FABRICATION AND PERFORMANCE ANALYSIS OF VALVELESS PULSE JET ENGINE

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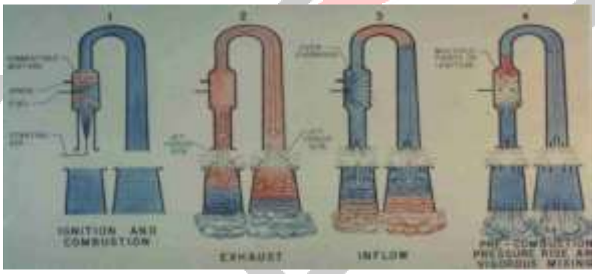
***Abstract*: Pulse jets are gaining attention of many engineers because of their simplicity, low cost of manufacturing and high propulsive power. Pulse jet engine's efficiency is low and therefore it became a hot debate, as efficiency is also very important. And moreover, high noise levels usually make 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 new applications. In this study, testing is performed on the 9lbs valve less pulse jet engine. The main objective in the project is to fabricate and conduct the performance test on Impulse Jet Engine. The pulse jet used in this study is valve less pulse jet working on LPG fuel cited by Bruce Simpson. Some major modifications were made to exhaust tail pipe and U-bend, and further more engine's thrust power was scaled down to 9lbs from 55lbs. Except U-bend section, all remaining components of engine were made by using Galvanized Iron Sheet. U-bend section which plays a major role in the working is made by using stainless steel. And all these individual components are joined to form a single body by Acetylene gas welding. In our work, Valve-less Pulse Jet Engine was studied theoretically and practically. Performance of engine was calculated at various fuel flow rate.**

***Keywords*: Valveless Pulsejet Engine, Impulse Jet Engine, U-bend section, LPG fuel, AUTO CAD**

1. INTRODUCTION:

Valveless pulsejet engines have no moving parts and use only their geometry to control the flow of exhaust out of the engine. Valveless pulsejets expel exhaust out of both the intakes and the exhaust, though most try to have the majority of exhaust go out of the longer tail pipe for more efficient propulsion.

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.



Working principle of a Valveless Pulsejet Engine

2. LITERATURE SURVEY:

Bruce Simpson [1] reported in his book "The Enthusiast's Guide to Pulsejet Engine", that "He made a pulsejet engine of 55lbs by taking Lockwood's design as reference and made some minor modifications to Lockwood's design.

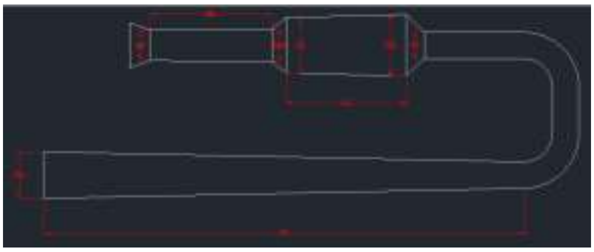
Michel Kadenacy [2] who obtained a French patent for an engine utilizing the effect operation of a pulsejet engine. There are also European and US patents. In simple terms, the momentum of the exhaust gas leaving the cylinder of an internal combustion engine creates a pressure-drop in the cylinder which assists the flow of a fresh charge of air, or fuel-air mixture, into the cylinder. The effect can be maximized by careful design of the inlet and exhaust passages.

Berthelot and Vieille, and Mallard and Le Chatelier discovered [3] a combustion mode propagating at a velocity ranging from 1.5 to 2.5 km/s. This combustion mode arose when gas was ignited with a high-explosive charge.

Two French engineers, Esnault and Peltrie, patented a design for an engine that drove a turbine wheel. This engine worked based on the principle of two opposing pulsating combustion columns fitted in a single straight, tubular chamber working out of phase from one another [4].

