After being lifted to an altitude of 25 km by a balloon, the unmanned space vehicle (USV) glides for close to two and a half minutes, executing a series of flight maneuvers and collecting a wealth of measurement data.

Testing the onboard computer of an unmanned space vehicle

Diving Back to Earth

The Centro Italiano Ricerche Aerospaziali (the Italian Aerospace Research Center, or CIRA) is using an unmanned space vehicle (USV) to research technologies that are vital to the development of future space transporters. The onboard computer used in the test flights previously underwent comprehensive testing with the aid of dSPACE tools.

The Alternative to an Expendable Vehicle

Even before the age of the Space Shuttles came to an end with their very last flight in mid-2011, various research facilities across the world had initiated development programs for alternatives. After all, the idea of a reusable space transporter is an extremely attractive one, as it has enormous potential for saving costs and avoiding space debris as compared with expendable vehicles. For example, it does not result in burnt-out rocket stages orbiting the Earth as hazardous junk. CIRA is using a USV as a "flying laboratory" for research into all the important aspects of developing the reusable space transporters of the future, such as thermodynamics, elasticity, heat shield technologies, navigation techniques, flight mechanics, etc. The USV already performed two test flights and provided valuable data on factors such as the pressure, force and temperature conditions on the outer shell.

Figure 1: The approx. 9 m long USV glides powerlessly back to Earth, guided only by an onboard computer.

Nosedive, Size XXL

The second test flight took place on April 11, 2010, when the USV was first lifted to an altitude of 25 km with the aid of a stratospheric balloon. After undocking from the balloon, it executed a two-minute-long glide during which it executed a measurement program, and finally parachuted into the sea off the coast of Sardinia (figure 3). Its speed was mostly around Mach 1, but for a while it was also approx. Mach 1.2. During the flight, the USV constantly collected all the data (flight altitude, speed, acceleration, etc.) that was necessary for the onboard computer to guide it safely. The onboard computer itself had previously undergone an intensive test program using a dSPACE system.

Flight Guidance System for Autonomous Gliding

To control the gliding flight right up to splashdown, the USV uses various sensors to collect data on its position, attitude, speed, acceleration, etc.:

- Magnetometer (to determine the USV's attitude relative to the Earth's magnetic field)
- Acceleration sensors (MEMS acceleration meters, i.e., micro-electric mechanical systems)
- Optic fiber gyroscope (to determine the USV's attitude relative to its trajectory)
- GPS sensors (Global Positioning System to measure position and speed)
- Air data system (for example, to determine the Mach number via back pressure sensors)

The onboard computer processes the measurement data from all these systems in real time and uses it to compute the commands needed to adjust the control surfaces and ensure that the USV's autonomous gliding flight goes according to plan. "We simulate the flight including all the sensor values with the dSPACE system," explains Giovanni Cuciniello, responsible for the Guidance, Navigation and Control (GNC) Laboratory at CIRA. "This means we can test the onboard computer before the USV even leaves the ground." The USV is studded with all sorts of sensors, such as the more than 300 piezo sensors that measure the pressure distribution on the outer shell during flight. Engineers can use this data to optimize aspects such as the shape of the USV.

Testing the Flight Control System

The dSPACE system (figure 4) for testing the flight control system consists of a DS1005 Processor Board (which computes the flight sequence including the associated sensor values) and various I/O boards for connection to the onboard computer. The experiment software dSPACE ControlDesk is used to monitor and control all the experiments. Typical tasks performed by ControlDesk are monitoring and recording the simulated environment, and possibly changing it, for example, increasing the balloon ascent velocity or varying gust strength during free flight. ControlDesk also allows failures to be injected in the simu-

> "We were able to test the onboard computer's functions comprehensively before the flight with the aid of the dSPACE system."
>
> *Giovanni Cuciniello, CIRA*

