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Design and analysis of sounding rocket

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Abstract

This document includes method for designing sounding rocket.This article includes analytical method of designing rocket.A sounding rocket, sometimes called a research rocket, is an instrument-carrying rocket designed to take measurements and perform scientific experiments during itssub-orbital flight The rockets are used to carry instruments from 48 to 145 km above the surface of the Earth,the altitude generally between weather balloons and satellites; the maximum altitude for balloons is about 40 km and the minimum for satellites is approximately 121 km. Our rocket altitude is about 3000 feet (3 Km). Sounding rockets often use solid state rocket motors. Avionics are the electronic systems used in rockets, aircraft,artificial satellites, andspacecraft.Our avionics system is used for sounding rocket tracking and recovering it successfully.

I. INTRODUCTION

Sounding rockets have been used for scientific research since the late 1950s and were originally implemented in meteorological and upper atmosphere studies.These rockets, or research rockets, are data-collecting spacecraft carrying scientific instruments to conduct experiments during sub-orbital flight. They are typically used to test and calibrate satellite and spacecraft instrumentation, and fly for less than 30 minutes. Efficient and cheap, sounding rockets are of small size enough to launch from temporary sites, and their experiments can be developed in about six months.

Sounding rocket has a single or two-stage solid-fuel propulsion system, the service systems (rate control, telemetry module, recovery system and the scientific payload (the section that carries the instruments to conduct experiments). They are sub-orbital carriers, which means that they do not go into orbit around Earth. The rockets follow a parabolic trajectory from launch to landing, which, for the case of the rockets used by European Space Agency, provide a low gravity environment of between six and thirteen minutes.

The sounding rocket is divided into two parts: the scientific payload, which carries the instruments for experimentation and data collection, and the rocket motor, which propels the rocket into space and separates from the payload after launch. Data collected by sounding rockets are transferred to researchers on the ground during the flight via telemetry, which is similar to how a radio system works. The payload remains in space for five to twenty minutes to conduct the experiment, and then returns to Earth under a parachute and is collected for future application.

These rockets produce microgravity conditions for longer periods than airplanes, or drop towers, and tubes. An experiment is placed in the rocket, which is launched and then allowed to free-fall back to Earth surface.Sounding rocket follows a parabolic arc, like the aircraft, but goes above the Earth's atmosphere, where drag does not disturb microgravity conditions. The typical flight profile of a sounding rocket is the following: subsequent to a launch and as the rocket motor uses up its propellants it separates from the vehicle; the payload continues into space after separation from the motor(s) and begins conducting the experiments; when the experiments are completed, the payload re-enters the atmosphere and a parachute is deployed, bringing the payload gently back to Earth; the payload is then

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retrieved (by retrieving the payload a considerable saving can be achieved because the payload or parts of the payload and experiments can be refurbished and flown again).

The project work includes ;

1. To study the basic basics of the designing of the rocket.
2. To study the various materials and perform the analysis for them.
3. To analyse composite structures with their behaviour under the stress
4. Developing the onboard electronics system for the rocket

II. DESIGNING OF ROCKET

Reducing the number of parts and making the assembly easier and simple was one of the primary goals. Various innovative thoughts were brainstormed for individual subsystems of the rocket. The major subsystems were designed and an outside-in design methodology has opted. The subsystems are reducing the number of parts and making the assembly easier and simple was one of the primary goals. Various innovative thoughts were brainstormed for individual subsystems of the rocket. The major subsystems were designed and an outside-in design methodology has opted. The subsystems are listed below :

1) Propulsion system
2) Aero-structure system
3) Recovery system
4) Payload system
5) Avionics bay

A. Propulsion System

Motor **:**

The motor is the main unit of the propulsion system. The rocket can be powered by either solid, liquid or hybrid propellant as per IREC guidelines. Owing to the following factors, we chose to use a commercially available solid motor.

1) Student-researched and developed motors involve copious amounts of research,
2) testing and safety measures. We had a limited set of resources and experience.
3) Availability of materials of the right type in the Indian market.
4) COTS Solid propellants seemed the most appropriate option given our situation.

