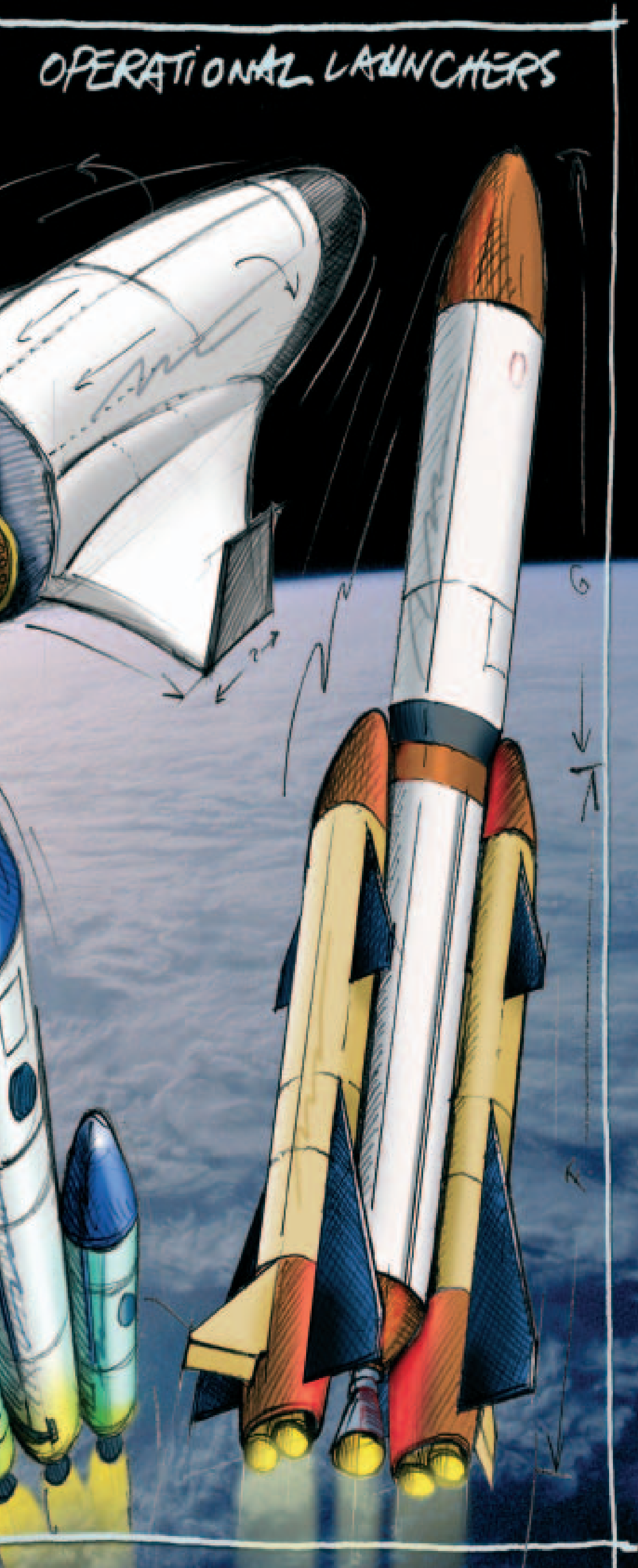
The Road to the Next-Generation European Launcher

