Computer illustration of the SHEFEX II heat shield experiment planned for early 2011. The navigation systems of the payload nose cone are undergoing intensive pre-launch testing with a dSPACE system.

Beating the Heat

Testing the navigation system for the SHEFEX II heat shield experiment

While developing a new space glider, the German Aerospace Center is investigating new heat shield technologies in their SHEFEX II program. A nose cone mounted on the tip of a high-altitude research rocket is scheduled for launch in early 2011 to test a new type of heat shield constructed from flat panels. This will be easier to maintain and much less expensive than the heat shields on current spacecraft. The navigation system for the reentry nose cone, which carries the payload, is undergoing thorough prior testing on a dSPACE system.

New Type of Heat Shield

The heat shield of the U.S. Space Shuttle has more than 20,000 differently shaped curved panels, each of them fitting just one specific location on the shuttle. This means high manufacturing costs for the panels and high maintenance costs for the heat shield. So the German Aerospace Center (DLR) is trying a completely different approach in SHEFEX II (Sharp Edge Flight Experiment).
All the panels are flat, and there are only a few basic shapes. This simplifies manufacture, and the heat shield also needs much less maintenance work. Moreover, the heat shield's facetted form, with its sharp corners and edges, has better aerodynamic properties. With the SHEFEX technology, the space glider is simple to assemble and therefore less expensive, and can touch down with the same precision as a space shuttle. The SHEFEX program aims to test the new heat shield technology with a high-altitude test rocket flight.

Navigation by IMU, GPS and the Stars

During its return to Earth, the payload nose cone will be guided by 4 small fins called canards. Its speed, position, and attitude (alignment of its longitudinal axis with the direction of flight) have to be known at every point in time. Three different navigation systems are used to measure these variables:

- Inertial measurement unit (IMU): Monitors the high dynamics of the payload nose cone and its attitude in relation to its trajectory (sampling rate 400 Hz)
- Global Positioning System (GPS): Measures the position and speed (sampling rate 1 Hz).
- Star tracker: Navigates by the stars with the aid of a camera (sampling rate 1 Hz).

This combination of three systems ensures high precision and reliability. The dSPACE system's task is to simulate the flight sequence, including navigation signals, in order to test the interaction between all the components before the actual flight.

dSPACE System for Flight Simulation

The dSPACE system for ground-based navigation system tests essentially consists of the DS1006 Processor Board (to calculate the trajectory and the navigation system signals according to the current flight attitude) and various I/O boards (to connect to the navigation systems). There are several test steps. In the first, the experiment setup consists solely of the dSPACE system and the navigation computer. The actual navigation devices (IMU, GPS, star tracker) are not connected yet, so their signals are all simulated by the dSPACE system. This test phase validates and optimizes the basic functionality of the navigation software. The navigation devices are connected stepwise after the first phase has been completed.
In the second step, the GPS and a

Figure 1: Left: The payload nose cone is just over 2 m long and has flat thermal protection panels.
Right: Mounting the panels. Underneath the panels lie temperature sensors, pressure sensors and other devices for in-flight measurements.

