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A Study on Rocker-Bogie Suspension for a Planetary Rover Prototype

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ABSTRACT

In light of the notable rocker-bogie mechanism, this paper shows an ideal plan of a rocker-bogie suspension framework so as to ensure high mobile steadiness as well as excellent versatility of a prototype rover vehicle while traversing through rough terrains. It is essentially a suspension arrangement utilized in mechanical automated vehicles utilized explicitly for space investigation. The rocker-bogie suspension-based rovers have been effectively presented for the Mars Pathfinder and Mars Exploration Rover (MER) and Mars Science Laboratory (MSL) missions led by zenith space investigation laboratories all through the world. The proposed suspension framework is presently the most supported structure for each space investigation organization. It is basically a mechanism which comprises of two arms with wheel mounted to each and the two arms are associated through a versatile joint. The current development in design has been studied as well as a different approach towards designing the basic structure of suspension has been done. It has been further verified using various static and dynamic load calculations, solid modelling computer aided design software and simulation software for analysis and testing.

Keywords: *Rover; Planetary; Rocker-bogie; Suspension.*

1.0 Introduction

Suspension is isolated into non-autonomous suspension and free suspension. These two sorts of suspensions are broadly utilized in general vehicles. General vehicles can go on urban streets and expressways but they can't go on unpleasant streets or incredibly uneven streets. The rocker-bogie suspension is proposed to take care of that issue. It is generally used in planetary rovers. Rocker-bogie suspension deals with the locomotion and stability of the rover vehicle. The rover is designed such that it can traverse various difficult terrains and overcome large obstacles in its path while maintaining proper durability and avoiding any unnecessary tumbling in any direction. Most of the components have been made out of aluminum to reduce the overall weight.

The rocker-bogie configuration has no springs or stub axles for each wheel, enabling the rover to move over obstructions, (for example, rocks) that are up to double the wheel's width in size while keeping every one of the six wheels on the ground. Likewise, with any suspension framework, the tilt strength is restricted by the stature of the focal point of gravity. Frameworks utilizing springs will in general tip all the more effectively as the stacked side yields. The framework is intended to be utilized at moderate speed of around 10 centimeters for every second (3.9 in/s) in order to limit dynamic stuns and significant harm to the vehicle while surmounting sizable hindrances.

Rocker, some portion of the term originates from the rocking part of the bigger, forward leg on each side of the suspension framework. These rockers are associated with one another and the vehicle undercarriage through a differential. Comparative with the body, when one rocker goes up, the different goes down. The suspension keeps up the normal pitch edge of the two rockers. One end of a rocker is fitted to a drive wheel, and the opposite end is pivoted to the bogie. The "bogie" portion of the term alludes to the smaller, rearward leg that turns to the rocker in the center and which has a drive wheel at each end. Bogies were generally utilized as burden

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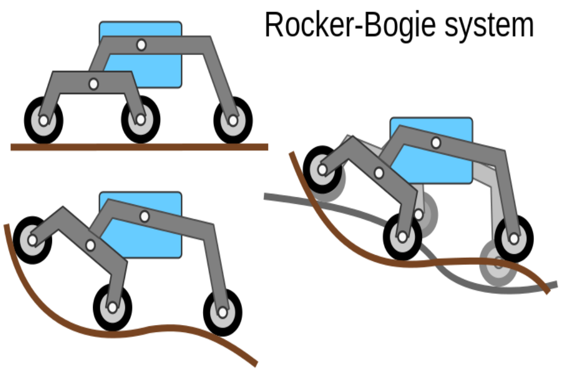
wheels in the tracks of armed force tanks as idlers circulating the heap over the territory, and were additionally ordinarily utilized in trailers of semi-trailer trucks. The two tanks and semi-trailers presently lean toward trailing arm suspensions.

1.2. Mechanism

So as to go over a vertical hindrance face, the front wheels are constrained against the obstruction by the center and back wheels. The revolution of the front wheel at that point lifts the front of the vehicle up and over the object. The center wheel is then squeezed against the object by the back wheels against the obstruction by the front until it is lifted up and over. At long last, the back wheel is pulled over the object by the front two wheels. During each wheel's traversal of the object, forward advancement of the vehicle is eased back or totally stopped. This isn't an issue for the operational rates at which these vehicles have been worked to date.

Figure 1: Mechanism of Rocker-Bogie Suspension



Feature	Advantage
No use of springs in suspension	- Doesn't tend to tip/tilt - Can climb high obstacles - Rover doesn't oscillate too much
Independent left/right traversing	- Both the sides can independently traverse different obstacles - Normal reaction remains in control
6 wheels, instead of 4	- Increases normal reaction, traction and stability - Increases independent behaviour of rover - Keeps the rover powered in case of failure in wheel/motor
Differential	- Reduces the main body tilting by half - Jerk experienced by one side is transferred to another in the opposite direction, thus increasing normal reaction

2.0 Literature Review

2.1 Introduction

Inception of rocker bogie suspension framework can be followed to the improvement of planetary rover which are portable robots, particularly intended to proceed onward a planet surface. Earlier, movers were tele operated like the Lunokhod I while late ones are completely self-sufficient, for example, FIDO, Discovery and as of late created Curiosity Mars exploration vehicle. The rovers should have been extremely powerful and dependable, as it needs to withstand dust, solid breezes, corrosion and huge temperature changes under baffling conditions. Most extreme rover vehicles stay controlled by batteries which are energized by solar photovoltaic boards during the day introduced over their surface. The motion arrangement of rover vehicles stays urgent to empower it to arrive at target destinations, direct research, and gather information and to situate itself as indicated by the interest. There are three primary sorts of rover vehicle locomotion invented so far for example wheeled, legged and caterpillar motion. The primary contrast between the different structures of planetary robots lies in the kind of movement framework.

