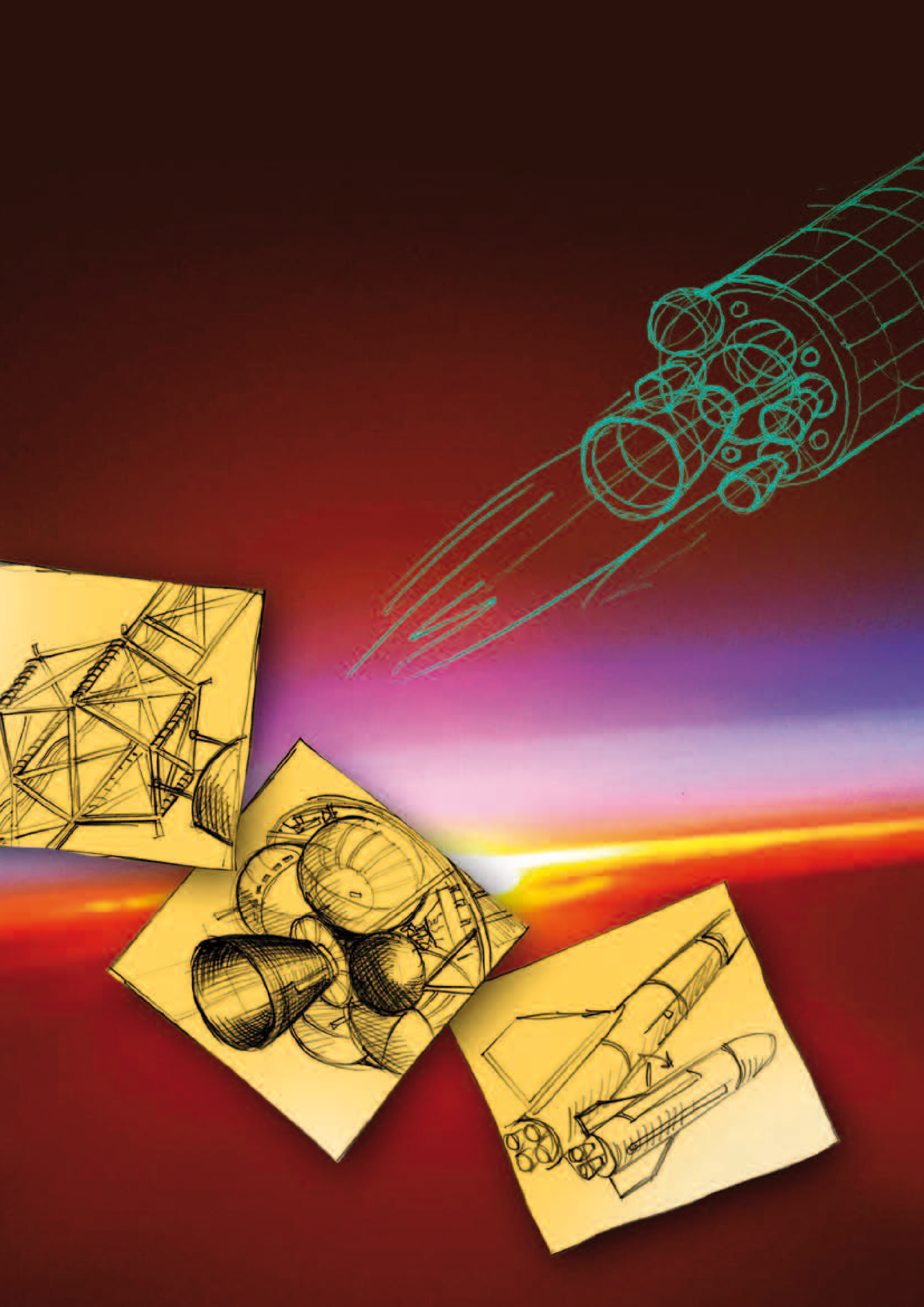


→ A TOUCHSTONE FOR SUCCESS

Core technology activity for future launchers

Guy Ramusat
Future Launchers Preparatory Programme (FLPP), Directorate of Launchers, ESA HQ, Paris, France

Whether you're going into Earth orbit, exploring distant worlds, or coming back home, the first and last few hundred kilometres of the journey are always the toughest part. The Core Technology project of ESA's Future Launcher Preparatory Programme is helping to prepare future access to space, and make it cheaper, safer and more flexible than today.

