Vega: The European Small-Launcher Programme

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By the end of 2001, the development programme for Europe's new small Vega launcher was well underway. The System Preliminary Design Review had been concluded in July 2001 with positive results, confirming that the technical baseline is sound and consistent with the strict system and programmatic requirements. At motor-development level, the Zefiro motor that will power Vega's second stage has already undergone one demonstration and two development full-scale firing tests at the Sardinia test range. The next key milestones are the System Design Review (SDR) foreseen for early 2003 and the Critical Design Review (CDR) scheduled for March 2004. The parallel activities for Vega's new first-stage P80 motor and for the ground segment are also progressing according to plan, and are consistent with a first Vega qualification flight by the end of 2005.

Background

The origins of the Vega Programme go back to the early 1990s, when studies were performed in several European countries to investigate the possibility of complementing, in the lower payload class, the performance range offered by the Ariane family of launchers. The Italian Space Agency (ASI) and Italian industry, in particular, were very active in developing concepts and starting pre-development work based on established knowhow in solid propulsion. When the various configuration options began to converge and the technical feasibility was confirmed, the investigations were extended to include a more detailed definition in terms of a market analysis and related cost targets.

As a conclusion of these preparatory activities, in February 1998 ASI proposed that a small launcher – in the meantime called 'Vega' – be developed within the ESA framework as a co-operative project with other ESA Member States. The main requirements as then defined were:
- launch of an 800 kg payload into Sun-synchronous orbit (SSO) at 1200 km altitude
- launch from Kourou, French Guiana
- a 2 m payload-envelope diameter
- maximum synergy with other Ariane developments
- low recurring cost (less than US$ 20 million)
- a first launch before early 2003.

The programme was adopted by ESA in June 1998, but the funding was limited to a Step 1, with the aim of getting the full approval by the European Ministers meeting in Brussels in May 1999. This milestone was not met, however, because it was not possible to obtain a wide consensus from ESA's Member States for participation in the programme. This gave rise to a period of political uncertainty and to a series of negotiations aimed at finding an agreeable compromise. It is important, on the other hand, to record that during the same period the technical definition work continued without major disruption, and development tests on the Zefiro motor were successfully conducted.

The subsequent extension of the duration of Step 1 provided the opportunity to revisit and update the market analysis, based on the evolution taking place in terms of potential customers and competitors. The result of this exercise indicated the need to refocus the reference mission towards Earth-observation payloads, and to increase Vega's performance to be able to launch a 1500 kg satellite into a 700 km polar orbit, whilst still maintaining the cost target. Several iterations were performed to optimise the configuration, the results of which are summarised later in this article.

One of the major options selected after technical and programmatic trade-offs is represented by the adoption, as the first stage for Vega, of a new high-performance solid motor featuring several technology advances, in particular a filament-wound (FW) case structure not yet available in Europe for the size, propellant mass and internal pressure combination needed. This new motor, called P80 FW in association with the 80 tonnes of propellant mass, will not only offer increased performance and lower production costs, but also pave the way to future applications for medium-size launchers complementary to Ariane-5 and for a new generation of boosters for Ariane-5 itself.

After about two years of definition and consolidation activities, the Vega configuration, including the new P80 FW first stage, two additional solid stages (Zefiro 23 and Zefiro 9) as, respectively, second and third stages, and the upper module AVUM, was established and ready for development as an ESA programme. On the other hand, the choice of the P80 FW implied a stretching of the duration of the programme to allow for the demonstration of the new technologies involved. Consequently, the first launch of Vega is now scheduled by the end of 2005. The formal funding was granted by the participating European States in December 2000, within a financial envelope of 335 million Euros. Seven countries have subscribed to the programme: Italy, France, Spain, Belgium, the Netherlands, Switzerland and Sweden. In parallel, the development of the P80 FW motor was approved, with a budget of 123 million Euros, about half of which is provided by Fiat-Avio as an industrial contribution. In addition to Italy, France, Belgium and the Netherlands are participating in the funding of the P80 development.

Market opportunities for the Vega launcher

The decision to develop a small launcher is a response to a Resolution in the Space Transportation Strategy adopted by the ESA Council in June 2000, aiming at: *"completing, in the medium term, the range of launch services offered by the addition of European-manufactured small and medium launcher, complementary to Ariane, consistent with diversified users' needs and relying on common elements, such as stages, subsystems, technologies, production facilities and operational infrastructure, thereby increasing the European launcher industry's competitiveness".*

Vega will also satisfy a potential market for launching small satellites identified in several forecasts. NASA, for example, is putting an emphasis on 'small missions' making use of low-mass satellites and low-capacity launch vehicles, and several European space agencies, especially the French and Italian agencies, will follow similar paths. The development of small-satellite standard platforms, such as Minisat, Proteus and PRIMA, has already been initiated. It is expected that the availability of such standard platforms will attract several applications, allowing cost reductions and new project starts.