3. SYSTEM DEVELOPMENT:
3.1 FABRICATION:

This project relates to a pulse jet engine and, more particularly, to a valve less pulse jet engine having a hollow, U-shaped combustor of non-uniform cross section from end to end thereof. The sizes of the aforementioned openings N_I and N_O, C_I and C_O, T_I and T_O are expressed in diameter rather than circular areas,then dimensionless ratios can be established directly with various combustor section lengths; and in this respect, the length of the nozzle between the openings N_O and N_I is taken to be N_L, the length of the combustion chamber between the openings C_O and C_I is taken to be C_L, and the length of the tail pipe between the openings $T_I$and T_O is taken to be T_L .



As explained, the combustor is of non-uniform cross section from and to end thereof and in considering the size of the opening in any particular combustor section the mean opening size thereof is advantageously used. Accordingly, the mean opening size N_M is taken for the nozzle and the mean opening sizes C_M and T_M are used with reference to the combustion chamber and tail pipe. The following relationships based on all of the foregoing dimensions have been found to be exceedingly important:

$$^{N_L}/_{N_M}, C_L/C_M, \ T_L/T_M$$

And in numerical terms it has been found that the ratio$\frac{N_L}{N_M}$, should be in the range of about 3.50 to 4.25, the ratio C_L/C_M should be in the range of about 1.25 to 1.75, and the ratio T_L/T_M should be in the range of about 26 to 29.

Considering a specific example of a valve less pulse jet engine of circular cross section at any plane taken there across and of non-uniform cross section there along (where each section of the combustor is frusta-conical and the mean diameter thereof is located at a position there along one third of its length as measured from the largest opening), the following lengths and diameter appear:

N_L= 9.0944mm, C_L= 8.9763mm, and T_L = 35.826772mm;

N_I= 2.322mm, N_O = 2.5196mm, N_M= 2.41945mm;

C_I= 4.2125mm, C_O= 4.6850mm, where C_M= 4.44875mm;

T_I= 2.007874mm, T_O= 3.543307mm, where T_M= 2.7755905mm.

Accordingly, the following relationships are presented:

$\frac{N_L}{N_M}$=3.7588, C_L/C_M=2.0177, T_L/T_M =12.9078

In the same engine, the transition sections have half angles of 45 degrees and the ratios of the openings thereof are:

$$C_I/N_O = 1.6718, \text{ and } \ C_O/T_I = 2.333313$$

Finally, we got the following measurements after following the method explained above

2-D Diagram of Valveless Pulsejet Engine

3.1.1 Making of components:

1. Nozzle section:

It's actually quite hard to mark out an easily visible pattern on GI sheet with a regular Scribe. The problem is that the metal is very shiny and also quite hard. What we done is using a length of solid wire (not string or cord because it stretches) and have someone hold one end very firmly against what will be the center of the radius, while we prescribe the required arc by holding our scribe firmly against the wire at the desired radius and cut with the help of a hand cutters. These are done according to the dimensions which are shown in the figure.

[**Note:** All the dimensions mentioned in this chapter are in mm.]

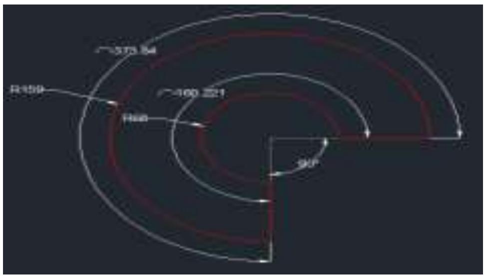
Surface Development of Inlet Nozzle

Fabricated Intake Nozzle Section

After the cutting of these sections, we rolled it and made it to form in the shape of a nozzle with the help of a gas welding as shown in above figure.

