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Solid Rocket Motor for Experimental Sounding Rockets

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Abstract

Experimental Sounding rockets are major contributors for research in the field of aerospace engineering. However, experimental sounding rockets are rarely used by institutes in India for student research projects. A major factor that forestalls the use of sounding rockets in student research projects is the unavailability of rocket motors which involves complex machining and explosive propellants, this problem was encountered by us while developing sounding rocket for research and learning purpose.

The paper is focused on design and construction of a solid rocket motor that can be utilised as the main propulsion unit in experimental sounding rockets by researchers.

Initially, basic designs were evaluated and the different concepts of propellant configuration were observed. The availability, ease of manufacturing and casting of propellants was a major factor in determining the suitable propellant. Based on these observations the theoretical values of the combustion chamber parameters were obtained and the materials were selected accordingly. A basic small scale experimental design was fabricated and tested extensively. Integrating all the testing and theoretical data the final motor was fabricated and tested for expected outputs.

The paper explains all the factors involved in construction of a rocket motor of desired specific impulse and will act as a valuable asset for students engaged in experimental rocketry. The motor constructed will be utilized in a sounding rocket intended for atmospheric and aerodynamic research for student learning. The motor can be also utilized as a propulsion unit in research fields other than aerospace and will be an affordable propulsion unit for research purposes.

Keywords: rocket motor, propellant, propulsion, design.

1. Introduction

Very few institutes are involved in practical rocketry, as it requires typical construction and deals in explosives raising safety concerns. Moreover it requires expensive test rigs and machining techniques. A student build rocket motor involves use of explosive chemicals and requires extensive testing of the prototypes and materials before starting the actual construction. The construction is affected by limited availability of key materials and chemicals.

A solid rocket motor is a rocket motor that uses a solid mixture of chemicals as its propellant. Nozzle is the part of motor responsible for thrust generation and experiences high amount of temperature and pressure changes. Both propellant and nozzle are crucial for design and construction of rocket motor.

The paper focuses upon development of‘L’ class solid rocket motor by using the materials and chemicals which are commercially available and will act as an alternative to escape conventional problems like propellant procurement, expensive materials and complex machining. Development of rocket motor enables student researchers to experience and learn the crucial aspects of rocket engineering practically.

2. Operating Principle

Principal of operation is shown in Figure 1. Initially the propellant is ignited and it burns at a rapid rate producing gases. These gases develop pressure inside the combustion chamber and this pressure force the gases to pass through the only exit available, which is the nozzle. Nozzle first reduces the area of exit in order to increase the velocity of exhaust gases and gases reach supersonic velocity at the nozzle throat. Now the area is increased to further increase the velocity, as according to supersonics increase in area produces increase in the velocity. The pressure decreases when gases flow through the nozzle.

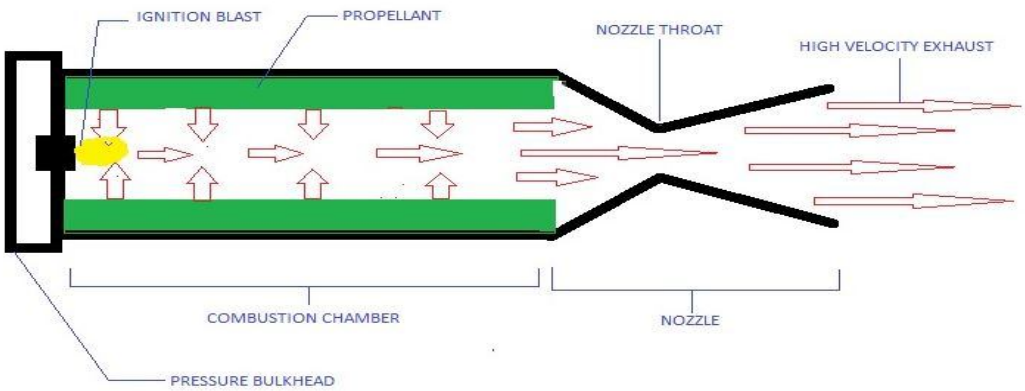

Figure 1: Behaviour of gases after the ignition of propellant inside combustion chamber.

