CHAPTER 1

INTRODUCTION

1.1 Multi-Terrain Climbing Vehicle

A Multi-Terrain Climbing Vehicle, also known as an All-Terrain Climbing Vehicle (ATCV), is a type of vehicle designed to traverse various types of difficult terrain. These vehicles are typically equipped with special wheels, tracks, or legs that allow them to climb over obstacles, such as rocks, steep inclines, and uneven surfaces.

One example of a Multi-Terrain Climbing Vehicle is the NASA Mars Rover as shown in Fig 1.1. The Mars Rover is a robotic vehicle designed to explore the surface of Mars. It has six wheels that can move independently, which allows it to climb over rocks and navigate difficult terrain. Additionally, the Mars Rover is equipped with a robotic arm that can collect soil samples and other data from the surface of Mars. Another example of a Multi-Terrain Climbing Vehicle is the DARPA Legged Squad Support System (LS3) as shown in Fig 1.2. The LS3 is a robotic vehicle designed to assist soldiers in carrying heavy loads across difficult terrain. It has four legs that can move independently, which allows it to climb over obstacles and navigate difficult terrain. Additionally, the LS3 is equipped with sensors that allow it to follow soldiers and avoid obstacles in real-time.

Fig. 1.1: NASA Mars Rover **Fig 1.2: DARPA ROBOT**

1.2 History of Multi-Terrain Climbing Vehicle

The history of Multi-Terrain Climbing Vehicles can be traced back to the early 20th century when the first off-road vehicles were developed for military use. These vehicles were designed to navigate difficult terrain and were used in World War I and II for transportation and supply purposes. In the 1960s, the development of the Lunar Rover by NASA marked a major milestone in the history of Multi-Terrain Climbing Vehicles. The Lunar Rover was a four-wheeled vehicle designed to transport astronauts on the Moon's surface. It was equipped with a range of scientific instruments and could travel up to 8 mph (13 km/h).

In the following decades, Multi-Terrain Climbing Vehicles continued to be developed for a variety of applications. In the 1980s, the development of the Mars Rover began, which resulted in several generations of rovers being sent to explore the surface of Mars. These rovers were designed to operate in the harsh conditions of the Martian environment and were equipped with advanced scientific instruments to collect data and samples.

In the 21st century, Multi-Terrain Climbing Vehicles have continued to evolve, with advances in technology enabling more advanced designs and capabilities. For example, the development of the LS3 by DARPA in the 2010s marked a major milestone in the development of legged robots for military use. The LS3 was designed to follow soldiers and carry heavy equipment across difficult terrain.

Today, Multi-Terrain Climbing Vehicles continue to be developed for a range of applications, including exploration, research, military operations, and industrial use. They have become an essential tool for navigating difficult terrain and performing tasks in hazardous environments.

1.3 Concept of Multi-Terrain Vehicle

Multi-Terrain Climbing Vehicles have a wide range of applications, from exploration and research to military and industrial use. They are typically designed to be rugged, reliable, and capable of operating in extreme environments.

Here, under this Project we will be focusing on developing a complete working model of the Multi-Terrain Climbing Vehicle. In continuation with this we will be carrying out the Design and Analysis of different critical components involved.

The MTCV can climb onto any obstacles stairs, bumps, etc. It can move along any surface be it sand, rocks, concrete, or grass as it has suspension arrangements. This concept was used in the Mars Rover as well, and we are still in the learning stage of this concept. We are focusing on the Fabrication of an efficient Wheel design which is both compatible and economical. The more efficient the design of Wheel is, more efficient will be the working of our Multi Terrain Climbing Vehicle as shown in Fig 1.3.

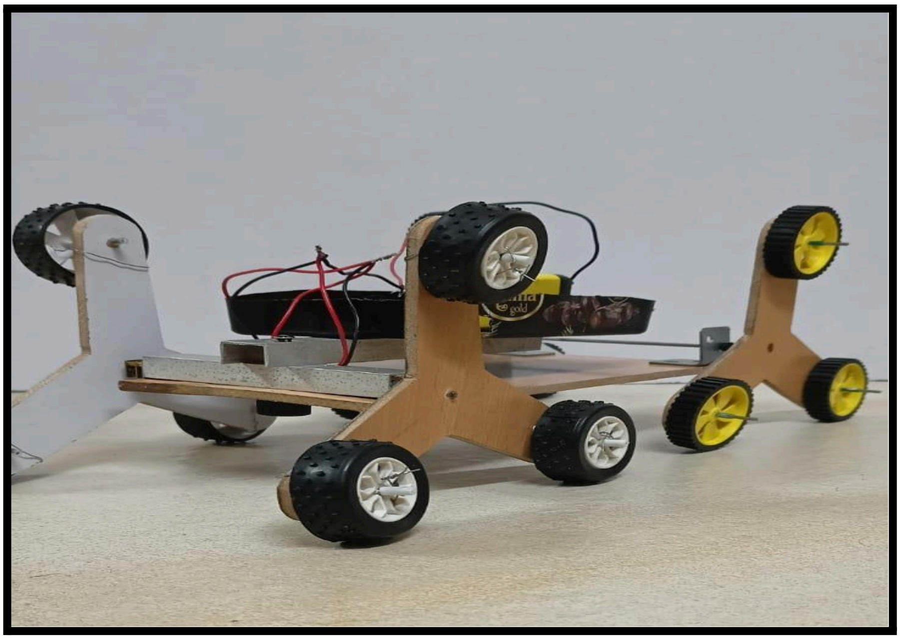


Fig. 1.3: Model of MTCV

Multi-Terrain Climbing Vehicles come in various shapes and sizes. Some are designed to have wheels or tracks, while others have legs or a combination of both. For example, the Mars Rover has six wheels, while the LS3 has four legs.

Multi-Terrain Climbing Vehicles have numerous applications. They are used in exploration, research, search and rescue, military operations, and industrial settings. For example, they can be used to explore remote areas, collect data in hazardous environments, transport supplies and equipment, and perform maintenance tasks in hard-to-reach locations.

Multi-Terrain Climbing Vehicles have several advantages over other types of vehicles. They can traverse difficult terrain that traditional vehicles cannot, such as steep inclines, rocky surfaces, and soft ground. They can also operate in extreme environments, such as deserts, forests, and Polar Regions.

Multi-Terrain Climbing Vehicles also face several challenges. They require advanced technology and engineering to design and build, and they can be expensive to produce and maintain. Additionally, they can be difficult to control, especially in uneven terrain, and they may require specialized training to operate.

The development of Multi-Terrain Climbing Vehicles is ongoing, with researchers and engineers exploring new designs and technologies. Some future developments may include more advanced sensors and control systems, greater mobility and adaptability, and increased automation and autonomy.

1.4 Types of Multi-Terrain Climbing Vehicle

There are several types of Multi-Terrain Climbing Vehicles, each designed for a specific purpose and with its own unique features. Here are some examples:

1. **Wheeled Multi-Terrain Climbing Vehicles:** These vehicles are equipped with wheels that are designed to traverse difficult terrain, such as rocks, sand, and mud. Some wheeled Multi-Terrain Climbing Vehicles have adjustable suspension systems to help them climb over obstacles.
2. **Tracked Multi-Terrain Climbing Vehicles:** These vehicles are equipped with tracks that provide greater traction and stability than wheels, allowing them to traverse even more difficult terrain, such as steep inclines and rocky surfaces.
3. **Legged Multi-Terrain Climbing Vehicles:** These vehicles are equipped with legs or other types of locomotion systems that allow them to climb over obstacles and traverse uneven terrain. Legged Multi-Terrain Climbing Vehicles are particularly useful in areas where wheels or tracks may not be effective, such as on steep inclines or in areas with soft ground.

4. **Hybrid Multi-Terrain Climbing Vehicles:** These vehicles combine two or more types of locomotion systems to provide greater versatility and mobility. For example, a hybrid Multi-Terrain Climbing Vehicle might have both wheels and tracks, or both legs and wheels.
5. **Robotic Multi-Terrain Climbing Vehicles:** These vehicles are typically unmanned and controlled remotely or autonomously. They are equipped with sensors and cameras that allow them to navigate difficult terrain and perform tasks in hazardous environments without risking human lives.

1.5 Need of Multi Terrain Climbing Vehicle

Multi-Terrain Climbing Vehicles are needed for a variety of reasons and applications. Here are some of the main reasons why Multi-Terrain Climbing Vehicles are important:

- **Exploration:** Multi-Terrain Climbing Vehicles are essential for exploring remote and challenging environments, such as deserts, mountains, forests, and polar regions. They can collect data, samples, and images from these areas, providing valuable information for scientific research and discovery.
- **Search and Rescue:** Multi-Terrain Climbing Vehicles can be used to search for and rescue people in difficult-to-reach areas, such as mountainous terrain, forests, and disaster zones. They can transport medical equipment and supplies, and can also provide real-time video and communication to rescue teams.
- **Military Operations:** Multi-Terrain Climbing Vehicles are used by the military for a variety of purposes, such as reconnaissance, transport, and logistics. They can operate in challenging and hostile environments, providing support to troops and performing tasks that would be too dangerous for humans.
- **Industrial Use:** Multi-Terrain Climbing Vehicles are used in industries such as mining, construction, and forestry, where they can navigate difficult terrain and perform tasks that would be difficult or impossible for traditional vehicles.
- **Environmental Monitoring:** Multi-Terrain Climbing Vehicles can be equipped with sensors and cameras to monitor the environment, such as tracking wildlife populations, measuring air and water quality, and detecting changes in the landscape.

CHAPTER 2

LITERATURE SURVEY

A. Spickler et al. [1] described a comprehensive review of legged robots for military applications, including Multi-Terrain Climbing Vehicles. They discussed the various challenges and opportunities of legged locomotion in military settings, and provides an overview of existing legged robot systems.

F. Fraundorfer et al. [2] presents a study on terrain classification for Multi-Terrain Climbing Vehicles equipped with wheels or tracks. The authors use computer vision techniques to classify terrain types based on visual features, and evaluate the performance of their approach on real-world datasets.

C. Edsinger et al. [3] investigated and studied the design and development of a hybrid tracked-wheeled Multi-Terrain Climbing Vehicle for mining applications. The authors describe the vehicle's features, such as its ability to climb steep slopes and navigate through soft terrain, and evaluate its performance in a real-world mining environment.

A. S. Ijspeert et al. [4] presented a study on multi-robot exploration using a combination of legged and wheeled Multi-Terrain Climbing Vehicles. The authors discuss the challenges of coordinating multiple robots in rough terrain, and present experimental results on the performance of their system.

Murray J Lawn et al. [5] designed a dual section tracked stair climbing wheelchair "the Nagasaki Stair climber" has been developed in Nagasaki. The wheelchair has been used in the Nagasaki area to assist the elderly and disabled whose local terrain has led to mobility difficulties or being housebound. A control system has been added to the proven dual track mechanism wheelchair. The control system provides for automation of all aspects necessary in the control of the wheelchair including a guidance system.

R Rajasekar et al. [6] studied the commercially available wheel chairs for amputees do not have the functionality for climbing staircases. In this project, they have designed a manually operated wheelchair that can travel on both plane terrains and also in the staircases.

In this project, instead of using normal wheels they have used Penta wheel.

The main aim of this project is to provide stability to the person who travels in the wheel chair (i.e., a large support base and maintain the overall center of gravity as low as possible).

Mohammad Iqbal et al. [7] describe the mechanical design and development of Tri-Star wheel system for surveillance mobile robot. This projects aimed to provide mechanical design, simulation and testing of main part of the automated stair climbing robot which using the Tri-Star wheel. This paper helps to establish the Tri-Star Wheel Parameters. Deriving the Tri-Star wheel parameters depends on the position of Tri-Star wheel on stairs. It depends on two parameters, the distance between the edge of wheel on lower stair and the face of the next stair (L1), and the distance between the edge of wheel on topper stair and the face of next stair (L2).

Adhyanth G Ajay et al. [8] designed and analyzed a frame or Web made of Poly Methyl Methacrylate or PMMA in short, commonly known as Acrylic or Acrylic glass, is used to form the TriStar wheel. PMMA is known to have a compressive yield strength of 18000 psi or around 120 N/mm2. The important property that PMMA holds is that it is light weight, several times lighter than Steel. This light weight design will allow us to increase the load on the trolley. The only issue is that PMMA has lower compressive stress than steel, which will increase the chances of failure of the web.

P.Jey Praveen Raj et al. [9] analysed the design of the clamp using static structural analysis in this project. The hub of the clamp was fixed to the hollow shaft by welded joint and then the analysis was carried out. The hollow shaft is fixed to the body frame with the help of bearings. Two ball bearings are used to connect shaft with frame and the load is acts through it to shaft. The ends of the hollow shaft are fixed to TriStar wheels. The analysis of this hollow shaft was also considered in order to determine whether the design is safe or not.

Shubham S. Shiwarkar et al. [10] modified the two wheel trolley into tri-wheel for easy mode of transportation with addition of relaxation chair. They carried out necessary Shear Force and Bending Moment calculations.

CHAPTER 3

PROBLEM IDENTIFICATION

Such kind of Vehicles are very costly, our aim is to make such a Climbing Vehicle which is most cost efficient and easily adaptable. Also, if our execution is successful it can be used in Defense Industry as they do not always work on the plain ground level. The actual fields are very irregular and steep climbing. It can also be implemented at domestic level I.e. Staircases which is our main focus at the initial stage of project.

Here are some common problems and challenges associated with current Multi-Terrain Climbing Vehicles:

1. **Power and Energy Efficiency:** Multi-Terrain Climbing Vehicles often require a significant amount of power to operate, especially when navigating difficult terrain. Improving energy efficiency and power management is an ongoing challenge for designers of Multi-Terrain Climbing Vehicles.
2. **Stability and Control:** Maintaining stability and control in rough terrain is another challenge for Multi-Terrain Climbing Vehicles. Uneven surfaces, slopes, and obstacles can cause instability and affect the vehicle's performance.
3. **Durability and Maintenance:** Multi-Terrain Climbing Vehicles need to be able to withstand the harsh environments in which they operate. They may be exposed to extreme temperatures, moisture, and dust, which can affect their performance and durability. Regular maintenance is also necessary to keep them in working order.
4. **Cost and Accessibility:** Multi-Terrain Climbing Vehicles can be expensive to design, build, and maintain, which can limit their accessibility to certain industries and applications.

Overall, improving the power efficiency, stability, durability, sensing and perception, navigation, and accessibility of Multi-Terrain Climbing Vehicles are important areas of research and development to overcome the current problems associated with these vehicles.

CHAPTER 4

OBJECTIVES

Through this project, at first our idea is to study and understand the actual problem involved with the functioning of existing Multi Terrain Climbing Vehicle. We aim to study the existing fabrications and put our ideas in fabricating a design which is very much compatible as well as economical. After this, we aim at focusing on deciding the material involved.During this process we'll Brainstorm about the different materials available which can withstand high stresses and are very much durable. The fabricated design will then be imported to the Analysis Software in order to check for Maximum Stress and Strain values and to determine whether our design will be efficient or not. After careful consideration of the Design and Material we will start building up the actual model which will have the utmost compatibility and will be considered most economical for the problem gap we have observed.

Important Points to consider while building up the project:

- **Conducting a thorough literature review:** Before one start fabricating its own design, it's important to conduct a thorough literature review to understand the existing Multi Terrain Climbing Vehicle designs and the materials used in their fabrication. This will help us identify the gaps in the current designs and come up with innovative ideas.
- **Considering safety factors:** When designing and fabricating the Multi Terrain Climbing Vehicle, it's important to consider safety factors such as stability, weight distribution, and load capacity. We don't want the vehicle to tip over or malfunction while in use.
- **Testing and validating the design:** Once we have the fabricated design, it's important to test and validate it before using it in actual applications. One can

conduct mechanical and performance testing to ensure that it meets the required specifications and is compatible with the intended applications.

- **Optimizing for cost-efficiency:** As we mentioned, cost efficiency is a key consideration in our project. We can optimize the design and material selection to reduce costs while still maintaining high performance and durability.

