January 2014

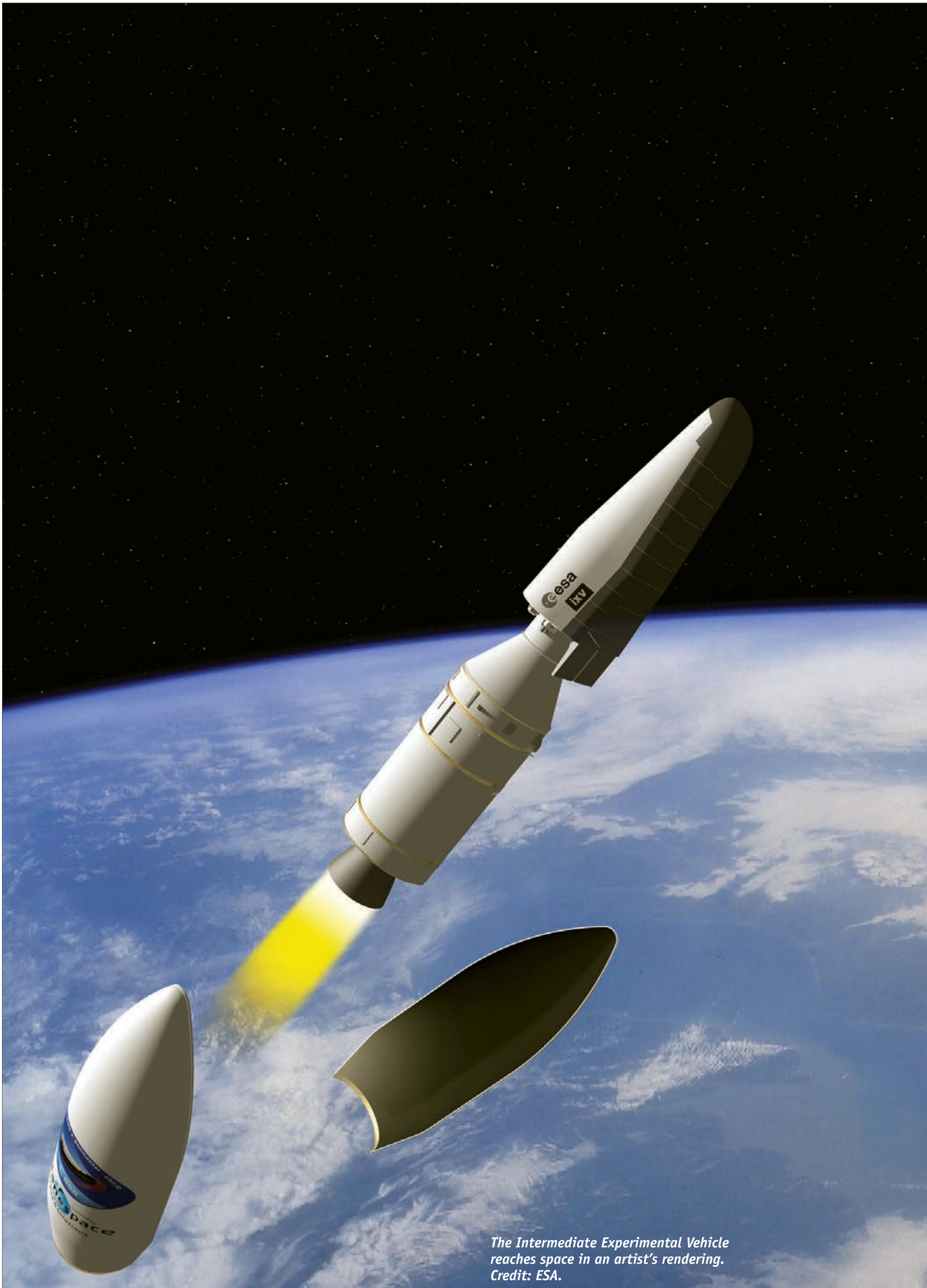
AEROSPACE
AMERICA

UNMANNED UNRESTRICTED

Why opening the airspace to strange, new craft will be harder than it sounds page 28

The value of a mentor page 18
Dueling satcom providers page 38

A PUBLICATION OF THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS



The Intermediate Experimental Vehicle reaches space in an artist's rendering. Credit: ESA.

