ABSTRACT

1.Landing is one of the most maneuvering occurring in aircraft. Landing gear is considered as a nonlinear structure due to its complicate behavior. During landing period large amount of impact forces are transferred into nose gear and main landing gear. The main objective of this project is to present design of Spacecraft landing leg using CATIA V5 software to study the behavior of landing leg as per actual working condition. Static loads are applied over the landing leg assembly and impact forces are determined.

2.This mini project presents the methodology to design the landing system for spacecraft landing legs for soft landing on the Moon surface. The landing leg preliminary design is based on the requirements of the stability distance and ground clearance.

3.Results show that the honeycomb absorber has a more effective energy absorption than the metal bellow absorber. The landing system with honeycomb absorber has a smaller sizing as well. However, reusability of the honeycomb absorber is not possible. The structural mass of the landing system is estimated based on the required design parameters and design requirements from the landing analysis. .

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SYMBOLS

C_d – Coefficient of Drag

ρ - Lunar atmospheric density ≈ 1.2 kg/m^3

A - Exposed base area = 2.3 × 2.5 m^2

m - Dry mass of the lander in kg

g - Acceleration due to gravity on the Moon = 1.64 m/s^2

h - Height in m

θ - Inclination of the lander legs

v - Relative entry velocity in m/s

P_p - Pressure exerted by piston in Pa

P_1 - Pressure exerted by the hydraulic fluid in Pa

d_1 - Piston diameter in m = 0.015m

d_2 - Piston rod diameter in m = 0.01m

a - Piston area in m^2

β - Ballistic coefficient in kg/m^3

CHAPTER 1

INTRODUCTION

Making humans multi-planetary species has become an ultimate goal to human race. To meet this goal, landing is done by carrying large number of scientific, cargo and manned landers on moon.

In the past lunar missions, several landers had already landed successfully on the surface. Missions such as Apollo program made several attempts on both hard impact landings and soft landings since 1950's. The experiences of these landings from these missions had contributed much to current knowledge of the moon and also the successful design of the different landers. The landing gear preliminary design is based on the requirements of the stability distance and ground clearance.

A lander is a spacecraft which descends toward and come to rest on the surface of an astronomical body. A lander makes a soft landing after which the probe remains functional. Landing may be accomplished by controlled descent and set down on landing gear, with the possible additional of post landing attachment mechanism for celestial bodies with low gravity.

The landing legs are designed to dampen the initial impact to avoid bouncing.
Landing on moon is tricky. A lander headed to the moon can go as fast as 24,816 miles(39937kilometers) per hour. To land smoothly, these spacecraft need to slow down before touching the surface.

Another important parameter to be taken care of is the structure of lander legs. The materials used to construct the lander legs should have high strength to weight ratio so that possibility of failure of the lander legs is minimized with the increase in stability of the structure without increasing the weight of the aircraft.

The structural mass of the landing system is estimated based on the required design parameters and design requirements from the landing analysis. Aluminum alloy and carbon fiber reinforced plastic are both assessed. Carbon fiber reinforced plastic has much weight saving compared to aluminum alloy due to its high strength to weight ratio.

LANDING CHALLENGES

For a successful landing of lander, the mission has to address several challenges arising due to thickness of Lunar atmosphere, low elevation, short EDL period and surface hazards which include the distribution of large seized rocks, craters, terrains and devil dust storms. Especially, legged landers have rock hazards as their largest challenge and the EDL time (5-8 minutes) is not sufficient to perform all the entry, descent and landing phase accurately. Past landers used Aluminum honeycomb, foam plastic, air bags and crushable carbon fibers for impact attenuation. These attenuators will limit the landing mass to 0.6 ton. In future manned lander missions, it is necessary to land large cargoes, habitat and rockets. In landing large masses, several factors are taken into consideration. . Factors such as diameter of aero-shell, parachute and ballistic coefficient are limited.

CHAPTER 2

LITERATURE REVIEW

To understand the landing dynamics of a lander on the moon, it is important to find out more about the past missions to the moon as well as other landers which had made it successfully to other planets.

The landing design process and stability analysis of space lander is well documented by Yuanyuan Liu[1] presented the overall design and performance prediction of spacecraft intended to accomplish soft landing on the moon, due to uncertainties of the landing site and flight states of the vehicle at touchdown, the landing stability is systematically studied in this article by employing the techniques of computer experiments.

Landing robotic spacecraft and humans on the surface of moon has become one of the inevitable technological necessity for humans. Soviet landers made use of foam plastic as their primary shock absorber. Inspite of using efficient shock absorbers, some landers fail to perform touchdown phase , these technological challengers are described by Malaya Kumar Biswal[2].

A discussion has been done on the mechanical design and working by Ramesh Naidu[3], which includes past and present lander machines, crashed landers report, landing challenges and scientific background.

Any two objects that have mass attract each other with a force we call gravity. This discussion on gravity, force exerted and escape to space is described by G. Jeffrey Taylor, Linda[4]

In 1966, lunar-9 became the first spacecraft to achieve soft landing on the surface of the moon , following shortly by surveyor-1 [5] which demonstrated our technology in soft landing a spacecraft on the celestial surface. Further successful soft landing by surveyor programme finally led to the Apollo-11 mission which landed the first human on the moon in 1969

A lander headed to the moon can go as fast as 39937 kilometers per hour.to land smoothly, these spacecraft need to slow down before touching the surface. How Chandrayaan-2 will reduce speed for soft landing is discussed by NASA[6].

The landing planning strategy are to anticipate the lunar environmental problems and to plan the landing approach so that the combined spacecraft systems, will most effectively improve the probability of attaining a safe landing. This problems are studied by Dipl.-ing Lars witte[7].

A landing gear arrangement for a spacecraft that includes pural landing legs connected to and extending from a spacecraft body. These arrangements of landing gear is studied by Robert Buchwald[8].

Oblique and uneven terrains can severely limit the degree of landing safety, especially when the lander is carrying passengers, so mission adaptive landing gear is designed and analyzed for its function of automatic adjustment before touchdown. This mission adaptive landers are studied by Mingyang Huang[9].

One of the important goals of Space missions is to lower the mass and improve efficient volume for reduced launch costs. The concepts of habitats for lunar outpost missions are discussed by W. Keith belvin.[10]

OBJECTIVES

- To design and analyze the landing legs of space landers to withstand the force exerted due to impact load while landing on the surface of moon, which enable soft-landing thereby increasing the probability of success in forthcoming landing missions.