CHAPTER 5

METHODOLOGY

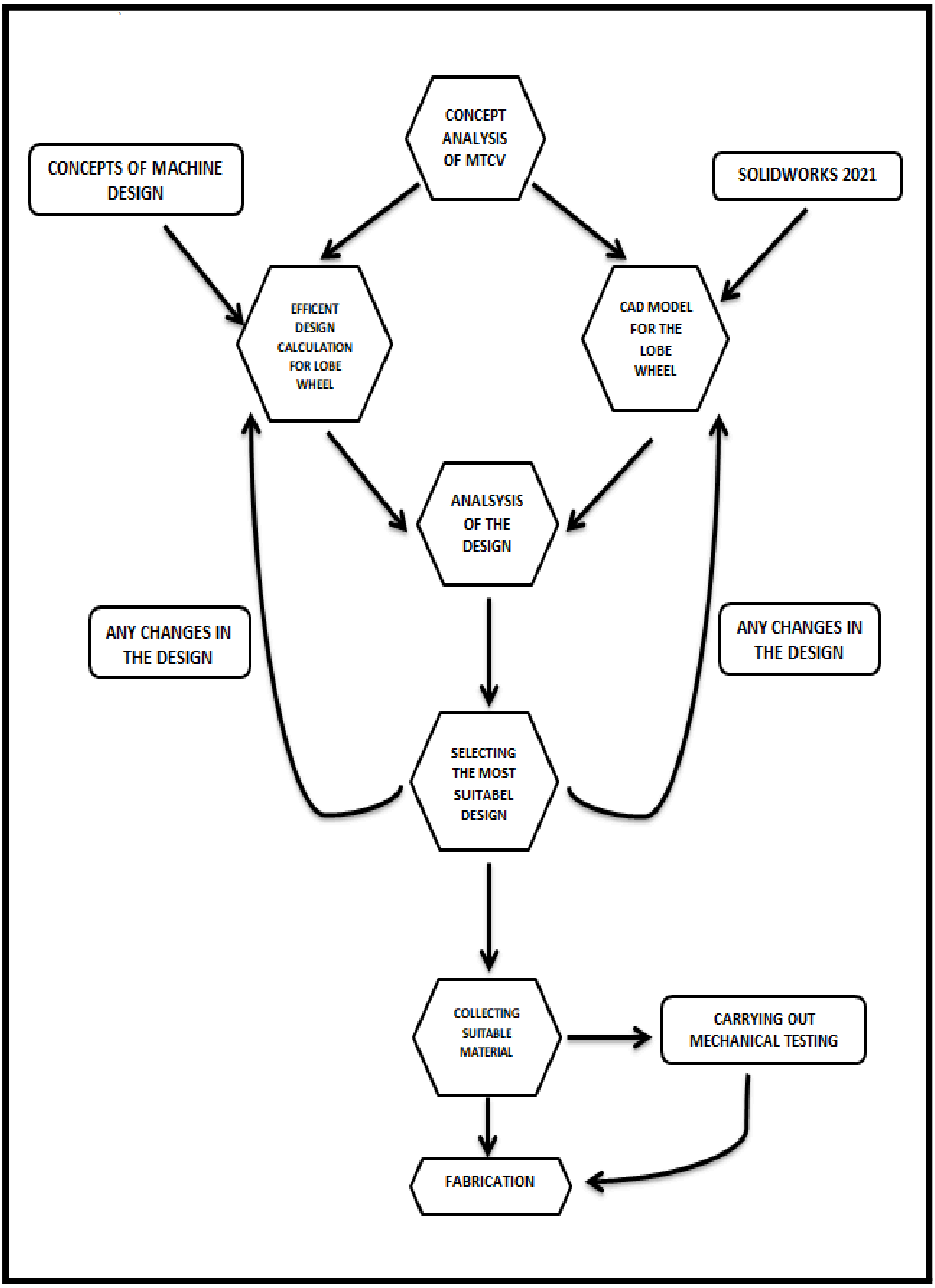


Fig. 5.1: Flowchart of Methodology

The project "Design, Fabrication, and Analysis of a Multi-Terrain Climbing Vehicle" involves creating a vehicle capable of traversing various types of terrain. Here's a suggested methodology for undertaking this project:

- **Define project objectives:** Clearly outline the goals and objectives of the project. Determine the specific requirements and constraints for the multi-terrain climbing vehicle, such as the maximum weight, size limitations, desired speed, and types of terrains it should be able to navigate.

- **Research and literature review:** Conduct a comprehensive literature review to gather information about existing multi-terrain vehicles, climbing mechanisms, materials, and relevant technologies. This will help you understand the state-of-the-art, identify potential design solutions, and learn from previous research.

- **Conceptual design:** Generate multiple design concepts for the climbing vehicle. Consider different mechanisms, propulsion systems, chassis designs, and climbing methods. Evaluate the pros and cons of each concept based on factors such as feasibility, cost, performance, and safety.

- **Detailed design:** Select the most promising design concept and develop a detailed design. Create 3D models and engineering drawings using computer-aided design (CAD) software. Specify the materials, dimensions, and assembly techniques for each component of the climbing vehicle.

- **Component fabrication:** Fabricate the various components of the climbing vehicle based on the design specifications. Utilize appropriate manufacturing processes, such as machining, welding, 3D printing, or composite fabrication, depending on the materials and complexity of the parts.

- **Assembly and integration:** Assemble the fabricated components to construct the multi-terrain climbing vehicle.

Ensure proper alignment and fitment of all parts. Integrate the propulsion system, control mechanisms, sensors, and any other required subsystems.

- **Testing and analysis:** Conduct comprehensive tests to evaluate the performance and capabilities of the climbing vehicle. Test it on different terrains, such as rocky surfaces, inclined planes, and uneven terrain. Measure parameters like speed, stability, load capacity, and power consumption. Analyse the test results to identify areas for improvement and optimization.
- **Iterative design improvements:** Based on the testing and analysis results, refine the design of the climbing vehicle. Modify or replace components that are underperforming or not meeting the desired objectives. Iterate through the design, fabrication, and testing steps to enhance the vehicle's performance and reliability.
- **Final evaluation and documentation:** Once the climbing vehicle meets the project objectives, perform a final evaluation to validate its capabilities. Document the entire design, fabrication, and testing processes, including detailed specifications, drawings, test results, and any modifications made during the project. Prepare a comprehensive project report summarizing the methodology, findings, and conclusions.

Remember that this methodology is just a general guideline, and you may need to adapt it to suit the specific requirements and resources available for your project.

CHAPTER 6

DESIGN OF MULTI-TERRAIN CLIMBING VEHICLE

6.1 Concept of Tri-Star Wheel

The Tri-Star wheel is a type of wheel that has three arms or spokes arranged in a triangular pattern. It is commonly used in Multi Terrain Climbing Vehicles (MTCVs) because of its ability to provide better traction and stability on uneven and rocky terrain.

The Tri-Star wheel design allows for the wheel to adjust to the contours of the terrain, providing better grip and traction than traditional wheels. The triangular shape of the wheel also distributes the weight of the vehicle more evenly, reducing the risk of sinking into soft or muddy ground.

One of the advantages of the Tri-Star wheel is its versatility. It can be used on a variety of terrain types, including rocks, mud, and sand. Additionally, the design is simple and easy to maintain, which makes it a cost-effective solution for MTCVs.

However, the Tri-Star wheel design also has some limitations. It may not be as efficient on flat and even surfaces as traditional wheels, and it can be more difficult to maneuver in tight spaces. As with any wheel design, the performance of the Tri-Star wheel will depend on the specific application and terrain type.

In summary, the Tri-Star wheel is a useful design for Multi Terrain Climbing Vehicles, providing better traction and stability on uneven and rocky terrain. However, its performance may vary depending on the specific application and terrain type.

The Tri-Star wheel is utilized in multi-terrain climbing vehicles due to its remarkable off-road capabilities. Its three-talked plan upgrades grasp and solidness on whimsical surfaces, permitting the vehicle to arrange troublesome landscape without any problem. The Tri-Star wheel's durability and adaptability make it an excellent choice for off-road vehicles.

6.1.1 Advantages of a Tri-Star Wheel

Some advantages of a Tri-Star wheel over normal wheels:

- **Better traction:** The Tri-Star wheel provides better traction on uneven and rocky terrain than normal wheels. Its triangular shape allows it to adjust to the contours of the terrain, providing better grip and stability.
- **Improved stability:** The triangular shape of the Tri-Star wheel distributes the weight of the vehicle more evenly, reducing the risk of sinking into soft or muddy ground. This improves the stability of the vehicle on uneven terrain.
- **Greater manoeuvrability:** The Tri-Star wheel design allows for better manoeuvrability on uneven terrain. Its shape and flexibility allow it to move more easily over obstacles and navigate tight spaces.
- **Cost-effective:** The Tri-Star wheel design is simple and easy to maintain, which makes it a cost-effective solution for Multi Terrain Climbing Vehicles.
- **Versatility:** The Tri-Star wheel can be used on a variety of terrain types, including rocks, mud, and sand, making it a versatile solution for Multi Terrain Climbing Vehicles.

Fig. 6.1: Lobe Wheel

Overall, the Tri-Star wheel as shown in Fig 6.1 provides several advantages over normal wheels, including better traction, improved stability, greater manoeuvrability, cost-effectiveness, and versatility.

6.1.2 Motion of Tri-Star Wheels on Stairs

The proposed motion for climbing stairs as illustrated in Fig 6.2 is a step-by-step process that allows the Multi Terrain Climbing Vehicle to overcome the obstacle of stairs. The Tri-Star wheel system is designed in a way that allows for one wheel to make contact with the stair surface while the other wheels remain in contact with the ground, providing stability to the vehicle.

In step 1, the Tri-Star wheel system allows wheel "b" to touch the stair, which causes it to get stuck and rotate the front part of the vehicle towards the obstacle. In step 2, wheel "a" contacts the stair surface as the rear part of the vehicle moves forward, pushing the front part along the vertical surface of the stair.

Steps 3 to 4 show the vehicle climbing onto the upper surface of the stair as the front part of the vehicle continues to climb while the rear part makes contact with the stair surface. In step 5, the front part is climbing to the next step while the rear part is starting to contact the stair surface. Steps 6 to 9 show the rear part of the vehicle vertically moving along the stair surface, aided by the pulling forces of the front part, and the rear motor being actuated to easily climb the rear part.

Finally, step 10 shows that the entire Multi Terrain Climbing Vehicle is on top of the stair, having successfully completed the process of climbing stairs using the Tri-Star wheel system.

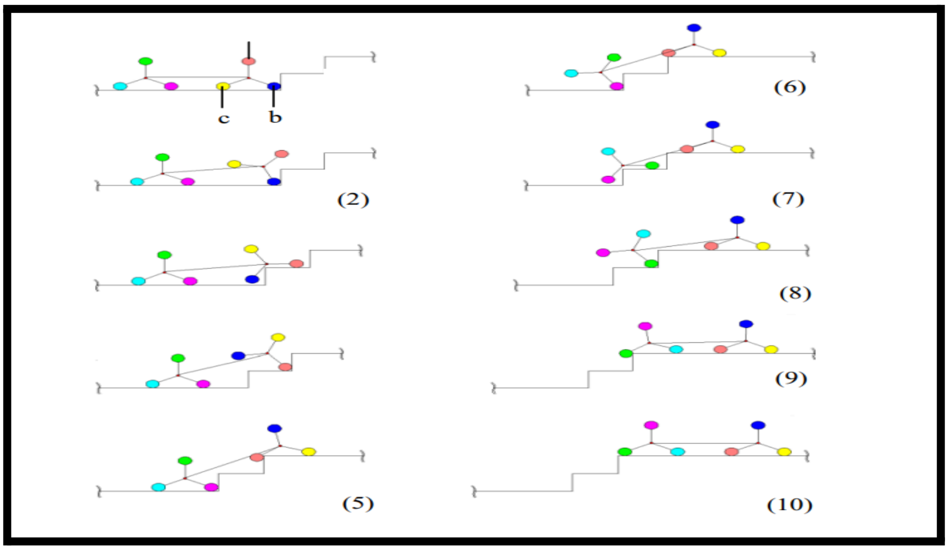


Fig. 6.2: Motion of Tri- Stair Wheels

6.1.3 Driving Mode of Tri-Star Wheel

Because two wheels (of the three present in each Tri-Wheel assembly) are in contact with the ground and operate as normal wheels, this concept takes advantage of the wheel's optimal performance on flat terrain. Because the Tri-Wheel's orientation is not locked in place relative to the robot body, the wheels are able to passively pivot about the main drive shaft located at the centroid of each Tri-Wheel assembly.

This allows for effective adaptation to grades and slopes. Fig 6.3 shows this ability to pivot and maintain contact with a smooth, sloped surface. The red arrows surrounding each wheel indicate the same angular velocity as the three wheels spin during driving mode. In this scenario, two wheels are in contact with the ground and contributing to the driving motion of the robot or vehicle.

The black arrow located at the centroid of each Tri-Wheel represents the overall linear velocity induced in each mechanism as a result of the rotation of the wheels.

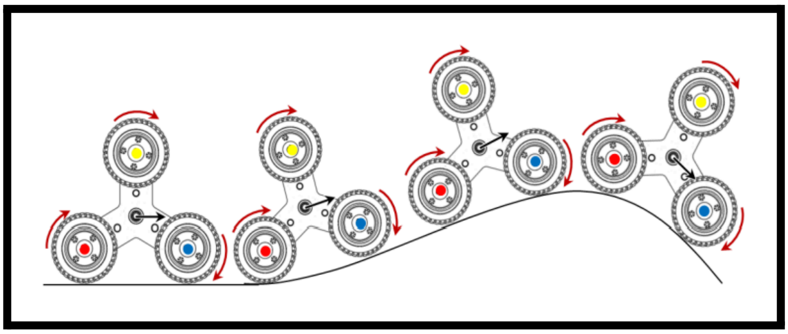


Fig. 6.3: Driving Mode

While this mode does allow for smooth operation on even surfaces, it also has the advantage of absorbing obstacles encountered such as rocks or other debris that are larger than the diameter of one wheel. When moving across a surface, if the leading ground wheel of one Tri-Wheel assembly comes into contact with an obstruction, that wheel will kick back, and the third wheel (top wheel) that was previously not in contact with the ground will rotate forward and assume the position of the leading ground wheel. The assembly will then continue its linear motion.

For this reason, the Tri-Wheel is optimal for uneven terrain; each assembly is independently operated, and if an obstacle is encountered on only the left side of the vehicle, for instance, the others Tri-Wheel assemblies can maintain balance and continue to propel the robot forward.

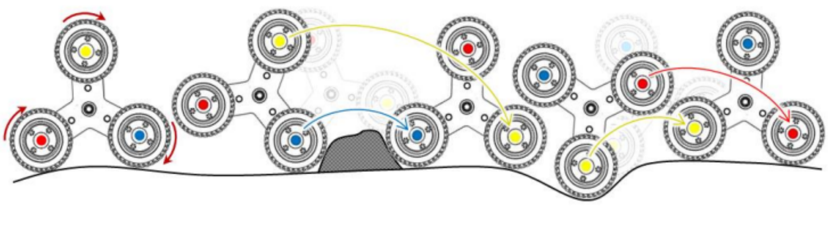


Figure 2.3: Absorbing Obstacles in Passive Tumbling Mode

Fig. 6.4: Absorbing Obstacles

The above figure illustrates this process of passively absorbing obstacles while in driving mode. Note that the arrows encircling the three wheels once again represent the angular velocity as the mechanism to advances forward.

As in Fig 6.4, these wheels continue to rotate throughout the entire figure; arrows are omitted after the first Tri-Wheel instance for clarity of the image. This figure displays the Tri-Wheel mechanism reaction to a positive obstacle (a rock or some debris) and a negative obstacle (a crevice or depression). Beginning with the leftmost instance, the Tri-Wheel proceeds forward in normal driving mode. When the leading (blue) wheel comes into contact with the positive obstacle, the natural reaction of the mechanism is to rotate forward such that the top (yellow) wheel assumes the position of the blue wheel to absorb the obstacle and continue its forward motion. When the negative obstacle is encountered, the leading (yellow) wheel becomes somewhat stuck in the depression.

As a response, the Tri-Wheel continues to spin its wheels, and the top (red) wheel flips forward to assume the yellow wheel's previous position. Once the negative obstacle is cleared, the Tri-Wheel continues to drive forward in its typical driving mode. Recall that in general, a wheel can only surmount an obstacle that is less than or equal to the radius of the wheel. However with the Tri-Wheel mechanism, if an obstruction of height greater than the radius of a single wheel is encountered, the assembly absorbs the obstacle and rotates about its central axel to flip over the object and continue moving.

