DEPARTMENT OF ENGINEERING DESIGN

COURSE PROJECT

ED4060

DESIGN OF MECHANICAL SYSTEMS 2

ROCKER - BOGIE MECHANISM

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1 ABSTRACT :

The objective of this project is to design an efficient rocker-bogie mechanism for multi-terrain traversal while keeping balance focusing on the terrain of Mars.The mechanism would be capable of traversing in any kind of terrain autonomously.It would help in several testing of the Martian soil,atmosphere and underground sensing for minerals .
The application of the mechanism could be extended to several other projects on planet earth such as i)Sowing and cultivation in hilly terrains ii)Autonomous sensing in uneven mines and forests iii)military and civil purposes.
The mechanism could be implemented in healthcare applications such as stair climbing wheelchair for the differently-abled people. The applications for the rocker-bogie mechanism is vast and designing an efficient mechanism would help in several other fields as well.
What follows is a detailed report of all the processes involved in the traversal of different uneven terrains and the steps we as a team came across in designing and testing the rocker-bogie mechanism.

2 INTRODUCTION :

The rocker-bogie mechanism system was initially used for the Mars Rover and is currently NASA's preferred design for rover wheel suspension. The perfectly designed wheel suspension allows the vehicle to travel over very uneven or rough terrain and even proceed over obstacles of several types.
This rocker suspension is a type of mechanism that allows a six wheel vehicle to constantly keep all six wheels in contact with a surface when driving on uneven terrain surfaces.
This report describes a method of driving a rocker-bogie rover so that it can progressively step over most obstacles rather than impacting and climbing over them. Some machine changes are suggested to gather the maximum profit and to greatly increase the effective speed of future rovers.
The rocker-bogie mechanism is one of the most popular suspension mechanisms, which was initially designed for space travel vehicles having its own deep history embedded in its development.By design it is a wheel robot which comprises 6 motorized wheels.

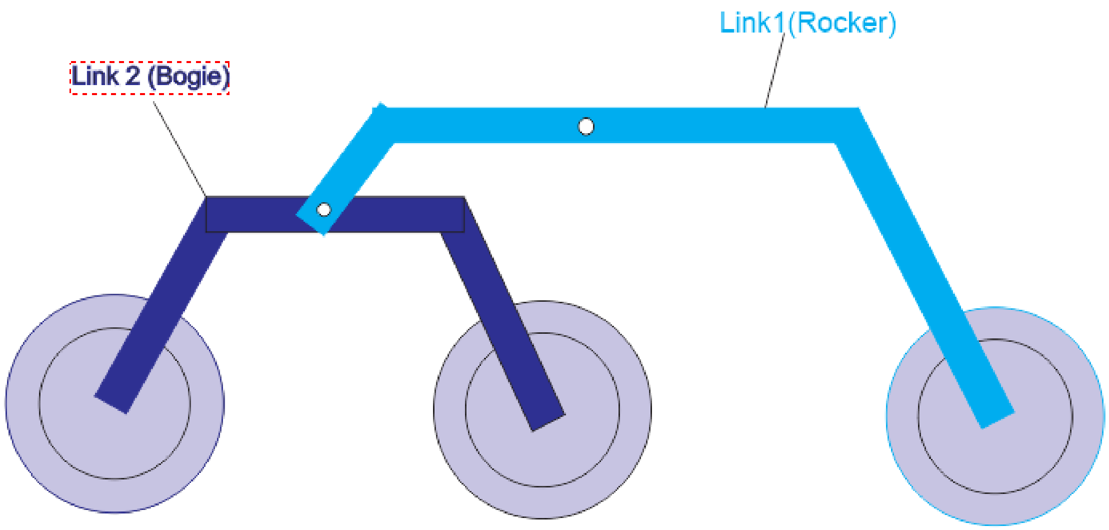


Figure 1: Rocker-Bogie Mechanism

The word "rocker" describes the back part of the larger links present on both sides of the suspension system and these rockers are connected to each other and the vehicle chassis through a selectively modified differential in order to balance the bogie.

By construction it has a main frame containing two linkages on each side that are called the "rocker" (see Figure 1). One end of the rocker is connected to the back wheel, and the other end is connected to maintain the center of gravity of the entire vehicle as according to the motion, when one rocker moves down-word, the other goes upward (Figure 1). It plays a vital role to maintain the average pitch angle of both rocker and bogie by allowing both rockers to move as per the situation. As per the actual design, one end of a rocker is joined with a drive wheel and the other end is pivoted to a bogie which gives required moment and degree of freedom.