2.Intake tapered section:

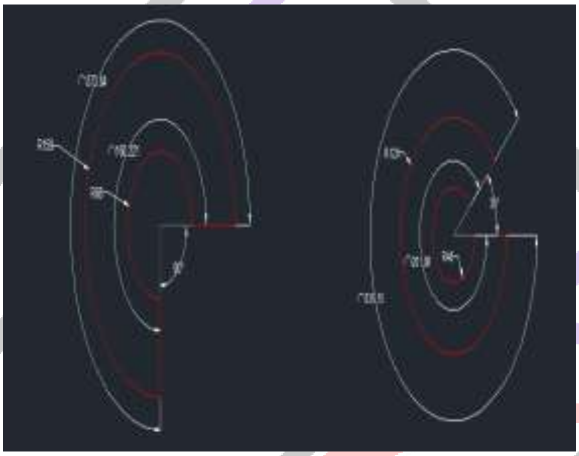
It is also built by using the dimensions from the drawing and rolled it, and made it in form of tapered section using gas welding which is shown in Figure-3.5 & 3.6.



Surface Development of Intake Tapered Section

Fabricated Intake Tapered Section

3.Tapered components joining before and after combustion chamber:

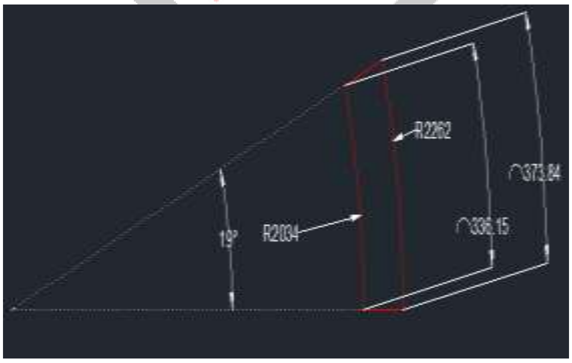


Surface Development of components before and after Combustion Chamber

Here, the making of tapered components that are joining before and after combustion chamber.

4.Combustion chamber:

Now, it is a slightly diffused section which containing one opening which is in the form of tapered section and is done by the same procedure as we followed for the component 1 simultaneously the ending tapered section also. As mentioned above, the cross sectional area was cut and rolled and further welded it to make in this form which is shown in figures



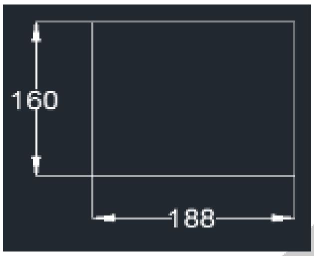
Surface Development of Combustion Chamber

Fabricated Combustion Chamber

5.Tube between combustion chamber and U-tube:

It is also done by the same procedure as we mentioned earlier and after doing it, the obtained component is shown in figure

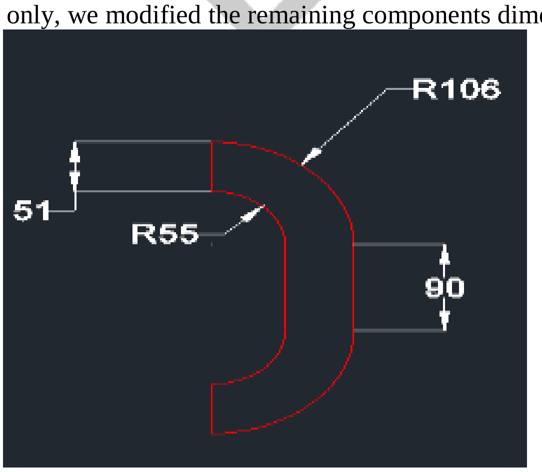
Surface Development of Component In between Combustion Chamber and U-section



Fabricated component joining Combustion Chamber and U-Section

6. U-tube section:

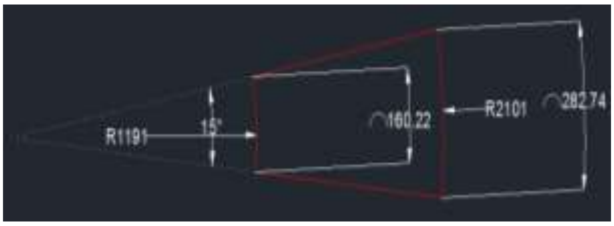
It is the main component of this engine and here we used a 2-inch diameter hollow tube of thickness 1.3mm which is taken from the junkyard. Based on this section only, we modified the remaining components dimensions which are explained earlier.