- To select and incorporate materials with high strength to weight ratio for the construction of landing legs of lander.

CHAPTER 4

METHODOLOGY

- **LEVEL 1: THE KNOWLEDGE AND PREQUISITE**

At this stage, acquiring maximum knowledge in the field selected is of utmost importance. Studying about the past lunar landing missions performed and cause of failure which helps in selecting the parameters to be considered. Various research papers and articles have to be studied in order to gauge the parameters for consideration. The structure and working of the lander components have to understood to design and analyze the lander. Parameters such as density of the Lunar surface and Drag coefficient on the Moon have to be assumed for calculation.

- ## LEVEL 2 : DETERMINATION OF FORCES ACTING ON SPACECRAFT

The impact load on the lander legs at the time of landing have to be calculated in order to evaluate the ability of the primary and secondary legs to withstand this load. This is accomplished by resolving the resultant force into its components on each lander leg. The Principle of Conservation of Energy have to applied in order to calculate the Impact force. Subsequently, the force absorbed by the spring system and hydraulic system in the lander leg has to be calculated using suitable equation. Finally the Euler's critical load has to be calculated to test for failure of the lander legs with different materials.

- ## LEVEL 3 : MISSION EXERCISE

Design the landing legs of spacecraft using CATIA-V5 software.

- ## LEVEL 4 : MATERIAL SELECTION

Suitable material has to be selected for the landing legs and shock absorber and also the properties when static stress is induced have to be compared. Different materials are selected for the spring system, piston and piston rod and are tested for failure. Materials with high Modulus of Elasticity and low mass density are preferred. Some of the choices are Titanium, Carbon fiber etc.

- ## LEVEL 5: PERFORMANCE EVALUATION

Conducting the various analyses of the landing legs by applying suitable boundary conditions and obtaining the required results using the software ANSYS.

- **LEVEL 6 : COMPARISON TECHNIQUES**

Comparison of the parameters on the landing legs for different materials

CHAPTER 5

PLAN OF WORK

- The preliminary design of the lander legs, the structure and design parameter of spacecraft should be known.
- For the structure and design requirement of spacecraft, several assumptions are to be taken based on the mission requirement, like gravity effects, mass, density, drag coefficient, base area of spacecraft, ground clearance, etc.
- Atmospheric changes with respect to the Moon have to be considered.
- Then calculating the coefficient of drag and relative entry velocity associated with Moon's atmosphere.
- Calculations of total force exerted by the surface of Moon on the lander at the time of hitting the ground. This force creates large impact load on all the four landing legs. It is assumed that all four landing legs share same amount of impact load.
- To reduce this impact, the type of crushable absorbers, landing gears, struts and number of legs are considered.
- After the considerations, the parameters of lander legs which should not affect the engine exhaust are calculated.
- Selecting the materials having high strength at the same time with low weight.
- Then designing the legs of the spacecraft landers in the software.
- Analyzing the lander legs by giving input of impact load and materials in the software.

CHAPTER 6

WORK CARRIED OUT

Literature review has been done through studying various documents, reports on previous lunar landing missions.

6.1 CALCULATIONS

CALCULATION OF IMPACT VELOCITY AND IMPACT FORCE

- The concept of free fall will be applied here. The propellant's that provide thrust in the reverse direction are assumed to turned off when the lander is at a height of h=4m from the Mons's surface to avoid the propellant's affecting the lander legs.
- Hence we can consider that the lander is in the state of free fall when it falls from a height of 4m .
- The mass of the lander is taken to be m=1471kg (with reference to Vikram lander of Chandrayan 2).
- Using the equation of motion the impact velocity can be calculated as,

$$V=\sqrt{2gh}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

- Where g is the acceleration due to gravity of the moon,
  g=1.62m/s^2 (approximately 1/6th of the earth).
- Impact velocity v = $\sqrt{2 \times 162 \times 4}$ = 3.6m/s
- The impact force is calculated by applying the principle of conservation of energy. The kinetic energy of the lander at the instant it lands on the moon's surface is converted into displacement work that makes the lander legs get displaced to small depth on the moon's surface.
- For practical calculation the displacement is assumed to be 0.1m because the surface is considered to be elastic and impact force is calculated assuming flat surface only.
- Hence, from the principle of conservation of energy.
- Instantaneous kinetic energy of the lander at the instant it lands on the moon's surface = displacement work done by the lander legs --------------------(2)
- The Kinetic energy is given by,

$$K=\frac{1}{2}mv^2\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

  Where m = mass of the lander=1471kg
  v = impact velocity = 3.6m/s

$$K = \frac{1}{2} \times 1471 \times 3.6^2 = 9832j$$

- The displacement work,

$$W = F\times d\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

  Where, F is the force of impact to be calculated.