3 HISTORY OF ROVERS:

3.1 Lunkhod

The first planetary geological exploration rover selected was "Lunakhod" which has been sent Moon twice with USSR – Luna missions to gather information around settled site and send images of enviornment. Lunakhod was guided in realtime by a 5-person team at the Deep Space Center near Moscow, USSR. Lunakhod-2 toured the lunar Mare Imbrium (Sea of Rains) for eleven months in one of the greatest successes travelled 37 km on Moon terrain.

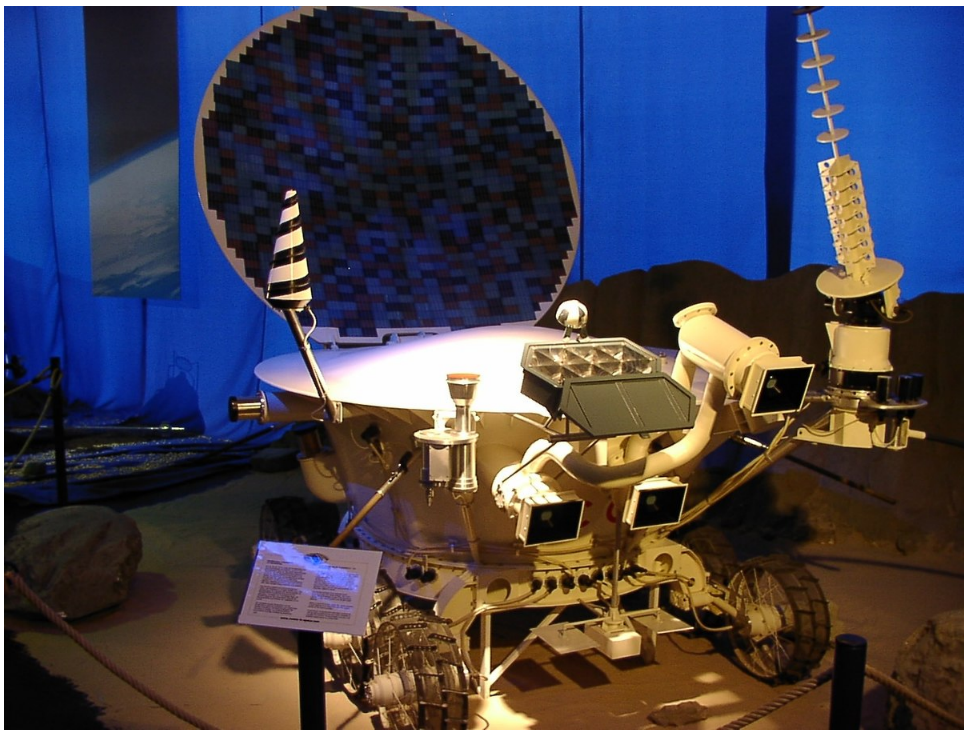


Figure 2: Lunkhod

3.2 Nanorover

Another rover to active suspension system is nanorover which was invented for exploration of small celestial bodies like comets and asteroids in space. Small dimensional characteristics and lightweight are advantages of this robot. .
This system consist of four wheels with 6 cm diameter. Each wheel is con-

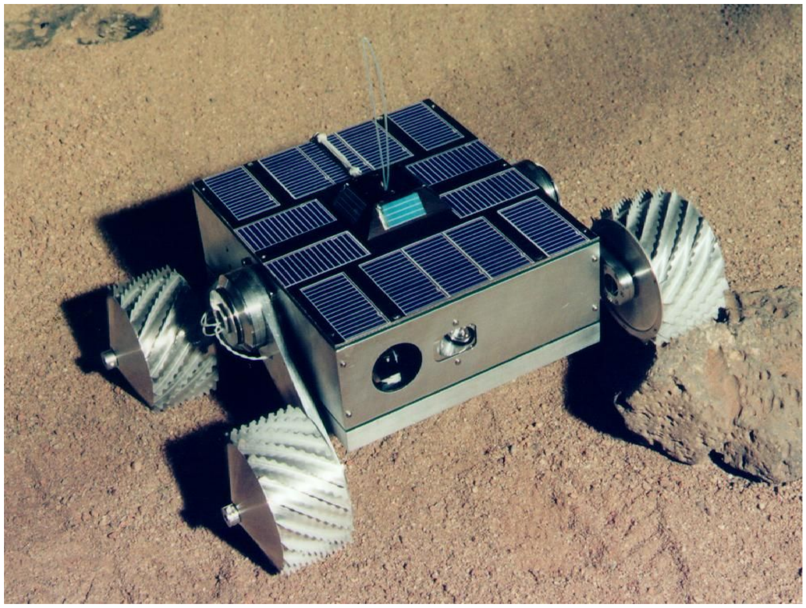


Figure 3: Nanorover

nected to the chassis with independent positioned struts. Since the robot can operate on both sides (upside-down), overturning was not a problem. Onboard computers can also manipulate the suspension systems for arranging tractor forces.

