

# **Case Studies on NASA Mars Rover's Mobility System**

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## **Abstract**

Motion simulation files based on Working Model 2D™ are developed to simulate Mars rover's mobility system. The rover's mobility system, referred to as the Rocker-Bogie Mobility System, consists of six wheels on mobile links to provide the maneuverability to traverse on the rocky and sandy surface on Mars. Case study courseware was developed to demonstrate the mobility of the vehicle and highlight the need for dynamic analysis, and surveys were conducted for feedback and improvement after class presentation.

## **Introduction**

Mars Pathfinder landed on Mars on July 4, 1997 following a seven-month cruise through interplanetary space [Bickler 1998]. After landing, the rover named Sojourner was deployed from the lander and began a mission to conduct technology experiments including wheel-soil interactions, autonomous navigation and hazard avoidance. The success of this mission rekindled public's interest in space mission, and NASA setup a popular website [JPL 1999] on this mission including numerous photographs and videos.

North Carolina Agricultural and Technical State University is a leading university of a NASA grant - Partnership Award for the Integration of Research into Mathematics, Science, Engineering & Technology Undergraduate Education (PAIR). The PAIR grant is intended to improve undergraduate education in the areas of mathematics, science, engineering and technology (MSET) by directly benefiting from the experiences of NASA field centers, affiliated industrial partners and academic institutions.

One of the grant's objectives is to enhance core courses in the MSET curriculum through the development of portable learning modules. Sojourner is chosen as the subject to develop course modules for statics, dynamics, and instrumentation laboratories. For statics and dynamics, Sojourner's mobility system is selected to demonstrate theories and principles in these mechanics courses.

Working Model 2D (WM2D) is a powerful engineering analysis and motion simulation software on personal computers. A user can sketch a mechanical system using a variety of simple geometric primitives. Then sketch additional constraints (joints, springs, and dampers) and actuators (cylinders and motors). WM2D then uses its simulation engine to set the mechanical system in motion. Video simulation files can be generated from these WM2D files to be replayed independent of the WM2D program. The author has been using the software in the past few years to simulate various mechanisms with some success [Wang 2000].

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## Sojourner's Mobility System

The rover has a size of a microwave oven with dimensions of 280 mm in height, 630 mm in length, and 480 mm in width. The mobility system, referred to as the rocker-bogie mobility system, consists of a set of six wheels on mobile links, as shown in Fig. 1. The front and center wheels are joined on each side to form bogies. These bogies pivot freely at the front of rocker links. The rockers each have a rear wheel at the other end, and are pivoted freely at a point near the rover's center of gravity. The rockers are connected to the main body with a differential mechanism so that the pitch angle of the body is the average of the pitch angles of the two rockers [Bickler 1992]. Figure 2 shows a computer model with key components annotated.



Figure 1 Mars Rover Sojourner

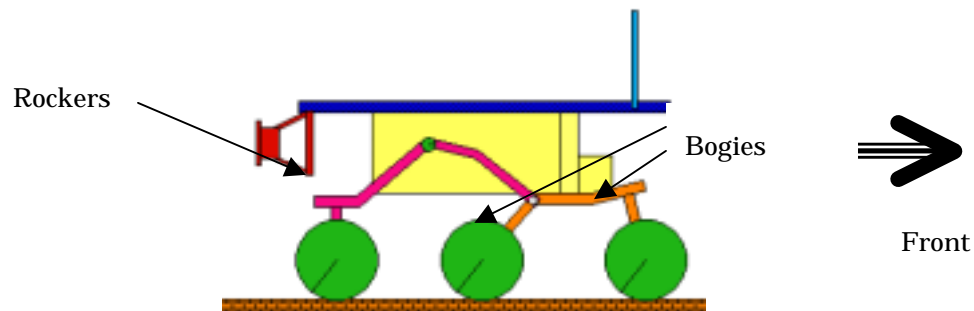


Figure 2 Computer Model of Sojourner

The vehicle has a top speed of 0.4m/min, and each wheel is independently actuated and geared (2000:1), providing sufficient torque to travel in soft sand. To increase traction even more, the wheels have metal cleats that protrude 10 millimeters to dig into the sand. Each wheel has a diameter of 130 mm and a width of 79 mm. The front and rear wheels are independently steerable, providing the capability for the vehicle to turn in place.

## **Motion Simulation of the Mobility System**

Since the simulation files are developed on Working Model 2D, the rocker-bogies on both sides are assumed moving in synchronization, and the rocker joint is disabled (fixed) since there is no need of the differential mechanism to average the pitch angles. Fig. 3 shows the process of the rover going over an obstacle.

With the rocker-bogie system, the rover can climb over a step, with its height one and a half times the diameter of the wheels, as shown in Fig. 4. Its step climbing capability is much superior than that of a truck, as shown in Fig. 5. These two figures also illustrate the reason that six wheels are used in the rover design. When front wheels of the rover are over an obstacle, they get pushed by the other four. This results in more climbing traction, and a lesser fraction of the weight being lifted, as compared to a four-wheel vehicle.