Considerably subsequent to creating numerous legged and crossover robots, most analysts still spotlight on wheeled design for rover vehicles in view of its locomotion ease and focal points and among wheeled movement plan, the rocker bogie suspension framework-based structure stay generally supported. The antiquated FIDO rover and the Sojourner contain 6 autonomously directed and driven wheels suspended from a rocker-bogie system for most extreme suspension and ground clearance. Rocky Seven Rover has a comparative suspension framework simply contrast in front wheels. The Nanorover and Nomad Rovers have four guided wheels suspended from two bogies and CRAB Rover uses two parallel bogie-systems on each side to conquer objects and huge gaps. To the extent the underlying examination is concerned, the product advancement looks for an ideal in the restricted solution space given an underlying arrangement and infer a scientific model to sum up rover suspension parameters which characterize the geometry of the rocker bogie framework. The target behind advancement of rocker bogie suspension framework is to build up a framework which limits the vitality utilization, the vertical removal of the rover vehicle's center of gravity and its pitch angle. In this exploration our undertaking is to move the significant favorable circumstances installed with the rocker bogie framework into customary vehicles so as to expel solace and complexities present in regular suspension framework as a rule and suspension arrangement of substantial vehicles specifically.

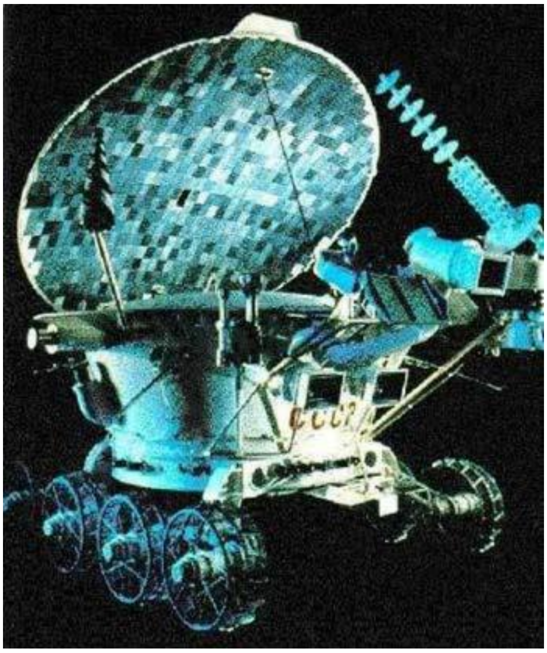
2.2 Development in the design of rocker-bogie for planetary rovers

2.2.1 The rocker-bogie suspension for planetary rover designed by soviets

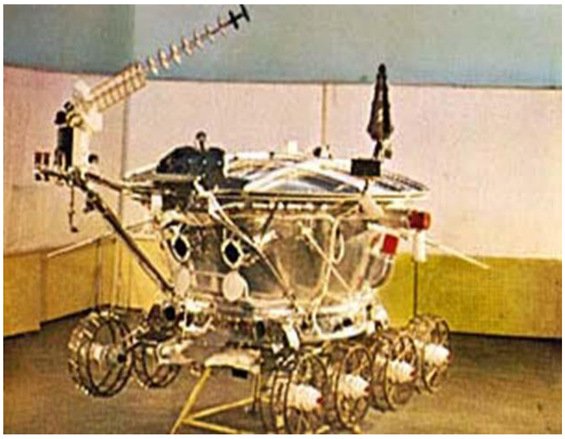
In 1970, Luna 17 carried Lunokhod 1 which is the world's first lunar exploration vehicle onto the lunar surface [7]. As shown in Figure 1 (a), Lunokhod 1 is about 756 kg and the body size is 4.42m × 2.15m × 1.92m. The structure of this vehicle is divided into upper and lower parts. The upper part is the sealed instrument compartment manufactured from magnesium alloy and the lower part is the automatic walking chassis which the eight wheels are independently drove. It can climb the 30-degree slope. It can also cross the 40-cm barrier and the 60-cm gully. The ground moving speed is 1km/h or 2 km/ h.

Figure 2: Two kinds of Lunokhod

(a) Lunokhod 1



(b) Lunokhod 2



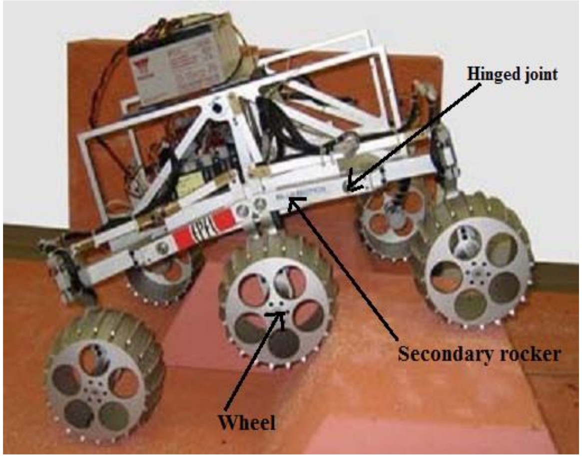
The Lunokhod 2 was carried by the Luna 21 in 1973 and landed in the eastern part of the Moon [8-9]. As shown in Figure 2 (b), the configuration of the vehicle is similar to Lunokhod 1. However, the structure was improved, the speed of movement was increased, and the scope of activities was bigger than the Lunokhod 1.

2.2.2 The rocker-bogie suspension for planetary rover designed by swiss

In 2002, Swiss Federal Institute of Technology and Automation Systems Laboratory (ASL) developed a prototype of six-wheel detection vehicle called shrimp [10]. The shrimp is about 3.1kg, which the front fork-parallelogram rocker suspension is used. As shown in Figure 2, the shrimp was climbing stairs. The stability of the shrimp is good and the traffic ability of the shrimp is strong. But the area of carrying in this vehicle is greatly limited due to the limitation of the suspension structure. The suspension structure is also complicated.