d is the displacement of the lander legs = 0.1m

W= F × 0.1

- From equation (2),

W=K

$$F_{imp} \times 0.1 = 9532$$

$$F_{imp} = \frac{9532}{0.1} = 95320N$$

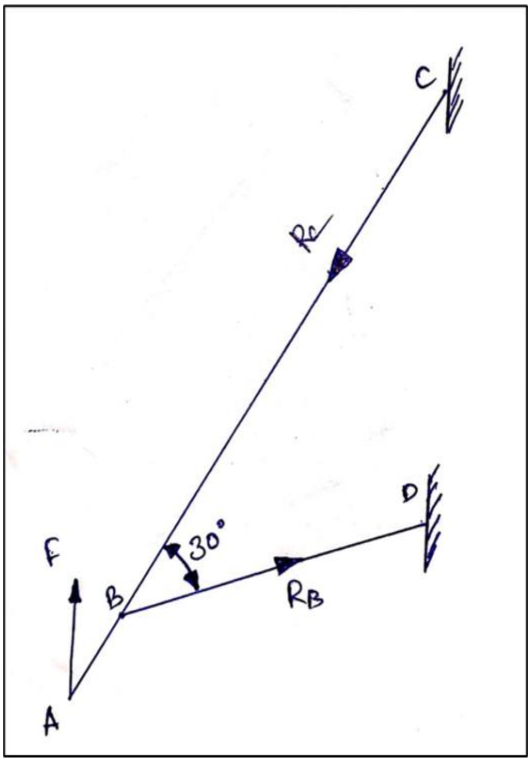
$$F_{imp} = 95.32N$$

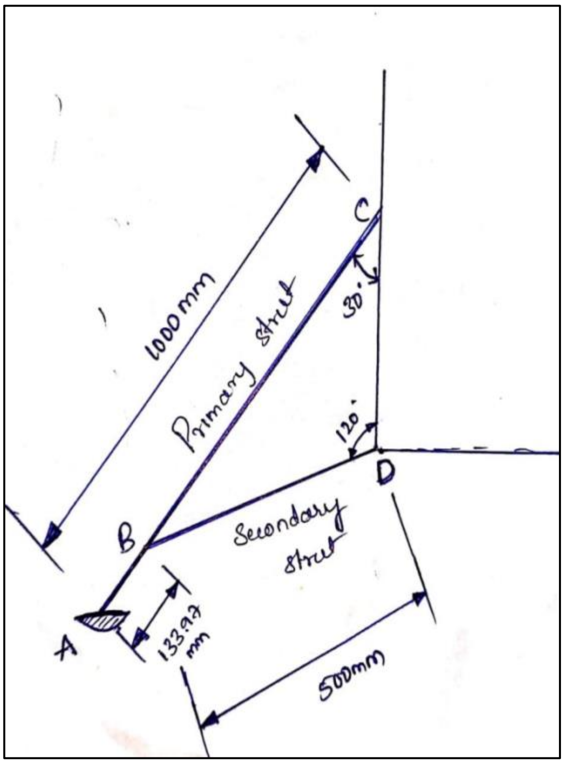
- This is the force of impact on the lander leg during landing.

- If we assume that this force is shared equally by all the four legs, then forces of the impact on each lander legs will be, $F = \frac{F_{imp}}{4}$

$F_{imp} = 95.32kN$ / 4 =23.83kN

Calculation of reactions using free body diagram





- Various reaction are developed when force is applied at point A. The directions of the forces are assumed. If the force is estimated to be '-ve' then the direction will be opposite to what we considered.
- The geometry required for taking moments we shown below,

L=AC=1000mm

L'=BC=1000-133.97=866.03mm

$$AE=L\times \sin 30=1000\times \frac{1}{2} = 500mm$$

$$DF=BD\times \sin 30=500\times \frac{1}{2}=250mm$$

$$CD' = L'\times \sin 30=866.03\times \frac{1}{2} = 433.02mm$$

Taking moment about 'C'

$$\sum \boldsymbol{M_c} = 0$$

$$- F \times AE + \boldsymbol{R_B} \times CD1 = 0$$

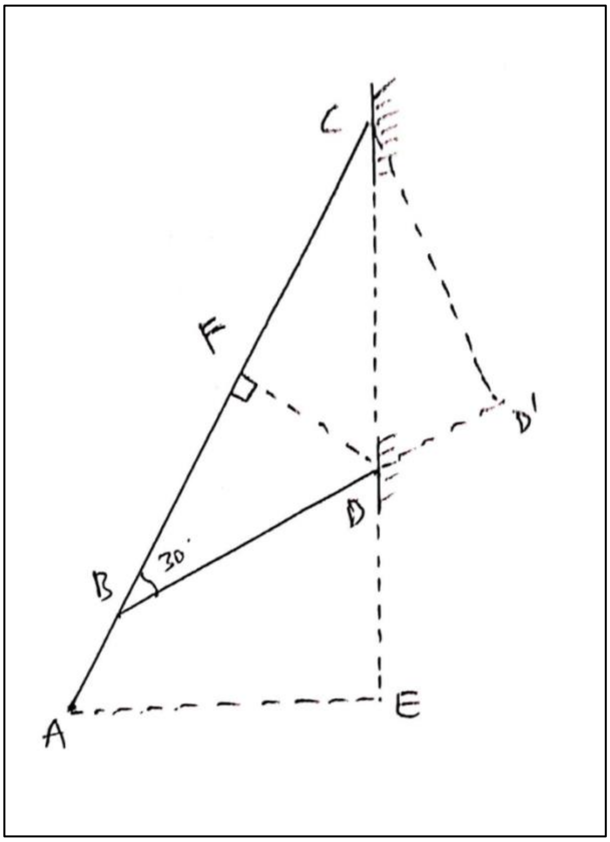
$$\boldsymbol{R_B = \frac{F \times AE}{CD1} = \frac{23.83 \times 500}{433.02} = 21.03kN}$$

Taking moment about point 'D'

$$\boldsymbol{\sum M_D = 0}$$

$$-F \times AE + R_C \times DF = 0$$

$$R_C = \frac{F \times AE}{DF} = \frac{23.83 \times 500}{250} = 47.66kN$$



STIFFNESS OF SPRING

- Type of spring = smosc-v

- Spring index = 6
- Spring constant or stiffness = $\frac{\pi d^4 N}{32R^3L(1-0.2sin^2\alpha)}$

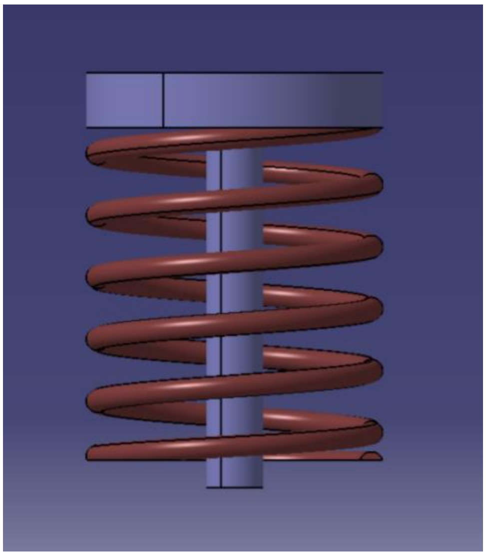
  Where, R – mean radius of the coil = 12mm

  L – length of the spring = 59.5mm

  N – modulus of rigidity = 79.6GPa

  D – diameter of wire or rod = 4mm

  Therefore the stiffness or spring constant of the spring is calculated by substituting above values = 200N/mm.