The mobility system has no springs, which improves Sojourner's traction. When a wheel is raised with an elastic system, the normal force at the wheel increases according to the spring rate of the suspension system. The greater force on the raised wheel makes it more difficult to propel the vehicle as it takes normal force away from remaining wheels, reducing their traction (friction force). In Fig. 6, the normal force on the front and rear of an automobile are shown graphically as the vehicle goes through a ditch. An automotive wishbone suspension system is also modeled, as shown in Fig. 7, for comparison with the rocker-bogie system.

### **Discussion**

A twenty-minute power point presentation with motion simulation files was given to dynamics classes at NC A&T State University in the past two semesters to demonstrate the need of dynamic analysis. Through these simulation files, students have a better appreciation of suspension system of the rover and of an automobile, and have a deeper understanding of topics in friction and vibration addressed in the textbook. Visualizing machinery in motion is one of challenging aspects to many engineering students, and this supplementary courseware is attempted meet this need.

Surveys were conducted in classes for feedback and improvement of the courseware demonstrated, and students responded very favorably of these case studies. For future work, the differential mechanism to balance the difference of pitch angles of either side should be modeled with Working Model 3D. The case study courseware, once fully developed, will be placed on the project website for dissemination.

### **Acknowledgment**

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### **References**

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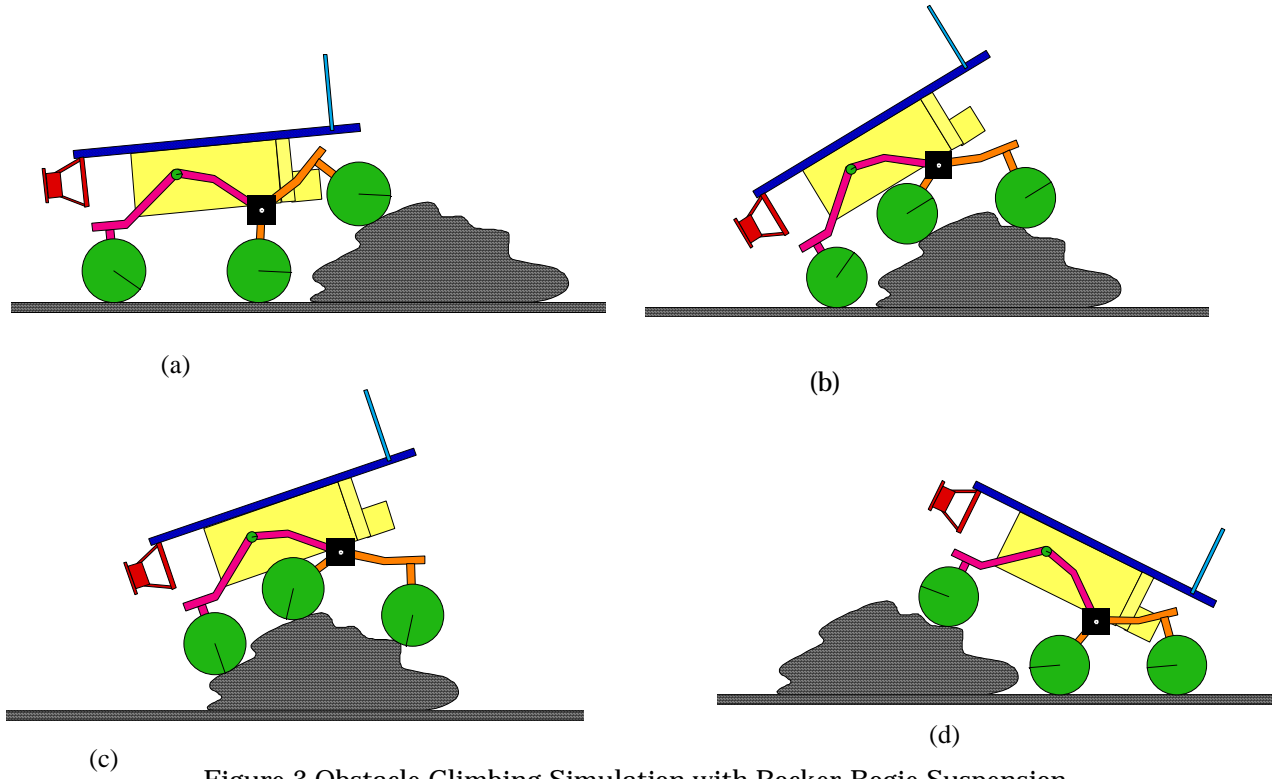


