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Vega C *Light*, a flexible and low cost solution for small satellites

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Abstract
The Vega C *Light* is a 3-stage Launch Vehicle which configuration is based on (i) Vega's flight proven items as well as on (ii) Vega C's items currently under development that will complement the portfolio of services offered by AVIO with solutions dedicated to the 1-500kg mass class of satellites.
Being this configuration mostly derived from Vega and Vega C elements (currently worldwide champions of reliability and flexibility), programmatic and technical hazards are quite limited, while the competitive advantages are enhanced thanks to innovative solutions in the development and the operations.

1. Introduction – Context and Market demand

Within the satellite demand that will be addressed by Ariane 6 and Vega C, the segment under 500 kg mass encompasses a variety of market segments and types of customers, commercial and institutional.
Up to now, most satellites under 500 kg launched by ESA-developed launchers have been piggy-backing. Nevertheless, in response to this growing demand, in particular that of European institutional nature, Council, at the occasion of the ministerial level in December 2016, endorsed the Light satellites Low-cost Launch service (LLL) initiative. This initiative encompasses a number of activities required to define, develop and qualify the products, processes and organization to provide timely, low-cost, standardized launch service solutions suited to the needs of satellites under 500 kg based on Ariane 6 and Vega/Vega C launch systems, as per the classes listed in the table below.

Table 1: Class of Small Payloads

Class 1	200.1 kg – 500 Kg
Class 2	60.1 kg – 200 Kg
Class 3 (incl. 12U+)	25.1 Kg – 60 Kg
Class 4 (incl. 1U, 3U, 6U)	1 Kg – 25 Kg

Several market studies have been recently performed by several companies leading to different results. But there appears to be one widely accepted consensus: the market will continue to dramatically expand in the near future and nanosatellites will remain the primary driver. Most future small satellites are expected to be part of constellations and mega-constellations and Earth observation applications will dominate the market in the classes 2 to 4, followed by technology and education. Telecom applications are expected to dominate in class 1.
Over the last few years, large number of companies have entered the satellite industry, motivated by the significant reduction of manufacturing cost. Globally, companies are developing relatively inexpensive small satellites, which facilitate services almost equivalent to the traditional big satellites that serve governmental agencies or public sector industries. The market of small satellites is expected to show robust growth rate due to increasing rate of investments in the space industry not only by the government organizations, but also by private investors. A major advantage with

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small satellites is that they allow business and scientific establishments, educational institutions, non-spacefaring states, non-profit organizations, and even individuals an easier access to space.
Advancements in satellite miniaturization, increasing capability of electronic technology, ascending demand for small satellite constellations, and increase in the deployment of small satellites for commercial end users are driving the growth of the market. In addition to this, developing safe, low-cost, and small payload satellite to launch beyond low-earth orbit, clean-up and removal of space debris act as the major challenges to the market.
Advancements in small satellite structure, and increase in the requirement of low cost launching sites for small launch vehicles are expected to create lucrative opportunities for the market in the coming years. The commercial end user is expected to witness a high growth rate owing to the development of small satellite constellations for varied applications such as earth observation, provision of global wireless internet system and telecommunication, among others. The demand for small satellites across different geographies in the near future is expected to be promising, with North America having the highest market share, followed by Asia-Pacific, Europe, and Rest of the World.
As the services offered by these satellites continue to grow in demand, so does the demand for launch services.
The Vega C *Light* goal is to cover the needs in terms of performance and cost for the users in the short/medium and long term, including the capability to provide cost-effective launch opportunities for small satellites.
Thanks to the Vega heritage, Avio has acquired a great knowledge of the small satellites market. Indeed, with Vega and Vega C, AVIO can currently offer piggyback and rideshare solutions to the 1-500 kg mass class of satellites. The Vega C *Light* will complement the portfolio of services with solutions dedicated to this class of satellites. The Vega C *Light* is a 3-stage Launch Vehicle which configuration is based on (i) Vega's flight proven items as well as on (ii) Vega C's items currently under development. It is 17 m tall, 2.4 m wide (first stage max diameter), with a mass of nearly 55 tons at lift off. Basically, it is made up of:
- 3 Solid Rocket Motors (SRM) using Aluminum as fuel and Ammonium Perchlorate as Oxidizer plus Auxiliary Propulsive & Attitude Control System (APACS);
- Payload Fairing (PLF), 2 m in diameter providing accommodation to single payloads (Micro-, MiniSats), or constellations of SmallSats.

