The Future of European Launchers: The ESA Perspective

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Introduction

After an initial pioneering period in the sixties, the applications of space in the strategic and the commercial arenas, mainly in the fields of telecommunications and Earth observation, began to emerge. It therefore made sense for Europe to equip itself with independent means to guarantee its access to space. Development of the Ariane launcher was undertaken, which became a striking commercial success that far exceeded even the most optimistic forecasts. One of the main reasons for this success was the immediate focus on commercial activities.

Given that the launch-services market is undergoing a radical restructuring, Europe has to be able to offer a more complete package of services in order to maintain a sufficient level of industrial activity and reduce production costs. Therefore, for Europe to retain and improve the competitiveness of its launchers on the world stage and to satisfy evolving market demands, an optimised range of launch vehicles is needed. This immediately leads to two distinct objectives, which are: to maintain European launcher competitiveness in the short and medium term (up to 2010), and to prepare the necessary steps for the timely development of the new systems that will be required for longer term competition (2010 - 2020).

With the transformation of the Soviet Union and the changing political scenario, a totally new environment has emerged in the 1990s. As the Space Station has become an international cooperative effort, the launchers developed for military purposes in the countries that were previously part of the Soviet Union have progressively become available to the Western market for use as commercial launchers, together with a large amount of related technology. At the same time, the consolidation of the US aerospace industry has created huge corporations with strong interests in the space launcher field The satellite communications market has also evolved, with the burgeoning number of satellites required to provide the new services and the introduction of the LEO and MEO constellation concepts to serve the entire globe.

The increased competition and the newly arising markets are forcing industry towards optimised products and reduced launch prices. The greater availability of launchers is allowing the satellite manufacturers to choose and to drive launcher evolution, rather than having to adapt their designs to a few available launch vehicles.

All of these factors have totally changed the environment in which Europe had initiated the development of its own launch vehicle. One therefore has to examine the steps that now have to be taken to preserve the initial objectives of independent access to space and commercial success in the new worldwide scenario, in coherence with today's European strategic, economic and political interests.

European objectives

Modern society relies heavily on telecom-munications and the associated services. This reliance has been further accentuated by the rapid emergence of information technology. It is essential not only for strategic and economic reasons, but also for political and cultural reasons, that Europe retains an independent satellite manufacturing and operating capability.

Inability to autonomously launch satellites manufactured in Europe would soon lead to the inability to preserve the satellite and space manufacturing industry, as well as restricting access to downstream application markets in the face of fully developed and organised US competition. US industry, reshaped by consolidation, is able to produce satellites and launchers within the same company, often providing the customer with a turn-key service. Europe has a growing ambition to play an active role in peacekeeping actions and disaster prevention and mitigation; this also requires a well-developed European space infrastructure for Earth observation and telecommunications, available without delay and without third-party dependency.

Preserving an independent capability for access to space is and remains therefore an essential goal for Europe. Considering the relatively limited governmental budgets available, it would appear that the objective of independence and unrestricted access may only be achievable if Europe is capable of maintaining full competitiveness on the world market. Independence must also be maintained under the condition of affordability within the European system, including governments, industry and the launch service operator, Arianespace.

Expendable-launcher activities
Launch-service providers currently competing worldwide have historically benefited from their respective governments' development of launch vehicles and the associated ground infrastructure. Such vehicles, developed for strategic reasons, have progressively become available for commercial exploitation, without requiring amortisation of the development costs. Governments also developed the launch bases and their infrastructure as part of the effort required to enter the elite of States with independent access to space.

In the last years, strong emphasis has been placed, in particular in the USA, on a drastic reduction in the cost of access to space. The sharing of work within the USA is regulated by the Presidential policy, which attributes to the Department of Defense the task of developing a new cost-effective generation of expendable launchers, through the Evolved Expendable Launch Vehicle (EELV) programme, and to NASA the task of identifying, evaluating and demonstrating the technologies required for a new generation of Reusable Launch Vehicles (RLVs).

The EELV's objective is to achieve reductions in the cost of expendable launchers of the order of 25%, by making use of conventional technologies coupled with improved and simplified manufacturing processes, vehicle designs optimised for cost, and streamlined integration and launch operations. The programme is also designed to reaffirm the supremacy of the United States in the world launch-service market. The programme relies on government funding, complemented with investments by the two large US aerospace corporations, Boeing and Lockheed Martin.

The EELV programme will generate two modern families of launch vehicles, Delta-4 and Atlas-V, which in synergy with the existing smaller Delta-2, Athena, Taurus and Pegasus vehicles, will allow the USA to cover the entire range of launch services, from small to very heavy payloads, commercial and governmental missions, into LEO or towards interplanetary journeys. As part of the programme, the existing ground infrastructure will also be modernised and improved processing methods will be adopted.