The increase in velocity and difference between exit and atmospheric pressure generates thrust. Thrust is given by the equation below.

(1)

Where F is Thrust or force, mis mass flow rate, V_e is exhaust velocity, p_e is exit pressure, p_o is atmospheric pressure and A_e is exit area of nozzle.

Propellant

A propellant is a mixture of chemicals which burns rapidly when ignited. Major components of propellant are oxidizer and fuel. Oxidizer provides oxygen for fuel burning. The ratio of these two components alters the burn rate of propellant which alters chamber parameters.

2.1- Zinc-Sulphur

It is a mixture of Zinc metal dust and powdered sulphur also referred as “micrograin”. Its optimum mixture is 2.06 parts zinc to one part sulphur by weight, after testing various ratios and considering the data available, a 65%Zinc/35%Sulphur (by weight) was selected.

The propellant was processed by mixing the two constituents in the desired ratio and casting was done by manual compression of the propellant using standard weights. Flame temperature test of the processed propellant was done using thermocouples and a temperature recording of 1245˚C was noted.

Figure 2: Propellant flame temperature test.

2.2-Rocket Candy

The second propellant used for initial experiments was a combination of Potassium Nitrate and sugar. Potassium nitrate acts as Oxidizer and Sugar serves as Fuel, a 65/35 ratio of oxidizer- to-fuel is used for rocket motors.

The propellant was processed by mixing the constituents in desired ratio and dissolving them in water and then evaporating the water and keeping a temperature around 130˚C to obtain a semi solid mixture, this mixture then casted in a mould of desired shape. Test reported a flame temperature of 1347˚C.

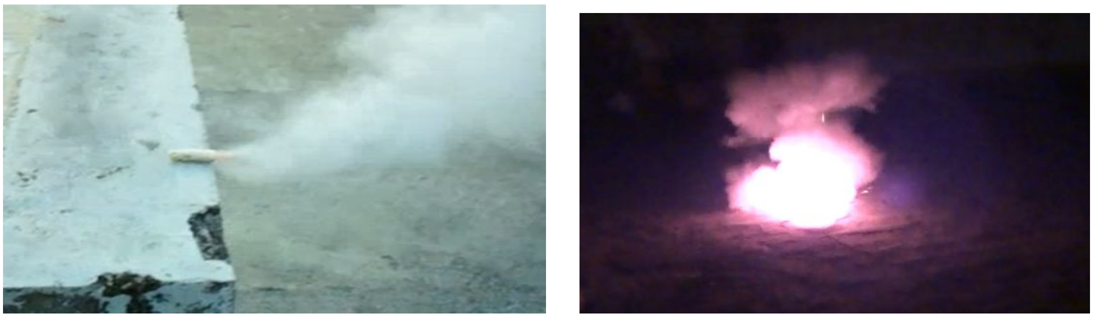

Figure 3: Independent burn test of rocket candy (left), flame temperature test of rocket candy (right).

2.3 Propellant Selection

Considering the properties of both and evaluating on the base of following aspects Rocket candy was selected for final testing.

- Rocket candy has a high flame temperature compared to Zinc-Sulphur.
- Weight of Zinc-Sulphur is more as zinc has more density and results in high propellant mass.
- Rocket candy can be casted into desired shape easily and maintains uniformity, on the other hand Zinc-Sulphur required casting by manually compressing the powdered mixture which limits its casting only for end burning fuel configuration and uniform mixture is rare.

