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Structural Design and Analysis of High-Powered Model Rockets using OpenRocket

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Abstract--- **Model rockets fall under the category of high-powered small rockets. Usually, a model rocket has a single stage or two stage separation. These high-powered model rockets can be used for educational purposes such as understanding and practically experimenting the concepts of external vehicle forces, rocket stability, aerodynamics, thrusting, and testing purposes, especially for rocket enthusiasts. Model rockets are inexpensive and mostly does not require any legal concerns for its launch. The model rocket designed in this study aimed to achieve an apogee of 2000m or more, with the total length less than 1m and weigh less than 750 grams. The software tool used for this is OpenRocket. The material for nose cone, the payload tube, transition, recovery or parachute tube, booster tube and fins were selected based on the density and weight constrains. The modelled rocket can carry a payload of 50 grams and a recovery system with canopy and shroud lines. This developed prototype rocket is powered with a solid motor which can support its ignition and thrusting. Finally, the study shows the apogee achieved, vertical velocity and the maximum acceleration achieved for the high-powered model rocket.**

Index Terms— **High powered rocket design, model rocket, apogee, model rocket stability, solid propellent**

I. INTRODUCTION

Model rockets are small, feasible and experimental rockets designed to reach low altitudes ranging from 1000 to 11,000 metres. In general, these rockets are built up of simple materials such as wood, PVC, carbon fibre, plastics and many other lightweight composite materials. Parts of the model rocket include nose cone, avionics bay or payload tube, recovery system, parachute tube, booster tube and fins. [1]

The design and shape of nose cone plays a crucial role in directing the air flow around the rocket. The design configurations of the nose cone vary depending on the application of the rocket such as commercial, high powered or interplanetary missions. It also affects the percentage of drag, weight, and thrust of the flight. [2] All the electronic components such as the circuits and other connections of the rocket are placed safely in the avionics bay. The body tube is the basic airframe of the rocket to which all other parts are attached. The recovery system consists of a parachute or streamer which will safely return the model. The recovery wadding prevents the hot gases from damaging the recovery system.[3] The fins provide stability and selection of the shape of the fins depend on the apogee to be reaches and other applications. Fins are present in the rear end of the rocket to support the flight by assisting with stability control and preventing the rocket to wobble The engine mount securely holds the rocket engine.[4]

The rocket is launched in a vertical launch guide using a static test pad, this ensures that the rocket is in an upright position until it has sufficient velocity for the fins to aerodynamically stabilize the flight. After clearing the launch guide the rocket attains free powered flight.[5] The motor accelerates the rocket in a vertical and aerodynamically stabilized way. The recovery system is released when the rocket is nearing the apogee, with the upward firing of a pyrotechnical ejection which pressurizes the model rocket and opens the recovery device.[6] In this work, the objective is to design a rocket which is capable of reaching an apogee of 2000 metres and weight less than 750 grams. This goal was achieved using an open-source modelling software called OpenRocket. The design along with the flight simulations of the maximum velocity and acceleration were performed with the assistance of this software tool.

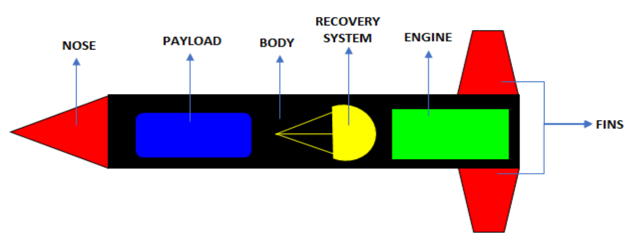

Figure 1: Graphical Representation of Structure of the Model Rockets [7]

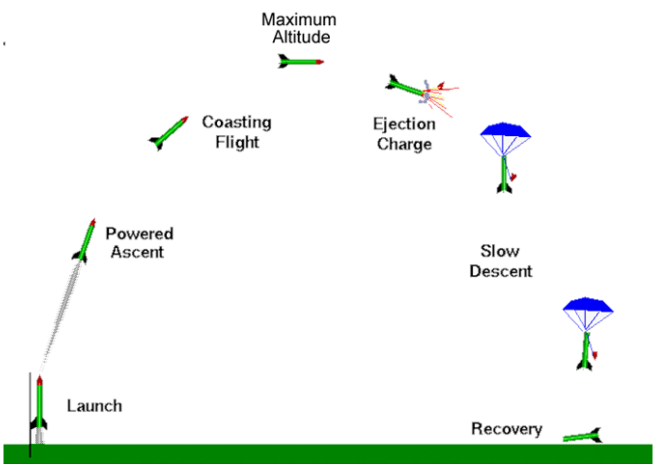

Figure 2: Flight Path of Model Rocket [8]

II. EXPERIMENTAL SETUP

The nose cone, body tube, recovery tube, booster tube, fins and the rocket motor were selected based on the constraints and the available materials. The constraints for the following experimental design of the model rocket involve, the overall mass of the rocket including the motor should be less than 750 grams, maximum apogee to be reached was targeted as 2000m, maximum acceleration of the rocket was to attain at least $100m/s^2$, maximum velocity greater than 250 m/s and finally the cost of fabrication & launch should be inexpensive.

