

# SIMPACK Masters Skydiving

The Institute of Flight Research at the German Aerospace Center (DLR), Braunschweig, contributes to research and testing technologies for reusable space vehicles. The testing system has the name ALEX, which is a parafoil-load-vehicle for demonstration of an autonomous, soft, and precise landing. The design of a control-concept pre-supposes fundamental knowledge of the system characteristics and performance. In other words a model is required, which reproduces the vehicle's reactions to control inputs. As flight test data indicates, the system reacts not only to steering inputs by performing manoeuvres, but also by a motion of the load relative to the parafoil. That motion is characterized by kinematics and aerodynamics, so a suitable simulation environment should consider both.

## Relative Motion

The parafoil and the capsule (load) are not linked stiffly. Lines and belts allow different deformations of the system. These additional degrees of freedom are: Relative yawing, relative rolling, lateral shifting and relative pitching.

The relative motion can be measured using a video-system which is rigidly mounted on the load with view to the parafoil. Relative motion is represented as a displacement of the canopy within the captured image. To extract quantitative measurements from the video data, the image sequence has to be analyzed by so called tracking-algorithms. This procedure makes the parafoil's position and orientation available.

## Kinematics

Video analysis yielded data that represent certain system qualities. A model of this system has to perform preferably the same way if it should be suitable for simulation and further analysis. Thus high demands are posed on the model; it must map the real

geometry very closely. All elements involved in the relative motion should also be considered in kinematic modeling. With SIMPACK the complexity of such a model is easy to handle.

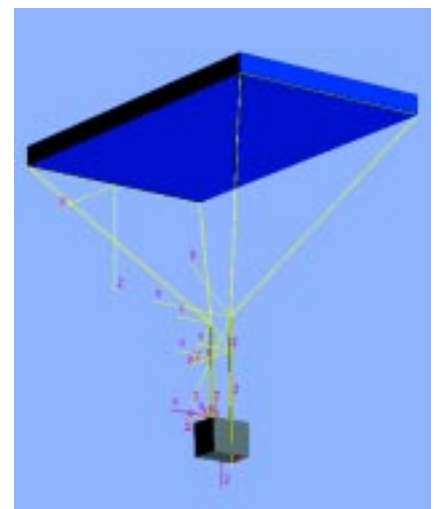
For setting up the model, first, lines and belts have been combined to functional units and then "translated" into SIMPACK-elements, for example "rods" or "prisms". Lengthening and flexibility of the lines are neglected. The underlying reason for that simplification is the initial tension of the system, resulting from the counteracting forces lift and weight. These forces prevent the lines from getting slack.

For the definition of connections between the bodies different joints, spring-damper elements and constraints have been used. The actuators and the control lines for the steering of the parafoil are represented by standard force-elements.

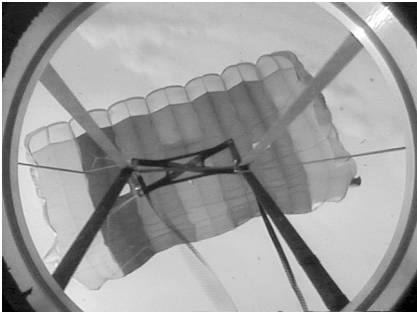
The parafoil-load-model covers 8 bodies with approximately 50 states. Not included are external, aerodynamic forces and moments that actuate the possible motions.



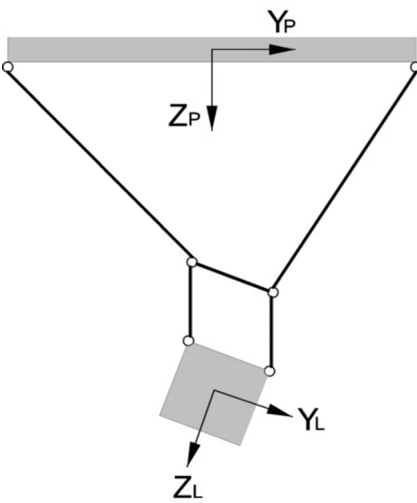
Alex-System



SIMPACK: Kinematic Model



Video Representation of Relative Motion



Example of Relative Motion: Relative Rolling

## Aerodynamics

The aerodynamic behavior of our parafoil-load-system has already been modeled under the MATLAB SIMULINK environment for previous investigations. It's a simple flight mechanical 3 DOF model, which matches the flight performance of the overall system sufficiently. This conventional model, describing only the rigid body motion, is to be enhanced by the introduction of additional degrees of freedom to allow relative motion as well.

## Teamwork by Co-Simulation

Each of the models has its advantage, MATLAB allows easy preprocessing of flight test data and offers mathematical libraries for various engineering problems, and SIMPACK features powerful solvers especially for kinematic tasks and convenient 3D-visualization.

The Co-Simulation Interface COSI offers the opportunity to retain all these advantages and merge the two simulation tools. SIMULINK first computes the aerodynamic forces and moments resulting from control inputs and the initial states. This information is passed over to SIMPACK, which simulates

the kinematic behavior and returns the appropriate states back to SIMULINK.

## Parameter Estimation

After the overall-model has been set up it's necessary to tune the model parameters. Since a real system, equipped with various sensors, is simulated, it is possible to compare computed and measured states. Tuning of the parameters should result in a least possible difference between data from measurement and simulation.

The estimation of the parameters is done automatically with the help of an output-error-method (FITLAB) which is implemented under MATLAB by DLR Braunschweig.

## Fields of application

Having assembled and tuned the simulation environment, it is finally ready for utilisation. One practical use of this model is to find correction terms for flight data measurements. Understanding the relative motion allows to transform measurements taken from the capsule in corresponding values of the parafoil. Another application is performing simulation studies to find out whether relative motion has to be considered for the design of the flight controller or not.

SIMPACK and SIMULINK make a perfect team to simulate flight mechanics plus kinematics. This combination is suitable for more than the analysis of parafoil.

