# USE OF DIFFERENT SIMULATION METHODS FOR DESIGN OF EXPERIMENTAL ROVER

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In this study results of various simulation methods are evaluated used for design of experimental prototype rover. The proposed rover must satisfy requirements for operation in specific conditions. Simulation environment of V-REP software is used for verification of proper functionality of kinematics of the rover and for the draft of fundamental parameters. Deformation of beams are simulated in the Structure module of the software product PTC Creo and suspension system is verified in the Mechanics module in this software. By the application of simulations in the design process of experimental rover, possible problems can be detected before prototype production. The advantage is that behavior of several kinematic structures can be compared and evaluated their characteristics. By matching combinations of simulation tasks, some important parameters can be verified by multiple methods.

**KEYWORDS**

Rover, Simulation, Kinematics, Suspension system, FEM Analysis

## INTRODUCTION

Rovers for extraterrestrial missions have specific requirements. Undercarriage must be extremely stable and universal because conditions in the operating environment are not predictable. Kinematics of the suspension system is a key factor to overcome all the obstacles and complete the task. Rovers are designed for much smaller velocities than conventional vehicles used in everyday life. Special type of suspension kinematics can be used with optimal terrain permeability. This is related to soft suspension with springs and dampers with optimal parameters.

Wheels are usually used for planetary rover for their simplicity. Compared to tracked and legged robot platforms they contain fewer mechanical parts and are easier to control. Rocker buggy are most commonly used kinematic types in planetary rovers [Thueer 2008]. Their kinematics allow the rovers to traverse large obstacles and very challenging terrain. However these rovers are often bound to move at slow speeds due to lack of compliance for dynamic forces. This causes lunar and mars missions to be conducted in a limited area. Increasing the rover speed could allow a more extensive exploration. Increased speed puts the rover under the influence of more vibrations. Using rover kinematics with damped mechanism could therefore increase the safety of the scientific payload. Multi body mechanisms like rocker bogie often use 6 or 8 wheels. With weight constrains on the whole system, using fewer wheels and motors makes the system more efficient.

Dynamic simulations are usually used to test the rover kinematics. Seegmiller and Wettergreen demonstrated a passively steered rover in simulation with physical validation, proving that passive steering can be used to traverse long distances [Seemiller 2011]. Carlone et. al. presented 4-wheel skid steering rover with passive averaging suspension[Carlone 2013]. Kubota proposed an active suspension 6-wheel robot and used simulation to evaluate its parameters [Kubota 2013]. Active suspension can improve mobility through rough terrain. The efficiency of actively articulated robots further depends on the control algorithms [Iagnemma 2003].

In recent years, a number of robotic competitions have taken place. Notably events like University Rover Challenge and European Rover Challenge. Robots using rocker suspensions are a popular choice amongst participating teams, however several teams have chosen to use different kinematic structures for their robots. Parallelogram suspension shows a lot of potential for use in a more dynamic rover operation. Passive spring suspensions efficiency depends on proper spring rates and damping parameters. In this paper we simulate a rover with parallelogram suspension to determine usability of such suspension system for planetary rovers and further specify optimal kinematic configuration and damping parameters.

## 1 SIMULATED MODELS

### *1.1 Problem tested in simulation*

The main goal of the dynamic analysis is to get optimal parameters of springs for rover suspension system. Springs are modelled in two situations. First situation is breaking with rover from maximal velocity to complete stop. In this scenario we measure the length of the spring. When the rover stops, springs of front suspension decrease its length. The minimal length is settled by damper actuation length and connection points of suspension on the rover. This simulation gives us minimal stiffness of the spring.

Second situation is obstacle crossing. In this situation we simulate lifting one of the wheels to the specific height – maximal obstacle height. During lifting we measure reactions of other wheels with the ground and check whether we do not lose traction. This simulation gives us a maximal stiffness of the spring.

### *1.2 Simulated environment*

In this article we compare results from two different simulations. Creo simulations are done in Mechanism module of the software PTC Creo, for comparison we used robotic simulation framework V-REP[Rohmer 2013] in connection with MatLab. The model consists of basic dynamic shapes connected with joints. The size and inertial parameters of each part is set to correspond with the dynamic simulation in Creo Parametric. We simulated undercarriage suspension models optimized and simplified for both software. Models are simulated in the environment of Earth gravity. In V-REP is possible to choose different dynamics engines. For our simulations we used Newton Dynamics engine with life-like physics behavior.