Europe's reentry demo

Getting to orbit and back with a powered, winged craft poses fascinating engineering challenges. Space technology consultant Mark Williamson explains the European Space Agency's effort to solve one of the key problems — getting back into the atmosphere safely.

ANALYSIS
by Mark Williamson

The field of atmospheric re-entry was once dominated by governments that needed the capability to launch and return people from orbit, namely the United States, Russia and China. That's beginning to change. Re-entry technologies such as thermal protection systems and guidance, navigation and control were important to Japan's Hayabusa spacecraft, which returned dust from the asteroid Itokawa in 2010. They're now used by commercial companies to return cargo from the International Space Station. But these craft are ballistic capsules that must be launched on rockets, and they return to Earth with limited steering capabilities. The Holy Grail would be a spaceplane that would take off from a runway, reach orbit on its own power, and land on a runway. An example would be the proposed Skylon craft now in early stages of development by Reaction Engines Ltd. of Abingdon, U.K.

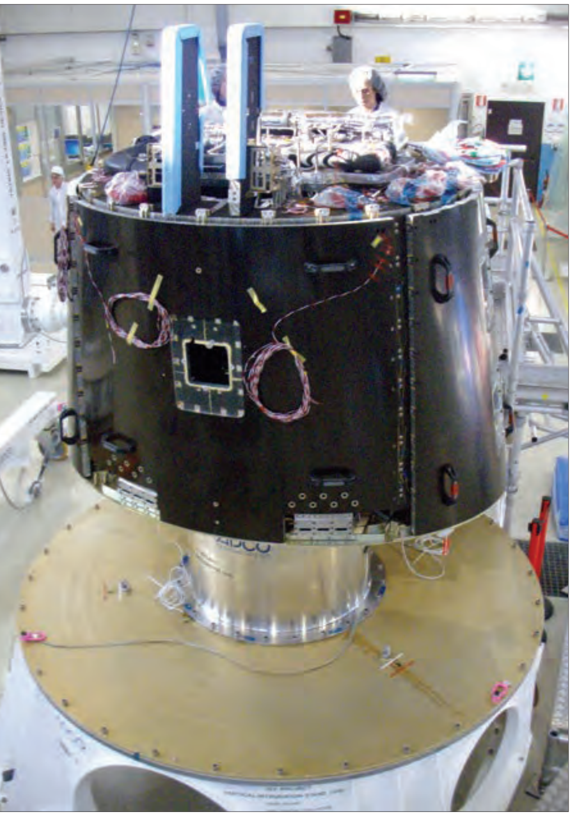
Returning any craft to Earth is challenging because of friction with the atmosphere, but guiding it to a runway is even more of a challenge. This is easier for a winged craft, such as the space shuttle or Skylon, than it is for a capsule, but the wings add complexity and weight. This is where IXV, the Intermediate Experimental Vehicle, comes in. Its wedge-shaped profile represents an intermediate step between a simple ballistic re-entry capsule and a future spaceplane.

The European Space Agency has long recognized the importance of atmospheric re-entry to both manned and unmanned spaceflight, and the ESA-funded IXV demonstrator is the latest manifestation of this recognition. ESA expects to launch IXV on a Vega rocket from the Guiana Space Centre in August in a suborbital demonstration of thermal and guidance technologies that a future powered spaceplane like Skylon would need to reenter the atmosphere and land. IXV will splash down in the Pacific.

Arguably most important is that IXV could one day lead to what some in Europe have long wished for: the ability to conduct manned space missions without recourse to other nations.

Flying brick

So, why should it interest those outside of Europe that ESA is playing catch-up on a re-entry technology mastered decades ago by the U.S. in the Space Shuttle program and the erstwhile Soviet Union in the Buran program?



The rear segment of the Intermediate Experimental Vehicle on an integration stand. Credit: ESA/Thales Alenia Space.

The potential advantage for European countries lies in their penchant for applying technology to commercial applications – in the satellite manufacturing and launch industries, for example. That ESA is funding a re-entry demonstrator suggests the potential for future commercial application.