An Ariane-5 launch

Ariane-5 improvements
To keep up with the above developments in the satellite market and with the growing launch-vehicle competition, ESA has proposed to European governments several improvements to the existing Ariane-5 launcher, which have been approved and are already being implemented. They will provide greater mission versatility, will increase the launcher's performance, and will also streamline production and operations, thereby reducing the specific launch cost. These improvements will be delivered by the Ariane-5 Evolution Programme, focussed on improvement of the launcher lower composite by the adoption of the larger thrust Vulcain-2 engine, and the Ariane-5 Plus Programme, focussed on improving the upper stages by adding a restart capability and the introduction of cryogenic propellants. A new upper stage cryogenic engine, Vinci, is also being developed.

With such improvements Ariane-5 will progressively acquire the capabilities required for dual launches into GTO of the latest and heaviest telecommunications satellites, and for the deployment in Low Earth Orbit (LEO) of satellite constellations.

In parallel, Arianespace is working with European industry to reduce manufacturing and operating costs. The streamlining of the industrial organisation, through the consolidation of European industry, is also expected to lead to cost reductions and more effective management.

The strategic goal is to serve as much as possible of the commercial GTO satellite market with multiple launches, so as to reduce the vehicle specific cost and maintain a sufficiently high production level, even in a market that, in terms of number of launches, has not grown as much as was expected a few years ago.

The Vulcain-2 motor under test at Lampoldshausen (D)

Complementary launchers

While these improvements will allow Ariane-5 to cope with the heaviest payloads in an economically effective manner, completion of the range of launch services offered by Europe is still a necessity, in particular through the addition of small and medium-size launchers complementing Ariane-5 for the lighter classes of payload and for Low Earth Orbit.

The diversification of the satellite market has led to a demand for launch services outside the traditional GEO orbit. Based on the history of launches conducted over the last few years, there is a clear concentration of payloads with masses of between 500 and 1500 kg being launched into LEO, corresponding essentially to governmental scientific and Earth-observation missions. Such missions, mainly sponsored by the space agencies, are aimed at the demonstration of technologies or the investigation of specific scientific phenomena with limited investments. While most of these missions demand dedicated launches into particular orbits, limitations on overall mission cost require the use of low-cost launch vehicles. Estimates made by ESA, Arianespace and industry foresee 30 – 35 missions over the next ten years from European governmental agencies in this payload class. Some of these missions will be the result of cooperative programmes and will probably fly on non-European vehicles, but more payloads will be identified from those countries that cannot rely on an independent capability for access to space.

Also considerable demand for launch services into LEO has come from the first generation of satellite constellations. The initial narrow-band constellations (i.e. Orbcomm) were composed of satellites weighing just a few hundred kilograms and used small launchers for orbit injection. The wide-band systems, such as Iridium and Globalstar, rely on satellites with masses of several hundred kilograms, which have been launched on medium-sized launchers, such as the Long March, Delta-2 and Soyuz. The next generation of broad-band systems (Skybridge, Teledesic, etc.) will rely on satellites weighing 1.5 – 2 tons, placed into higher orbits, and will require launch capabilities of 4 – 6 tons to LEO.

So it is expected that if, following the final commercial outcome of the first generation, a second generation of constellations is realised, a medium-lift launch vehicle with such capabilities to LEO will be ideally placed to serve such a market. This type of vehicle is also ideally sized for governmental missions in polar Earth orbit, as are required for civil and military Earth observation (Spot, Helios) or meteorology (Metop). The number of these missions is insufficient to justify by itself the development of a dedicated vehicle, but the use of a heavy launcher such as Ariane-5 may well involve unacceptable cost or schedule constraints.

Europe has two choices in the face of the growing demand for diversified launch services:
– to strengthen the European launcher industry by developing a coherent family of European launch vehicles, or

– to procure launch vehicles available on the market at the lowest possible cost to complement Ariane-5 in the lighter payload classes.

In the short term, the second option can be easily implemented by making use of the launch vehicles from the former Soviet Union or other non-market-economy countries, through the creation of joint ventures or direct procurement from foreign entities. While this option may be satisfactory for the customer and for the launch operator, it brings neither economic nor technical advantages to the European launcher industry.

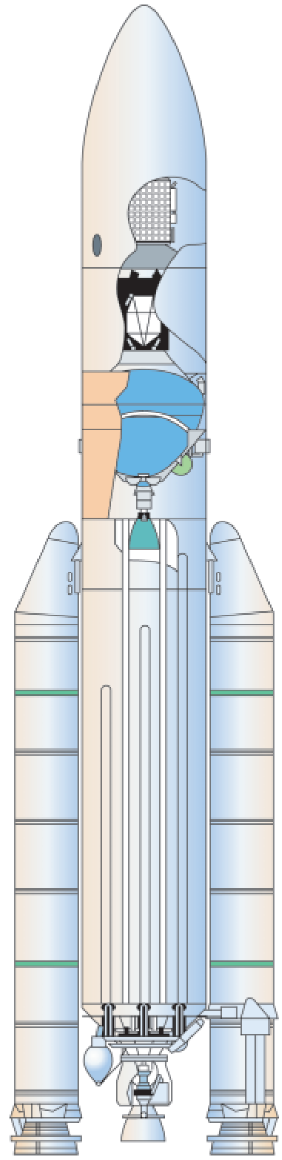
In the 1990's the European launcher industry enjoyed a favourable situation, with full production of the Ariane-4 vehicle for the commercial market in the presence of relatively weak and disorganised competition and, at the same time, was engaged in the large, government-sponsored, Ariane-5 development programme. The termination of Ariane-4 production is leading to the shutting down of several production lines all over Europe, at a time when the main Ariane-5 development effort is also being completed. The work foreseen for the Ariane-5 improvements concerns only selected areas and industry will have to rely primarily on production work and hence commercial success in the marketplace.