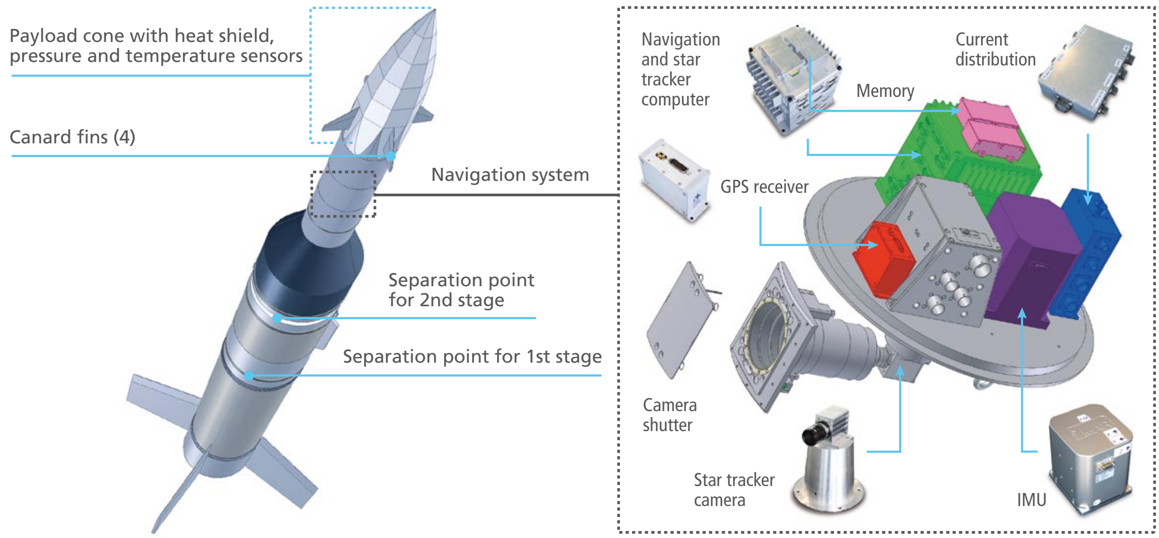

Figure 2: The Brazilian two-stage solid fuel VS-40 rocket is just over 12 m long. It carries the nose cone with the heat shield and the navigation system to an altitude of approx. 140 km.

GPS signal generator are connected so that GPS navigation can be tested. The third step then connects the IMU, which is mounted on an ACUTRONIC rotation table to simulate different craft movements (figure 3). In the final step, the star tracker is integrated into the setup. It receives a simulated map of the stars from a Jenoptik sky simulator. Because of the high velocities involved, time delays in GPS measurements seriously affect the navigation solution. Synchronizing the measurement signals with the navigation computer's internal clock is therefore a major focus. The control models are developed with MATLAB®/Simulink®. The signals and settings of each test are observed and visualized during run time by the experiment software dSPACE ControlDesk®.

Falling at Mach 10 from an Altitude of 140 km

The rocket is due to be launched from the test site in Woomera, Australia, in 2011. It is expected to reach an altitude of 140 km in a flight lasting approx. 10 minutes. After the flight, the payload nose cone with the heat shield will be parachuted down for a soft landing in the desert approx. 830 km away. The IMU can be used for navigation throughout the entire flight, unlike the GPS, which is anticipated to fail for a short time during reentry into the Earth's atmosphere. This is because the payload nose cone will be split to bring it down abruptly from hypersonic to subsonic. It will go into a fast spin during this procedure, making it practically impossible for the GPS antennas to continue receiving signals. At the apogee, the star tracker will be activated to compare the positions of the stars with the stored star maps and to determine the relative attitude of the payload nose cone to the trajectory.

REX Free Flyer, the Reusable Space Glider

In the reentry phase, the approx. 160 sensors in the payload nose cone will collect a wealth of data on the pressure and temperature distribution on the heat shield. SHEFEX engineers are investigating several different thermal protection technologies, most of them the DLR's own fiber ceramic developments. One of them will be active cooling, in which a gas is ejected from pores in the thermal protection panels to form a heat-insulating layer. This will be the first time active cooling is used in the entire history of space travel.

Stephen Steffes
Stephen Steffes is a project engineer working on the SHEFEX navigation system at the German Aerospace Center in Bremen, Germany.