Being this configuration mostly derived from Vega and Vega C elements (currently worldwide champions of reliability and flexibility), programmatic and technical hazards are quite limited, while the competitive advantages are enhanced compared to other innovative solutions, namely:
- The launcher APACS is a green, innovative, low cost concept developed and qualified for the Vega C *Light* purposes.
- Structures are being developed in the frame of Vega C program, leveraging Avio and its current supply chain heritage and expertise;
- Avionics is derived and optimized from the Vega C program.
- Fast time to launch and launch campaign thanks to a smart operational concept

The Vega C *Light* reference capability to circular SSO, 500 km is about 300 kg, but, depending on the specific mission parameters (altitude: 200-700 km, inclination: from equatorial to-SSO) the performance can be extended to a 50-500 kg Payload mass range. The Launch System is designed to be compatible with different spaceports.
The Vega C *Light* represents a new service since it offers dedicated solutions for all the satellites demanding a launch to these orbits.

2. A *Light* concept also in terms of organization and management

The "*Light*" term applies not only to the size of the item but it suites also to the organization and management with the objective to reduce time for development, non-recurring and recurring costs. This is reflected to all management aspects, namely:

- the development plan: some system tests may be eliminated or reduced based on the heritage acquired on previous programs and the high level of confidence on simulation tools. On the other hand, for those aspects where a strong heritage is not found the rapid prototyping approach is proposed;
- supply chain management, product assurance, configuration, product and documentation management: many processes have been simplified;
- industrial organization and governance: AVIO is responsible and design authority for the complete Launch System, is Launch System Provider and Operator. Furthermore, many Launch Vehicle items and Launch Support Means shall be developed internally. This is dramatically reducing the number of interfaces thus leading to a simplified approach in terms of documentation and exchange of the information between system and sub-system level.

Finally the "*Light*" term is the driver for the conception of launch campaign operations drastically minimized with respect to traditional approaches as described in §6.

3. The Vega-C *Light* Launch System

Here follows a description of the launch system.

The Vega C *Light* Launch System consists of the Vega-C *Light* Launcher System and the Vega-C *Light* Launch Complex. More specifically:

● The Launcher System
● Launch Complex (or Ground Segment)
● The Payload (or Spacecraft)

The Vega-C *Light* Launch System includes all the existing, modified or new equipment, facilities, services and Launch Complex infrastructure necessary to launch one or more P/L and to place it into the required orbits, respecting the specified environment for the P/L and the safety and operational constraints.

Here follows a description of the launcher system consisting of Launch Vehicle and Launch Support Means-

3.1. The Launch Vehicle

The Vega *C Light* is conceived as a composition of building blocks from previous programs. It is highly derived from Vega and Vega C especially as far as the first two stages are concerned.

It consists of:

✓ a **1st stage** motor based on the Z40 SRM (Solid Rocket Motor) and related TVC (Thrust Vector Control), both common with the Vega-C LV, under development and qualification.
✓ a **2nd stage** motor, based on Z9 SRM and related TVC, both common with the Vega and Vega C LV and currently in operation;
✓ **3rd stage**, based on a Vega AVUM stage, but with a solid propulsion module replacing the Liquid Propulsion System; Propulsion shall be ensured by Z2 SRM whose development is on-going based on technologies inherited from Z9 SRM

The main components used to build them up have the following operational status:

✓ the Z40FS SRM is derived from Z40 SRM that is currently under development in the frame of the Vega -C program (funded by ESA). Z40 has accomplished successfully the CDR phase and is ready to approach QR; the item has already passed the qualification test and will be used in a first operational flight in 2020.
✓ Z9 SRM is presently operational as the 3rd stage of Vega LV.
✓ The APACS is derived from H_2O_2 Roll & Attitude Control System being developed in the frame of Vega C and Vega E.

GNC algorithms are mostly derived from Vega and Vega C with the introduction of new features for the three stages management. In particular:

- New control algorithms for mechanical loads limitation during the atmospheric flight phase
- Close loop guidance strategies during third stage flight for dispersion recovery
- Use of residual APACS energy for orbit circularization, Payload injection accuracy achievement and de-orbiting of upper stage.

