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Design of Pulse Jet Engine for UAV

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***Abstract*— Research and development of pulsejet engines has been mainly confined to enthusiast circles. There is an emphasis on adapting the Pulsejet technology to smaller aircrafts or to the Unmanned Aerial Vehicle. The aim of this project is to develop a pulsejet engine and study the effects of free stream flight speed on performance of these pulsejet engines. The primary design requirement is that engine must produce a Thrust of 2.5kg. The current effort is focused on using the analytical method to attain the required configuration of the pulsejet engine and then, use computational software to simulate and predict the working nature of the pulsejet.**

Keywords—Pulsejet; Unmanned Aerial Vehicle , Analytical Methods,Simulation, Thrust.

Nomenclature:

P – Pressure
T – Temperature
ν – Specific Volume
V – Velocity
S – Entropy
Q – Heat Energy
μ – Kinematic Viscosity
h – Enthalpy
γ – Adiabatic Index
M – Mach Number
m – Mass
ρ – Density
Cv – Specific Heat at Constant Volume
Cp – Specific Heat at Constant Pressure
a – Speed of Sound
I – Total Impulse
s - Specific Fuel Consumption
C - Calorific Value
A – Area
L – Length
D - Diameter
V - Volume
F – Force

I. INTRODUCTION

A Pulsejet Engine is essentially a hollow tube that utilizes sound waves to induce fluid flow and produce thrust. Pulsejet engine is one of the simplest forms of air breathing propulsion ever developed. Pulsejet engines have few moving parts making them economical to construct and maintain. These are scalable, light weight, low cost and fairly efficient at converting fuel to heat and thrust and there is no such thing as a "misfire" in a pulse jet. The main advantage of the pulsejet engines is their simple construction without any moving parts. These advantages make them ideal for use in Unmanned Aerial Vehicles (UAVs).

The aim of project is to design a pulse jet engine which can be used in UAV’s for generating required power. The engine must produce a Thrust of 4 kg. The operating conditions are taken to be the standard cruise conditions for low speed UAV’s. For reference, the operating velocity of the flight is taken as 120-185 km/hr

II. LITERATURE REVIEW

The concept of the first pulsed jet can be traced back to an 1882 Publication by Nikolai Egorovich Zhukovsky. His paper, ‘On the reaction force of in-and-out oscillating flowing liquid’, is the first reference to the ‘Vapor Pulse Jet’. The subject of the paper was developed in two subsequent editions published in 1885 and 1908.

Fig 1 Argus Pulsejet Engine

Serious interest in pulsejet engines was not established again until the late 1920’s, when German engineer Paul Schmidt (Reynst 1961) accidentally rediscovered the pulsed combustion principal whilst attempting to achieve detonation within an engine. The most well known and most successful application for pulsejet engines came in 1941 with the first test flight of the German V-1 flying bomb

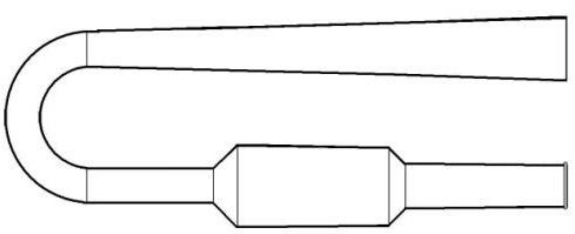

Fig 2 *Lockwood and Hiller's Pulsejet engine*

Lockwood and Hiller developed a U-shape engine that claimed to have an extremely high thrust to weight ratio (Lockwood, 1952). They experimented with many ways to increase thrust as well for the purpose of making a lightweight engine.

A. Types of Pulsejet Engines

Based on the valve these can be classified into two types. They are

- Valveless Pulsejet Engine
- Valved Pulsejet Engine

These can be further classified based on shape of pulse jet engine into three types. They are:

- Inline System
- U-shaped System
- Linear System

III. PULSEJET THEORY

A pulsejet's operation can be explained by combining two-cycles: the Lenoir Cycle which consists of isentropic compression followed by constant volume heat addition and then adiabatic expansion and the Humphrey Cycle, which operates similarly but has an isentropic compression added to the cycle. Pulsejets typically have a very small compression ratio that reaches a maximum at around 1.7.