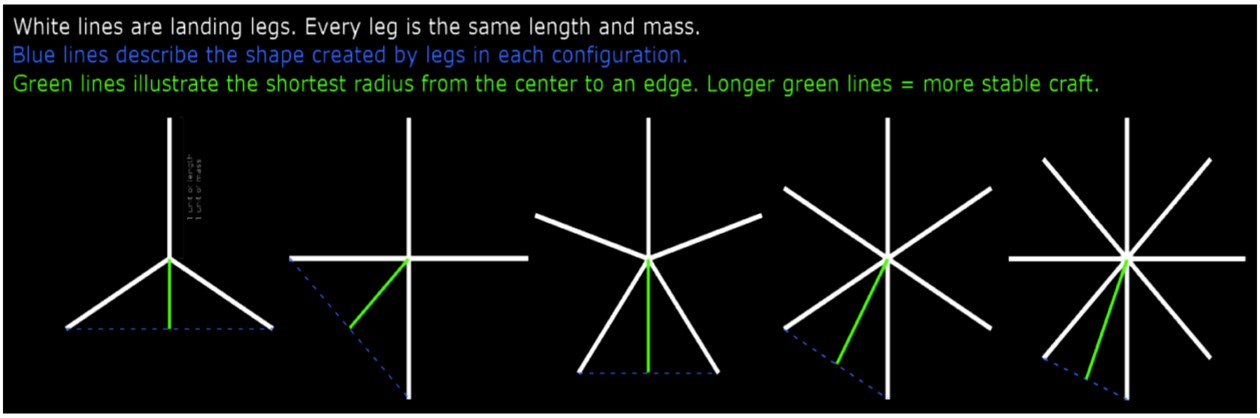
DESIGN AND DEVELOPMENT

- In order to model and simulate the landing system, design parameters are identified to size the landing gear.

- The design chosen to define the four-legged cantilever landing gear system and will determine the structural and mass sizing of the landing gear initial design.
- The cantilever design has the secondary struts connected to the lower end of the primary strut upper section and to the main body structure.
- Both the lower section of the primary strut and the secondary struts have energy absorber elements incorporated within the internal cylinder of the struts.

WHY ARE FOUR LANDING LEGS SELECTED?

- Five fixed legs was the main option considered at first, however this was not thought to have a wide enough foot print for reliable landings.
- Three legs were probably not robust enough, they do not appear to have been considered seriously for any length of time.
- Eventually selection for final design of four widely-splayed legs, which were stored folded.

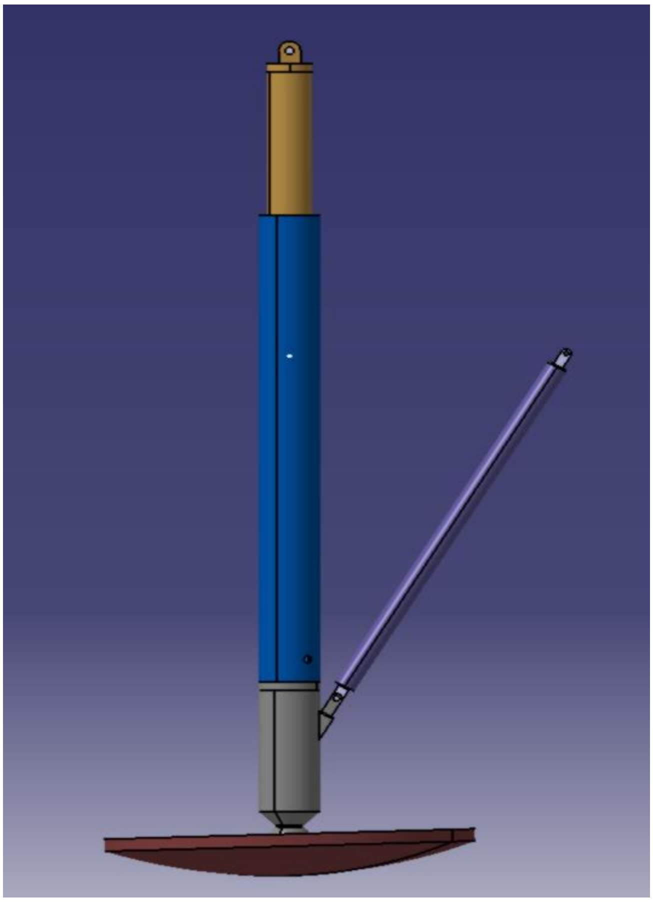


LANDING LEG

- The joints connecting the body structure and both primary and secondary struts are pivoted on ball joints for landing flexibility.

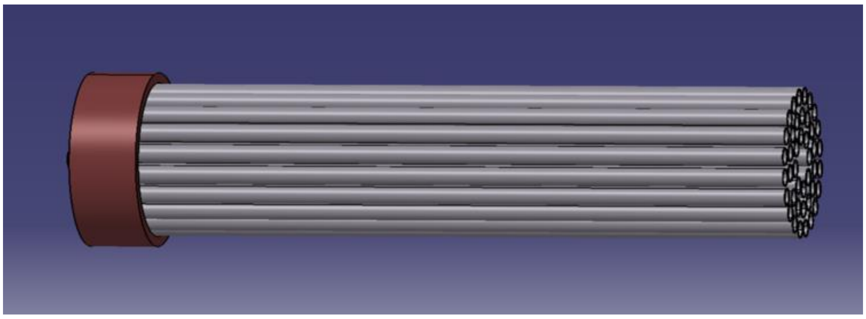
- The primary strut is subjected mainly to bending moment because of the secondary strut and compressive loading from the energy absorber element in the primary strut.

- The footpad supports the mass of the lander against the lunar regolith. Large footpad surface area would prevent deep penetration of the ground as compared to smaller footpad surface area. The shape of the footpad also affect the friction force acting on the footpad.



