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Design of Rocker-Bogie Mechanism

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Chapter 1
INTRODUCTION OF PROJECT

1.1 BASIC DESCRIPTION

NASA recently started an ambitious exploration program of Mars. Pathfinder is the first over explorer in this program. Future rovers will need to travel several kilometers over periods of months and manipulate rock and soil samples.

The term "rocker" describes the rocking aspect of the larger links present each side of the suspension system and balance the bogie as these rockers are connected to each other and the vehicle chassis through a modified differential.

In the system, "bogie" refers to the conjoining links that have a drive wheel attached at each end. Bogies were commonly used to bare loading as tracks of army tanks as idlers distributing the load over the terrain. Bogies were also quite commonly used on the trailers of semitrailer trucks as that very time the trucks will have to carry much heavier load.[1]

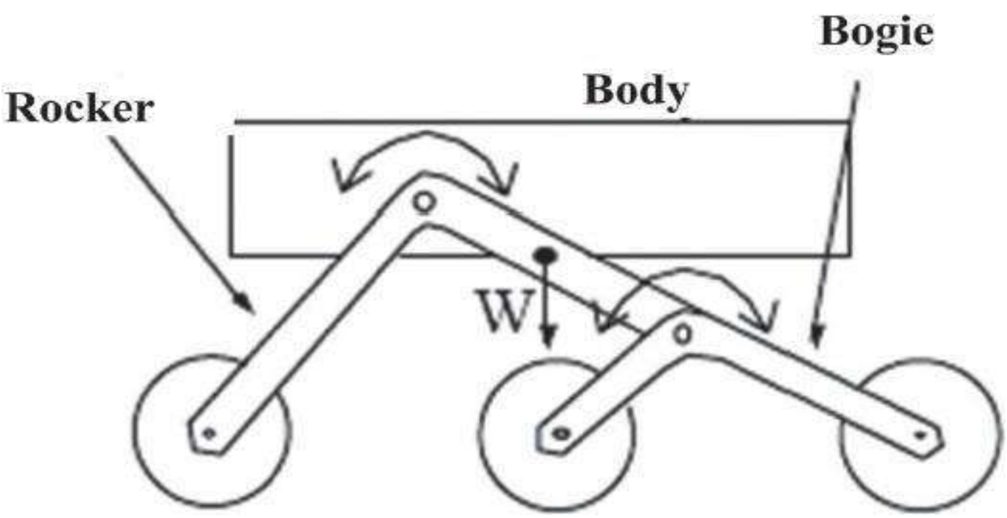

Figure 1.1Line Diagram of Rocker Bogie Mechanism

As accordance with the motion to maintain centre of gravity of entire vehicle, when one rocker moves up-ward, the other goes down. The chassis plays vital role to maintain the average pitch angle of both rockers by allowing both rockers to move as per the situation.[4]

The physics of these rovers is quite complex. To design and control these analytical models of how the rover interacts with its environment are essential. Models are also needed for rover action planning. Simple mobility analysis of rocker-bogie vehicles have been developed and used for design evaluation in the available published works.

The rocker-bogie configuration is modeled as a planer system. Improving the performances of a simpler four wheel rover has also been explored.[2]

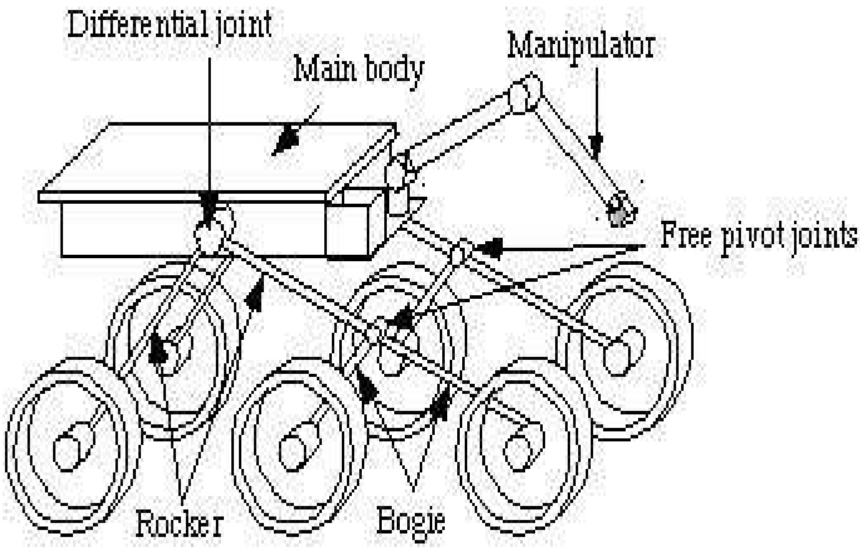

Figure 1.2 Three Dimensional view of Rocker Bogie Mechanism

1.2 HISTORY OF ROVERS

1.2.1 LUNAKHOD

The first planetary exploration rover was "Lunakhod" which has been sent Moon2 times with USSR – Luna missions to gather information around landing site and send pictures of terrain.

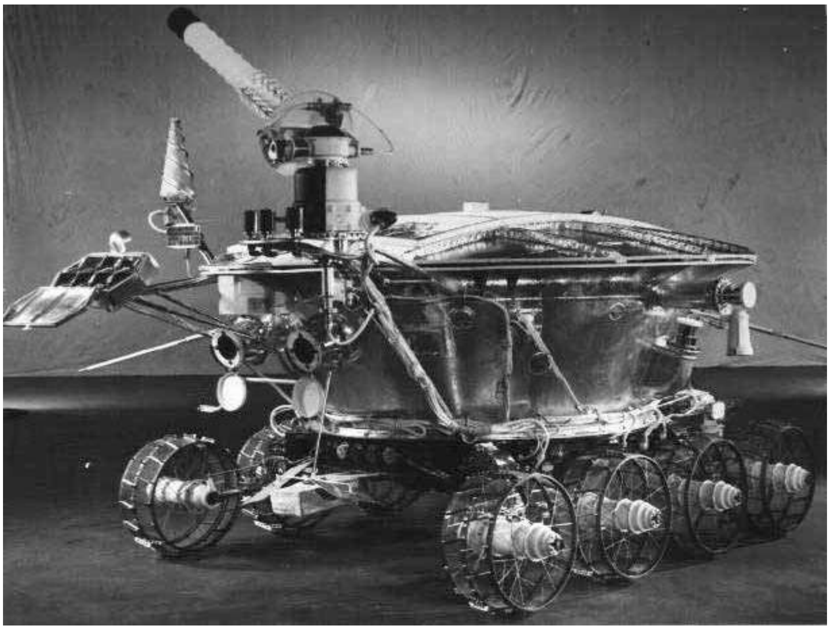

Figure 1.3 First Planetary Exploration Rover "Lunokhod"

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Lunakhod has guided in real-time by a five-person team at the Deep Space Center near Moscow, USSR. Lunakhod-2 toured the lunar Mare Imbrium for 11 months in one of the greatest successes travelled 37 km on Moon surface.[3]

1.2.2 SOJOURNER

In 1996, NASA – Jet Propulsion Laboratory and California Institute of Technology have designed new rovers with identical structure named Sojourner and Marie-Curie.

These small rovers were only 10.5 kilograms and microwave were oversized Rover Sojourner launched with Pathfinder landing module in December 1996. [3]

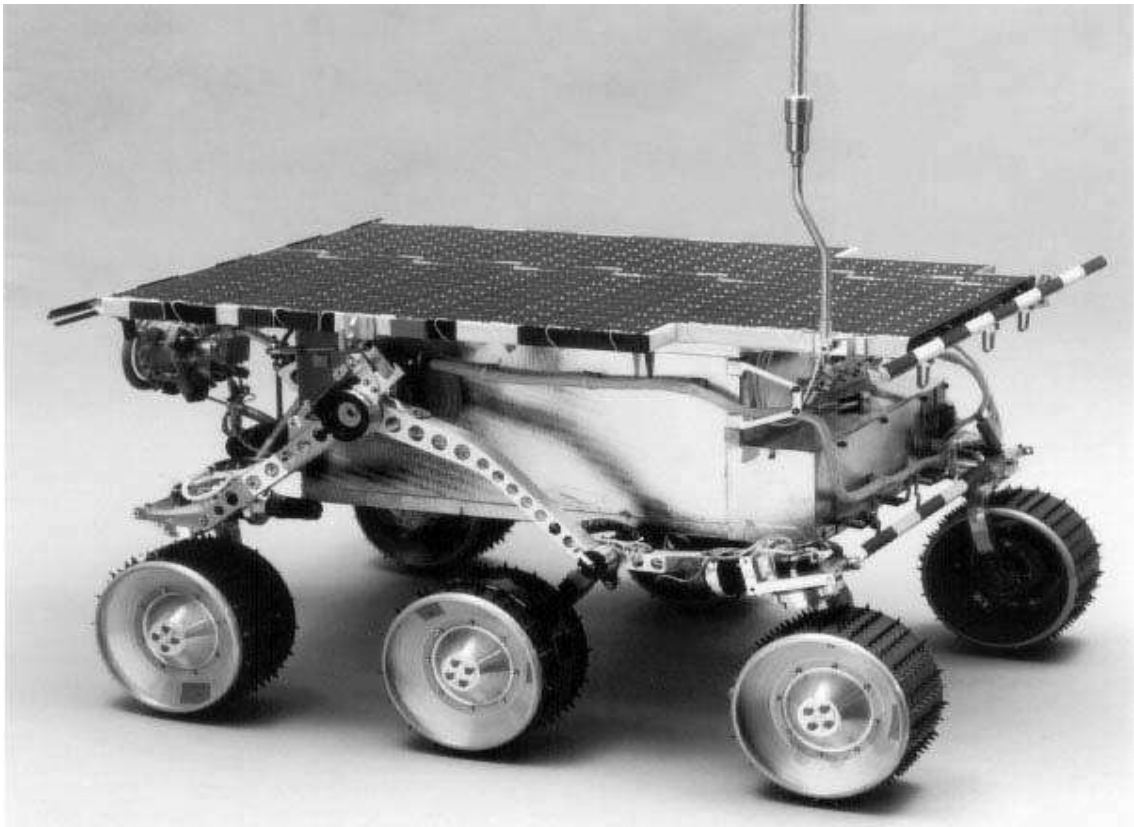

Figure 1.4 NASA - JPL Sojourner Rover

1.2.3 INFLATABLE ROVER

Another alternative to move on a harsh environment is to have big wheels. If a rover has large wheels compared to obstacles.

it can easily operate over most of the Martian rocky surface. Inflatable rover has 3 wheels which are driven by motors.[3]