Artist's impression of a Vega launch

Based on market trends, 25-30 commercial GEO satellites per year are currently foreseen in the next decade, which means that Ariane-5 may be limited to a maximum of 6 to 7 commercial launches per year. This in turn may lead to under-use of the production facilities and important reductions in the industrial workforce.

To preserve Europe's independent access to space at an affordable cost, the commercial success of Ariane-5 is a pre-requisite. A key factor in this respect is the launch rate and the associated increase in production with the consequent economies of scale. Ideally for the European launcher industry, therefore, any requirement for launch services in addition to Ariane-5 should be based on the same components, use the same production facilities and launch infrastructure in Europe and French Guiana, and involve the same operational teams, in order to get maximum synergy.

As far as industrial or risk-capital investments in new launcher developments are concerned, they need to be pursued for all those activities that involve limited risk and offer a return on investment in a time interval acceptable for the financial markets. This is the case, for example, for hardware or vehicle improvements, which rely on previous developments, improvement of stages, or integration of existing elements to build up a new system. Nevertheless, government support must be provided for those activities consisting of the development of innovative technologies, new vehicles or stages, or the associated ground infrastructure, for which the risk is higher and where present world market pricing prevents the quick amortisation of the investments.



Artist's impression of Ariane-5 ESC-B

Vega

For the above reasons, ESA has proposed, following an Italian initiative, to undertake, with the participation of several of its Member States, the development of the Vega small launcher, targeting the market for small governmental missions to LEO in the payload class up to 1500 kg. This small launcher is intended to provide Europe with a low cost and flexible capability for comparatively quick access to space, on request. The production means required for such a development, and in particular those related to solid propulsion, are available from the Ariane, and other national programmes.

In the version currently under consideration, Vega consists of three solid stages (P80, Zefiro and P7), which inject the upper composite into a low-altitude elliptical orbit. A liquid upper module, known as AVUM (Attitude Control and Vernier Upper Module), is included in the upper

Possible medium-launcher configuration

composite to improve the accuracy of the primary injection (compensation of solid-propulsion performance scatter), to circularise the orbit and to perform the de-orbiting manoeuvre at the end of the mission. The AVUM also provides roll control during the final boost phases and three-axis control during ballistic phases and before payload separation. It may also be used to achieve the unconventional orbits required, for example, for some scientific missions.

The first stage, P80, will foster the development of the advanced technologies required for a new generation of solid motors with higher performance and lower cost, including a large-diameter filament-wound case for high-pressure operation, a nozzle using a new flexible joint, new thermal protections and an electric actuation system for the nozzle. This motor has replaced the initial low-cost metallic motor derived from the Ariane-5 booster, due both to its greater performance, which allows most of the small-mission requirements to be covered, including heavy radar satellites, and to the opportunity of using the Vega development to advance the solid-propulsion technology required for future improvements to Ariane-5.

The Zefiro motor, whose development was initiated by FiatAvio with company funding and a contract from the Italian Space Agency, is the second stage of Vega. It has a low-mass carbon-epoxy case, manufactured with filament-winding technology using high-strength pre-impregnated carbon fibre and a carbon phenolic nozzle with 3D carbon-carbon throat insert. Two successful motor tests have already been performed, and a third is in preparation. Currently, the propellant loading is being increased from 16 to 23 tons, by increasing the length of the motor.

The third stage is a 7-ton solid motor derived from Zefiro, but a liquid storable stage using a turbopump-fed engine was considered as a possible alternative to replace this third stage and the vernier module (AVUM). Such an engine could be derived from the current Ariane-5 upper-stage engine and would be mainly developed on the basis of industrial investments.

The Vega configurations described would use the same technologies, the same production facilities, the same operational infrastructure, the same launch pad and the same teams as the Ariane-5 launcher, thereby achieving maximum synergy and contributing to Ariane-5 cost reductions.

A European medium-size launcher

To serve the satellite-constellation market and medium-size governmental missions, a medium-size European launch vehicle may be developed, making use of elements derived from Ariane-5 and the small launcher. The market for such launcher is largely dependent on the success of the concept of constellations in LEO and MEO and, although its development is currently being studied by ESA, it will be undertaken only once the market is confirmed. Evidence as to the outcome of the first generation of constellations is expected to become available at the end of 2001.