Large numbers of spacecraft manufacturers worldwide rely on the healthy and competitive European expendable launcher vehicle fleet – namely Ariane-5 and soon Soyuz and Vega – to successfully transport their various payloads into space.

However, in general, these commercial launch vehicles are based mainly on 'conventional' rocket technology. Today's expendable launchers have reached a 'plateau' in terms of technical implementation and cost per flight.

Novel technological solutions, which cope with the ever-changing environmental loading conditions from launch until to payload delivery in orbit, are required to improve performance and reduce the cost of access to space, while still keeping high reliability.

Since the beginning of the 1990s, and backed up by a long-term vision, ESA has performed several trade studies to identify and assess new and innovative approaches or concepts for advanced as well as reusable launch vehicle systems. However, these attempts have never yielded development programmes, due to the changing market requirements and funding issues.

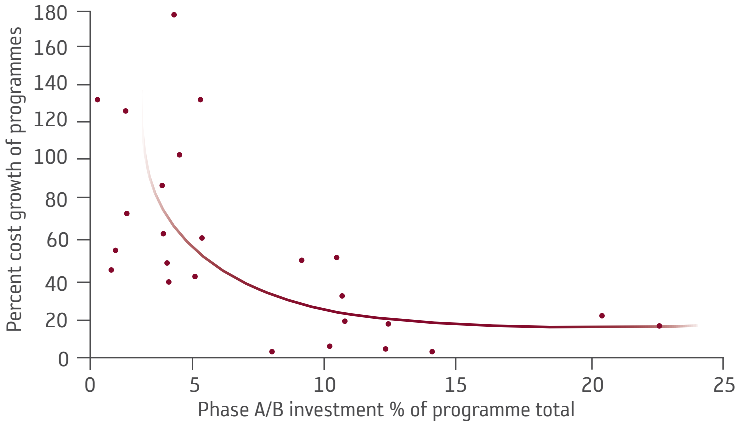
In 2004, together with several ESA Member States and European industry, ESA agreed to forge ahead with projects to assess next-generation launcher concepts, to look at European current situation and to foster future prospects in this field. The Future Launchers Preparatory Programme (FLPP) currently evaluates the development provisions required to design and build these future launchers for the most critical technologies in relation with the system studies.

Over the past 50 years, large budgets were spent worldwide on technology development programmes to dramatically increase the launch vehicle performances, to reduce costs and to provide safer and more reliable access to space. New system studies and associated technology capabilities are essential elements to support future Earth-to-orbit transportation developments, allowing the reduction of both development risk and associated costs.

Statistics based on 30 years of NASA civil space programmes argue in favour of the fact that investment spent in technology and the definition phases had actually reduced cost overruns. During those 30 years, 'no project enjoyed less than a 40% cost overrun unless it was preceded by an investment in studies and technology of at least 5 to 10% of the actual project budget', and a strong prior investment in such areas invariably tended to lower the cost overrun. Such results have also been confirmed by US military programmes.

At ESA agency level, the establishment of plans for advancing the development of critical technologies are considered as well as the introduction of technology readiness reviews for projects, in connection with System Requirement Reviews (SRRs), allowing a better identification and mitigation of technology risks. This reflects the importance of the technologies in the preparatory activities.

Representing a sizeable European investment, the general objective of the FLP Programme is to prepare these technical



↑

Prior investment invariably teads to lower cost overruns, as found in US Space programmes (W. E. Hammond - Space Transportation, A System Approach to Analysis and Design - AIAA series, 1999)

elements as well programmatic ones to make an informed decision in the future on the best operational launch vehicle system to respond to the future institutional needs, while maintaining competitiveness on the commercial market at that time.

This innovative and flexible programme has been investing in the development of industrial launcher technology capabilities in some main transatmospheric and space cargo transportation areas since 2004. How well ESA does this will be a major determining factor in Europe's effectiveness in providing for this assured access to space in the future.