Safeguard Subsystem SAS is based on Vega C SAS with the introduction of self destruction logic and Radio Frequency systems compatible with Launch Base.
For the first step of the activity anyway the Vega C have been assumed as baseline for preliminary studies.

The upper part of the LV is composed by:

1) A Payload Adapter (PLA) integrated on the third stage, which provide the mechanical and electrical interface to the payload, and where the separation system is located (for single or multiple launch)
2) Whereas needed a dispenser for deployment of constellations

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3) A Payload Fairing (PLF), which provide the aerodynamic protection during ascent phase. A standard product is chosen for that.

The PLA provides easy access to the Payload(s) and to the electrical Ifs, thus allowing all the checks and fueling operation (when requested) before flight. The PLA is versioned to offer a wide range of mechanical I/F based on the customer needs. Further to the standard 937mm I/F, the 610mm and 432mm I/F and a simple platform with dedicated and missionisable bolted footprint based on Payload Separation System I/F.

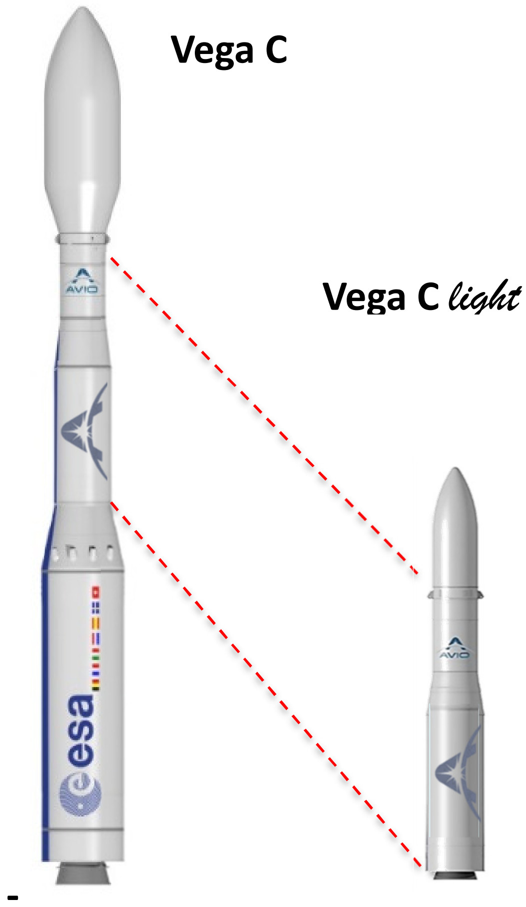

Figure 1: Vega C *Light* derived items

3.1.1. A balance of new development and qualified items

The Vega C *Light* is strongly based on items already qualified or ready to be qualified especially as far as the propulsion items are concerned. For these “off the shelf items” a formal process of suitability assessment culminating with a EQSR (Equipment Qualification Status Review) shall be held in order to certify the adequacy for Vega C *Light* launcher.
Vega C *Light* subsystems can be classified in three categories:

- Newly developed hardware.
- Re-used hardware without modifications.
- Re-used hardware with modifications.

For the last group the above process is applied.
For non AVIO newly developed items a standard qualification approach based on reviews, development and qualification models is pursued. For AVIO newly development items an integrated approach between system and subsystem is adopted with significant simplification of processes and management of interfaces.
Re-used hardware with modifications shall be subjected to delta qualification assessment.

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Among the newly developed systems in particular the pyrotechnics and the autonomous termination system are playing an important role for cost reduction and the compatibility for different spaceports.

3.1.2. Pyrotechnics

Along the program a new Pyrotechnics concept is going to be developed for following functions:

- A: Ignition of a solid rocket motor (SRM)
- B: Ignition of a cluster of retro-rockets (RR used for first stage distancing after jettisoning)
- C: Severance of an inter-stage for stage separation
- D: Neutralization of a stage

Currently the typical scheme for the signal transmission for the above functions is shown in Figure 2

