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Design, Analysis and Simulation of a Single Stage Rocket (Launch Vehicle) Using RockSim

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This project describes the design, analysis, assembly and simulation of a single stage model rocket systems, one designed with traditional subsystems for structural, avionics, combustion chamber and recovery integrated to give a desired altitude. The analysis was based on using Rocksim 9.6 to model the different parts that made up a rocket. Aluminium was used for designing the nose cone, the fuselage and the fin set. The combustion chamber, clamps, and nozzle were designed by making use of steel. Because of the high temperature and pressure being generated from the combustion of propellant, steel was suggested. The main and drogue parachutes were designed using tubular Kevlar. And the bulk-head was designed using Basswood. For the recovering of the rocket after launch, main and drogue parachutes were incorporated into the fuselages.

Keywords: Rocket; aluminium; combustion chamber; nozzle; bulk-head; fuselage; parachute.

1. INTRODUCTION

Rockets are devices that contain all the elements necessary for propulsion within themselves. They are most useful for space travel and when high thrust rapid acceleration is required. Applications include boosting payloads to low-earth orbit, missiles, satellite station-keeping and orbit transfers, and interplanetary missions. Rockets are typified by the high velocity of the gas that is accelerated through a supersonic nozzle to generate thrust. They can be further classified according to the propellant state, the thrust level, and the type of engine cycle that is used [3]. A rocket design can be as simple as a cardboard tube filled with black powder, but to make an efficient, accurate rocket or missile involves design, simulation and construction of the different parts that made up a rocket. A rocket is made up of some major systems:

- The Structural System
- The Payload System
- The Control and Guidance System, and,
- The Propulsion System, etc. [1]

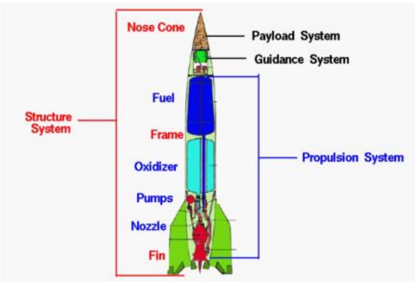

Figure 1: Major rocket systems [2].

The structural system, or frame, is similar to the fuselage of an airplane which is made up of the nose cone, fuselage (body tube) and the fins. The frame is made from very strong but light weight materials, like titanium or aluminium, and usually employs long "stringers" which run from the top to the bottom which are connected to "hoops" which run around the circumference. The nose cone is the tip of the rocket. It could be made of different shapes, conical, ogive, etc. This allows for minimum aerodynamic drag or resistance. The fuselage or frame of the rocket is usually in a vessel form. It serves as a support for the rocket. It houses the recovery system and the combustion chamber. The fins are also attached to the fuselage. Fins are attached to some rockets at the bottom of the frame to provide stability during the flight [2]. The payload system of a rocket depends on the rocket's mission. The earliest payloads on rockets were fireworks for celebrating holidays. Following World War II, many countries developed guided ballistic missiles armed with nuclear warheads for payloads. The same rockets were modified to launch satellites with a wide range of missions; communications, weather monitoring, spying, planetary exploration, and observatories, like the Hubble Space Telescope. Special rockets were developed to launch people into earth orbit and onto the surface of the Moon [2]. The guidance system of a rocket may include very sophisticated sensors, on-board computers, radars, and communication equipment to maneuver the rocket in flight. Many different methods have been developed to control rockets in flight. The V2 guidance system included small vanes in the exhaust of the nozzle to deflect the thrust from the engine. Modern rockets typically rotate the nozzle to maneuver the rocket. The guidance system must also provide some level of stability so that the rocket does not tumble in flight [2]. There are two main classes of propulsion systems, liquid rocket engines and solid rocket engines. The V2 used a liquid rocket engine consisting of fuel and oxidizer (propellant) tanks, pumps, a combustion chamber with nozzle, and the associated plumbing. The Space Shuttle, Delta II, and Titan III all use solid rocket strap-ons [2]. The various rocket parts described above have been grouped by function into structure, payload, guidance, and propulsion systems. There are other possible groupings. For the purpose of weight determination and flight performance, engineers often group the payload, structure, propulsion structure (nozzle, pumps, tanks, etc.), and guidance into a single empty weight parameter. The remaining propellant weight then becomes the only factor that changes with time when determining rocket performance [2].