Europe's investment in a craft that looks more like a spaceplane than a capsule comes as NASA and its commercial partners are largely focused on capsules reminiscent of the Apollo era. Specifically, SpaceX and Orbital Sciences have chosen the capsule solution for reasons of cost and relative ease of implementation. The drawback to capsules is that they're unable to carry payloads of large dimensions and mass. Bucking the trend is Sierra Nevada's Dream Chaser, which owes its heritage to NASA's proposed HL-20 Personnel Launch System lifting-body design of the late 1980s.

A lifting body is usually defined as a craft that produces aerodynamic lift using its body or fuselage rather than wings. ESA's project manager for IXV, Giorgio Tumino, explains that lifting bodies "have the advantages of capsules and winged bodies, without their disadvantages." Although capsules are simple and efficient, they have "problems in maneuverability, controllability and comfort if re-entering from orbit through off-nominal scenarios"—for example, if the angle of entry is too steep, he says. Winged bodies are best for maneuverability and controllability, but are "complex and expensive."

Research in the 1960s and 1970s produced a range of short, stubby lifting bodies predominantly with upturned tail-fins of various shapes and sizes to provide stability. Likewise, most of the craft proposed in the 1990s, such as the NASA-Defense Department X-30 National Aero-Space Plane and NASA's X-33 Venturestar, had between two and four fins at various angles to the main body.

The debt owed by the space shuttle program to lifting body research has been well documented, but it is worth remembering that, much like its forebears, each shuttle orbiter had a single chance at landing because it lacked engines. Although its wings endowed it with an enhanced cross-range capability, allowing it to glide to the left or right of its initial entry trajectory, the shuttle was—to recall a nickname coined during approach and landing tests of the 1970s—a "flying brick."

A glance at the outline of the IXV shows it to be different from most previous lifting bodies in its relative lack of aerodynamic control surfaces, having just two horizontal flaps at the base of the rear fuselage. Tumino says that "IXV will be the first-ever lifting body without even winglets to be flown on a mission fully representative of a return from low Earth orbit," which implies a body with an entry speed of approximately 7.5 kilometers per second.

The trick in providing stability without wings, winglets or tailfins, Tumino explains, is to design a shape that is "intrinsically stable longitudinally and laterally," effectively absorbing the winglet cross-section within the solid body of the fuselage. This is possible only because of modern-day computer optimization techniques and joined-up thinking in mission design: For example, the 40-degree angle of attack on re-entry means that any rudder would be, as Tumino says, "in the shadow of the vehicle" and therefore ineffective. As the IXV flies in an intrinsically stable configuration—the antithesis of today's fighter aircraft—any perturbations can be corrected by minimal adjustments of its rear body flaps and its roll, pitch and yaw thrusters, which are also programmed to maneuver the craft through re-entry and landing.

Not having winglets or tailfins smooths the upper aerodynamic surfaces, which reduces complexity and therefore manufacturing costs, while increasing the internal volume available for instruments and payloads. Not least, Tumino adds, is that "if we had winglets, we would need a larger fairing"—and a bigger, more expensive launch vehicle.

Given the long history of lifting bodies and atmospheric re-entry systems, it seems fair to ask what, apart from its shape, makes IXV special. Luigi Quaglino, senior vice president for exploration and science at Thales Alenia Space, is direct in his response: "IXV is special for Europe because it is actually going to fly." Apart from that, he sees IXV as "a clear step ahead for Europe" with respect to advanced guidance, navigation and control and active aerodynamic flight control.

For a craft designed to re-enter the Earth's atmosphere and land at a given position on the surface, thermal protection and guidance are among the main engineering challenges. From a systems engineering standpoint, says Quaglino, a key aspect was to ensure "the best compromise" between robustness and simplicity in the design.

To avoid what Quaglino terms "an extensive use of the tiles and blankets approach" of the space shuttle, IXV adopts a ceramic-metal composite, or CMC, approach based on relatively larger elements compared to the tiles that protected the shuttle orbiters. For a future operational craft, he adds, this choice offers more effective, simpler maintenance and "an obvious improvement of the overall vehicle reusability." CMCs are restricted to the nose cone, leading edges and flaps, while other areas are covered in ablative materials that dissipate re-entry heat by erosion.

As far as guidance and control are concerned, IXV will be an entirely autonomous spacecraft that uses more than 300 sensors to assess its attitude and thermal environment and respond accordingly using its reaction control thrusters and body flaps. Lift is produced by the lifting body design itself, but the challenge for the avionics subsystem is to match this with a natural tendency to fall because of gravity, while guiding the craft along a specified re-entry corridor to a predetermined touchdown point. It's what Buzz Lightyear would have called "falling with style."