From a technical point of view, the recent evolution in Earth-observation technologies is allowing a reduction in satellite masses. Optical and infrared detectors are now much smaller and, even in the field of radar observation, all-weather surveillance can be performed using satellites with masses of around 1 ton. ESA's Earth-Observation Programme currently has two main components: Earth Explorer, science-driven missions, and Earth Watch for application missions. Both are based on multiple small missions instead of another single large satellite like Envisat. Small satellites are increasingly being considered a suitable alternative to traditional satellites for visible- and radar-imaging military Earth-observation missions also.

For its scientific missions too, ESA is proposing a family of small satellites to demonstrate enabling technologies to be used for future larger missions (SMART for electric propulsion, etc.).

In the field of telecommunications, two possible types of mission are identified for small launchers. 'Little LEO' constellations, which are dedicated to data transmission, store and forward services in real time and messaging applications, are based on satellites weighing some hundreds of kilogrammes. These satellites may be launched as a single or multiple payload by a small launcher. 'Big LEO' constellations are based on satellites of about one ton. For these systems, spares management is not a trivial process, and the timely replacement of a failed spacecraft typically in less than two months allows a major saving. With constellations relying on a very large number of satellites, the market potential for small launchers is linked to the need for such replacements, it being understood that the overall deployment strategy will rely mainly on medium and heavy launchers.

As a result of several different, independent assessments of the potential market for a European small launcher, it has been estimated that the number of European (and a few non-European) governmental missions that will make use of a small launcher will initially be of the order of two per year, and may grow to four per year after 2005, with a total of 30 to 35 launches in the period 2004 – 2013.

Current projections show that for little-LEO constellation deployment, and for big-LEO (e.g. Globalstar, Iridium) and broadband LEO satellite replacement, the market is very uncertain. Taking into account the rapid changes and the uncertainties as to how constellations will develop, the number of additional payloads originating from the commercial applications is estimated to be one or two per year. In the long term, an increased launch rate may be envisaged as a consequence of two possible events:

- confirmation of the validity of the small-mission approach

- improvements in miniaturisation technologies for small satellites.

In conclusion, combining the forecasts for the various categories of customers described above, the projected market for a European small launcher may be three to four launches per year in the initial years, starting from 2004. This is expected to grow to five or six launches per year once the service is well established, and the vehicle is marketed internationally by an experienced organisation such as Arianespace. This projected market represents a realistic baseline for Vega operations.

Obviously, the key parameter driving the commercial success of a new launcher is the cost of the launch service it can offer. The target set for Vega from the beginning of the programme was that of being at least 15% cheaper than the market competitors offering western standards of launch services. Figure 1 provides a comparison of Vega's position vis-à-vis estimates for other launchers.

Vega small-launcher objectives

On the basis of the identified European needs, particularly in the field of radar satellite systems, and of the requirements emerging from the market survey, the in-orbit capability for the reference mission is specified as:

- 1500 kg of payload to a 700 km altitude, circular polar orbit
- Kourou as the launch site.

In addition to the reference mission, Vega will be able to launch satellites for a wide range of missions and applications, for instance with a range of orbital inclinations from 5.2 degrees to SSO, altitudes between 300 and 1500 km, and payload masses between 300 and 2500 kg.

Vega provides a minimum payload dynamic envelope, in a single launch configuration, defined by a cylindrical volume of 2.35 m diameter and 3.5 m height, plus an additional conical volume of 2.8 m (with a height of 2.8 m). Growth-potential studies are being carried out to investigate the design impact of increasing the length and/or diameter. The payload is supported by a standard 937 mm-diameter mechanical interface, the separation device being provided by the launcher. The probability of a Vega launcher failing to inject its payload into the specified orbit, due to failure or malfunction of any component, shall not exceed 0.02 (i.e. minimum reliability of 0.98, with a confidence level of 60%).