Figure 3: (a): The Shrimp

Figure 3: (b): The Six Rounds of the Prototype Vehicle



In 2004, Switzerland ASL developed the six rounds of the prototype vehicle called crab, which the bilateral double parallelogram rocker suspension is used [11]. Each side of the suspension is made up of two sets of the parallelogram secondary rocker hinged at the middle wheel and a main rocker. The pole of each set of the secondary rocker is connected with the wheel. The middle pole of secondary rocker is fixedly connected with the main rocker. The main rocker is connected to the vehicle body with a differential mechanism. As shown in Figure 3, the crab was crossing the vertical wall. The stability of this vehicle is good and the terrain adaptability is strong. The platform area of carrying is much better than the shrimp. But the suspension structure is still complex.

2.2.3 The rocker-bogie suspension for planetary rover designed by american

In 1987, JPL of NASA presented Rocky1 that is a basic prototype of a small 6-wheel rover which firstly used the rocker-bogie suspension [12]. The wheel radius is 4 cm. The wheel to ground distance at the same side is identical. All the wheels can be independently driven. The portion between the rear wheel and hinged joint is the primary rocker. The portion between front wheel and hinged joint is the secondary rocker. The height of free hinged joint is higher than the axis of the wheel. As it was showed in Figure 4, the rover was traveling through an obstacle without any problem. This experience revealed that the negotiation ability and the traffic ability of this rover is strong. The revolution angle of main rocker cannot be very large due to the limitation of suspension system.

Later, JPL developed lots of rovers. The Rocky 8 is the newest rover [13]. The weight reached up 30 kg (Showed in Figure 5). The wheel to ground distance at the same side is also identical. Each wheel can be also independently driven. The height of hinged joint is also greater than the centre line of the wheel. The Rocky 8 can carry more valid loading weight. It can travel at a long distance and avid obstacles.

Figure 4: Rocky 1

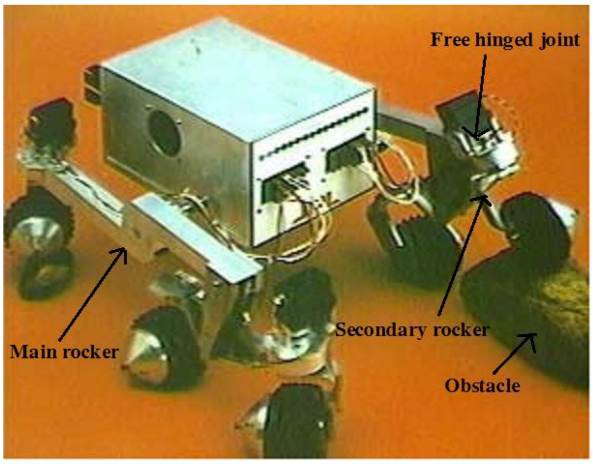


Figure 5: Rocky 8

Future combat system (FCS) designed by the U.S. Army combines many kinds of systems, which is a multifunction, networking, light and intelligent weapon system [14]. This system is gradually equipped by the U.S. Army, as the technology matures. The robot vehicle is called mule as the main transport equipment of FCS, which is used to transport weapons, ammunitions and supplies for army's [15]. One mule can support two infantry classes and also can accompany them on the complex terrain. The primary mission of mules is transporting equipment and rucksacks about 900~1100 kg and transporting the wounded soldier to safe place.

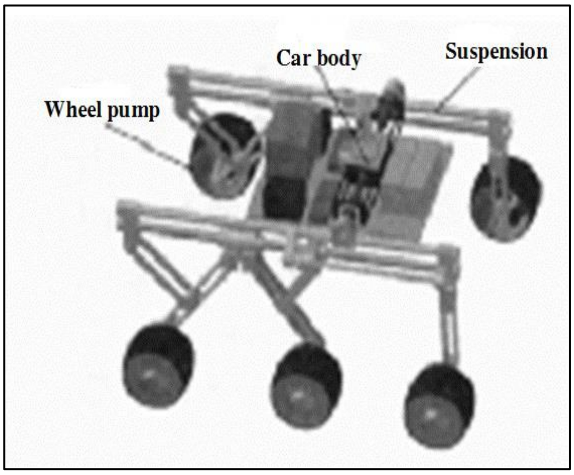
Figure 6: Mule

From the Figure 6, it showed that the mule could travel on the complex terrain with high manoeuvrability. "Mule" was equipped with independent articulated suspension of 6×6 chassis. Mule used brake steering device and hybrid electric drive system. The hub of each tire is equipped with an electric motor. Mule has a high resistance to destruction. If a tire is damaged or destroyed, the remaining five tires still be able to maintain sufficient mobility. The height of obstacle which the mule can across reached 1.5 m, which is much more than any other active wheeled or tracked vehicle equipped by the U.S. Army. The width of the trench which the mule can across reached 1.5 m. The slope angle is more than 40 degrees. The wade depth is at least 1.25 m.

2.2.4 The rocker-bogie suspension for the planetary rover designed by chinese

National Defense University of Science and Technology designed a new type of folded-deployed suspension, known as the two-crank-slider suspension [16]. As shown in Figure 7, the left and right suspension is symmetrical and each suspension is composed of the main rocker, two cranks, two connecting rods, two slider and torsion bar spring. The left and right suspension is connected with differential mechanism through the spline. The center of the differential mechanism is attached to the body. Both side suspensions are rotatable relative to the vehicle body. Each wheel is driven by a wheel pump. But the crank rotation angle is limited.