3. Design

3.1 Initial design

Motor was divided into three basic parts: head, combustion chamber and nozzle section. All these were joined separately allowing ease in loading the propellant and ignition system. Retain screws were installed on both head and nozzle sections. The head section had an inbuilt reusable space for ignition charge. The fuel was loaded in two segments and was separated by spacer ring (a simple ring of metal intended to separate the two segments).The prototype had two propellant grain segments each 150mm long and having 24mm core diameter and 58mm outer diameter with outer surface inhibited. Total mass of the grain was 1.919 Kg which gave a total burn surface area of 31378 mm^2

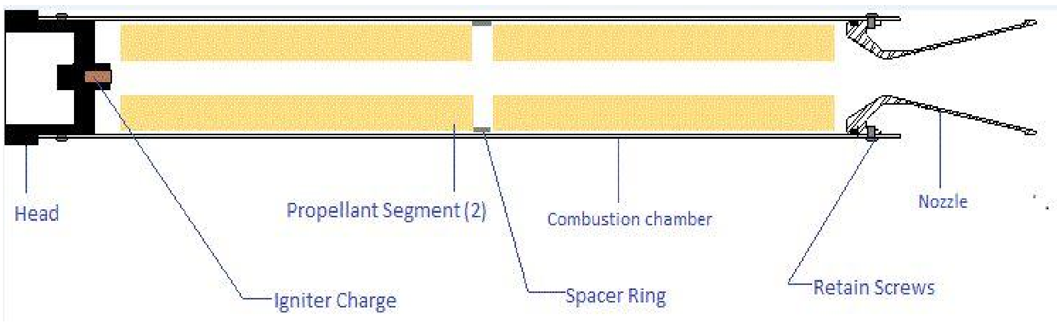

Figure 4: Basic design of prototype motor.

3.1.1 Nozzle

Nozzle is the part responsible for production of thrust in a rocket motor; it increases the velocity of exhaust gases. A de Laval (convergent-divergent) nozzle with a convergence angle of 30° and divergence angle of 12° with an expansion ratio of 10:1 was used for prototype design. Nozzle is described in detail in figure 5.

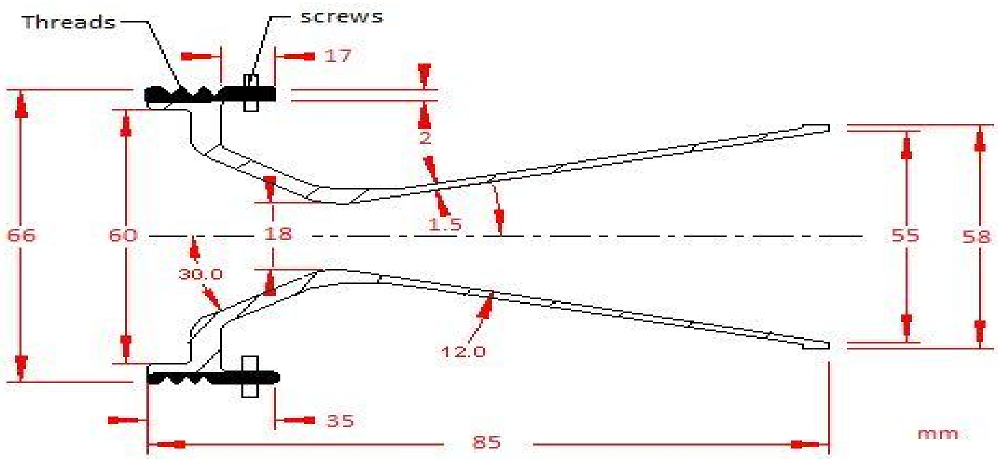

Figure 5: Nozzle design parameters.

3.2 Analysis

Design of the prototype was theoretically analysed for performance on SRM design software and the results were analysed to evaluate suitable materials for fabrication.

Software analysis of the prototype resulted in a peak chamber pressure of 2.52 MPa and a peak thrust of 1015 N with a total impulse of 1411 N-sec and specific impulse of 120.8 sec.