6.2 Kinematic Analysis of Tri-Star Wheel

6.2.1 Introduction and Nomenclature

Following the selection of the Tri-Wheel concept, derived requirements for a final mechanism that meets the stated research objectives must be obtained. The starting point of this process is a kinematic analysis that explains where the mechanism is in space. This ultimately governs the overall size of the Tri-Wheel that is suitable for stair climbing, the most challenging requirement. The kinematic analysis also seeks to converge on two parameters through optimization: the radius of each individual wheel r and the distance between the centroid of the Tri-Wheel and the centre of one wheel c, the spoke length. These variables are shown in Fig 6.5 in relation to a Tri-Wheel.

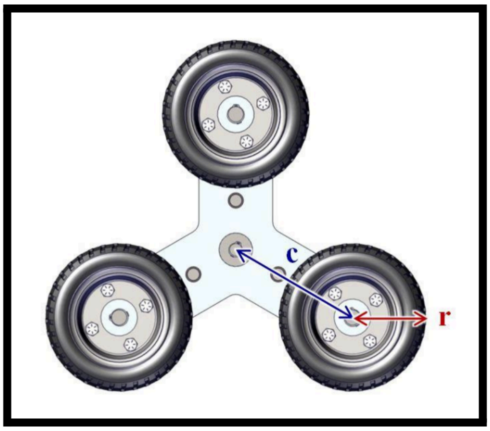


Fig. 6.5: Tri-Star Wheel Nomenclature

In order to derive the optimal values for r and c, an overall analysis of the Tri Wheel's motion during Tumbling Mode is required since this mode of operation is utilized to climb stairs. Studying this motion provides an understanding of where the three wheels and the centroid of the mechanism are located at strategic points. Once this general relationship is understood, the size of the Tri-Wheel is able to be optimized for the task of climbing stairs from a quantitative perspective.

The following sections explain the mathematical relationship that relates the three vertices of the mechanism (its three wheels) as well as its centroid and plot each of these four points in space. With this information, optimization for stair climbing can be investigated.

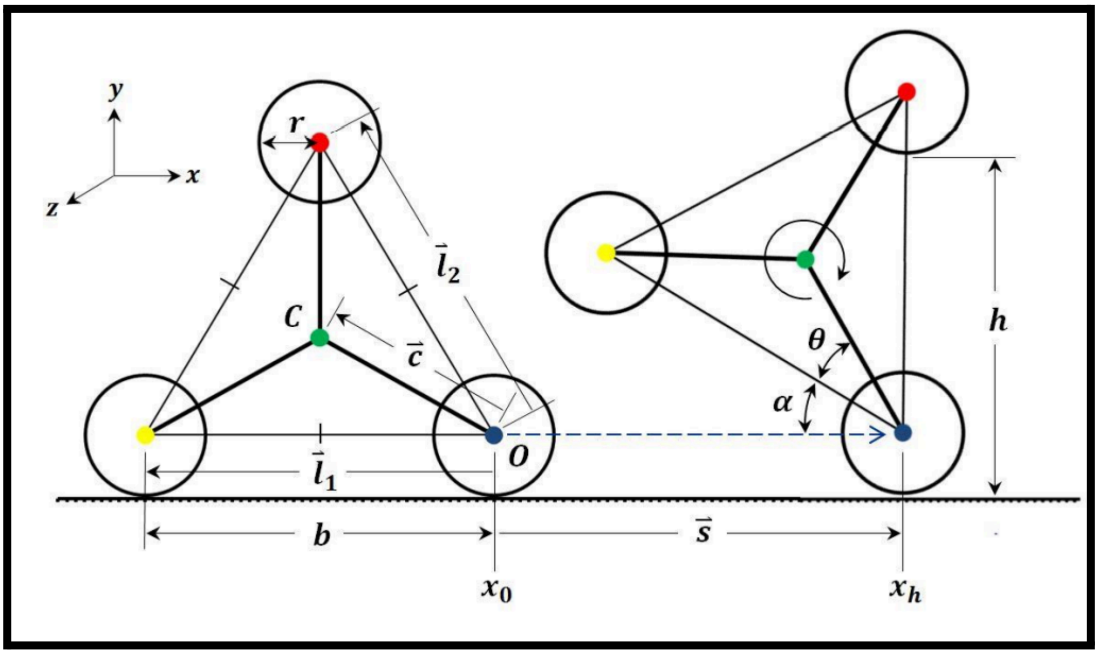


Fig. 6.6: Nomenclature

Fig 6.6 is a simplified representation of the Tri-Wheel geometry labelled with the vectors, angles, lengths, and points referenced throughout the kinematics analysis. All lengths are measured in units of inches, and angles are measured in degrees. As this figure relays, the basic structure of the Tri-Wheel derives from an equilateral triangle. the actual Tri-Wheel mechanism shown in Fig 6.5, notice that each wheel is connected to the centroid ***C***, but there is no physical element connecting one wheel directly to another wheel. For purposes of this analysis, Fig 6.6 includes these lines connecting the three wheels to facilitate easy measurement of angles.

In Fig 6.6, each equivalent side length is labelled ***b*** and provides the distance between the centroids of any two wheels. Throughout the process of tumbling, all three individual wheels will assume different positions. In other words, the red wheel will not always be at the top, and the blue wheel will not always be leading. In order to climb over obstacles, the wheels must exchange places in a clockwise or counter clockwise direction (depending on the direction in which the motor is driven) as the assembly walks over these obstructions.

For this reason, it is prudent to establish consistent terminology for describing the wheel positions beyond the use of colour. Looking at the wheel configuration provided in

Fig 6.6, the wheel positions are defined as follows: red—top wheel, yellow—trailing ground wheel, blue—leading ground wheel. The leading ground wheel is the translating pivot point for tumbling motion while the top wheel will land on or above the obstacle to be overcome. During Tumbling Mode, the trailing ground wheel simply serves to complete the cycle.

Point O marks the origin of rotation (the horizontally translating pivot point), which is always placed at the centre of the leading ground wheel. Vector $\vec{l_1}$ has a magnitude equal to the side length band gives the position of the trailing ground wheel with respect to the leading ground wheel. Vector $\vec{l_2}$ is similarly of magnitude b and provides the position of the top wheel with respect to the leading ground wheel.

The vector $\vec{c}$ represents the spoke length already discussed and gives the position of the Tri- Wheel centroid ***C*** with respect to the leading ground wheel. The initial horizontal position of the leading ground wheel (of point ***O***) is labelled x_0 . Once the braking mechanism has been engaged and the Tri-Wheel begins to rotate about the leading ground wheel, the vector $\vec{s}$ is used to measure the horizontal distance travelled by the leading ground wheel. As the trailing ground wheel begins to lift off the ground, the angle α emerges as a measure of how much the Tri-Wheel has rotated from its initial state with two wheels planted on the ground. Specifically, α is the angle from the reference horizontal to the theoretical base of the equilateral triangle. Beginning at 0°, α will end at 120° for a full rotation of the Tri-Wheel.

Angle θ always equals 30° due to the properties of an equilateral triangle and measures the degree of separation between the triangle's base and the vector $\vec{c}$. There are six similar θ angles in the Tri-Wheel. In Tumbling Mode, the top wheel will reach its maximum vertical height when it is directly above the leading ground wheel. The horizontal distance at which this occurs is labelled x_h where $h = h_{max}$.

Lastly, the distance ***h*** represents the distance from the ground to the lowest point of the top wheel—the step approach height. It is evident in examining the diagram that this height h is actually equivalent to the side length ***b*** when maximized.

When the Tri-Wheel is engaged in Tumbling Mode, the leading ground wheel advances forward (while rolling) as the rest of the assembly rotates about it. There is a relationship between the angle of rotation, the wheel radius, and the translation. Consider now the case in which the leading ground wheel does not translate during rotation of the assembly. Rather, if the leading ground wheel is imagined to be fixed as the rest of the Tri-Wheel assembly pivots about it, the resulting motion establishes another mode of operation called Inching Mode.

While Inching Mode and the means by which the leading wheel would be fixed during rotation are not investigated in this project, this motion is the simplest to model and the best place to begin kinematic analysis. In future applications, the ability for one wheel to become fixed in place might prove advantageous for climbing out of soft soils or dislodging the Tri-Wheel assembly from other potential failure modes.

6.2.2 Inching Mode

Inching Mode is best described as a simplified, theoretical form of Tumbling Mode. In order to obtain the rotational trajectory for each wheel as well as the centroid in a Tri-Wheel mechanism, a rigid body transformation matrix is used to map the coordinates of each of the four points in question. Positions of these four points are expressed uniquely by vectors throughout the rotation. The methodology is to write expressions for these vectors in the initial configuration shown in the leftmost Tri-Wheel of Fig 6 .2 and then plot their locations with the help of a rotation matrix. Referencing the right-handed coordinate frame shown in the same figure, the rotation of the assembly occurs in the negative z-direction. In this case, the rotation matrix is modelled as a basic Euler Angle rotation about the z-axis written as,

$$R_z(-\propto_z) = \begin{bmatrix} \cos(-\alpha) & -\sin(-\alpha) & 0 \\ \sin(-\alpha) & \cos(-\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(6.1)$$

Using the properties of the sine and cosine function, this expression can be further simplified as follows for the rotation of a negative angle.

$$R_z(-\propto_z) = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$ …................................. (6.2)

Next, the vectors $\vec{c}$, $\vec{l}_1$, $\vec{l}_2$, are written corresponding to their positions in Fig 6.2. All of these vectors are written with respect to the angle θ, which was previously defined to always equal 30°.

$$\vec{c} = -c\cos\theta\,\boldsymbol{i} + c\sin\theta\,\boldsymbol{j} + 0\boldsymbol{k}$$ ……………………………………….. (6.3)

$$\vec{l}_1 = -2c\cos\theta\boldsymbol{i} + 0\boldsymbol{j} + 0\boldsymbol{k}$$ ……………………………………….…...... (6.4)

$$\vec{l}_2 = -(2c\cos\theta)(\cos 60)\,\boldsymbol{i} + (2c\cos\theta)(\sin 60)\,\boldsymbol{j} + 0\boldsymbol{k}$$ ...... (6.5)

The value of θ = 30° can then be substituted into these general expressions:

$$\vec{c} = -\frac{\sqrt{3}}{2}c\boldsymbol{i} + \frac{1}{2}c\boldsymbol{j} + 0\boldsymbol{k}$$ ……………………………………………... (6.6)

$$\vec{l}_1 = -\sqrt{3}c\boldsymbol{i} + 0\boldsymbol{j} + 0\boldsymbol{k}$$ ………………………………………………… (6.7)

$$\vec{l}_2 = -\frac{\sqrt{3}}{2}c\boldsymbol{i} + \frac{3}{2}c\boldsymbol{j} + 0\boldsymbol{k}$$ ……………………………………………… (6.8)

These vectors expressions can now be rearranged into column vectors and multiplied by the rotation matrix given by Equation (6.2). This matrix multiplication is shown below.

$$[\vec{c}'] = [\,R_z(-\propto_z)] * [\vec{c}]$$ ……………………..……………….. (6.9)

$$[\vec{c}'] = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} -\left(\sqrt{3}/2\right)c \\ (1/2)c \\ 0 \end{bmatrix}$$

……………………. (6.10)

$$[\vec{c}'] = \begin{bmatrix} -\left\{\left(\sqrt{3}/2\right)\cos\alpha\right\}c + \{(1/2)\sin\alpha\}c \\ \left\{\left(\sqrt{3}/2\right)\sin\alpha\right\}c + \{(1/2)\cos\alpha\}c \\ 0 \end{bmatrix}$$

…………………. (6.11)

$$[\vec{l}_1{}'] = [\,R_z(-\alpha_z)] * [\vec{l}_1]$$

…………………… (6.12)

$$[\vec{l}_1{}'] = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} -\sqrt{3}c \\ 0 \\ 0 \end{bmatrix}$$

……………………. (6.13)

$$[\vec{l}_1{}'] = \begin{bmatrix} -(\sqrt{3}\cos\alpha)c \\ (\sqrt{3}\sin\alpha)c \\ 0 \end{bmatrix}$$

………………………… (6.14)

$$[\vec{l}_2{}'] = [\,R_z(-\alpha_z)] * [\vec{l}_2]$$

…………………..... (6.15)

$$[\vec{l}_2{}'] = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} -\left(\sqrt{3}/2\right)c \\ (3/2)c \\ 0 \end{bmatrix}$$

…………… (6.16)

$$[\vec{l}_2{}'] = \begin{bmatrix} -\left\{\left(\sqrt{3}/2\right)\cos\alpha\right\}c + \{(3/2)\sin\alpha\}c \\ \left\{\left(\sqrt{3}/2\right)\sin\alpha\right\}c + \{(3/2)\cos\alpha\}c \\ 0 \end{bmatrix}$$

…………….. (6.17)

Equations (6.11), (6.14), and (6.17) are the final desired expressions. The prime symbol next to each vector on the left hand side of each equation denotes a transformation. Code is then written to iterate through these three expressions and determine the x and y positions of the three vectors during a full rotation of the Tri-Wheel in Inching Mode.

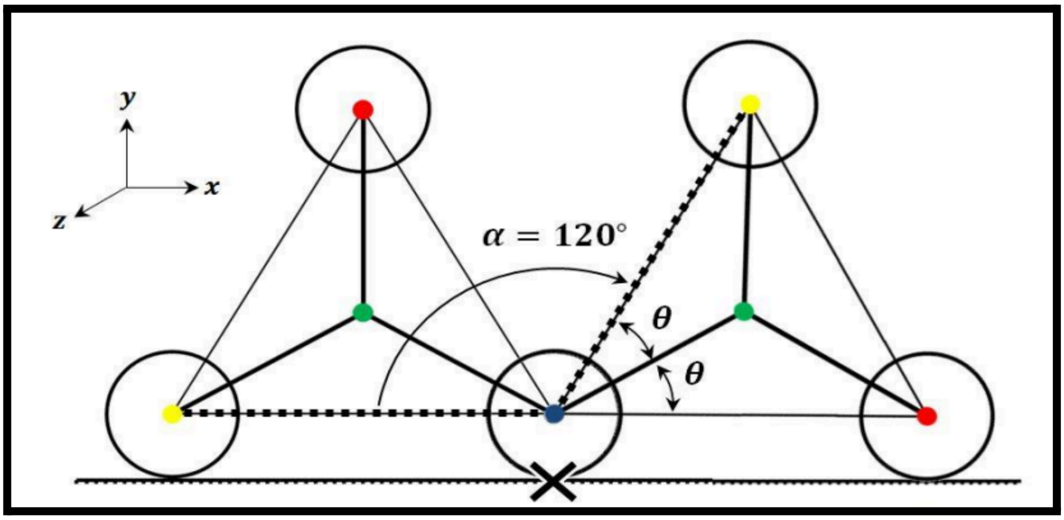


Fig. 6.7: Stable Condition

The above Fig 6.7 shows one full rotation of the mechanism. Here, the X denotes a fixed leading ground wheel such that the entire assembly can pivot and rotate about it. Because each angle in an equilateral triangle is equal to 60°, the Tri-Wheel undergoes a rotation of 120° for a full rotation. Thus, Equations (6.11), (6.14), and (6.17) are iterated through for values of $0^o < \alpha < 120^o$ and any given value of ***c.***

Once the red top wheel rotates 120° such that it is firmly planted on the ground, the red wheel is fixed in place and becomes the new leading ground wheel. It is important to note that in writing these vector expressions, the zero reference horizontal is located at the centre of the leading ground wheel.

For purposes of plotting the data, the zero horizontal will be relocated to beneath the wheels. In other words, the data obtained through the vector expressions is still valid, but it will be translated vertically to account for the wheel radius.