There are 4 forces which act on model rockets. These are weight, thrust, drag and lift. Magnitude and the direction of these forces vary depending on the mass, direction of wind, rocket motor and flight path of the rocket. The rocket is subjected in a vertical direction, but there will be a slight tilt in the direction of flight path due to the direction of wind, this is known as "weather cocking". Due to weather cocking, the path of the flight will be inclined to a local vertical and horizontal. Hence, the path of the rocket is not truly vertical. [9]

Weather cocking is a major factor to be considered before launch of model rockets. But in case of commercial space launch rockets, this factor is negligible. It is because after a certain point in the density of air decrease causing no effects of wind on the rocket. For smaller rockets such as high-powered model rockets are launched, the wind-blown acts on the centre of pressure and make the rocket to tilt towards the direction of the wind during its thrust phase and drift slightly during the non-thrusting phase.

The flight path depends on the relative magnitude of the wind as well as the velocity of the rocket. The lift forces make the rocket spin about the centre of gravity (CG) and produce a new flight path with the wind. This aligns the rocket with the direction of flow of wind, hence there is no longer any lift force. If 'V' represents the velocity of rcoekt and 'W' represents the weight of the model rocket then the angle of tilt in due to weather cocking can be calculated as tan θ, where θ is the angle of inclination with respect to the horizontal direction. The anlge of tilt is given as: $\tan\theta = V/W$.

III. MATERIALS AND METHODS

Centre of gravity (CG) and centre of pressure (CP) plays a critical role with respect to calculating the stability. If the mass distribution of the rocket is uniform then the location of CG is exactly at the centre of the rocket which is the most desired for attaining a stable flight path. [10] The stability and balancing of the rocket can be rectified only depending on the position of the centre of gravity (CG) and centre of pressure (CP). These two factors decisively judge the stability of rocket.[11] The selection of the material and design of the parts of the rocket are given with justification as follows.

3.1 Nose Cone

"Haack Series" nose cone shape selected for the design to reduce the drag and produced. The length of the nose cone is 10cm with a base diameter of 5.5cm, wall thickness of 2mm. The material selected for the nose cone is "Blue Tube" which has a density of $1.3g/cm^3$. The mass of the nose with an estimated regular paint for the component as 60μm is 22.7g.

3.2 Body Tube

The material selected for body tube is Plywood birch with a density of $0.63g/cm^3$. The length of the body tube was desinged for 10cm, with outer diameter of 4.5cm, and inner diameter of 4.1cm. Payload section was occupied with 35mm or 3.5 cm with mass of 200g. Therefore, the total mass occupied by the body tube as well as the specified mass of payload accumulated to 217g.

3.3 Transition

The shape of the transition tube selected is conical. Conical shape for preferred due to better straightness. The transition length of 2.5cm, fore diameter larger diameter of 4.5cm and the after diameter narrower diameter as 3.5cm. The wall thickness considered for this transition was 0.2cm. The material selected was Plywood(birch) with density of $0.63g/cm^3$. The weight of the transition tube was 3.83g.

3.4 Recovery system

For the material of parachute Ripston Nylon of 63g/m3 was selected with elastic chords of 6 lines. Each elastic chodrs

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were 30cm long. The length of the parachute was 9cm and the diameter of the canopy was 70cm resulting to the overall mas of 29g.

3.5 Fins

A total of 3 fins were selected for this design to stabilize and balance the rocket. Trapezoidal fins were selected for its simplicity in fabrication and maintainence. The swept angle of each fin was 61.4˚, root chord of 5cm, tip chord of 5cm and height of the fin was 3cm. All three fins were attached 1cm from the booster tube.

Table 1. Parameters and design of fins

PARAMETERS	CONFIGURATION
Fin Type	Trapezoidal
Number of Fins	3
Height	3 cm
Root	5 cm
Swept Angle	61.8 degrees
Root Chord	5 cm

The mass distribution for each component, the length of each part in the model rocket, the density of the materials used and the preferred shape for the components is listed in the following image.