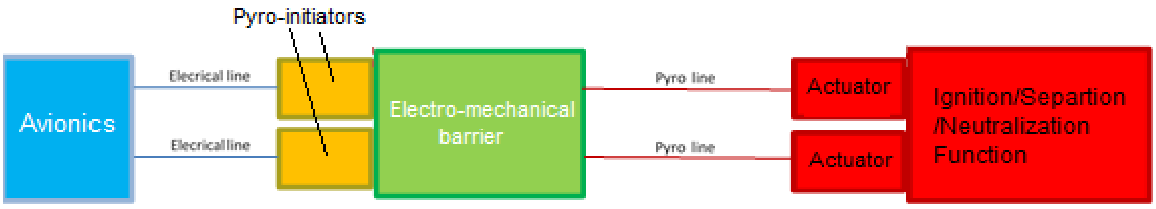

Figure 2: Traditional pyro-technical systems

The objectives of this concept shall be:

- Reduction in the storage and handling of energetic material at all sites from manufacture to launch, including integration operations at both and challenging transport arrangements in between.
- The opportunity to reduce integration time and costs at launch site.
- Increase in safety – reducing the exposure of hazardous materials to personnel.
- Improvements in performance and eradication of quality issues associated with existing components.
- Reduction of mass.
- Improvements to reliability by incorporation of on-board safety checks which cannot be performed to validate integrated explosive transfer lines.

The need is to eliminate as much as possible the pyro-lines and to move the segregation and the signal conversion system as much as close to of initiator.
This new concept is not still in the current baseline. The maiden flight configuration will use traditional systems. The new concept shall be introduced along the program to be operational on 2023.

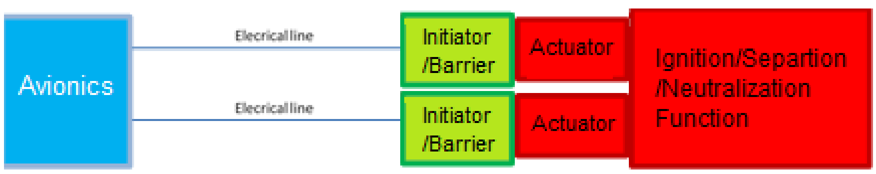

Figure 3: Proposed approach

3.1.3. Autonomous Flight Termination System

The Vega C *Light* shall be operated from several spaceports. For some of them, still under development, the zones allocated for vehicle fragment re-entry in case of failure have very limited extension. This implies for failures occurring during the first seconds of flight a strategy for a very quick neutralization.
The Vega C *Light* adopts an Autonomous Flight Termination System to reduce drastically the intervention delay in case of failure and consequently the extension the zone for re-entry of vehicle fragments re-entry.

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For first flights this system shall be used in redundant way with the traditional localization and neutralization ground based systems. The final objective, in compliance with local norms and rules, is the elimination of the ground based systems.
Traditional Localization function is based on radar tracking with ground intervention as a fully independent mean for localization. However, this architecture implies a significant cost not only in terms of on-board recurrent units but also in terms of ground infrastructure and operations. Moreover, it reduces the mission flexibility due to the dependence of the ground tracking radar coverage (visibility) and introduces hazards in the vicinities of the launch site.

A solution based on GNSS receiver is already in place in the United States. The robustness of the GNSS receiver navigation can be improved using an INS sensor to overcome the weaknesses of a GPS-based only system in terms of integrity and continuity as required for a safety critical function.

The localization and navigation function is used to perform onboard an Autonomous Flight Termination System (ATS). The ATS allows to avoid relying on real time communication network over the first part of the flight reducing therefore the preparation, timing and operation cost, as well as avoiding the hazard due to the inherent delay of the human reaction.

The navigation unit in order to be suitable for localization should implement these additional functions:

- Impact Point Prediction is required to compute the fallout area (nominal + covariance). The Instantaneous Impact Point (IIP) is the point where the launch vehicle has been calculated to impact the terrain if it remains on a ballistic free fall trajectory after a failure.
- In case the flight termination system becomes autonomous, it must be able to replicate the flight termination rules. These flight termination rules are dependent on the mission profile, launcher, time of flight, environment. Therefore, high flexibility is required both in the selection and in the evaluation. It is achieved by enabling configurable mission rules and a dedicated processing on board for implementing the logic for each mission. The availability of several rules allows a logic in which a single violation cannot lead to a termination command.

The development is also focused on a dedicated independent and missionisable software.