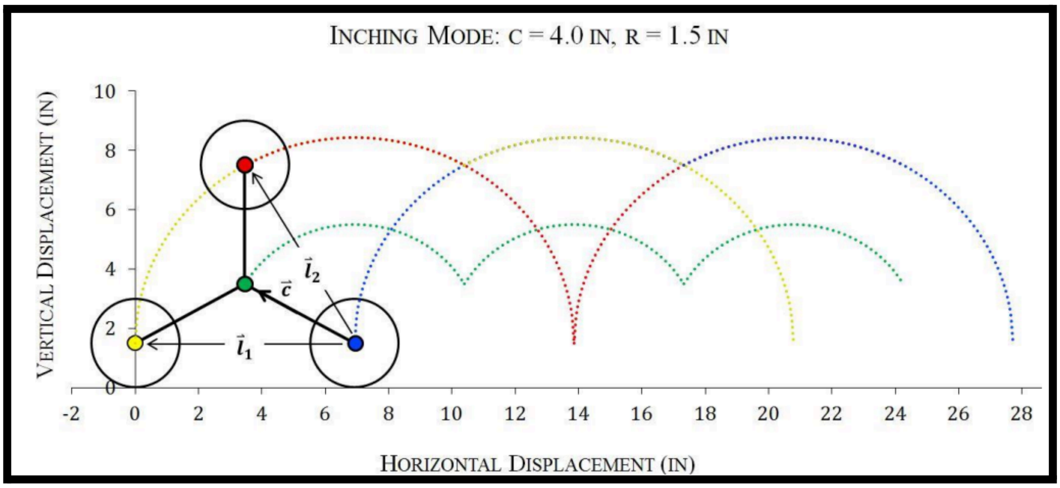


Fig. 6.8: Horizontal Displacement

From this graph, it is possible to determine what the maximum vertical displacement is and where it occurs in the rotational cycle. For this sizing, Fig 6.8 reveals that the maximum vertical displacement reached by the three wheel centres is equal to 8.43 in (21.41 cm). The maximum vertical displacement reached by the centroid is 5.5 in (13.97 cm). Another important observation is the angle of ***α*** at which the top wheel, centroid, and trailing ground wheel reach their maximum vertical displacements. The vectors reach their maximum vertical displacements as, ***l_2 at $\alpha = 30^o$, $\vec{c}$ at $\alpha = 60^o$, and $\vec{l}_1$ at $\alpha = 90^o$***.

6.3 Tri-Star Wheel Frame

The frame of a Tri-Star Wheel Structure is an essential component as it provides the necessary support and structure to the wheel system. The frame serves as a foundation that holds the wheel components together, maintains the relative position of the wheels, and ensures that the wheel assembly is aligned with the vehicle's body. Here is some of the key importance of the frame in a Tri-Star Wheel Structure:

- **Provides structural support:** The frame provides the necessary structural support for the wheels to function effectively. It also distributes the weight of the vehicle evenly across the wheels, ensuring that the wheels are not overloaded and can operate optimally.
- **Maintains the relative position of the wheels:** The frame ensures that the wheels are in the correct position relative to each other and the vehicle's body. This is

critical to ensure that the vehicle maintains stability, and the wheels operate as a single unit.

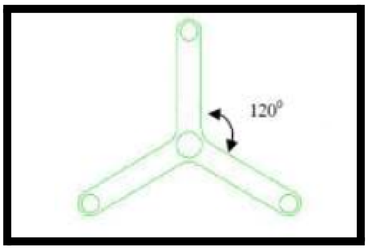
- **Enhances durability:** The frame adds strength to the wheel assembly, which improves its durability and ability to withstand stress and impact. A sturdy frame can help the wheels to withstand harsh terrains and other challenging conditions.
- **Supports additional components:** The frame provides a secure platform for mounting additional components such as motors, sensors, and other electronics that are necessary for the wheel system to operate effectively.

Overall, the frame is a crucial component in a Tri-Star Wheel Structure as it provides support, stability, and durability to the wheel system. It helps to ensure that the wheels can function effectively and that the vehicle can navigate challenging terrains safely and efficiently.

6.3.1 Types of Tri-Wheel Frame

The different types of Wheel Frames available,

- **Straight Wheel Frame**
- **Curved Wheel Frame**
- **Quasi-Planetary Wheel Frame**



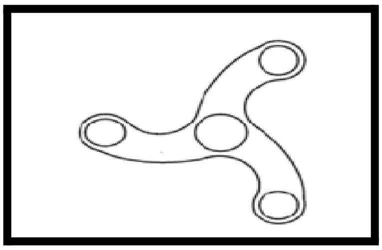


Fig. 6.9: Straight Frame **Fig. 6.10: Curved Frame**

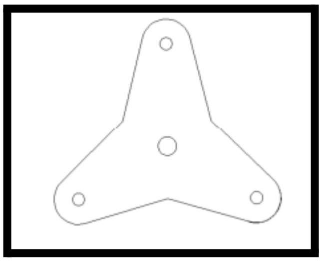


Fig. 6.11: Quasi-Planetary Wheel Frame

6.3.2 Benefits of Quasi-Planetary Wheel Frame

The Quasi Planetary Wheel Frame is a unique type of wheel frame design that can offer several benefits for Multi Terrain Climbing Vehicles. Here are some of the potential benefits:

- **Increased traction:** The quasi planetary wheel frame design allows for multiple wheels to make contact with the terrain at the same time, increasing the overall traction of the vehicle. This can be especially useful in challenging terrain conditions, such as steep inclines or loose surfaces.
- **Improved stability**: The multiple wheels on the quasi planetary wheel frame can also improve the stability of the vehicle, reducing the risk of tipping over or losing control in uneven terrain.
- **Enhanced manoeuvrability:** The quasi planetary wheel frame allows for greater manoeuvrability, as the individual wheels can move independently of each other. This can be useful for navigating around obstacles or tight spaces.
- **Reduced stress on individual wheels:** With multiple wheels sharing the load, the stress on each individual wheel is reduced, potentially increasing the lifespan of the wheels and reducing maintenance costs.

Overall, the quasi planetary wheel frame can offer several potential benefits for Multi Terrain Climbing Vehicles, making it a popular choice for certain applications.

6.3.3 Computer Aided Drawing of Quasi-Planetary Wheel Frame

Computer-Aided Drawing (CAD) is an essential tool for engineers and designers in any project, as it allows them to create and visualize 2D and 3D models of their designs before they are physically constructed as shown in figures below.

CAD software streamlines the design process and enables designers to quickly create and modify designs. This helps to save time and resources, allowing designers to focus on other important aspects of the project.

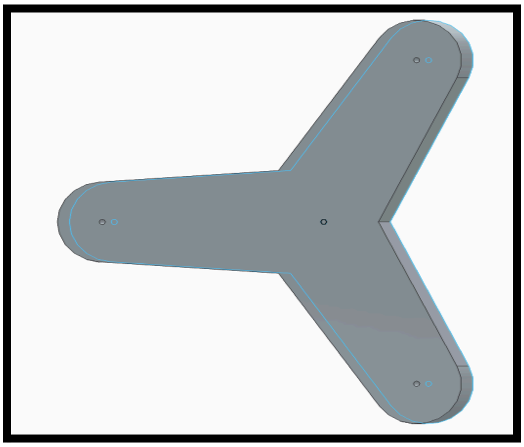


Fig. 6.12: Tri-Star Wheel CAD Model

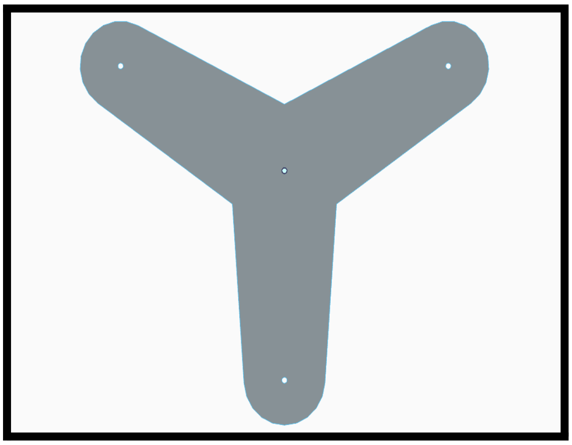


Fig. 6.13: Tri-Star Wheel Front Face

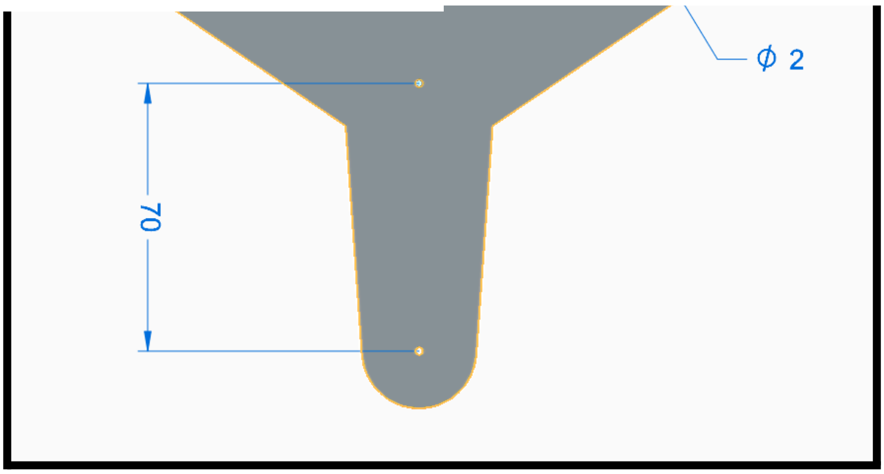


Fig. 6.14: CAD Model of Tri-Star Frame

The design of the Tri-Star Wheel Frame is made in Solid Edge 2023 Version in order to incorporate all the necessary details and features. This Frame Design is typically made to have as less as possible Stress Concentrations.

The wheel for the Tri-Star Wheel Frame is also designed in Solid Edge 2023 to have a complete assembly with the Frame as well as the Wheel for further analysis.

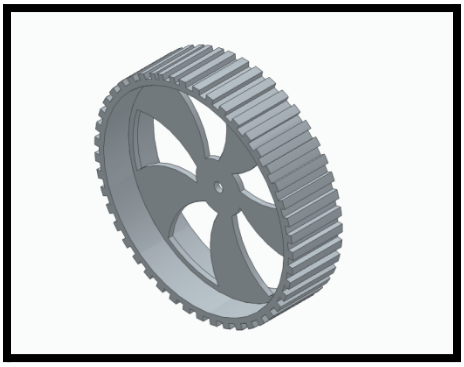


Fig. 6.15: Wheel CAD Model

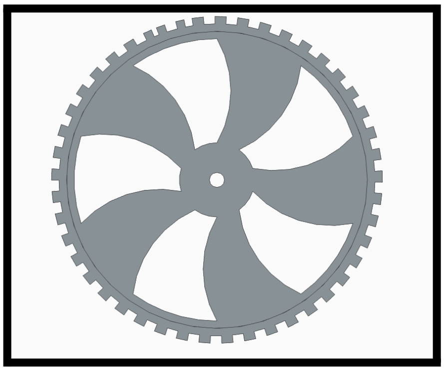


Fig. 6.16: Front Face of Wheel

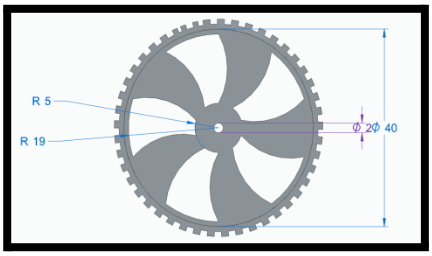


Fig. 6.17: Wheel Dimensions

6.4 Tri-Star Wheel Dimensional Parameters

Deriving the Tri-Star wheel parameters depends on the position of Tri-Star wheel on stairs. It depends on two parameters, the distance between the edge of wheel on lower stair and the face of the next stair(L1), and the distance between the edge of wheel on topper stair and the face of next stair (L2), as shown in Fig 6.18.

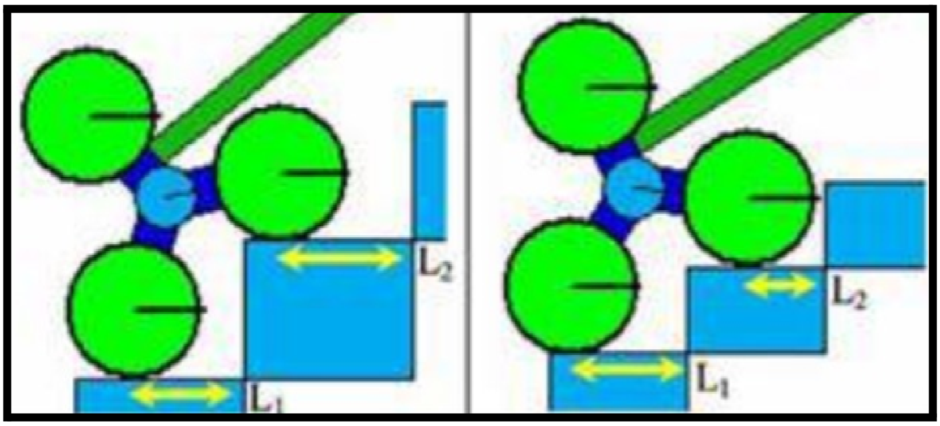


Fig. 6.18: Stair Case Parameters

By comparing these parameters, three states may occur as follow:

- **L1 < L2**
- **L1 >L2**
- **L1 = L2**

Based on these states, the third states (L1 = L2) will be used as the reference of project to design the Tri-Star wheel. In this case, the L1 and L2 don't change and remain constant while climbing stairs. Therefore the case (1) and case (2) are not suitable since the robot will encounter the problems while climbing stairs, but the case (3) is suitable for climbing robot smoothly.

It should be noted that the value of L1 and L2 for derivation of the parameters maybe any values but equal. L1 and L2 are assumed equal to the radius of angular wheel (L1=L2=r).

In the design of Tri-Star wheel, five parameters are important which are the heights of the stairs (a), width of stairs (b), radius of regular wheel (r), radius of Tri-Star wheel, the distance between the center of Tri-Star wheel and the center of its wheel (R) and the thickness of holders that fix the wheel on its place on Tri-Star wheel (2t), as shown in fig 6.19.

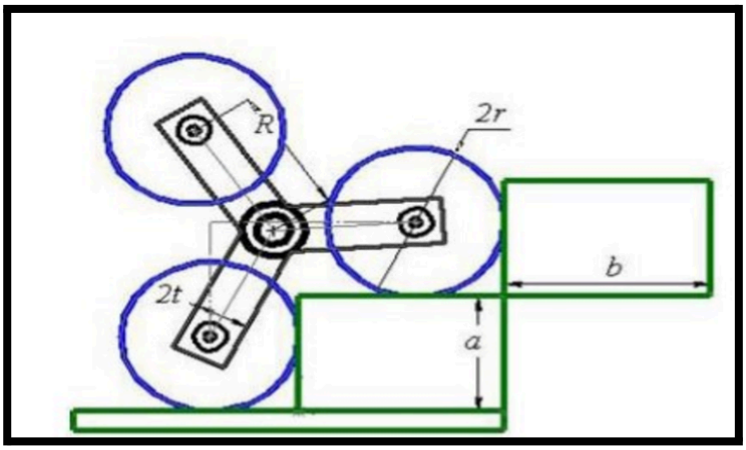


Fig. 6.19: Derivation Diagram

Tri-Star wheels have been designed for traversing stairs with height 60 mm and width 120 mm. Refer Fig 6.19, to calculate the length of the tri star plates and minimum and max radius of wheels the following formulas are used,

To calculate the distance between the Frame Centre and the Centre of the Wheel, the following formula is used.

$$R = \sqrt{\left(\left(a^2 + b^2\right)/3\right)}$$ ………………………………………………………………..

(6.18)

Where ***"a"*** is the Height of the Stair = 60 mm and ***"b"*** is the Width of the Stair = 120 mm.

Thus, using this ***"R = 77.45 mm ".*** Thus, this value of ***"R"*** is used to determine the basic dimension of Tri Star Wheel.

The minimum value radius of regular wheel (r_{min}) to prevent collision of the holders the stair is derived as ,

$$r_{min} = \frac{6Rt + a(3b + \sqrt{3}a)}{(3-\sqrt{3})a + (3+\sqrt{3})b}$$ ………………………………………………………… (6.19)

Thus, the value of r_{min} is obtained as, r_{min} ***= 35.516 mm.***

The maximum value radius of the regular wheels (r_{max}) to prevent the collision of the wheels together is,

$$r_{max} = \sqrt{\frac{a^2+b^2}{2}} \quad \text{.......... (6.20)}$$

The value so obtained is, r_{max} = ***94.868 mm***.