Figure 7: A New Type of Folded-Deployed Suspension



Harbin Institute of Technology created the rocker-style inspection vehicles [17]. This suspension is similar to Rocky 1. The supplementary rocker can revolve about the hinge on the primary rocker and the right and left primary rocker arms can realize the differential movement around the differential mechanism so that the 6 wheels always touch the ground at the same time. In addition, the mobile sub-system consists of the 6 full-drive rounds. On the one hand, it increases adhesion and traction. On the other hand, if one or even two wheels fail to work, the remaining wheels continue to run.

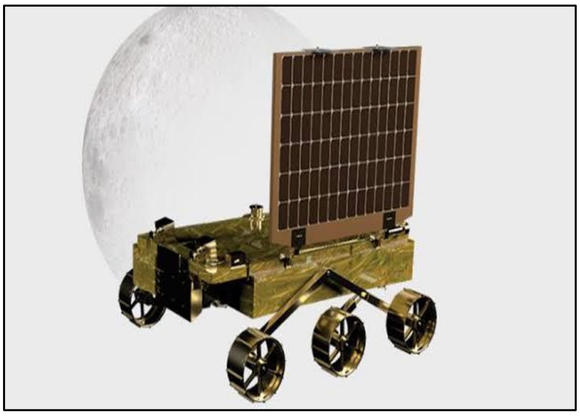
2.2.5 The rocker-bogie suspension for planetary rover designed by india

The rover vehicle's mass was around 27 kg (60lb) and was intended to work on solar oriented power. The rover was to proceed onward 6 wheels navigating 500 meters on the lunar surface at the pace of 1 cm for each second, performing nearby examination and sending the information to the Vikram lander, which would have communicated it to the Earth station. The rover was equipped with the following for navigation:

- Stereoscopic camera-based 3D vision: two 1-megapixel, monochromatic NAVCAMs before the rover to give the ground control group a 3D perspective on the encompassing territory, and help in way arranging by producing an advanced elevated model of the landscape. IIT Kanpur added to the improvement of the subsystems for light-based guide creation and movement making arrangements for the rover.
- Control and motor dynamics: the rover design has a rocker-bogie suspension system and has six wheels, each of which are driven by independent brushless DC electric motors. Steering system is achieved by differential speed of the wheels also called skid steering.

The expected operating time of Pragyan rover was supposed to be one lunar day or around 14 Earth days, as the onboard electronics were not designed to sustain the freezing lunar night. The power system had a solar-powered sleep/wake-up cycle applied, which could have led to longer service time than was planned.

Figure 8: Pragyan Rover



- Dimensions of rover: 0.9 * 0.75 * 0.85 m
- Power required: 50 Watts
- Travelling speed: 1 cm/sec
- Planned mission operating time: ≤14 days

2.3 Future scope

Rocker-bogie suspension system can be implemented in exploration rovers for the following purposes: -

- It can be used in rovers designed for assisting astronauts in space operations and it can act as a path finder.
- It could be useful for implementation in rovers for space missions too as recently it was used in NASA’s Mars Rover Curiosity and ISRO’s Lunar Rover Pragyan. The following mechanism takes into consideration the roughness of the surface it is driven on.
- The rovers with rocker bogie generally have larger wheels as compared to objects; therefore, it can easily function over maximum of the Martian rocks.
- It can be used in rovers made for excavation purposes in coal mines.
- It can be used in rovers that act as spy robots and for military operations too due to capability of working in off-road conditions.
- It can be used in heavy machinery cranes and bulldozers for ease in traversing through rough terrains

3.0 Design Methodology and Calculations

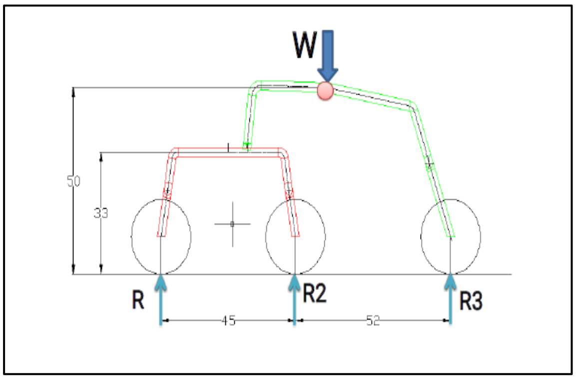
3.1 Overview of design methodology

Assumptions:

- We chose a wheelbase of 100cm according to the general limitations in rover competition specific rulebooks.
- It was assumed that all of the load on chassis is concentrated at a point at the center, i.e. also the hinge point of rocker.
- A high ground clearance of 50cm was assumed so that the rover easily encompasses larger obstacles over the wheels.
- The shape of links was designed on AutoCAD to minimize the possibility of collision between bogie and arm during climbing and descending.
- The middle wheel is positioned at the center to distribute load on the wheels equally
- All the rest of the lengths, including the lengths of the links were automatically obtained by restricting the parameters mentioned above on the CAD model.
- Rovers operate on extremely low speeds(3km/h), therefore any dynamic force due to acceleration of the vehicle is neglected

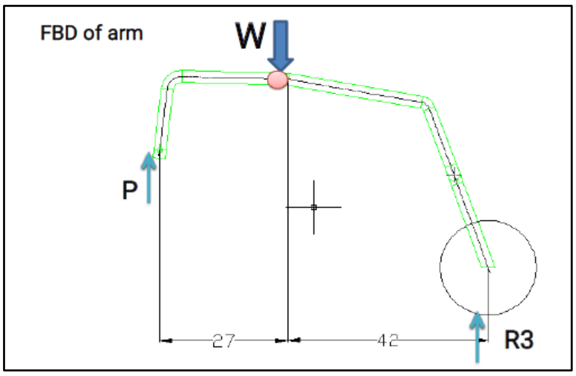
A study of the climbing capacity of different bogie hinge point configurations was done to optimize the value of traction and climbing capacity, as follows: -