Resurging interest

Few technology development programs start from scratch, and IXV is no exception: It relies on a wealth of heritage data from both sides of the Atlantic.

Arguably most relevant of the bewildering array of NASA X-vehicles is the X-40 Space Maneuver Vehicle, designed to investigate aerodynamics and guidance for the agency's X-37 Future-X reusable launch vehicle project. With a length of 6.5 meters and all-up weight of some 1.6 tons, it was similar to the IXV, which is 5 m long and weighs about 2 tons. The X-40 made seven test flights between 1998 and 2001, before the X-37 itself was transferred to the Department of Defense, where in 2004 it became the X-37B Orbital Test Vehicle, conducting three orbital missions between 2010 and 2012.

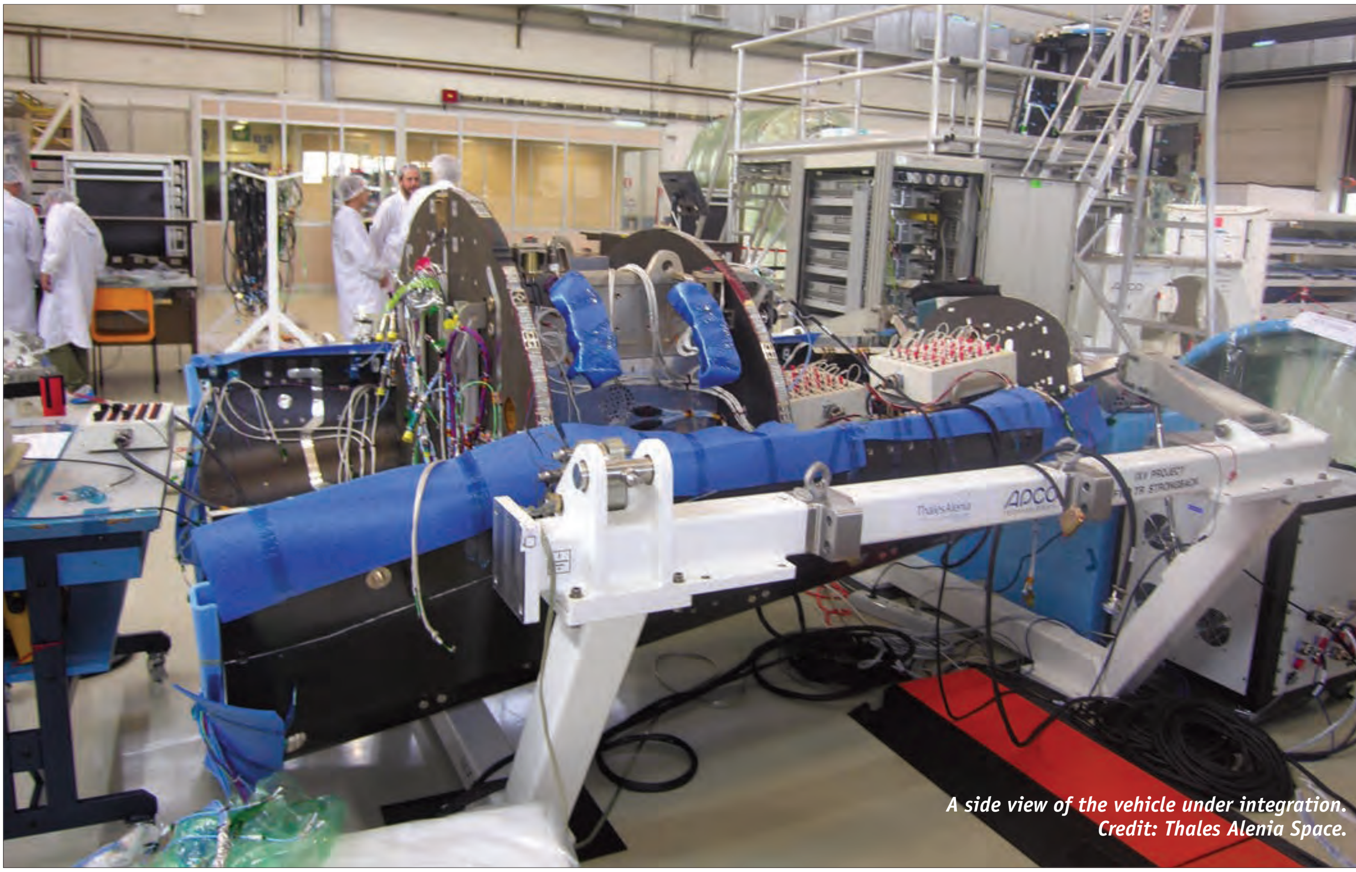
Apart from a number of study-based technology programs, Europe can claim heritage from Hermes, a lifting-body craft proposed by the French space agency CNES as an Ariane 5-launched three-seat shuttle. Although it was approved as an ESA project in 1987, it failed to meet its cost or performance goals and was cancelled in 1992 before any flight hardware had been built.