Nose cone	Blue tube (1.3 g/cm³)	Haack series	Len: 10 cm	Mass: 22.7 g
Body tube	Plywood (birch) (0.63 g/cm³)	Dia$_{in}$ 4.1 cm Dia$_{out}$ 4.5 cm	Len: 10 cm	Mass: 17 g
Unspecified		Dia$_{out}$ 3.5 cm		Mass: 200 g
Transition	Plywood (birch) (0.63 g/cm³)	Fore Dia: 4.5 cm Aft Dia: 3.5 cm	Len: 2.5 cm	Mass: 3.83 g
Body tube	Plywood (birch) (0.63 g/cm³)	Dia$_{in}$ 3.1 cm Dia$_{out}$ 3.5 cm	Len: 11 cm	Mass: 14.4 g
Parachute	Ripstop nylon (67 g/m²)	Dia$_{out}$ 70 cm	Len: 9 cm	Mass: 29 g
Shroud Lines	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)	Lines: 6	Len: 30 cm	
Shock cord	Elastic cord (round 2 mm, 1/16 in) (1.8 g/m)		Len: 40 cm	Mass: 0.72 g
Body tube	Plywood (birch) (0.63 g/cm³)	Dia$_{in}$ 3.1 cm Dia$_{out}$ 3.5 cm	Len: 17.5 cm	Mass: 22.9 g

Figure 3. Mass distribuition of each component of the model rocket

IV. RESULTS & DISCUSSION

The modelled rocket was tested for stability using the stability margin formula. The stability margin (SM) determines the stability of the rocket. Stability margin (SM) is where the distance between the centre of gravity and centre of pressure is divided by the diameter 'd' of the body of the rocket.[12] The general rule while designing a model rocket is that the stability margin should be greater than 1 but less than 2 can be simplified as (1 <SM< 2). The stability margin (SM) is given by the formula:

$$SM = \frac{CG - CP}{d}$$

After the testing of the stability, for performing the simulation, a specific rocket motor was chosen. The chosen rocket motor was AeroTech H55-W which has a diameter of 29mm and length of 191mm. This was fitted in the booster tube. This motor had the power to produce an

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impulse of 162.3Ns which helped in reaching an apogee of 2053m by estimating the average windspeed in locality of 4m/s. the following table 2, shows the specifications of the motor selected.

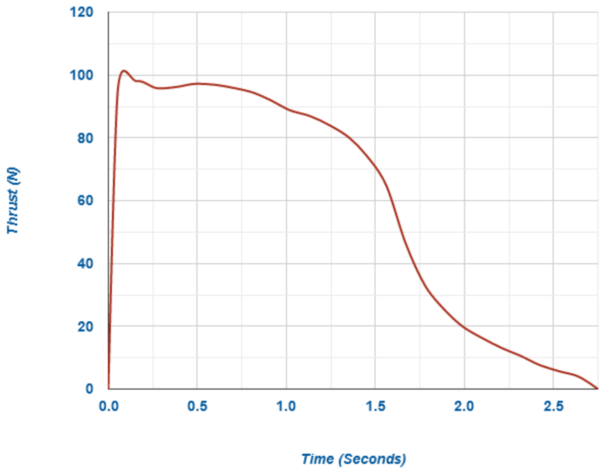

Figure 4. Time Thrust curve for AeroTech H55

Table 2. Motor Specifications

PARAMETERS	MODEL & CAPACITY
Manufacturer	AeroTech
Model	H55
Diameter	29 mm
Length	191 mm
Total Impulse	162.3 Ns
Maximum Thrust	113.3 N
Average Thrust	55.0 N
Propellent Weight	100 g
Propellent	White Lightning
Total mass	188 g

Rocket engines are two major kinds; liquid and solid rockets.The fuel and oxygen supply required for combustions is kept separately in a liquid rocket and injected into the burning chamber of the nozzle.
The fuel and oxidizer are mixed together in a solid rake and packed in a solid cylindrical propellant.
The propellant does not ignite under normal temperature circumstances but burns if exposed to an external heat source. Some kind of igniter is utilised at the end of the propellant facing the nozzle to fire a solid rocket engine.
The heat exhaust gas that propels this rocket and the "inflame front" that flows inside the fuel is created when the propellant burns. When the burning begins, all the propellant will be burnt.You can halt the thrust with a liquid missile by cutting off the fuel or oxidizer flow. However, you must destroy the casing with a solid rocket in order to stop the motor. The heavy and sophisticated liquid rockets tend to be due to pumps that transport the fuel and oxidizer, and generally you put the fuel and oxidizer into the racket shortly before starting. A solid missile is considerably easier to handle and may wait before launching for years.