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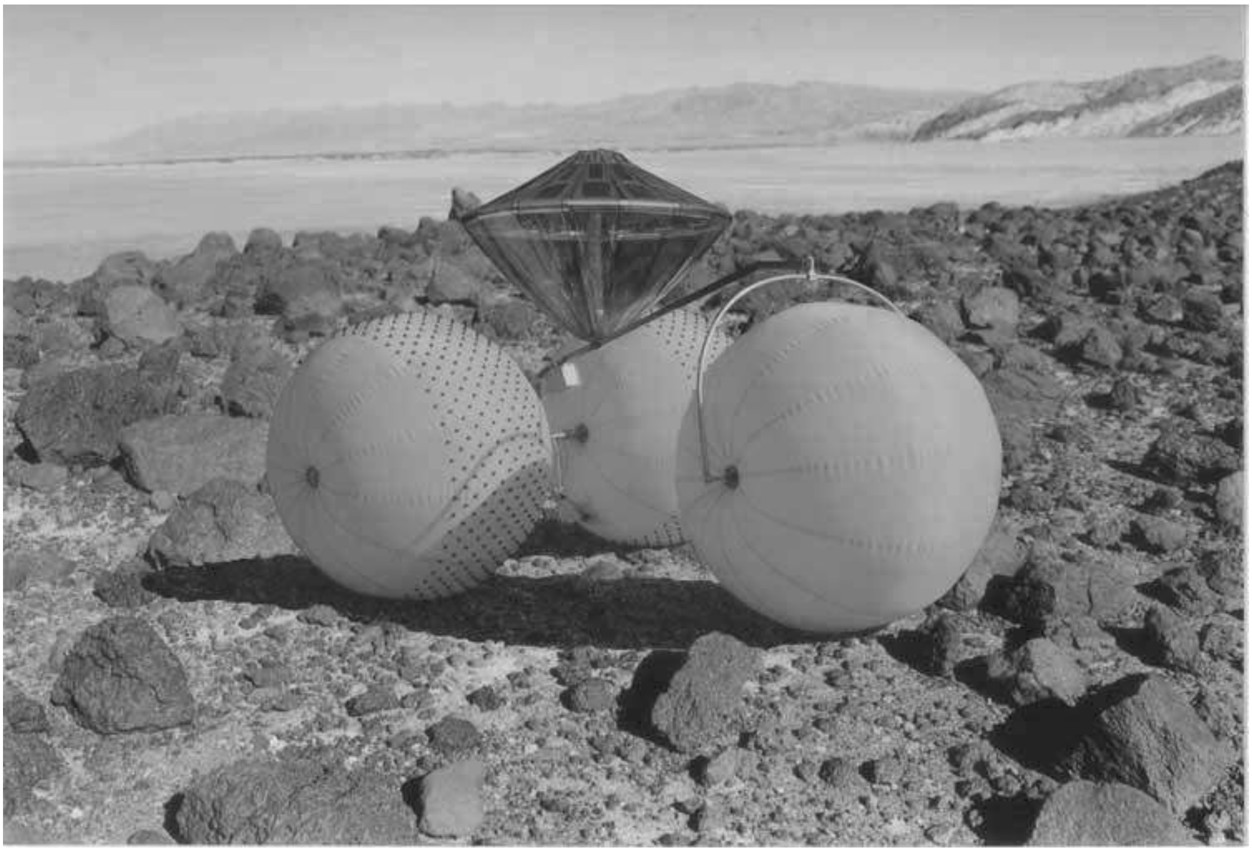

Figure 1.5 Inflatable Rover

1. 3 ADVANTAGES

- The design incorporates independent motors for each wheel. There are no springs or axles, making the design simpler and more reliable.
- Rocker Bogie Suspension can withstand a tilt of at least 50^0 in any direction without overturning, which is the biggest advantage of heavy loaded vehicle.
- It can move in harsh environment
- It can work in place which are beyond human reach
- Rocker Bogie consisting of no spring and stub axle in each wheel which allows the chasis to climb over any obstacle such as rocks, ditches, sands etc. that are upto double the wheels diameter in size while keeping all the wheels on ground for maximum time.

Chapter 2
LITERATURE REVIEW

2.1 STUDY

The rocker-bogie system is the suspension arrangement used in the MarS rovers (mechanical robot) introduced for the Mars Pathfinder and also used on the Mars Exploration Rover (MER) and Mars Science Laboratory (MSL) missions. It is currently NASA's favored design.[8]

The term "rocker" comes from the rocking aspect of the larger link on each side of the suspension system. These rockers are connected to each other and the vehicle chassis through a differential. Relative to the chassis, when one rocker goes up, the other goes down. The chassis maintains the average pitch angle of both rockers. One end of a rocker is fitted with a drive wheel and the other end is pivoted to a bogie.

The term "bogie" refers to the links that have a drive wheel at each end. Bogies were commonly used as load wheels in the tracks of army tanks as idlers distributing the load over the terrain. Bogies were also quite commonly used on the trailers of semitrailer trucks. Both applications now prefer trailing arm suspensions

The rocker-bogie design has no springs or stub axles for each wheel, allowing the rover to climb over obstacles, such as rocks, that are up to twice the wheel's diameter in size while keeping all six wheels on the ground. As with any suspension system, the tilt stability is limited by the height of the center of gravity. Systems using springs tend to tip more easily as the loaded side yields.[9]

Based on the center of mass, the *Curiosity* rover of the Mars Science Laboratory mission can withstand a tilt of at least 45 degrees in any direction without overturning, but automatic sensors limit the rover from exceeding 30-degree tilts. The system is designed to be used at slow speed of around 10 centimeters per second (3.9 in/s) so as to minimize dynamic shocks and consequential damage to the vehicle when surmounting sizable obstacles.

JPL states that this rocker bogie system reduces the motion of the main MER vehicle body by half compared to other suspension systems. Each of the rover's six wheels has an independent motor. The two front and two rear wheels have individual steering motors which allow the vehicle to turn in place. Each wheel also has cleats, providing grip for climbing in soft sand and scrambling over rocks. The maximum speed of the robots operated in this way is limited to eliminate as many dynamic effects as possible so that the motors can be geared down, thus enabling each wheel to individually lift a large portion of the entire vehicle's mass.[6]

In order to go over a vertical obstacle face, the front wheels are forced against the obstacle by the center and rear wheels. The rotation of the front wheel then lifts the front of the vehicle up and over the obstacle. The middle wheel is then pressed against the obstacle by the rear wheels and pulled against the obstacle by the front until it is lifted up and over. Finally, the rear wheel is pulled over the obstacle by the front two wheels. During each wheel's traversal of the obstacle, forward progress of the vehicle is slowed or completely halted. This is not an issue for the operational speeds at which these vehicles have been operated to date.

One of the future applications of rovers will be to assist astronauts during surface operations. To be a useful assistant, the rover will need to be able to move much faster than human walking speed or at least equivalent. Other missions which have been proposed, such as the Sun-Synchronous Lunar Rover, require even greater speeds (4–10 km/h).[5]

Rocker Bogie Suspension has the specialty of being able to climb over obstacles twice the diameter of the wheel, that too without compromising the stability of the rover as a whole. Some features make it a real design.

1. The mechanism allows to climb over high obstacles, while keeping all the six wheels in contact with the ground. This is only true at the operational speeds of rovers like Curiosity which is around 10 cm/s.
2. The two sides (left and right) move independently, and hence the rover can traverse terrains where the right and left rockers go over different type of obstacles.
3. The mechanism is designed such as due to the independent motion of right and left rockers, the pitching of the chassis or the rover body remains an average of the two rockers.
4. System with spring suspensions are susceptible to tip-over sideways easily than rocker-bogie. Curiosity, by design, can sustain over 50 deg tilt in any direction.
5. The design incorporates independent motors for each wheel. There are no springs or axles, making the design simpler and more reliable.
6. The design reduces the main body motion by half, compared to any other suspension. The jerk experienced by any of the wheel is transferred to the body as a rotation via the differential connecting the two rockers, not as translation like conventional suspensions.

Over the past decade, the rocker-bogie suspension design has become a proven mobility application known for its superior vehicle stability and obstacle-climbing capability. Following several technology and research rover implementations, the system was successfully flown as part of Mars Pathfinder’s Sojourner rover. When the Mars Exploration Rover (MER) Project was first proposed, the use of a rocker-bogie suspension was the obvious choice due to its extensive heritage. The challenge posed by MER was to design a lightweight rocker-bogie suspension that would permit the mobility to stow within the limited space available and deploy into a configuration that the rover could then safely use to egress from the lander and explore the Martian surface. This paper will describe how the MER rocker-bogie suspension subsystem was able to meet these conflicting design requirements while highlighting the variety of deployment and latch mechanisms employed in the design.[7]

The primary role of the MER suspension subsystem is to provide the rover with a mobility system that has the kinematic range to permit the rover to safely traverse 20 cm obstacles and allow the wheel assemblies to rotate for rover “arc-turn” and “turn-in-place” maneuvers. In addition to these general stability requirements, there were several requirements unique to the particular issues of the MER vehicle. Specifically, the suspension was required to

1.) Stow in an extremely small space and deploy the mobility into a stance that would provide the rover with 45 degree stability

2.) Absorb a large percentage of the impact loads the rover would experience during lander egress and surface traverse.

The rocker-bogie suspension is a mechanism that, along with a differential, enables a six-wheeled vehicle to passively keep all six wheels in contact with a surface even when driving on severely uneven terrain (Figure 2.2)

There are two key advantages to this feature. The first advantage is that the wheels’ pressure on the ground will be equilibrated. This is extremely important in soft terrain where excessive ground pressure can result in the vehicle sinking into the driving surface. The second advantage is that while climbing over hard, uneven terrain, all six wheels will nominally remain in contact with the surface and under load, helping to propel the vehicle over the terrain. MER takes advantage of this configuration by integrating each wheel with a drive actuator, maximizing the vehicle’s motive force capability. Another key feature of the suspension that has not been emphasized in previous technology and flight applications is the ability to absorb significant driving loads. In the past, rocker-bogie suspensions have been used on rovers where the loads generated during driving have been relatively low. Therefore, the suspension served primarily as a “rigid” kinematic link between the rover body and the wheels. However, the MER rover has the challenge of egressing from a lander poised on airbags and surface features, a maneuver that could require the vehicle to drop from a significant height above the surface.[11]

Instruments that had been stowed during the landing phase of the mission will be deployed during driving and were not designed to withstand large loads in their science-gathering configuration. A compelling design requirement was to therefore create a “soft” suspension to limit the accelerations experienced by the payload during driving. However, one of the more challenging design issues to address was how soft to make the suspension. A suspension that was too soft will result in large deflections where the rover body or its science appendages may contact Martian surface features in an uncontrolled manner. Therefore, * Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA Proceedings of the 37th Aerospace Mechanisms Symposium, Johnson Space Center, May 19-21, 2004 185 the suspension had to be designed to give the rover a ride somewhere between a luxury vehicle and a truck. The suspension system stiffness target was one that would produce a translational impact load no greater than 6 G’s and not let the rover body deflect below a 20 cm ground height. The resulting suspension structural members were fabricated from tapered, welded, titanium box beams tuned to meet these requirements. The design of these elements also provides exceptional bending and torsional capability while minimizing the volume and mass impact to the spacecraft.[10]

The last and most difficult design requirement was to create a suspension that would stow within the tetrahedral lander, unfold and latch into a deployed configuration, and provide the rover with the ground clearance and stability necessary to navigate the Martian surface. This task required significant coordination with other rover and lander subsystems in order to produce a deployment sequence free of static or dynamic interferences.

2.2 **BACKGROUND**

The type of locomotion used by a mobile robot is crucial for the robot to perform its task and reach its goal in a given environment. This work focuses on the optimization of the design of a planetary rover’s wheel suspension system subject to optimizing well defined mobility metrics. As robots evolve from industrial fixed base robots to autonomous mobile platforms, the concept of locomotion in robotics becomes much more important. Similar to nature, also robot locomotion must be adapted to the given terrain or task.[12]

The optimal type of locomotion must be applied in a challenging environment. The scope of this work is to design an efficient Mars Rover suspension system and to develop and implement a Genetic Algorithm methodology which optimizes the design of the locomotion system and can be applied to diverse mechanisms or other problems. As the Mars Rover is a mobile robot, the wheel suspension system of the rover is most crucial. It allows for movement, mobility and stability of the robot while it is travelling through a Mars environment. The rover must be able to traverse over obstacles of at least half its wheel diameter and keep its stability on slopes or other rough or hazardous terrain. Hence, the Page 200

Proceedings from 10th Australian Space Science Conference, 2010 suspension system is to be optimized using a Genetic Algorithm. A planetary rover is a mobile robot which is especially designed to move on a planet surface. Early rovers were teleoperated like the Lunokhod I while recent ones are fully autonomous, such as FIDO . The rover has to be very robust and reliable, as it has to withstand dust, strong winds, corrosion and large temperature changes. Most rovers are powered by batteries which are recharged by solar panels during the day. Therefore, the rover must position itself in such a way that the solar energy received is maximized.[12]

The rover's locomotion system is crucial to enable it to reach a goal, conduct experiments, gather data and to position itself. Generally three main types of rover locomotion exist, namely wheeled, legged and caterpillar locomotion.

The key difference between the miscellaneous designs of planetary robots lies in the type of locomotion system. Even though many legged and hybrid robots have been presented in literature, most researchers still focus on wheeled locomotion for rovers.

