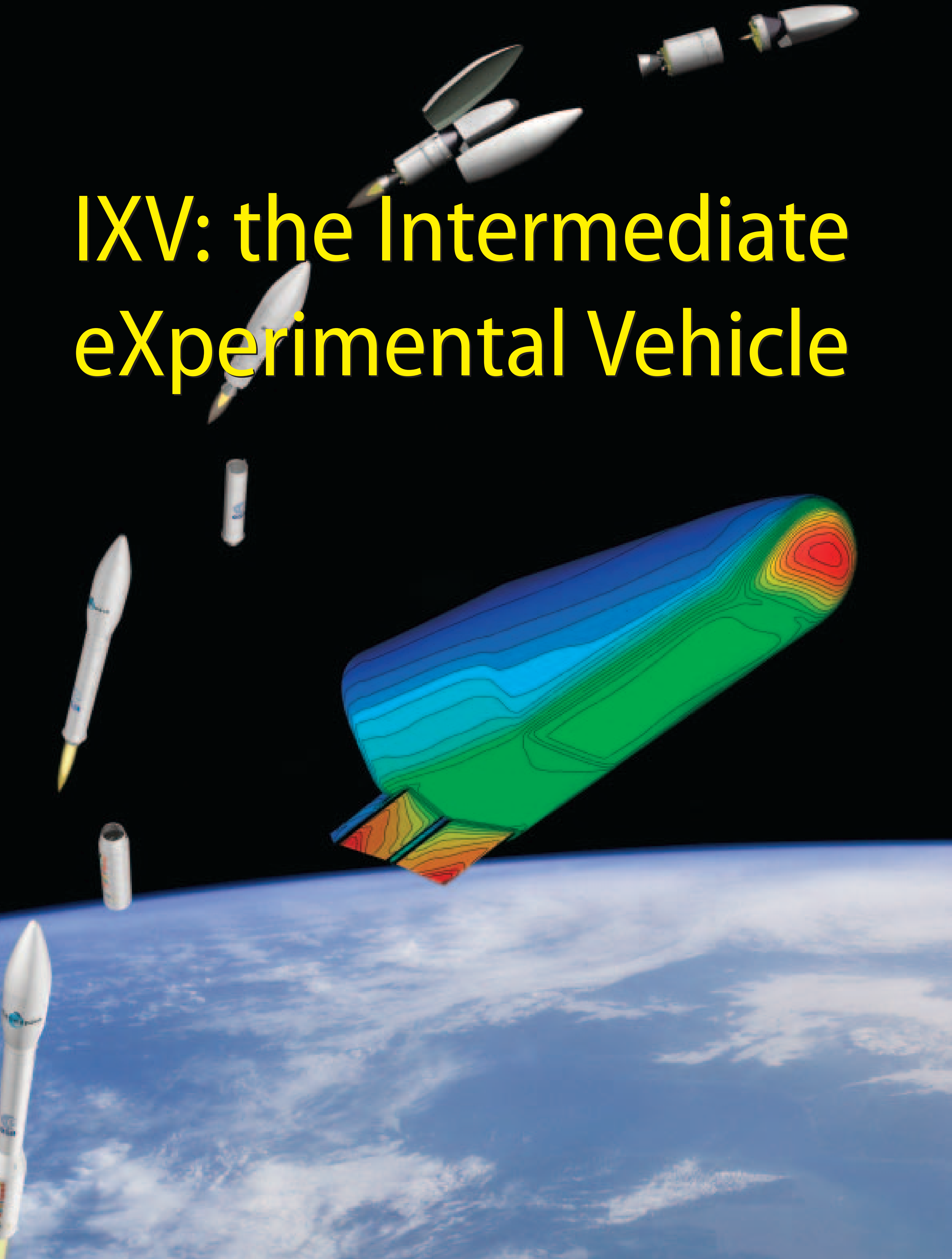
IXV: the Intermediate eXperimental Vehicle