Figure 9: Ground Reactions on Horizontal Plane



R1, R2, R3 are the ground reactions of wheels on one side of the rocker bogie arrangement

Figure 10: FBD of Arm



P is assumed to be a combined effect of R1 and R2

Taking moment about hinged point

⇨ P*27=R3*42

Therefore almost 60% of load W is transferred to point (having pin connection between bogie and arm)

⇨ P=0.6*W

And around 40% of load W is transferred to the contact point of the rear wheel

⇨ R3=0.4*W

This leads to a stable balance of the chassis

Case1

In this case the hinge point is set a little offset from the center to analyze the climbing capacity of rover in such configuration

Taking moment about pin connection of bogie and arm

⇨ R1*29=R2*16

Therefore almost 65% of load P is transferred to the middle wheel

⇨ R2=0.65*P

And 35% of load P is transferred to the front wheel

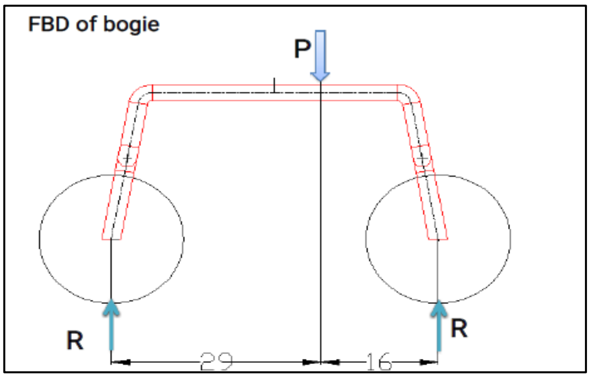
⇨ R1=0.35*P

➢ R3=0.4*W

➢ R2=0.6*0.65*W

➢ R1=0.6*0.35*W

Figure 11: FBD of Bogie



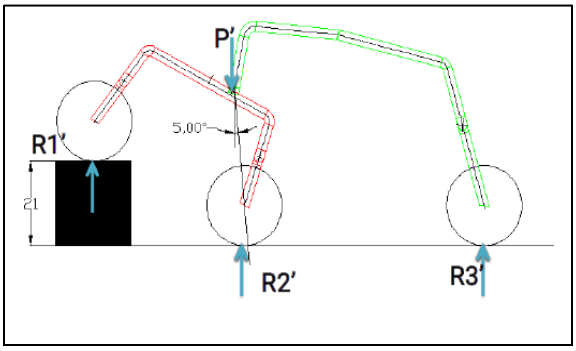
3.1.1 Climbing analysis

3.1.1.1 Position 1

For climbing the obstacle without losing contact of any wheel from ground, it is necessary that the line of action of reaction force R2'should always behind the line of action of force P'. This will generate a counter clockwise direction moment so that the front wheel will always keep in contact with ground.

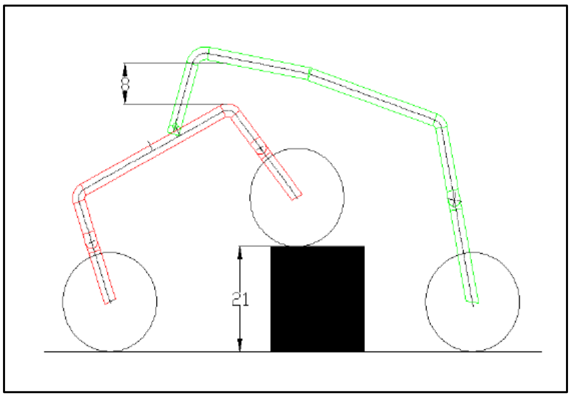
- ➢ In limiting case the line of action of both forces are in a line this mean the reaction force R1' is equal to zero,
- ➢ By considering small counter clockwise moment, the maximum climbing step height is limited to 21cm (max).

Figure 12: Climbing Analysis at Position 1



3.1.1.2 Position 2

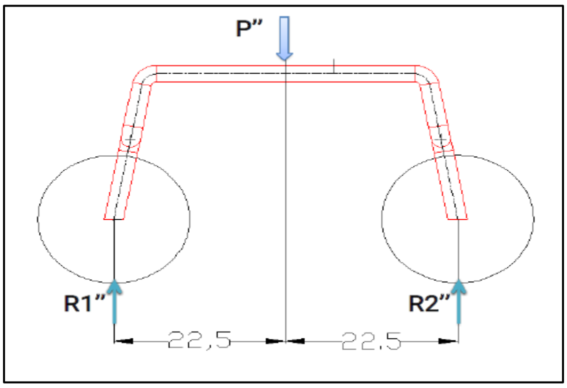
Figure 13: Climbing Analysis at Position 2



- ➢ In step climbing(position2) with 21cm obstacle height, there is no clash between bogie and arm. (8cm clearance)
  With this type of configuration (case1)
- ➢ Maximum step climbing is obtained as 21cm.
- ➢ Better climbing capacity.
- ➢ Plenty of clearance between bogie and arm in the Position 2, while declining that means lesser risk of collision.

3.1.1.3 Case 2

Figure 14: FBD of Bogie



In case 2, pin connection of arm with bogie is at center between first and second wheel. And the load P is 60% of the load W.