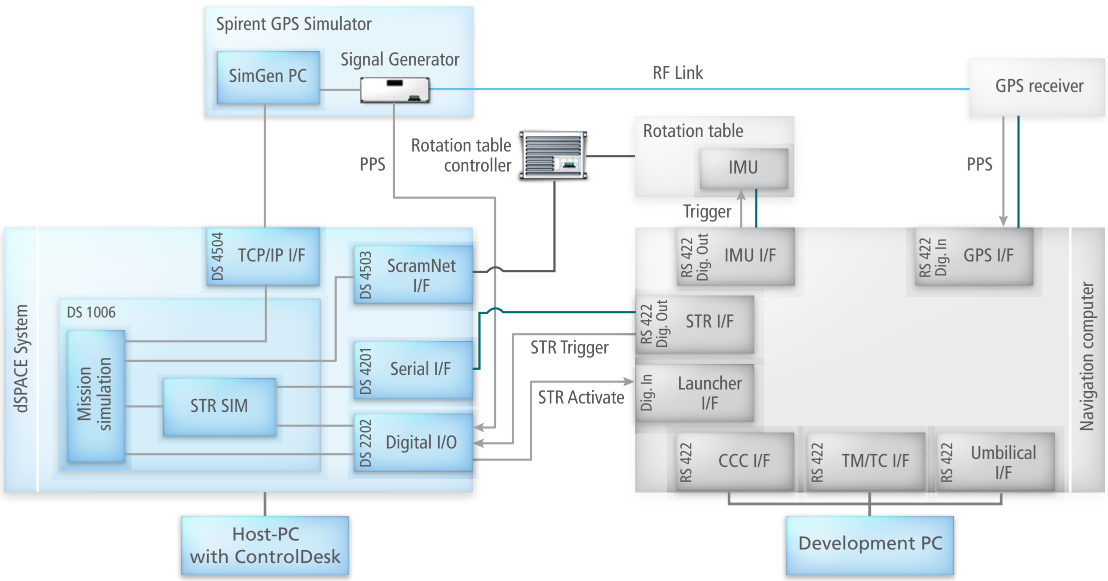

Figure 3: One of the test scenarios. The dSPACE system tests the navigation computer, to which the GPS and the inertial measurement unit (IMU) are connected as real components. The star tracker (STR SIM) is simulated by the dSPACE system.

> "The dSPACE system lets us simulate the entire mission on the ground and test every detail of our navigation system."
>
> *Stephen Steffes, DLR (German Aerospace Center)*

These tests on new heat shield technologies are part of a long-term development project. The ultimate goal is to create a completely new kind of space glider, called the REX Free Flyer, which could become available around 2020 to bring experiments back to earth from a zero-gravity environment. ■

Stephen Steffes
German Aerospace Center

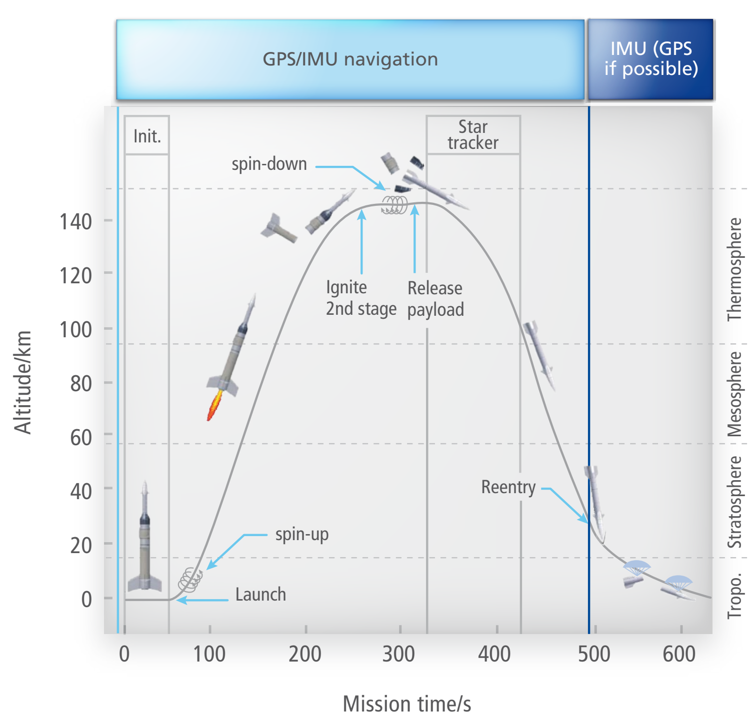

Figure 4: All the navigation systems will be used during the approx. 10-minute flight. During reentry, approx. 160 sensors will measure the temperature and pressure distribution on the heat shield.