3.3 Sojourner

In 1996, NASA – Jet Propulsion Laboratory and California Institute of Technology have designed improved rovers with similar structure named Sojourner and Marie-Curie. These tiny rovers were only 10.5 kilograms and microwave oven sized. Rover Sojourner was established with Pathfinder landing module in December 1996. Marie Curie rover was also planned to send Mars with 2001 mission but was cancelled.

Operators have sent commands via lander Pathfinder and they examined rocks and soil components of Mars more than 3 months. Sojourner was a breaking point of exploration rovers with its unique six-wheeled suspension system which can overcome one and a half wheel diameter height obstacles that is similar to an auto-mobile passing over a table sized obstacle.

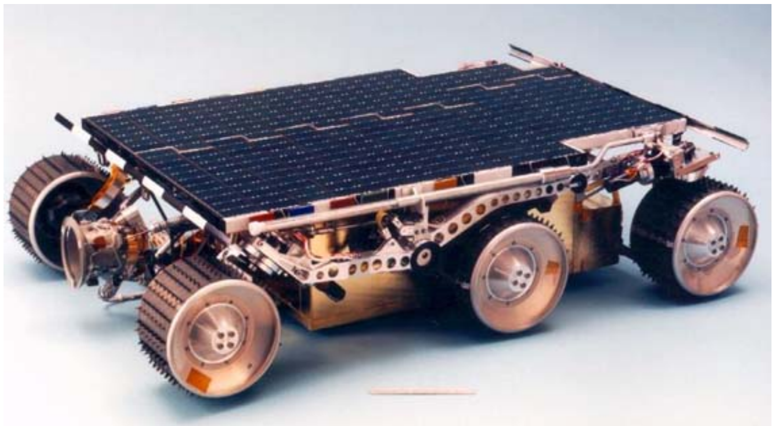


Figure 4: JPL Sojourner Rover

3.4 Shrimp

Shrimp is also a different six-wheeled rover which designed by Swiss Federal Institute of Technology – EPFL. It has a one front four-bar to climb over obstacles up to two wheel diameter with no stability problem.
The Middle has four wheels which have parallelogram bogie which balances the wheel reaction forces during climbing. Single back and front wheels connected directly to the main body also driven by motor to increase the climbing capacity.

Figure 5: Shrimp vehicle

3.5 Inflatable Rover

Another alternative to move on a hard environment is to have big wheels. If a rover has larger wheels compared to obstacles, it can easily operate over most of the uneven rocky surface. Researches show that inflatable rover with 1.5 meter wheel diameter can travel about 99Inflatable rover has 3 wheels which the motor drives.

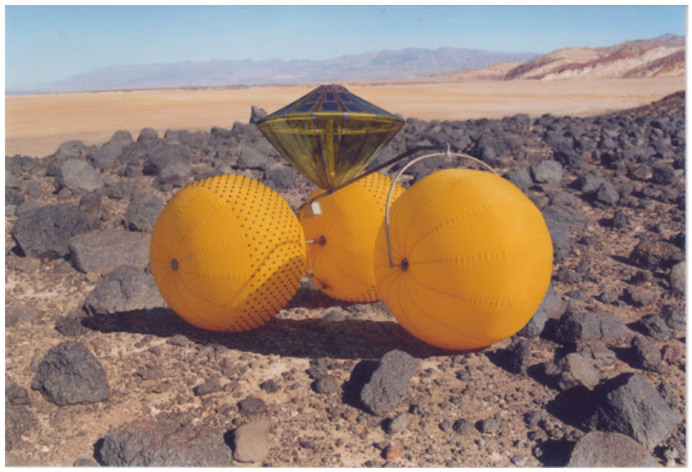


Figure 6: Inflatable Rover

4 IDEATION:

4.1 Choosing rocker-bogie and relevant software

We started our project around the time the Perseverance rover was launched by Nasa to Mars. Since this was something that interested all of us, we decided to look for a mechanism involved in the rover. This was how we came across the rocker-bogie mechanism, which is the most commonly used mechanism in rovers and many other vehicles which are used to traverse uneven terrains.