The favoured design for a wheeled planetary rover's suspension system is the rocker-bogie mechanism. Numerous variations of the this mechanism have been presented in literature. The FIDO rover and the Sojourner have six independently steered and driven wheels suspended from a rocker-bogie mechanism. The Rocky7 Rover has a similar suspension system, but only the front wheels are steered. The Nanorover and the Nomad have four steered wheels suspended from two bogies, a variation of the rocker-bogie mechanism. The CRAB Rover uses two parallel bogie mechanisms on each side to overcome obstacles. Lamon et al. optimize a simplified quasi-static model of the six-wheeled rover Shrimp. The motor torques are optimized subject to minimizing the slip of the wheels, hence the odometric error and power consumption are minimized. The optimization seeks for an optimum in the constrained solution space given an initial solution. Li et al. derive a mathematical model to optimize rover suspension parameters which define the geometry of the rocker-bogie. The objective is to minimize the energy consumption, the vertical displacement of the rover's centre of mass and its pitch angle. The authors make use of a sequential quadratic programming algorithm. Iagnemma and Dubowsky introduce an algorithm which optimizes individual wheel ground contact forces. The objective is to optimize traction and to minimize power consumption.[12]

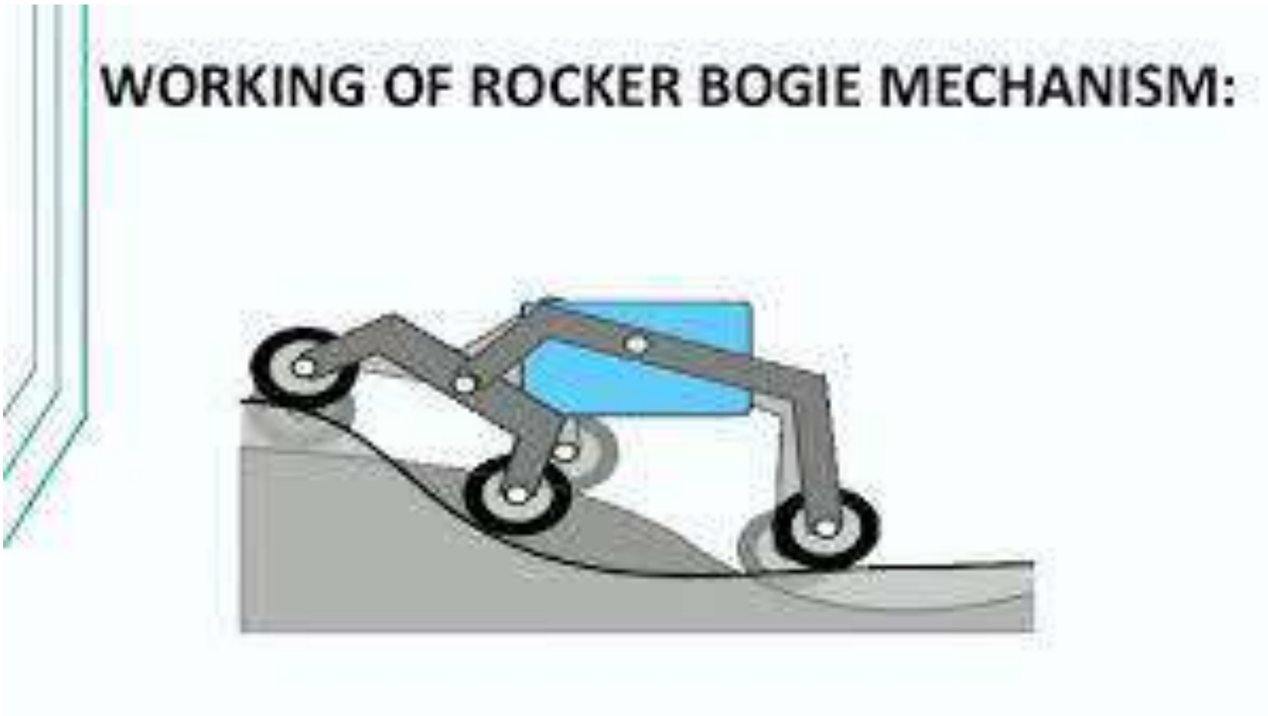

Figure 2.1 RBM on uneven path

2.3 FUTURE SCOPE

- It's future application will be assist astronauts during space operations, it will act as a path finder too.
- It can be useful in space mission too, recently it is used in Mars Rover. This mechanism takes consideration on unevenness of the surface it is driving on.
- This rover has larger wheel as compared to obstacles, It can easily operate over most of the Martian rocks.
- It is also used in coal mines, act as a spy robot and in military operation too.

Chapter 3

DESIGN OF ROCKER BOGIE MECHANISM

3.1 MASS CALCULATION OF PARTS

Here mass of assembly is given below with moment of inertia

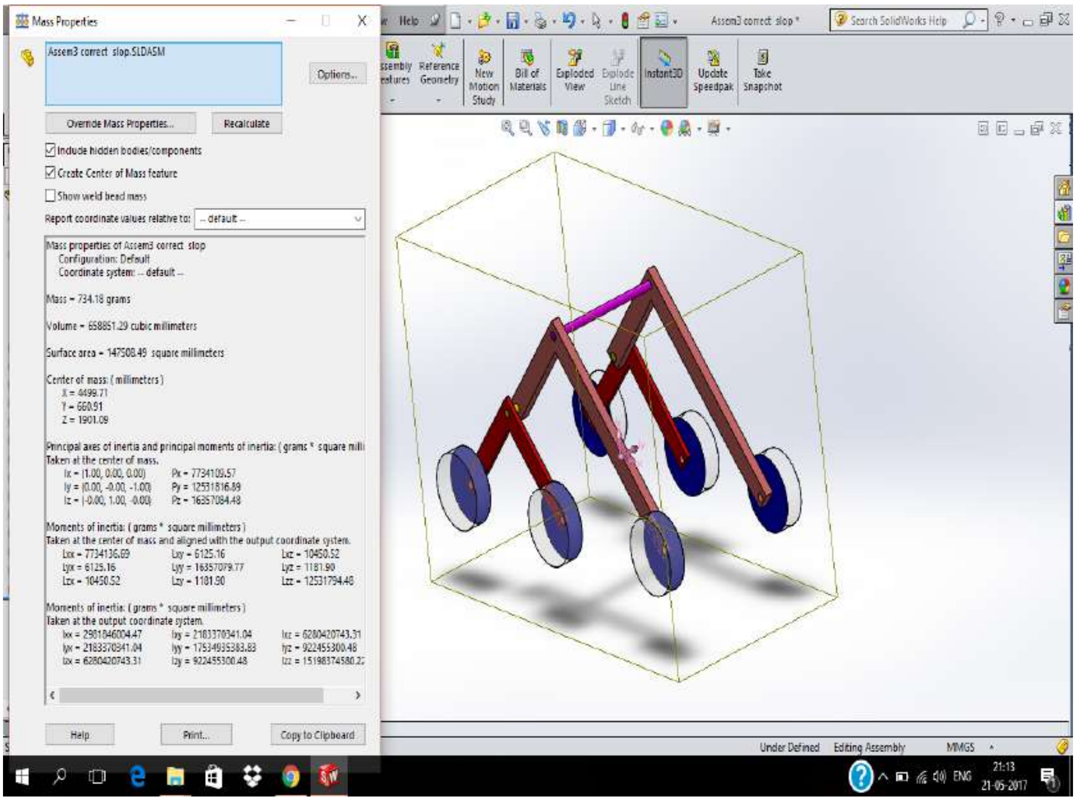

Figure 3.1 mass calculation of RBM

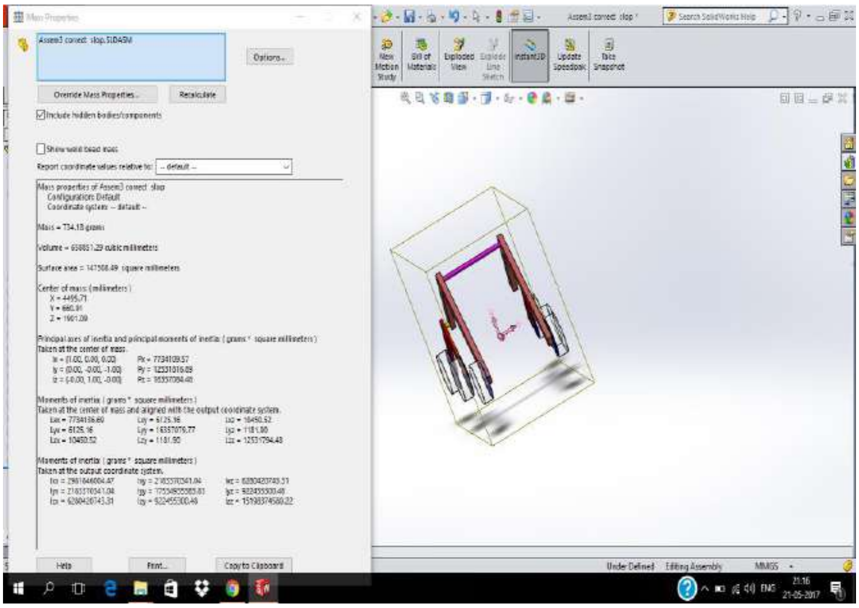

Figure 3.2 moment of inertia analysis of RBM

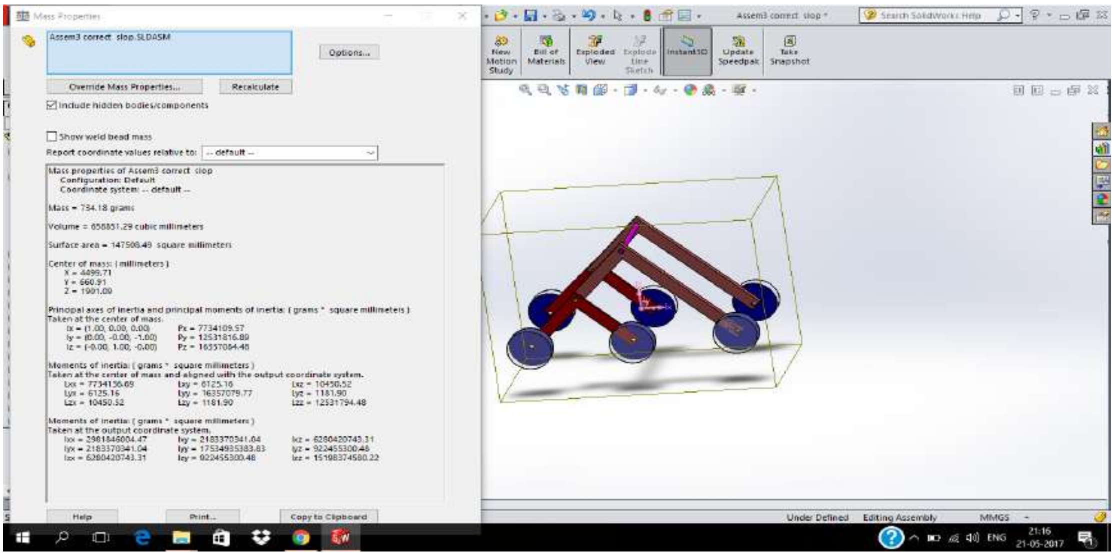

Figure 3.3 area & volume analysis of RBM

3.2 SELECTION OF MATERIAL

Selection of material is an important step in designing of any component

The main advantages of material selection are :

- It increases the reliability of product
- It reduces the cost of product
- It can also optimize the weight of product