Limiting the cost whilst preserving and improving the launcher's competitiveness, is one of the major objectives in Vega's development. The key factor in that cost limitation is to streamline the industrial organisation and to maximise synergy with the Ariane launchers, by using the same components, the same production facilities and launch infrastructure, and relying on technologies, facilities and hardware developed within the Ariane and other national programmes. To improve competitiveness, the Vega development includes new technologies, particularly in the field of solid propulsion. All of these new technologies offer potential spin-offs to Ariane.

Consistent with the market projections and the performance to be offered, the ultimate programme objective is to achieve the qualification launch of Vega by the end of 2005.

Characteristics of the launcher

Vega is designed as a single-body vehicle composed of three solid-propulsion stages, an additional liquid-propulsion upper module, and a fairing for payload protection (Fig. 2).

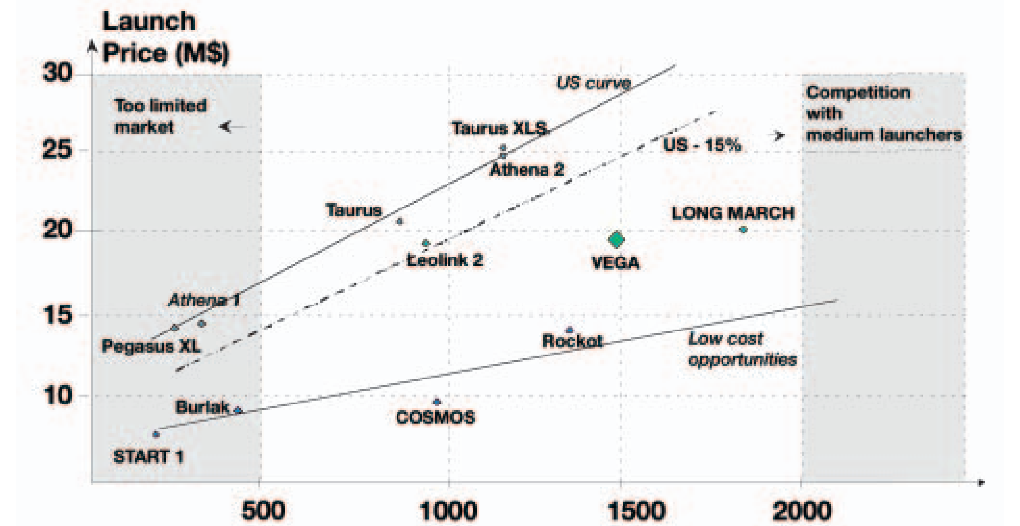


Figure 1. Price/performance comparison for Vega and other launchers

The three solid stages perform the injection of the upper composite into a low-altitude orbit. The liquid upper module, called 'AVUM' (Attitude and Vernier Upper Module), is necessary 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. This module will also provide roll control during the third-stage boost phase and the three-axis control during ballistic phases and before payload separation. The launch sequence is shown in Figure 3.

First stage

The first stage is based on the adoption of the new P80 solid-rocket motor to be developed through a parallel programme slice. This new motor is sized to respond to the basic requirements of the Vega first stage. The specific features of the P80 motor development are described later. In addition to the P80 motor, the first stage is composed of the structural elements needed to connect it to the second stage (interstage 1/2 aft part) and to the ground infrastructure (interstage 0/1), and to host the stage avionics. Those airframes are aluminium shells, with integrated stiffeners on the inside. The rear skirt (interstage 0/1) is a cylindrical structure, while the interstage 1/2 is a conical structure, in order to match the different stage diameters.

Second stage

The propulsion for the Vega second stage is based on a stretched version of the Zefiro 16 solid-rocket motor (SRM), with the propellant mass increased to 23.8 tons. Three firing tests of the Zefiro motor have been performed, in June 1998, June 1999, and December 2000,