According to Tumino, a resurgence of interest occurred in the early 2000s when several European concept studies highlighted a desire to perform "the next step in the technology maturation process." In technological terms, this included integrating "critical atmospheric re-entry technologies," including advanced thermal protection, guidance and navigation, aerodynamics and control algorithms, to verify performance in conditions representative of a re-entry from low Earth orbit. With respect to system aspects, adds Tumino, this would mean progressing beyond Europe's Atmospheric Re-entry Demonstrator —a quasi-ballistic capsule flown in 1998—by "defining a lifting vehicle with higher lift-over-drag coefficients than a capsule, and therefore higher maneuverability and controllability, as an intermediate step toward future applications."

A drop test of the full-scale model took place in June 2013. Credit: ESA.

This marked the genesis of the Intermediate Experimental Vehicle, initiated as part of ESA's Future Launcher Preparatory Program in 2004. According to Quaglino, following "a thorough industrial trade-off on shape and system concepts…the concept selected for the IXV was a lifting re-entry body," designed for launch by ESA's Vega rocket on an equatorial trajectory leading to re-entry and parachute-assisted splashdown in the Pacific Ocean about 100 minutes later.

The program reached a key milestone on June 19, 2013, at the Salto di Quirra test range in the Tyrrhenian Sea off the east coast of Sardinia, Italy. A full-scale model was released from a helicopter in a drop test from 3,000 meters, reproducing the final descent and splashdown phase of the proposed mission. According to Quaglino, the objective is to complete the IXV's System Qualification and



A side view of the vehicle under integration. Credit: Thales Alenia Space.

Acceptance Review by mid-year, with a launch "foreseen in August 2014."

Although the IXV's development cost is around 150 million euros, Quaglino expects this to rise to some 170 million euros when ground segment procurement, the launch campaign, recovery and initial postflight analysis are included. Thus, in the context of space systems development, IXV is certainly not an expensive program, especially considering its strategic importance in terms of research and development for Europe.

The front and rear segments mated into a single assembly. Credit: ESA/Thales Alenia Space.

Next steps

According to Tumino, a broad consensus on atmospheric re-entry research has produced a flight demonstration roadmap that will see an evolution of IXV through PRIDE, the Program of In-orbit Demonstration for Europe, for which Tumino is also project manager.

Although Quaglino warns that IXV evolution "may follow different paths," his current expectation is that PRIDE will involve "a small winged vehicle launched to LEO [low Earth orbit] by Vega." The program will add "two important technological bricks to the current IXV mission," he suggests: orbital operations, and autonomous guidance to an automated landing (as opposed to a splashdown as with IXV). "It is an extremely challenging and demanding mission," says Quaglino, that would lead eventually to "a fully reusable transportation system" for satellite servicing and other missions in LEO. In other words, the holy grail of the space community for the majority of the Space Age—and arguably before that.

Tumino is currently focused on the IXV. "The successful accomplishment of the IXV mission," he concludes, "is a fundamental step for Europe to validate the performance of critical atmospheric re-entry technologies in the hypersonic flight regime required for any future operational system."

Indeed, he notes a number of initiatives in Europe that would benefit from a successful IXV mission, including the U.K.'s Skylon, Germany's Spaceliner and the proposed Astrium spaceplane. "All these different European initiatives indicate a wide range of re-entry technology applications," says Tumino.

Perhaps most important, they indicate that Europe is not content, in the longer term, to rely on other nations for guaranteed access to space.