Europe Among the World Players in Atmospheric Reentry

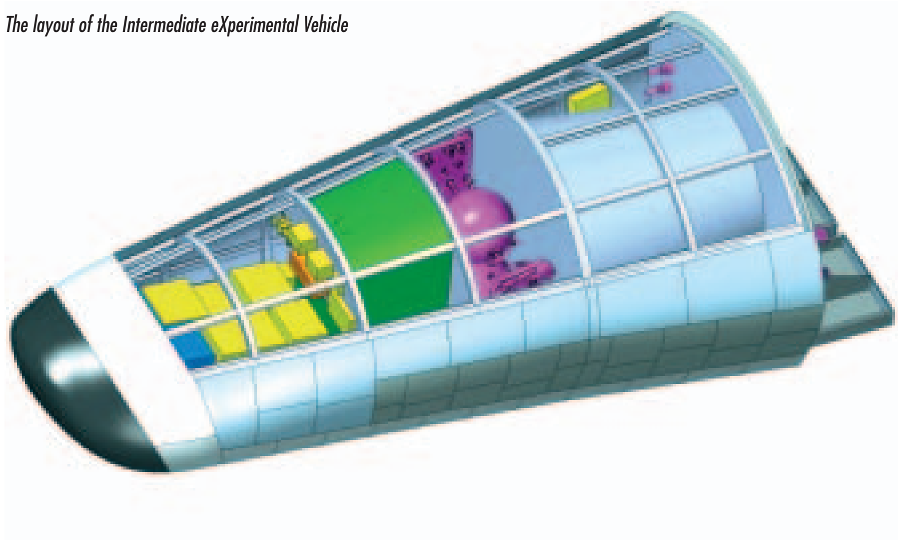
Giorgio Tumino
Future Launchers Preparatory Programme,
Directorate of Launchers, Paris, France

Yves Gerard
Next Generation Launcher Prime S.p.A., Turin,
Italy

With the objective of placing Europe among the world's space players in the strategic area of atmospheric reentry in future international transportation, exploration and scientific projects, several studies on experimental vehicle concepts and improvements of critical reentry technologies have paved the way for the flight of an experimental craft. The Intermedidate eXperimental Vehicle is building on previous achievements at the system (such as the Atmospheric Reentry Demonstrator) and technology levels, and providing a unique means of establishing Europe's autonomous position in this international field.

Introduction

Returning to Earth from orbit is still a challenge, as the loss of Space Shuttle *Columbia* tragically underlined. Braking from 7.7 km/s through the atmosphere to a safe and precise landing calls for a wide range of demanding technologies to be mastered. The number of experimental reentry vehicles studied in recent years by ESA, France, Germany and Italy underlines Europe's need for flight experience with reentry systems and technologies in order to consolidate its position among the world's space players in this strategic field. Europe must be able to play a more ambitious role in international cooperation in space transportation, exploration and scientific projects. ESA's Future Launchers Preparatory Programme (FLPP) was conceived by its Member States to provide a framework for, among other technology challenges, the development of the Intermediate eXperimental Vehicle (IXV) by 2010.



The layout of the Intermediate eXperimental Vehicle

Project Definition and Status

ESA and its industrial prime contractor Next Generation Launcher Prime SpA (I), a joint venture between Astrium (F, D) and Finmeccanica (I), assisted by ASI, CNES, DLR and ESTEC, initiated the IXV project at the beginning of 2005 by defining the mission objectives and maturing the design.

The objectives include the complete and deep identification of what experiments Europe needs in reentry technology, with an optimised plan of flight experiments that trades cost against technology maturity needs.

A thorough comparison has been performed for all the existing ESA and national concepts against shared criteria, focusing on: experiment requirements (technology and systems), programme requirements (technology readiness, development schedule and cost) and risk mitigation (design feasibility, maturity, robustness and growth potential).

The result of the trade-off has led to the selection of the slender lifting body configuration. The baseline design builds upon the extensive national (CNES/ Pre-X) and ESA (AREV: Atmospheric Reentry Experimental Vehicle) efforts.

The contractors are now working on Phase-B1 (preliminary design definition), targeting a system requirements review by mid-2007.