– An overview of the FLPP

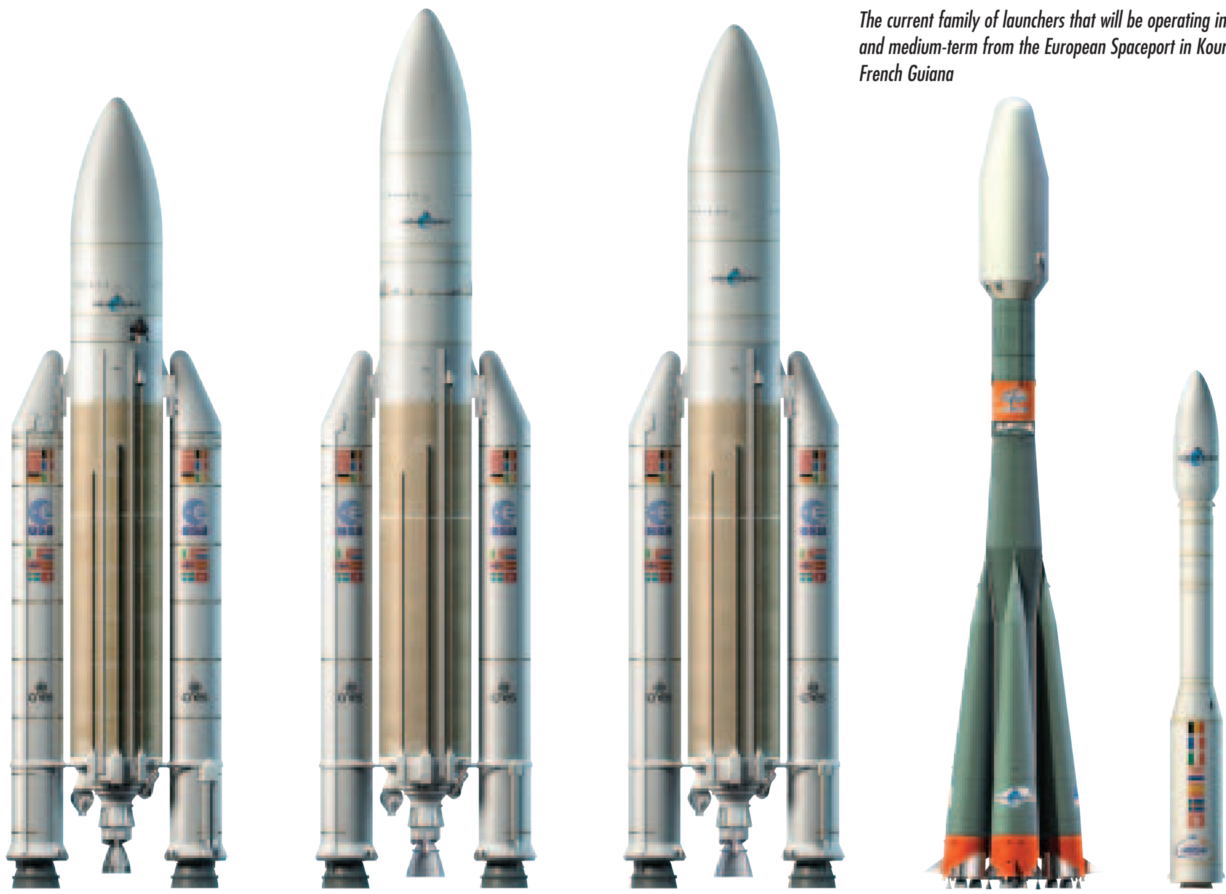


Jürgen Ackermann, Jérôme Breteau,
Jens Kauffmann, Guy Ramusat
& Giorgio Tumino
Future Launchers Preparatory Programme,
Directorate of Launchers, ESA, Paris

The Future Launchers Preparatory Programme (FLPP) was approved by the last ESA Ministerial Council and began in February 2004, ending a long period without a programme dedicated to future launchers at the European level. The aim is to prepare the Next Generation Launcher to be operational around 2020. System studies and technology activities therefore need to be conducted, including ground and in-flight tests, to foster new technologies capable of providing high performance and reliability, together with low life-cycle costs. The final choice between an expendable or reusable type of launch vehicle will be made on the basis of proven technological readiness and consolidated cost and risk assessments.

Programmatics

The Agency's Future Launchers Preparatory Programme was initiated in February 2004 with the aim of preparing for the development of Europe's Next-Generation Launcher (NGL). The FLPP is designed to strengthen European industry's innovative technology competences and foster progress in the launcher field in order to safeguard Europe's guaranteed access to space in the longer term. The choice for the best Earth-to-orbit launch system architecture is essentially between an advanced expendable launcher and a fully or partially reusable vehicle. The final decision will be made on the basis of competitive launch cost and market requirements, such as expected commercial payloads and the European institutional mission needs stemming, for



The current family of launchers that will be operating in the near- and medium-term from the European Spaceport in Kourou, French Guiana

Ariane-5 G **Ariane-5 ECA** **Ariane-5 ES** **Soyuz** **Vega**

instance, from the new ESA space exploration programme and the implementation of European Union policy concerning environment, security and defence.