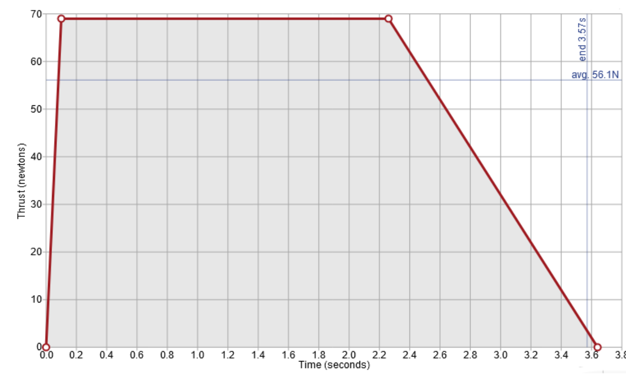

Figure 5. AeroTech H55 Motor Simulation graph

The following figure 4 depicts the modelled rocket in OpenRocket. It can be seen that the total length of the rocket is 55.5cm with maximum diameter of 4.5cm. The mass of the rocket with the AeroTech H55 motor is 450g.

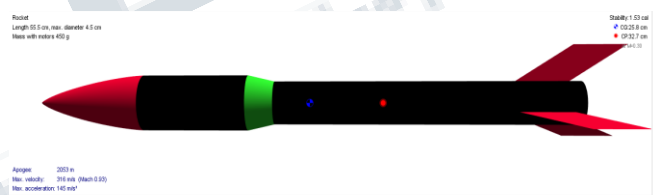

Figure 6: 3-d Model of high-powered rocket designed in OpenRocket Software

Figure 5 illustrates the half cut or the unfinished design of the model rocket. The length and mass of the rocket are designed withing the specified constrains. However, during the launch, the centre of gravity (CG) is dependent on the burn time. The centre of gravity (CG) will move upwards to the rocket due to the fuel and oxidizer placed I the rear end of the rocket.[13] The centre of pressure (CP) is dependent on the velocity of the rocket in the medium through which it flies, in this case air.

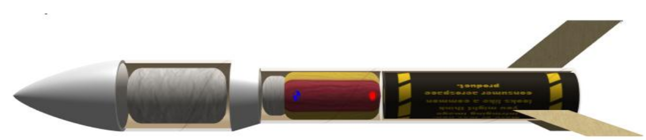

Figure 7: Unfinished view of the designed model rocket

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Figure 6 shows the results of simulation. With the simulation results it was confirmed that the modelled rocket could reach an apogee of 2031m, with vertical velocity 316m/s of and maximum acceleration as 145m/s^2. The time taken to reach the apogee was 17.4 seconds. The Mach number of this simulation was derived to be 0.93 which states clearly that the flight path is transonic as Mach<1. The graph in figure 7, illustrates the simulation of the vertical velocity (m/s) and vertical acceleration(m/s^2) with respect to the time in seconds.

Fig 6: Results of simulation of flight path

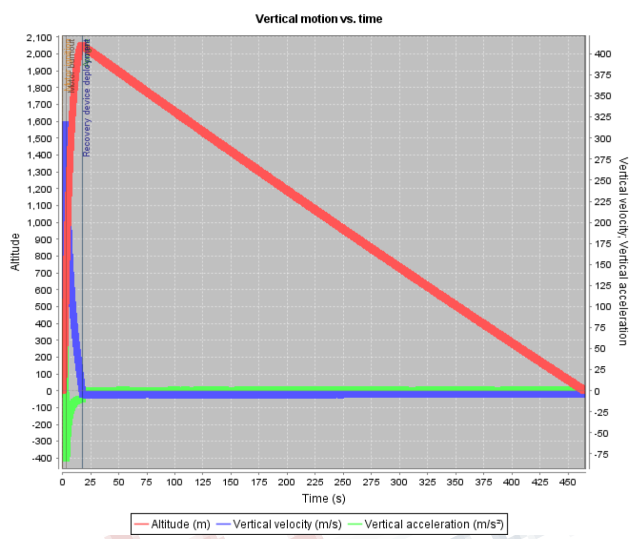

Fig 7. Simulation of maximum velocity, maximum acceleration and apogee

V. CONCLUSION

The designed high-power model rocket using OpenRocket software tool is capable of having an apogee of 2053 m, with vertical velocity 316 m/s of and maximum acceleration as 145 m/s2. Overall length of the rocket designed 55.5 cm, The total mass of the rocket including the motors is 450 grams, Acceleration achieved by the design rocket is 145m/s^2, Maximum velocity achieved by the design rocket is 316m/s. The apogee reached by the rocket with H55 AeroTech motor is 2053m, motion of rocket is transonic as it has a Mach number of 0.93. Model rocket with this apogee are legal to launch and easier for rocket enthusiast and students to learn the concepts of rocketry and flight paths better. Further enhancement of this study could be done by implementing the concepts of design in real time with the assistance of the avionics support system and detailed design of the recovery system.

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