Past and current European programmes developed the Ariane, Vega and Soyuz at CSG launch vehicle assets, as

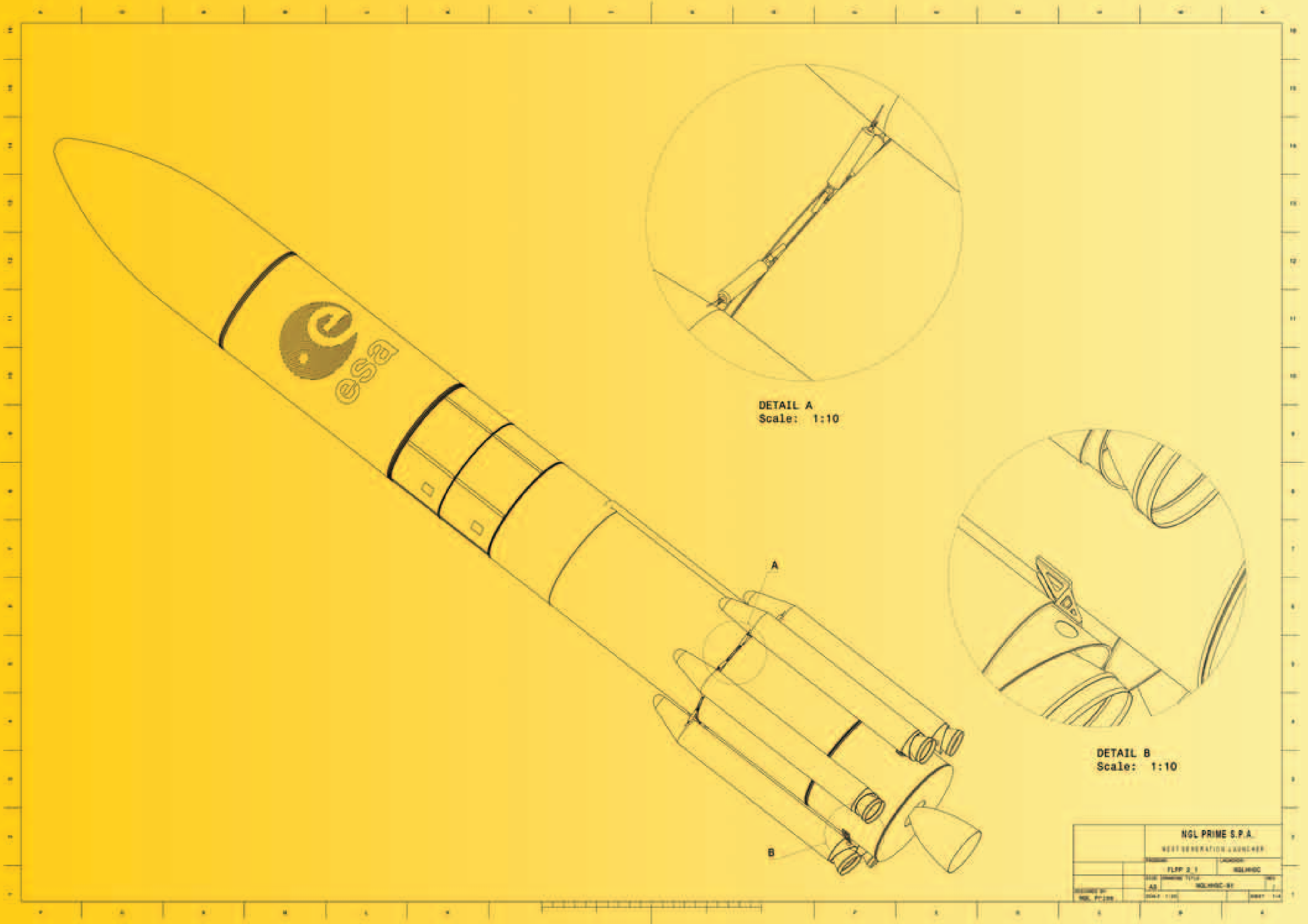
→ Industrial Policy

The FLP Programme is an ESA optional programme, where 13 Member States are participating, with a balanced subscription between the three major contributors (France, Germany and Italy). The industrial organisation, where new industrial schemes are implemented, reflects this configuration.

NGL Prime SpA, a joint venture of EADS SPACE (70%) and Finmeccanica (30%), has the responsibility, with their subcontractors, for the NGL system activities, the management of several technologies and is responsible for the overall Technology Development and Verification Plan.

The Joint Propulsion Team, a consortium of EADS Astrium Space Transportation GmbH, Avio SpA and SNECMA, is responsible, with their subcontractors, for main stage propulsion technologies and the related High-thrust Engine integrated demonstrator.