Several configurations are presently being analysed, which are all built around existing elements, such as the Ariane-5 P230 booster, the Vega P80 motor, the Ariane-5 L10 storable upper stage with new turbopump-fed engine or new cryogenic stages (H18, H25) based on the Vinci engine, development of which is just being initiated for Ariane-5. Three possible options are P230/P80/L10, P230/H25 and P80/P80/H18. The final choice will depend essentially on the performance required and timing on the market, as Europe must not miss out on the launch opportunities provided by the second generation of constellations, if these are realised. A scenario identified by Arianespace in the event of successful development of the second generation puts the demand for constellation deployment at the equivalent of ‘nine half-Ariane-5 launchers’ per year.

The medium-sized launch vehicle based on the above elements will help to satisfy these market requirements, whilst simultaneously benefitting the overall Ariane system with increased production needs and synergy of operations. The development of a launcher of this class, relying largely on existing components and ground infrastructure, may be mainly funded by private investment, if the corresponding market demand is indeed confirmed.

X-33

Reusable-launcher activities

It is believed that the only potential means for further significant reduction of the recurrent launch cost is to make the launcher partially or completely reusable and to greatly increase its reliability, while preserving its operability. Reductions of one order of magnitude or more with respect to the Space Shuttle have been mentioned as the objectives of several studies and technology developments being supported by NASA and the US Air Force. In the framework of its Reusable Launch Vehicle (RLV) activities, NASA has initiated such developments as the DC-XA, X-34 and X-37 experimental vehicles, the X-33 RLV demonstrator, and many other studies and technology activities devoted to advancing the level of maturity of the critical technologies.

This trend is confirmed in the US Federal Budget request for 2001, which foresees an allocation of about 4.5 billion dollars in the period 2001–2005 for the Space Launch Initiative, covering RLV technology development and demonstration. This technology maturation phase is expected to be followed by a decision in the USA to develop a new vehicle, funded either by the government alone or jointly by government and industry.

A major driver for the USA in developing an RLV is the need to replace the ageing Space Shuttle fleet. The Shuttle, with its large cargo capability, will be the main player in the construction and operation of the International Space Station, but its high operation and maintenance costs and the need for major vehicle refurbishment lead NASA to envisage a decision on the development of a second-generation reusable transportation system by 2005. Trade-offs of various solutions are currently being performed, with a view to producing an operational vehicle by 2012.

The US military could decide, more or less at the same time, to develop a sub-orbital or orbital, global-reach space plane to satisfy military mission requirements. This interest is confirmed by a number of developments sponsored by the US Air Force, such as the initial DC-X vehicle, the X-40A and the military participation in the NASA X-37 financing. Such a global-reach space plane would be government funded and would not be available for commercial applications, although there would be the technology return to industry.

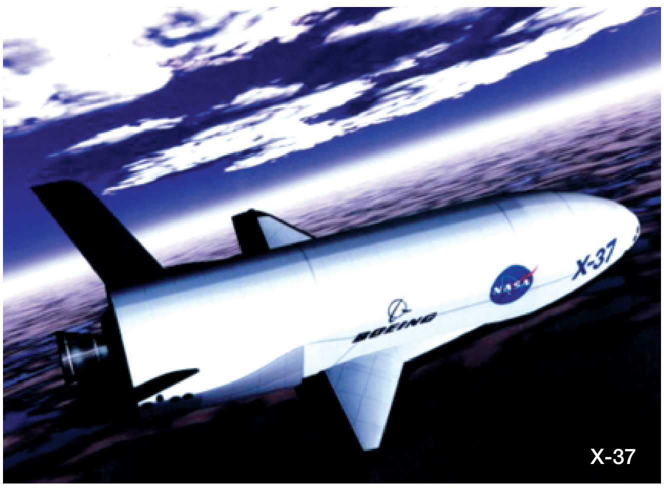
In parallel, there are a number of private initiatives aimed at developing orbital or sub-orbital reusable vehicles for the smaller payload classes. Some of them have gained official support under the NASA programmes and one or more of these proposed concepts might receive sufficient funds to provide a reusable or semi-reusable small launcher. Demonstrations of air breathing high-speed propulsion systems are also being pursued in the USA and around 2005 these systems could be considered for the initial development of long-range, high-speed military applications.

Although it is not clear that the anticipated large cost reductions can indeed be achieved in the short or medium term, these on-going developments in the USA will allow a better understanding of the critical areas, the development of new technologies and the operation in flight of several experimental vehicles. In the longer term (2015 – 2020), therefore, Europe cannot be sure of maintaining its market share by the use of conventional expendable launchers, if a technical break-through is achieved elsewhere. Such step may initially result from the need to satisfy US national requirements, but it could also heavily affect the worldwide commercial launch service scenario.