Figure 2. The Vega launcher

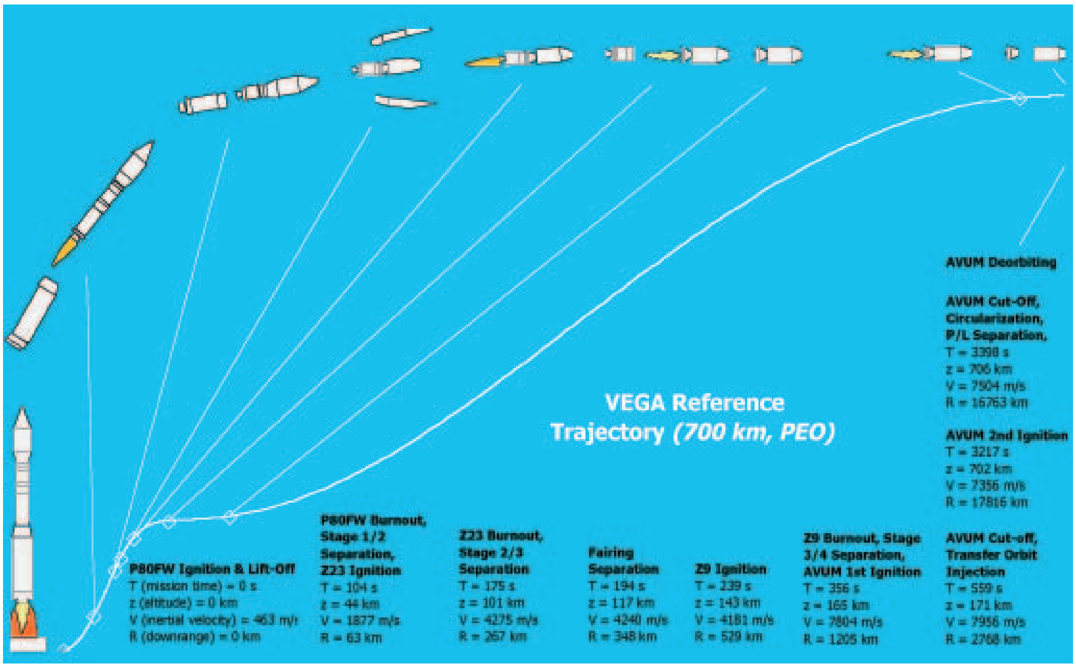


Figure 3. The Vega launch sequence

all with good results. Figures 4 and 5 show the last firing test performed on 15 December, at the Salto di Quirra test bench in Sardinia.

The new stretched SRM is known as Zefiro 23 and employs:
- a lightweight carbon-epoxy case
- low-density EPDM-based thermal insulation, charged with glass microspheres
- HTPB 1912 composite propellant
- a moving nozzle, based on flexible-joint technology.

Polar fittings and interstage flanges are high-strength aluminium forgings. The propellant grain has a finocyl shape, with the star section in the aft zone of the motor near to the maximum polar opening. The star-shaped section consists of a conventional star, with a 3D-transition region coupled to the cylindrical region. The maximum vacuum thrust and pressure of Zefiro 23 SRM are 1200 kN and 95 bars, respectively. The nominal burning duration of the second stage is about 71 sec. The nozzle throat diameter is 294 mm and the expansion ratio is about 25. In addition to the Zefiro motor, the second stage includes the structural elements needed to connect it to adjacent stages and to host the stage avionics. In particular, interstage 2/3 is an aluminium cylindrical structure composed of shells with integrated stiffeners on the inside.

Figure 4. The Zefiro 16 QM1 firing test at Salto di Quirra, Sardinia, on 15 December 2000

Figure 5. Preparation of the Zefiro 16 QM1 motor for the firing test on the Salto di Quirra test bench

Third stage

The Vega third-stage propulsion is based on a solid-rocket motor with a propellant mass of 9 tons, known as Zefiro 9 SRM, and strictly derived from Zefiro 16. Zefiro 9 employs a carbon-epoxy filament-wound case, a low-density EPDM-based thermal insulation, HTPB 1912 composite propellant, and a moving nozzle based on flexible-joint technology. Its maximum vacuum thrust and combustion pressure are 280 kN and 67 bars, respectively. SRM ignition occurs after a coasting phase of several seconds (according to the required trajectory), after Zefiro 23's burnout. The nominal SRM combustion duration is about 117 seconds. The nozzle throat diameter is 164 mm and the expansion ratio is 56.

The interstage connects Zefiro 9 to the AVUM, and hosts the stage avionics and the safeguard main unit.

AVUM

The AVUM upper stage is composed of two different sections, one hosting the propulsion elements (APM: AVUM Propulsion Module) and one dedicated to the vehicle equipment bay (AAM: AVUM Avionics Module). The APM provides attitude control and axial thrust during the final phases of flight, in accordance with the mission requirements. It fulfils the following functions:

- roll control during third- and fourth-stage flight
- attitude control during coasting flight and the in-orbit phase
- correction of axial velocity error due to solid-rocket-motor performance scatter
- generation of the required velocity change for orbit circularisation
- satellite pointing
- satellite-release manoeuvres
- empty-stage de-orbiting.

The current technical baseline includes the adoption of a liquid bipropellant system for the primary manoeuvres, using nitrogen tetroxide (NTO) as oxidiser and unsymmetrical monomethyl-hydrazine (UDMH) as fuel, both fed by gaseous helium under pressure, and a cold-gas system (GN2) for attitude control.

