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LUNAR LANDER LANDING MODELING AND SIMULATION IN SIMSCAPE

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The landing gear is a critical subsystem of a lander for a successful landing on the moon or a planet. During a landing event, structural loading, energy absorption and toppling stability are important factors for the landing gear development. These aspects can be studied using simulations.

The landing gear comprising the primary struct, secondary structs, footpad, and joints, is easily modeled using Simscape Multibody toolbox. The energy absorption mechanisms in the structs is readily modeled using Simulink and Multibody blocks based on the relative motions of the inner and outer cylinder of the structures. During touchdown, the footpads strike the lunar surface, and the contact forces can be modeled including the soil mechanical properties. Slosh dynamics are included using a mechanical pendulum model. Tip-over controllers are developed using Simulink blocks and toolboxes.

This model was intensively tested manually then additionally with Monte Carlo simulation. It offers the opportunity for landing stability study, i.e. the max slope a lander can land without tipping over in 3D realistic landing situations.

INTRODUCTION/MODELING

The landing gear is a critical subsystem of a lander for a successful landing on the moon or a planet. For the Apollo program, Lunar module (LM) landing gear touchdown dynamics was both experimentally tested (Reference 1) and simulated by computer (Reference 2). During a landing event, structural loading, energy absorption and toppling stability are important factors for the landing gear development.

Landing legs usually have a primary strut and two secondary struts equipped with an energy absorption mechanism, as with the LM landing gear shown in Figure 1(a) (Reference 3). The landing leg structure can be easily modeled using Simscape Multibody toolbox. The Simscape Multibody toolbox's Body Elements, Joints, Frames and Transforms libraries contain blocks which can be graphically connected to model the leg struts, the footpad, the joint connecting the primary strut to the secondary struts, and joints connecting the legs to the vehicle main body. The energy absorption mechanisms in the struts, such as a spring-dashpot damper, can be easily modeled using

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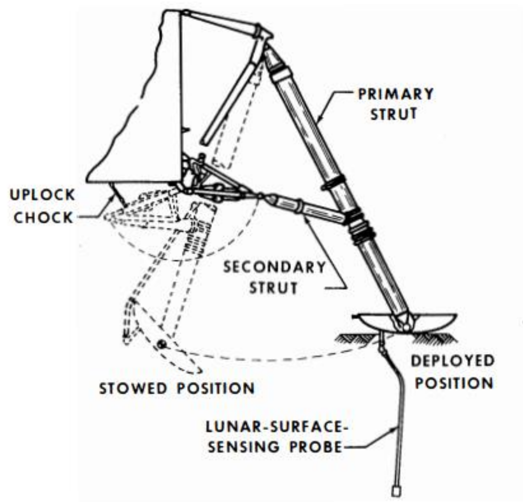
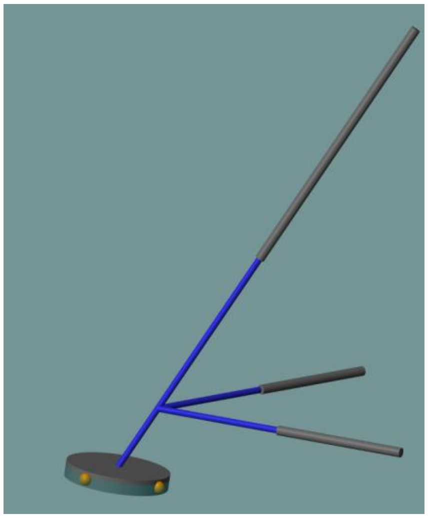
Simulink and Multibody blocks based on the relative motions of the inner and outer cylinder of the struts. The Multibody toolbox provides a Transform Sensor block which can output translational and rotational motion variables between two frames, which are used to compute the dissipative forces. The General Variable Mass block is used to specify the mass properties of each leg element including mass and moments of inertia. A sample landing leg model developed in Simscape is shown in Figure 1(b).



