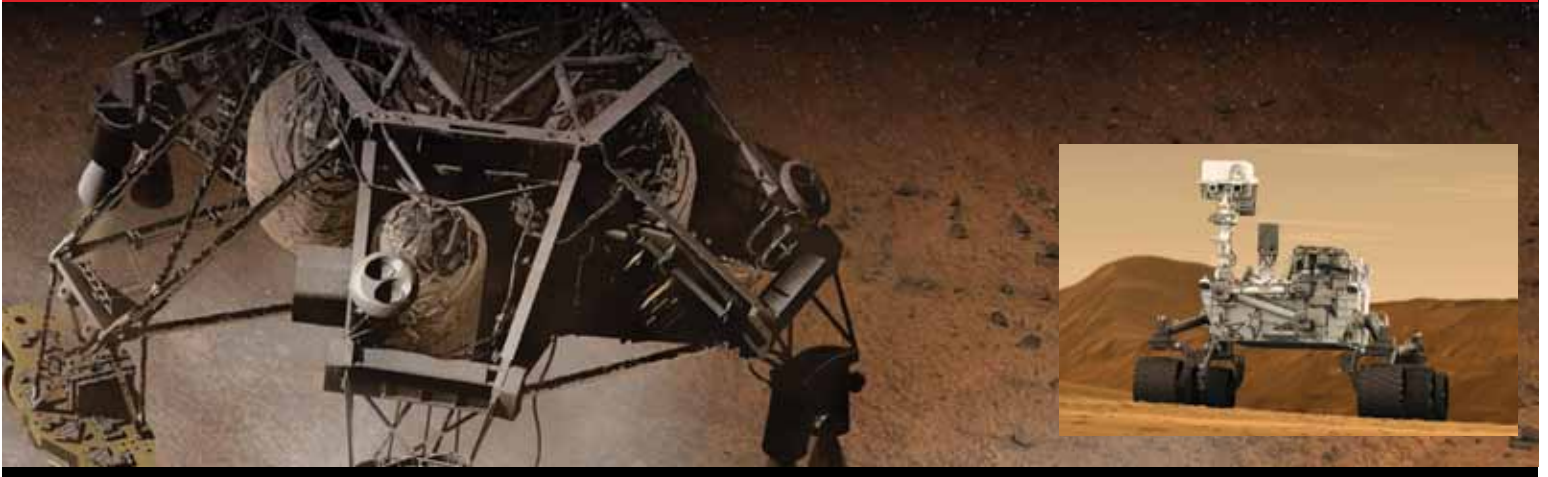


MSC Software: Case Study - NASA/JPL-Caltech

Only One Chance to Get it Right

Adams Simulations Help Curiosity Rover Make Perfect Touchdown on Mars



Based on an interview with Dr. Chia-Yen Peng, Principal & Lead Engineer for the Loads and Dynamic Simulation team at JPL.

Mars Science Laboratory is a robotic space probe mission that successfully landed Curiosity, a Mars rover, in Gale Crater on Mars on August 5th, 2012. The sky crane landing sequence required the rover to transform from its stowed flight configuration to landing configuration while being lowered to Mars wheels down from the descent stage. The final entry, descent, and sky crane landing phase was called “seven minutes of terror” by NASA engineers because of its complexity and the fact that human intervention from earth was impossible.

NASA Jet Propulsion Laboratory (JPL) engineers simulated this final sky crane landing sequence using MSC Software’s Adams multibody dynamics software. The simulation identified problems with the initial concept design and guided engineers as they resolved these issues and made the

design more robust. The simulation was also used to validate the landing sequence and determine loads on subassemblies and components. The controls software code that guides the mission through the sky crane landing sequence was integrated into the Adams environment to validate and tune its performance. The accuracy of these simulations was proven by the success of the mission.

Complex Landing Sequence

The Curiosity rover is about twice as long and five times as heavy as previous Mars Spirit and Opportunity rovers. Landing such a large payload on Mars is challenging because the atmosphere on Mars is too thin for parachutes and aerobraking to be effective yet still thick enough to create the potential for stability and impingement problems when decelerating with rockets. Also at 900 kg the Curiosity rover is too heavy to use airbags to cushion the shock of

Key Highlights:

Industry

Aerospace



Challenge

Validate the landing sequence and determine loads on subassemblies and components on the Curiosity Rover during its historic landing sequence on Mars.