The total propellant loading will be between 250 and 400 kg, depending on the configuration definition and the mission to be performed.

The AAM hosts the main elements of the launch vehicle's avionics subsystems.

Upper composite
The upper composite includes the payload adapter and the fairing. The upper-stage configuration imposes the use of a conical structure in order to provide the required payload standard interface of 937 mm diameter. The reuse of an existing Ariane adapter design is foreseen.

For the fairing, a two-shell configuration has been defined, with a 2.6 m external-diameter cylindrical part and a total height of 7.5 m – including a 3.5 m cylindrical part. The structure is made of two composite shells, composed of aluminium honeycomb and carbon skins. Several access doors are provided on each shell. Moreover, the fairing is equipped with venting ports (Ariane-5 type). The fairing is jettisoned by the combined action of a clamp-band attachment and pyrotechnic longitudinal separation system during the coasting phase between the second- and third-stage propulsion phases.

Avionics
To keep the development and recurring costs to a minimum, Vega's avionics will be largely based on the adaptation of existing hardware and/or components already under development. For the same reason, particular attention has been paid to defining the most appropriate architecture for the avionics subsystems. The baseline architecture consists of a centralised approach, somewhat similar to the Ariane-5 concept. Four main subsystems are defined for the electrical system:

- Power Supply and Distribution
- Telemetry
- Localisation and Safeguard
- Flight Control and Mission Management.

The safeguard subsystem is the only Vega chain with complete redundancy, in order to comply with the launch safety requirements. For the functional subsystems, there are specific redundancies at equipment level, where relevant, to improve the launcher's reliability.

The Flight Control Subsystem will use an on-board programmable flight computer, an Inertial Measurement Unit (directly derived from that used on Ariane-5), and thrust-vector control electronics for guidance, navigation and control. A multi-functional box will deliver electrical commands for mission management, and stage and payload separations on reception of signals sent by the on-board computer. The telemetry subsystem will be similar to that of Ariane-5, as it must be compatible with existing standards and protocols in use in ground stations.

For the safeguard subsystem, the Ariane-5 tracking architecture will be applied, reusing already developed components (transponders, antennas). The destruct functions will be managed through new equipment, the Safeguard Master Units (SMUs) and Safeguard Remote Units (SRUs) located in the stages.

Main features of the P80 motor

The improvement of solid-propulsion capabilities by the adoption of advanced technologies is one of the building blocks of the European strategy. The development effort has two primary objectives:

- demonstration of most of the technologies necessary to guarantee the Ariane-5 solid-rocket booster's competitiveness
- development and qualification of the first stage of the European small launcher, representing the first step towards a new generation of European solid motors (Fig. 6).