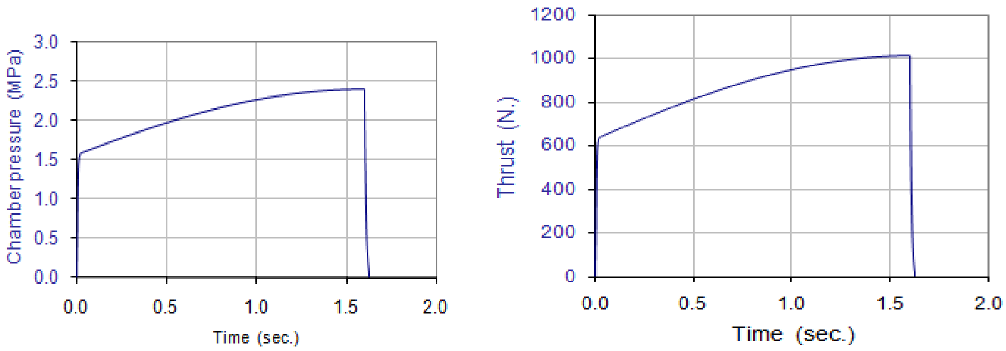

Figure 4: Graphs depicting the variation of motor Chamber pressure and thrust with burn time.

3.3 Material Selection

Different materials were selected for different parts of the motor. Major factors like density, cost and availability affected the selection process.

3.3.1 Aluminium 6061-T6

It is an alloy of aluminium with magnesium and silicone as major alloying elements and is widely used in aircraft construction industry. With a density of 2.7g/cm^3 it is best suited for experimental projects in aerospace and its ease of machining is advantageous. The following properties of the alloy were observed for calculation of design pressure and burst pressure of the casing.

Table 1: Properties of Al 6061-T6.

Properties	Yield Strength(MPa)	Ultimate Strength(MPa)	Modulus of Elasticity(Mpa)	Poisson Ratio	Strength Ratio (Fty/Ftu)	Burst Factor
Values	241	290	68310	0.33	0.831	1.337

Casing analysis of the materials was done and the following equations were used in the analysis.

$P_D =$ —— (2)

Design pressure P_D was obtained from the above equation where, t is wall thickness of casing, Fty is yield strength, Dis external diameter of chamber and S is design safety factor which was kept 1.5.

$P_U =$ —— (3)

Burst pressure P_U was obtained from the above formula where, B is burst factor and rest all are same from the previous equation.

Calculations resulted in a design pressure of 8.03MPa and a burst pressure of 16.11MPa which gave a burst safety factor S_U of 2.01. Comparing the peak chamber pressure of the motor and design pressure, Al 6061-T6 was selected for the construction of motor and the pressure bulkhead of the motor.

3.3.2 Mild Steel

Mild steel also known as plain carbon steel is widely used in construction sites. The steel has a density of $7.8 g/cm^3$. The steel is compared for high temperature behaviour with other materials available by observing the graph shown below.

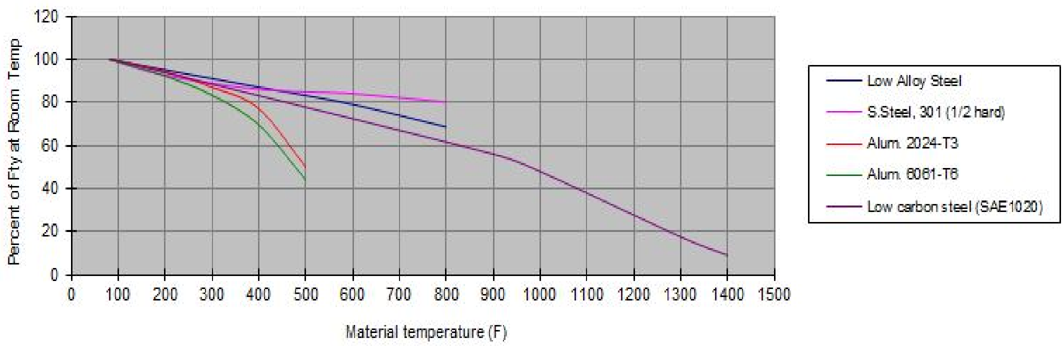

Figure 5: Graph showingvariation of material yield strength with temperature.

