THE DESIGN AND DEVELOPMENT OF A NOZZLE TO SUIT LIQUID FUEL THRUST DEVICE

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ABSTRACT

This project is a laboratory simulated small rocket engines system. The rocket engine is a relatively simple device in which the propellants are burned and the resulting high pressure gases are expanded through a specially shaped nozzle to produce thrust. Thrust is a mechanical force. It is generated through the reaction of accelerating a mass of gas. The gas is accelerated to the rear and the engine (and aircraft) is accelerated in the opposite direction. To accelerate the gas, we need some kind of propulsion system. Gas pressurized propellant tanks and simple propellant flow controls make operation of a small liquid fuel rocket engine as simple as operating an automobile engine. The combustion chamber and the nozzle form the main part of the engine, wherein the thrust is developed. The combustion chamber comprises the injector through which the propellants enter the vaporization, mixing and combustion zones and the restriction leading to the nozzle. The function of the nozzle is to convert the chemical thermal energy generated in the combustion chamber into kinetic energy. The nozzle converts the slow moving, high pressure, high temperature gas in the combustion chamber into high velocity gas of lower pressure and temperature. All the theories are based on the thermodynamics and fluid mechanics principle.

Keywords: rocket engines, nozzle, thrust, combustion chamber

1.0 INTRODUCTION

Nozzle is a relatively simple device, just a specially shaped tube through which hot gases flow. Rockets typically use a fixed convergent section followed by a fixed divergent section for the design of the nozzle. This nozzle configuration is called a convergent-divergent, or CD, nozzle. In a CD rocket nozzle, the hot exhaust leaves the combustion chamber and converges down to the minimum area, or throat, of the nozzle. The analysis of a rocket nozzle flow involves the study of steady one-dimensional compressible flow of an ideal gas. The actual flow differs somewhat from this simplified model particularly in regard to the presence of solid or liquid particles in the flow stream. The analysis of compressible flow involves four equation of particular interest continuity, momentum, energy and the equation of state. These equations are applied to design a nozzle with the objective of accelerating the combustion gases (and particles) to as high an exit velocity as possible. This is achieved by designing the necessary nozzle profile with the conditions that isentropic flow is to be aimed for. This necessitates minimizing frictional effect, flow disturbances and conditions which can lead to shock losses. As well, heat losses would have to be minimized.

The nozzle represents a key part of a rocket motor. This component serves to accelerate a voluminous mass of stationary combustion gases to supersonic velocities within a very short distance, and in doing so, produces useful thrust. In accomplishing this remarkable feat, a nozzle is subjected to very high pressures, and rapid, dense gas flow at high temperatures. As such, a
nozzle must be fabricated from a material that will be capable of withstanding such conditions of structural and thermal loading. As well, any restrictions to the free flow of gases must be minimized, which necessitates a smooth, suitably profiled flow surface. Considering the effort and time invested in making such a nozzle, multiple usages are obviously desired. Fortunately, stainless steel is well suited to this application, at least, for many popular amateur propellants. Stainless steel machines relatively well and tends to produce a better surface finish with less effort and produces less problematic chips. Stainless steel should be used with caution as this material may be less resistant to high temperatures than mild steel. Alloy steel should not be used, due to its lower melting point and difficulty in machining. Low melting point alloys such as aluminum and brass are not suitable for multi-usage nozzles, unless a high temperature resistant "throat inset" is used (which complicates the manufacturing).

However, the more rational approach to rocket motor design and construction involves designing a nozzle to achieve a particular performance goal. This design process defines the nozzle shape and dimensions. Key design parameters for a standard conical de Laval nozzle are the convergent and divergent angles, and the diameters of the inlet, throat, and exit. As well, the exterior profile of the nozzle is sculpted to minimize the mass of the finished nozzle. A nozzle that does not have a sculpted exterior will work nearly as well. It is important to recognize that the more care and effort that is put into creating an accurate and detailed drawing, the less laborious the effort to fabricate the nozzle and combustion chamber and the less likelihood of making a mistake during machining which could relegate hours of effort to the scrap bin. CAD software programs (even basic ones) are ideal for producing a suitable nozzle and combustion chamber drawing. Machining of the nozzle is more difficult, complex shape and also need for accuracy aspects of lathe use, compare with combustion chamber.

The combustion chamber should be built as a one-piece unit. This arrangement, while more difficult from a machining point of view, eliminates the requirement for a joint of some kind between the two parts; this joint would be exposed to the hot combustion gases on one side and would, in all probability, fail. Building the combustion chamber and nozzle in one piece eliminates this potential failure point. Care must be exercised during the machining of the stainless steel chamber and nozzle to ensure constant wall thickness and the correct taper in the nozzle region. The bolts holding the two components together (and in this case also holding the assembly to the test mounts) must withstand this force with and adequate safety factor (typically a factor of two). The strength of these bolts, however, depends to some extent on the adequacy of the threads in tapped holes, the tapped material, and the bolt tightening procedure used in assembly.