The Reference Mission

The IXV baseline mission is driven by using Vega as the launcher, with critical safety issues that call for Vega's stages to fall over uninhabited areas and the experimental vehicle to fly over sparsely populated regions.

The reference mission plans a launch from Kourou (French Guiana) into an orbit with a 70º inclination, followed by a landing in the North European Aerospace Test Range at Kiruna (S). The scenario is being refined (see below), and backup schemes leading to a sea landing are also being considered.

IXV will be delivered into an orbit of 180 x 307.2 km, where Vega's upper stage will fire above the Pacific Ocean off the coast of Chile to trigger reentry.

IXV will begin formal reentry 120 km above the Atlantic Ocean, at a speed of 7700 m/s and an angle of 1.19º below the horizontal. The reentry trajectory lasting around 20 minutes will be controlled by a combination of moving aerodynamic surfaces and thrusters from hypersonic speeds at 120 km altitude down to Mach 2.0, while travelling a surface distance of 7500 km. All the while, it will gather large quantities of data to verify the performance of several critical reentry technologies.

IXV will then be slowed from Mach 2 by a set of parachutes deployed by drogue 'chutes, before airbags inflate to soften the landing.

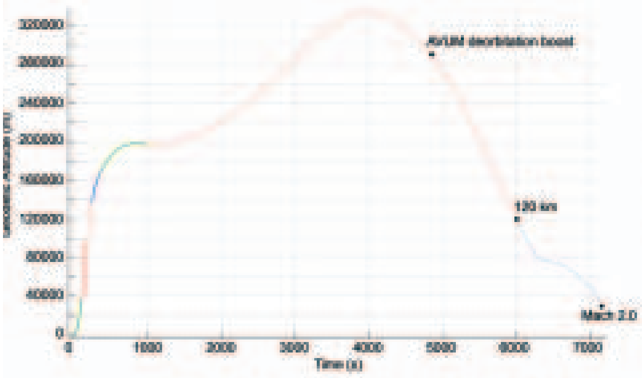
Even though the end-to-end trajectory lies principally over low-population territories, a failure during reentry has risks that need to be thoroughly identified, assessed and mitigated at an early stage in the project.

A study is therefore under way by industry as a first step in Phase-B1 to assess how the safety requirements affect the mission, with a comparison of all the feasible mission scenarios. The landing scenario and area will soon be selected by ESA with technical assistance from ASI, CNES, DLR, ESTEC and recommendations from industry.

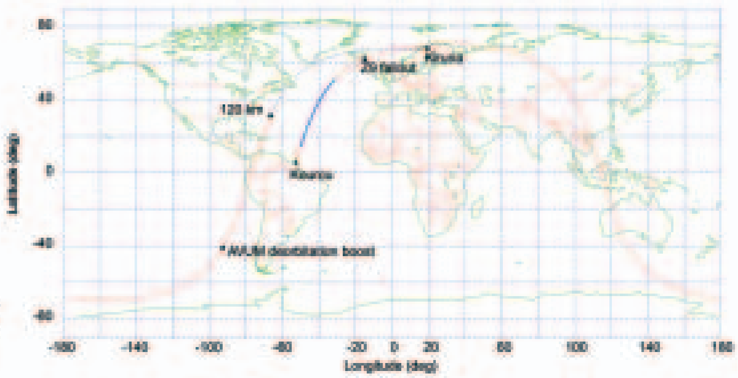
Reentry System and Technology

From experience with ambitious experimental vehicles around the world, such as NASA's series of X-vehicles, there is general consensus within Europe's space community that a step-by-step flight programme is the best approach. It limits the risks, allows stepped costs and ensures that progressively more sophisticated developments benefit from the results of relatively low-cost missions.

Since 2002, ESA has focused on an optimised long-term scheme of flight experiments. Further consolidation with industry in 2005 confirmed the Intermediate eXperimental Vehicle as the core of this effort. IXV integrates key technologies at the system level, including thermal protection and active aerodynamic control surfaces. This is a significant advance on Europe's previous flying testbeds, although the shape is not necessarily representative of



The IXV trajectory from launch to Mach 2



The current reference trajectory from Kourou to Kiruna

future operational vehicles (this explains the *Intermediate* in the name).