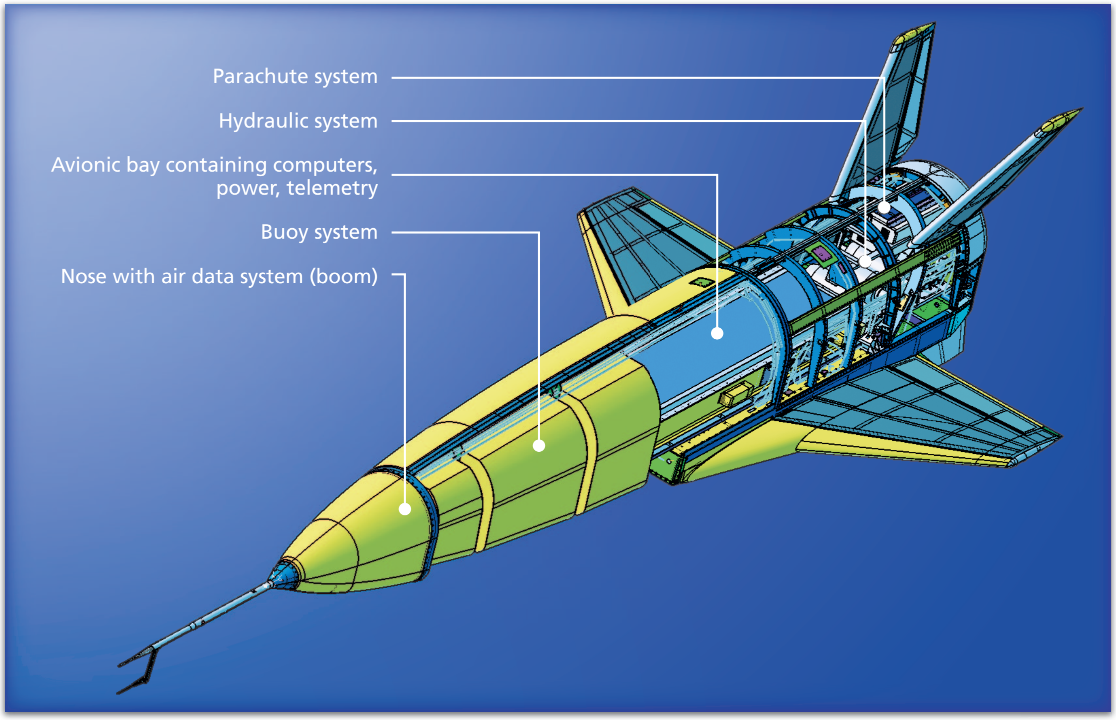
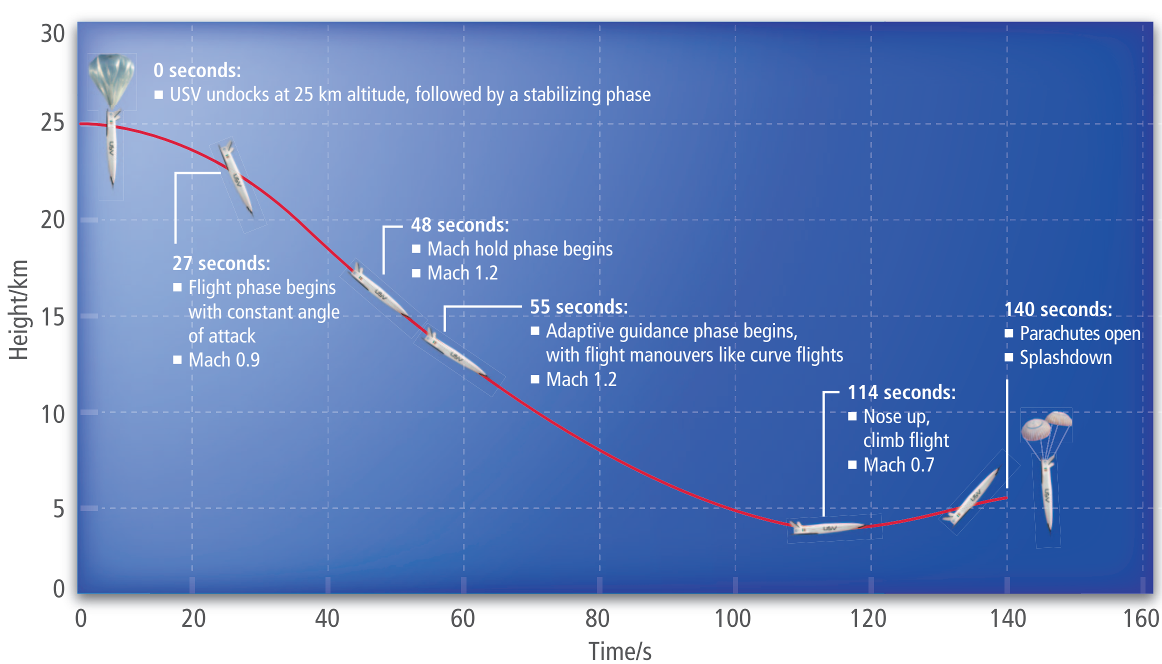


Figure 2: Structure of the USV. Its outer shell is studded with devices such as hundreds of pressure sensors.

lated balloon and vehicle subsystems in order to analyze the system's reactions. Compared with traditional research and development methods, using the dSPACE real-time control platform enabled faster and more complete development of the flight control system; the advantages are both the reduction in time and costs for the system development cycle and also improvements in system reliability.

The tests are performed in 3 stages: (1) software-in-the-loop, (2) mobile

Figure 3: During the two-minute gliding flight, the sensors on the outer shell collect a mass of measurement data during all sorts of flight maneuvers.