Therefore R1”=R2’’

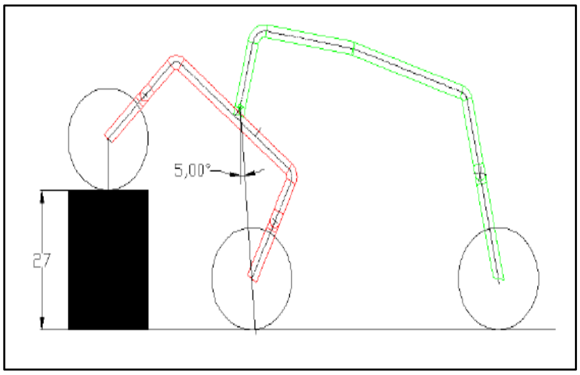
- ➢ R3=0.4*W'
- ➢ R2=0.3*W
- ➢ R1=0.3*W

This configuration provides better traction as the values of normal reactions on wheels are closer to each other.

3.1.2 Climbing Analysis

3.1.2.1 Position 1

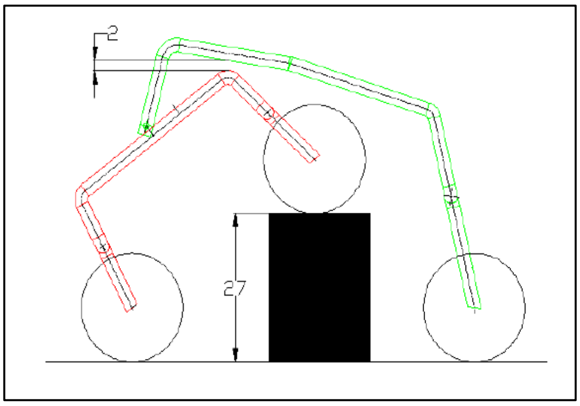
Figure 15: Climbing Analysis at Position 1



- ➢ By considering small counter clockwise moment, the maximum climbing step height is limited to 27cm (max) with this type of configuration.

3.1.2.2 Position 2

Figure 16: Climbing Analysis at Position 2



In step climbing (position2) with 27cm obstacle height, there is no clash between bogie and arm (2cm clearance). With this type of configuration-

- ➢ Maximum step climbing is obtained as 27cm
- ➢ Better traction as compared with case1
- ➢ Only 2cm of clearance left in Position 2 while declining that leads to greater risk of collision between bogie and arm as compared to Case1.

3.2 Components in the assembly

Our vehicle's structure has been primarily divided into three systems that enables easy identification and troubleshooting of failures and maintenance by enhancing accessibility to its various constituents. The three parts include: Chassis, Suspension system and Wheels. Solidworks model as well as Finite element analysis for different stress values have been shown for the given components.

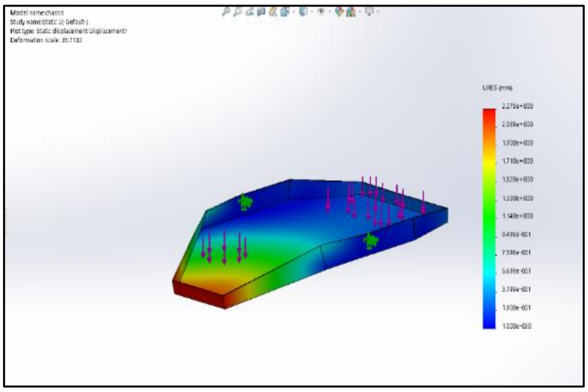


Figure 17: FEA Analysis of Chassis

3.2.1Chassis

A robust octagonal structure has been chosen from various designs as it provides greater clearance for the movement of driving members and links and also a wider space for placing electrical components and differential mechanism also, walls of this structure provide a safer and dust free environment for electrical components by enveloping them under an acrylic sheet. A differential mechanism has been provided to distribute the various forces while traversing different terrains. The main advantage of this mechanism is that the pitch angle of chassis is the average of the pitch angles of right and left sides of suspension system.

3.2.2 Suspension system

The suspension system of rover consists of rocker bogie mechanism. The rocker-bogie configuration has no springs or stub axles for each wheel, enabling the rover to move over impediments, for example, rocks, that are up to double the wheel's diameter in size while keeping every one of the six wheels on the ground. Rocker Bogie suspension provides the purpose of stabilizing the rover at rough terrains. By virtue of rocker and bogie links, this suspension system provides optimal weight distribution as well as high climbing capacity while smoothly traversing through terrains. The system has been provided with two hinge point configurations that allow us to manually adjust between climbing capacity and magnitude of traction. As with any suspension system, the tilt stability is restricted by the height of the centre of gravity, therefore we have provided with heavy wheels and partially in-wheel drive motors to lower the centre of gravity while maintaining high ground clearance. Also, to attain full traction on wheels, the links have been bent such that most of the rover's weight is concentrated on the wheels.

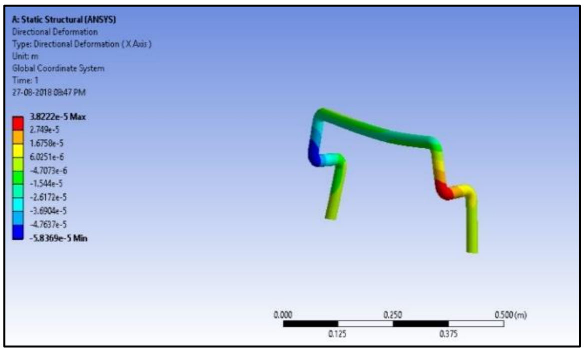


Figure 18: FEA Analysis of Bogie Link

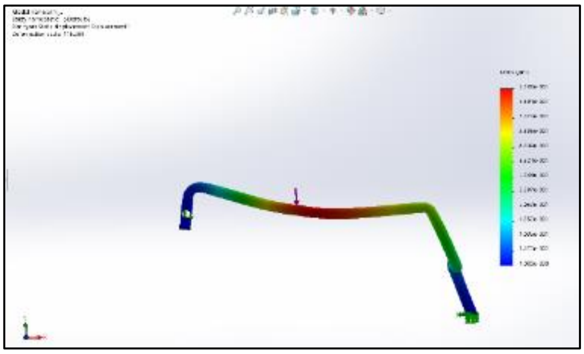


Figure 19: FEA Analysis of Rocker Link

3.2.3 Differential-purpose

- In a real rover, the rocker bogie mechanisms of left and right sides are connected to each other and to the body through a mechanism called differential.
- The differential is what keeps the body level. Relative to the body, when one rocker goes up, other goes down.
- Relative to the ground, the body pitch angle is always half of the angles of left and right rockers.