3.2. The Launch Support Means

To make the launch system independent from the lunch base a set of portable means are developed. Some of them will be used in the nominal operational flow for the launch preparation (i.e. EILT, ATB, Fluid GSE see after). Other means will be adopted whereas some items and functions provided by the Spaceport may not give an adequate interface or support to the launch preparation and operations. This is the case of portable TT&C stations, portable LCC and portable Launch Pad.
Namely they are:

- Erection Integration & Launch Truck (EILT): Mechanical system required to integrate, transport, erect and place the LV on the LP
- Portable Telemetry, Tracking and tele Command Station: facility to provide RF interface between LV and ground
- Avionic Test Control Bench: launch System Control Bench and the Launch System application software
- Portable Launch Control Center: facility to manage the LV Avionics Checkout and the Launch Countdown
- Fluid GSE: all fluid systems that are required for Launch Vehicle integration, fueling and operations
- Portable Launch Pad Adapter: mechanical interface between the LP and the LV
- Other GSE: all other mechanical, electrical and fluidic system that are in interface and required for LV and A3 integration and operations. They shall include all the hardware and software means necessary for:

  - Manufacturing and integration of all subsystems and stages/assemblies
  - Testing during development phase, qualifying and accepting all subsystems and stages/assemblies
  - Handling and transportation of subsystems and stages/assemblies from the manufacturing
  - Location to the intended assembly building
  - Storage in the productions sites of subsystems and stages/assemblies prior to their transportation to Launch site
  - Performing the acceptance testing off all subsystems and stages/assemblies
  - Assembling the Launch Vehicle Launcher Integration Zone
  - Performing the checkout of the Launch Vehicle, at each step of its final integration

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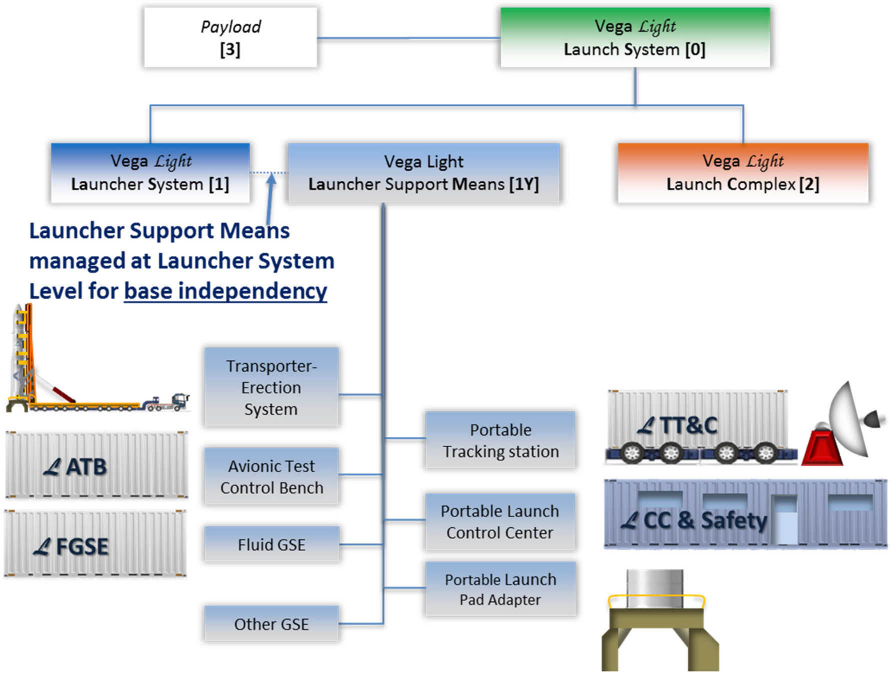

Figure 4: Vega C *Light* Launch Support Means Product Structure

4. The Launch Complex

The Launch Complex, whose responsibility is left to the spaceport operator, consists in:

- the Launch Ground Means (LGM), including the elements not directly interfacing with the Launch Vehicle, e.g. the civil infrastructure (roads, exhaust duct, launch table, lightening protection system), the energy system (electrical power), the HVAC system, the ATEX zones, the systems control center (CCS), the Payload Processing Facilities.
- the Launch Range: Range facilities and means, though not formally part of the Launch System, required to provide the necessary services and support for carrying out a launch campaign and to ensure safety and security of persons, assets, and protection of the environment, e.g. the downrange stations for vehicle tracking, flight data acquisition and launch vehicle neutralization.