The FLTP programme

Back in 1994, ESA proposed the Future European Space Transportation Investigations Programme (FESTIP) to its Member States, in order to study possible RLV concepts and initiate the development of the related technologies. Several launcher concepts were subsequently designed

NASA X-vehicles

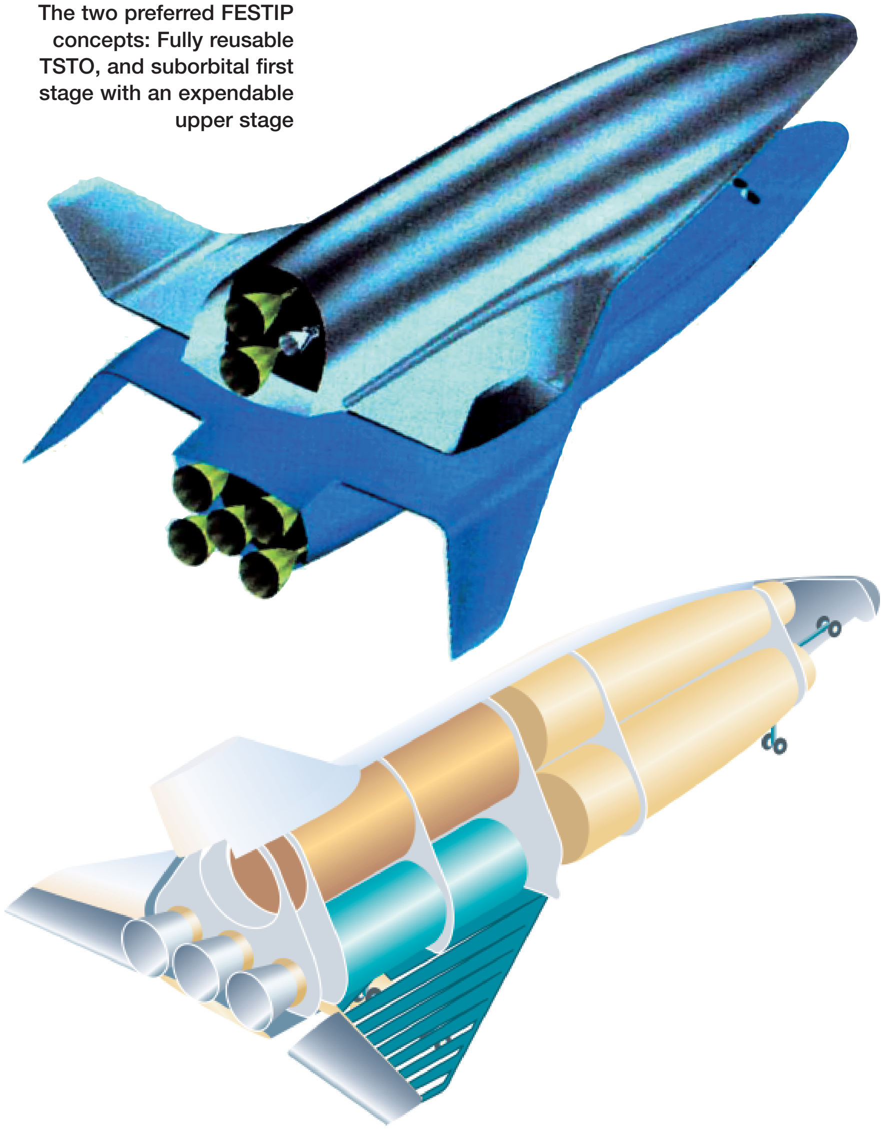


X-37

X-34

at a sufficient level of detail to perform comparisons and evaluations of the technological developments required, and the associated development and launch-service costs were also assessed. In parallel, a number of critical technical problems were analysed and hardware developments aimed at demonstrating possible solutions were performed.

To further its understanding of launcher reusability, already investigated in FESTIP and other national programmes, and to improve the related European technology level, ESA proposed a new optional programme to its Member States in 1999, namely the Future Launchers Technologies Programme (FLTP), the primary objectives of which are:
- to confirm the interest of launcher reusability
- to identify, develop and validate the technologies required to make possible the development of a new generation of cost effective launchers
- to elaborate a plan for the ground and in-flight experimentation and demonstrations required to achieve a sufficient level of confidence prior to the vehicle development phase and to progressively implement such demonstrations
- to provide, through the analysis of candidate vehicle concepts and the synthesis of the technology activities, elements in support of a possible programmatic decision on the initiation of a European development programme for the next generation of launchers, which is currently not expected to be required before 2007.



The two preferred FESTIP concepts: Fully reusable TSTO, and suborbital first stage with an expendable upper stage

The technology developments represent the largest part of the activities in the first period of the FLTP (1999–2001). In particular, strong emphasis is placed on propulsion, large launcher structures and reusability aspects (e.g. health monitoring, inspections).