More than 60 companies, institutes or universities are involved in these activities. The programme benefits from this large industrial effort, where subcontractors can be involved early in system studies for trade-offs, and organisations not currently working on ESA-developed launchers can promote their know-how for future involvement.



esa
A
B
DETAIL A
Scale: 1:10
DETAIL B
Scale: 1:10
NGL PRIME S.P.A.
FLPP 3.1
A3

well as the required systems and industrial competencies in this field. However, to maintain these competencies, and a competitive European position, more-challenging programmes have to be put in place.

The technological know-how in all launch vehicle fields cannot be considered as something 'once gained and never lost', especially because Europe must respond to the future institutional launch vehicle requirements and be able to compete in the strong commercial market.

On the other hand, it not wise to depend on as-yet-unavailable technology to reach a fixed schedule and cost in a future launch vehicle development programme. The FLPP Core Technology project, with its various subsystem demonstrators, will demonstrate feasibility and answer the

↑

System studies on various Expendable Launch Vehicle concepts, baselines for technology activities (NGL Prime)

question for each concept: "Does the technology for a Next Generation Launcher exist, or is it within reach?"

The technology activities already carried out over FLPP Period 1 show that the technology assumptions are achievable. Whether the current FLP Programme is a success or not will depend on the follow-up applications. For instance, the technology improvement of the ceramic shield elements will support future re-entry vehicles and the FLPP Expander Engine Demonstrator activity led yet to a building block application in the post-Ariane ECA programme.

With the technical support of the ESA's European Space Technology and Research Centre (Noordwijk), as well as European national space agencies and research organisations, the FLPP Core Technology project enables ESA to capitalise on launcher technology as one of the steps to prepare for future cheaper, safer and more flexible access to space.

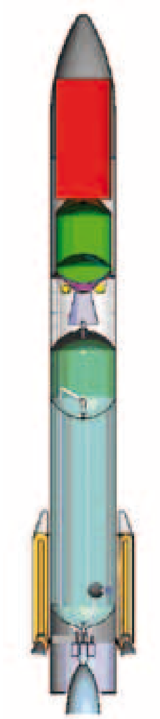
Through technology, the FLPP is also an opening for new entrants to the launchers sector. As such, the whole FLPP programme will contribute to unleashing the true potential of space to the long-term benefit of the European citizens and the industry of ESA Member States.

Snapshot of FLPP activities

The preparation of these technical and programmatic elements is based on the maturation of enabling technologies that will mitigate risks in any future space transportation system development. The Period-1 of FLPP, which was decided in 2003 and is covering the years 2004–6, was focused on system studies and technology developments for the preparation of the Reusable Launch Vehicles (RLV) for the Next Generation Launcher (NGL).

The second period of FLPP was adopted in 2005 and is now under way. The contents of this second period have been oriented towards Expendable Launch Vehicles (ELV). A first step was adopted in 2005 and Step 2 was approved at the ESA Ministerial Council in November 2008, with the objectives to continue for the preparation of the NGL for the distant future, and to contribute to the preparation of short/medium-term decisions.

The programme implements a system-driven approach, largely addressing integrated demonstrators, as the most efficient way to increase the technology readiness level and address at the same time system-level capabilities, motivating and federating industry teams and capabilities behind concrete technological end-products, from their initial definition to their manufacturing, ground/flight testing and exploitation of results. Various launch vehicle system concepts (NGL or other advanced concepts) target an initial operating capability between 2025 and 2035, depending on the type of vehicle eventually selected for development. Aside from launch vehicle system concepts



←

Cross-section view inside a typical future launcher. Several key technologies are required to develop such a high-performance launcher (NGL Prime) and configurations, the areas of liquid propulsion for main stages and upper stages, cryogenic issues for upper stages and atmospheric reentry are also being investigated in the frame of FLPP (see *Bulletin* 123, August 2005), at the levels of either technology or integrated demonstrators (e.g. the IXV for reentry technologies and the High-thrust Engine Demonstrator for main stage propulsion technologies, see *Bulletin* 128, November 2006).

Technology constituents of FLPP

Current FLPP technology demonstration activities focus on various technologies and integration methods to improve reliability and reduce design cycle time, to refine analytical techniques, to increase robustness, to provide assessments which will yield high-fidelity information early in the design process, and all in order to derive cost-effective technologies for launchers. Some of the technologies developed in this activity may find application in the short and medium terms on evolutions of the current ESA-developed launchers.