3.2.1 DATA OF PLASTIC ABS PC

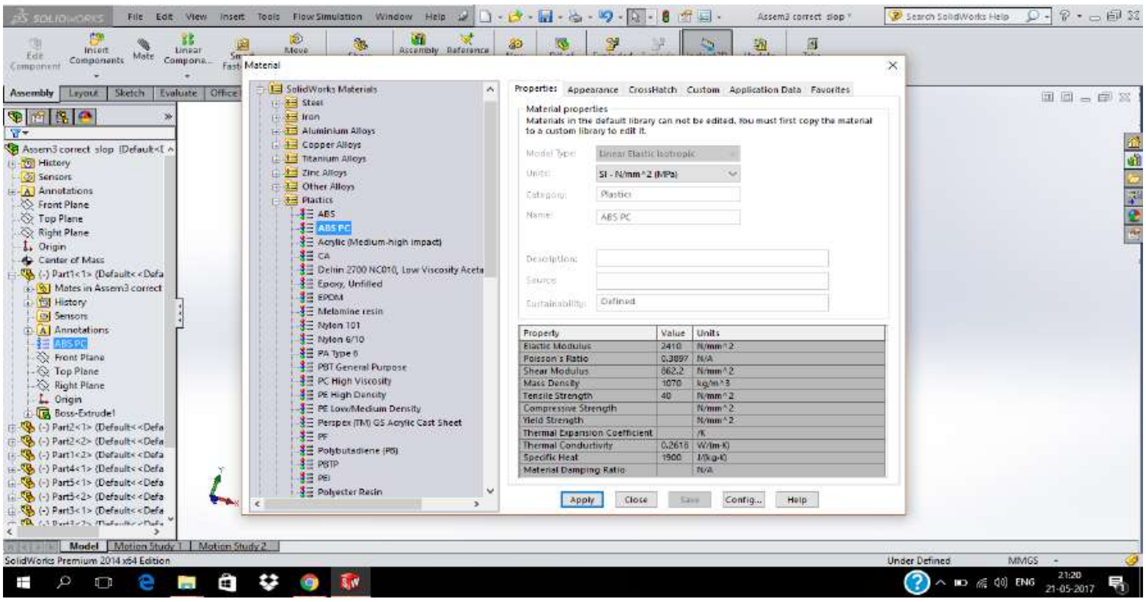

Figure 3.4 data regarding ABS PC plastics

3.2.2 DATA OF 1350 ALUMINIUM ALLOY

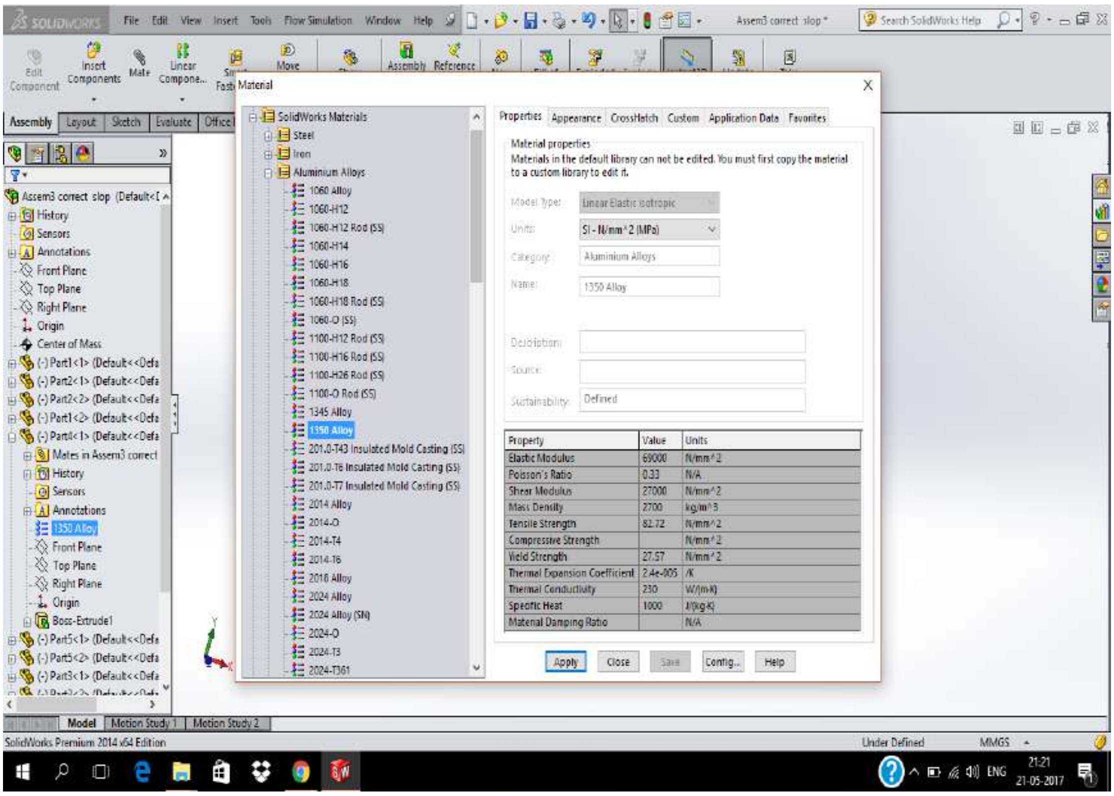

Figure 3.5 data regarding 1350 ALUMINIUM ALLOY

3.2.3 DATA OF PLAIN CARBON STEEL

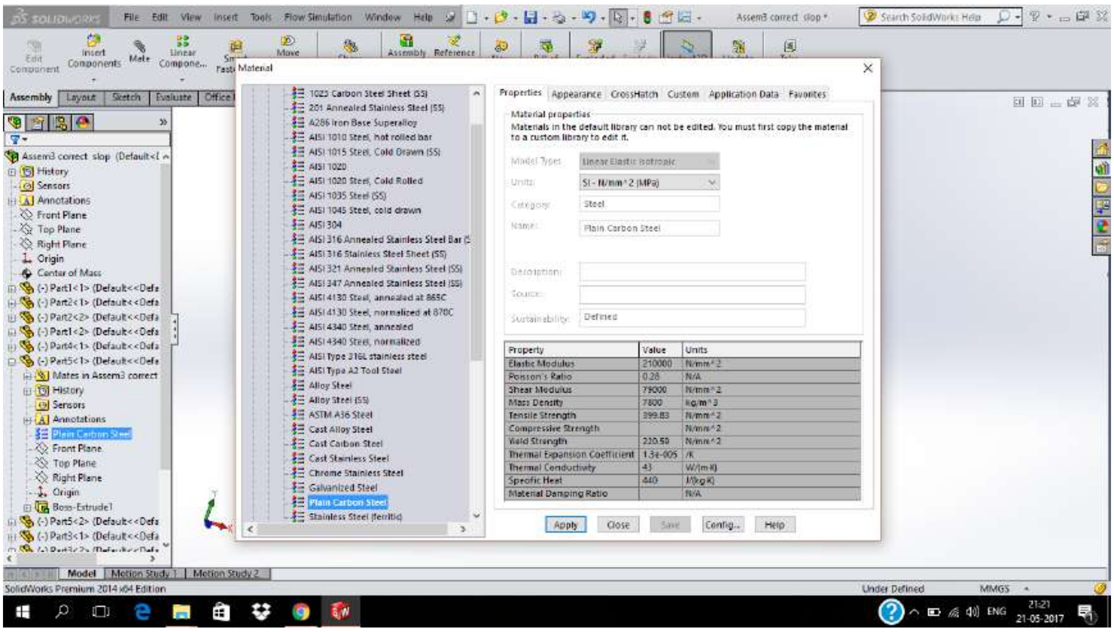

Figure 3.6 data regarding PLAIN CARBON STEEL

3.2DESIGN OF COMPONENTS

3.2.1 DESIGN OF WHEELS

$V = \pi$ D N/60

Assumed required speed is 10 cm/s i.e. 100 mm/s

100 = π D N/60

DN = 1909.86

Now value of D & N are taken from table 3.1.1

D	N
40	47.75
50	38.2
60	31.83
70	27.28
80	23.87
90	21.22
100	19.1

Table 3.1 calculation of Diameter and RPM

So the selected D-N combination is –

D = 70 mm , N = 27.28 rpm

Now Drafting of wheel is done on Solid works with wheel diameter of 70 mm .

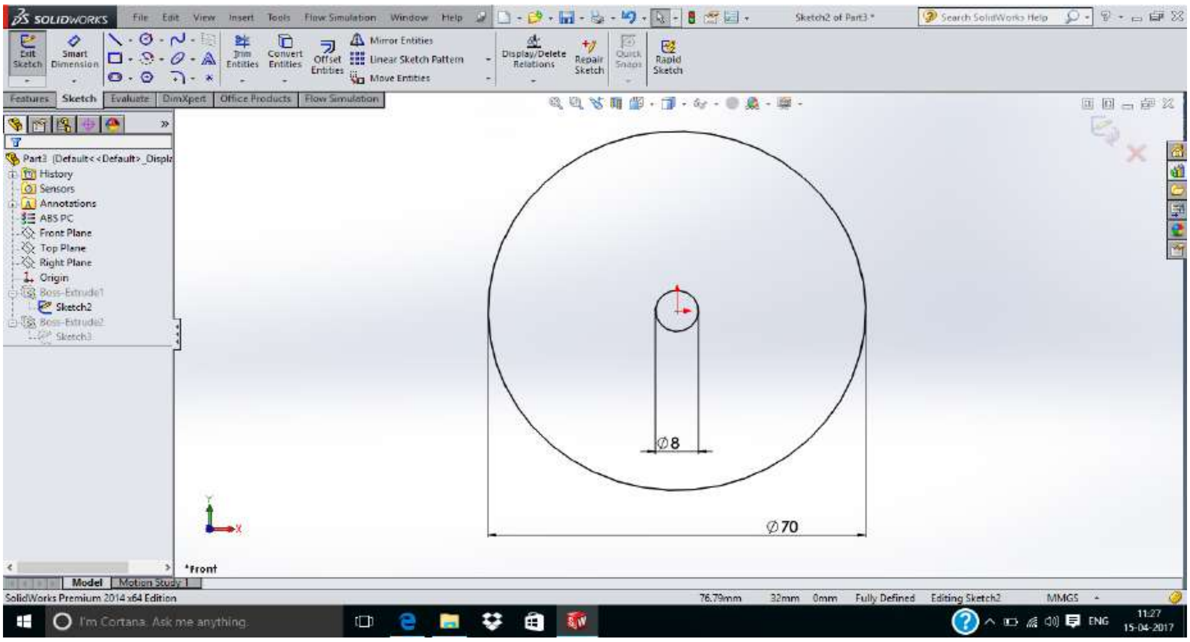

Figure 3.7 sketch of wheel

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Wheels are designed & drafted in such a way so that use of material should be less & weight is less