It is outlined that the Launch Complex may include facilities shared with other launch systems.

5. Missions

Vega -C *Light* shall be able to launch satellites from class 4 (1 kg – 25 kg) to class 1 (200 kg – 500 kg) into orbit in a wide range of orbits, in order to maximize the light satellites market demand coverage.

The Mission Range for Single Payload and Constellation (aggregate mass 50-500kg) is on orbit altitude from 200 to 700km and orbital plane inclination from Equatorial to Sun Synchronous Orbit
The Launch Vehicle Standard Mission Range is defined as follows:

Table 2: Mission Range

Orbit	Mission	Number of orbits	Perigee	Apogee	Inclination
[-]	[-]	[-]	[Km]	[Km]	[deg]
LEO (*)	SPL/MPL	1	[200 700]	[200 700]	[5,2 SSO]

(*) Circular or Elliptical Orbits

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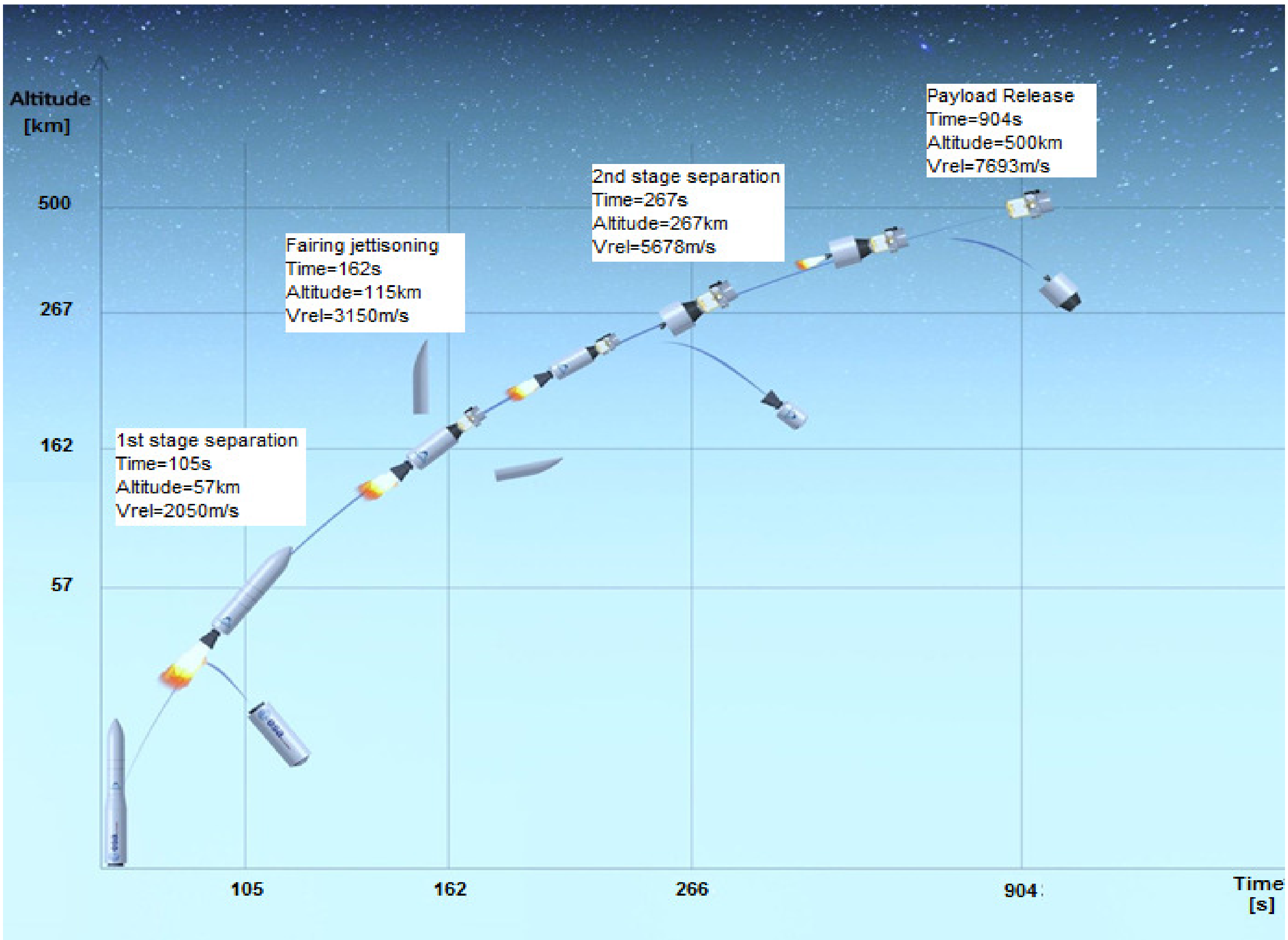