Mean value of Radius***(r) = 65.192 mm***

Maximum allowable height of stair,

$$a_{max} = \sqrt{3R^2 - r^2} \quad \text{.......... (6.21)}$$

The value is obtained as, a_{max} = ***117.24 mm***

Designed height is much lower than the allowable height.

6.5 Profile Analysis of Tri-Star Wheel on Staircase

The profile analysis of a Tri-Star wheel on a staircase involves analysing the shape and dimensions of the wheel to ensure that it can navigate the stairs safely and effectively. Here are some key factors to consider when performing a profile analysis of a Tri-Star wheel on a staircase:

1. **Wheel diameter:** The diameter of the Tri-Star wheel is an important factor to consider as it impacts the clearance height of the wheel when moving up or down stairs. The diameter of the wheel must be small enough to clear the stairs but large enough to provide stability and support.
2. **Tread width:** The width of the tread on the Tri-Star wheel is also an important factor to consider as it affects the stability of the wheel while on the stairs. The tread width should be wide enough to provide stability but not too wide that it cannot fit comfortably between the stairs.

3. **Frame height:** The height of the Tri-Star wheel frame is critical in determining the clearance of the wheel when navigating the stairs. The frame should be designed to provide enough clearance between the stairs while still maintaining stability and support for the user.
4. **Wheelbase:** The wheelbase of the Tri-Star wheel is critical in determining the stability of the wheel while on the stairs. The wheelbase should be designed to provide enough stability and support while still allowing for manoeuvrability on the stairs.

In summary, performing a profile analysis of a Tri-Star wheel on a staircase as shown in fig 6.20 and fig 6.21 involves analysing the shape and dimensions of the wheel to ensure that it can navigate the stairs safely and effectively.

Factors to consider include the wheel diameter tread width, frame height, axle length, and wheelbase.

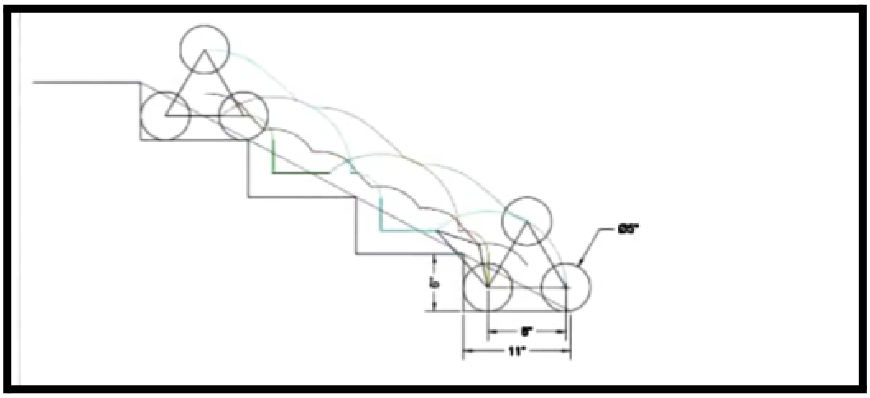


Fig. 6.20: Profile Analysis for Wheel Diameter 3.8 Cm

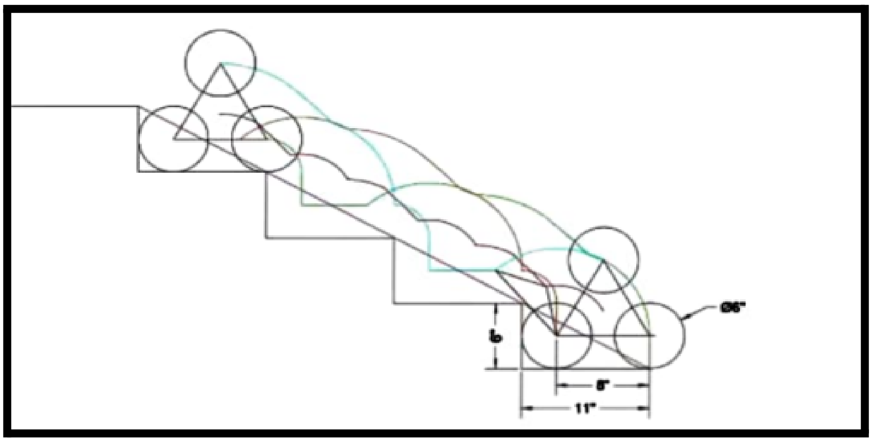


Fig. 6.21: Profile Analysis for Wheel Diameter 4.6 Cm

6.6 Computer Aided Drawing of the Final Assembly of MTCV

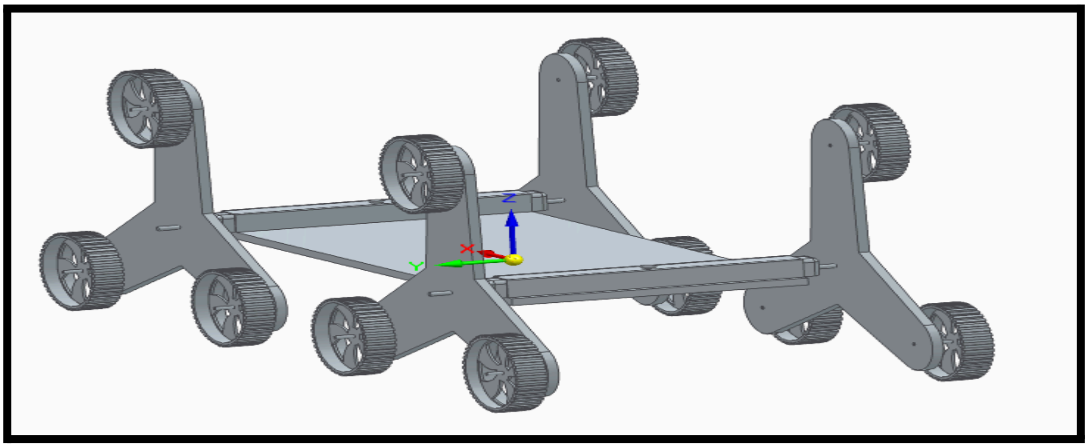


Fig. 6.22: Isometric View of MTCV

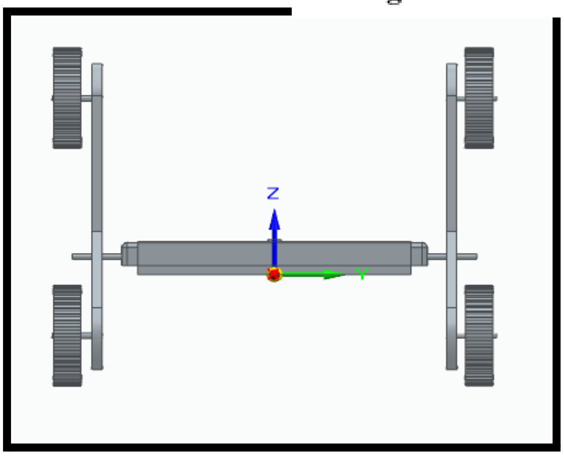


Fig. 6.23: Front View of MTCV

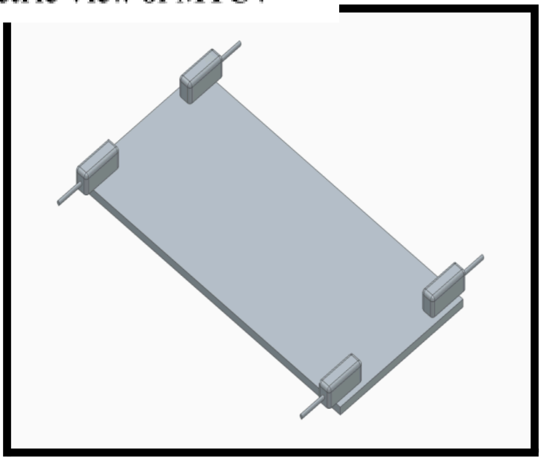


Fig. 6.24: Top View of MTCV Body

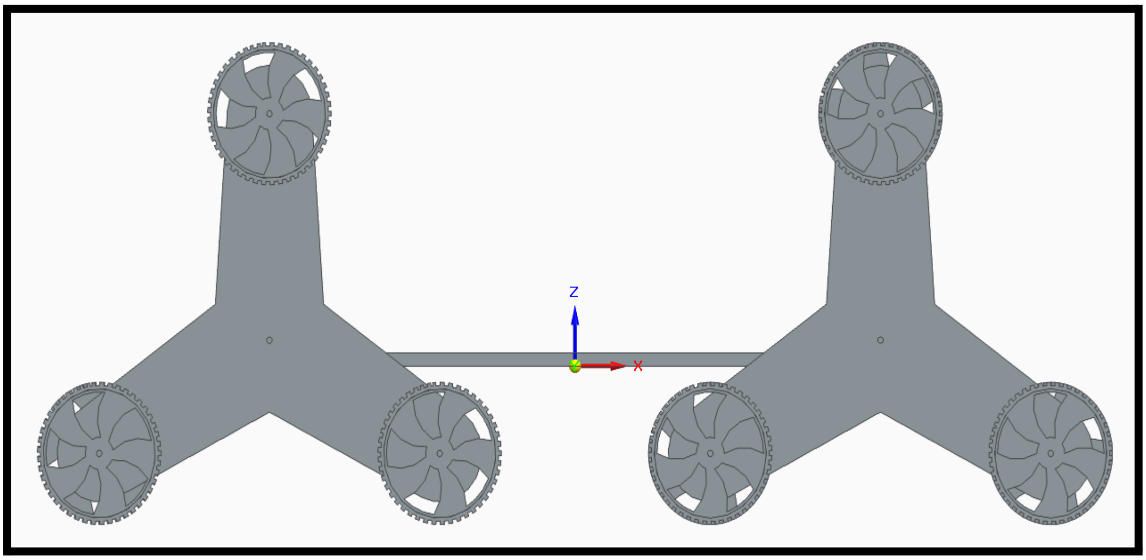


Fig. 6.24: Side View of MTCV Body

CHAPTER 7

FABRICATION OF MULTI-TERRAIN CLIMBING VEHICLE

7.1 Introduction

The fabrication of a multi-terrain climbing vehicle involves several steps and processes. Here are some of the key steps involved:

- **Design:** The first step in the fabrication process is to design the multi-terrain climbing vehicle. This involves creating a 3D model of the vehicle using computer-aided design (CAD) software. The design should take into account the vehicle's intended use, terrain, and required capabilities.

- **Material selection:** Once the design is complete, the next step is to select the materials for the vehicle. Common materials used for multi-terrain climbing vehicles include aluminum, carbon fiber, and titanium. The choice of material will depend on the vehicle's intended use, weight, and strength requirements.
- **Cutting and shaping:** The next step is to cut and shape the materials into the desired size and shape. This can be done using a variety of tools and techniques, including CNC machines, laser cutters, and water jets.
- **Assembly:** The assembly process involves attaching the wheels, and other components to the frame.
- **Electrical and mechanical systems:** The next step is to install the electrical and mechanical systems. This includes the motor, battery, controller, and other components that are necessary for the vehicle to operate.
- **Testing and debugging:** Once the vehicle is assembled, it is important to test and debug the system to ensure that it functions properly. This involves running the vehicle through a series of tests to check its performance and identify any issues that need to be addressed.

- **Finishing:** The final step is to finish the vehicle. This involves painting the vehicle and adding any other finishing touches that are necessary to complete the fabrication process.

In summary, the fabrication of a multi-terrain climbing vehicle involves several steps, including design, material selection, cutting and shaping, assembly, electrical and mechanical systems, testing and debugging, and finishing. The process requires a combination of specialized skills and expertise in a variety of areas, including engineering, fabrication, and electronics.

7.2 Material Selection for the Multi-Terrain Climbing Vehicle

7.2.1 Criteria for Material Selection

The criteria for material selection for a multi-terrain climbing vehicle depend on various factors, including the vehicle's intended use, weight, strength requirements, durability, and cost. Here are some common criteria that can be used to guide material selection for a multi-terrain climbing vehicle:

- **Strength:** The material should be strong enough to support the weight of the vehicle and withstand the forces that it will encounter while climbing on different terrains. High-strength materials like aluminium, carbon fibre, and titanium are commonly used for this purpose.
- **Weight:** The material should be lightweight to ensure that the vehicle is not too heavy and can move efficiently on different terrains. Lightweight materials like carbon fibre and aluminium are commonly used for this purpose.
- **Durability:** The material should be durable enough to withstand wear and tear from exposure to different terrains and weather conditions. Materials like titanium and stainless steel are known for their durability and resistance to corrosion.
- **Cost:** The material should be cost-effective, especially for large-scale production. Materials like aluminium and steel are often more cost-effective compared to exotic materials like carbon fibre or titanium.
- **Availability:** The material should be readily available in the market. This ensures that there is a steady supply of materials for production and avoids delays due to material shortages.
- **Machinability:** The material should be easy to machine and fabricate. Materials that are difficult to machine can lead to increased production costs and lead times.
- **Eco-friendliness:** The material should be environmentally friendly, with minimal environmental impact during production and disposal. Recyclable materials like aluminium and steel are commonly used for this purpose.

In summary, the criteria for material selection for a multi-terrain climbing vehicle depend on various factors, including strength, weight, durability, cost, availability, machinability, and eco-friendliness. Careful consideration of these factors can help to ensure that the materials selected are appropriate for the intended use of the vehicle and that the vehicle is durable, efficient, and cost-effective.

7.2.2 Polypropylene Plastic (PP) As A Material for Tri-Star Wheel Frame

Polypropylene is a type of thermoplastic polymer that is commonly used in a variety of applications due to its high strength, low density, and good chemical resistance. It is also relatively inexpensive and easy to manufacture, making it a popular choice for a range of products. When it comes to using polypropylene for the Tri-Star wheel frame, there are a few advantages and disadvantages to consider:

Advantages:

- **Lightweight:** Polypropylene is a lightweight material, which is important for the Tri-Star wheel frame to reduce the overall weight of the vehicle.
- **Good strength:** Polypropylene has good strength and stiffness, which makes it suitable for use in a range of structural applications.
- **Good chemical resistance:** Polypropylene has good resistance to chemicals, making it suitable for use in harsh environments.
- **Cost-effective:** Polypropylene is a relatively inexpensive material, which makes it a cost-effective option for manufacturing the Tri-Star wheel frame.

Disadvantages:

- **Low temperature resistance:** Polypropylene has a relatively low melting point and can become brittle at low temperatures, which may limit its use in certain applications.
- **Low impact resistance:** Polypropylene has lower impact resistance compared to other materials like polycarbonate, which may be a concern in high-impact applications.

Overall, polypropylene can be a suitable choice for the Tri-Star wheel frame as shown in Fig 7.1 due to its lightweight, good strength, and cost-effectiveness. However, its low temperature and impact resistance should be taken into consideration, and it may not be the best choice for applications where these factors are critical.

Fig. 7.1: PP Material Frame

7.2.3 Selection of Wood against Polypropylene Plastic For Tri Star Wheel Frame

There are several advantages of choosing wood over polypropylene plastic for the Tri-Star wheel frame, including:

- **Aesthetic appeal:** Wood has a natural, warm appearance that many people find appealing. The grain patterns and colours of wood can also provide a unique, one-of-a-kind look that is difficult to achieve with plastic.
- **Environmentally friendly:** Wood is a renewable resource that is biodegradable and has a lower carbon footprint than plastic. Choosing wood over plastic for the Tri-Star wheel frame can be an environmentally conscious decision.
- **Strength and durability:** They are incredibly strong and durable. They can withstand heavy loads, impacts, and other stresses without deforming or breaking.
- **Customization:** Wood can be easily cut, carved, and shaped to fit specific design requirements. This allows for a high degree of customization in the Tri-Star wheel frame's shape and size.
- **Low thermal conductivity:** Wood is a poor conductor of heat, which means that it can insulate against extreme temperatures. This can be an advantage in certain

environments where the Tri-Star wheel frame may be exposed to extreme heat or cold.

Thus, choosing wood over polypropylene plastic for the Tri-Star wheel frame as shown in Fig 7.2 can provide a unique and aesthetically appealing look, while also being environmentally friendly, strong and durable, customizable, and a good insulator.