It is essential for Europe to retain its autonomous, affordable and competitive access to space both now and in the future. The near-term needs are covered by the European launcher workhorse Ariane-5, to be complemented in the near future by the Vega small launch vehicle and operation of the Russian Soyuz launcher also from Kourou. Looking further ahead, however, Europe must already begin to prepare the programmatic and technical ground in order to be able to undertake the development of an NGL a decade from now.

Among the various solutions promising affordable access to space, Reusable Launch Vehicles (RLVs) offer the potential for major cost reductions well beyond those provided by on-going improvements to Expendable Launch Vehicles (ELVs). Before being able to make a sound choice between an ELV and an RLV for the Next Generation Launcher, a number of critical reusability-related technologies need to be developed and demonstrated, as well as acquiring RLV system-level expertise. Before finally deciding on the NGL's development, there is a need for sufficient maturity of system and technology competencies to assess the associated costs and risks.

Industrial Policy

It was decided at the outset to grant all NGL-related activities within FLPP to an industrial prime contractor, and EADS and Finmeccanica have therefore created a new company, provisionally called 'NGL Prime Co'.

The industrial work at system and technology level began at the end of 2004, with a comprehensive road map of activities that will provide, step by step, the results needed for the decision on the NGL to be taken at the end of the decade.

The industrial activities in 2005 encompass RLV system concept studies together with the preparation of on-ground demonstrations for various structure and propulsion subsystems, as well as the progressive implementation of in-flight demonstrations with testbeds and experimental vehicles.

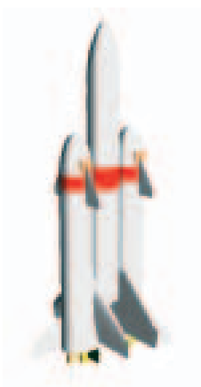
In its first two years, the FLPP programme is concentrating on assessing the attractiveness of reusability from the launcher affordability and robustness standpoints. Decisive progress has to be made, however, with respect to current technology to achieve a robust, low-cost, reusable system. The system requirements, overall development logic and technological demonstrations required to design and build such a demanding vehicle are going to be assessed, focusing on the most critical areas, like propulsion, materials and structures, aerothermodynamics, vehicle health management and avionics. These new technologies will be able to foster new system concepts. In addition, Europe plans to develop and operate hypersonic experimental vehicles for flight demonstrations, when deemed necessary to overcome technology barriers, study critical flight phases and assess reusability.

A cornerstone of the European launchers strategy is optimum use of available resources. Therefore on the one hand a harmonisation of all European activities for future launchers has been initiated, and on the other the FLPP will permit the progressive restructuring of the European industrial landscape in preparation for a future cost-effective NGL development and exploitation programme. From the start, a number of cooperative activities in the RLV field have been identified, not least with Russia.

System Studies

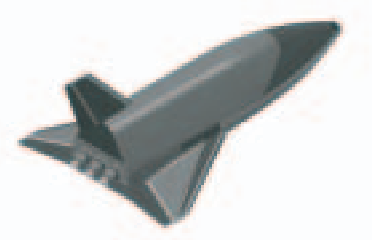
There is already a solid base of experience and technology in Europe for the design of ELVs, which is being exploited to establish the system-level capabilities needed to assess the risks inherent in developing and operating RLVs. One of the main goals of the FLPP studies is to assess the attractiveness of launcher reusability by comparing the economic features of the best RLV options accessible for Europe with the possible ELV solutions on the basis of comparable Technology Readiness Level (TRL).

The system work will have to accomplish multiple objectives. RLV system design concepts will be developed to allow quantification of performance, flexibility of operations, reliability, cost and safety. On the basis of these concepts, a number of system-level trade-offs dealing with such aspects as propellant combinations, stage arrangements, launch modes and return-flight options will be performed. A further task will be to elaborate guidelines and well-quantified objectives for the RLV technology developments in order to be able to monitor their coherence and feed the results into the vehicle concept studies. The objectives for the in-flight and on-ground experiments and demonstrations will also be derived from the system needs. At a later stage, i.e. during FLPP Period-2, system studies of expendable NGL concepts will be started, leading to a thorough trade-off between the ELV and RLV concepts. This important decision will be largely based on the final mission specification, but will also rely on the results of critical-technology validation tests.