HONEYCOMB STRUCTURE

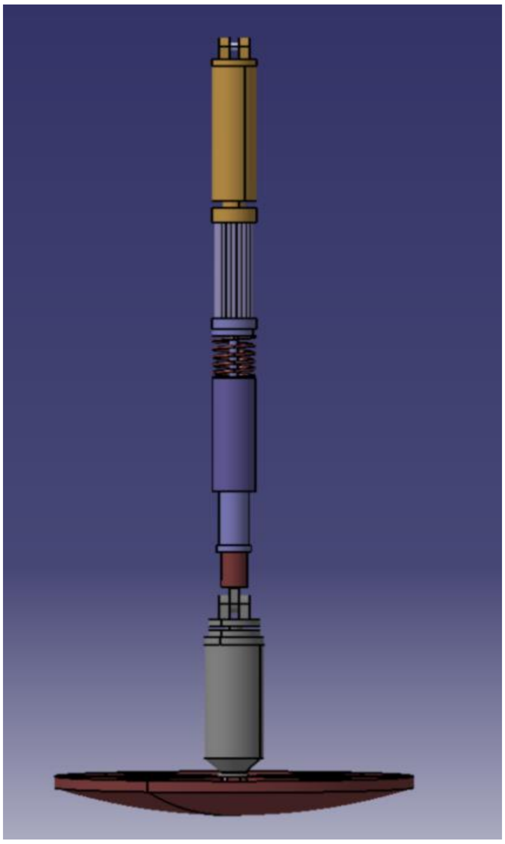
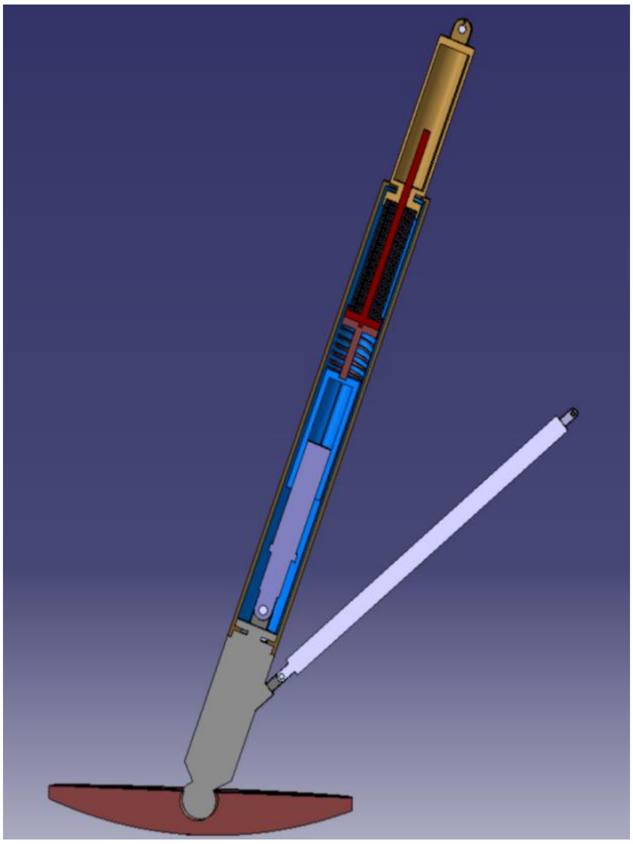
- The energy absorber elements are located in the upper section of the primary strut and in the secondary strut.
- The function of the energy absorber element is to absorb energy by stroking and it depends on the load stroke curve of the shock absorber.
- The energy absorption of the crushable element is based on the designed crushing force and the stroke of the crushed length. Therefore the Length of Aluminum honeycomb structure is taken as 150mm as it absorb the maximum energy.



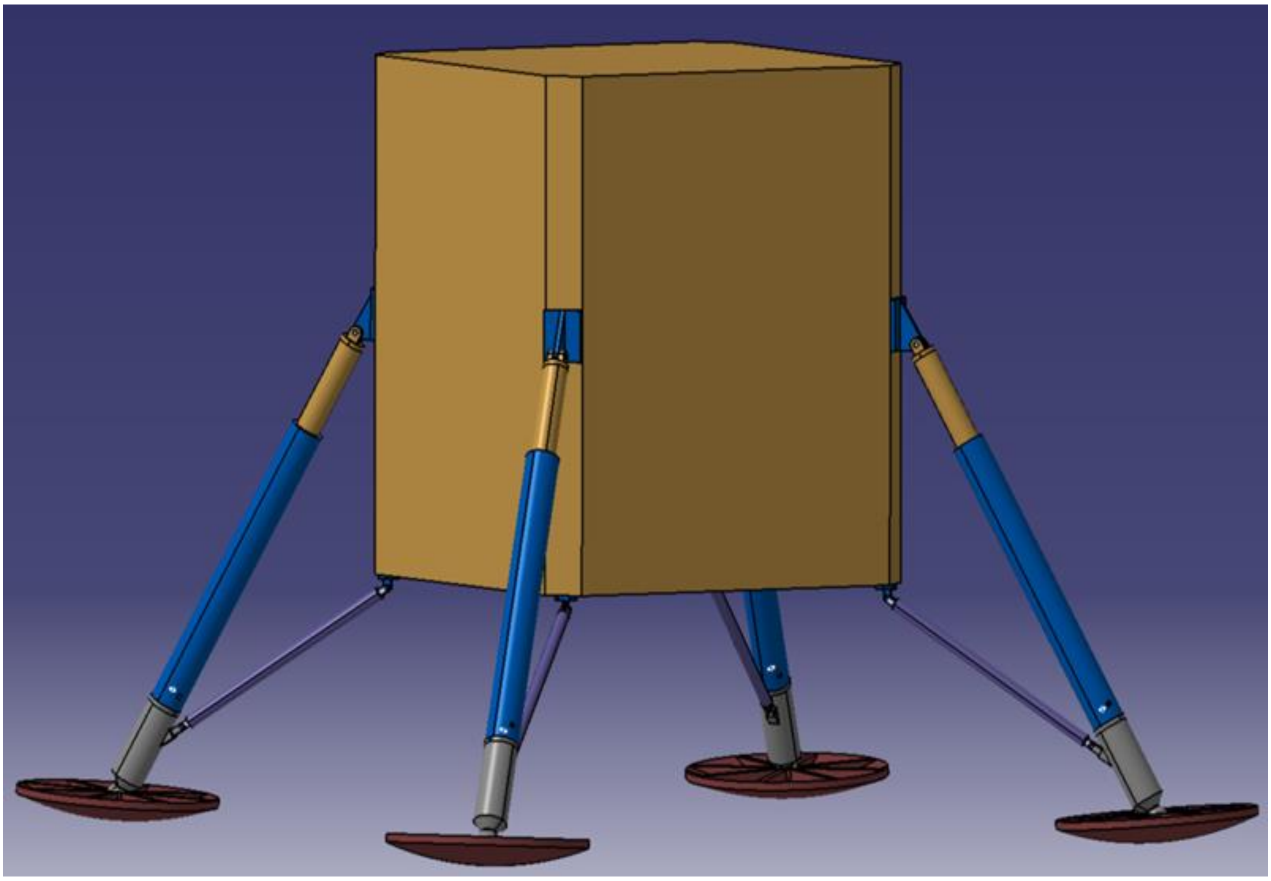
SECONDARY STRUT

- The secondary struts provide lateral resistance to the primary strut and resist the spread of the primary struts during landing.
- Length of the secondary strut is approximately 0.5m to absorb the impact and reduce the impact energy on lander and the body is fully rigid.
- The secondary strut is mainly loaded only in the axial direction.

Final design of landing legs.