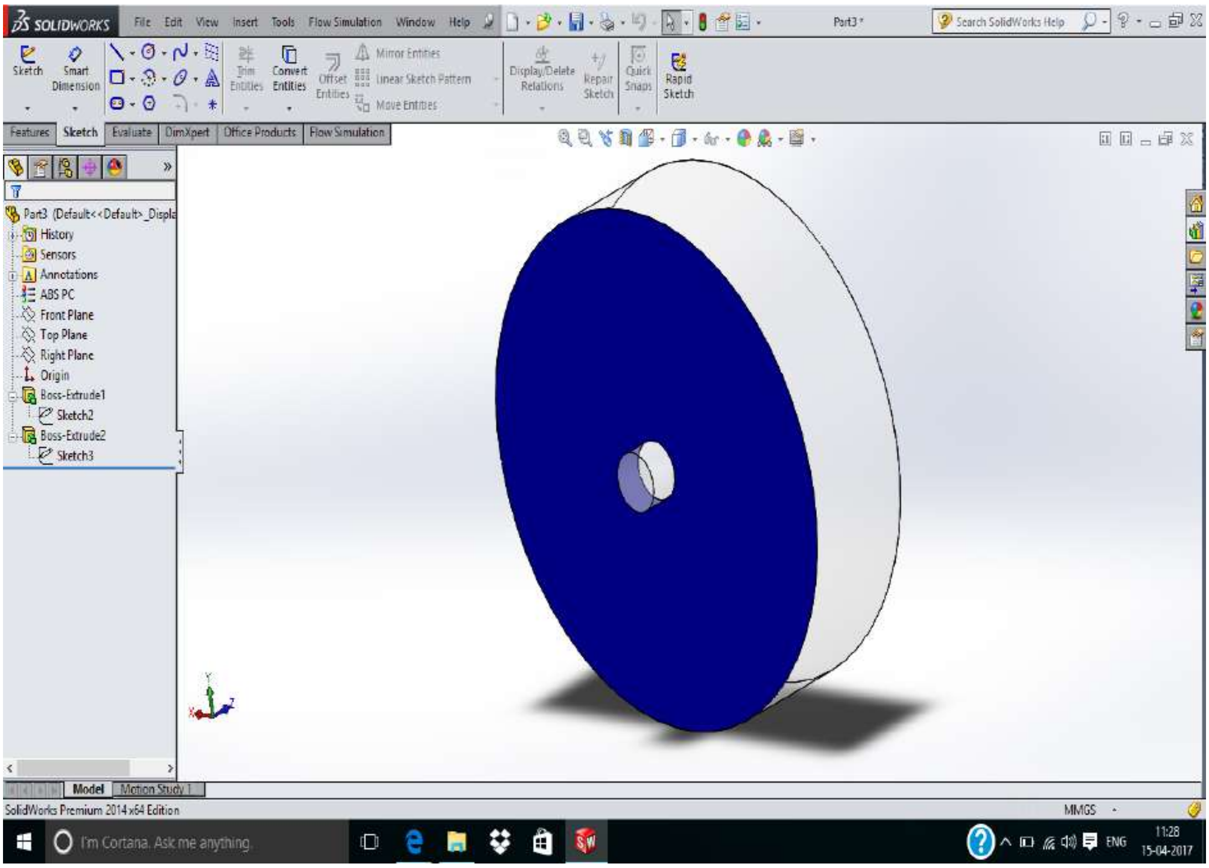
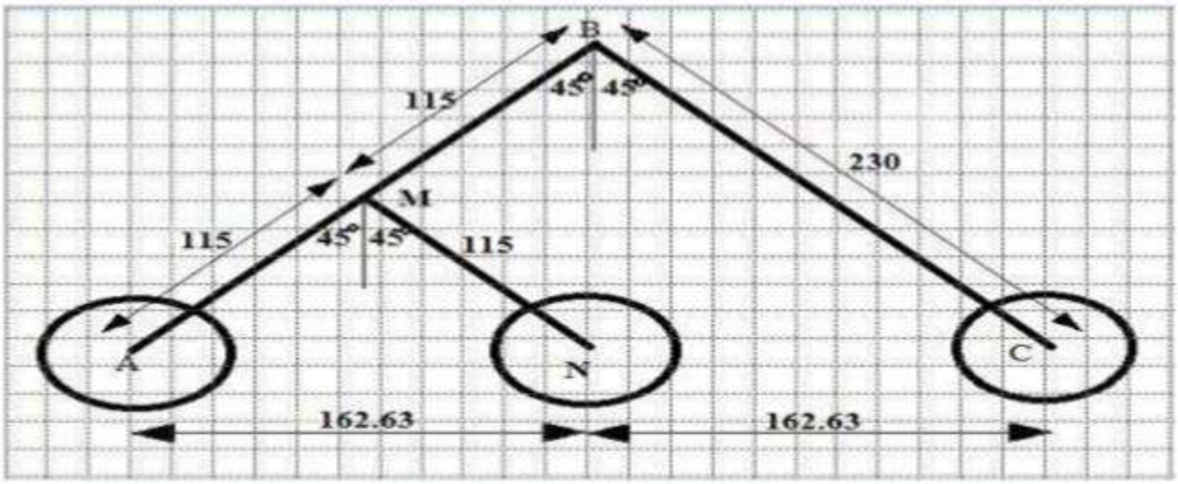


Figure 3.8 drafted model of wheel

3.1.2 DESIGN OF LINKS



If horizontal length of stairs is 400 mm

Then wheel base = horizontal length of stairs – ($R_f + R_r$)

R_f = radius of front wheel

R_r = radius of rear wheel

So wheel base = 400 – (35+35)

Wheel base = 330 mm

Let $\theta = 45^0$

In Triangle BNC, Angle BNC = 90^0

Angle NBC = Angle NCB = 45^0

Therefore, NC = NB

$NC^2 + NB^2 = BC^2$ (from Pythagoras theorem)

$BC^2 = 2(NC^2)$ ……. (1)