A. Lenoir Cycle

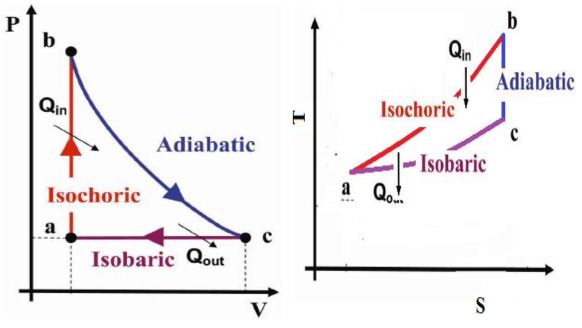

Fig 3 Lenoir Cycle

The Lenoir Cycle consists of three thermodynamic processes

Process a – b : Heat Addition at Constant Volume

Process b – c : Isentropic Expansion

Process c – a : Heat Rejection at Constant Pressure

B. Humphrey Cycle

The Humphrey cycle is a thermodynamic cycle similar to the pulse detonation engine cycle. The ideal Humphrey cycle consists of 4 processes they are:

Process a – b : Isentropic compression

Process b – c : Constant-volume heat addition.

Process c – d : Isentropic Expansion of the gas

Process d – a : Constant-pressure heat rejection

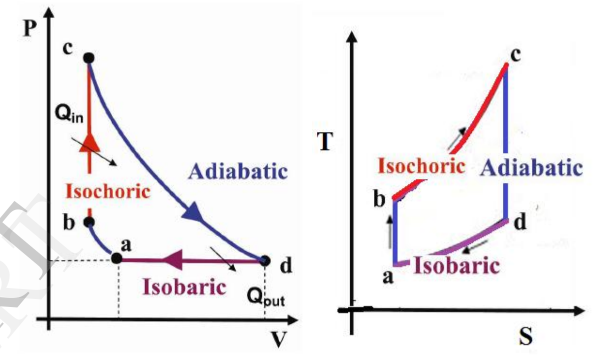

Fig 4 Humphrey Cycle

IV. CYCLE ANALYSIS

Consider a pulsejet placed at a free stream of Mach Number (M). The fluid is compressed from free stream to combustion chamber. Since, the compression from free stream to stagnation condition follows inverse isentropic expansion the combustion chamber conditions are stagnation.

$$\frac{P_C}{P_1} = \left(1 + \frac{(\gamma-1)M^2}{2}\right)^{\frac{\gamma}{\gamma-1}}$$

$$\frac{T_C}{T_1} = \left(1 + \frac{(\gamma-1)M^2}{2}\right)$$

Because of bad shape of the diffuser for pulsejet engines, only a part of kinetic energy is recovered as pressure energy. This can be assumed as

$$P_2 = 0.5\ P_1$$

As the air enters the combustion chamber the temperature will be same as that of free stream. So, the temperature at the inlet of the combustion chamber will be same as that of free stream i.e.,

$$T_2 = T_1$$

A. Combustion Chamber

Since the combustion process occurs at constant volume. The heat added per unit mass is given by

$$h = Cv\ (T_3 - T_2)$$

Where T3 is temperature at the end of combustion process

$$h= \frac{C_p}{\gamma}T_3\left(1-\frac{P_2}{P_3}\right)$$

B. Impulse Calculation

$$V= \sqrt{\frac{2\gamma}{\gamma-1}\frac{P}{\rho}\left(1-\left(\frac{P}{P_o}\right)^{\frac{\gamma-1}{\gamma}}\right)}$$

$$dI = \sqrt{\frac{2\gamma}{\gamma-1}\frac{P}{\rho}\left[1-\left(\frac{P}{P_o}\right)^{\frac{\gamma-1}{\gamma}}\right]}\frac{1}{\gamma}\rho\vartheta\frac{dP}{P}$$

$$I = \frac{1}{\gamma}\sqrt{\frac{2\gamma}{\gamma-1}}(\vartheta\rho_3)\sqrt{\frac{P_3}{\rho_3}}\int_{\frac{P}{P_3}}^{1}\left(\sqrt{\epsilon^{\frac{1-\gamma}{\gamma}}\left[1-\left(\frac{P}{P_3}\right)^{\frac{\gamma-1}{\gamma}}\epsilon^{\frac{1-\gamma}{\gamma}}\right]}\right)d\epsilon$$

$$\frac{V_3}{a_3} = \frac{1}{\gamma}\sqrt{\frac{2}{\gamma-1}}\int_{\frac{P}{P_3}}^{1}\left(\sqrt{\epsilon^{\frac{1-\gamma}{\gamma}}\left[1-\left(\frac{P}{P_3}\right)^{\frac{\gamma-1}{\gamma}}\epsilon^{\frac{1-\gamma}{\gamma}}\right]}\right)d\epsilon$$