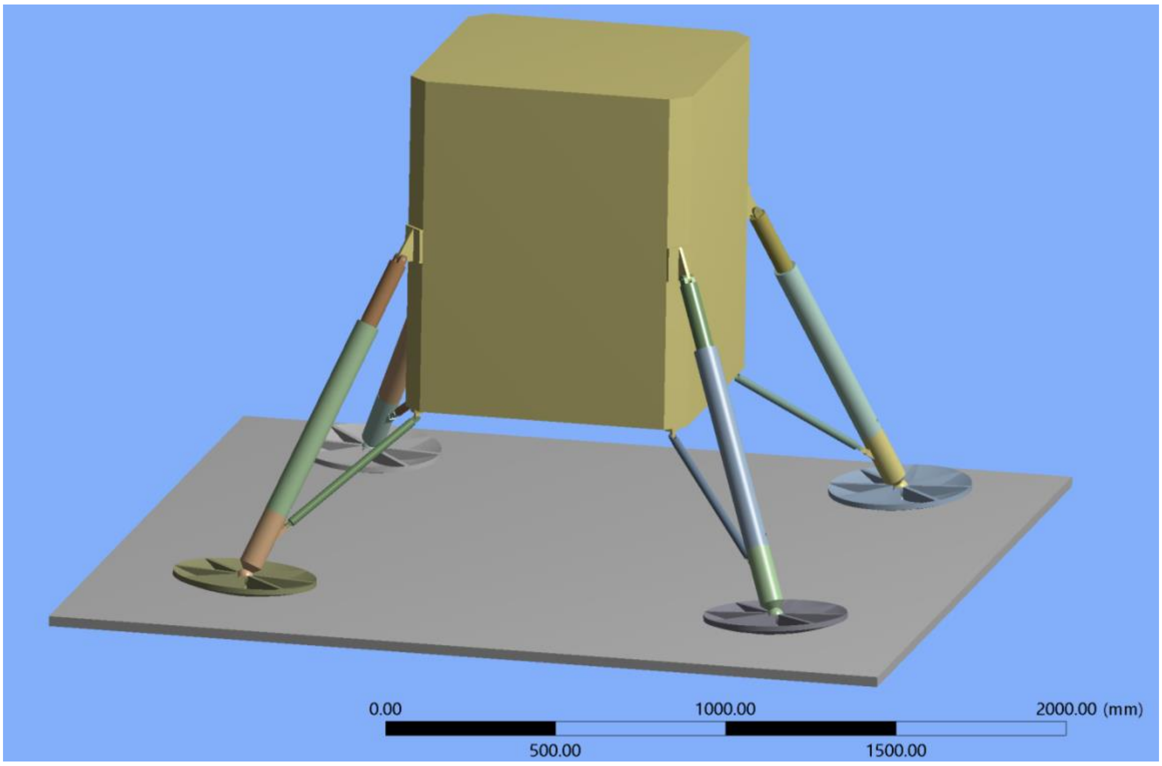
FINAL DESIGN



MATERIAL AND ITS PROPERTIES

PARTS	MATERIALS	PROPERTIES	CHARACTERSITES	REASON
1) Foot pod	Polycarbonates	Density, D= 1380 kg/m^3 Young Modulus, E = 21.4 GPa Poisson's ratio, P= 0.37	1) High impact strength 2) High dimensonal stability 3) Good electrical properties	It can be used over a wide temperature range.
2) Shaft	Mild Steel	D = 7870 kg/m^3 E = 205 GPa P = 0.29	1) High Resistance to breakage 2) High tensile and impact strength	They have resistance to breakage
3) Honey comb structure	Aluminium alloy	D = 2700 kg/m^3 E = 71.7 GPa P = 0.33	1) Ductile 2) Corrosion resistant 3) High electrical Conductivity	It can be easily crushed.
4) Spring (swosc-v) & Piston and piston rod	Stainless steel	D = 8000 kg/m^3 E = 21.4 GPa P = 0.37	1) High impact strength 2) High dimensional stability 3) Good electrical properties	It can absorb large force.
5) Secondary strut, Hollow cylinder and other parts.	Carbon Fibre Reinforced Polymer or Graphene or C-C composites	D = 1750 kg/m^3 E = 228 GPa P = 0.3 D = 2800 kg/m^3 E = 1 TPa P = 0.33 D = 1830 kg/m^3 E = 200 Gpa P = 0.21	1. High tensile strength 2. High strength to weight ratio 1. Max. Youngs modulus 2. Great optical and mechanical properties 1. High strength and toughness 2. Good stiffness to weight and strength to weight ratio	High bending Resistance.

ANALYSIS

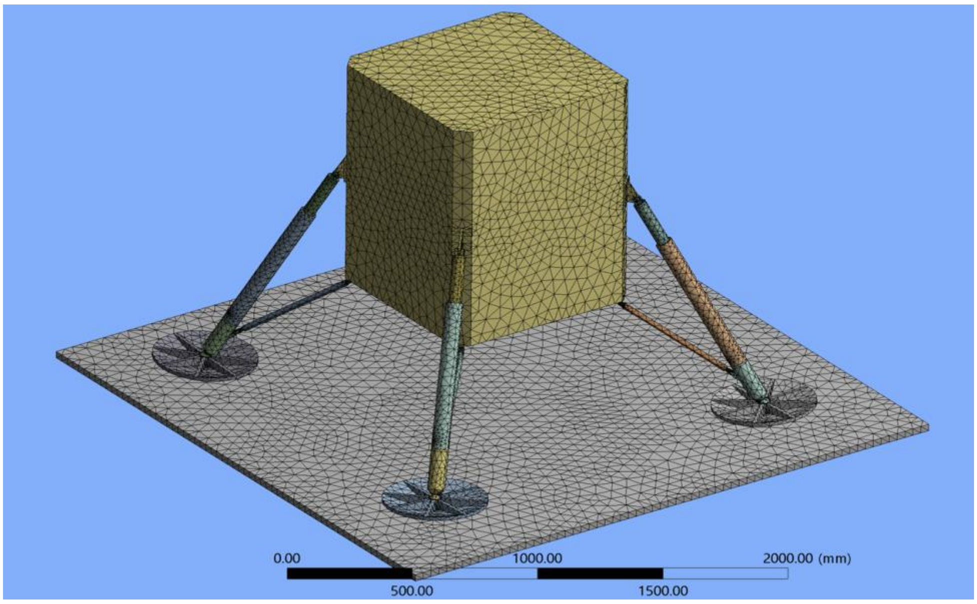


MESHING

- Static structural analysis for lander using software ANSYS and meshing is done in fine relevance center and high smoothing quality.