Criteria for motor selection :

1) Total Impulse required for flight trajectory (10k feet apogee)
2) Minimum Thrust to Weight ratio of 5
3) Physical dimensions of the casing
4) Cost of Casing Hardware and reload Experimental Sounding Rocket Association 3
5) Availability of reload

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Total mass of the rocket at lift-off is 27 kg. And we opted to go with the dead payload for this with 3U volume, due to this, the diameter of the Body tubes increased substantially leading to high drag.

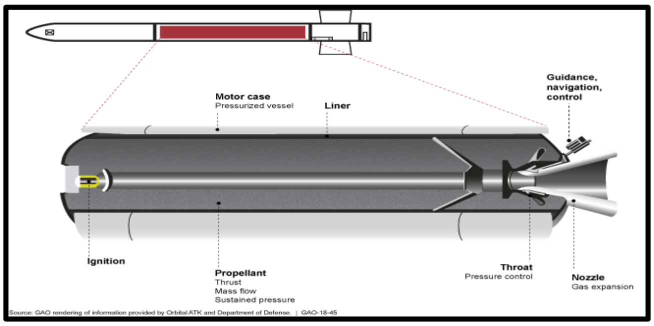

Figure 1. Motor design

Prop. Weight:	4711 g
Average Thrust:	2500.0 N
Maximum Thrust:	3710.9 N
Total impulse:	9671.0 Ns
Burn Time:	3.9 S
Isp:	209 s
Case Info:	RMS-98/10240
Propellant Info	Blue Thunder

Iterations for selecting Motor :

Motor Name	Thrust (N)	Apogee (m)	Velocity (Mach)	Weight (N)	Stability (C)
L1390G-P	1390	1316	0.4	163	1.7
L1500T-P	1390	1316	0.50	183	2.42
L2200G-18	2200	1860	0.65	207	2.37
M1305M-P	1305	2458	0.71	230	1.96
M1500R-P	1550	1972	0.65	216	2.34
M1845-P	1845	3025	0.8	227	2.01
M2000-R	2000	3275	0.88	226	2.01

M2500 T-P	2500	3461	0.96	240	2.38

Table No.2

***B. Structure* :**

The rocket structure is comprised of the following components:

- Nose Tip
- Nose Cone
- Payload and Avionics bay Tube
- Main chute body tube
- Motor Retention System
- Bulkheads
- Fins

General aerodynamic properties:

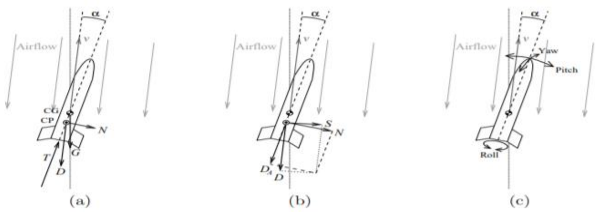

Figure 3.1: (a) Forces acting on a rocket in free flight: gravity G, motor thrust T, drag D and normal force N. (b) Perpendicular component pairs of the total aerodynamical force: normal force N and axial drag D_A; side force S and drag D. (c) The pitch, yaw and roll directions of a model rocket.

Figure 2. General Aerodynamic Properties

The aerodynamic forces acting on a rocket are usually split into components.The two most important aerodynamic force components of interest in a typical model rocket are the normal force and drag. The aerodynamic normal force is the force component that generates the corrective moment around the CG and provides stabilization of the rocket. The drag of a rocket is defined as the force component parallel to the velocity of the rocket. This is the aerodynamic force that opposes the movement of the rocket through the air. Figure 2 shows the thrust, gravity, normal force and drag of a rocket in free flight. It should be noted that if the rocket is flying at an angle of attack $\alpha > 0$, then the normal force and drag are not perpendicular. In order to have independent force components, it is necessary to define component pairs that are always perpendicular to one another. Two such pairs are the normal force and axial drag, or side force and drag. The two pairs coincide if the angle of attack is zero. The component pair that will be used as a basis for the flight simulations is the normal force and axial drag.

Aerodynamic force coefficients :

When studying rocket configurations, the absolute force values are often difficult to interpret, since many factors affect them. In order to get a value better suited for comparison, the forces are normalized by the current dynamic pressure q = 1 2 ρv2 0 and some characteristic area Aref to get a nondimensional force coefficient.The moments are normalized by the dynamic pressure, characteristic area and characteristic length d.