On seeing this rocker bogie, we decided to try to simulate what was seen in the rover as closely as possible, but we soon discovered that it was way more complex than it looked, with a very complex chassis. So we tried to simulate just the 6 wheel mechanism, with the differential (which itself is a very complex mechanism by itself) to the best of our ability.

On doing some research into the rocker-bogie, we found that it could be used

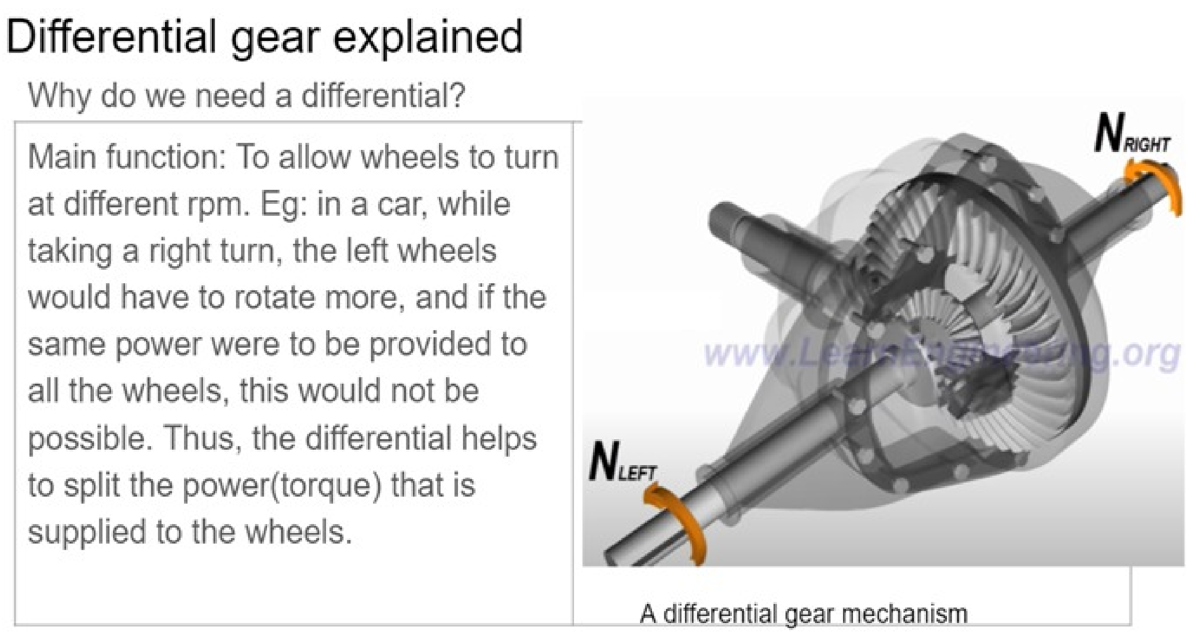
in rescue and search operations on Earth also since this is right now the most popular and widely used mechanism for an unmanned traverse of uneven and dangerous paths, including but not limited to slippery regions like on mountain slopes and also uneven terrains in terms of obstacles(like on Mars).
We explored multiple Softwares -Autodesk fusion 360 and Ansys rather extensively for our simulations and decided on MATLAB -SIMULINK and SIMSCAPE because of the variety of the libraries that are available in MATLAB which made simulations across terrains easier. We also managed to find reasonably well-explained tutorials for the same.
One issue that we faced was that it was rather difficult to make our 3D model in MATLAB. What worked better for us was making the model in Fusion 360 and importing it as an ipt file to MATLAB. We found that we could then simulate the joints and contacts in MATLAB from the imported model. There was a slight nag with respect to the various transformations that we had to give for our imported model, but this was still easier than sketching our model in 3D in MATLAB.

4.2 The Differential - the suspension in the rocker-bogie system:

The differential is one of the key components of the rocker-bogie. We can even go on to say that this is possibly the most important feature of the rocker-bogie.
As we know, one of the key features of the rocker-bogie is that at any point, all the 6 wheels would be in contact with the ground. This is true even when the only side of the rocker-bogie, i.e. only one side has to traverse over an obstacle. At this point, it is the differential that helps to maintain contact at all 6 wheels. This in addition to providing stability in the sense of the normal force not being too much at one wheel, also helps to power over obstacles easier as there is 1 motor attached to each wheel which helps propel the vehicle over the terrain.
There is another variant of the differential called the differential gear system. While the basic concepts involved are the same, here, (at least the way it's used in regular vehicles like cars), there is only 1 motor and the differential gear helps to decide what fraction of the [power should go to each wheel.
We decided to choose a differential gear, because rather than a differential

rod. The basic mechanism of a differential gear has been explained below for a simple turning system in a car.