Considering that mild steel exhibit almost similar effect of temperature on its strength as experienced by Stainless Steel,cost difference and the complex machining of nozzle required a malleable material which does not break on lathe operations; mild steel was selected for the fabrication of nozzle.

Figure 6: Mild Steel nozzle of prototype rocket motor.

4. Testing and Development

4.1 Prototype

Testing of the prototype was successful and no damage to the structure was observed. The setup recorded a peak thrust of 997 N and a burn time of approximately 1.5 sec.

Similar testing was repeated several times to arrive at concrete decision that the design is safe and all components are behaving as expected.The convergence of software and practical results was proved and same software was used for designing main motor.

Figure 7: Static testing of prototype.

4.2 Main Motor

The design for main motor was revised, nozzle expansion ratio was changed to 14:1 as no major erosion was observed and all other basic design principles were kept same. Main motor had four propellant segments each 100 mm long with a total grain mass og 3.4 Kg and a total burn area of 62714 mm^2. Main motor is explained in detail in the figure 8.

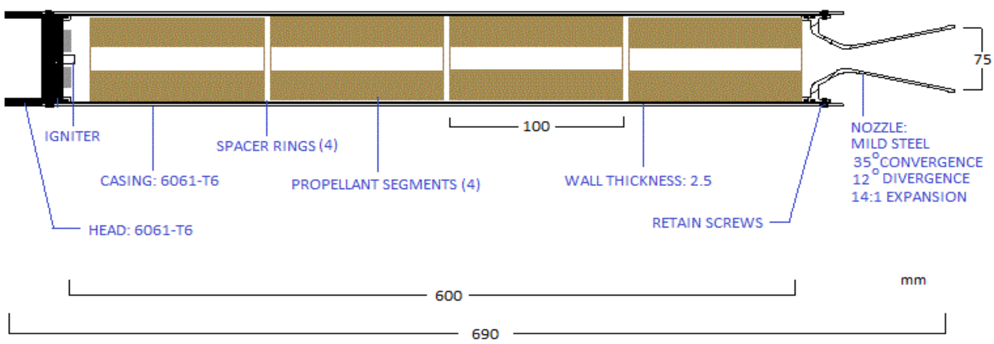

Figure 8: Detailed description of main motor design.

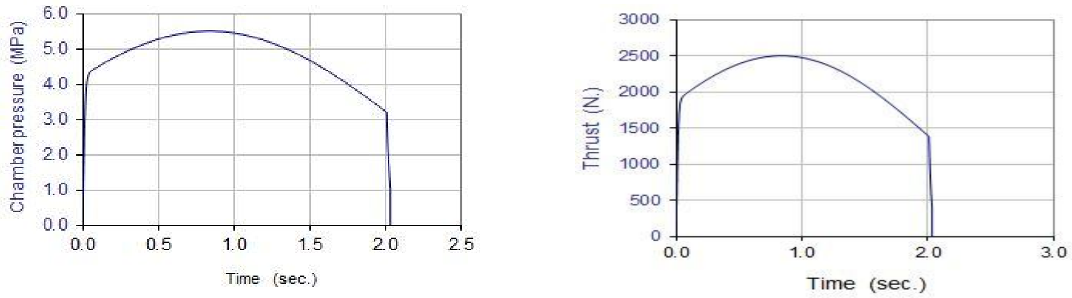

Figure 9: Graphs describing the variation of main motor chamber pressure and thrust with time.

Figure 9: Exhaust smoke during the static testing of main motor.

Static testing of the main motor was successful and resulted in a maximum thrust of 2498 N. Motor produced total impulse of 4365 N-sec with specific impulse of 130.6 sec, making it an L class rocket motor.

5. Conclusion

A solid rocket motor is successfully developed and can be utilized as propulsion unit in experiments. Motor parameters can be varied according the outputs required. The test results show that the Total Impulse and Specific Impulse generated by the motor are suitable for sounding rocket applications.

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