IXV is a lifting reentry body, with its shape resulting from the set of design requirements, including the need to maximise the internal volume for carrying experiments. The goal is to get the most out of the vehicle while guaranteeing the mass (limited by Vega's capacity) and centre-of-gravity location.

The primary objectives of the IXV project can be grouped into three categories: reentry system demonstration, technology experimentation and technology validation.

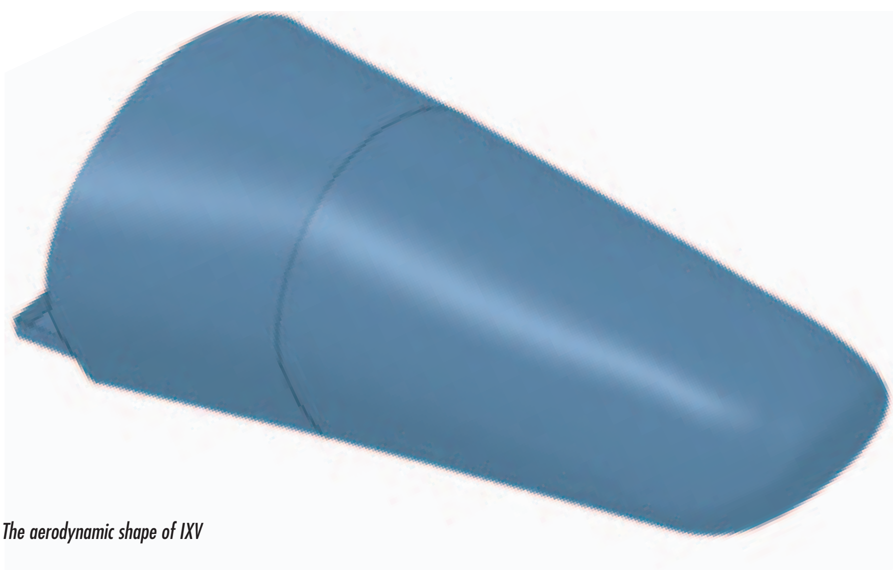
The first focuses on gaining experience in lifting and aerodynamically controlled reentry, which would be a significant advance on earlier ballistic and quasi-ballistic efforts, such as the Atmospheric Reentry Demonstrator capsule flown by ESA in 1998. Europe needs to go through the entire design loop for such a complex system, specify the entire system development phases in detail, address the manufacturing and assembly issues of critical reentry technologies, the integration of these key technologies at the system level (during the design, assembly, testing and operations), perform overall system integration and verification for a vehicle fully loaded with advanced and innovative instrumentation, and conduct the flight while ensuring the highest safety for the ground below.

The reentry technology experiments centre on verifying the performance of system-integrated advanced thermal protection and hot structures under realistic flight conditions. These include advanced ceramic and metallic assemblies, insulation, attachments, junctions and seals, as well as advanced guidance navigation and control techniques.

This verification of performance in flight builds on previous efforts and ground verification, and aims at maturing the technologies for operational space applications.

Reentry technology validation focuses on gathering representative reentry performance data in order to investigate aerothermodynamic phenomena and validate system design tools, evaluating the behaviour of air around a lifting body for atmospheric entry in the hypersonic regime (above Mach 5). The most interesting phenomena stem from the behaviour of the airflow around the vehicle, when the air molecules break apart to dissipate the high energies involved in reentry and the perfect-gas laws are no longer valid. This complex situation affects the interaction between shockwave and boundary-layer flows, the interaction between shockwaves, the transition from laminar-to-turbulent boundary-layer flows, the transitional boundary-layer separation, the heating of thermal protection materials by turbulent boundary-layer flows, the overheating owing to external cavities, the behaviour of materials' catalytic properties, the materials' oxidation, the reduction in efficiency of the control surfaces through boundary-layer flow separation, and the efficiency of the reaction control system.