- If we attach the rockers to the body with an axle or two pivot points, the body will tip forward or backward until it hits the ground. The differential makes the rover body to remain stable and prevents it from tilting.
- The differential makes it possible for one side or both sides of the rover to overcome keeping the body stable with low pitch angle.

Figure 20: Balancing of Chassis Roll Angle

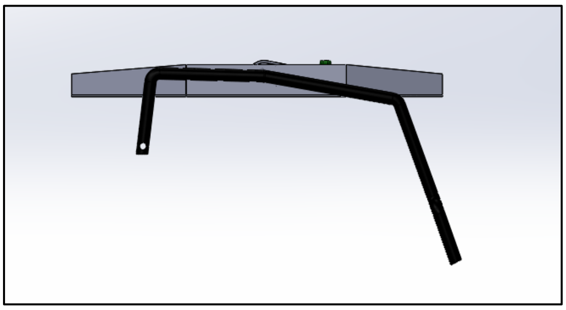


Figure 21: Balancing of Chassis Pitch Angle

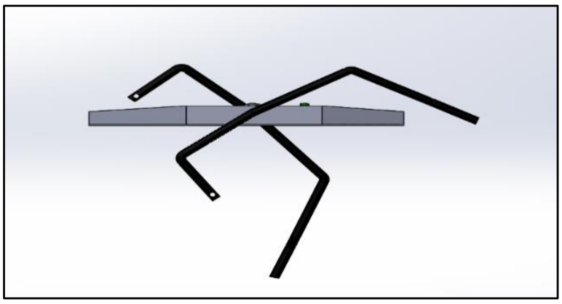


Table 2: Types of Differential Mechanisms

Bevel Gear Differential	Differential Bar
Bevel Gear assembly housed inside the body.	Assembly consisting of different bars of short length.
Two bevel gears connect to two rocker arms and the third (middle) gear connects to the body.	Differential bar is pivoted on its middle point to the body and its ends are connected to the rocker arms through some short length links.
Easy to manufacture and assemble.	Difficult to fabricate, converting motion is complex.
Reliable and has more strength due to steel alloy bevel gears.	Not much reliable.
The assembly is compact and can be easily housed inside the body.	The assembly needs separate space to work and interferes with other components.

On the basis of the above comparison between bevel gear differential and differential bar, bevel gear differential was chosen because of the advantages in its mechanism. A separate compartment for the differential mechanism inside the rover body for preventing the dust particles from entering. Therefore, the gears can work smoothly.

Figure 22: Configuration of Differential

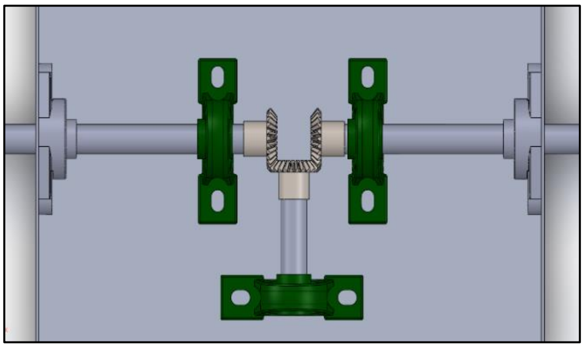


Table 3: Configuration of Differenetial

Part	Material	Quantity
Bevel Gears	EN8, Hardened	3
Shafts	Aluminium	3
Plummer Blocks	Cast Iron	4-6

3.2.4 Wheels and hub

Wheels have the important function to support the load of the rover and help navigate through different terrains, like sandy, non- cohesive soil as well as hard, dry terrain. In addition to these features, wheels also perform the function of providing an elastic behaviour to increase contact force and flexibility as well as reducing overall vibrations and jerks. Balloon tyres are used. These tyres provide with excellent strength at light weight. However, the main reason for using balloon tyres is the flexibility in traction that they provide. On the tyres we have used rubber strips for better ground control and extra traction. The traction in these types of tyres is controlled by lowering the air pressure inside them.

The wheel hub is custom-made from aluminium and is designed to completely hold the motor in itself. In-wheeling helps in the optimum utilization of space while reducing the danger of motor-damage. The intricate hub is manufactured using CNC machining.

Figure 23: Wheel Hub

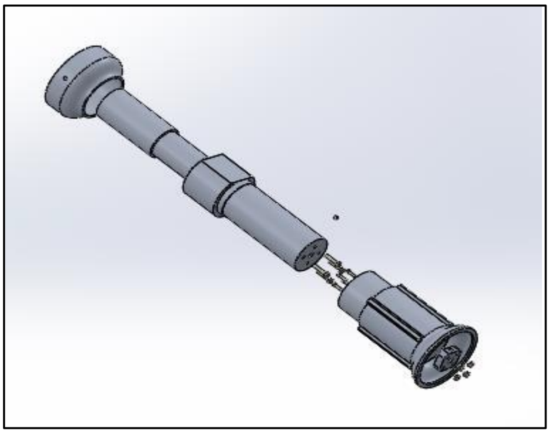


Figure 24: Balloon Tyre

3.2.5 Functions of wheels in a mars rover

- To have elastic behaviour to increase contact force.
- To climb rough slopes (<= 50 degrees) without slipping off.
- It should be of optimal weight such that it should bring the centre of mass of rover downwards.
- It should have a design to contain motors within it so as to counteract the moment of motor.