(a)



(b)

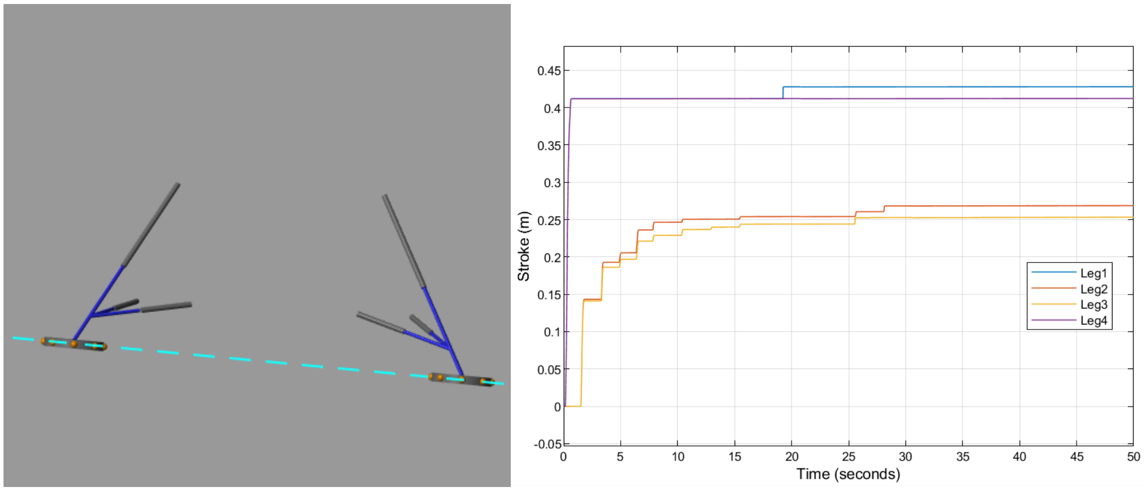
Figure 1. LM landing leg (a) and leg model in Simscape (b)

During a lander touchdown, the footpads strike the lunar surface and there is dynamic interaction between the landing legs and the lunar soil. It is important to model the footpad and soil interaction in a landing performance assessment. The surface can be model as a plane using the Infinite Plane block. The contact forces can be modeling using the Spatial Contact Force block, where the normal force is computed based on the footpad penetration, specified soil stiffness, and damping coefficient and the friction force is computed based on the normal force and the soil friction coefficient. The soil mechanical properties computed based on Apollo touchdown data can be found in Reference 4. In the simulation, the landing contact normal force is initially modeled using a linear spring-damper method provided within Simscape. But this method is too conservative without considering the inelastic deformation of the lunar regolith and increased soil stiffness with increasing footpad penetration. A custom nonlinear contact normal force model is also developed to simulate the landing events with increased accuracy.

SIMULATION

Having modeled the landing leg structure, energy attenuation, and contact forces, landing dynamics under various landing modes (Reference 5) can be simulated given the vehicle states and local slope at touchdown. The model can be instrumented to output key variables such as stroke, penetration depth, tilt angle and vehicle body rates, so the structural integrity and toppling stability for a given landing leg design can be assessed against the requirements. Figure 2(a) shows the lander stable landing on a 4.6 degrees slope for the passive 2-2-over landing mode (Reference 5) and Figure 2(b) shows the primary structure stroke distances.

To successfully land on steeper slopes, hot gas thrusters can be fired during touchdown to prevent the vehicle from tipping over via feedback control logic. Because Simscape is embedded inside Simulink, it is very easy to model different tip-over control strategies using various Simulink blocks and toolboxes. For higher fidelity modeling, the slosh dynamics of the liquid propellant in tanks can be easily modeled using a pendulum mechanical model using Simscape Multibody library.



(a) (b)

Figure 3. Stable landing, 2-2-over landing mode (a) and primary structure stroke (b)

CONCLUSION

First, this model was intensively tested manually then through Monte Carlo simulation. It offers the opportunity for landing stability study, i.e. the max slope a lander can land without tipping over in 3D realistic landing situations.

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