LFBB concept (Courtesy of DLR)

FLPP Period-1 is characterised by a focused approach, aiming at the selection of one preferred RLV concept for each of two preliminary 'reference missions'. The availability of results from a number of previous national and European RLV studies, such as ESA's Future European Space Transportation Investigation Programme (FESTIP, 1995-1998), allow FLPP to focus just on what are seen as the currently most promising concepts, namely:



Sub-orbital concept (Courtesy of DLR)

- semi-reusable concepts using a Liquid Fly-Back Booster (LFBB) or Reusable First Stage (RFS)
- sub-orbital concepts
- fully reusable Two Stage To Orbit (TSTO) concepts.

Considerable experience in the analysis of these options already exists in Europe. Aside from FESTIP, other studies have been performed in recent years in France (e.g. SYS RLV) and Germany (e.g. ASTRA) on concepts belonging to these categories and their results will also be exploited in the FLPP system activities. The semi-reusable RLV concepts are an attractive area for potential cooperation with Russia, where joint activities on the analysis of reusable liquid stages will be considered.

Single Stage To Orbit (SSTO) concepts and air-breathing ascent propulsion systems (e.g. Scramjet) will not be addressed as they do not meet the technology-maturity requirements.

In-flight Experimentation

For any RLV development effort, in-flight

TSTO concept (Courtesy of CNES)

The European Heritage Regarding RLVs

Several system studies were conducted during the 1980s to investigate possible concepts for a European RLV, both at ESA level (FLS, WLC, RRL, FESTIP, as well as the Hermes Programme which included some RLV-related technologies and facilities) and at national level (Hotol, Sanger, Taranis, Star-H, WLC, STS 2000, FLS and RRL).

In 1998, ESA flew the Atmospheric Re-entry Demonstrator (ARD) capsule, which provided valuable information on atmospheric re-entry.

The Agency's Future Launchers Technologies Programme (FLTP) was approved in 1999 with the objectives of confirming the interest of launcher reusability under realistic assumptions, and of identifying, developing and validating the required technologies. The unbalanced participation in the programme by Member States and the consequent problems with implementing procedures resulted in the FLTP being put on hold.

Several programmes were, however, set up in Europe, both at national level (e.g. Astra, Prora and Prepha, as well as vehicle concept studies like Boomerang, Astral, USV and Everest) and ESA level (X-38/CRV), to foster the development of some of the technologies required for future reusable space transportation systems.

Moreover, some specific RLV technologies are still being developed within the ESA Technology Research Programme (TRP) and General Support Technology Programme (GSTP).

experimentation is indispensable both for validating system and technology performance models, as well as for gathering the first operational experience. Past experience with experimental vehicles shows that a step-by-step flight-demonstration approach allows one to limit the risks with a progressive investment effort, especially for the most technically challenging developments.

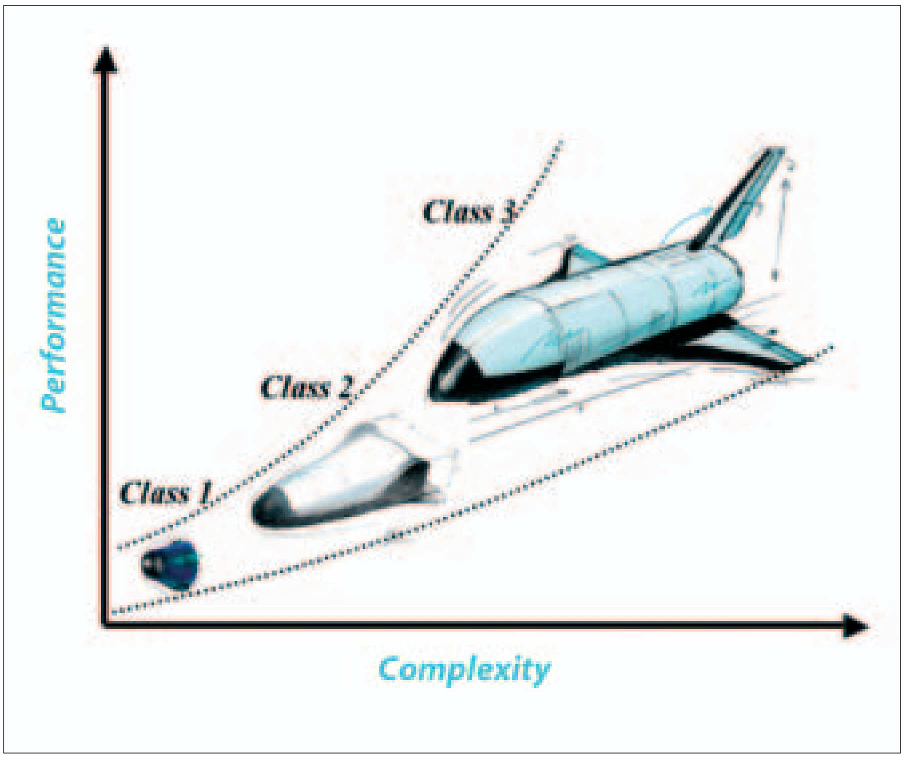
The various European studies and projects conducted to date involving in-flight experimentation have been evaluated in the frame of an ESA 'harmonisation' study, resulting in the identification of three distinct in-flight experimentation levels, or classes of vehicles:

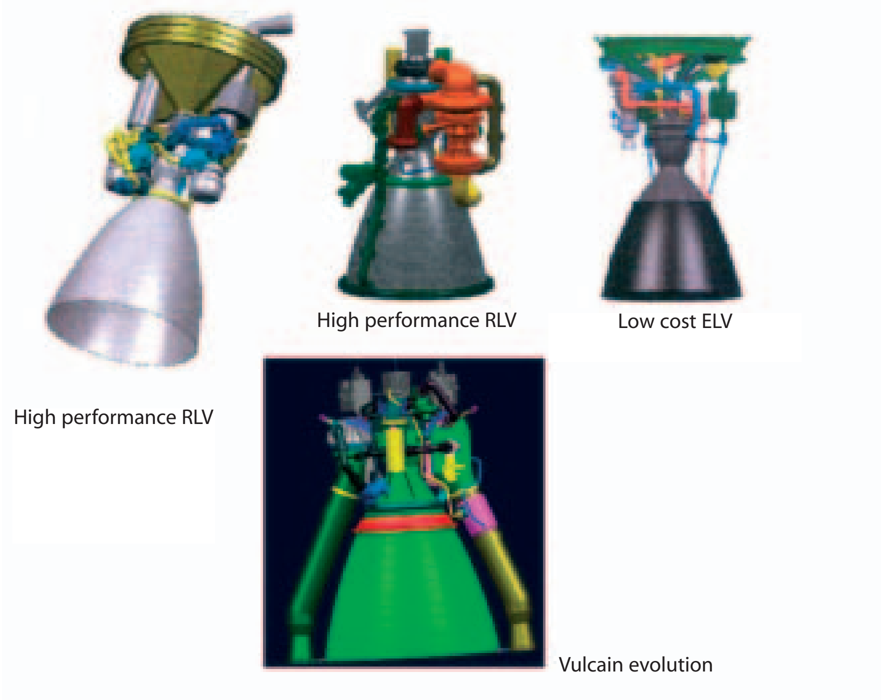
Class-1: *'Flying Test Beds'*, focusing on design-tool validation and dedicated to a single discipline, and thus not concept or system representative.

Class-2: 'Intermediate Experimental Vehicles', focusing on the integration at system level of key technologies, such as vehicle thermal-protection and health-management system components and flight controllability by means of aerodynamic control surfaces.

Class-3: 'Experimental Vehicles', aiming at validation of a combination of technologies and system-design capabilities, such as shape representativeness, fully integrated thermal-protection systems, guidance, navigation and control, vehicle health-management systems, reusability and operations.

An approach taking into account these three classes of vehicles has been adopted for the FLPP in order to reduce the development risks. Considering the existing planned development schedule for a series of Class-1 type vehicles (e.g. EXPERT, PHOENIX-1, etc.), it was deemed appropriate for FLPP to focus on Class-2 and Class-3 and so the industrial system team has been tasked in Period-1 to:
- define an optimised long-term in-flight experimentation strategy
- select the most promising Class-2 Intermediate Experimental Vehicle (IXV) and perform a consolidation





Concepts for potential engines for Reusable or Expendable Launch Vehicles (Courtesy of SNECMA Moteurs)

(Phase-A type) study of the proposed concept as part of the short-term in-flight experimentation strategy
– identify promising Class-3 vehicle concepts, such as Reuse-X, reflecting on among other things specific propulsion system requirements.

The concepts selected will be further investigated during the second part of FLPP Period-1.