Chemical rocket propulsion technology activities represent a large part of these technology activities (see *Bulletin* 134, May 2008). Beside the propulsion activities, the FLPP Core Technology theme is structured to cover subsystems for the NGL ELVs and to a lesser extent, as part of Period 1 activities, RLVs future developments. This area of the FLPP programme is the result of a multidisciplinary approach, based on a technology logic and 'roadmap' (TDVP), and research as well as development and testing of technology demonstrations which are carried out to achieve a 'minds on' (system-driven) and 'hands on' (integrated demonstrator) maturation approach of the various enabling technologies. In addition, the programme framework assures that the technologies have maximum application owing to synergy with the other activities of FLPP. To close the loop, the concepts studied by the system rely to varying degrees on the development of technologies that are needed to mitigate architecture risk.

↑

Automatic isogrid CFPR panel construction (EADS CASA Espacio)

The FLPP Core Technology portfolio includes major challenges in the numerous technical areas relevant to launch fabrication to mastering materials, processes, design and structures, avionics, pyrotechnics, aerodynamics and aerothermodynamics issues, health monitoring, ground test facilities, etc. Part of these activities is also dealing with investigations in promising technologies at early stage of maturation that might lead to potential technical breakthroughs.

The improvements of individual technologies, as well as sub-system integrated technologies, are assessed according to the Technology Readiness Level (TRL) scale. The TRL (from 1 to 9) index ranking is set up for each product/subsystem based on various parameters, such as materials/components characterisation and availability, processes maturity, type of element, element analysis, and element verification environment.

The accomplishments

Structures, materials and processes technology

Due to the unique requirements of launch vehicles, the overall structural architecture – including tanks, structures and thermal protection – must achieve, as a design goal, the lowest mass possible compatible with the combined mechanical, thermal and fatigue loads and cost objectives. Major challenges include reducing overall structural mass, manage structural margins for robustness, containment of cryogenic hydrogen and oxygen propellants, reusable thermal protection system for RLV, etc.

Future launch vehicle requirements, for instance in upper-stage structures, will require higher structural efficiency which in turn will need investigations into new materials and new processing technologies. Emerging technologies that can significantly reduce the dry mass are studied in the programme. The leap in technology is the development of low specific mass materials and stiff structures that can withstand high stresses. This development of these advanced materials and processes must be carried out well ahead of the design phase.

Optimisation of design, using non-conventional structural concepts and investigation of characteristics associated with future in-orbit manoeuvres, will introduce improvements that can initially verified on representative vehicle structural models. These structural demonstrations will have to follow concepts and system requirements defined during the system phase of the programme.

Carbon-fibre reinforced polymer (CFRP) structures

The latest conceptual designs for reusable space transportation systems require unprecedented and very large lightweight metal and composite airframe structures.

An investigation and characterisation of a reusable bismaleimide (BMI) resin-based CFRP structure was performed in high-temperature and harsh environment conditions, using an isogrid stiffened intertank panel demonstrator manufactured with an automated facility, and a wing box type structure. Optical fibre sensors were integrated in the test demonstrators to monitor potential damage during cyclic testing. This represents a step forward towards large unpressurised lightweight CFRP structures.

The heat transfer from hot spots to the surrounding composite structure was investigated with CFRP panel combining heavy load and high temperature resistant properties.

Thermal Protection Systems (TPS) and hot structures
The reusable NGL system concepts studies and IXV development have spurred technology activities related to structures used in harsh environment. These activities were carried out in order to validate dedicated critical ceramic and metallic TPS architectures as well as ceramic matrix composites (CMC) hot structures. Vehicle trajectory peak heat flux and dynamic pressure dictate the TPS shingle outer surface material. Heat loading decides the thickness of the insulation material stack. Before being applied to future operational developments, these subsystems were defined through computational fluid dynamics (CFD) methods, plasma wind-tunnel tests and in-flight experimentations. The demonstrator structural integrity verifications are benefiting from the existing European high-temperature mechanical testing chambers and plasma flow facilities.