The experiment objectives are being translated into the vehicle design via an



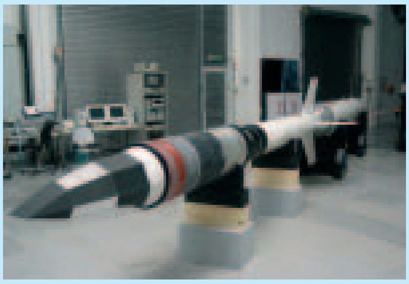
The aerodynamic shape of IXV

The IXV is Europe's next logical technology step after the successful flight of ESA's Atmospheric Reentry Demonstrator, and the important complementary national efforts in Germany on the Phoenix-1, a winged vehicle released by helicopter for autonomous runway landings, and on the Shefex-1, a sharply pointed body launched by a 2-stage rocket for testing advanced materials, and in Italy on the USV-1, a slender winged laboratory released from a balloon for transonic-to-supersonic flights.

ESA's Atmospheric Reentry Demonstrator

Phoenix-1 (EADS-ST)

Shefex-1: 'Sharp Edge Flight Experiment' (DLR)



USV-1: 'Unmanned Space Vehicle' (CIRA)

extensive flight-measurement plan that accommodates:

- important layer measurements for IXV's guidance, navigation and control system and for ground controllers to monitor the mission's progress;
- Vehicle Model Identification (VMI) measurements for post-flight reconstruction of IXV's dynamic behaviour and environment;
- IXV's mandatory core experiments on the reentry enabling technologies;
- complementary passenger experiments that are not directly necessary for mission success but will increase the technological return.

The current IXV baseline design is the result of extensive analyses, including mission and trajectories, aeroshape design optimisation, computational fluid dynamics for aerodynamics and aerothermodynamics, flying-quality assessment for longitudinal/lateral stability, trimmability and controllability of the vehicle. Additional analysis and significant testing, including thermal, mechanical and wind and plasma tunnels, are planned for the upcoming project phases to help select the final system and subsystem designs.

Complementary Passenger Experiments

In order to maximise the mission's technological return, ESA organised scientific and industrial workshops in 2005. The impressive response highlighted the wide interest in using the flight for complementary research to benefit future launchers, exploration and science. More than 50 passenger experiment proposals have been received by ESA from European industry, research centres and universities. They address innovative techniques and instrumentation for investigating aerothermodynamic phenomena, innovative materials and concepts for thermal protection and hot structures, and additional methods for guidance, navigation, control and structural health monitoring.

The proposed instrumentation includes thermocouples, heat-flux and pressure sensors, combined heat-flux, temperature and pressure sensors and/or probes, flush air data system, antennas, reflectometers, catalytic sensors, slip flow and skin friction sensors, advanced pyrometric temperature and heat-flux sensors, a miniaturised spectrometer/pressure system, an infrared thermography system, a combined Rayleigh lidar and electron beam fluorescence system, and high-resolution temperature-mapping systems.

The innovative materials and concepts proposals include actively cooled systems, ceramic nanostructures, metallic matrix composites, ultra-high-temperature ceramics, self-healing oxidation protection, high-performance insulation, secondary protection layer systems, intermetallics, aged ceramics, borosilicon carbonitride (SiBNC) polymer ceramic fibre technology, and smart thermal protection.

Suggested techniques for guidance, navigation and control include realtime GPS and/or Galileo signal tracking for accurate navigation and attitude determination during reentry, realtime trajectory control and new autonomous and highly adaptive guidance software. Proposals for structural health monitoring look at the vibro-acoustic environment and structural damping.

ESA and NGL Prime SpA are making a detailed evaluation of the compatibility between each passenger experiment and the IXV system to assess the technical and programme impacts, including feasibility, reliability, risk and cost. They are important issues because these passenger experiments would be integrated into a system baseline that is already significantly loaded with its own functional and VMI measurements and core experiments.