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Velocity region :

Most of the aerodynamic properties of rockets vary with the speed of the rocket. The important parameter is the Mach number, which is the freestream velocity of the rocket divided by the local speed of sound M = v0 c .The velocity range encountered by rockets is divided into regions with different impacts on the aerodynamic properties.

In subsonic flight all of the airflow around the rocket occurs below the velocity of sound. This is the case for approximately M less than 0.8. At very low Mach numbers air can be effectively treated as an incompressible fluid, but already above $M \approx 0.3$ some compressibility issues may have to be considered. In transonic flight some of the air flowing around the rocket accelerates above the speed of sound, while at other places it is subsonic.

Drag Forces:

Air flowing around a solid body causes drag, which resists the movement of the object relative to the air. Drag forces arise from two basic mechanisms, the air pressure distribution around the rocket and skin friction. The pressure distribution is further divided into body pressure drag (including shock waves generated as supersonic speeds), parasitic pressure drag due to protrusions such as launch lugs and base drag. Additional sources of drag include interference between the fins and body and vortices generated at fin tips when flying at an angle of attack. The different drag sources are depicted. Each drag source will be analyzed separately; the interference drag and fin-tip vortices will be ignored as small compared to the other sources.

The frontal area of rocket is 0.0172 m^2 and velocity is 303 m/s

Drag force = $\frac{1}{2} * \rho * A * V^2 * C_d$

$= \frac{1}{2} * 1.005 * 0.0172 * 0.65 * 303^2$

= 515 N

G force calculations :

$$G_f = 1 + \frac{Ac}{g}$$

$$= 1 + \frac{101}{9.81}$$

$$= 11.2956 \text{ G}$$

Mass and moment of inertia calculations :

Converting the forces and moments into linear and angular acceleration requires knowledge of the rocket's mass and moments of inertia. The mass of a component can be easily calculated from its volume and density. Due to the highly symmetrical nature of rockets, the rocket centerline is commonly a principal axis for the moments of inertia. Furthermore, the moments of inertia around the y- and z-axes are very close to one another. Therefore as a simplification only two moments of inertia are calculated, the longitudinal and rotational moment of inertia. These can be easily calculated for each component using standard formulae and combined to yield the moments of the entire rocket.

This is a good way of calculating the mass, CG and inertia of a rocket during the design phase. However, actual rocket components often have a slightly different density or additional sources of mass such as glue attached to them. These cannot be effectively modeled by the simulator, since it would be extremely tedious to define all these properties. Instead, some properties of the components can be overridden to utilize measured values.

Mass of the rocket :

$$I_{zz} = 1/2 * m * r^2$$

$= 1/2 * (23.5)(0.078)^2$
$=0.01748\ kg.m^2$

$$I_{xx} = I_{yy} = 1/2 * m * (3r^2 + h^2)$$

$=1/2 * (23.5)(3(75 * 10^3) + (222 * 10)^2)$
$= 58.1062\ kg - m^2$

Weight Distribution:

Name of Part	Weight (grams)
Body tube and bulkheads	9018
Fin set	480
Avionics bey	1200
Payload	6200
Parachute assembly	2015
Mounts	1000
Bolts,Washers,Nuts,Heli coil	950

Table No. 3

Black powder calculations :

$$T = 3307\ R$$
$$F = 700\ lbf$$
$$R = 266\ in.lbf/lbf$$
$$D = 5.90\ in$$
$$L = 7.872\ in$$
$$A = \frac{\pi}{4} * D^2$$

$= \frac{\pi}{4} * 5.92^2$
$= 27.33\ in^2$

$$V = 215.166\ in^3$$
$$PV = mRT$$
$$m = PV / RT$$

$$m = \frac{700 * 215.16}{3307 * 266}$$

= 0.001715 $slug$

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$$m \ = 3.5359 \ grams \ of \ black \ powder$$