4.3 The Differential explained:



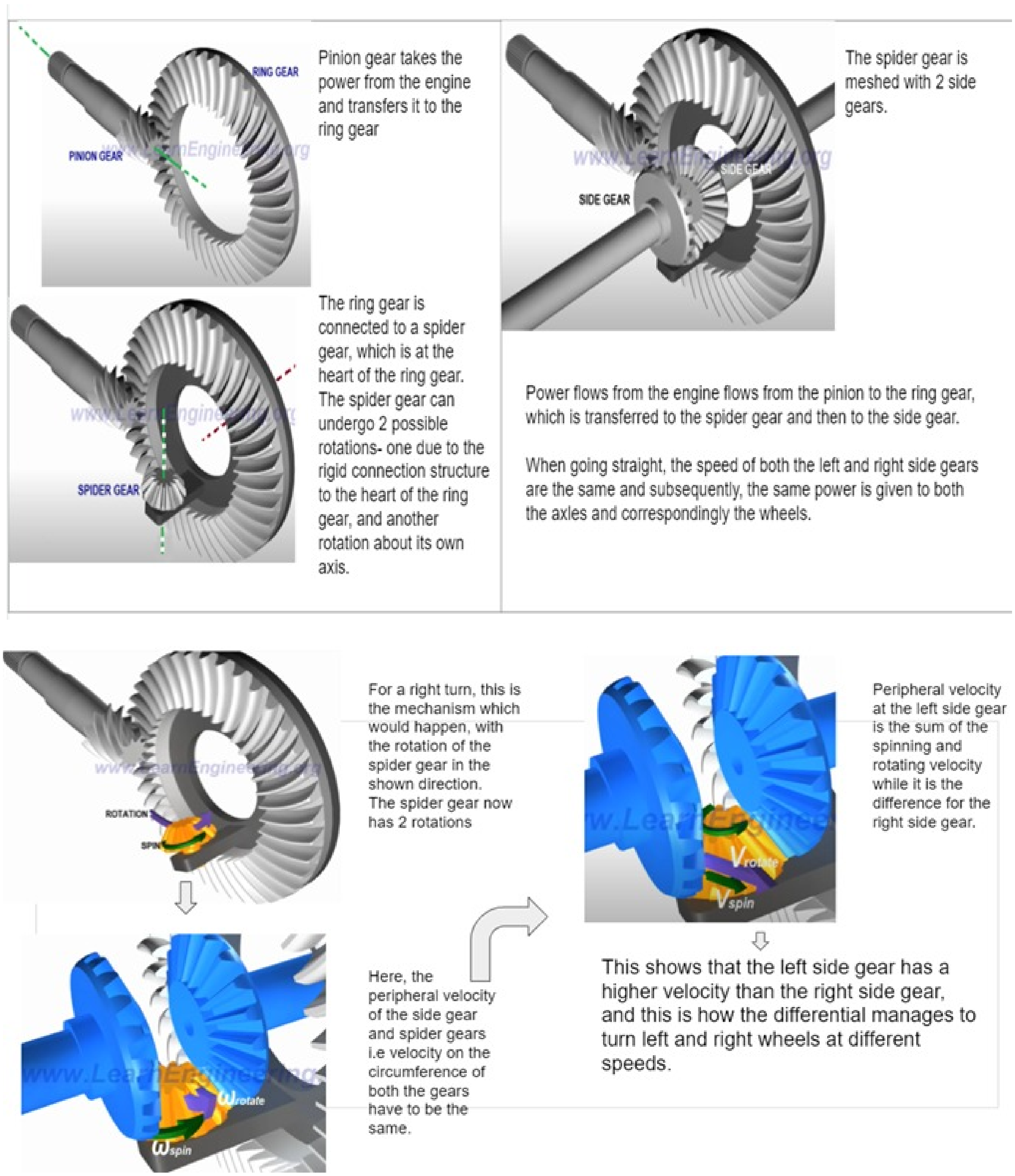


Figure 7: (visuals and corresponding explanation credit in the endnote)

5 TIME-LINE OF OUR PROJECT:

5.1 Weeks 1 and 2:

The first week was spent exploring various possible topics for our project. There were other topics we considered as the mechanism of a robotic window cleaner, but as already mentioned above, the rocker-bogie mechanism was what we felt was the best topic.
The 2nd week consisted mainly of looking into research papers and patents relevant to the rocker-bogie mechanism. There were quite a few ones we got, but the ones that we used mainly have been given as references in the endnote below. It was a bit of a struggle to find literature that we could understand, as a mechanism as complex as rocker-bogie which is extensively used by NASA was indeed a formidable challenge.