$= 2(165^2)$

BC = 233.33 mm

Rounding off to 230 mm

BC = 230 mm

Substituting in eqn (1) we get,

$230^2 = 2(NC^2)$

NC = 162.63 mm

Also,

NC = AN = 162.6 mm

In Triangle AMN, angle AMN = 90^0

$AM^2 + MN^2 = AN^2$

$2(AM^2) = AN^2$

AM = 114.99

AM = 115 mm

Now due to symmetry,

AM = MN =115 mm

$$BM = AB – AM$$

$$= 230-115$$

$$\boxed{BM = 115\ mm}$$

Height of RBM

$$Height^2 = BC^2 – NC^2$$

$$Height^2 = 230^2 – 162.63^2$$

$$Height = 162.4\ mm$$

$$Net\ Height = Height + radius\ of\ wheel$$

$$= 162.4 + 35$$

$$= 197.64\ mm$$

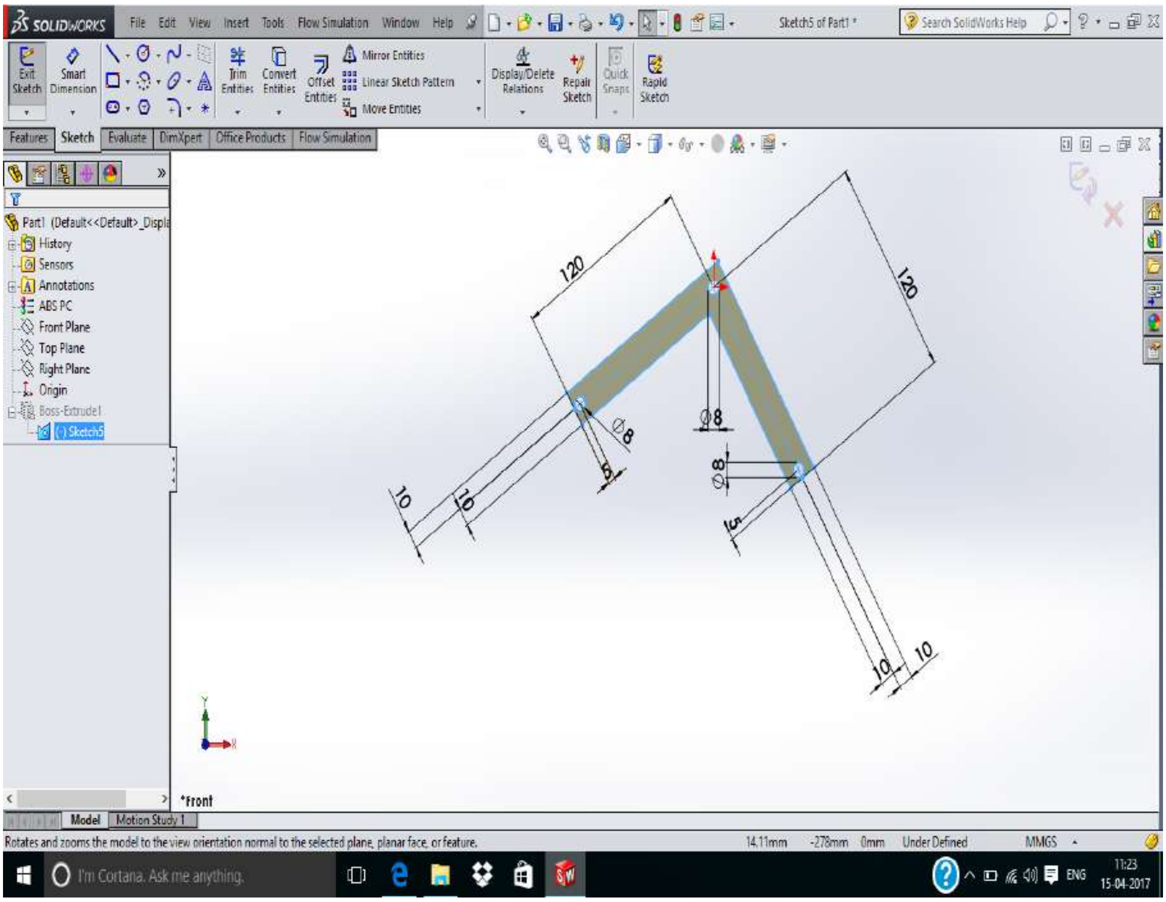


Figure 3.9 sketch diagram of bogie

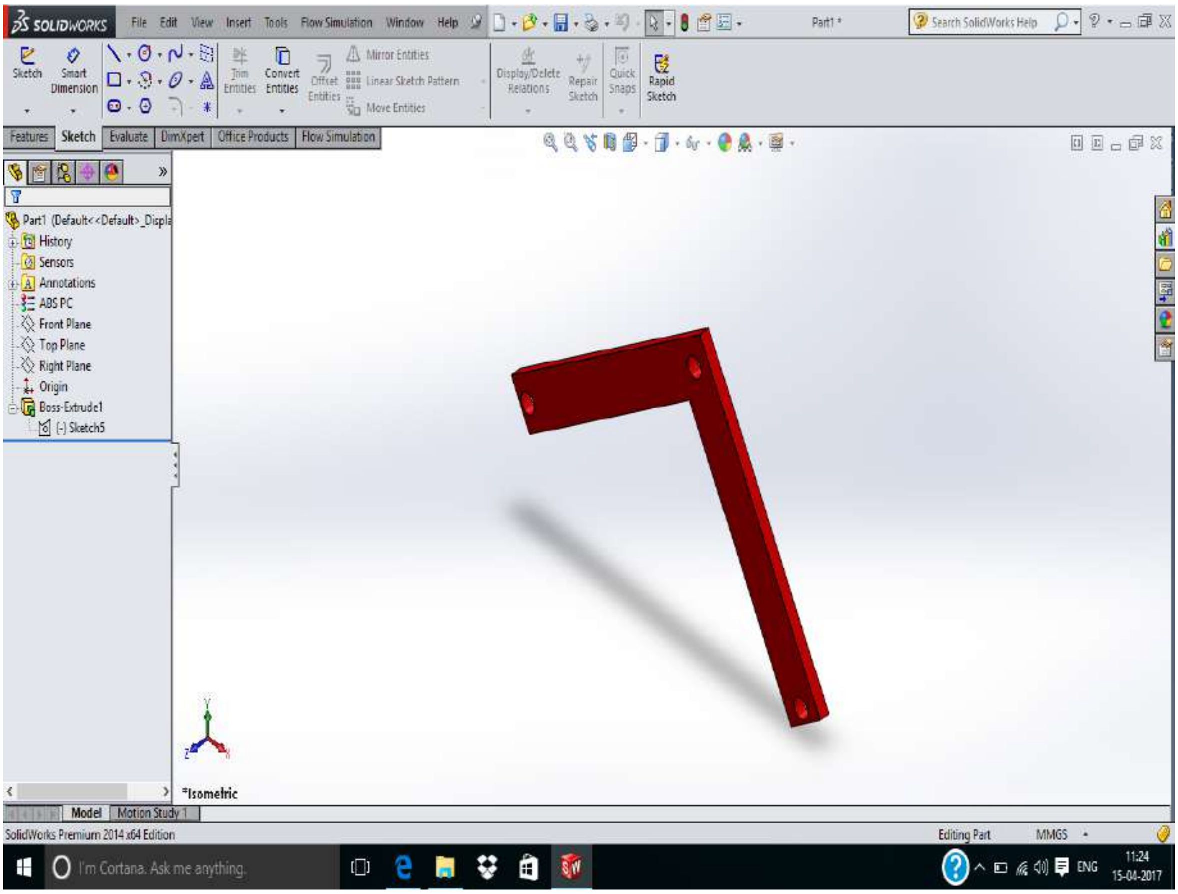


Figure 3.10 three dimensional view of bogie

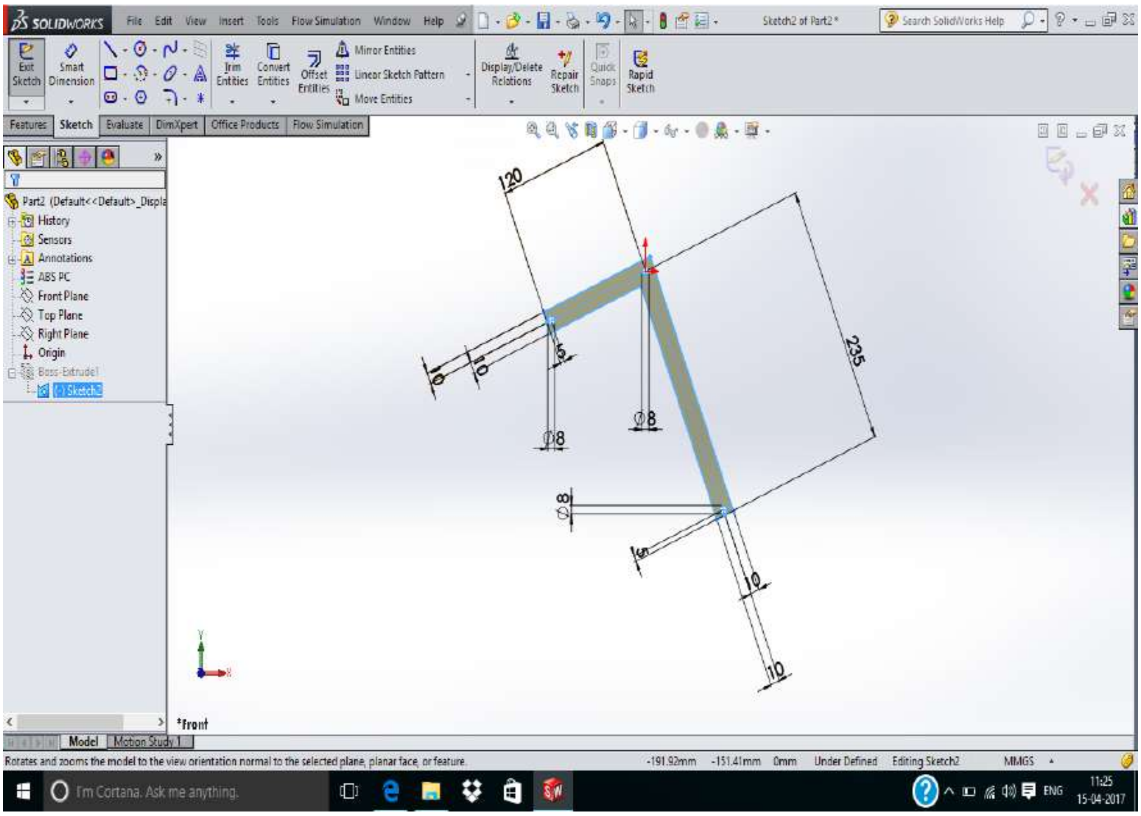


Figure 3.11 sketch diagram of rocker

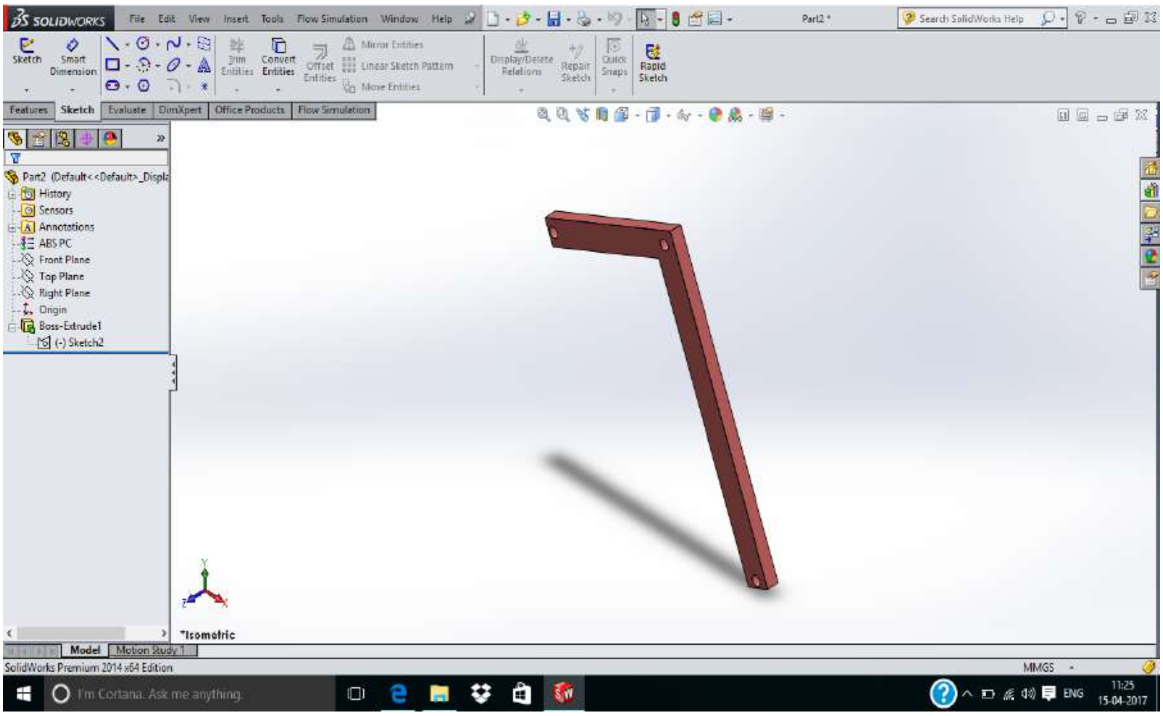


Figure 3.12 Draft diagram of rocker

3.1.3 DESIGN OF DIFFERENTIAL

Diameter of differential is taken as holes present in rocker i.e. 8 mm

Length of differential is equal to width of RBM.

Let width of RBM is 200 mm

So length of differential = 200 mm

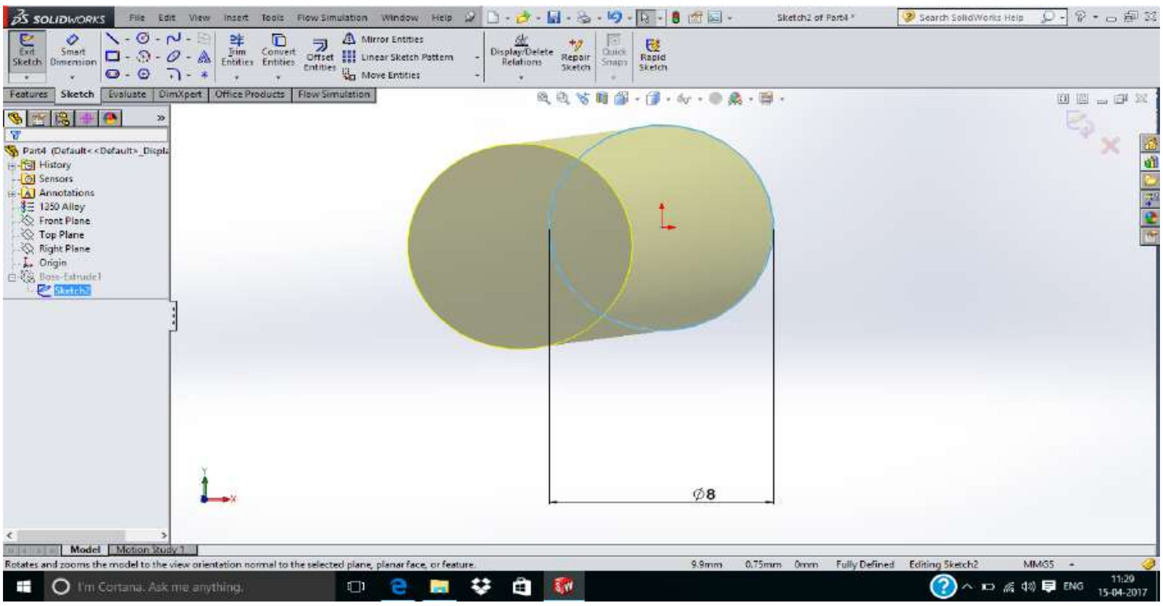


Figure 3.13 Differential of RBM

3.1.3 DESIGN OF FREE PIVOT JOINT

Diameter of joint is equal to hole diameter i.e 8 mm

Length of joint is 20 mm

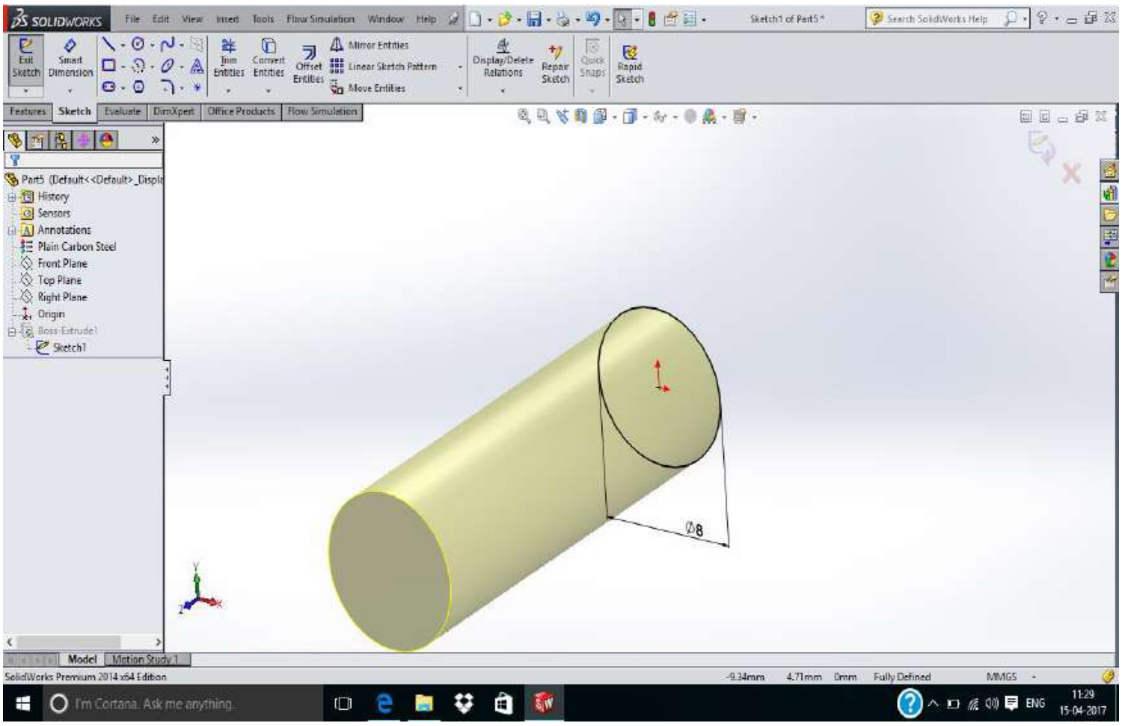


Figure 3.14 Free Pivot Joint

3.2 ASSEMBLY OF COMPONENTS

- Rocker is connected to bogie with the help of free pivot joint ,this joint is a hinged joint not fixed.
- Both rockers are connected with a differential so that RBM can move on uneven path smoothly.
- All six wheels are connected to bogie & rocker with the help of free pivot joint.