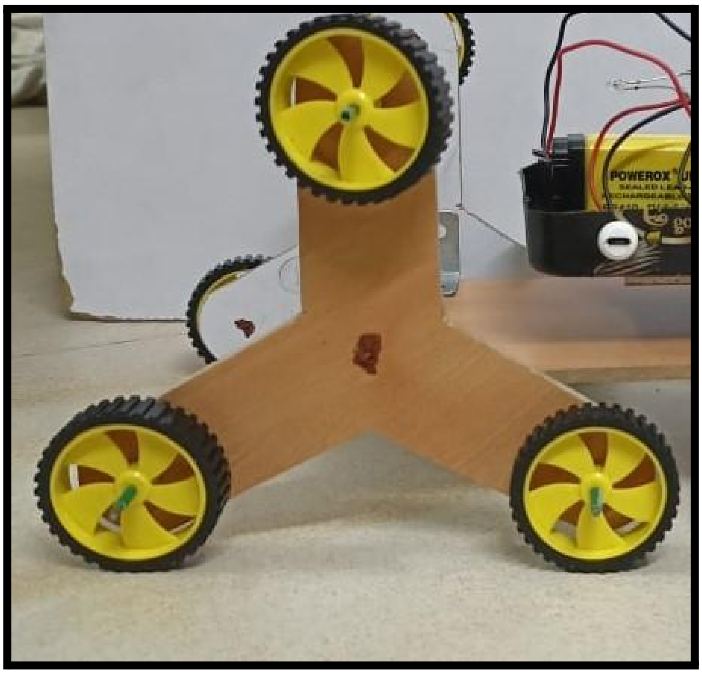


Fig. 7.2: Wood Tri-Star Wheel Frame

7.2.4 Mechanical Properties of Wood

Wood is a natural material that has been used for thousands of years in various applications, including construction, furniture, and tools. Here are some of the key mechanical properties of wood:

- **Strength:** The strength of wood varies depending on the species, grade, and direction of the grain. Wood is strongest along the direction of the grain and weaker perpendicular to it.
- **Stiffness:** Wood is a relatively stiff material, meaning that it resists bending and deformation. Again, the stiffness of wood depends on the species, grade, and direction of the grain.

- **Hardness:** Wood hardness is measured using the Janka hardness test. This measures the force required to embed a steel ball into the wood to a depth of half its diameter. Hardness varies widely among wood species.
- **Toughness:** Wood is a tough material that can absorb energy without breaking. This property makes it suitable for applications where impact resistance is important.
- **Density:** Wood has a relatively low density compared to metals and plastics, which can make it a good choice for applications where weight is a concern.

Moisture content: Wood is hygroscopic, which means it can absorb and release moisture. The mechanical properties of wood are affected by its moisture content. Wood that is too wet or too dry can be weaker and less durable. Refer to its properties in fig 7.3.

Parameter name	Value	Units
Density	400	kg/m^3
Young's modulus in axial direction (wood fiber direction)	11	GPA
Young's modulus in transversal* direction	0.37	GPA
Shear modulus	0.69	GPA
Poisson's ratio v_{ar}**	0.4	-
Poisson's ratio v_{rt}**	0.01	-
Poisson's ratio v_{at}**	0.4	-
Bulk modulus	10	GPA
Shear strength	2.5	MPA
Longitudinal strength	20	MPA
Transversal strength in tension	0.5	MPA
Transversal strength in compression	2	MPA

Fig. 7.3: Mechanical Properties of Wood

7.2.5 Material for the Wheels of Multi-Terrain Climbing Vehicle

The wheel is particularly made up of Reinforced Nylon Rubber with PVC Plastic inside frame as shown in Fig 7.4.Reinforced nylon rubber is a composite material that combines the properties of nylon and rubber. Here are some of the key properties of reinforced nylon rubber:

- **High strength:** Reinforced nylon rubber has high tensile strength and can withstand high levels of stress and strain.
- **Abrasion resistance**: The addition of rubber to nylon enhances the material's ability to resist abrasion and wear, making it suitable for applications where friction and impact are present.

- **Chemical resistance**: Reinforced nylon rubber is resistant to many chemicals, oils, and solvents, making it useful in harsh environments.
- **Flexibility:** The rubber in reinforced nylon rubber improves the material's flexibility and ability to bend and flex without cracking.
- **Noise reduction**: Reinforced nylon rubber can also help reduce noise and vibration in applications where these are a concern.
- **Thermal stability:** Reinforced nylon rubber has good thermal stability and can maintain its properties at high temperatures.

Fig. 7.4: Nylon Reinforced Rubber Wheel

Reinforced nylon rubber is a high-strength material with good abrasion resistance, chemical resistance, and flexibility. These properties make it useful in a wide range of applications, including automotive parts, industrial equipment, and consumer products.

7.2.6 Wood with Aluminum as A Body For Multi Terrain Climbing Vehicle

Using wood with an aluminium frame as the body for a multi-terrain climbing vehicle as shown in Fig 7.5 and Fig 7.6 can offer several advantages:

- **Lightweight:** Wood is a lightweight material compared to many metals and plastics, making it a good choice for the body of a climbing vehicle. An aluminium frame can provide additional strength while still keeping the overall weight low.
- **Strength:** While wood may not be as strong as some other materials, it can be reinforced with an aluminium frame to provide additional strength and durability.

- **Flexibility:** Wood is a relatively flexible material, which can help absorb shocks and vibrations when the vehicle is moving over rough terrain.
- **Sustainability:** Wood is a renewable resource, and using it as a material for the vehicle body can be more environmentally friendly than using non-renewable materials.
- **Aesthetics:** Wood can provide a unique and attractive appearance for the vehicle, which can be appealing to some users.

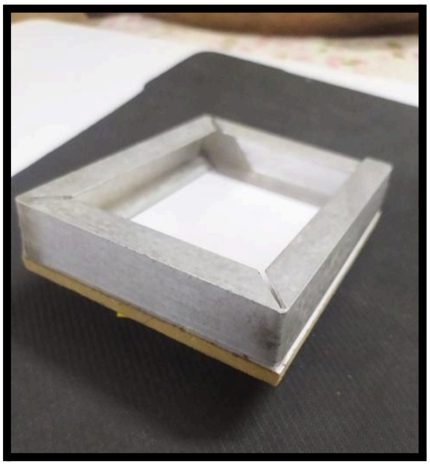


Fig. 7.5: MTCV Body

(Al Frame)

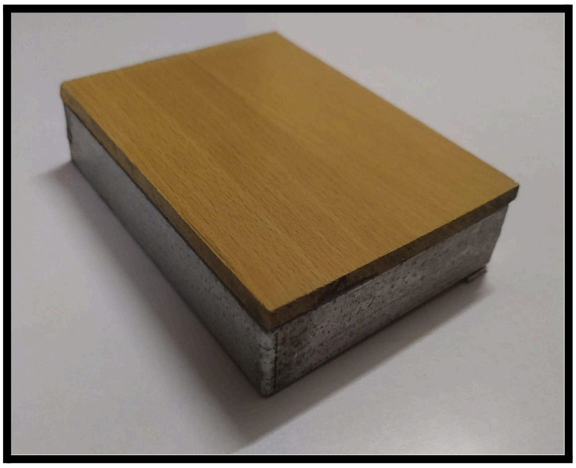


Fig. 7.6: Top View of MTCV Body

7.3 Fabrication of Multi-Terrain Climbing Vehicle

The fabrication of MTCV involves various steps of making the Tri-Star Wheel assembly, Electronic circuitry and the Body of the Vehicle.

7.3.1 Making of the Tri-Star Wheel

Here are some general steps for making a Tri-Star Wheel frame from wood using sawing techniques:

- **Materials:** Gather the materials needed, including wood boards of appropriate size and thickness, saws (such as a table saw, band saw, or jigsaw), measuring tools (such as a ruler or tape measure), and clamps.

- **Design:** Develop a design or blueprint for the Tri-Star Wheel frame, taking into consideration the required dimensions and any specific design features required.
- **Cut wood**: Use a saw to cut the wood into the required lengths and shapes, according to the design. For example, use a table saw to cut straight lines and angles, or a jigsaw to cut curves or intricate shapes.
- **Sanding:** Sand the wood pieces to smooth any rough edges and create a uniform surface for joining.
- **Joining:** Use wood glue and clamps to join the wood pieces together, following the design. Allow the glue to dry completely before proceeding.
- **Finishing:** Sand the assembled Tri-Star Wheel frame to create a smooth surface, and apply any desired finishes, such as paint or varnish.
- **Assembly:** Once the Tri-Star Wheel frame is complete, it can be attached to the Tri-Star wheels and any other necessary components to create a functional assembly.

It is important to note that the specific techniques and tools used may vary depending on the available equipment and the desired design. It is also important to follow proper safety procedures when working with saws and other cutting tools.

Fig. 7.7: Cutting of Wood Frame

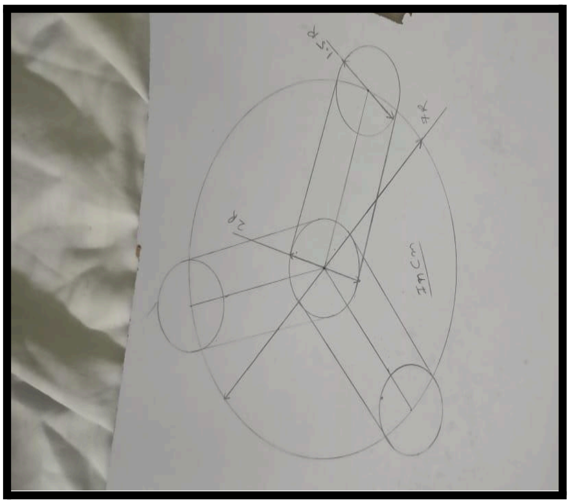


Fig. 7.8: Design of Wood Frame

The above Fig 7.8 depicts the Design of Tri-Star Wheel Frame on the wood in order to carve out the exact frame with accurate dimensions. Fig 7.7 depicts the Sawing of Wood using a Saw. This process was done under utmost safety. Accurate carving out of the durable Tri-Star Wheel frame was thus obtained.

Fig. 7.9: Sanding of Wood Frame

Fig. 7.10: Final Wood Frame

Fig 7.9 depicts the Sanding of the Wheel Frame on an Abrasive surface in order to have good finishing and close tolerances. It also helps in having smooth semi-circle curves at the end of the Frame.

Fig 7.10 depicts the Final Frame for the Tri-Star Wheel assembly. After this, necessary holes are drilled in order to complete the assembly with Wheels.

7.3.2 Making of Body of Multi-Terrain Climbing Vehicle

The body of the Multi-Terrain Climbing Vehicle is made with wood as the base and Aluminium as the lining or the boundary of the body to have durability for the electronic circuitry involving heavy battery. The aluminium lining on the outside is made by applying force on the Aluminium strip at certain angles at regular intervals to have a square shaped body. On the top, a wooden piece of same dimension is provided.

7.3.3 Electronic Circuitry

- **Gear Motor(Qty. – 4):** A gear motor as shown in Fig 7.11 is a mechanical system consisting of an electric motor and a gearbox containing a series of gears. The function of the gearbox coupled to the motor is to reduce its speed and increase its torque to do a given job at a given speed. A gear motor is a motor designed with an integrated gearbox. Gear motors function as torque multipliers and speed reducers thus requiring less power to move a given load. The design of the gearbox structure, type of gears, lubrication and type of coupling affects its performance.

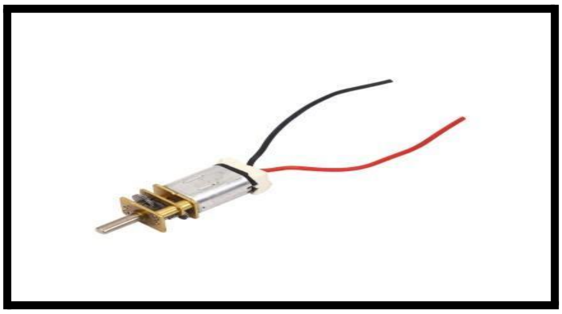


Fig. 7.11: DC Gear Motor

- **LED Indicator:** LED indicators are illuminated components used to show the status of a function, a battery, or electronics.

- **Resistor (1K Ohm ± 5% 1/4W):** Resistor as shown in Fig 7.12 is defined as a passive electrical component with two terminals that are used for either limiting or regulating the flow of electric current in electrical circuits. The main purpose of resistor is to reduce the current flow and to lower the voltage in any particular portion of the circuit.

Fig. 7.12: Resistor

- **P-N Diode:** A p–n diode is a type of semiconductor diode based upon the p–n junction. The diode conducts current in only one direction, and it is made by joining a p-type semiconducting layer to an n-type semiconducting layer.
- **DC 5V Battery and Switch**
- **Female B-Type USB**

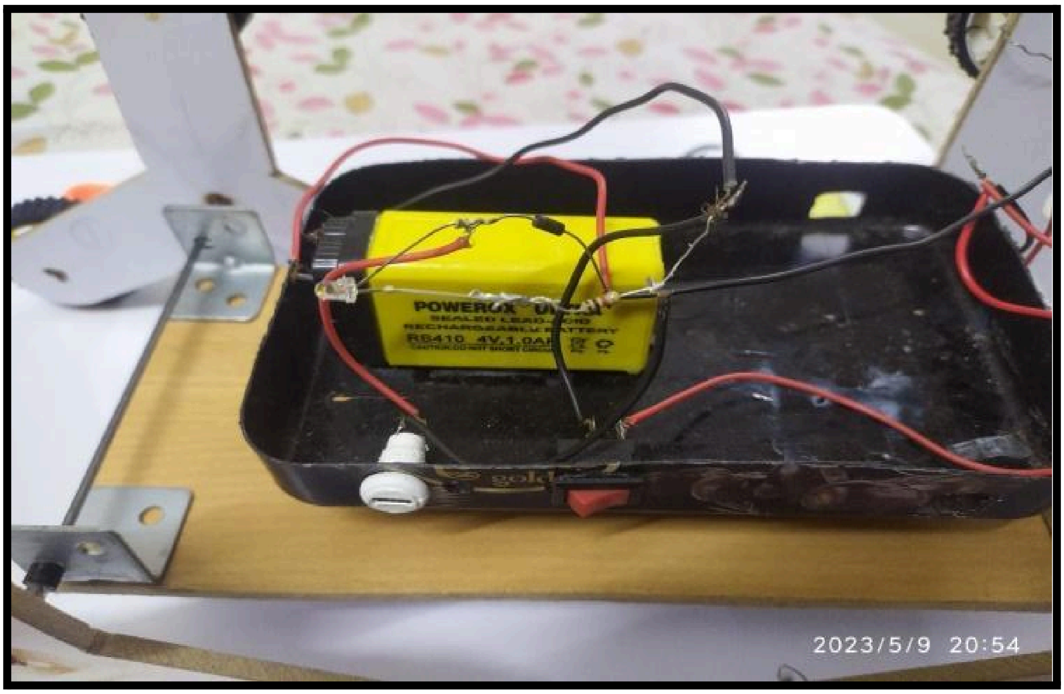


Fig. 7.13: Electronic Circuitry

7.3.4 Initial Design of Multi-Terrain Climbing Vehicle

The initial assembly of the MTCV included a Single Trailing Wheel at the back with Poly-Propylene Plastic Frame. Though, the making was more economical we had one major drawback. The Vehicle while trying to climb the even or uneven surfaces had a lot of Vibrations. Due to this, it created an imbalance in the vehicle. Thus, we had to replace the material for the frame, such that its durable and it could hold the electronic circuitry without creating much dis-balance in the Vehicle. Thus, we decided to switch from Poly-Propylene Plastic Frame to a Wood Frame, in order to solve this issue as shown in fig 7.14 and fig 7.15.