3.3 Material selection for components

3.3.1 Material selection parameters for suspension system

(a) Purpose

- Should have enough strength to be able to withstand jerks and extreme terrains like bumps and pits.
- Should be lightweight so that it can lift and drop easily according to the terrain.
- Should be able to support chassis and all its weight with minimal deflection.

(b) Process

- Should be easily bendable and possess enough strength after bending process.

(c) Availability and cost

- Should be readily available with material report and parameters
- Should not be very expensive.
- Since Aluminium meets all the requirements of our suspension system, we decided to use Aluminium for the links. Also, most of the other components were being manufactured with Aluminium, it would be easy for us to mate and fasten these components with each other.

3.3.2 Material selection parameters for rover chassis

A comparison was made between Mild Steel, Aluminium and Composite materials for the manufacturing of rover body. It was observed that Aluminium provided sufficient strength with minimal deflection and also proved as a light weight material for the body. It is 3 times lighter than MS and provides sufficient strength according to our analysis. Also, composites could be a good option for light weight material, but due to high prices and difficulty in usage, they were discarded as an option.

Table 4: Material Selection for Chassis

Mechanical Properties	Values
Hardness, Brinell	30
Ultimate Tensile Strength	111 MPa
Yield Tensile Strength	68.9 MPa
Shear Modulus	25.9 GPa
Modulus Of Elasticity	68.5 GPa

3.3.3 Material selection parameters for bevel gears

It can be clearly seen from the comparison that steel alloy is a better option for manufacturing bevel gears.

Another comparison was made between different types of steel alloys, namely – EN8, EN9, SAE 8620 as -

*EN means European Norms

Table 5: Material Selection for Bevel Gears

Parameters	Aluminium Alloy	Steel Alloy
Strength	Not as strong as steel.	Very tough and resilient.
Machinability	Very good machinability, easy to cut, form and machine.	Harder and difficult to work with.
Weight	Light in weight.	Heavy in weight.
Wear Rate	Very high wear rate.	Low wear rate.

Table 6: **Comparison between EN9, EN8, SAE8620**

Properties	EN 9 (AISI 1055)	EN 8 (AISI 1040)	SAE 8620
Ultimate Tensile strength	660 MPa	620 Mpa	633 Mpa
Yield Tensile strength	560 MPa	415 MPa	385 Mpa
Modulus of elasticity	190-210 GPa	190-210 GPa	205 GPa
Shear modulus	80 GPa	80 GPa	73 GPa
Poisson’s ratio	0.27-0.30	0.27-0.30	0.3
Hardness, Rockwell B	92	93	90

It can be seen that all the available materials have comparable mechanical properties and each of them can be used for the manufacturing of bevel gears.

Since, the cost of EN 8 was the lowest, it was chosen for the bevel gears.

4.0 Conclusions

The research paper has introduced new design concepts for the suspension system of a Rover Prototype and the country-wise current development in rocker-bogie designs has been studied. Further, stress analysis under different dynamic as well as static conditions was done for the design and appropriate material selection has been done for its fabrication.

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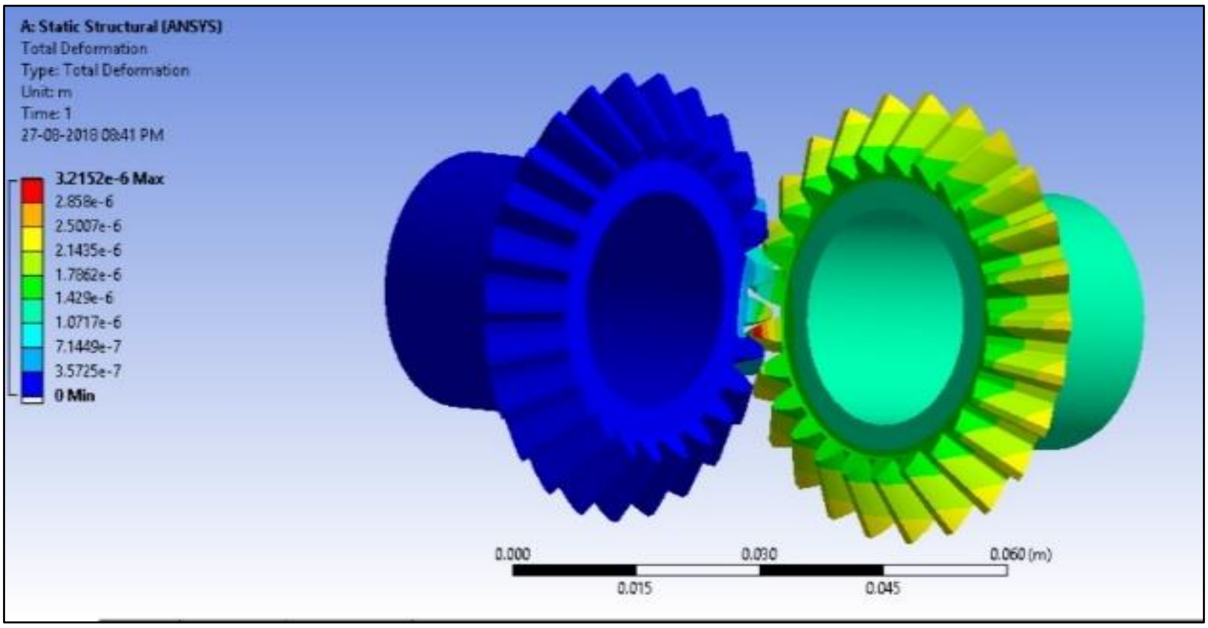
Figure 25: FEA Analysis of Bevel Gear Tooth Force



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