### 1.3 *Parallelogram suspension*

The rover has four wheels with motors in each wheel. Since rovers with differential drive are prone to slip on loose surfaces, rotating wheels into the driving direction is desirable. To angle the wheels, each wheel has a drive mechanism to rotate it around vertical axis. The parallelogram kinematic structure keeps all the vertical axes of rotation parallel to each other, thus keeping a unified drive profile.

In V-REP simulation framework the model - Figure 1. is created from basic elements (blocks, cylinders) which are interconnected with joints. Joints have different dynamic properties and behave like pins or motors. Elements have its dynamic properties set according to real model. Springs and dampers are represented with components which have adjustable parameters of stiffness, length and damping.

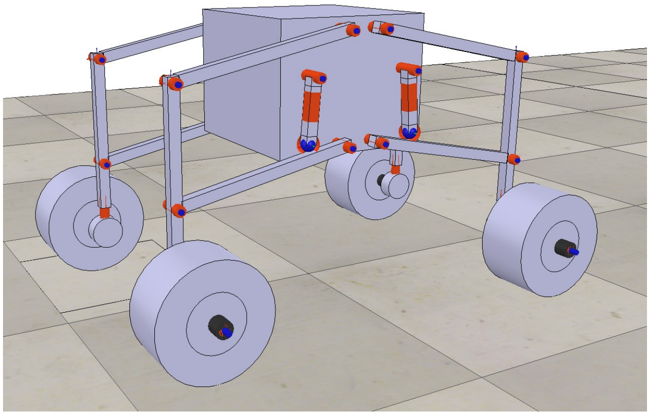


**Figure 1.** Dynamic simulation model with parallelogram suspension in V-REP

In Creo the simulation model - Figure 2. consists of either real components with precise dynamic properties – profiles and from components acting like rover body. Parts of the rover chassis are interconnected with simulation connections – pins, balls and bearings which establish proper behavior. Springs and dampers are also simulation components of Creo Mechanism.

Both models have different simplifications according to simulation software, but dynamic properties and spring/dampers parameters are the same in both models so that results are comparable.

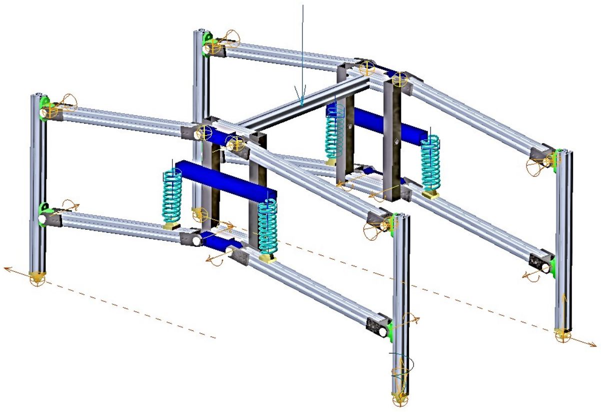


**Figure 2.** Dynamic simulation model with parallelogram suspension in Creo

### 1.4 *Lever suspension*

This model - Figure 3. is a simplified version of the parallelogram suspension model. This concept was simulated in V-REP to measure difference between parallel and simple kinematic design. In lever suspension is fewer mechanical components therefore it offers lighter design. Contrary to the previous model, the vertical rotation axes are not parallel to each other at all times, which is important for precise vertical steering of the wheel.

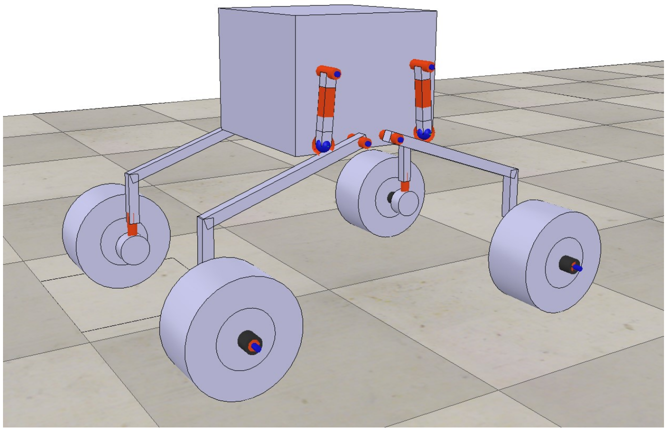


**Figure 3.** Dynamic simulation model with lever suspension

The lever structure was simulated to check whether closed parallel structure give us right results.