2.0 LITERATURE REVIEW

A small liquid rocket engine generally has two types of applications, which is either as auxiliary propulsion or as boost propulsion. Sutton (1986) gives an overview of typical characteristics of these categories; Table 1.0 below summaries the most important characteristics and differences. This project will only focus on design, analysis and optimization of liquid rocket engines of the boost propulsion, as for these engines many different and rather complex engine cycles exist. Each cycle has its advantages and disadvantages in dry mass, wet mass, reliability, cost, specific impulse and etc. When looking to the history of rocket engines one can see a trend in time towards higher combustion pressures, M. Kaufmann (1987) identifies that the reasons for this are a more compact overall design, higher specific impulse and the resulting higher payload percentages of launch vehicles with high pressure engines.
Table 1.0: Characteristics of the two main categories of liquid rocket engines.

3.0 METHODOLOGY

The first stage of this project is about finding related information regarding on how to determine the thrust developed by designing and development of the nozzle to suit liquid fuel thrust device. The concept of the nozzle and system included the theoretical analysis has been studied. In doing this, information regarding this analysis is obtain from the text books and had been discussed with advisor.

The important objective in the first stage is to obtain the measurable thermodynamics and fluid mechanics properties such as temperature, thrust, and pressure also flow rate. To achieve the objective, the device such as nozzle and the test stand are fabricated. Once the experimental and analysis is carried out, some improvements is suggested or recommended.

Figure 1.0: Design Steps
Figure 2.0: Combustion Chamber and Nozzle Assembly

Figure 3.0: Ignition Attachment
4.0 RESULT AND DISCUSSION

This project is considering the static tests because it only involving the engine system which is not including any aircraft used. In this project, the method to measure the thrust is by using a sensor that will convert input analog signal to digital output signal in term of bit. That is why the calibration using conventional weight scale is needed before the data for thrust measurement is taken. During the force calibration process, the distance calibration is also takes place. This matter is important to determine the velocity and acceleration of the cart when the thrust is produce. By doing this calibration we can determine the real thrust force.

Figure 4.0: The Increment of Bit Due To Time Increment

Figure 5.0: The Increment of Mass Due to increment of Time
By referring to the result (tables and graphs) that is obtained above, it is found that the initial displacement of the thrust device is given in the graph where it is displaced to 0.25 cm from rest condition in 0.6 second. So the initial velocity is given by:

\[ V = \frac{S}{t} \]

\[ V = \frac{0.0025\ m}{0.6\ s} ; \ V = 0.0042\ m/s \]

Then it is stopped for about 1.8 second where this condition is considered as no velocity condition. From that condition it displaced to 2.5 cm in 0.2 second. This condition can be considered as maximum thrust and the velocity at this condition is given by:

\[ V = \frac{0.019\ m}{0.2\ s} \]

\[ V = 0.095\ m/s \]

So from the velocity that is determined above, the acceleration can be obtained. The acceleration of the thrust device is given by:

\[ a = \frac{V - U}{t} \]

\[ a = 0.5\ m/s^2 \]

The thrust force is the product of mass of the thrust device and its acceleration and is given by:

\[ F = ma \]

\[ F = (3\ kg)(0.5\ m/s^2) \]

\[ F = 1.5\ N \]

Thrust of the combustor is related on how fast and how much hot gas exhausts passes through the nozzle. Since there are increase total amount of propellant, the propellant reaction also increase
in terms of heat and pressure. Heat and pressure in the combustion chamber will affect the total mass flow rate at the nozzle. The theoretical relation state that, mass flow rates at the nozzle will produce net thrust of the combustor. From the result, it showed that the velocity of the propellant is proportional to the amount of flow rate and as mentioned above the propellant reaction is related to the amount of flow rate too. If the chemical reaction is increased the amount of hot exhaust that passes through the nozzle will also increase. The exit velocity that determined by the shape of the rocket nozzle is supersonic.

5.0 CONCLUSION

This system is equivalent to the theoretical design where the thrust developed is equal to total mass flow rate of the propellant multiply by exit velocity. This can be proved by applying the following relation;

\[ F = \dot{m}V_e \]

As the mass flow increase the thrust will also increase and due to the effect of heat and pressure inside the chamber. The fluid pressure that is related to the momentum of the gas molecule acts perpendicular to any boundary impose to it if there are net changes of pressure in the flow direction hence additional in momentum. The design of the nozzle will determine the exit velocity for a given pressure and temperature. The maximum flow through the nozzle is determined by the throat diameter due to the occurrence of choke.

6.0 REFERENCES