U-Section

7.Tail Pipe:

It is a long diffused section for reducing the pressure of the gases. Here the rolling of this long section is very important because it is not so easy to roll. So, first cut the cross sectional area of this section from the sheet and we folded it gently from the both sides with the help of our hands and welded it which is shown below.



Surface Development of Tapered Tail Section

Fabricated Tapered Tail Section

8. Fuel injector:

As per the dimensions given on the plans, we marked the spacing of the holes and punched slightly with the help of a center punch; this is because to guide the drill bit in the same line and drilled holes from one end to other end that means hole through the tube. These holes are made along the length side.

Fuel Injector

3.2 ASSEMBLY OF ALL COMPONENTS:

All the mentioned above components are joined according to the design as shown early by the use of gas welding and smooth surface finish is given after completion of welding to all the parts. And make a hole at the opening section of the combustion chamber to insert the fuel injector normal to the combustion chamber.

Valveless Pulsejet Engine Designed in CAD

Assembled Valveless Pulsejet Engine with gas Cylinder

Testing of Valveless Pulsejet Engine attached to a four wheeled trolley

4. PERFORMANCE ANALYSIS:

4.1 THEORETICAL ANALYSIS:

The ideal thermodynamic cycle of pulse jet is shown in figure. It consists of two reversible adiabatic processes, one reversible isochoric process and one reversible isobaric process. It is assumed that air is the only working fluid and let 1kg/s is the fixed mass of air undergoing the cycle of operations as described below. In the cycle, air is compressed partially in the process 1-2 reversibly and adiabatically. Heat is then added to air reversibly at constant volume in process 2-3. Work is done by expanding air reversibly and adiabatically in process 3-4. Heat is rejected by air reversibly at constant pressure in process 4-1, and the system (air) comes back to its initial state.

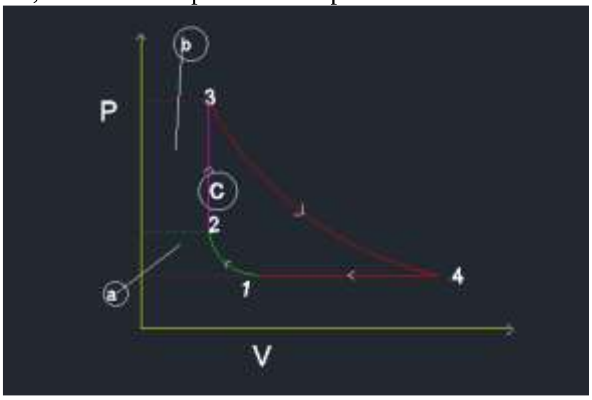
Let,

T1 be the initial inlet temperature of air having corresponding Pressure P1,

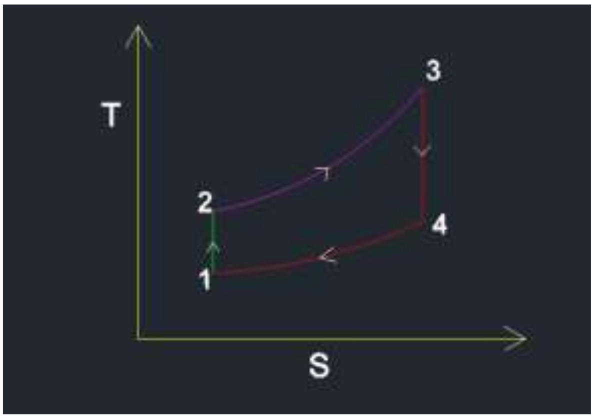
T2, P2 be the temperature and pressure respectively of the air after heat addition,

T3, P3 be the temperature and pressure of air after expansion in tail section and

T4, P4 be the temperature and pressure of air after heat loss.