A variety of reusable TPS concepts are being developed and verified in this programme, addressing the requirements of future hypersonic vehicles. Selection of the optimum TPS for a particular vehicle is a complex and challenging task that requires consideration of not only mass, but also operability, aerodynamic shape preservation, maintenance with rapid turnaround capabilities, durability, initial cost, life-cycle cost, and integration with the vehicle structures, including cryogenic propellant tanks.

> **“Does the technology for a Next Generation Launcher exist, or is it within reach?”**

Based on a European heritage, three main families of ‘passive’ TPS are generally considered to achieve the required goals of future operational lift/drag efficient orbit-to-Earth reusable hypersonic vehicles, namely: metallic panels, rigid CMC shingles and flexible ceramic blankets.

Reusable launch vehicles also require highly loaded structural components, exposed to medium to high heat fluxes. Examples of these components are nose caps, leading edges of wings, body-flaps, ailerons, flaps and rudders.

Cryogenic upper-stage activities
The activity concerning the cryogenic upper-stage technologies is part of the system-driven technology development approach implemented within the FLPP. This approach ensures consistency at launcher system level between: (i) launcher system concept definition and selection activities and (ii) several lines of launcher technology developments in propulsion, materials and structures, and upper-stage cryotechnologies carried out under separate activities and performed in parallel by different industrial teams.

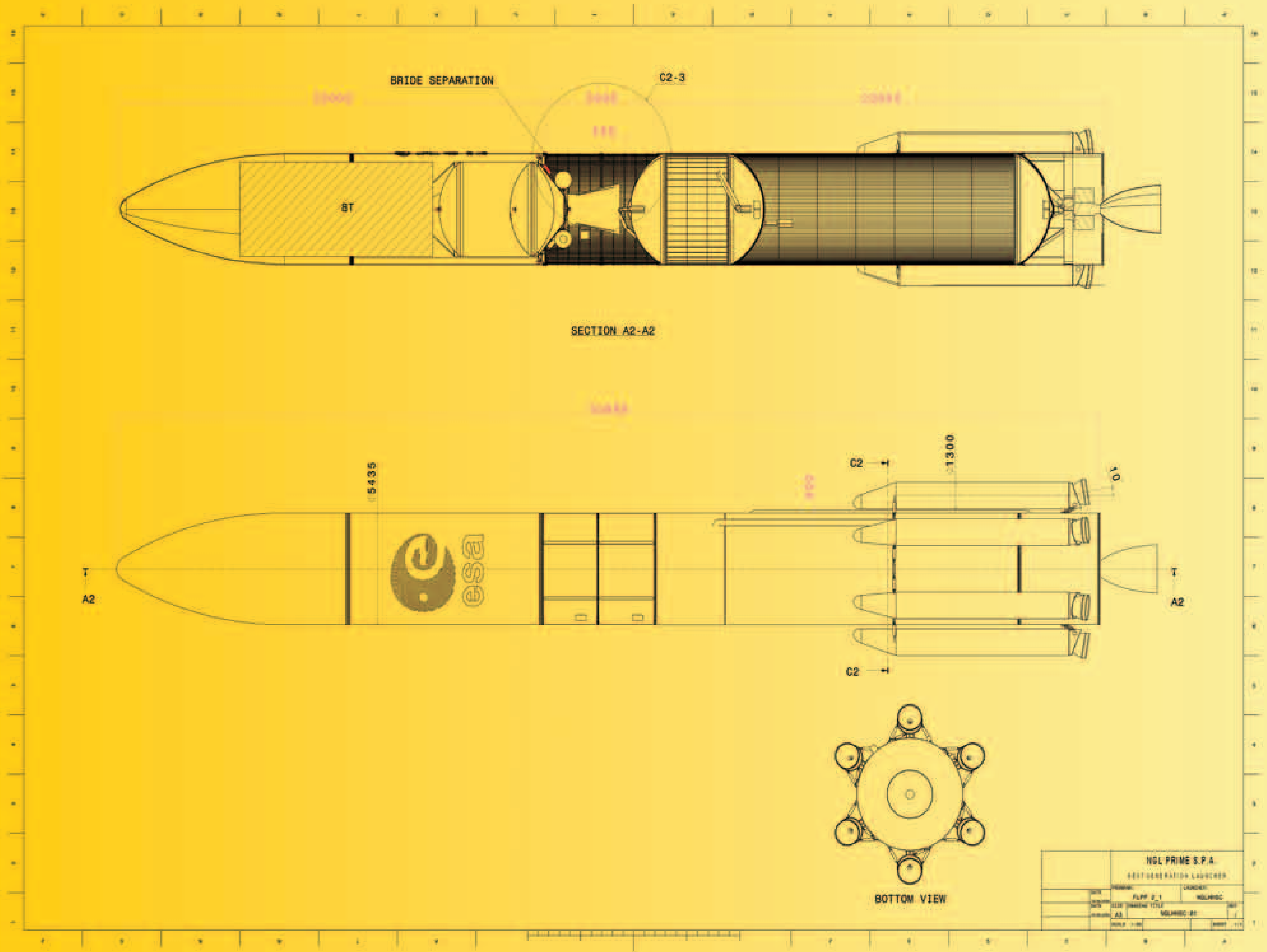
The activity identifies and develops critical technologies, enabling versatile missions and improving the performances of a reignitable cryogenic upper stage. The cryotechnology