Simulation parameters for springs and dampers were set to specific values. Spring constant of stiffness is set to 8 N/m and length of the spring in equilibrium position is set to 130 mm. Damper constant is set up to 0.1 N.s/m

## 2 SIMULATION

### 2.1 *Obstacle crossing*

The forces exerted on the undercarriage mechanism are measured while lifting one wheel of the rover. This simulation is designed to measure the reactions in each wheel while omitting forward and backward rocking. Obstacle is 100 mm high which is a value of a rover’s wheel radius. This obstacle is crossed over with one wheel.

In the V-REP simulation right front wheel is lifted by a cube that follows a vertical sinusoidal trajectory starting on the ground and the end position is 100 mm above the ground - Figure 4.

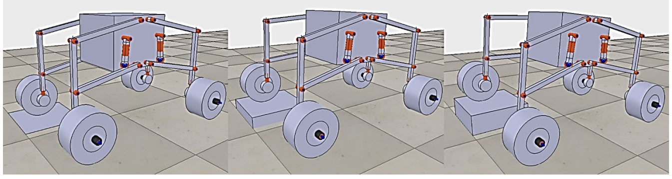


**Figure 4.** Simulating an obstacle in V-REP

In Creo simulation is a translation motor situated in the right front leg which lifts the leg - Fig 5.. The linear motor has sinusoidal prescription with an amplitude of 50 mm and horizontal offset of 50 mm. Duration of the dynamic analysis is 5 seconds which is also a half of the sinusoidal period. In the simulation the wheel runs up to the height of 100 mm and back down to the ground.

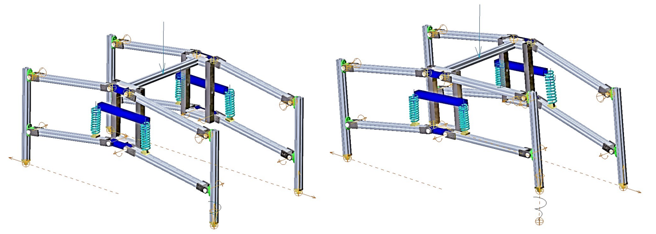
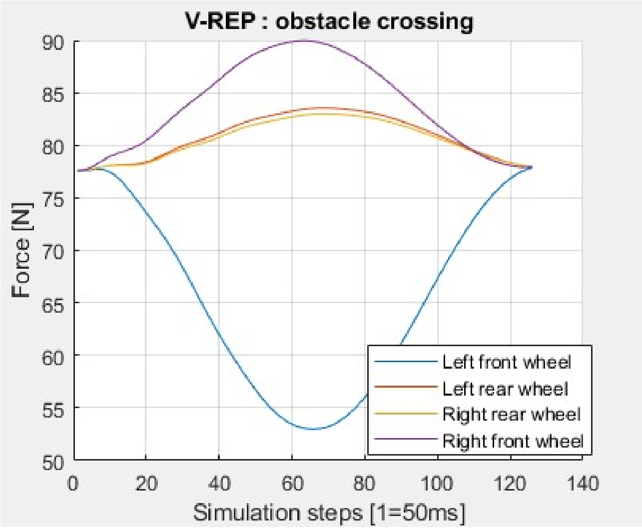


**Figure 5.** Simulating an obstacle in Creo

Two graphs in Figure 6. show the reaction forces in each wheel along the vertical axes. First graph is from V-REP simulation results processed in Matlab, second graph is from Creo simulation. In both cases the weight is shifted on the lifted wheel and both rear wheels, while the load on left front wheel decreases. The load pattern in graphs is similar in both simulations.

In the balanced position is the weight of the rover equally distributed and the reaction force is 77.5 N (78.8 N) in each wheel. Values in brackets are from Creo simulation. In the right front wheel which is lifted connection reaction increases to the maximal value 90N (88.3 N). Rear wheels reach almost the same values 83.5 N (84.3 N) and the most important information is decreased force in left front wheel. This reaction decreases to 53 N (56.5 N) and is crucial for the analysis. The reaction force should not decrease under a critical threshold value.