1.1 Material selection criteria

In rocket designs, material selection for the components or structure of a launch vehicle is of paramount importance. In the selection of materials for the rocket, it is desirable to use a material that has high-to-weight ratio, good mechanical properties and ease of fabrication. Choice of material considerations:

- Strength (Tensile, Compressive, etc).
- Availability of material
- Affordability/cost effectiveness
- Ease of fabrication
- Corrosion resistance
- Fracture toughness
- Thermal expansivity and conductivity
- Melting point of material [1].

2. DESIGN PARAMETERS FOR A SINGLE STAGE ROCKET [1]

2.1 Rocket structure dimensions:

2.1.1 Nose cone

We chose Aluminium because of its properties and heritage.

Thickness of Aluminum sheet used: 0.1 cm

Diameter of rocket = 30.2 cm

Total length of rocket = 384 cm

Fineness Ratio i.e. ratio of height to diameter of the rocket: L/D = 12.7

Front diameter of nose cone = 2 cm

Rear diameter of nose cone = 29.8 cm

Length of nose cone = 45 cm

2.1.2 Nose cone extension

We chose Alumnium because of its properties and heritage.

Thickness of Aluminum sheet used: 0.1 cm

Outer diameter = 29.8 cm

Inner diameter = 29.6 cm

Length = 20 cm

Location: 45 cm

2.1.3 Payload

We chose steel because of its properties and heritage.

Outer diameter = 6 cm

Inner diameter = 5.5 cm

Length = 20 cm

Location: 7.72 cm

2.1.4 Body tube 1

We chose Aluminium because of its properties and heritage.

Thickness of Aluminum sheet used: 0.1 cm

Outer diameter = 30.2 cm

Inner diameter = 30 cm

Length = 100 cm

2.1.5 Bulkhead (ring component)

We chose Basswood because of its properties and heritage.

Thickness: 1 cm

Outer diameter = 30 cm

Inner diameter = 0 cm

2.1.6 Electronics (Avionics) Bay

We chose Aluminium because of its properties and heritage.

Thickness: 0.1 cm

Outer diameter = 29.8 cm

Inner diameter = 29.6 cm

Location = 0.0

2.1.7 Electronics (Avionics) Bay stirp

We chose Aluminium because of its properties and heritage.

Thickness: 0.1 cm

Outer diameter = 30.2 cm

Inner diameter = 30 cm

2.1.8 Main Parachute

Material = ¼ in. tubular Kevlar

Thickness = 0.2 cm

Shape = round

Chute count = 1

Spill hole diameter = 18.8 cm

Drag coefficient = 0.75

Location = 23.10 cm

Shroud line material = ¼ in. tubular Kevlar

Shroud line length = 682 cm

Descent rate = 12.5678 m/s

Calculated descent rate mass = 70.9814428 kg

2.1.9 Body tube 2

We chose Alumnium because of its properties and heritage.

Thickness of Aluminum sheet used: 0.1 cm

Outer diameter = 30.2 cm

Inner diameter = 30 cm

Length = 180 cm

2.1.10 Fin sets

Fin count and shape = 4

Root chord length = 50 cm

Tip chord length = 25 cm

Sweep length = 24.162 cm

Sweep angle = 32.659 degrees

Semi span = 37.5 cm

Location = 130 cm

Thickness = 0.33 cm

Cross section = square

2.1.11 Combustion chamber

We chose steel because of its properties and heritage.