→ We are not alone!

One of the main roles of ESA is to consolidate space activities in Europe, drawing on all expertise of the Member States to realise a common vision. This is done by coordinating the technical activities of Member States’ national agencies, technical centres and research institutions, and by optimising and distributing work approved at Programme Board level.

ESA strengthens the levels of technical competences by avoiding duplication, by managing investments in a cooperative way and at the same time bearing down on industrial activity cost.

In applying this scheme, the FLPP Core Technology project also relies on the support, for example, of Italian space agency’s technical centre CIRA, the French centres at CNES Evry and Toulouse and German DLR centres.


BRIDE SEPARATION
C2-3
8T
SECTION A2-A2
5435
1300
10
C2
C2
A2
A2
esa
BOTTOM VIEW
NGL PRIME S.P.A.

FLPP covers the whole range of advanced technologies involved in launcher design: structures, pyrotechnics, propellant, reentry aerodynamics, for example.

project is organised in three parts: (i) activity dedicated to critical technologies selection, (ii) activity targeting the technology development to reach TRL5/6, and (iii) in-flight demonstration of gravity-dependent technologies.

On the other hand, the inert mass of an upper stage has a direct impact on launch vehicle performance. To maximise the payload mass, the upper stage must use lightweight structural concepts to improve the mass fraction of the stage. Therefore, it is critical that tailored and appropriate criteria and margins are used. For that reason, this technology activity is designed to demonstrate, through analysis and ground demonstrations, that system level and technology improvements of an advanced material tank wall system and innovative upper-stage primary structure and mechanisms can lead to mass decrease, cost efficiency and robustness, improved margins and operational flexibility of a reignitable expendable upper stage.

Avionics/health monitoring
Advanced avionics architecture will be required for all future launcher applications, providing the processing capability for the mission and launch vehicle management, health management, guidance, navigation, and control functions.

Ariane 5 has a well-known avionics system. But new requirements or obsolescence will lead to the definition of new computer/avionics architectures, and to the development of new flight application software. The main critical avionics technologies are the digital architecture for on-board computers with their associated software, and data buses (including optical fibre support) to provide high data rates, as well as health monitoring. To take into account all these needs and cover all missions envisaged today (especially reentries), these new architectures should be as modular and scalable as possible, in particular for redundancy.

The activity consists in consolidating a technology roadmap, preparing associated means and defining further development work necessary to bring these technologies to an operational qualification level.

Pyrotechnics
This FLPP technology activity initiates investigations to develop innovative techniques using pyrotechnic subsystems in term of concepts, manufacturing and integration of key functions (such as engines and large rocket motor ignition, ground-to-launcher, stage-to-stage and launcher-to-payload separation systems, release functions and launcher neutralisation and safety), as well as a momentum and maturation of these techniques for applications outside the space industry (in cars or aircraft, for example).

The innovative pyrotechnics subsystems for future launchers will be based on two types: ‘electro-pyrotechnics’ and ‘opto-pyrotechnics’. Improvements of conventional pyrotechnics based on electro-pyrotechnics draw on the accomplishments and wide experience gained so far in Europe; these devices have been used on European launchers since Ariane 1 and have been proved reliable and safe with use through to Ariane 5. Such pyrotechnics have been taken up for the Vega launcher. However, to be competitive, electro-pyrotechnic subsystems and devices must be upgraded to meet future needs in terms of size, cost and environmental regulations.