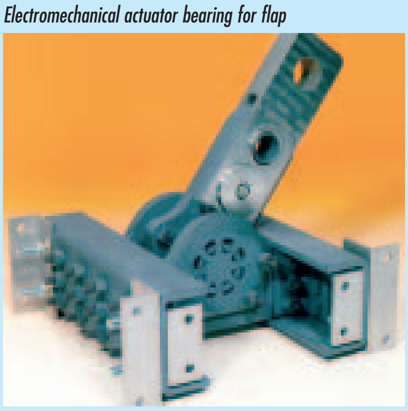
Project Schedule

The IXV project schedule runs across the different overlapping FLPP periods, with the ESA Councils at Ministerial Level as milestones for funding contribution and subscription. The

Europe has been developing advanced thermal protection systems and hot structures for space transportation systems for almost 20 years through a series of ESA and national programmes, such as Hermes, Manned Space Transportation Programme (MSTP), Future European Space Transportation Programme (FESTIP), Technology Research Programme (TRP), General Support Technology Programme (GSTP), ARD, Ausgewaehlte Systeme und Technologien fuer zukuenftige Raumtransport-Anwendungen (ASTRA), X-38/Crew Return Vehicle and FLPP-1/2.

Several thermal protection and hot-structure assemblies and components have been designed, developed, manufactured and qualified for flight. The final verification of their flight performance by IXV will provide Europe with advanced and competitive flight-proven hardware ready for future launchers, exploration and science applications.

Electromechanical actuator bearing for flap



Nosecap assembly (DLR)

Segments of a leading edge

project phasing allows the industrial work to continue smoothly.

Today's budget of about €55 million covers the completion of Phase-B, Phase-C and early phase-D, to the second quarter of 2009.

The IXV project cost-at-completion requires additional funding for completing Phase-D/E/F, including procurement of the Vega launch and post-flight evaluation of the performance. The additional funding is expected either at the next Ministerial Council, in mid-2008, and/or through additional contributions from cooperation with national and/or international agencies.

Industrial Organisation

The project is organised with well-defined levels of industrial responsibilities, reflecting the progressive restructuring of European industry for the development and exploitation of next-generation launchers. It merges the best industrial competences and ensures a single optimised overall system structure.

Under the responsibility of NGL Prime, the system activities focus on project management, planning, costing, control and system engineering. These include technology requirements, technical specifications, subsystem procurement, environments and internal/external interfaces, product assurance and safety.

NGL Prime contracts system support and subsystem design and production to level-1 companies, including Astrium (F, D) and Alcatel Alenia Space (I), and level-2 subcontracts to European industry and research organisations from ESA Member States participating in IXV. The subsystem efforts centre on structures, thermal protection and control, descent and recovery, guidance, navigation and control, power, data handling, telemetry, software, mechanisms, flap control, reaction control, ground and flight segments and flight test instrumentation.

Today's industrial team is growing to include all the required industrial and research organisations within Phase-B. This will allow a solid commitment on the schedule and cost-at-completion by the time of the Preliminary Design Review at the latest. It will also allow the industrial activities to ramp up smoothly after Phase-B.

ESA Member State Participation

IXV is supported by 11 Member States: Austria, Belgium, France, Germany, Ireland, Italy, Portugal, Spain, Sweden, Switzerland and The Netherlands. Although Europe lacks experience in developing such a complex lifting-body reentry system, the broad participation of Member States provides a large and efficient industrial organisation with all the competences to make the project a success.

National and International Cooperation

The nominal project planning and execution is done within ESA's FLPP, which is funding IXV activities up to early 2009. Although the rest of the funding is expected to be agreed upon at the next ESA Council at Ministerial Level in 2008, it is important to increase coordination and harmonisation with national programmes in order to avoid wasteful duplication and help to secure budget resources for the following IXV phases as soon as possible.

ESA is fostering cooperation with national agencies in Europe to streamline all the national activities on reentry systems and technologies towards the common IXV objectives. The Agency is evaluating the benefits and constraints stemming from project financing by multiple budgetary sources (including ESA and national), while maintaining its own coherent approach to ensure common industry policy principles for participating Member States.

ESA is also exploring cooperation opportunities with international agencies, such as in Russia, to benefit from the existing expertise in reentry systems in order to reduce experiment risks and costs, while maintaining the key objectives of Europe's technology experiments.