Pressure vs Volume diagram



Temperature vs Entropy diagram

In the above P-V diagram, area enclosed by points 12341 represents the work done in one complete cycle. And the letters surrounded in circle are used to calculated work done in a cycle. Work done is equal to area represented by "c" minus area of represented by and "a" and "b" together.

Temperatures obtained from experiments are

T1 = 305 K, T2 = 307 K, T3 = 1308 K, T4 = 852.6 K

Process 1-2 is isentropic compression

$$\frac{T_1}{T_2} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$$

$$P_2 = \frac{101325}{0.9778} = 103628.3080 \text{ Pa}$$

Process 2-3 is Constant volume heat addition

$$\frac{T_3}{T_2} = \frac{P_3}{P_2}$$

$$P_3 = 441517.3513 \text{ Pa}$$

Process 3-4 is Isentropic Expansion

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

$$P_4 = 101324.9733 \text{ Pa}$$

In constant volume heat addition process, heat supplied is given by

$$\dot{Q}_{Theoritical} = c_v \times (T_3 - T_2) = 0.275 \times (1308 - 307) = 275.3\text{KW}$$

The net work done in a cyclic process can be calculated from the area bounded with in the curve. From the P-V diagram, $\dot{W}_{net} = \dot{W}_C - [\dot{W}_a - \dot{W}_b]$

$$= \left\{\left(\frac{\gamma}{\gamma-1}\right) \times R \times T_4 \times \left[\left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] - \left[\left(\frac{\gamma}{\gamma-1}\right) \times R \times T_1 \times \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] + R[T_3 - T_2]\right\}$$

$$= 160.24456KW$$

Efficiency of the cycle is, $\dot{\eta}_{cycle} = \frac{Net\ Work\ Done}{Heat\ Supplied}$

$$\dot{\eta}_{cycle} = \frac{\dot{W}_{net}}{\dot{Q}_{Supplied}} = \frac{160.244}{275.3} = 0.582$$

$$\dot{\eta}_{cycle} = 0.582 = 58.2\%$$

4.2 EXPERIMENTAL ANALYSIS:

Temperature at Surfaces and Inside the Engine

Position of Thermocouple	Surface Temperature(°C)	Inside Temperature(°C)
Position-1	175	469
Position-2	345	513.2
Position-3	394	579.6
Position-4	508	750
Position-5	650	1035
Position-6	440	520
Position-7	410	450
Position -8	400	410

Rate of fuel consumption,

$$\dot{m}_f = \frac{\textit{Rate of air consumption}(m_a)}{\textit{air fuel ratio}}$$

$$= \frac{\rho \times A \times C_a}{15.5} = 0.000614 \text{ kg/s}$$

Rate of air consumption,

$$\dot{m}_a = \rho \times A \times C_a$$

$$\dot{m}_a = 0.000614 \text{ kg/s}$$

Thrust:

$$\text{Thrust} = \left[1 + \left(\frac{\dot{m}_f}{\dot{m}_a}\right)(C_j + C_a)\right]$$

$$= 36.1935 \text{ N/ kg of air /s}$$

Thrust power (T.P):

Thrust power = Forward Thrust ×Speed of Aircraft

$$\text{Thrust power} = \left(1 + \frac{\dot{m}_f}{\dot{m}_a}\right)(C_j + C_a)\, C_a \text{ W/kg}$$

Thrust power =144.7741 W/ kg of air

Propulsive Power (P.P):

$$\text{Propulsive Power} = \left(\frac{(1+\frac{\dot{m}_f}{\dot{m}_a})C_j^{\,2}}{2} - \frac{C_a^{\,2}}{2}\right) \text{ W/kg of air}$$

$$= 471.0323 \text{ W/ kg of air}$$

Propulsive Efficiency (η_{prop}):

$$\eta_{prop} = \frac{\text{Thrust power}}{\text{Propulsive power}}$$

$$= \frac{\left(1+\frac{m_f}{m_a}\right)(C_j+C_a)C_a}{\left(\frac{(1+\frac{m_f}{m_a})C_j^{\,2}}{2} - \frac{C_a^{\,2}}{2}\right)}$$

$$= 30.735\ \%$$

Heat Balance Sheet:

Heat supplied by fuel = (Heat loss through exhaust gases + Heat loss through convection + Heat loss through radiation +Thrust power)

Heat Supplied by fuel:

Heart Supplied by fuel $= \dot{m}_f \times C.V$

$= 18.863$ kW

Heat loss through Convection:

$\dot{Q}_{convection} = hA\Delta T$

Surfaces considered on Engine

Convectional heat loss through surface 1,

$\dot{Q}_{C1}$ = h. A_1. ΔT

=1126.204 W

Convectional heat loss through surface 2,

$\dot{Q}_{C2}$ = h. A_2 . ΔT

=280.274 W

Convectional heat loss through surface 3,

$\dot{Q}_{C3}$ = h. A_3 . ΔT

=140.969 W

Convectional heat loss through surface 4,

$\dot{Q}_{C4}$ = h. A_4 . ΔT

=121.682 W

Convectional heat loss through surface 5,

$\dot{Q}_{C5}$ = h. A_5 ΔT

=398.912 W

Convectional heat loss through surface 6,

$\dot{Q}_{C6}$ = h. A_6 ΔT

=41.179 W

Total convection heat loss through all the surfaces,

$\dot{Q}_{convection} = \dot{Q}_{C1} + \dot{Q}_{C2} + \dot{Q}_{C3} + \dot{Q}_{C4} + \dot{Q}_{C5} + \dot{Q}_{C6}$

= 2109.221 W

Heat loss through Radiation:

$\dot{Q}_{Radiation} = \varepsilon\sigma A T^4$ W

Radiation heat loss through the surface 1,

$\dot{Q}_{R1} = \varepsilon\sigma A_1 T^4$

=828.5009W

Radiation heat loss through the surface 2,

$\dot{Q}_{R2}$ = h. A_2 ΔT

= 849.935 W

Radiation heat loss through the surface 3,

$\dot{Q}_{R3}$ = h. A_3 ΔT

= 416.838 W

Radiation heat loss through the surface 4,

$\dot{Q}_{R4} = h.A_4\,\Delta T$

=359.868 W

Radiation heat loss through the surface 5,

$\dot{Q}_{R5} = h.A_5\,\Delta T$

=179.564 W

Radiation heat loss through the surface 6,

$\dot{Q}_{R6} = h.A_6\,\Delta T$

= 87.345 W

Total radiation heat loss through all the surfaces,

$$\dot{Q}_{Radiation} = (\dot{Q}_{R1} + \dot{Q}_{R2} + \dot{Q}_{R3} + \dot{Q}_{R4} + \dot{Q}_{R5} + \dot{Q}_{R6})$$

=3296.324 W

Heat Loss through Exhaust gases:

$$\dot{Q}_{exhaust} = [\dot{m}_f + \dot{m}_a) \times C_p \times \Delta T]$$

=5.831 KW

Unaccounted heat= {[(Heat supplied by fuel)] – [(Heat loss through exhaust gases) + (Heat loss through convection) + (Heat loss through radiation) + (Thrust power)]}

= 7.4811 KW

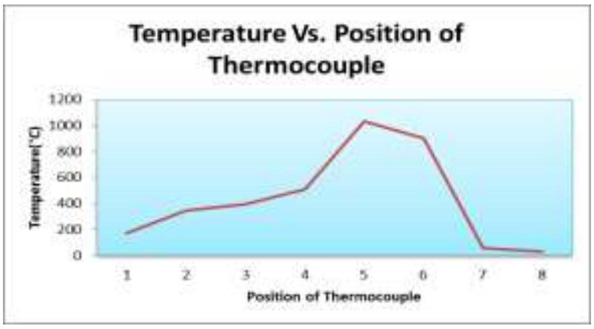
Thrust Specific fuel consumption (TSFC): It is the ratio of fuel consumption to the thrust developed.