Opto-pyrotechnics is a technology currently being evaluated worldwide as one of the key subsystems for the evolution of current launchers and future developments. These devices have the following advantages: reduced mass, recurring cost reduction (at both system and pyro-subsystem levels), improvements at Reliability, Availability, Maintainability, Safety level by the removal of primary explosives from the system, simplification of operations prior to launch, increase of safety, and immunity to electromagnetic interference and electrostatic discharge.

Densified propellants
Furthering European knowledge in slush hydrogen technologies, there is activity in assessing the feasibility and advantages of this type of propellant into the NGL concepts.

The advantages are due to the higher density and heat capacity that can be achieved by adding a solid fraction to liquid hydrogen. However this mixture presents a number of issues that still need to be resolved to make it a practical potential propellant for future space transportation.

The activity performed under FLPP is based on a promising 'snow-gun' preparation method, demonstrated at laboratory scale. The proposed work will be dedicated to the topics dealing with improvement of slush hydrogen production facilities measurement devices development, characterisation of stored slush (i.e. particles size over time, particle settling velocity), slush transfer (i.e. expulsion from tanks, flow through pipes and valves), long-term storage issues. The Critical Design Review of the pilot plant took place recently.

Parallel system studies were conducted to assess launch vehicle concepts based on combinations of densified propellants. Based on concurrent engineering activities, these preliminary investigations provided positive results; the use of densified propellants in existing launchers may give a payload mass increase between 2% and 10%, depending on the densification level, the application stage and the target orbit. Application to upper stages is easier (less propellant mass, less launcher modifications) and more effective (the structural mass fraction role is more important). The advantages and drawbacks related to the use of slush into propulsion systems have still to be evaluated further.

Aerodynamics

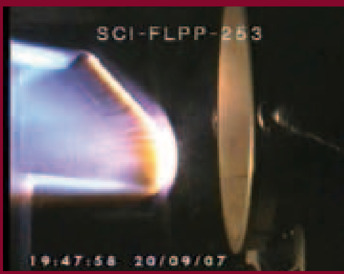
Preparation of future technologies is not only limited to on-board systems, but also covers methods for the design and analysis of the launcher itself. Aerodynamic analysis of any trans-atmospheric vehicle requires a database with both static and dynamic derivatives. However, conventional wind tunnel facilities cannot duplicate flight conditions for: (i) the hypersonic regime as the state of the flow field upstream of the model is not representative, the gas is partially dissociated when reaching the test section, or (ii) lower Mach numbers, where the aerodynamic coefficients are affected by the structure of the flow field in the wake.

The presence of a string holding the model disturbs the duplication of wake flow phenomena, which govern the stability behaviour. An advanced method to generate these coefficients is being investigated, based on an experimental method of free-flight stability assessment of vehicles where the model is moving into ambient gas at rest. The model can move freely around all axes, under correct influence of forces and damping. In addition, information on the detailed flow structure can be obtained (e.g. shock impingement and control surfaces).

Up to now this test method has been used for ballistic bodies, providing direct contributions to the aerodynamic database and also valuable data for code calibration. Of particular relevance are the studies of unsteady base flows as well as buffeting phenomena for the aft sections of launchers, the studies of separation events and of deployments. ■

↘

Test for IXV heatshield element in the Scirocco facility



→ Plasma wind tunnels for reentry simulation

One of the most critical aspects of a space mission is the 'reentry', the return of a vehicle from orbit into Earth's atmosphere. This hypersonic flight regime can be simulated with a wide range of ground-test facilities that duplicate aspects of atmospheric entry, such as total enthalpy and stagnation pressure for high altitudes.

- Inductive Plasma Wind Tunnel, or 'Plasmatron' (VKI, Belgium)

Unpolluted plasma flows of any gas can be produced by inductive heating. This facility uses a high-frequency generator and torch to generate a plasma flow, and is mainly devoted to the testing of specimens of TPS materials to be used in the manufacture of shingles of the FLPP CMC TPS demonstrator.

- Scirocco Plasma Wind Tunnel Facility (CIRA, Italy)

This facility consists of an arc-heated gas generator and an expansion nozzle exhausting in a vacuum chamber. Air is injected from an upstream reservoir in the gas generator and heated as it flows through a constricted section by the electric arc established between the cylindrical cathode and the annular anode before expanding in the nozzle. The FLPP CMC TPS demonstrator was tested in this facility.