Figure 5: Pictorial View of Vega C *Light* reference Mission

6. *Light* ConOps

The cost reduction is also based on an operation concept significantly simplified and optimized with respect to the Vega and Vega C experiences.
The picture shows a flow chart of main operations:

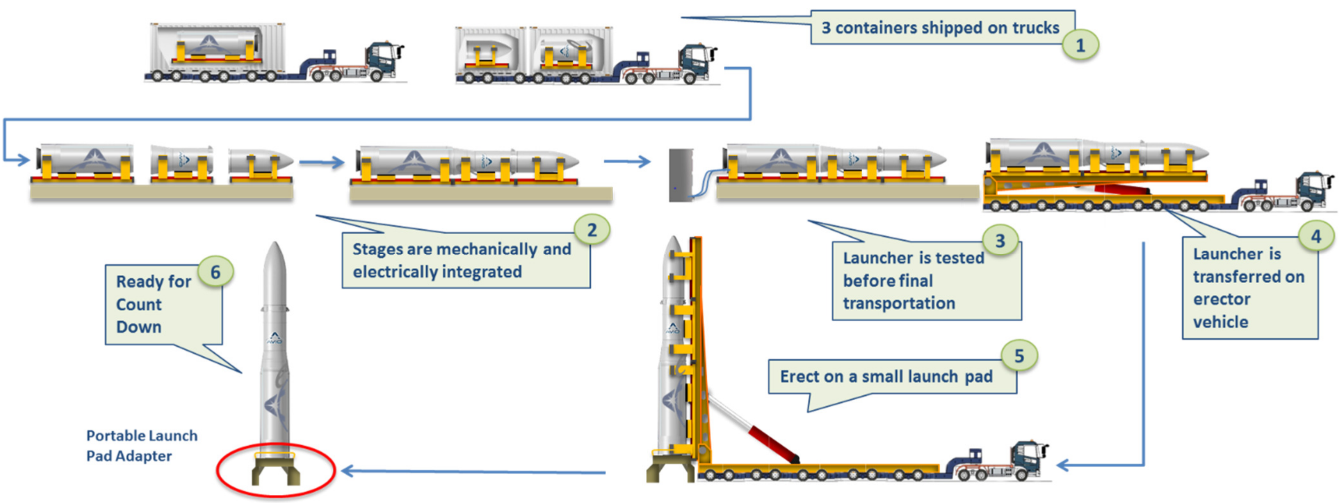

Figure 6: General LV AIT Approach at Launch site

- The stages are manufactured, assembled, integrated and tested in Italy (Colleferro), then shipped in order to store them in the designed storage area (SSA),
- In the (unique) clean room – PPF – the P/L is prepared and loaded eventually and then mated on PLA previously finalized on 3rd stage; the first two assemblies shall be mounted and locked on EILT then mated between them,
- Upper composite comes in LIZ, then aligned and mated to A1+A2,
- Avionic checkout is performed,
- APACS is loaded with propellant,
- Pyro initiators are integrated via small access windows on stages,
- EILT moves to the launch pad and proceeds with erection in vertical position,
- Dress rehearsal is ran
- Countdown and launch.

All these activities are designed to be carried out in a 5 days' timeframe (excluding transports and storages) under the Avio responsibility and with Avio coordinating a multi-industrial team made up of Avio and other partners/suppliers.

7. Conclusions

The Vega C *Light* Launch System development is highly based on qualified or ready to be qualified systems inherited from Avio previous programs. Some items are subject to delta qualification or to new development. A light approach in management of processes and operations speed up the system development and reduce the production and operational costs. Vega C *Light* is currently finalizing the phase B of his development approaching a Launch System Preliminary Review.