Bringing together the ESA programme and currently running national initiatives is clearly the best means of ensuring that in-flight experimentation really takes place in Europe and that a true technological return on the investments made is created for Member States. Given Russia's considerable experience in this field, its cooperation will also be considered with a view to reducing demonstration risks and the associated costs.

Propulsion

The main propulsion system's technical complexity and interaction with the overall performance and operational capabilities of an ELV or RLV gives propulsion a key role in launcher development and makes its operational implementation a major challenge. Today, operational experience with RLV rocket engines is still rather limited. The US Space Shuttle and the Russian Energia/Buran vehicles rely on the only flight-proven reusable (or robust) rocket engines, and their experiences have shown how technically demanding the reusability requirement really is. This is why the initiation of development in Europe of high-performance reusable rocket engines is an ambitious challenge that will have to be carefully responded to within FLPP. Success within the schedule foreseen will rely on existing European industrial and national-agency know-how and the fact that the key players of the European propulsion industry are members of the NGL Joint Propulsion Team defining the future engines.

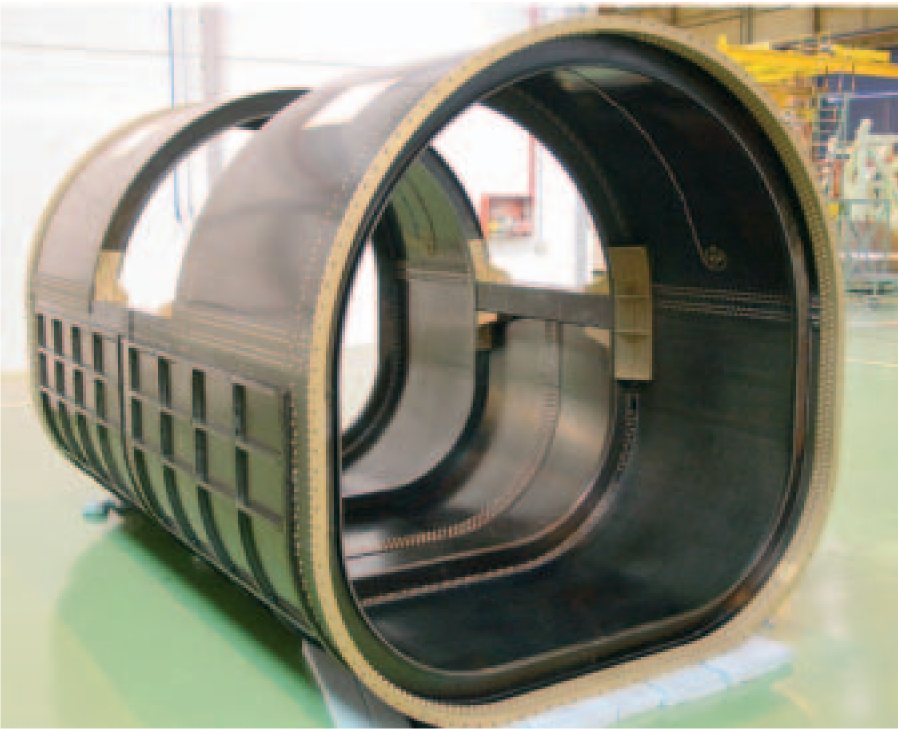
Basically, the propulsion activities in FLPP Period-1 include two parallel and interdependent sets of system and technology activities aiming at achieving appropriate technology-readiness levels for identified critical technologies. At system level, the studies and tradeoffs on propulsion cycles and architectures (gas generator, staged combustion, full-flow staged combustion), high-performance propellants (LOx-LH_2 and hydrocarbons), and requirements definition and design-method elaboration are being closely coordinated with the parallel launcher system studies. At technology level, activities on already identified critical technologies are in progress for major components such as turbo pumps, valves, health-monitoring systems, nozzles, thrust chambers and pre-burners. All of these activities involve representative testing at technology, component or subsystem level. A set of activities designed to improve solid-propulsion cost efficiency and combustion characteristics is also included in FLPP Period-1.

During FLPP Period-2, the technology-demonstration activities will be continued with increasingly representative scales of hardware. All key engine technologies will be test-proven with component and/or engine-level demonstrators before the final development decision for the Next Generation Launcher is taken.