This critical force will be subject of next measurement and testing with prototype of the rover and its movement on different materials. From the simulation with given parameters we can see, that decrease of the reaction force is around 30%.



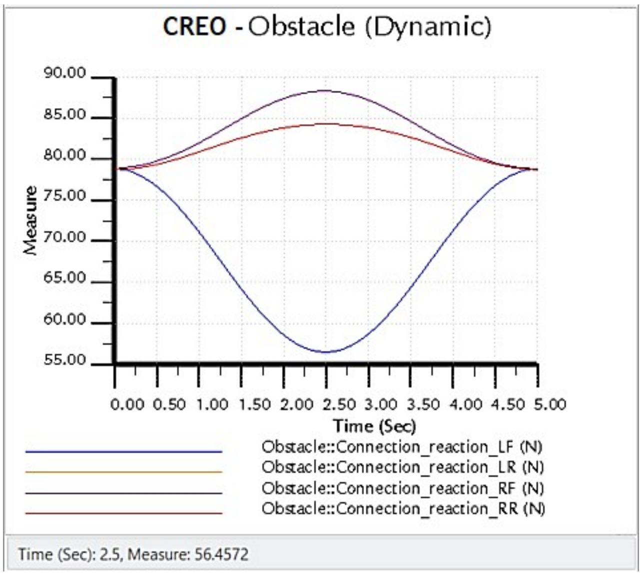


**Figure 6.** Obstacle crossing simulation results

### 2.2 *Acceleration and braking*

To measure the stiffness of the suspension we ran a simulation on a flat surface with set parameters. The rover is simulated for 5 seconds or 100 steps, each simulating 50 ms.

The simulation starts with the rover stationary. In V-REP the angular velocity of the wheels set to 5 rad/s or 47.7 RPM. With the wheel diameter of 200 mm, the set speed corresponds to 0.5 m/s. There is a 90 W motor in each wheel, causing the rover to accelerate quickly and then hold the set velocity. After few seconds of continuous ride when the chassis is balanced, the rover starts decelerating to a halt.

Figure 7. shows the velocity of rover COG in the driving direction. It is clear, that the parallelogram suspension is experiencing more oscillations, despite having the same spring rate and damping parameters. In comparison with lever suspension which does not have closed structure and balancing of the suspension is faster than of the parallelogram with 40% increase of COG velocity in the moment of braking.

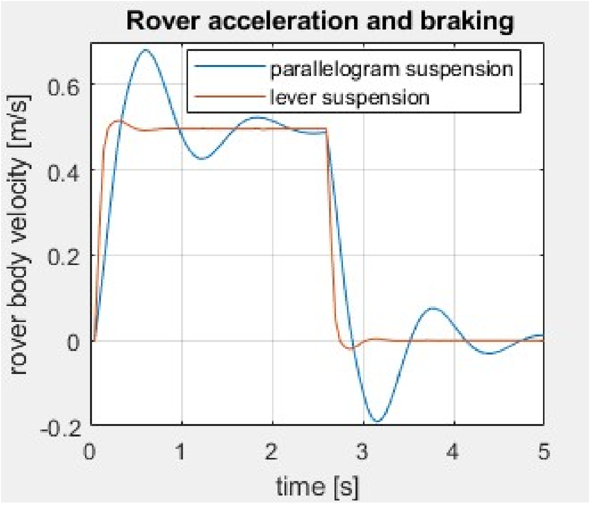


**Figure 7.** Rover velocity at instant acceleration

The oscillations are strongest around the axis perpendicular to the driving direction as shown in Figure 8. .The lever suspension reports lower oscillation spikes than parallelogram. The maximal value of the parallelogram body pitch is 8 degrees.