Outer diameter = 27 cm

Inner diameter = 26.079 cm

Location = 70 cm

2.1.12 Clamp 1

We chose steel because of its properties and heritage.

Outer diameter = 28.14 cm

Inner diameter = 27 cm

Location = 106 cm

2.1.13 Clamp 2

Outer diameter = 28.14 cm

Inner diameter = 27 cm

Location = 0.0 cm

2.1.14 Clamp 3

Outer diameter = 28.14 cm

Inner diameter = 27 cm

Location = 59.82 cm

2.1.15 Drogue Parachute

Shape = round

Outer diameter = 250 cm

Material = ¼ in. tubular Kevlar

Thickness = 0.33 cm

Spill hole diameter = 0.0 cm

Drag coefficient = 0.75

Location = 23.10 cm

Shroud line material = ¼ in. tubular Kevlar

Shroud line length = 455 cm

Shroud line count = 8

Descent rate = 17.5005 m/s

Calculated descent rate mass = 70.9814428 kg

2.1.16 Nozzle convergent

We chose steel because of its properties and heritage.

Thickness = 0.5 cm

Front diameter = 27 cm

Rear diameter = 8 cm

Length = 10 cm

2.1.17 Nozzle throat

Thickness = 0.5 cm

Outer diameter = 27 cm

Inner diameter = 8 cm

Length = 4 cm

2.1.18 Nozzle Divergent

Thickness = 0.5 cm

Front diameter = 8.2 cm

Rear diameter = 13 cm

Length = 15 cm

3. RESULTS AND DISCUSSIONS

Figure 2 below shows the Rocksim window for the design of the different parts that made up a single rocket as specified above, from the input parameters.

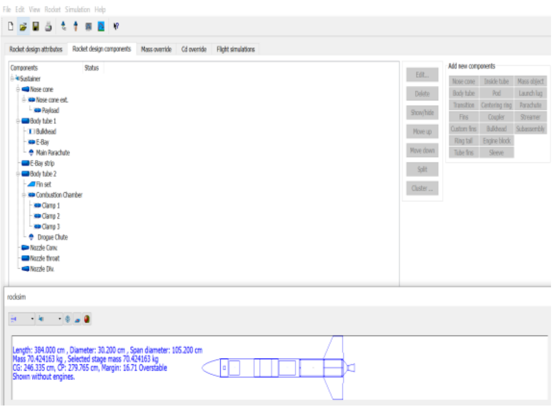

Figure 2: Rocksim window showing the different components of the rocket [4].

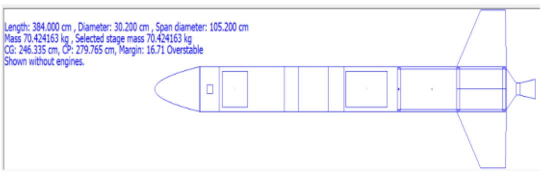

Figure 3: Exploded view of the rocket [4].

Figure 3 shows the designed rocket having a length of 384 cm, outer dimeter of 30.2 cm, and span diameter of 15.2 cm.

Figure 4 shows the designed rocket when the engine is loaded. The beauty of this propellant is the fact that it is an indigenous fuel designed, characterized, and produced at Centre for Space Transport and Propulsion, Epe, Lagos (CSTP) which is one of the Activities Centres of National Space Research and Development Agency, Abuja, Nigeria. As can be seen from Figure 4, the rocket has centres of gravity and pressure to be 275.635cm and 279.765 cm respectively, an indication that the rocket is stable. Also, the rocket has a positive margin of 2.06; which is a very aspect for the rocket to be stable during flight [4].

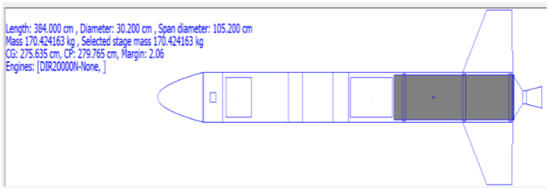

Figure 4: Loaded rocket engine [4].