The vehicle concept definition work is aimed at the definition of reference architectures and system concepts for future commercial operational vehicles. It deals more specifically with:
- the selection of dimensioning missions and the pre-design of a limited number of baseline configurations
- the identification of the technology requirements that must be met to make the concepts feasible
- the overall system architecture optimisation, with emphasis on operability and on re-usability assessment
- the performance of cost assessments, including technology development costs, launcher development costs and recurrent operating costs
- the technology-readiness assessment and the definition of the programmatic features for a potential future launcher development.

A large number of candidate concepts have been studied since the early eighties within the framework of the ESA activities and in national programmes. Recently, the ESA FESTIP programme made a systematic effort to compare reusable and partially reusable launcher concepts against common defined requirements and on the basis of common design rules. All of this work will serve as an input to the FLTP. Candidate concepts include both fully reusable and semi-reusable launchers.

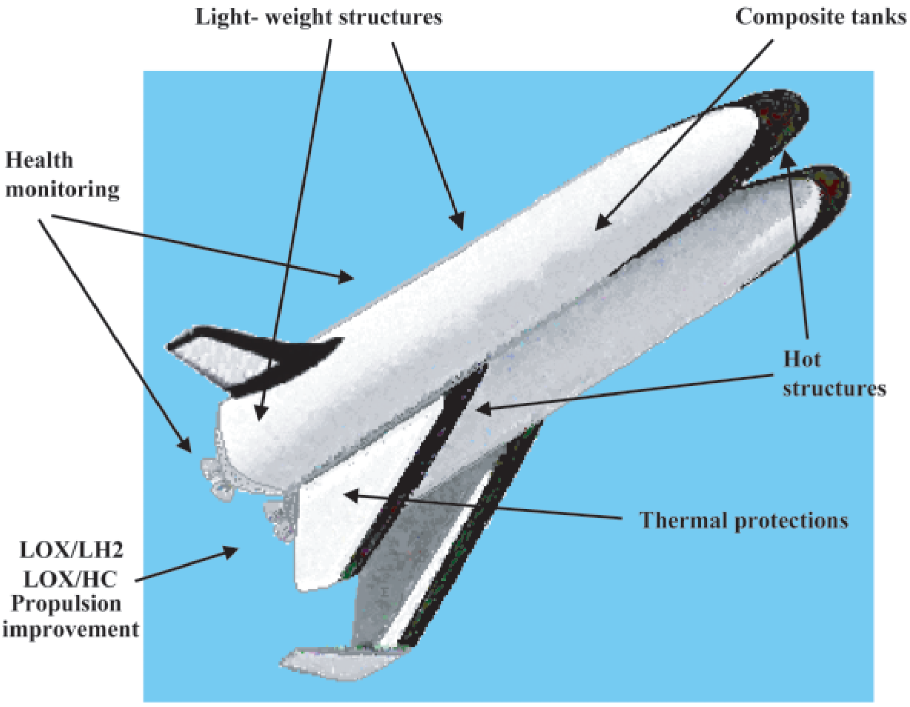
Semi-reusable concepts, whether Two-Stage-To-Orbit (TSTO), or multiple stage to orbit, can be considered as technically feasible with the present technology. Moreover, they can be viewed as a step towards the development of more advanced fully reusable concepts. Such concepts have been studied on several occasions in Europe. So far, the conclusion has been that the specific recurrent costs achieved are of the same order as those of today's Ariane-5 (for a higher launcher complexity). The competitiveness of these particular concepts is therefore difficult to demonstrate with respect to the ELVs expected to be available in 15 years from now, and even more so if the USA offers a fully Reusable Launch Vehicle (RLV) on the market. However, all of the possibilities for semi-reusable launchers have not yet been exhausted, which is why the work on such concepts is being pursued within the FLTP.

A particular type of semi-reusable launcher is the sub-orbital launcher, which requires somewhat more advanced technology, but still seems to be within reach. This vehicle does not achieve a stable orbit, so that its payload needs an additional boost to reach orbital velocity, to be provided by an expendable upper stage. The concept is technically promising, but its largest uncertainties are associated with its innovative operation cycle, which includes a downrange landing. Further studies should provide the elements needed to finally assess the feasibility and cost effectiveness of the concept.

Several fully reusable launcher concepts – both Single-Stage-To-Orbit (SSTO) and Two-Stage-To-Orbit (TSTO) – have been proposed worldwide. Some have even progressed towards the development phase. The TSTO family of fully reusable concepts appears to be feasible with the least technology innovation. Further concept trade-offs are required, in particular related to the return of the first stage to the launch base. Progress in propulsion technology may be required if the size of the vehicle is not to become excessive.

The rocket-propelled SSTO reusable launcher constitutes a large step in terms of the technology level required. This option was the goal of the work performed in the USA by Lockheed Martin. So far, the concept studies have shown a high potential for recurring-cost reductions, but with large uncertainties due, in particular, to the high sensitivity of the design to technological assumptions. Even for the USA, the technical difficulties and operational implications of realising an SSTO launcher are considerable and may not be resolved soon.