Thrust Specific Fuel Consumption = $\frac{\text{fuel consumption}}{\text{thrust developed}}$ $=1.6968 \times 10^{-5}$ kg /N of thrust / sec

4.3 RESULTS AND DISCUSSIONS:

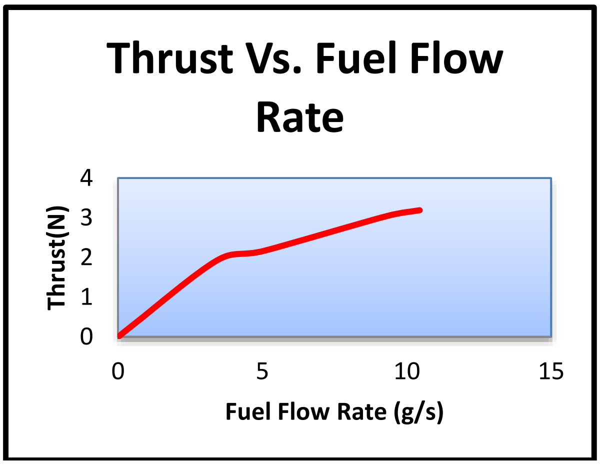
Representation of various points on Valveless Pulsejet

Calculations were also carried out at different fuel flow rates. Though mass of flow is varied, the temperatures at different positions of system will remain unchanged. But pressure changes thus thrust force available to propel the vehicle will change when fuel flow rate is changed. Results are furnished in the form of graphs.



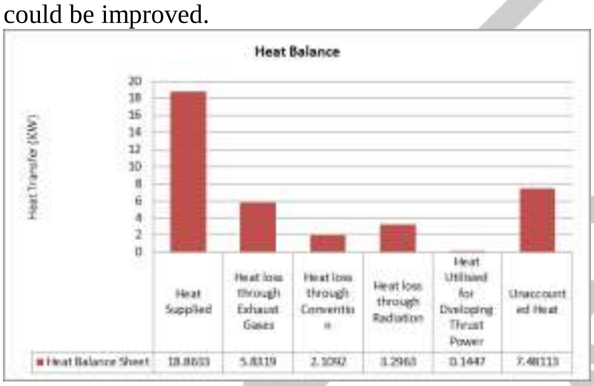
Graphical Representation of Temperature vs Thermocouple Position

The above figure shows the variation of the temperature across the different position of the Pulsejet Engine. The maximum temperature is found at combustion chamber. Since U-Tube channel traps heat for some time, there temperature has reached beyond the 550°C. Exhaust gases are always hot and contains huge amount of heat, whereas air entering the combustion chamber is relatively much cooler. Therefore tail pipe will be somewhat hot when compared with inlet nozzle portion. Therefore, there is slope variation on the either sides of combustion chamber.



Graphical Representation of Thrust vs Fuel Flow Rate

Heat transfer through different modes is shown in figure at fuel flow rate, $\dot{m}_f = 0.00614$Kg/s. From the results shown above, it is clear that heat loss through exhaust gases is more when compared with other modes of heat losses. If more heat energy is converted into Kinetic energy of gases at the exit, heat loss through exhaust gases could be minimized. Thus performance of pulsejet engine could be improved.



Heat Balance Sheet

5. CONCLUSION:

Valve less Pulsejet Engine was fabricated and its performance was studied. In present work, thrust power at various fuel supply rates was calculated and it was found that thrust power is increasing linearly with increase in fuel flow rate. Various losses such as heat loss through exhaust gases, heat loss through Convection and Radiation were calculated and furnished in the form of heat balance sheet.

FUTURE SCOPE:

From analysis, it is clear that heat loss through exhaust gases is very high when compared to any other heat loss. So, to obtain more thrust power, heat loss through exhaust gases has to be minimized.

Though noise and vibrations are common in any engineering device, this engine is producing much critical noise and vibrations which are beyond the limit. Making some modifications to the design and adding some components to absorb vibrations may bring good results.

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