The fuel is a solid propellant which has been tested and validated by team of scientists and engineers at CSTP. The advantages of having this engine added into the default software setting are that the propellant characterization, composition, and performance has been verified and validated through several static tests, unlike other engines in the default software which are like black-boxes and also, they are not readily available for the end users [5].

The 2-D profile of the rocket with engine at lift – off can be seen in Figure 5.

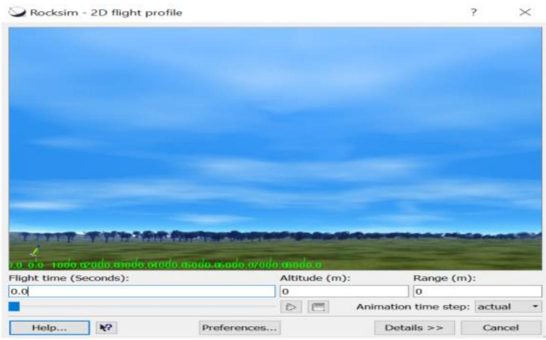

Figure 5: 2-D flight profile [4].

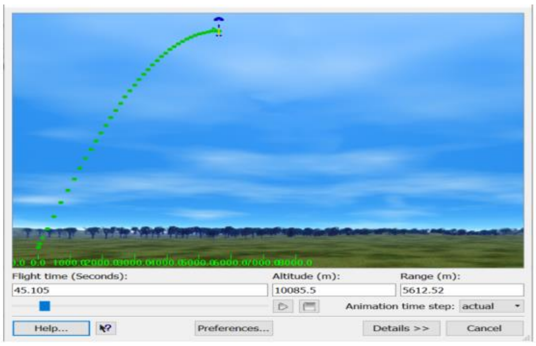

Figure 6: Rocket trajectory [4].

Figure 6 shows the rocket trajectory as it gets to apogee. As designed, the rocket would be recovered by both the main and drogue parachutes as specified in the input parameters. Also indicated is the time of flight which is 45.105 seconds, the maximum altitude attained which is 10,0085.5 m and range which is 5612.52 m.

The thrust versus time graph as indicated in Figure 7 to determine the maximum thrust generated by the propellent and the burn out time. As can be seen, the propellant generated about 20704 N and the propellant was exhausted after about 3 seconds.

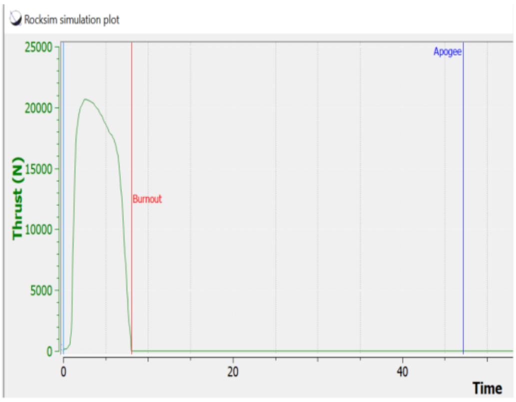

Figure 7: Thrust – time profile [4].

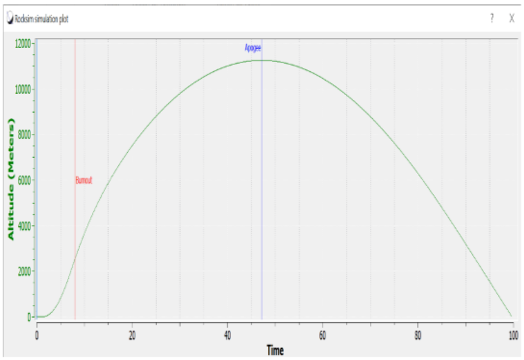

Figure 8: Altitude– time profile [4].

