. So a proper choice of the material is vital. Performing thorough analysis of some parameters like

- Elastic Modulus
- Yeild Strength
- Thermal Expansion Coefficient
- Ease of Manufacture
- Availability
- Cost

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VI. RESULTS

Using, combinations of different exhaust and inlet lengths the optimal design is obtained by plotting a graph between the total length of the engine and thrust output. A simulation program can be designed to aid the designer performance prediction of the pulsejets. The program predicts closely the performance of the experimental engine in a number of configurations. By performing the above analysis the optimal lengths can be obtained. The aim of the paper is to design a Focused Wave Engine with a thrust output of 3kg. The optimum intake and exhaust lengths obtained are as follows:

Table 4 Experimental configuration and thrust output

Intake Length	145mm
Exhaust Length	600mm
Thrust	2.549kg

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