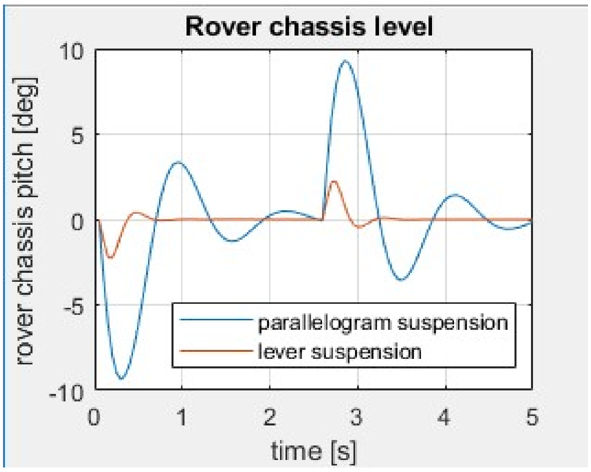


**Figure 8.** Rover chassis pitch during acceleration

To simulate suspension behavior, we measured separation distance between ends of the spring. When the rover decelerates rear springs are lightened and the length increases. Front springs are loaded and the length decreases. To set the rover suspension properly, measured values should be within a range of stroke of the damper.

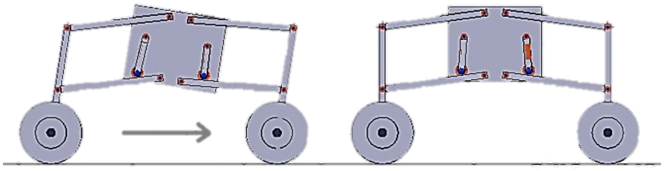


**Figure 9.** Rover behavior during stop in V-REP

In V-REP rover instantly decelerates from constant move with velocity 0.5 m/s - Figure 9. Rear wheels are blocked with no slipping and front wheels are set to free motion.

In Creo the initial velocity of the rover body is set to 500 mm/s. In the dynamic analysis rover change its state from initial movement to complete stop -Figure 10. Rear legs are connected to the ground with ball binding that allows rotations in all directions, but translations are blocked.

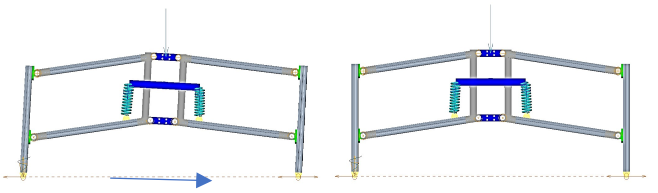
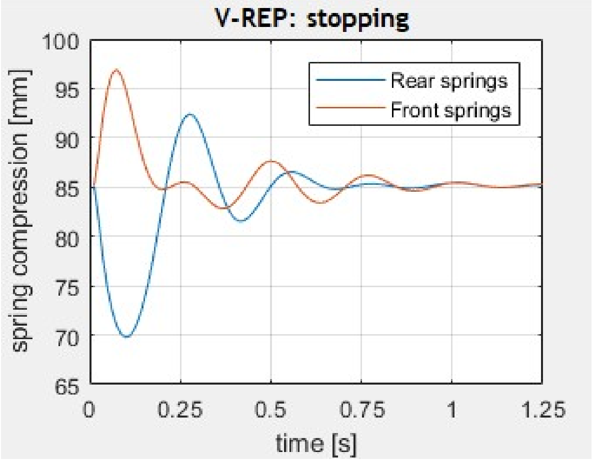


**Figure 10.** Rover behavior during stop in Creo

Front wheels have the bearing binding which allows all rotations and translation in the way of movement. The separation distance between ends of the spring is measured and plotted into graph see Figure 11.



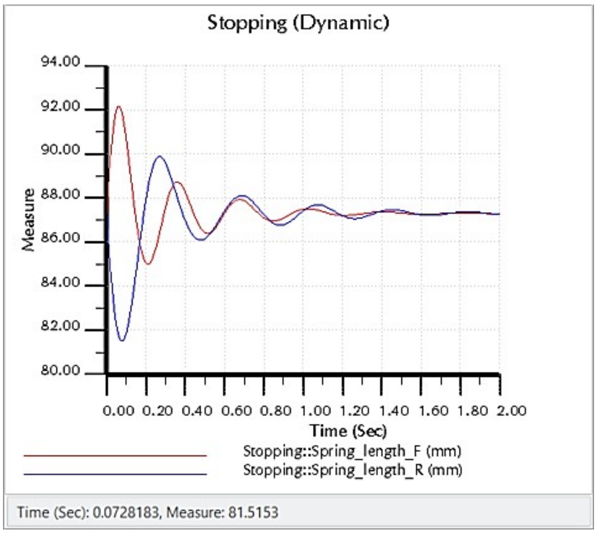


**Figure 11.** Spring length during stop

## 3 FEM ANALYSIS

### *3.1 Simulation model*

In the dynamic simulation we tested behavior of the solid model. Construction made ofaluminum profiles could perform bending deformations. During the mechanical design of the chassis, stress analyses were done using a simplified assembly model of the rover in the PTC Creo software system module Simulate. Computational model for FEM analysis is based on half of the rover.