-A paper that we found had some experimental data regarding the rocker-bogie
-A paper that had a few calculations and a bit of a component-wise split
-This was a Master's thesis paper that we managed to find and tried to understand and use as a reference for our project.
We went through some other literature also, but these were the most relevant ones we found.

5.2 Week 3:

In week 3, we continued our search for more relevant literature. We were able to make some headway in this aspect as we managed to find a few journal entries and patents relating to our project- the irjnet and ijisrt links journals specifically.
We also modelled a basic rocker-bogie mechanism using an existing model as a reference. With that we were able to able to place joints for the rocker, the bogie and a simple rod in place of the differential(not incorporating the differential yet)

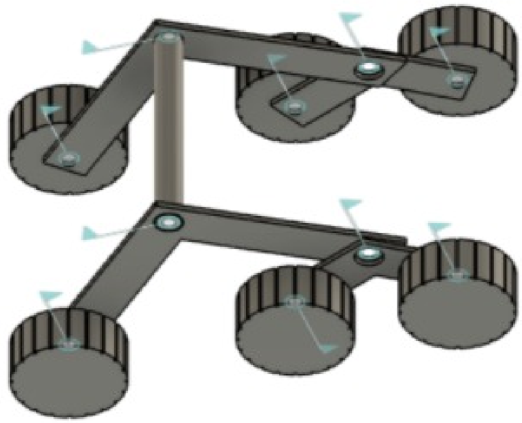


Figure 8: (visual of the mechanism we designed)

5.3 Week 4:

This week, we looked at ways to import the model into MATLAB from fusion. The majority of the week was spent learning about MATLAB SIMULINK and SIMSCAPE for the same.
We modelled the contact surface between the wheel and the ground which will constitute the first part of our analysis and simulated the same for a given input torque that can be applied through a motor of sorts. Initially, we faced the issue of the wheel not being stable but then we realised that the error was due to modelling problems and later we got rid of the instability by modelling the wheel better by changing parameters in the Simulink and simscape models. In the ending, we managed to model a wheel rotating over