Roll rate calculations :

$$a \ = \ 1/2 * \rho * A * V^2 * C_d * sin(\alpha)$$

$= 1/2 * 1.005 * 0.0172 * 303^2 * 0.65 * sin(6)$

$= 54.14 \ m/sec^2$

$$a \ = \ \omega^2 * r$$
$$54.14 = \omega^2 * 0.078$$
$$\omega = 0.5024 \ deg/sec$$

Deflection of bulkhead under the motor forces :

$$\varrho = flexural \ rigidity$$
$$E = 70 * 10^3 \ N/mm^2$$
$$\upsilon = 0.333$$
$$\varrho = Et^3/12(1-\upsilon^2)$$
$$\varrho = \frac{E * t}{12(1-\upsilon^2)}$$

$= \frac{70*10^3*5^3}{12(1-0.333^2)}$

$\mathbf{=0.818 \ Kn - m}$

$$W = \frac{p * r^4}{64 * D}$$

$= \frac{0.25*78^2}{64*818237.35}$

= 0.0322 $\boldsymbol{mm}$

C. Recovery System :

The first parachute (Drogue chute) is deployed at the apogee of 10k feet with the help of ejection charge.As the rocket descends, a secondary ejection charge is fired (at an altitude of 1500 feet.) a full-size parachute is ejected, bringing the rocket down to a much lower descent rate that will not damage the rocket upon hitting the ground. The purpose is that the rocket falls fast for most of the descent and doesn't drift very far. It is also called "close proximity" recovery.

The specifications of the Drogue chute and main chute is given in the following table :

Drogue chute	
Diameter	36 inches
Drag Coefficient	2.2
Shape	Toroidal

ISSN: 2233-7857 IJFGCN

Decent Rate	19.09 m/s
Manufacturer	Fruity Chutes

Table No.4

Main chute	
Diameter	84inches
Drag coefficient	2.2
Shape	Toroidal
Decent rate	6.23 m/s
Manufacturer	Fruity Chutes

Table No. 5

D. Avionics :

The purpose of the rocket avionics is to control parachute deployment while collecting rocket flight data and live vehicle tracking system. The rocket avionics system consists of two flight computers (Stratologger CF and a custom built flight computer). The Custom flight computer serves as a backup altimeter that measures the rocket's altitude during launch and stores in the ground station computer board and will fire a redundant igniter for the recovery charge after the Stratologger CF is programmed to.

This data can be collected after rocket recovery where the Stratologger flight computer is connected to the ground station computer via a PC Connect Data Transfer Kit. The Stratologger CF flight computer handles primary parachute deployment as well as determining the rocket state variables and flight status.

Rocket State Variables:

- Maximum Altitude
- Velocity
- Altitude
- Acceleration
- On Pad
- Thrust
- Apogee
- Descent velocity
- Drogue parachute Deployment
- Main parachute Deployment

E. Prototyping & testing and avionics:

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International Journal of Future Generation Communication and Networking
Vol. 13, No. 2s, (2020), pp. 920–932