The most important is setting of proper combination of bindings to simulate real rover behavior. In the simulation model - Figure 12. We use a combination of pin type connections which allow the movement of the rover in one translation axis and rotation around axis perpendicular to linear movement axis. This is achieved with beam idealization process of pin type binding. The second type is ball type binding representing ball joints. Simulation model is loaded with the force 250N representing weight of the rover body.

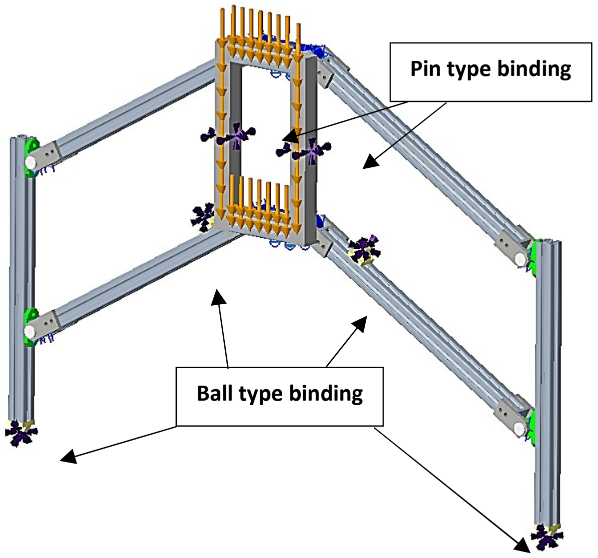


**Figure 12.** FEM simulation bindings

Overall results of the analysis shown in the Figure 13. Represent deformation in millimeters on the overall model. Maximal values are in the frame which is a simplification of rover body. Our scope is only deformation of the lower leg. Results of the deformation in lower leg are shown in Figure 14. with the maximal value of deformation of 0.06 mm.

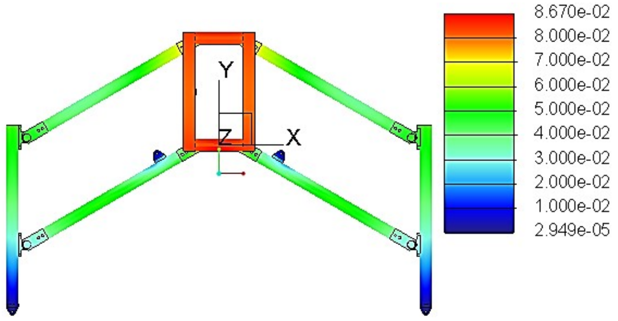


**Figure 13.** FEM simulation result of overall model

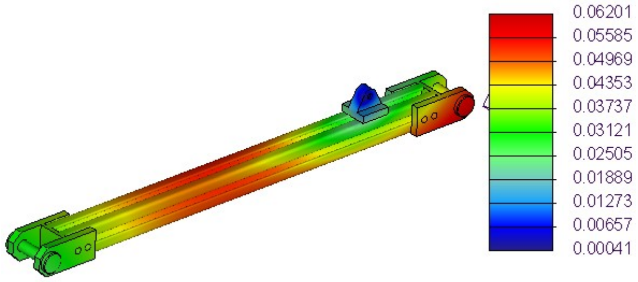


**Figure 14.** FEM simulation result of lower legl

## 4 CONCLUSIONS

The main goal of our research was preparation of the simulation environment to test special rover design. We compared two different approaches of simulation of the model and we got similar results. This proves we have properly set simulation models of the rover. Key factor of the simulation model is combination of bindings representing joints. Dynamic properties of model bodies are constant depending on used materials. Joints must allow rover the same movement as in real situation otherwise results are distorted.

Simulation binding definitionsvary in different software and many combinations had to be tested to achieve the right behavior of the model. Final setting brought proper behavior in the visualization in simulation software and also comparable results from two different software.

Results from FEM analysis report deformations in hundredths of millimeter on the leg 400 mm long. Deformation of the leg is not influencing the kinematics of the rover.

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