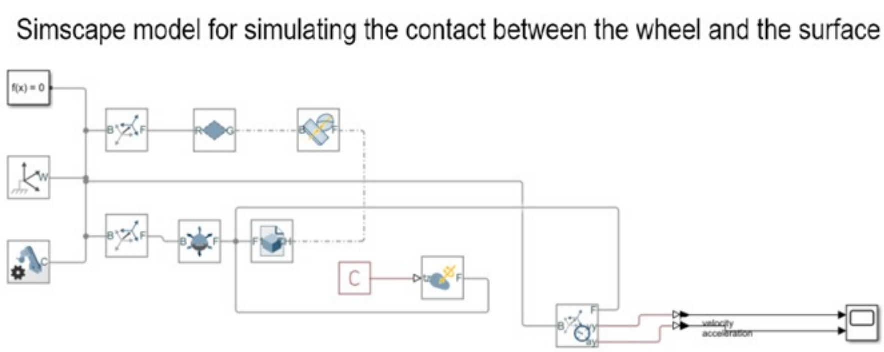


Figure 9: simscape model

the surface with all contacts properly specified

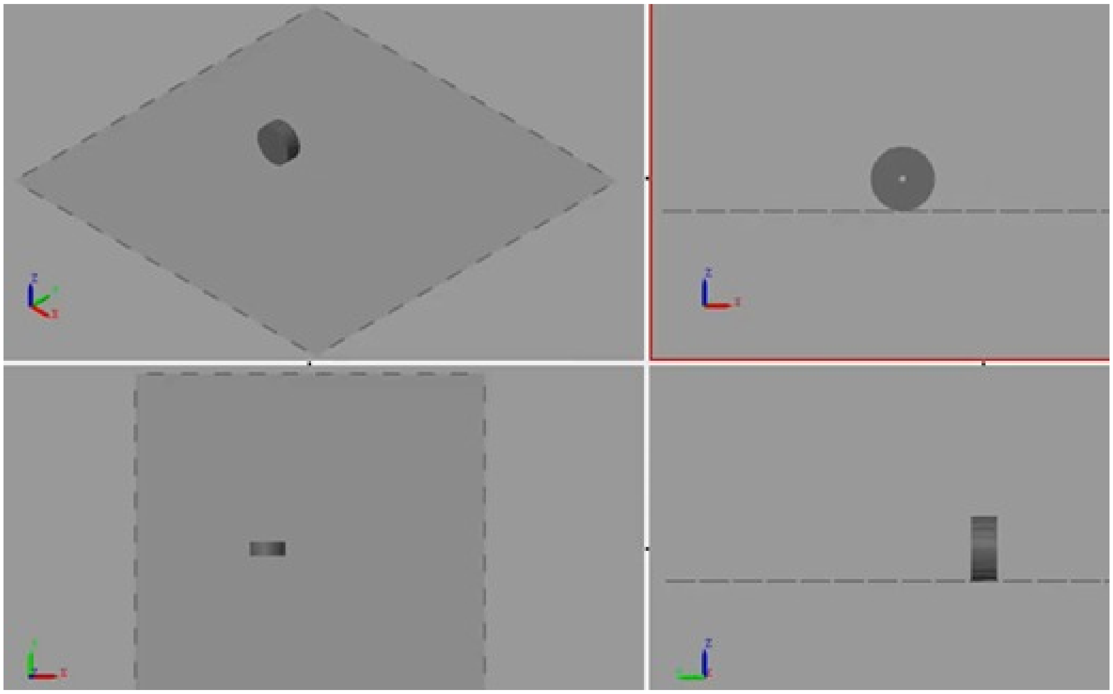


Figure 10: wheel: simscape model

5.4 Week 5:

This week, we modelled a simple chassis with 4 wheels, with the front and rear axles connected by a rod. A few key difficulties we faced were specifying the constraints for all the wheels and the connecting rod, which involved the desired translations for maintaining contact in the case of wheels with the ground and the chassis with the 2 axles.
We imported the 4 wheels separately and modelled the 2 rods in MATLAB for this week. We faced a bit of a hassle in figuring out which joint had to be modelled for the axles and the connecting rod and figured out that we had to use cylindrical joints and not rigid or spherical joints.
We also imported an incline from Fusion 360, which was just a small obstacle, and as expected in the absence of a suspension system, after crossing the obstacle the entire model was unevenly bouncing.

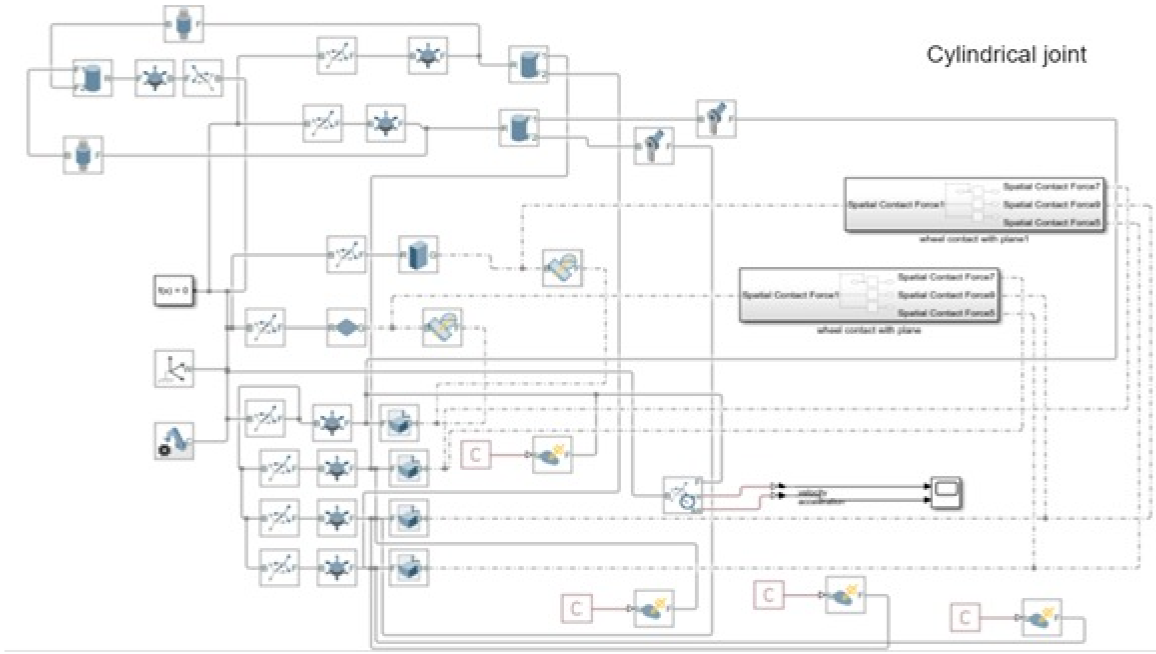
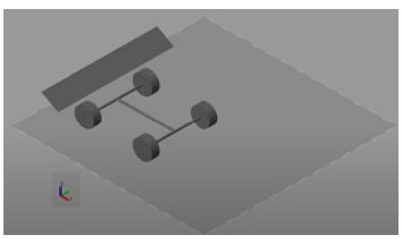
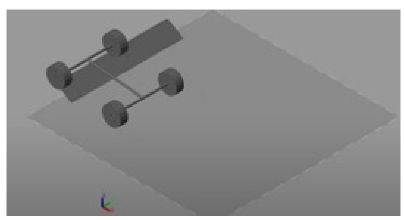