C. Specific Fuel Consumption

If we have an average mass flow rate (ṁ), the average thrust is ṁV_e. The thrust is diminished by intake momentum of ṁV_o. The actual thrust is ṁ (Ve - Vo). If 'C' is calorific value of the fuel and 'ɳ' is efficiency of combustion. Then specific fuel combustion can be calculated using

$$S = \frac{3600\,h}{778\,C\eta\,(V_e-V_o)}$$

D. Tharratt's Approach For Small Puilsejet Design

"The Propulsive Duct" paper condensed much of the known pulsejet theory into a few simple formulas and constants. When it comes to designing a powerful, reliable pulsejet engine the simple relations are valid. The validity of this formula has been verified against a wide number of different and proven pulsejet designs including the Argus V1 and Dynajet.

These equations are

1) A = 2.2F

2) Valve area = 0.23 x mean cross-sectional area

Apart from these equations, a few assumptions are to be made to attain at the actual design layout. They are

- L/D - 8
- Number of Valves - 10
- Number of Gaps - 10
- Efficiency of Valve - 70%

Table 1 *DESIGN CALCULATIONS*

Parameter	Magnitude	Units
Mean Area	32.258	cm^2
Mean Diameter	6.410	cm
Mean Volume	1654.292	cm^3
20% Volume	330.858	cm^3
Length of pulsejet engine	51.283	cm
Valve Area	7.419	cm^2
effective valve area	10.6	cm^2
Number of Valves	10	
Area of Each Valves	1.060	cm^2
Diameter of Each Valve	1.162	cm
Size of gaps	0.635	cm
Number of Gaps	10	
Circumference of valve center circle	17.970	cm
Diameter of Circle	5.723	cm
Diameter of circle	6.885	cm
Area of inner circle covering valves	14.650	cm^2
Inlet area	47.809	cm^2
Diameter of Inlet	7.804	cm
Length of Combustion Section	16.691	cm

V. MODELING AND ANALYSIS

The modeling of the pulsejet is done in ANSYS V12.0 and later, was analyzed in ANSYS Fluent

A. Modeling

The Modeling in ANSYS was done in design Modeler. The Design Modeler application is a parametric feature-based modeler. Its modeling paradigm is to sketch 2D profiles and use them to generate features. In CAD systems, features are collections of geometric shapes with which you add or cut material from a model. In the Design Modeler application, you can also use features to slice a model into separate bodies for improved mesh generation or to imprint faces for patch loading.

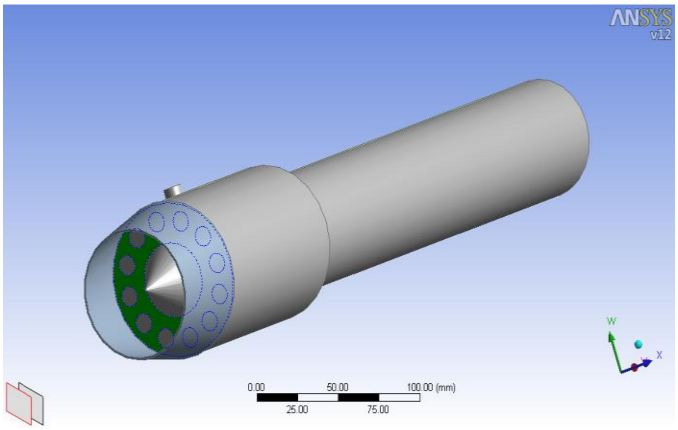

Fig 5 Pulsejet Modeled in ANSS

B. Analysis

As Mentioned, The analysis was done in ANSYS Fluent. The Fluent provides stage to perform combustion analysis using PDF Transport table method. Before analysis, the proper fuel to air fraction is found out using Stoichometric relation between air and Methane. The ration was found out to be 17.2.