Fig. 7.14: Initial Design of MTCV with PP Frame

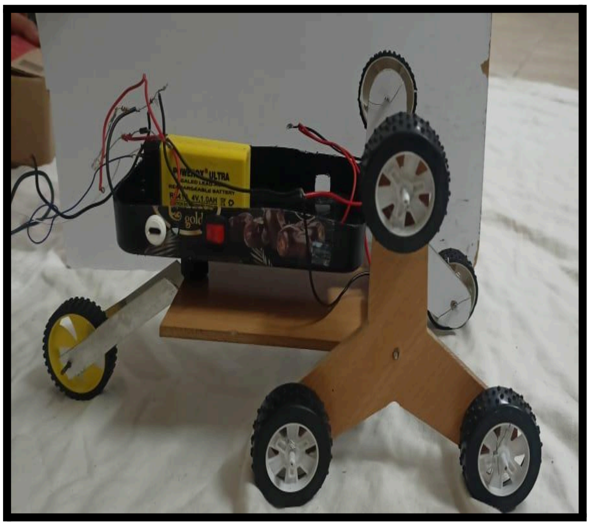


Fig. 7.15: Initial Design of MTCV with Wood Frame

Though the problem of excessive vibrations and misbalance was solved using a wooden frame for the Tri-Star Wheel assembly, there was a major issue in its application.

The vehicle was able to climb the obstacles from its front where the Tri-Star Wheel existed, but it couldn’t climb from its rare end having a trailing wheel, causing it to get stuck at back as shown in Fig 7.16.

This resisted the MTCV to climb higher altitude terrains and thus we needed a substitute for the Trailing Wheel as it was adding no design value to the system.

Fig. 7.16: Problems in Initial Design

7.3.5 Final Design of Multi-Terrain Climbing Vehicle

In order to overcome this issue, we thought of adding two more Tri-Star Wheels at the back of the MTCV. This will help in crossing any stairs or uneven terrain with utmost ease. Thus, instead of 2 Tri-Star Wheel Assembly we made use of 4 Tri-Star Wheel assemblies, such that it could easily climb surfaces like Stairs or any difficult terrain for that matter as shown in Fig 7.17 and Fig 7.18.

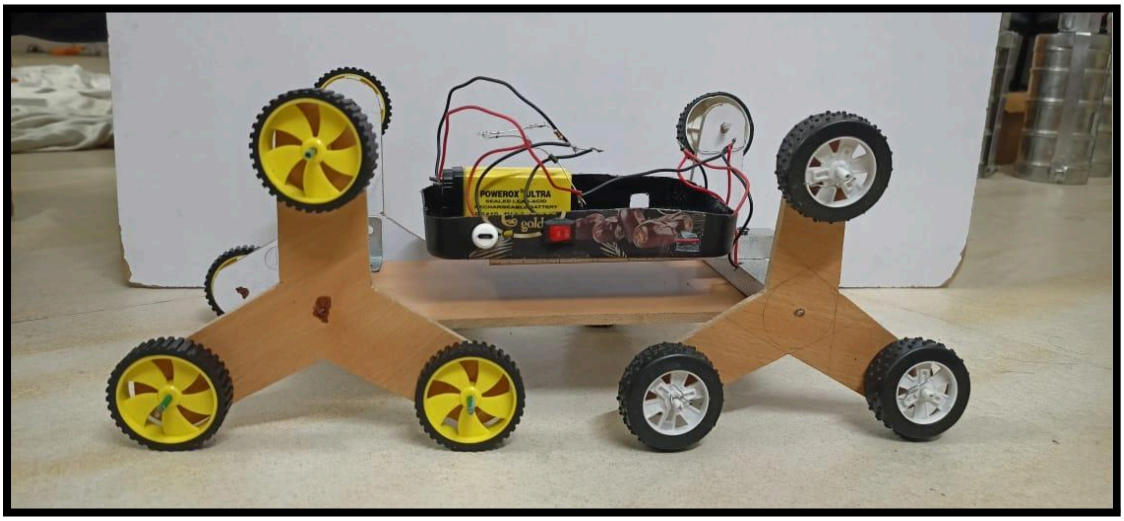


Fig. 7.17: FINAL DESIGN OF MTCV

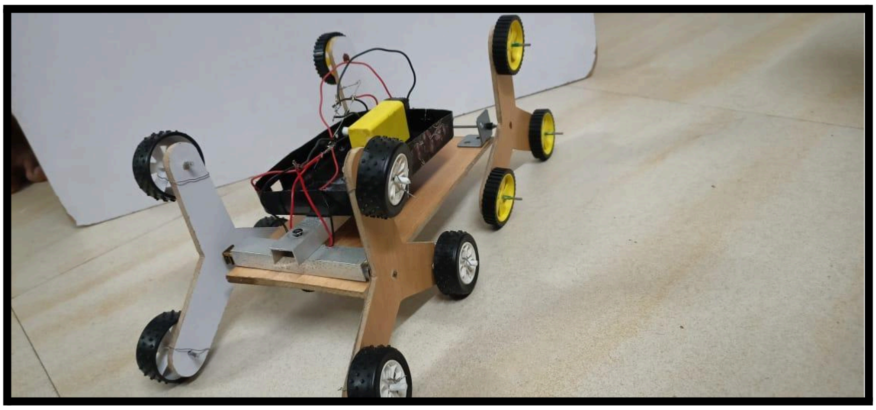


Fig. 7.17: FINAL DESIGN OF MTCV

After utilising Four Tri-Star Wheel Assembly with Wooden Frame, we could solve the basic difficulties with the MTCV. The vehicle was now very stable in climbing up the obstacles with absolutely no problem with either front or the rare end of the vehicle. This resulted in smooth functioning of the Multi-Terrain Climbing Vehicle.

7.4 Cost Estimation of the Project

Table 7.1: Cost Estimation of the Project

S.No	Item	Description	Rate	Quantity	Price
1.	Gear Motor	N20 12v Dc 600rpm Micro Metal Gear Motor	Rs. 129/- per motor	4	Rs. 516
2.	Wheels for MTCV	Nylon Reinforced Rubber Wheel	Rs. 25/- per Wheel	12	Rs. 300
3.	Battery	4V 1.0AH Rechargeable Battery	Rs. 28	1	Rs. 28
4.	Resistor	1K Ohm ± 5% 1/4W	Rs. 8	1	Rs. 8
5.	LED Indicator	Red LED Indicator	Rs. 10	1	Rs. 10
6.	Connecting Wires	Black and Red Connecting Wires	-	-	-
7.	P-N Diode		Rs.9	1	Rs. 9
8.	Female USB	B-Type		1	
9.		For Frame and Body(Reused from Hostel)	-	-	-
10.	Aluminium	Body Frame(Reused from Hostel)	-	-	-
11.	Switch	One-Way DC Switch	Rs.12	1	Rs.12

	TOTAL		Rs. 883

CHAPTER 8

ANALYSIS OF TRI-STAR WHEEL FRAME

8.1 Introduction

The analysis of a Tri-Star wheel frame, or any mechanical component, is essential for several reasons:

- **Structural Integrity:** Analysing the Tri-Star wheel frame helps ensure its structural integrity. By examining the design and materials used, engineers can identify potential weak points, stress concentrations, or areas susceptible to failure. This analysis enables them to make necessary modifications or improvements to enhance the overall strength and durability of the frame.
- **Performance Optimization:** Analysis allows engineers to optimize the performance of the Tri-Star wheel frame. They can evaluate factors such as weight distribution, aerodynamics, and vibration characteristics to improve efficiency, reduce energy consumption, and enhance handling capabilities. By understanding how different design variations affect performance, engineers can make informed decisions to achieve the desired outcomes.
- **Safety Considerations:** The analysis of the Tri-Star wheel frame is crucial for ensuring safety. By subjecting the frame to various simulated scenarios, engineers can assess its behaviour under different loads, impacts, or environmental conditions. This analysis helps identify potential hazards, structural weaknesses, or failure modes, allowing engineers to implement necessary measures to mitigate risks and ensure the safety of users.
- **Cost Optimization:** Analysing the Tri-Star wheel frame helps in cost optimization throughout its lifecycle. By identifying areas of over-engineering or unnecessary complexity, engineers can streamline the design and manufacturing process, reducing material and production costs. Furthermore, understanding the performance characteristics can guide decisions on selecting appropriate materials

and manufacturing techniques, minimizing expenses without compromising quality or reliability.

- **Innovation and Iteration:** Analysis provides insights that drive innovation and iteration. By simulating and evaluating different design variations, engineers can explore new concepts, assess their feasibility, and identify opportunities for improvement. This iterative process allows for continuous refinement and innovation, leading to the development of superior Tri-Star wheel frames that meet evolving market demands and user expectations.

8.2 About the Software

ANSYS software is a powerful engineering simulation tool widely used for analysis and design optimization in various industries. It offers a comprehensive suite of simulation capabilities that allow engineers to analyse and solve complex engineering problems. ANSYS software provides a broad range of analysis capabilities across multiple disciplines, including structural analysis, fluid dynamics (CFD), electromagnetics, and multiphasic simulations. It enables engineers to simulate and analyse the behaviour of components, systems, or processes under different operating conditions.

8.3 Structural Analysis in ANSYS Software

Steady state structural analysis is a type of structural analysis that examines the behaviour of a structure under constant or unchanging load conditions. In this analysis, the loads applied to the structure remain constant over time, and the structure reaches a state of equilibrium where the internal forces and deformations stabilize.

Key aspects of steady state structural analysis include:

- **Load Determination:** The first step in steady state analysis is to determine the external loads acting on the structure. These loads can include dead loads (permanent weights of the structure and its components), live loads (temporary or variable loads), and environmental loads (such as wind or seismic forces).
- **Equilibrium Analysis:** Once the loads are determined, the structural analysis involves solving the equilibrium equations.

This involves calculating the internal forces, deformations, and stresses within the structure to ensure that the structure is in a state of equilibrium.

- **Material Properties:** The analysis considers the material properties of the structure, such as the elastic modulus, Poisson's ratio, and yield strength. These properties determine how the structure responds to the applied loads and influences factors like stiffness, strength, and deformation behaviour.
- **Boundary Conditions:** The analysis takes into account the boundary conditions, which specify how the structure is supported or restrained. These conditions include fixed supports, pinned connections, or rollers, and they affect the distribution of forces and displacements within the structure.
- **Deformation and Stress Analysis:** Steady state analysis examines the deformations and stresses within the structure under the applied loads. This analysis helps determine factors like displacements, rotations, bending moments, shear forces, and axial forces, providing insights into the structural behavior and identifying critical areas of stress concentration.
- **Factor of Safety:** In steady state structural analysis, a factor of safety is often applied to ensure that the structure can safely withstand the applied loads. The factor of safety accounts for uncertainties in material properties, loading conditions, and other factors to provide a margin of safety against failure.

8.3.1 Steps to Perform Structural Analysis

Performing a structural analysis typically involves several steps to accurately assess the behaviour and response of a structure. Here is a generalized outline of the steps involved in structural analysis:

- **Problem Definition:** Clearly define the objective and scope of the structural analysis. Identify the type of structure, its purpose, and the specific conditions or constraints to be considered during analysis.

- **Geometry Modelling:** Create a geometric representation of the structure using appropriate software or tools. This involves defining the shape, dimensions, and connectivity of structural elements such as beams, columns, plates, or shells.

- **Material Properties:** Assign material properties to the structural elements. This includes specifying characteristics such as elastic modulus, Poisson's ratio, density, and yield strength. The choice of material properties depends on the actual materials used in the structure.
- **Boundary Conditions:** Define the boundary conditions that represent how the structure is supported or restrained. These conditions include fixed supports, pinned connections, rollers, or any other constraints. Properly defining boundary conditions is crucial for accurate analysis results.
- **Loadings:** Apply the relevant loads to the structure. These loads can include dead loads (permanent weights), live loads (variable loads), environmental loads (wind, seismic), or any other specified loads. Determine the magnitude, direction, and distribution of the loads based on the design requirements and relevant standards.
- **Mesh Generation:** Divide the structure into finite elements using meshing techniques. Meshing involves discretizing the structure into smaller elements to simplify the analysis process. The mesh density should be chosen carefully to ensure accurate representation of the structure and capture critical areas of stress concentration.
- **Analysis Setup:** Set up the analysis parameters and options. Select the appropriate analysis method, such as finite element analysis (FEA), and choose the desired analysis type (static, dynamic, buckling, etc.). Specify any additional analysis settings, such as convergence criteria or solution techniques.
- **Solve and Simulate:** Run the structural analysis using the chosen software or numerical methods. The analysis software will solve the equilibrium equations and calculate the structural responses, such as displacements, stresses, and strains, based on the applied loads and boundary conditions.

8.3.2 Meshing and Boundary Conditions for Analysis

In numerical simulations, meshing is the process of dividing a complex geometry into a collection of smaller, interconnected elements (mesh). It discretizes the domain, enabling precise analysis and computation as well as the approximation of physical phenomenon-governing equations.

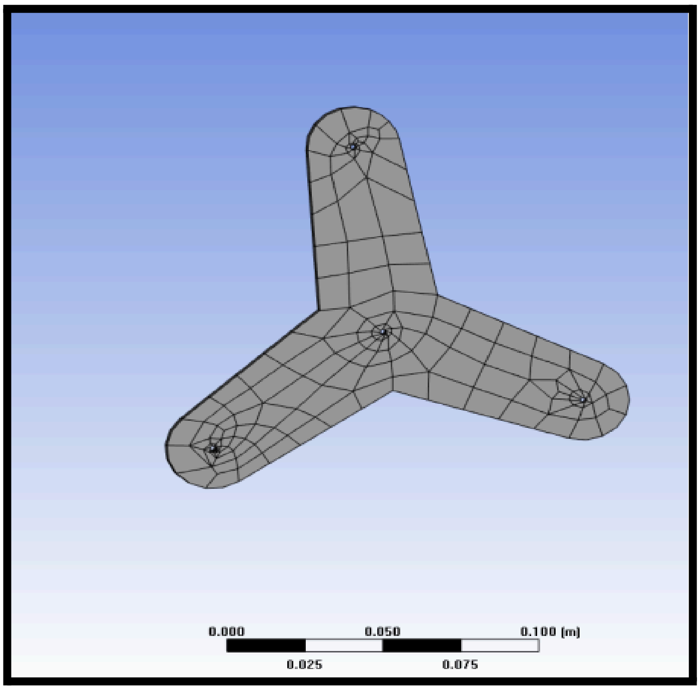


Fig. 8.1: Meshing of Tri-Star Frame

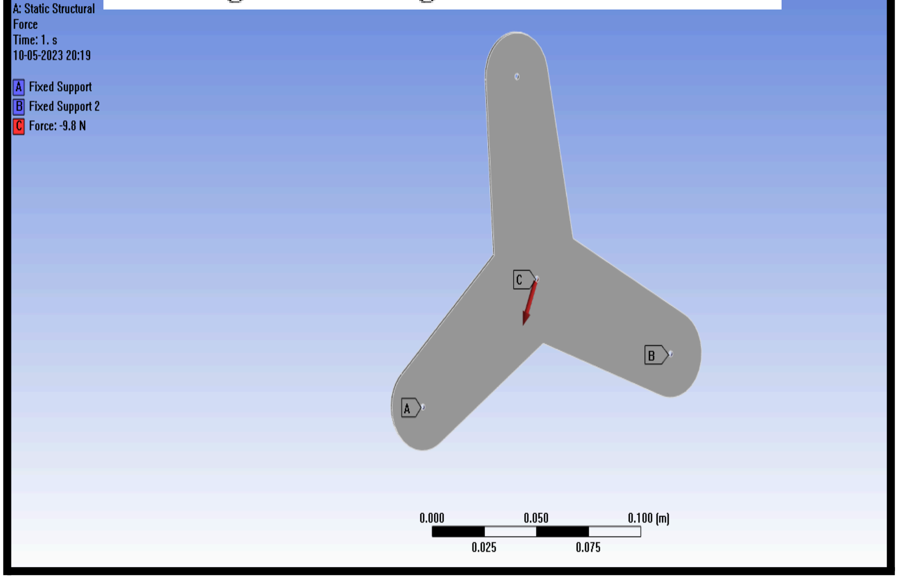


Fig. 8.2: Boundary Condition of Tri-Star Frame

8.3.3 Results of Structural Analysis

According to the given Boundary Conditions, after Meshing and applying the Boundary Conditions as shown in Fig 8.1 and Fig 8.2, required solutions are obtained from the ANSYS Software.