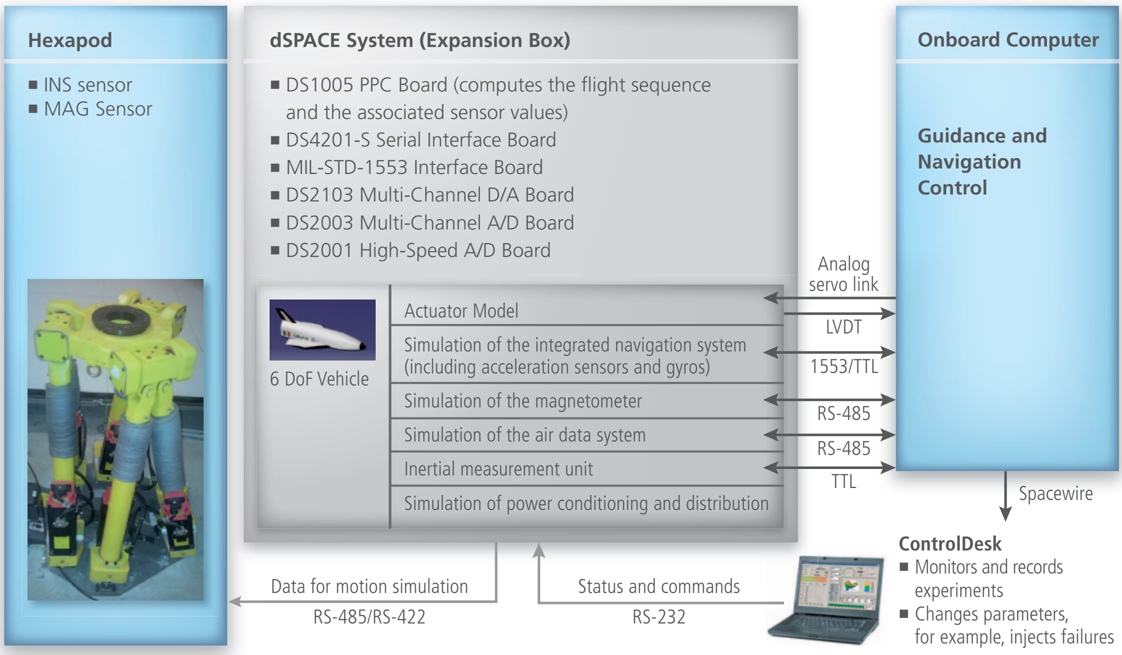


Figure 4: The dSPACE system computes the flight mechanics and sensor/actuator models in real time. This data is used to test the onboard computer. In parallel to this, the current flight movements are performed by a hexapod on which real sensors are mounted.

tests on a ground vehicle, (3) hardware-in-the-loop.

1. Software-in-the-loop:
This is a pretest to check the basic functions of the flight control software. The dSPACE system simulates the USV's flight mechanics properties and all its sensors. All the models were previously developed in MATLAB®/Simulink®. Real sensors are not yet integrated at this stage.

2. Mobile tests:
The real sensors were installed in a vehicle to test whether they work properly during drives (both alone and in interaction), for example, whether they process the constantly changing GPS data and acceleration values correctly.

3. Hardware-in-the-loop:
This step (figure 4) finally tests the exact onboard computer that will be used later in the mission. As in the software-in-the-loop test in step (1), the dSPACE system again simulates the flight mechanics and all the sensor values. This data is then passed to the onboard computer. Its reactions control a hexapod on which real sensors are mounted.

In the Future: Heat Shield Tests

Following the two flights already performed by the USV1, the aim of

> "The dSPACE real-time system speeds up development times, reduces costs, and increases the overall system reliability."
>
> *Giovanni Cuciniello, CIRA*

Figure 5: The new European VEGA rocket lifts off for its maiden flight on February 13, 2012. One of its future flight missions will be to carry CIRA's USV into orbit.

the future unmanned system USV3 is to perform a reentry mission from orbit to ground landing. In order to do this, the European VEGA rocket will lift the USV3 from the European spaceport in Kourou into a low-earth orbit (200-300 km altitude).

After completing a few orbits, the USV3 will execute a de-orbit to start its reentry at hypersonic speed and fly through the atmosphere autonomously from hypersonic down to supersonic, transonic and subsonic regimes to landing on a conventional runway. "It will be exciting to see whether all the systems on board the USV will still function as planned with outer shell temperatures of about 2000 °C," says Giovanni Cuciniello from CIRA. The long-term objective of CIRA's USV program is to develop a space transporter that takes off from the ground like an airplane, reaches its orbital altitude, and can then land on any airfield in the world. ■

Watch the full drop-flight test of the USV1 from preparations to lift-off to parachute landing.
www.youtube.com/watch?v=BhoXgWKjVL0

Giovanni Cuciniello
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