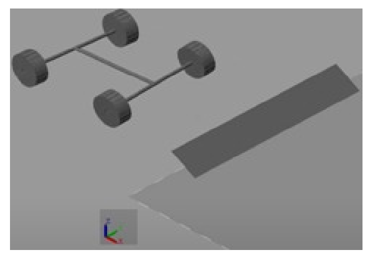
Figure 11: simscape model



(a) Going over smooth surface



(b) Climbing the incline



(c) Going down the incline

Figure 12: First 4 wheeled simscape model simulation

5.5 Week 6:

This week, we tried importing the entire rocker-bogie mechanism model that we had made in Fusion 360(with just a rod in place of the differential) into MATLAB and applying all the required constraints and contacts and transformation. This already had 2 connecting rods, and thus we used the suggestion we got last week.

We faced multiple difficulties here, including modelling the rocker-bogie itself, to importing it to MATLAB,m for which we discovered ipt format allowed you to intera t with the imported model as opposed to stl which we were previously using and also in incorporating all the required contacts for the wheels. We also made the obstacle a step of 90 degrees.

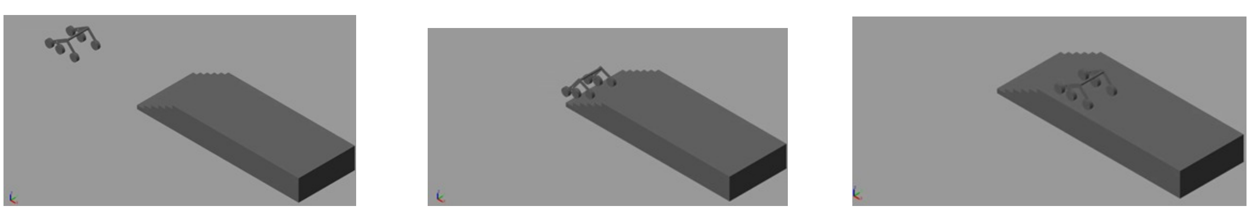
Figure 13: Travelling smoothly before the obstacle

Figure 14: We can see the rocker-bogie mechanism climbing the step

We can see that the rocker-bogie is now moving smoothly on the platform. 2 factors- the design of the rocker-bogie itself and also increasing the damping coefficients for the wheel contacts(does practically by using foam or rubber) helped in the reduction of bouncing

5.6 Week 7:

This week, we tried increasing the complexity of our obstacle course. We incorporated a staircase.



(a) Smoothly moving before encountering the obstacle

(b) Rocker bogie climbing the stairs

(c) Smooth movement after climbing stairs

Figure 15: Climbing multiple stairs

The issues we faced here was that at too small a torque for the wheels, it didn't climb the steps and if the torque was too high, it flew off. So we had to find the right balance of torque which we did by trial and error since we still did not have the analysis concerning the link length ratios and wheel diameters, other than from the literature.
This analysis however had a problem to be solved before it, which was the differential since all these obstacles were uniform That was what we planned on looking at for the subsequent week.

5.7 Week 8 and 9:

This week was spent almost entirely in search of literature that was easily understandable about the differential. It was during then that we got to know about the differential rod and differential gear, and we decided on the differential gear mechanism, which was explained in the above part in the theory for differential.
We also then managed to find a differential gearbox toolkit in SIMSCAPE and we are in the process of understanding it and the relevant parameters.

6 REFERENCES:

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