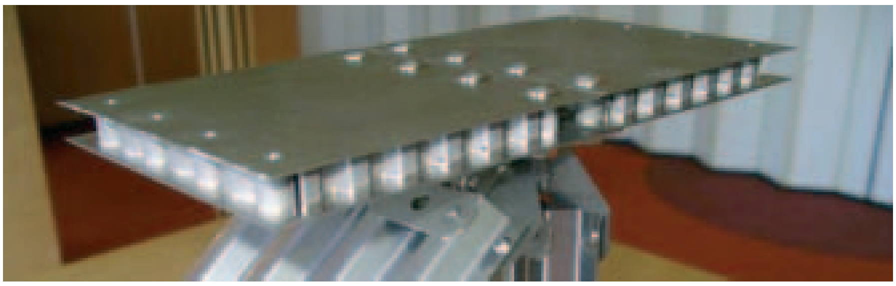
Risk management is a cornerstone of the FLPP propulsion activities due to the close interaction of the system-design activities with the convergence process at the propulsion system and technology levels.

Materials and Structures

A technology-development effort on structures and materials is included in the FLPP themes to distil a burgeoning array of advanced structural concepts down to those that are close enough to maturity for application in fully or partially reusable launch vehicles and should provide the best performance at an affordable cost. Major challenges include reducing overall structural mass, increasing structural margins for robustness, reusable containment of cryogenic hydrogen and oxygen propellants, reusable thermal-protection system, significantly reducing operational costs for inspection and re-validation of structures and sustainability, all of which must be addressed in close cooperation with the other themes of the programme.



CFRP intertank subscale demonstrator structure for a future reusable launcher, including an embedded fibre-optic health monitoring system (Courtesy EADS-CASA and Contraves Space)



Reusable rudder metallic structure building-block element (Courtesy of Dutch Space)

To be economically viable, the stages of an RLV must be able to withstand repeatedly the harsh environmental conditions encountered during all phases of the mission. All elements contributing to the dry mass of the vehicle (e.g. primary structures, engines, tanks, thermal-protection systems, etc.) must be cost effective and as light as possible in order to give each stage the structural index compatible with high robustness.

Improving the performance and reducing the cost of RLV primary structures largely relies on identifying and developing innovative reusable structural concepts and architectures, adequate advanced materials and manufacturing processes, and refined analytical techniques allowing reduced vehicle dry mass together with low operating costs. The various structural subsystems of a typical RLV will be subjected to complex loadings and temperature conditions, leading to severe thermo-mechanical gradients. The structures that carry loads from one part of the launcher to another must have good reliability, availability and maintainability and require as little maintenance, repair and overhaul as possible, which can partly be achieved through the use of 'structural health monitoring systems'. One approach is to use CFRP structures with fibre-optic sensors embedded at critical locations within the matrix and other innovative sensors attached to the structure's surface.

Propellant tanks form a large part of the vehicle's structure and dominate the airframe design effort, influencing as a consequence the aerodynamic and thermal aspects of the vehicle's configuration. The design and manufacture of large reusable cryogenic propellant tanks are very complex, be they metallic or composite structures. The fact that RLVs ascend into orbit full of cryogenic propellant and return with almost empty tanks presents particular thermal and structural challenges. Mastering the fabrication of reusable, high-volumetric-efficiency, cryogenic propellant tanks is therefore one of the key technologies for RLV development.

The FLPP will also address the development of an advanced, reusable thermal-protection system and load-carrying hot-structure subsystems. These will both protect the vehicle airframe from the thermal loads imposed by the high temperatures reached and the harsh environments encountered at several points during ascent and re-entry, and contribute to its external aerodynamic shape. The programme will begin to overcome the hurdles of developing reusable metallic and ceramic structures dedicated to large-area applications at elevated temperature. The thermal protection must not only be lightweight and cost-effective, but also durable, involving minimum maintenance or repair.

Conclusion

The Future Launchers Preparatory Programme will leverage existing European technology investments in the field of reusable concepts based on the large efforts made over the last 15 years with funding from ESA and national agencies. The challenge in the FLPP technology effort will be to define, design, analyse, build and test, either on the ground or in flight, various representative demonstrators validating the requirements defined in the FLPP system studies. This proactive demonstrator policy will foster rapid technology maturation, focusing on concrete targets such as the experimental vehicle (IXV) dedicated to reentry technologies. As a system-concept-driven technology programme, the FLPP combines innovation with addressing future market needs. r