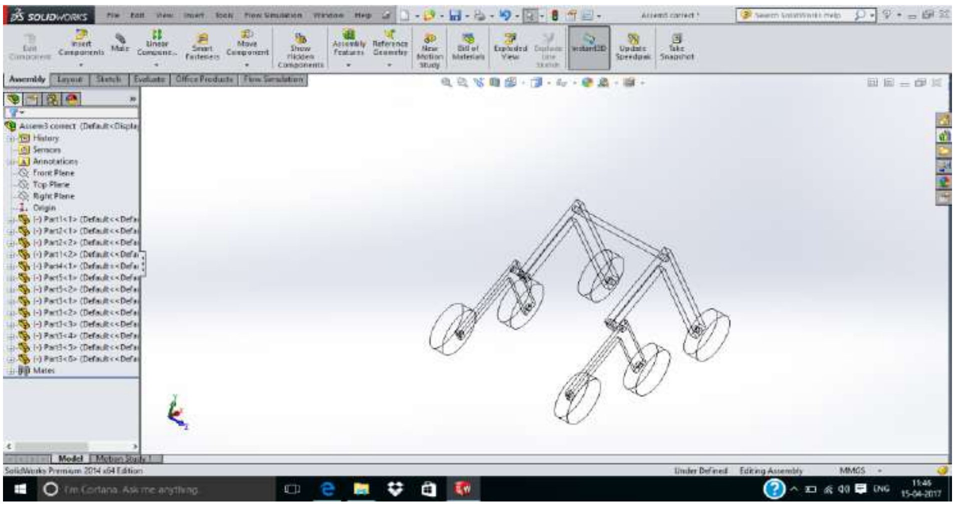


Figure 3.15 Assembled RBM

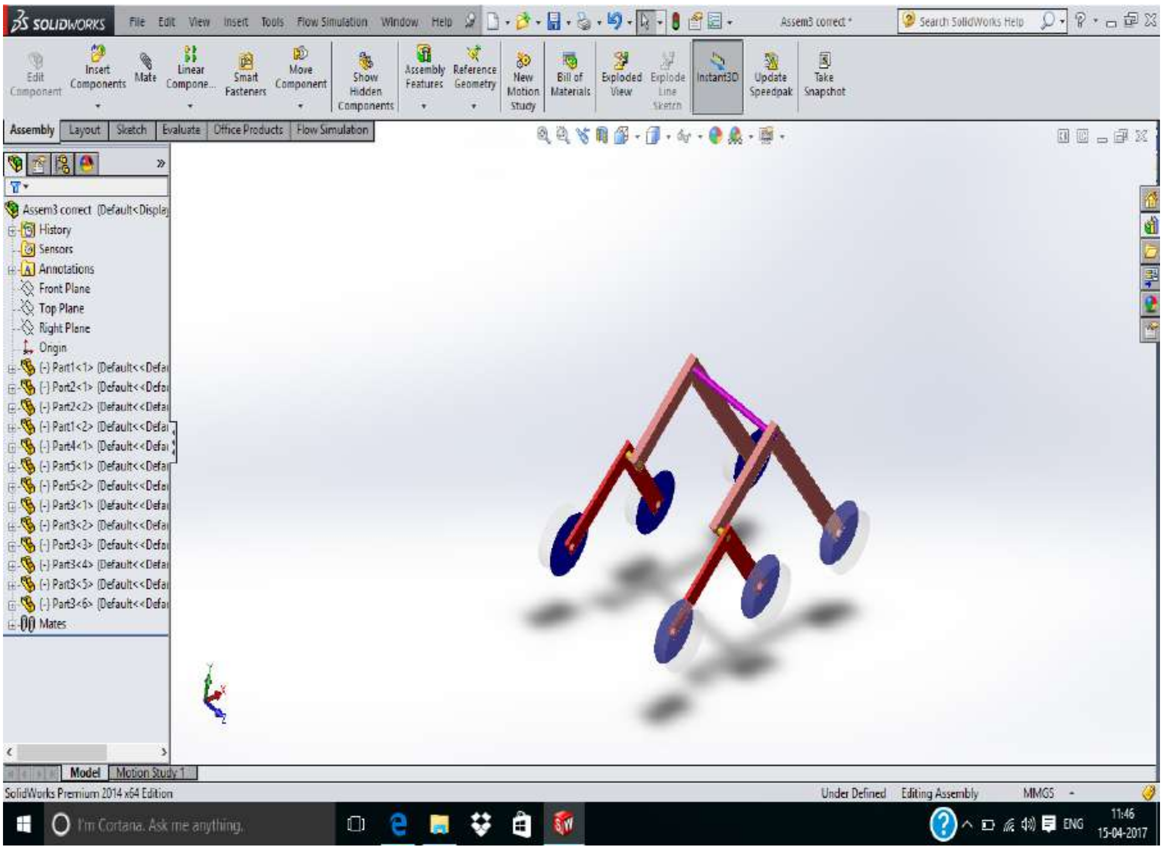


Figure 3.16 Model of RBM

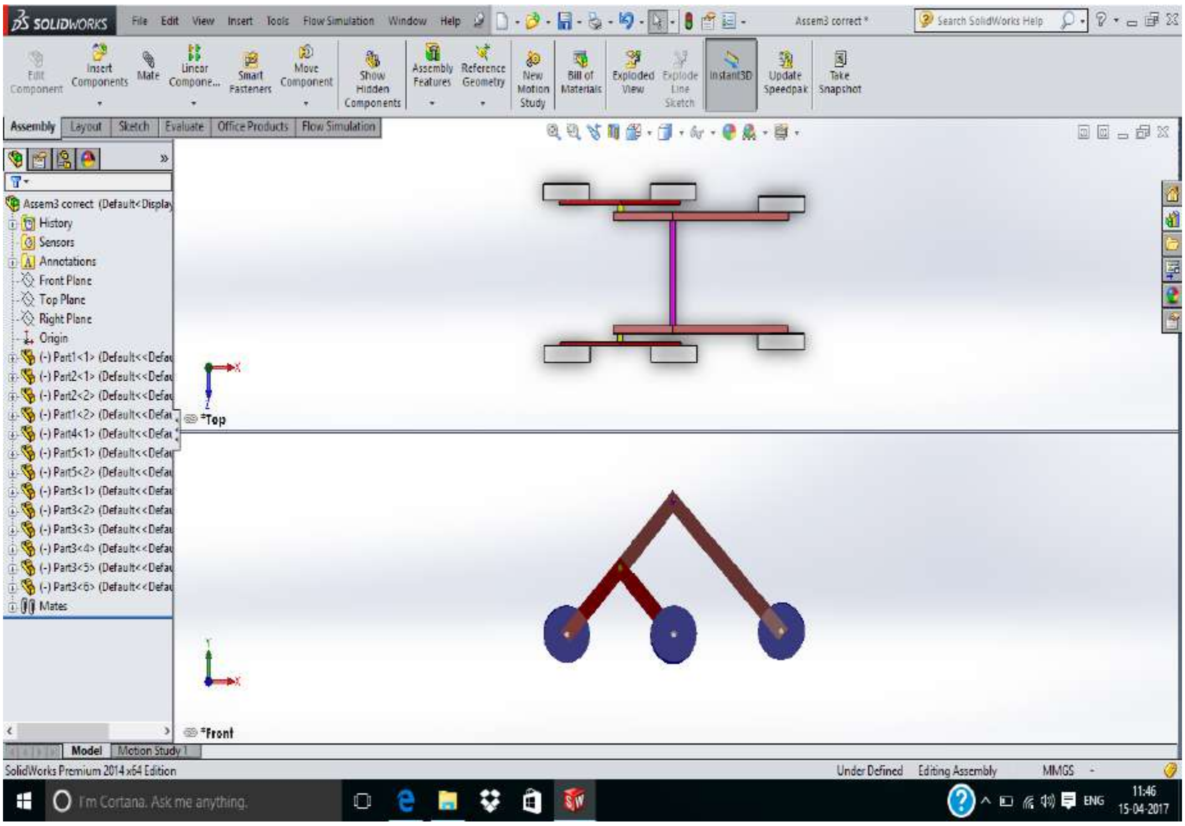


Figure 3.17 Top & Side view of RBM

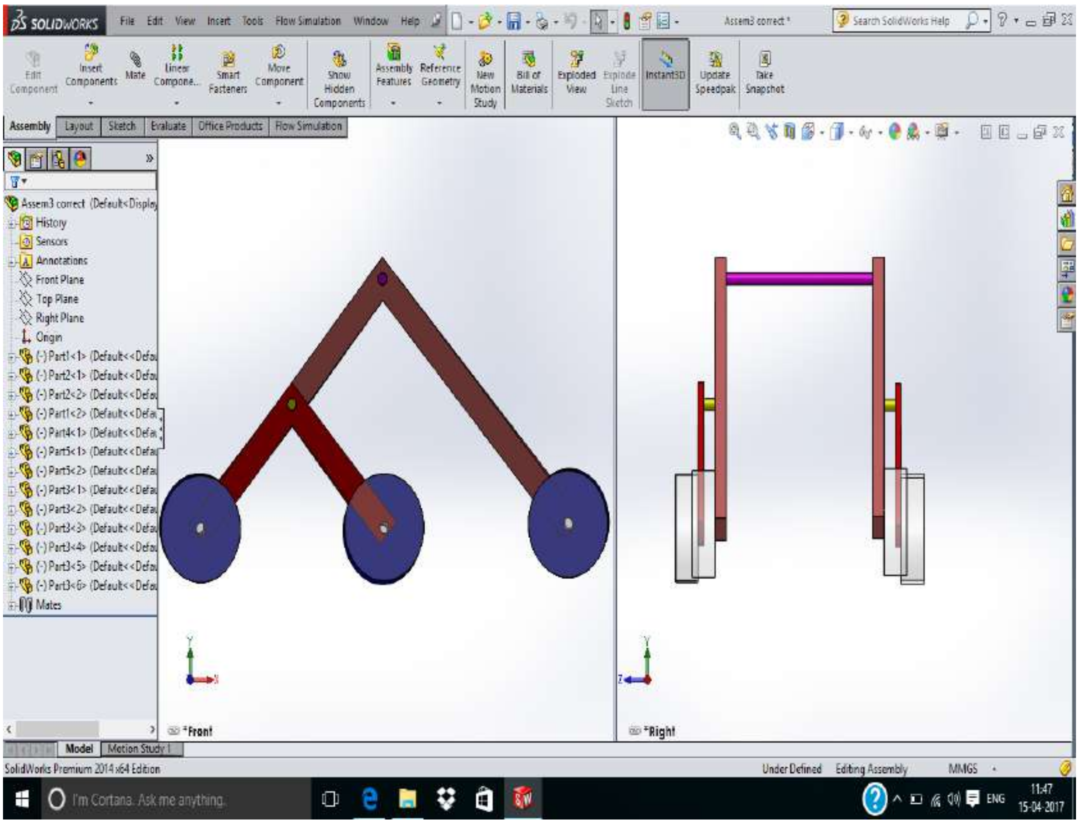


Figure 3.18 Side & Front of RBM

3.3 SIMULATION OF RBM

3.3.1 SIMULATION ON CURVED PATH

When RBM is move on curved path then bogie adjusts itself with the help of free pivot joint.