MSC Software Solutions

Adams

Benefits

- Optimize the design of every component to ensure their ability to withstand loads and successfully perform their mission
- Determine the bounding limit design loads that could be expected on every component.
- Ensure that there was no possibility of contact between the flight hardware

“The engineers at JPL were not able to test most of the critical mission events on Earth so they had to rely upon MSC Software simulation technology to design most of the hardware and control sequences for this mission.”

landing. One additional challenge is that the 14 minute trip required for a radio signal to travel from Mars to earth means that the vehicle must act autonomously without interactive control from Earth for the entire landing sequence.

NASA engineers addressed these challenges by developing a unique entry-descent-landing system. The aeroshell containing the heat shield, rover, descent stage, backshell and parachute, separated from the cruise stage ten minutes before entering the Martian atmosphere and fired thrusters to orient the heat shield facing Mars. The aeroshell slowed to about 578 meters per second at about 10 kilometers from Mars at which point a supersonic parachute deployed.

At about 1.8 kilometers altitude with the aeroshell traveling at 100 meters per second, the rover and descent stage dropped out. The descent stage fired its rocket thruster to slow to less than 1 meter per second and lowered the rover with a 7.6 meter tether consisting of three bridles and an umbilical cable carrying electrical signals to the Martian

surface. As the bridles unreeled, the rover's six motorized wheels snapped into position to prepare for landing. After landing, the rover fired explosive devices activating cable cutters to free itself from the descent stage and the descent stage crash landed hundreds of meters from the rover. At 6:33 a.m., the rover confirmed a successful landing.

Only One Chance to Get it Right

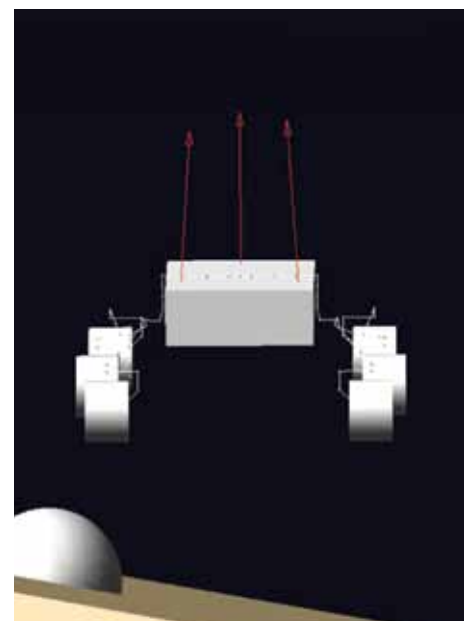
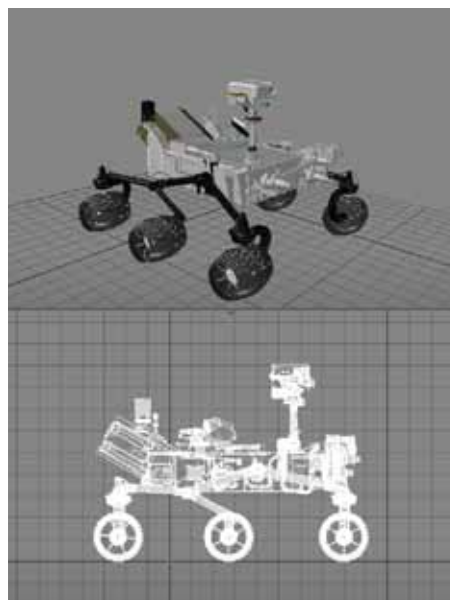
There was only one chance to get it right. The complex sequence either works perfectly or the entire mission goes up in a cloud of Martian dust as the rover is destroyed. Engineers cannot test the landing sequence on Earth because they can't duplicate Martian gravity, atmosphere, and the landing conditions on Earth. They can test individual components but the only way to test the complete sequence and determine the loads on the individual components is with simulation. The program engineers recognized the importance of

simulation from the very beginning and devoted an average of three people working with multibody dynamics over the life of the project.