- A tetrahedral meshing is used for the structure as it fits to the entire surface of the geometry.

- Since the model is a complex structure a tetrahedral mesh is more suitable as tetrahedral elements can better fit complex geometry.



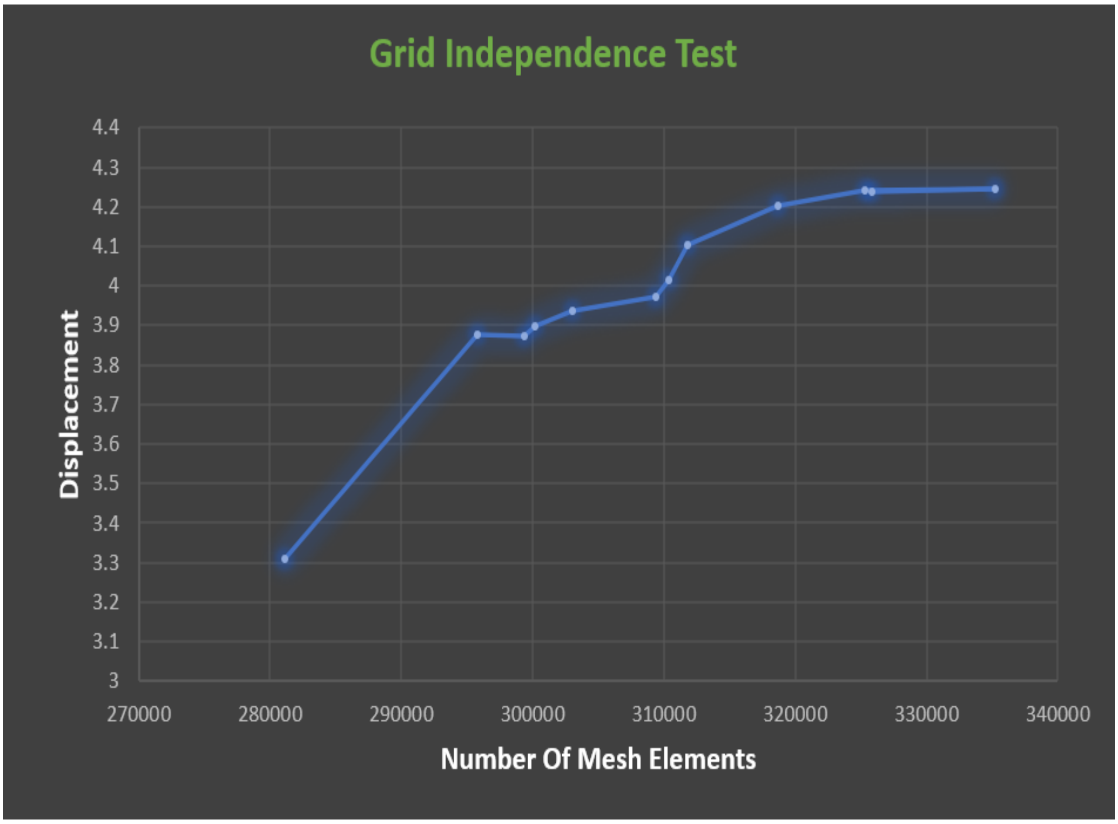
Meshing of Body

GRID INDEPENDENCE TEST

- Grid independence study is performed to reduce the influence of the number of grids or grid size on the structural results.

- The purpose of grid independence study is to show that the solution accuracy almost remains the same between medium and fine meshes.

- From plots for the constant load of 23.83 kN to each leg it is found out that a minimum of 3.2 lakh mesh elements is required for accurate results.



Graph of grid independent test.

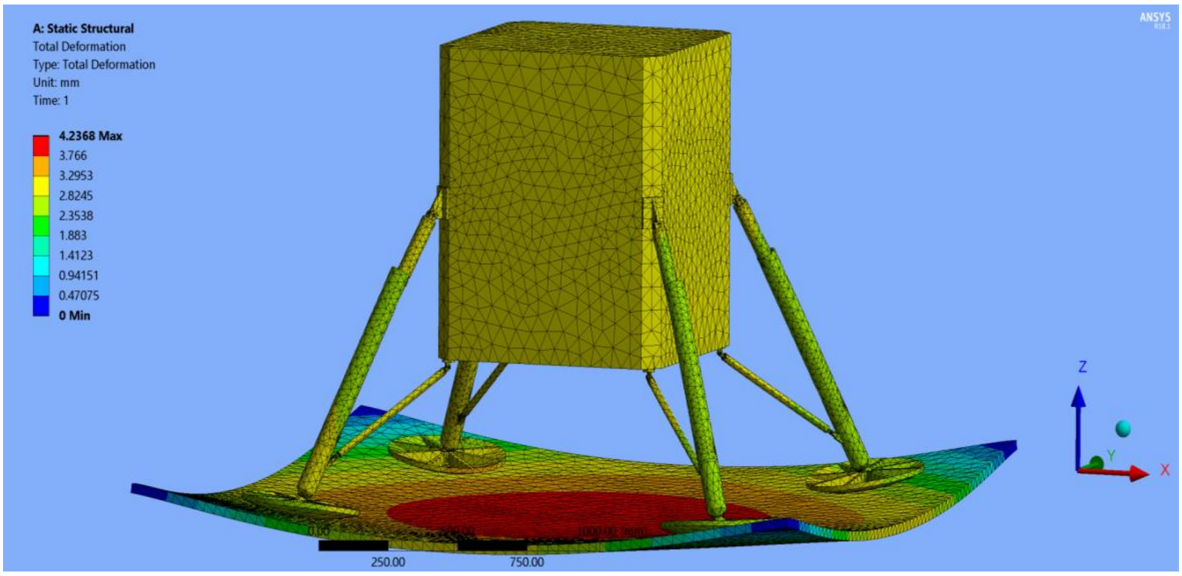
RESULTS AND DISCUSSION

- From study of Grid Independence test, for meshing concluded that the number of meshing elements for the geometry should be more than 3.2 lakh.