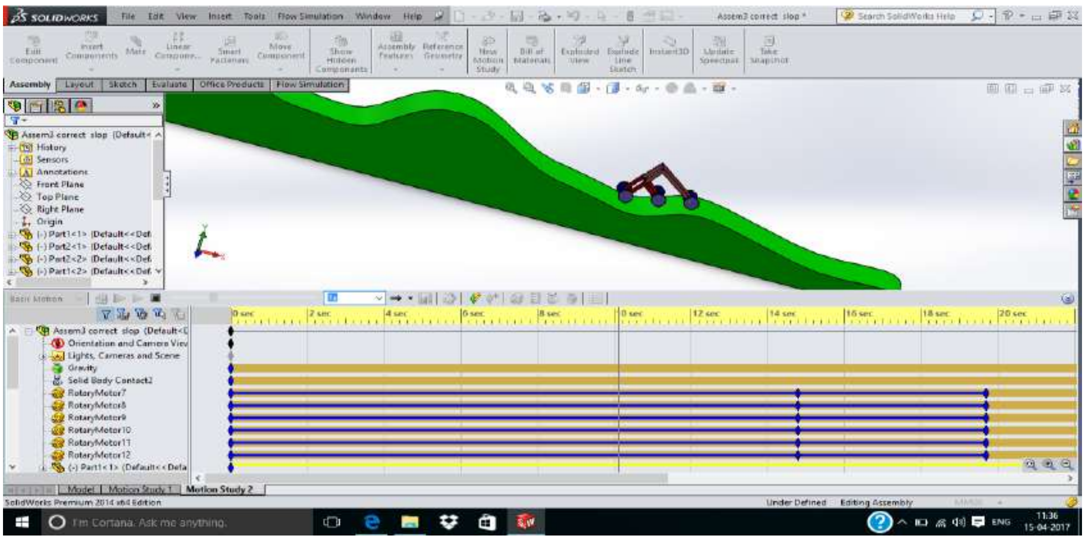


Figure 3.19 simulation of RBM on less sloped curve

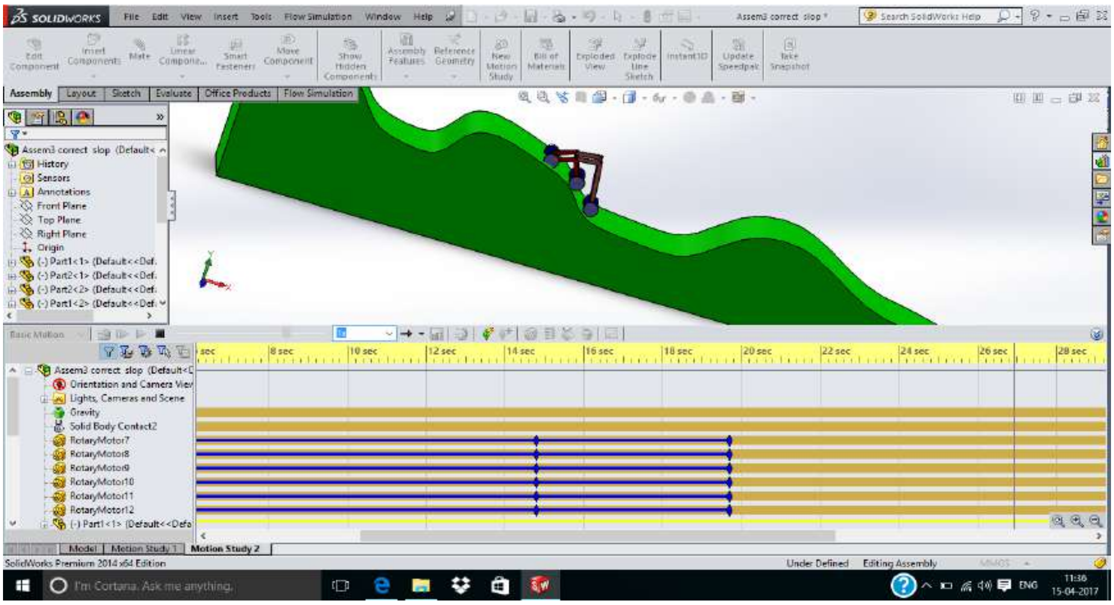


Figure 3.20 Simulation of RBM on a sloped curve path

3.3.2 SIMULATION OF RBM ON STEPS

RBM can climb on stairs with an angle 90^0

It is difficult to climb at 90^0. in this type of climbing high torque & friction are needed.

When bogie starts climbing on steps then motor on rocker end supports to climb bogie on steps.

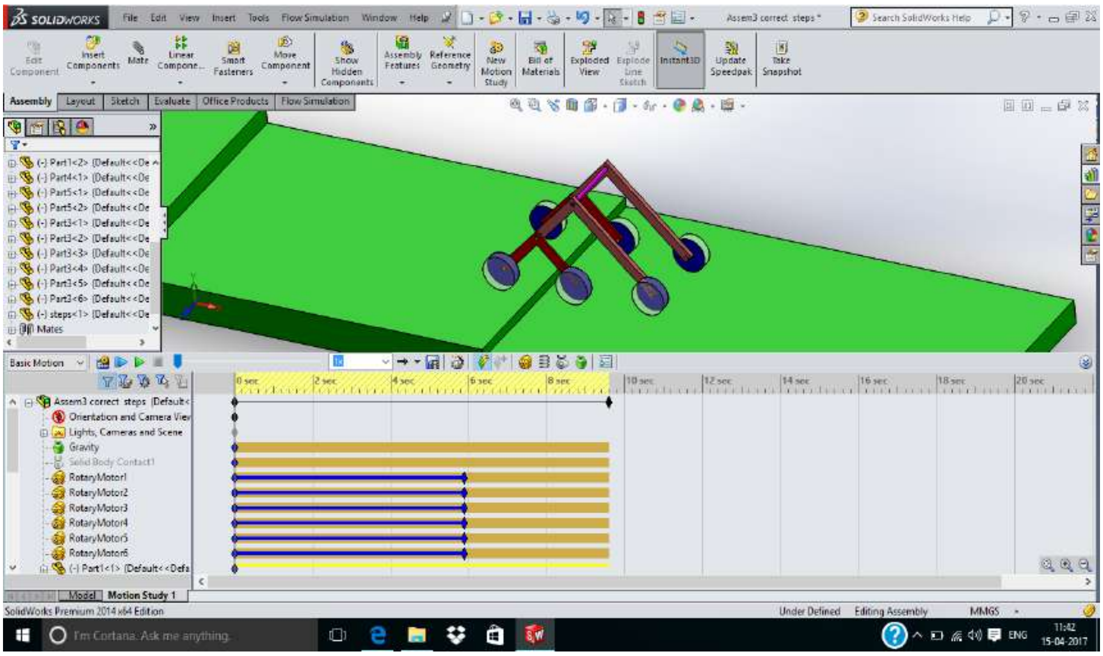


Figure 3.21 RBM climbing on small steps

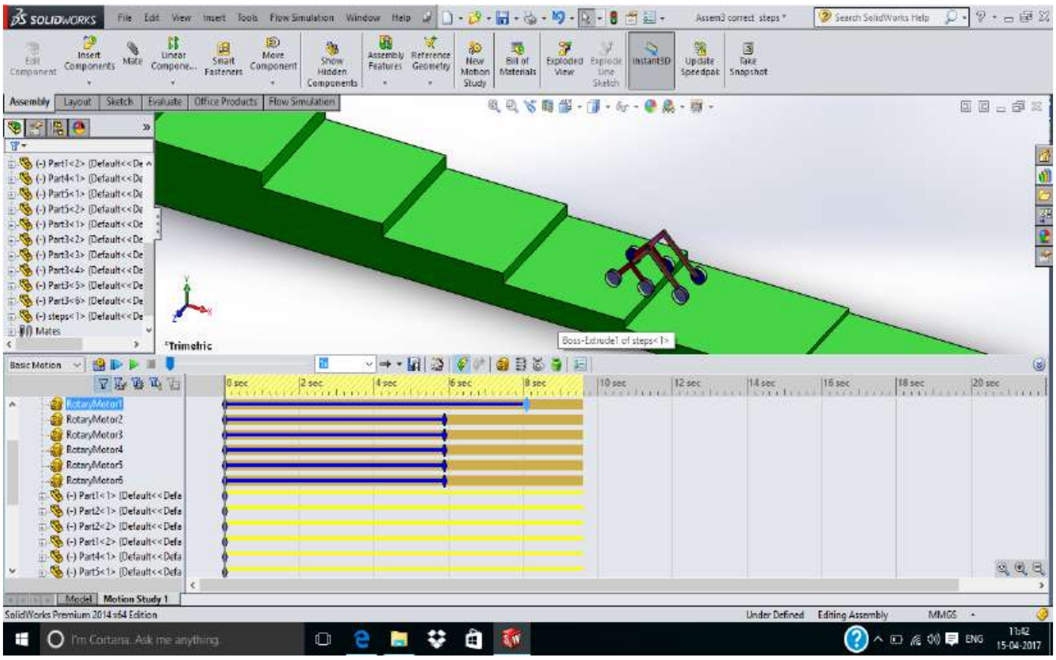


Figure 3.22 RBM climbing on large steps

Chapter 4

RESULT AND DISCUSSION

- After the realized simulation, the results has been generated and analyzed that the simulated model can run on a plane without any inclination with 10 cm/s.
- RBM can move on a curved path with slope
- RBM can climb on steps having less height but there is a difficulty to climb on large height steps.
- Centre of Gravity position in each of the two operating modes, contrasting the response of these two distinctive configurations of the rocker-bogie suspension against upcoming obstacles that can be present along the system generated obstacles and roadblocks.

Chapter 5

CONCLUSION OF RBM

Presented situation was faced presenting two modes of operation within same working principle which is a rocker-bogie system with a robust obstacles traverse features and another is an expanded support hexagon achieved by rotating the bogies of each side of the vehicle. The proposed paper produces a novel design in pursue of increasing the rocker-bogie mobility system in conventional heavy loading vehicle behavior when high-speed traversal is required.

The proposed modification increases in the stability margin and proved with valuable and profitable contrasting with the 3D model simulations done in SOLIDWORKS. In future, if the system installed in heavy vehicles and conventional off road vehicles, it will definitely decreases the complexity as well as power requirements to retain bumping within it

Future scopes of Rocker Bogie Mechanism are in military operations as a weapon carrier & for locating coal deposits in coal mines.

REFERENCES

[1] P. Panigrahi, A. Barik, Rajneesh R. & R. K. Sahu, "Introduction of Mechanical Gear Type Steering Mechanism to Rocker Bogie", Imperial Journal of Interdisciplinary Research (IJIR) Vol-2, Issue-5, ISSN: 2454-1362,2016.

[2] A. Bhole, S. H. Turlapati, Raja shekhar V. S, J. Dixit, S. V. Shah, Madhava Krishna K, "Design of a Robust Stair Climbing Compliant Modular Robot to Tackle Overhang on Stairs" arXiv:1607.03077v1 [cs.RO], 11 Jul 2016.

[3] M. D. Manik, A. S. Chauhan, S. Chakraborty, V. R. Tiwari, "Experimental Analysis of climbing stairs with the rocker-bogie mechanism", Vol-2 Issue-2 P.No. 957-960IJARIIE-ISSN(O)-2395- 4396, 2016.

[4] B. D. Harrington and C. Voorhees, "The Challenges of Designing sthe Rocker-Bogie Suspension for the Mars Exploration Rover", Proceedings of the 37th Aerospace Mechanisms Symposium, Johnson Space Center, page No. 185-1985, May 19-21, 2004.

[5] Y. L. Maske, S. V. Patil, S. Deshmukh, "Modeling and MBD simulation of stairclimbing robot with rocker bogie Mechanism", International Journal of Innovative Research in Technology, 101743, Volume 1 Issue 12, Page no. 267-273,ISSN: 2349-6002, 2015.

[6] N. Yadav, B. Bhardwaj, S. Bhardwaj, "Design analysis of Rocker Bogie Suspension System and Access the possibility to implement in Front Loading Vehicles", IOSR Journal of Mechanical and Civil Engineering, e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 3 Ver. III, PP 64-67, May - Jun. 2015.

[7] L. Bruzzone and G. Quaglia, "Review article: locomotion systems for ground mobile robots in unstructured environments", Mech. Sci., 3, 49–62, 2012. DOI:10.5194/ms-3-49-2012

[8] F. Ullrich, A. Haydar G., S. Sukkarieh, "Design Optimization of a Mars Rover's Rocker-Bogie Mechanism using Genetic Algorithms", Proceedings from 10th Australian Space Science Conference, Page No. 199-210, 2010.

[9]. Hong-an Yang, Luis Carlos Velasco Rojas*, Changkai Xia, Qiang Guo, School of Mechanical Engineering, Northwestern Polytechnic University, Xi'an, China, Dynamic Rocker-Bogie: A Stability Enhancement for High- Speed Traversal- Vol. 3, No. 3, September 2014, pp. 212~220 ISSN: 2089-4856.

[10]. R.E. Moore, Interval analysis (Englewood Cliffs, NJ: Prentice-Hall, 1966). (8)

[11]. Note that the title of the book is in lower case letters and italicized. There is no comma following the title. Place of publication and publisher are given.

[12]. Brooks Thomas; Graham Gold; Nick Sertic; DARK ROVER ROCKER-BOGIE OPTIMIZATION DESIGN, The University of British Columbia, Project Number 1076 January 18, 2011