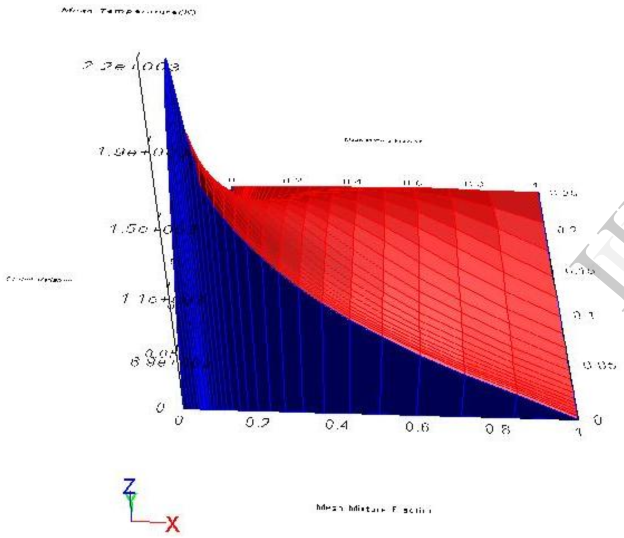

Fig 6 PDF Transport Table

The analysis was done for various operating conditions and varying from 10m/s to 50 m/s. apart from varying the velocity, the study of effect of diameter of exhaust pipe was done.