The reusable launcher concepts using advanced air-breathing propulsion, either in the form of a ramjet, supersonic combustion ramjet or air liquefaction, separation and collection techniques, require technologies that are very far from implementation on operational vehicles. This type of vehicle might be of interest for later generations of RLVs, which aim at a further significant reduction of recurrent costs. They are presently seen in Europe as a subject for long-term research. Initial applications for some of these types of propulsion (ramjet, scramjet) will be in the field of high-speed military craft.



FLTP technology demonstrators

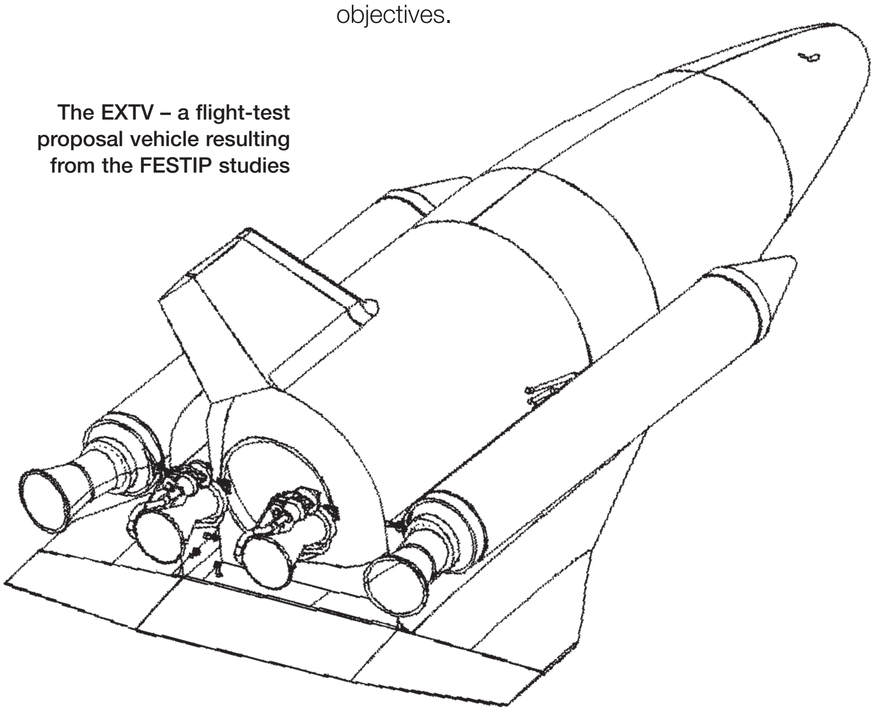
The FLTP technology-development and on-ground demonstration activities include:
- rocket-engine cycle analyses and definition of requirements for reusability
- propulsion component development and testing
- demonstration of lightweight reusable structures (cryogenic tanks, primary structures, thermal protection and hot structures)
- health-monitoring systems for structures and propulsion systems
- analysis and verification of critical aero-thermodynamic phenomena.

Rocket propulsion has advanced significantly through the Ariane programmes, which, in particular, have allowed Europe to gain experience with the operation of cryogenic engines. For new launcher concepts, further advances are required in order to introduce engine reusability and operability, to increase the level of performance and thrust. For example, fully reusable vehicles will benefit from higher-thrust cryogenic engines than those available in Europe today.

For these rocket engines, new components need to be developed, such as advanced nozzles, new types of injectors, simplified and more robust turbo machinery, electrically actuated precision valves, etc. Preliminary demonstration of these components is essential.

For reusable engines, reliability in flight and rapid maintenance on the ground are essential aspects. This means that a completely new design approach is required, which greatly reduces the need for acceptance testing, relies on an integrated health-monitoring system, and makes it possible to control or limit the effects of failures.

Launcher cost reduction and performance improvement also rely on advanced materials, manufacturing processes and improved structural concepts, which allow lower operating costs, reduced vehicle dry masses, as well as reliable, maintainable and health-monitored structures. As a design goal, the structures must have the lowest possible masses compatible with the combined mechanical, thermal and fatigue load, reusability and cost objectives.



The EXTV – a flight-test proposal vehicle resulting from the FESTIP studies

Europe has acquired experience in the manufacturing of metallic and composite expendable structures. Optimisation of design with regard to non-conventional reusable structural concepts and investigation of material characteristics associated with reusability (cyclic loading, environmental resistance, long-term compatibility with propellants, fatigue, operational life including reentry, repair techniques and non-destructive inspection) will induce structural ratio improvements that can only be verified by representative vehicle structure demonstrations.

Therefore within FLTP it is planned to design, manufacture and test:
– a low-mass, reusable composite cryogenic tank
– a light metallic (aluminium-lithium) cryogenic tank
– large airframe elements (inter-tank structure, thrust frame) with integrated health-monitoring systems
– metallic and non-metallic thermal-protection systems improved with respect to mass, reusability and operational constraints
– highly loaded hot structural elements such as wing leading edges, flaps and rudders, using metallic or composite (C/C and C/SiC) materials
– new health-monitoring and non-destructive-inspection techniques.