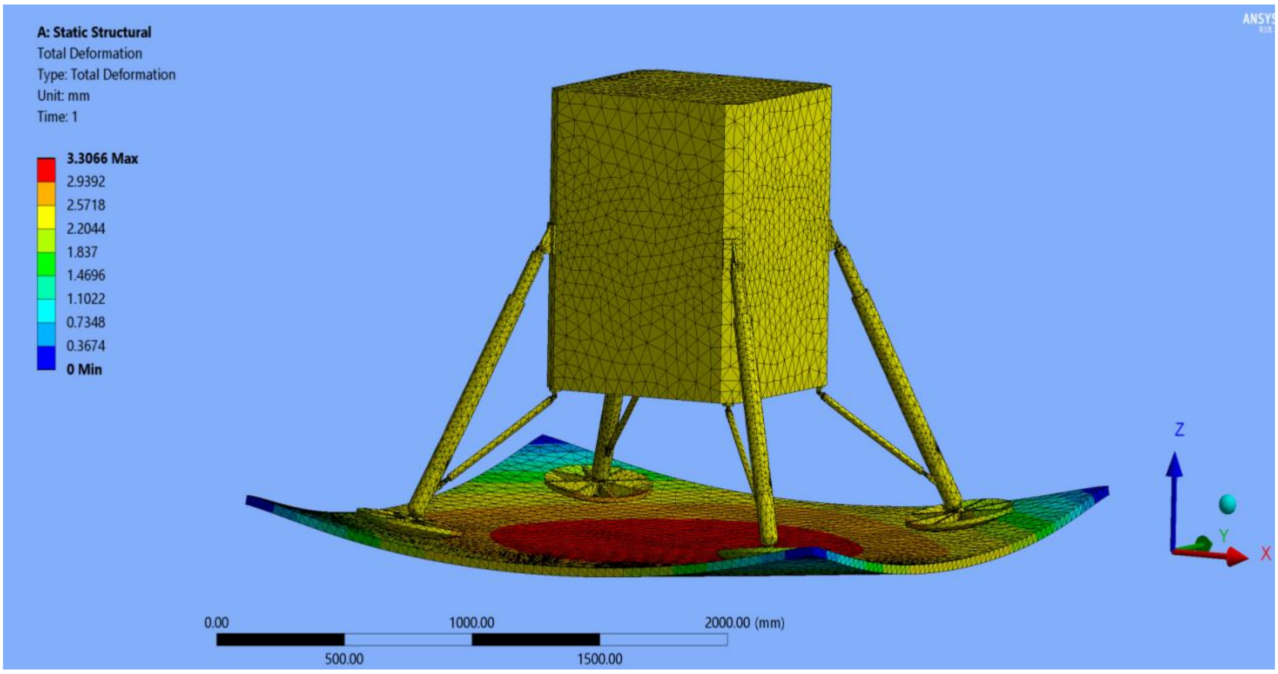
- After the analysis of geometry, the deformation occurred on the lander legs is recorded for various materials for the calculated impact load on the lander legs.

- Graphene material absorbs more impact energy than other materials, while with less deformation on impact.

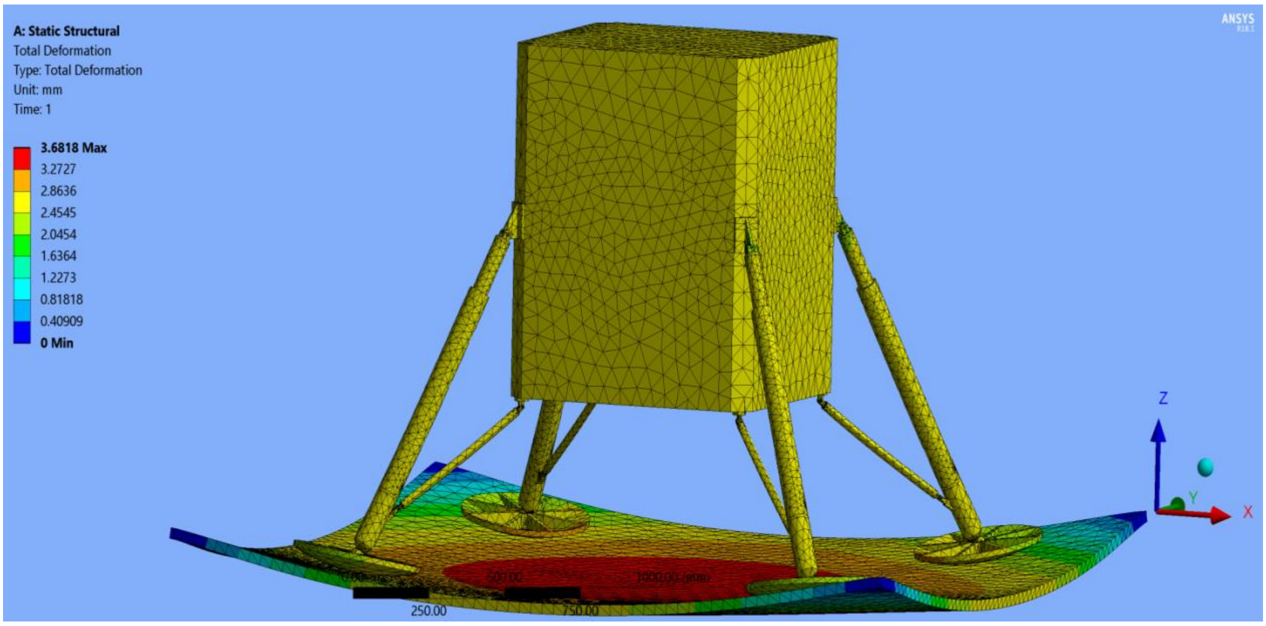
Material - Carbon fibre Reinforced Polymer, Deformation=4.23mm



Material – Graphene , Deformation – 3.3mm



Material- C-C composites, Deformation=3.68mm



CHAPTER 8

CONCLUSION

It is expected that through the design of the lander legs to withstand the impact loads while landing on the Moon without damaging the space lander.

Also it is expected that landing legs to withstand with the incorporated materials without compromising with the weight of the lander.

By considering the landing challenges and investigating about gravity and motion forces on the Moon, the target is to design and analyze the landing legs that will protect the spacecraft when they touch down.

CHAPTER 9

FUTURE SCOPE

- This preliminary study provides an initial baseline for the design of the landing system for space landers. Future work can be follow up to improve on the design and eventually leading it to the actual design of the landing system.

- Different landing configurations such as the inverted tripod landing gear design could be looked into as a comparison with the cantilever landing gear design. It is possible that other landing gear design type could provide a better mass and landing performance of the lander.

- More possibilities of other shock absorbers for space applications such as the electromagnetic shock absorbers or electromechanical shock absorbers can be studied and implemented into the landing model for landing performance comparison with the honeycomb absorbers.

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