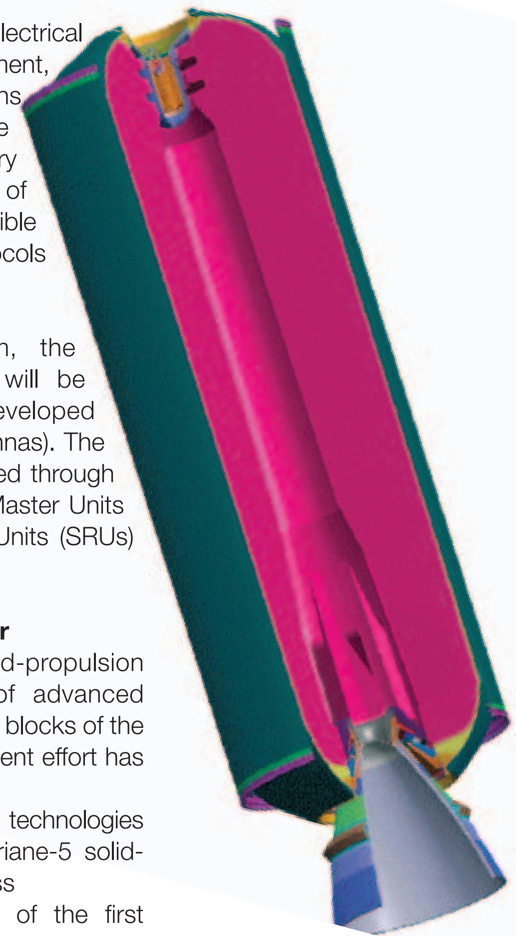


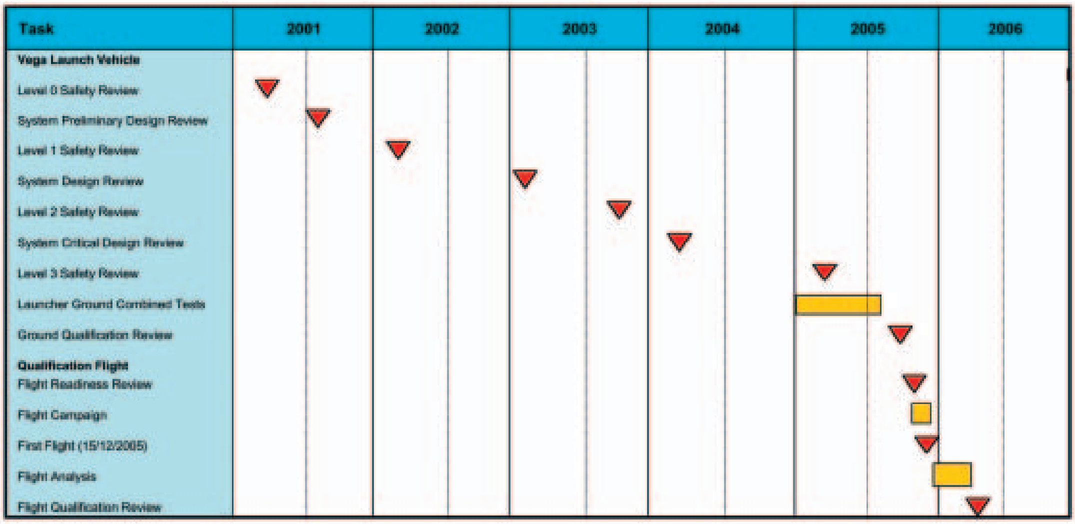
Figure 6. The P80 motor

The motor is tailored and is directly applicable to the Vega small launcher, but its scale is also representative for validating technologies applicable at a later stage to a new generation of Ariane-5 solid boosters. A comparison between a Vega first stage, based on current Ariane-5 technologies, and the new P80 solid boosters is shown in the accompanying table.

Table 1. Main technology choices

Component	P85 Metallic, Ariane-5 derived	P80 FW
Case	Metallic, re-use of Ariane-5, D6AC steel, two segments	CFRP monolithic carbon fibre
Propellant grain	Monolithic Finoxil aft star	Monolithic Finoxil aft star
Propellant	18 14 PBHT	19 12 PBHT
Insulation	GSM55-EG2 (Ariane-5)	EG1LDB3 (from Zefiro) low density
Nozzle throat	3D C/C	3D C/C new low-cost material
Exit cone	Metalllic housing + thermal protection	Composite, structural carbon phenolic
Flex joint	Boot-strap protection	Self-protected/low-torque
TVC actuator	Hydraulic	Electro-mechanical

Figure 7. The Vega Master Development Plan



The development milestones are consistent with the requirements of the Vega Small Launcher Development Plan, and the P80 Solid-Propulsion-Stage Demonstrator development, including its qualification at stage level, should therefore be completed by 2005 (Fig. 7). Maximum reduction of the recurring cost is a driving parameter at all levels of the solid-rocket motor's design (subsystems, components, equipment, ground infrastructure, operations, etc.).

The target of a 25–30 % reduction in recurring cost with respect to that of the 'metallic case boosters' has been set for both the Vega first stage and the new-generation Ariane-5 booster. There is a further reduction in the specific launch cost due to the increased performance achieved by the new generation of booster.

The ground segment

The European launch facility (CSG) in Kourou, French Guiana, offers a variety of launch azimuth capabilities (equatorial, polar and intermediate inclinations) and existing infrastructures, services and logistic support, which make it the natural choice for the new European small launcher. The actual site selected for Vega, following a trade-off between the different options possible in Kourou, is ELA-1, located between the Ariane-4 and Ariane-5 launch areas (Fig. 8).

The new Vega ground segment will make use of the existing Ariane infrastructure, such as the Ariane-1 launch pad at ELA-1 and the Ariane-5 Control Centre. Vega will be assembled on the launch pad. The assembly and integration operations will be performed in a new BIV (Bâtiment d'Intégration Vega) building. The BIV will be a mobile integration building which, after the launcher's final assembly, will move away from the launch pad. Launch operations will be conducted from a dedicated room within the Ariane-5 Control Centre (CDL-3).

Figure 8. The Vega launch and integration area