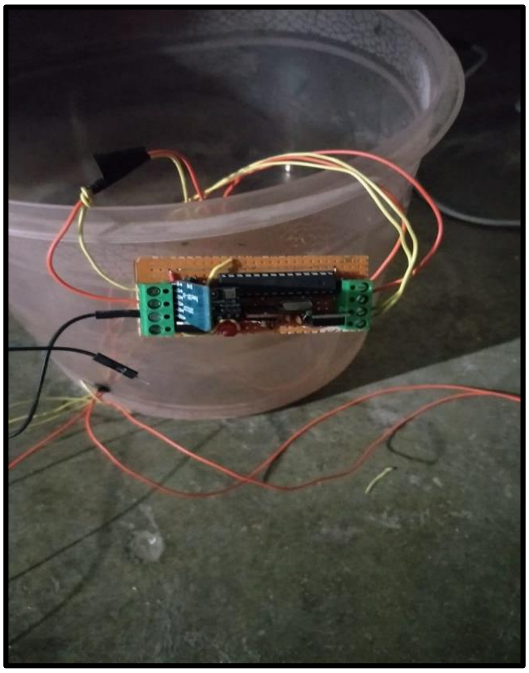

Figure 3.Altimeter testing

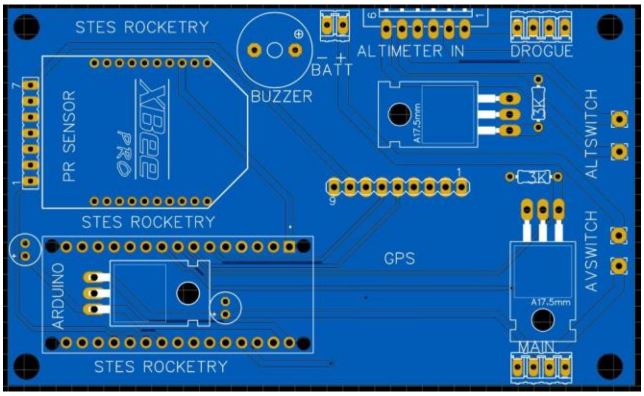

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Figure 4.Schematics and PCB designs