Figure 3 Obstacle Climbing Simulation with Rocker-Bogie Suspension

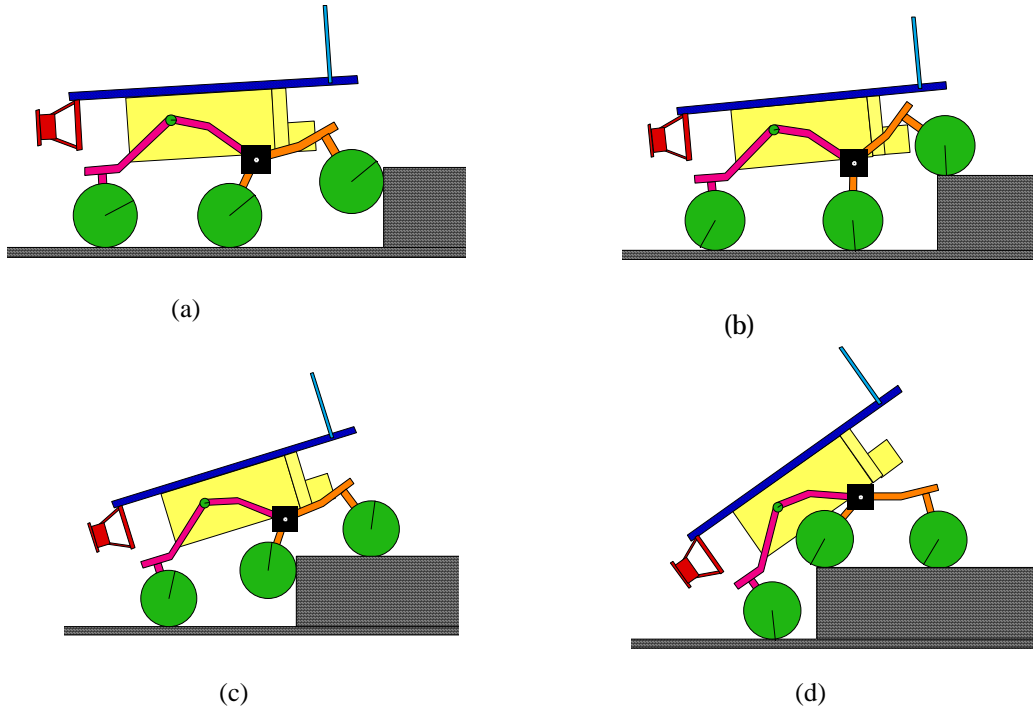


Figure 4 Step Climbing Simulation with Rocker-Bogie Suspension



Figure 5 Step Climbing of a Truck

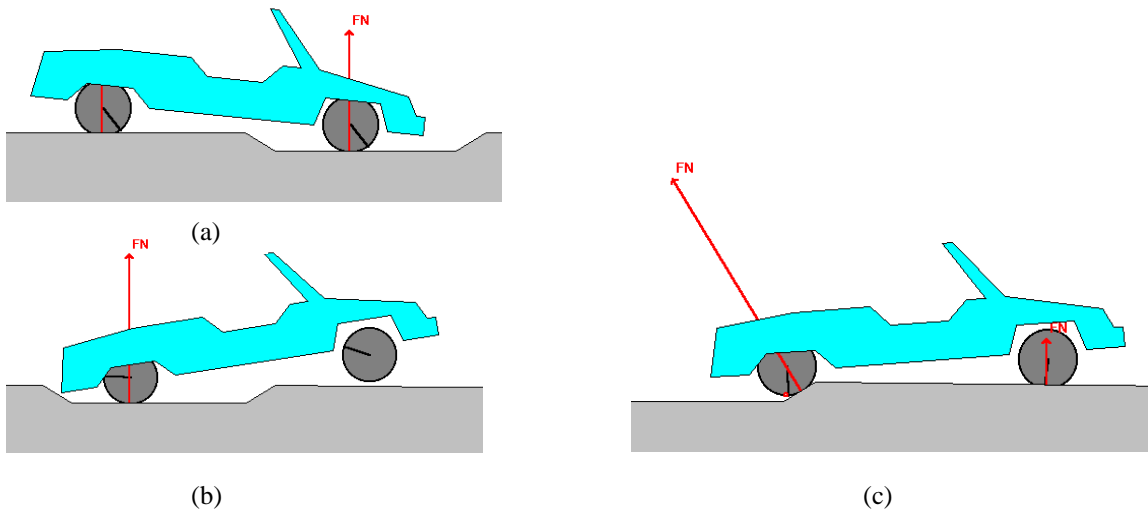


Figure 6 Normal Force Fluctuations as an Automobile Passing Through a Ditch

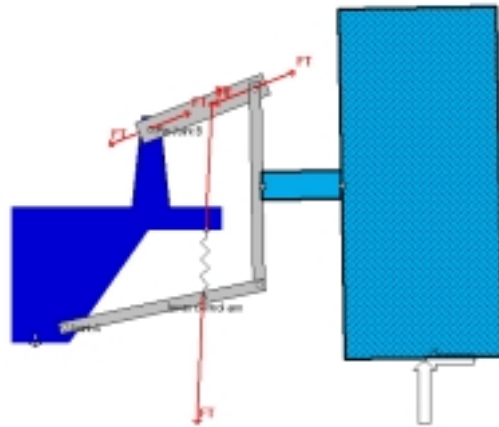


Figure 7 Automotive Suspension Simulation

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