Aerothermodynamics is also a key technology for reusable launchers, providing the necessary inputs to all other major technologies such as flight mechanics or structures and thermal protection.

Roughly ten years ago with the Hermes programme, a vast wealth of know-how and capabilities was generated in Europe. Similar achievements were acquired in national programmes such as Sänger or PREPHA, which have partly been advanced in FESTIP. At the same time, a number of large test facilities have been built throughout Europe, allowing a substantial extension of the possible test domains.

In order to preserve and improve the available European hypersonic know-how, in FLTP work will be performed on a limited number of basic aerothermodynamic launcher problems (e.g. base drag, effect of multiple propulsion plumes, shock-wave/boundary-layer interaction, laminar/turbulent transition, etc.), which are critical for the practical design of reusable launchers.

However, the area in which Europe needs to make major progress is that of in-flight experimentation. Many of the phenomena influencing the mission of a reusable launcher cannot be reproduced on the ground, and in-flight experimentation is the only means of verifying the theoretical predictions and reducing the technological risk, before starting full-scale vehicle development. Today Europe has no direct experience with high-speed flight and atmospheric reentry by large winged vehicles. Moreover, the shape of these vehicles is often driven by the high-speed flight qualities, resulting in poor low-speed aerodynamics, which makes it difficult to perform low-speed manoeuvres and automatic landings. No experience with the reusability of materials, structures and repeated operation of propulsion systems is available.

For similar reasons, great emphasis has been placed in the USA since the 60's on the design, manufacture and testing of dedicated experimental vehicles, which paved the way for the Space Shuttle's development. The Shuttle in turn is today providing a large amount of flight data, which the USA can use to design a second generation of reusable launch vehicles. Nevertheless, as mentioned above, several additional X-vehicles are currently being developed or are planned by NASA to gain additional operational experience in the various aspects of reusable launcher missions.

In Europe, atmospheric re-entry experience has been gained with ESA's Atmospheric Reentry Demonstrator (ARD) and other capsules developed at national level and in military activities. But none of these vehicles was reusable, nor had a shape comparable to a reusable launcher.

Within the FESTIP programme, ESA has pursued flight opportunities for passenger experiments on 'foreign' vehicles. For example, an agreement has been concluded with NASA which will allow repeated flights on the X-34 vehicle of two European thermal-protection systems.

In parallel, in the framework of the International Space Station activities, Europe is participating in the development of the X-38 and CRV vehicles, which with their demonstration flights will offer an additional opportunity for testing European elements under reentry conditions.

The preparation of a coherent flight experimentation approach is an essential part of the FLTP. The requisite flight activities will be defined at an early phase in the FLTP on the basis of the needs identified, including cost evaluation of the corresponding hardware development and testing. In-flight experiments will be progressively implemented according to the level of technological maturity achieved and the available flight opportunities.

Part of the overall FLTP in-flight experimentation activities will be:

- elaboration of a flight experimentation strategy
- definition of in-flight experiments as passengers on existing vehicles, including opportunities for international co-operation
- development and testing of flying testbeds focussing on the validation of specific technologies and operational aspects required for future European launchers
- elaboration of a technical and programmatic proposal for the development of the experimental vehicles required for mastering the various phases of the reusable launcher mission
- design, development and in-flight testing of selected experimental vehicles.

The definition of flight passenger experiments and testbeds will be initiated in the first phase of the programme. However, the major emphasis in this phase will be on the elaboration of proposals for experimental vehicles, to be implemented in the programme continuation.

The decision to actually develop a reusable launcher will largely depend on the evolution of the international market and competition. Since the Space Shuttle will remain in service until about 2012, a US RLV development decision is planned around 2005.

In formulating its own strategy, Europe will have to consider both autonomous developments as well as international cooperation, in order to advance its technology level. In particular, it should be taken into account that the first RLV in the USA may be developed for the governmental missions to the International Space Station and preparation of a space exploration infrastructure. Europe may be called upon to participate in some aspects of such development. Commercial vehicles will represent a later spin-off of the government-funded developments. Europe must therefore consider carefully what are the most effective steps for reducing the vehicle development risk to acceptable levels before possibly committing to its own RLV development effort around 2006 – 2007.

Conclusion

On the basis of the anticipated world-wide launch-service scenario outlined above and the already defined European objectives, three lines of action should be pursued:

- to maintain Ariane-5's competitiveness in the short and medium term, by improvements to the launcher (greater mission versatility, increased launcher performance, optimisation of production and operations) aimed at reducing specific launch cost
- to complete the range of launch services offered by the possible addition of European-manufactured small- and medium-sized launchers, in order to compete effectively on the international market
- to prepare the technology needed for the timely development of the new systems that may be required in the longer term (2015 – 2020).

These three steps will together allow Europe to retain its current leading position in the launch market and maintain its independent access to space, which is crucial for any future strategic space activity.