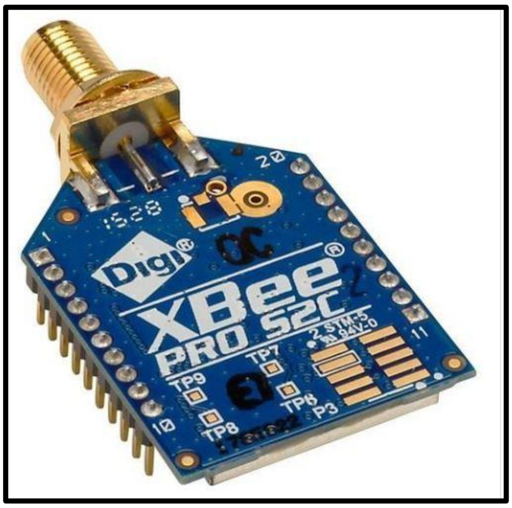

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Figure 5.Xbee Pro

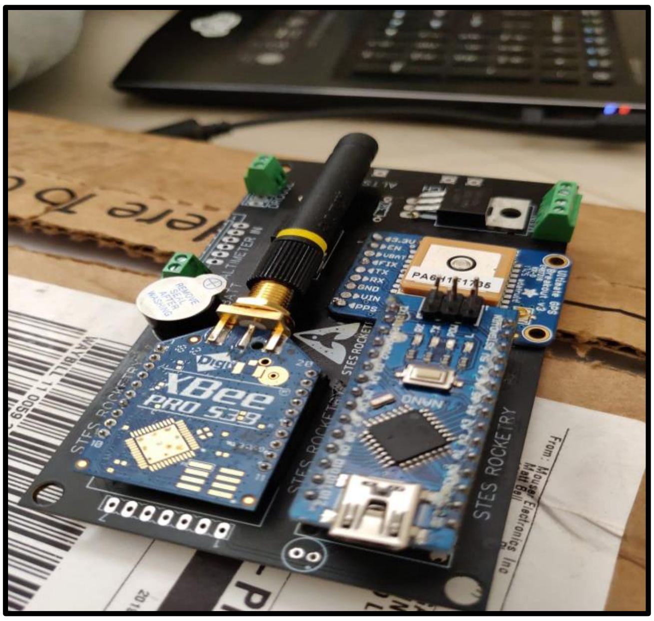

Figure 6.Final PCB Assembly

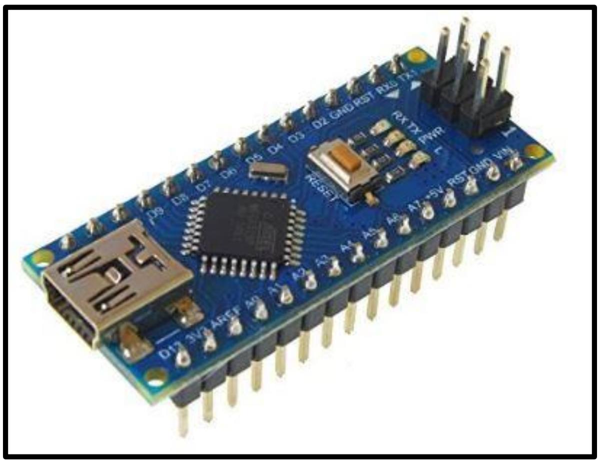

Figure 7. Arduino Nano microcontroller

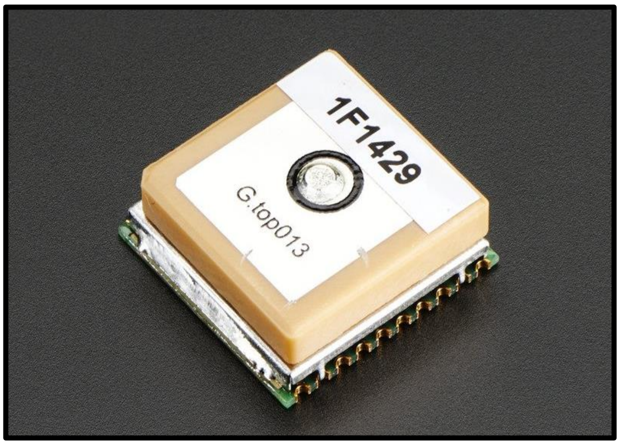

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Figure 8. GPS Module

F . Analysis:

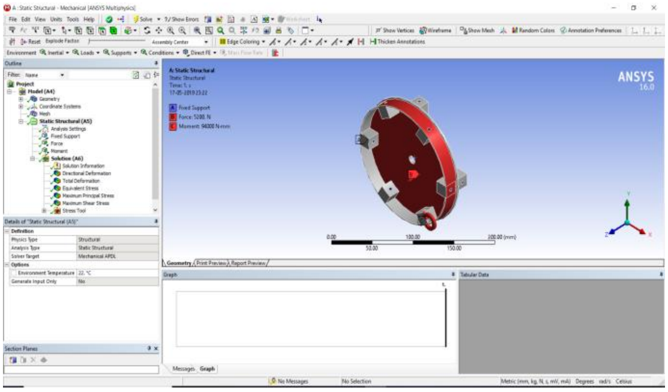

Figure 9.Forces acting on bulkhead

The bulkhead shown in the fig is used in parachute ejection chember. The impact force due to opening of the parachute is totally exerted on this bulkhead through the eye bolt. The impact force calculations are done analytically , by using calculations the diameter of bolt obtained is 10 mm. with FOS of 2.5.

The impact forces are passed to the bulkhead and carbon fiber tube through the eye bolt. In the first figure , bulkhead is applied to all boundary constaintants. Fixed supports are given at bolted connections and force of 5200 N is applied to at on the total surface.The thermal boundary conditions are neglected because strength of material used i.e AL 2048 is not vary much at temperature attained.

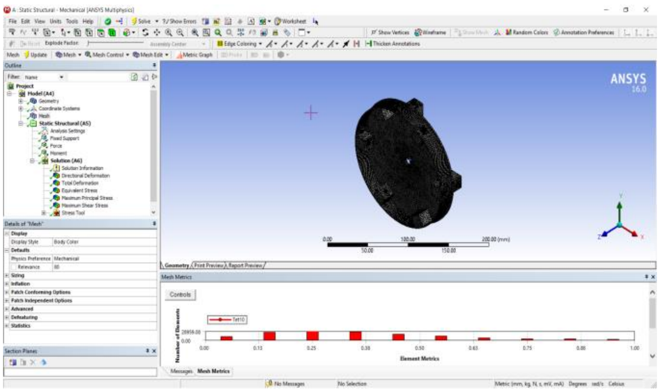

Figure 10. Meshing Of Bulkhead material

The meshing is done on the bulkhead with relevance of 80
after meshing is improved by using PH formulation.

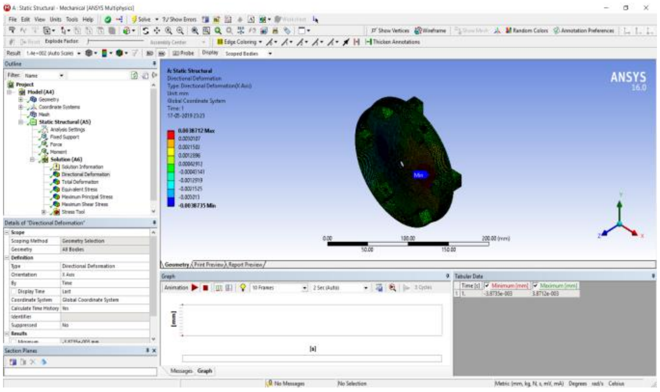

Figure 11. Directional Deformation(X Axis)

After applying boundary conditions and meshing von mises stress , total stress and total deformation as well as axial deformations are found.The figure above is showing the total deformation , According to analysis conducted the minimum and maximum deformation conducted at time is -0.0038775 mm and +0.0038712 mm resp. at fos of 2.5. This deformation is below the allowable deformation.So it is concluded that bulkhead can withstand this deformation.