VI. REDULTS AND DISCUSSION

A. Case-I –

Velocity=10m/s and Exhaust Pipe Radius= 32mm

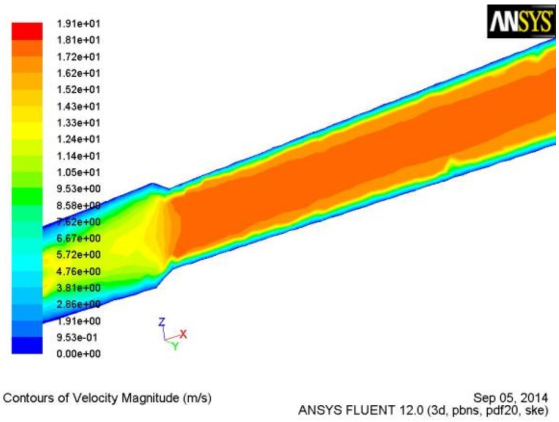

Fig 7 Velocity Contour

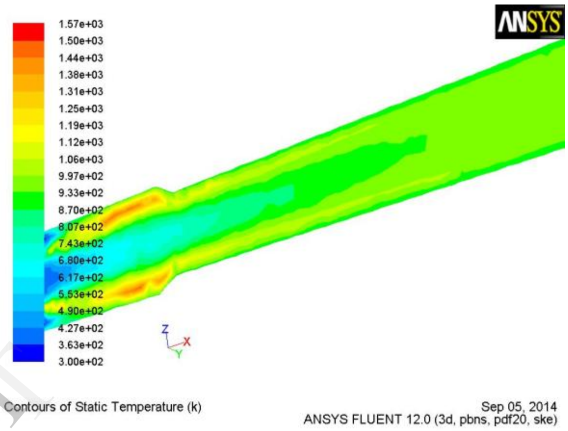

Fig 8 Temperature Contour

B. Case-I I–

Velocity=10m/s and Exhaust Pipe Radius= 28mm

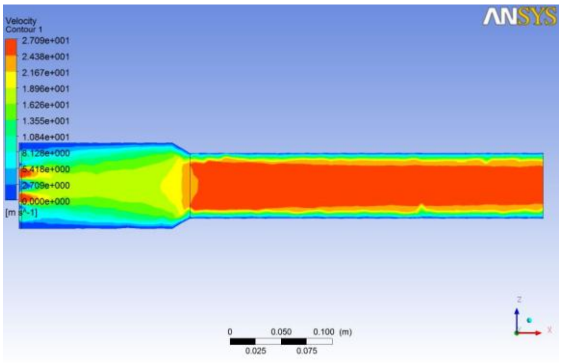

Fig 9 Velocity Contour

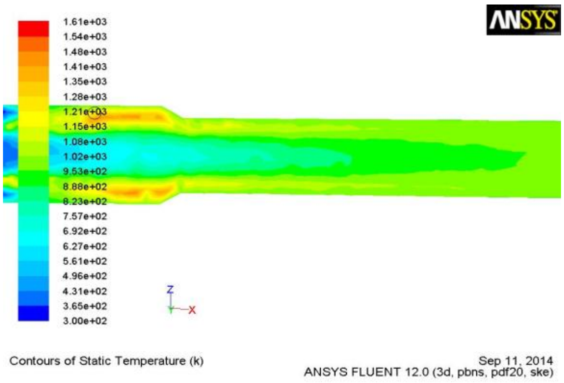

Fig 10 Temperature Contour

C. Case-III–

Velocity=20m/s and Exhaust Pipe Radius= 28mm

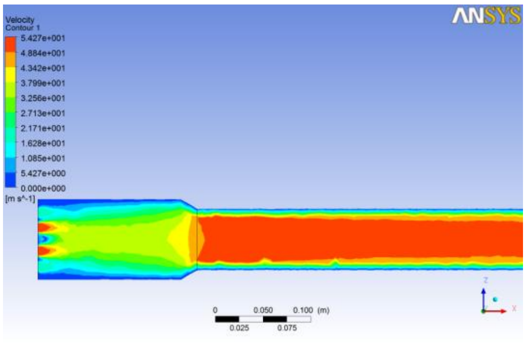

Fig 11 Velocity Contour

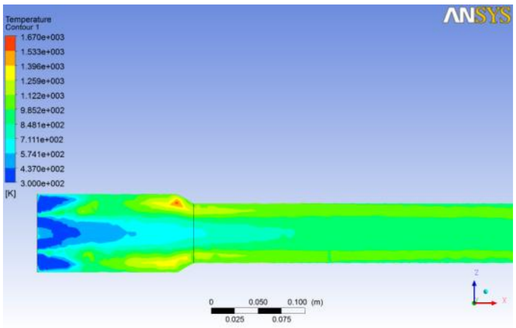

Fig 12 Temperature Contour

D. Case-IV–

Velocity=50m/s and Exhaust Pipe Radius= 28mm

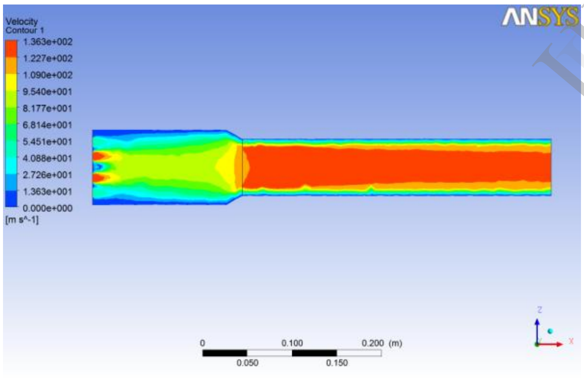

Fig 13 Velocity Contour

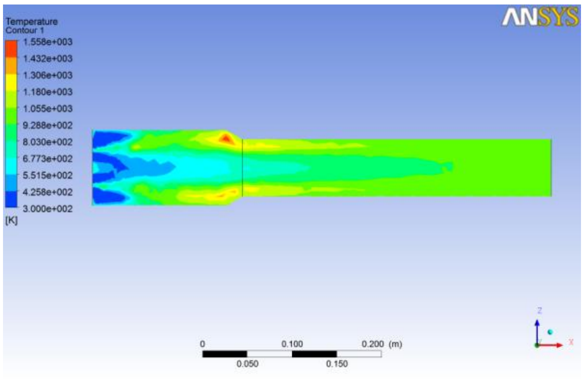

Fig 14 Temperature Contour

From the above results, The pulsejet is said to work successfully if it is able to maintain a stable pressure , with the minimum pressure below atmospheric pressure and also if the combustion of the reactants is localized to the combustion chamber with the majority of the combustion products going out through the exhaust pipe. Hence, the successful working of a pulsejet is quantitatively observed by monitoring the pressure, velocity and the temperature at specific points in the combustion chamber.

The Simulation was also helpful to draw the optimal operating conditions for pulsejet engine which include a low pressure in the combustion chamber, a high temperature for the fluid inside the pulsejet and completely filling the pulsejet with the fuel

VII..CONCLUSIONS

The present work on the design of Pulsejet engines presents interesting results on various design aspects. It enlightens the importance of having simplified expressions for attaining appropriate design. The result presents an interesting view of how the pulse jet runs with varying forward velocities of the flight. This also leads to future work that can be done to experimentally test these jets based on the CFD presented.

There are several conclusions that can be drawn from the work presented above

- Design of small size Pulsejet Engines is easy as large numbers of complex equations are eliminated.
- The thrust can be increased with decrease in the diameter of exhaust pipe for same operating condition.
- For Modeling the running pulsejet in a wind tunnel on a sting is very feasible and when compared with the experimental wind tunnel data
- CFD tests show feasibility of building a Pulsejet Engine
- They are inefficient when operated at low flight velocities

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