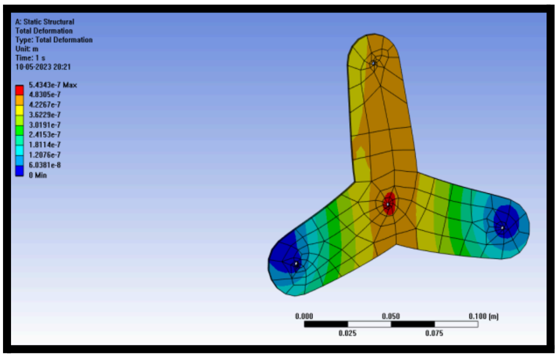


Fig. 8.3: Total Deformation

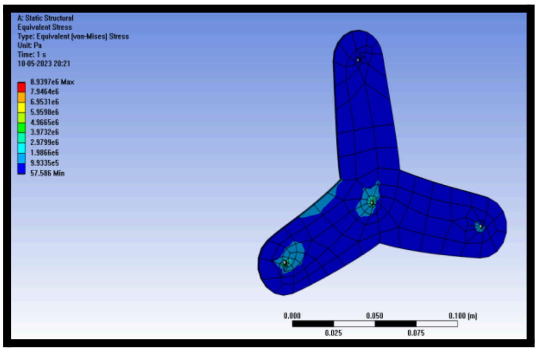


Fig. 8.4: Equivalent Von-Misses Stresses

When a structure is subjected to apply loads, its total deformation in ANSYS is measured, which sheds light on how the structure will respond to the loads. By measuring the combined impact of normal and shear stresses, known as von Misses stresses, it is possible to pinpoint areas of a structure that may collapse.

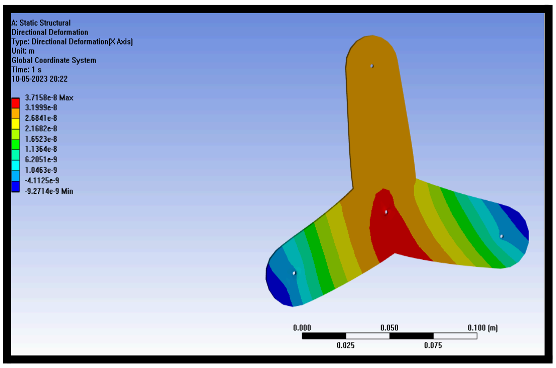


Fig. 8.5: Directional Deformation

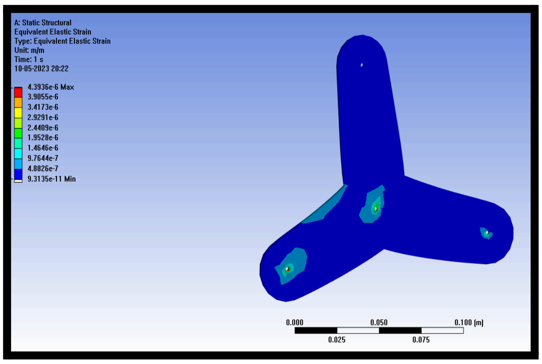


Fig. 8.6: Equivalent Elastic Strain

Directional deformation refers to the deformation or displacement of a material in a specific direction under applied forces or loads. It describes the extent and direction of the material's shape change due to external influences. Equivalent elastic strain, on the other hand, represents the magnitude of deformation or strain experienced by a material while undergoing elastic deformation. It quantifies the amount of elastic deformation the material has undergone and is typically expressed as a ratio or percentage.

Both directional deformation and equivalent elastic strain play significant roles in materials science and engineering. They help analyse the behaviour of materials under stress, determine their mechanical properties, and evaluate the structural integrity of components and structures. These concepts are essential for designing and testing materials and ensuring their safe and reliable performance in various applications.

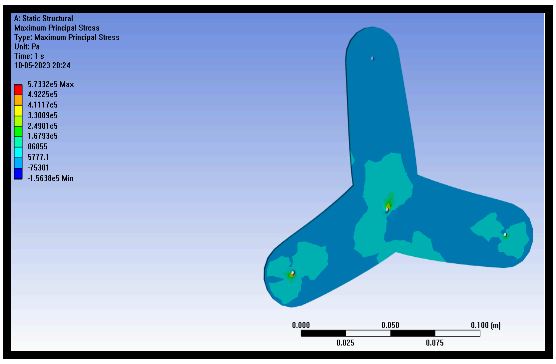


Fig. 8.7: Maximum Principal Stress

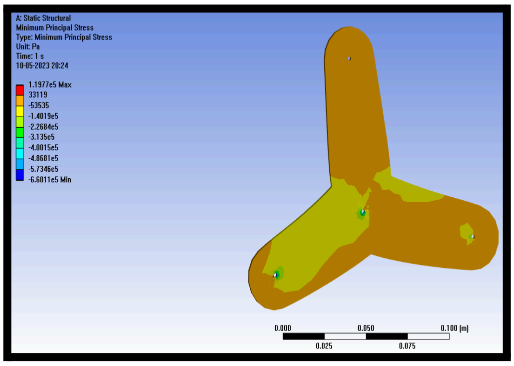


Fig. 8.8: Minimum Principal Stress

Maximum principal stress is the highest stress magnitude experienced at a point in a material, indicating the direction of failure. Minimum principal stress is the lowest stress magnitude at a point, indicating the direction of maximum compression. These values are crucial for analysing material failure and determining structural integrity.

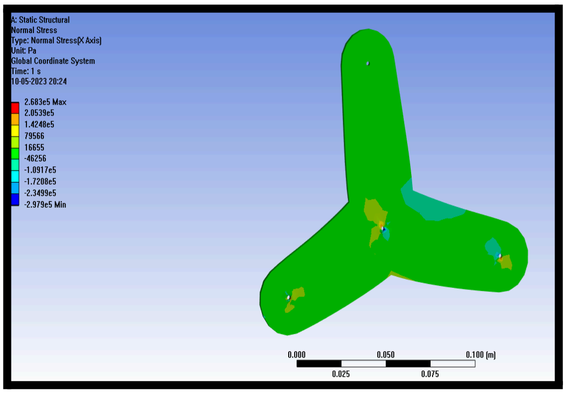


Fig. 8.9: Normal Stress

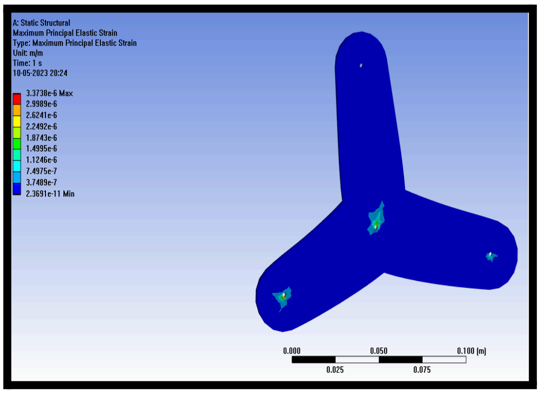


Fig. 8.10: Maximum Principal Elastic Strain

Normal stress in ANSYS refers to the stress acting perpendicular to a specific plane within a structure. It provides information about the distribution of forces and potential failure regions. Normal elastic strain represents the deformation or elongation of a material under normal stress, indicating the material's response to applied loads.

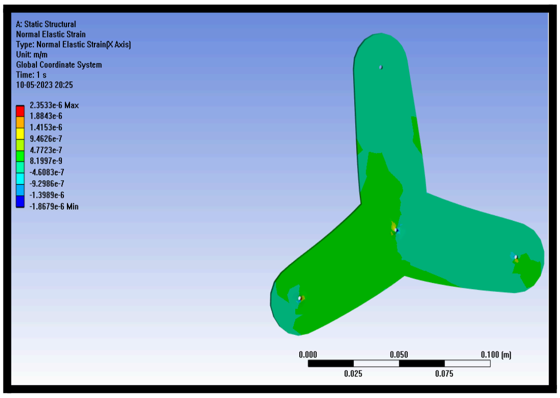


Fig. 8.11: Normal Elastic Strain

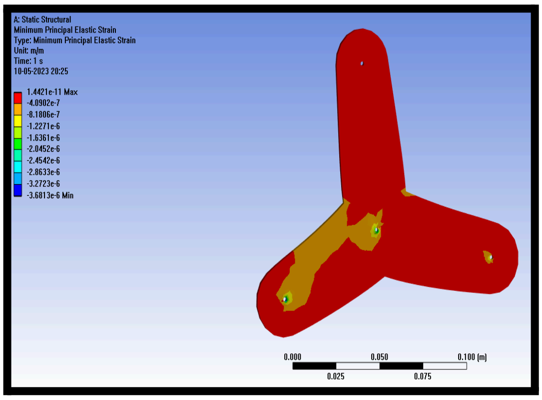


Fig. 8.12: Minimum Principle Elastic Strain

Maximum and minimum principal elastic strains in ANSYS are the maximum and minimum values of strain that occur at specific locations within a structure. These values are calculated based on the principal stress directions and can help identify critical areas prone to failure. Analysing the maximum and minimum principal strains provides insights into the structural integrity and potential failure modes, aiding in the design and optimization of the system.

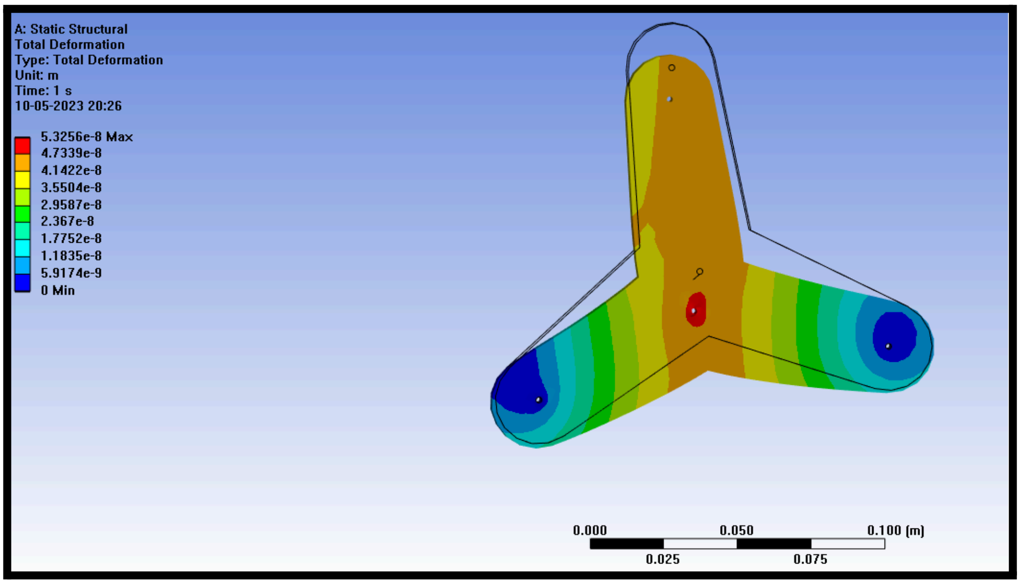


Fig. 8.13: Before and After Deformation For Tri-Star Wheel Frame

8.3.4 Interpretation

Interpreting results from ANSYS involves understanding the behaviour and response of a structure under applied loads.

This includes analysing quantities such as displacements, stresses, strains, and factors of safety. Results can be used to validate design specifications, identify areas of high stress or deformation, determine critical failure modes, and optimize the design for improved performance. Comparison with allowable limits, engineering standards, or theoretical predictions helps assess the safety and reliability of the structure.

Refereeing to the above figure, the maximum deformation and the Stress developed in a Tri-Star Wheel frame is at the Centre Hole of the Tri-Star Wheel Frame. This, is the reason that Maximum Von-Misses Stress is generated at the Centre Hole of Tri-Star Wheel Frame.

CHAPTER 9

CONCLUSION AND FUTURE SCOPE

9.1 Conclusion

In conclusion, the project "Design, Fabrication, and Analysis of Multi-Terrain Climbing Vehicle" aimed to develop a versatile vehicle capable of traversing diverse terrains and overcoming challenging obstacles. Throughout the project, several key objectives were achieved, and valuable insights were gained.

The design phase involved thorough research and conceptualization to identify the essential requirements of a multi-terrain climbing vehicle. The fabrication phase encompassed the construction of the vehicle according to the finalized design. The team worked diligently to procure the necessary materials, assemble components, and ensure structural integrity. Finite element analysis (FEA) was employed to assess the vehicle's structural integrity, stress distribution, and load-bearing capacity.

Overall, the project has resulted in the successful development of a Multi-Terrain Climbing Vehicle that fulfils its intended purpose. It demonstrates excellent capabilities in traversing diverse terrains and overcoming challenging obstacles. The vehicle's robust design, efficient power transmission, and adaptable suspension system contribute to its exceptional performance.

The project has provided valuable insights into the design, fabrication, and analysis of multi-terrain vehicles, with implications for various fields such as exploration, search and rescue, and transportation in rugged environments. The knowledge gained from this project can serve as a foundation for future advancements in multi-terrain vehicle technology. Additionally, on-going testing and evaluation should be conducted to validate the vehicle's long-term durability and performance in real-world scenarios.

Overall, the "Design, Fabrication, and Analysis of Multi-Terrain Climbing Vehicle" project has been a significant success, achieving its objectives and paving the way for further advancements in multi-terrain vehicle technology. The project team's dedication, collaboration, and technical expertise have been instrumental in the project's success.

9.2 Future Scope of Multi-Terrain Climbing Vehicle

The development of a multi-terrain climbing vehicle opens up various future possibilities and opportunities for improvement and expansion. Here are some potential future scopes for the multi-terrain climbing vehicle:

- **Enhanced Performance:** Further research and development can focus on enhancing the vehicle's performance characteristics. This includes improving its speed, manoeuvrability, and payload capacity. By optimizing the power transmission system, suspension design, and control mechanisms, the vehicle can achieve better overall performance in diverse terrains.
- **Autonomous Operation**: Integrating autonomous capabilities into the multi-terrain climbing vehicle can enhance its functionality and versatility. By incorporating advanced sensors, artificial intelligence algorithms, and navigation systems, the vehicle can navigate challenging terrains and obstacles without human intervention. This would make it suitable for applications such as remote exploration, surveillance, or search and rescue operations.
- **Energy Efficiency and Sustainability:** Future advancements can be directed towards making the vehicle more energy-efficient and environmentally friendly. This can involve exploring alternative power sources, such as hybrid or electric propulsion systems, to reduce reliance on fossil fuels. Additionally, incorporating regenerative braking or energy harvesting mechanisms can help improve the vehicle's overall energy efficiency.
- **Modular Design and Customization:** A future scope involves developing a modular design approach for the multi-terrain climbing vehicle. This would allow for easy customization and adaptation of the vehicle's components and configurations based on specific application requirements. Modular design would facilitate quick interchange ability of modules, making the vehicle adaptable for different tasks or environments.

- **Integration of Advanced Sensing and Imaging Technologies:** To enhance the vehicle's capabilities in various applications, integrating advanced sensing and imaging technologies can be explored. This includes incorporating LiDAR (Light Detection and Ranging), thermal imaging, or 3D mapping sensors to provide the vehicle with real-time data for obstacle detection, mapping, and environmental analysis.
- **Collaborative Swarm Systems:** Future developments could involve exploring the concept of swarm systems, where multiple multi-terrain climbing vehicles work collaboratively to accomplish complex tasks. This would require communication and coordination between vehicles, allowing them to distribute tasks, share information, and collectively achieve objectives in challenging environments.
- **Specific Application Adaptations:** The multi-terrain climbing vehicle can be further customized and adapted for specific applications or industries. For example, it could be tailored for agricultural tasks such as crop monitoring and spraying, or for industrial inspections of remote and difficult-to-reach areas. Adapting the vehicle's design and functionalities to address specific application requirements opens up new avenues for its utilization.
- **Reliability and Durability Enhancements:** Continued research can focus on improving the vehicle's reliability and durability, ensuring its robustness under extended usage in harsh environments. This involves conducting further tests, simulations, and analyses to identify potential weaknesses, address structural vulnerabilities, and optimize material selection to enhance the vehicle's long-term performance.

In summary, the future scope of the multi-terrain climbing vehicle encompasses a wide range of possibilities. Advancements in performance, autonomy, energy efficiency, modular design, sensing technologies, collaborative systems, specific application adaptations, and reliability will contribute to the continued evolution and utilization of multi-terrain climbing vehicles in various industries and challenging environments.

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