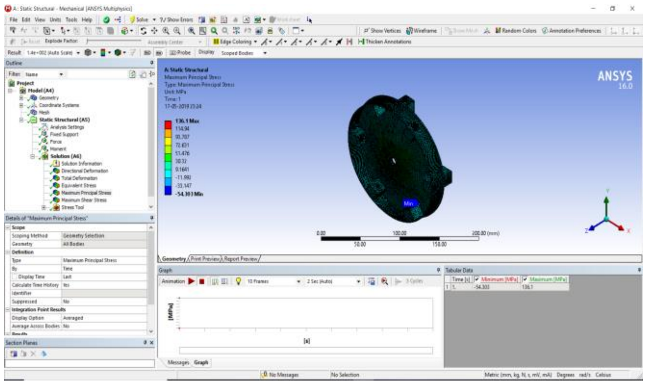

Figure 12.Maximum Principal stress

The von mises stress is also found out at the same time on the same boundary conditions. The minimum and maximum von mises obtained are 0.013545 Mpa and 133.99 Mpa resp. at fos 2.5 . These values obtained are below the working and ultimate stress of the material. So it is concluded that bulkhead will withstand these forces without fail.

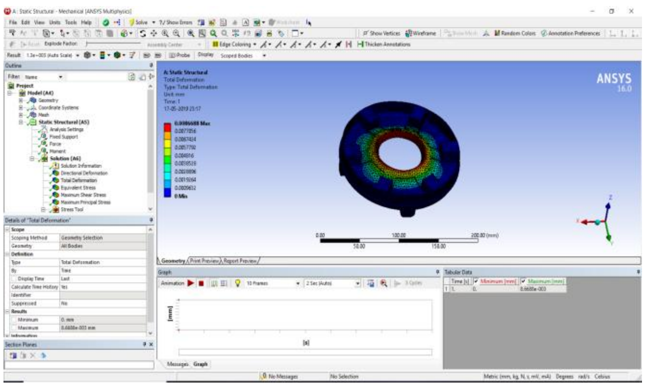

Figure 13.Total Deformation

The bulkhead shown above is the thrust bulkhead used to retain the motor to original position. It is only subjected to the thrust force of the motor which is 3711 N maximum. So the boundary condition is only force in an upward direction. Fixed supports are given at bolted connections . PH formulations are used for refining the mesh. The von mises stress found is 42.254 Mpa maximum and -11.771 Mpa minimum. The total deformation obtained is 0.008666 mm maximum. Both values are below the allowable values of material. From the result it is concluded that design of bulkhead is safe.

Conclusion

After reading the reports we understand the maximum forces on the rocket body are taken by bulkheads.The design of bulkhead should be such that it should have maximum purpose connecting body tubes,taking forces sustaining impact load during parachute opening and thrust of motor. material selection for the body tubes and bulkhead should be lightweight and strong sufficient.hence we decided to use carbon fiber material for body tubes and aluminium 6061 T6 material for bulkheads.Profile selection for the nose cone is based on slenderness ratio is selected between 2 and 4 for transonic speed rocket.the nose cone tip should be made up of material with high heat dissipation rate to dissipate heat generated due to rocket body and air friction.hence we decided to use aluminium 6061 for the nose cone tip.stability is measured in caliber.In case of rocket stability is distance between the center of gravity and center of pressure. After reading the reports we understand that stability of the rocket should be in between 1 to 3 to get stable flight performance. The number of fins and fin surface are two major factors while deciding the stability margin of the rocket.The weight distribution of the rocket should be such that the center of pressure lies below the center of gravity. All of the above parameters give stable flight performance.

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