Figure 8 shows the maximum altitude the rocket attained and the time to achieve the height. The rocket gets to apogee at about 10,123.34 meters and at 44.0181 seconds.

As shown in Figure 9, the range that the rocket covered at altitude of 10,123.34 meters is 5611.7714 meters.

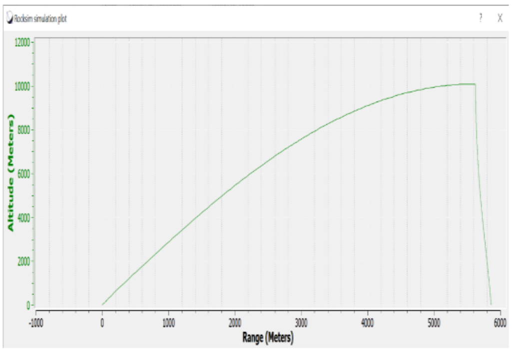

Figure 9: Altitude – range profile [4].

Figure 10 indicates the velocity rocket gained at every given time. The maximum velocity attained by the rocket is 632.1586 m/secs at 7.5251 seconds.

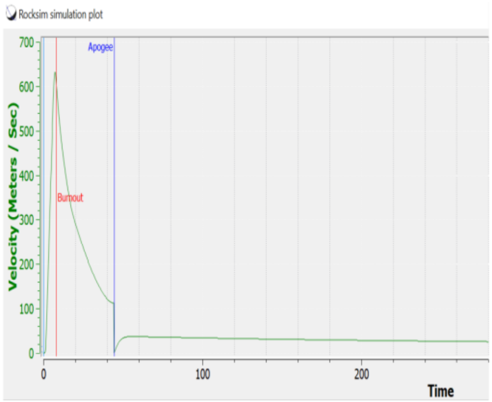

Figure 10: Velocity – time profile [4].

The acceleration versus time is shown in Figure 11. The maximum acceleration attained by the rocket is 135.37 m/s^2 at 3.3445 seconds.

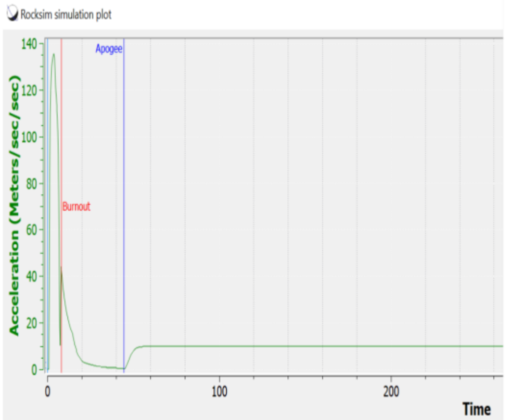

Figure 11: Acceleration – time profile [4].

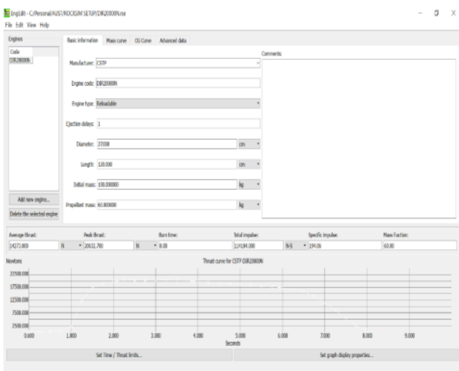

Figure 12: Basic propellant information [4].

Figure 12 shows the basic propellant information which includes the diameter, length, mass, average and peak thrust, burn time, total and specific impulses. The specific impulse achieved by the CSTP engine is 194.06 seconds [4].

4. CONCLUSION

The conclusion from this project are:

- It indicates the importance of material selection in designing the different components of a typical rocket.
- The material selected should be based on past experiences (heritage).
- Simple process in specifying the rocket components and ways to input them into the software.

5. REFERENCES

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