The rover, the most critical part of the simulation, was modeled to a high level of fidelity including many flexible elements some of which incorporated nonlinear stiffness and damping. The descent stage model is much simpler, consisting entirely of rigid bodies. In the beginning of the project, separate models were used for the rover separation, mobility deployment, and touchdown phases. During the later stages of the project, all of the models were merged into one. The combined model runs between 17 to 93 minutes on a four-CPU Hewlett Packard Unix workstation.

Determining Loads for Structural Design

Optimizing the design of every component in the payload was critical because of the





need to ensure their ability to withstand loads and successfully perform their mission while at the same time minimizing their weight because of the high cost of transporting incremental weight to Mars.

Adams was used to predict the loads on components and subassemblies and these loads in turn were used as input to structural analysis that optimized the design to provide the strength to withstand mission loads while minimizing size and weight. The philosophy of the modeling was not to try and predict every event to 100% accuracy but rather to determine the bounding limit design loads that could be expected on every component.

Prior to the Adams simulation, JPL engineers believed that the projected 1 meter per second maximum speed during touchdown would not induce particularly high loads on the rover. However, simulation showed the loads were

much higher than expected. The original expectations also were that the rover would be in a quiescent state when it touched down on the Martian surface but the Adams simulation showed that the rover was actually rotating and swinging as it landed. As a result, the rover structure was stiffened to mitigate these issues.

Later studies provided the additional surprise that the deployment of the rover's wheels and struts as originally planned generated even greater loads on some of the rover components than the touchdown. Simulation showed that the end of wheel deployment generated hammer-like blows on the rover suspension and frame.

JPL engineers addressed this problem by changing the timing of the wheels and struts deployment. Changing the timing of the wheels and struts deployment also reduced the swing rate and swing angle before touchdown.

The flight control software was written in C++. The people who wrote the controller software required a detailed mechanical model to accurately predict the system performance. The engineers overcame this issue by compiling the controller with the Adams solver. This made it possible to validate the system performance and tune the controller parameters with a detailed mechanical model. JPL engineers validated and updated the Adams model by correlating the simulation results to the test data.

The engineers at JPL were not able to test most of the critical mission events on Earth so they had to rely upon simulation to design most of the critical hardware and control sequences for this mission. The accuracy and thoroughness of the simulation results helped make it possible to successfully and precisely place the rover onto the Red Planet.

Image Credit: NASA/JPL-Caltech



Checking Other Aspects of the Landing Sequence

The most critical aspect of the separation between the rover and descent stage is the need to avoid contact between the flight hardware. The Adams simulation was used to check the clearance and ensure that there was no possibility of contact. In the final design there is very small clearance but no contact issues.

About MSC Software

MSC Software is one of the ten original software companies and the worldwide leader in multidiscipline simulation. As a trusted partner, MSC Software helps companies improve quality, save time and reduce costs associated with design and test of manufactured products. Academic institutions, researchers, and students employ MSC technology to expand individual knowledge as well as expand the horizon of simulation. MSC Software employs 1,000 professionals in 20 countries. For additional information about MSC Software's products and services, please visit www.mscsoftware.com.

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About Adams

Multibody Dynamics Simulation

Adams is the most widely used multibody dynamics and motion analysis software in the world. Adams helps engineers to study the dynamics of moving parts, how loads and forces are distributed throughout mechanical systems, and to improve and optimize the performance of their products.

Traditional "build and test" design methods are expensive, time consuming, and impossible to do sometimes. CAD-based tools help to evaluate things like interference between parts, and basic kinematic motion, but neglect the true physics-based dynamics of complex mechanical systems. FEA is suited for studying linear vibration and transient dynamics, but inefficient at analyzing large rotations and other highly nonlinear motion of full mechanical systems.

Adams multibody dynamics software enables engineers to easily create and test virtual prototypes of mechanical systems in a fraction of the time and cost required for physical build and test. Unlike most CAD embedded tools, Adams incorporates real physics by simultaneously solving equations for kinematics, statics, quasi-statics, and dynamics.

Utilizing multibody dynamics solution technology, Adams runs nonlinear dynamics in a fraction of the time required by FEA solutions. Loads and forces computed by Adams simulations improve the accuracy of FEA by providing better assessment of how they vary throughout a full range of motion and operating environments.

Optional modules available with Adams allow users to integrate mechanical components, pneumatics, hydraulics, electronics, and control systems technologies to build and test virtual prototypes that accurately account for the interactions between these subsystems.

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