THE VEGA SPACE TRANSPORTATION SYSTEM DEVELOPMENT: STATUS AND PERSPECTIVES

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Since its Maiden Flight in 2012, VEGA has successfully placed more than 20 satellites into different LEO, ranging from polar to equatorial, from orbital to sub-orbital, from single payload to multi-payloads, from institutional to commercial. Thanks to its reliability and versatility, VEGA is considered the reference European launch system for LEO satellites in the mass range of 1 to 1500 kg and above. Building on VEGA successes, in December 2014 the new VEGA C launch system development was approved by European Ministers, with the objective to develop a consolidated version of the launch system with an increased payload capability up to 2300 kg, and an enlarged payload fairing to capture typical Earth observation missions among other types of applications. In parallel, building further on the new VEGA C launch system, a series of spin-off products were initiated by the programme with the objective to widen the VEGA fulfilment of the market needs. Such spin-offs include: a. the Small Spacecraft Mission Service (SSMS) for smaller payloads, benefiting from the higher VEGA C performance and the growing market of small satellites developed by universities and research organizations, offering low cost ride-share opportunities for launch services into LEO; b. the Space Rider for payloads requiring return to Earth, providing a reusable orbital customisable/standardised laboratory for multiple space applications (e.g. microgravity, IOD/V for Earth observation, science, robotic exploration, telecommunications), able to perform in-orbit payloads operations, de-orbit, re-enter, land on ground, be relaunched after limited refurbishment, enabling routine “access to”, “operation in”, and “return from” space; c. the VEnUS for payloads requiring orbit-to-orbit transfer, extending VEGA application basis for satellites up to 1 ton to Medium Earth Orbits for constellation replacement, Highly Elliptic Earth Orbits for science/exploration applications, GEO complementary to the GTO by orbit raising; d. the VEGA Evolution preparation, to respond to market evolution, increasing further VEGA competitiveness, by achieving similar performances as VEGA C at reduced recurring costs, thanks to the reduction of number of stages, the introduction of new technologies, the increase of mission flexibility and launcher robustness. Thanks to these new developments the VEGA services will expand the market reach, possibly increasing the yearly launch rate up to 4, 5 and beyond.

The paper provides an up-to-date insight of the overall VEGA development programme objectives, status and planning.

I. INTRODUCTION
Since the maiden flight in February, 13th 2012, VEGA built a heritage of successes, with the first 12 consecutive flights successfully performed with extraordinary versatility, reliability and precision of orbit injection representing a unique record worldwide, making VEGA the reference European launch system for LEO satellites in the mass range of 1 to 1500 kg. Such VEGA versatility and accuracy was exploited in different missions, ranging from polar to equatorial, from single payload to multi-payloads, from institutional to commercial, from orbital to sub-orbital, the latter at the occasion of the 4th VEGA flight for the implementation of the IXV (Intermediate eXperimental Vehicle) sub-orbital mission, successfully testing in flight critical re-entry systems and technologies aspects, enabling future applications in the field of reusable space transportation.

Building on these successes, the VEGA and Space Rider development programmes are now consolidating under
a single ESA frame the VEGA space transportation system as a whole, integrating a series of products under development and/or preparation, such as:
- VEGA-C, for heavier and larger payloads;
- SSMS, for lighter and smaller payloads;
- Space Rider, for payloads requiring return to Earth;
- VENUS, for payloads requiring transfer of orbit;
- VEGA-E, for increasing competitiveness further.

The paper provides an up-to-date insight of the overall VEGA space transportation system objectives, status and planning.

II. VEGA C

Following VEGA’s successful flights sequence confirming its excellent performance and reliability, the consolidated version of VEGA launch system, so-called VEGA-C Launch System, has been conceived to further strengthen the position of the vehicle against its competitors in term of performance and operational cost, widening the fulfilment of the market needs without overlap with the ARIANE Launch System.

The VEGA-C Launch System development was approved on December the 2nd 2014 at the occasion of the ESA Council meeting at Ministers level held in Luxembourg, including also the P120C stage development in common with the ARIANE-6 Launch System.

More specifically, the VEGA-C Launch System development and qualification objectives are:
- to qualify a consolidated version of VEGA to better respond to the market needs, demonstrating an increase of performance (> 800 kg, thus up to 2300 Kg) with respect to the qualified VEGA performance in the reference orbit (i.e. 700 km circular Polar Earth Orbit), without increasing in exploitation costs;
- to reduce the dependency of the operational launch vehicle from non-European sources, by introducing European equipment and components, without increase in exploitation costs;
- to consolidate the technical and programmatic elements for the long-term evolutions of VEGA, addressing a larger European institutional customer base.

The VEGA-C Launch System includes the VEGA-C Launcher System and the VEGA-C Launch Base, whose key features are reported hereafter.

VEGA-C Launcher System

The Launcher System baseline configuration includes:
- a 1st stage based on the 142 tons of propellant P120C SRM (solid rocket motor) and related TVC (thrust vector control), common with ARIANE-6 for both A6-2 and A6-4 versions;
- a 2nd stage based on the 37 tons of propellant Zefiro 40 SRM and related TVC, with the SRM being derived from the AVIO demonstrator for solid propulsion technologies;
- a 3rd stage based on the 10 tons of propellant Zefiro 9 SRM, common with today’s VEGA launcher;
- a 4th stage, based on an improved version of the AVUM, so called AVUM+, introducing:
  o lower inert mass;
  o higher propellant loading;
  o higher avionics segregation, versatility and reliability;
- an improved payload adapter and an enlarged payload fairing, able to accommodate larger and heavier payloads.

Although strongly building on the VEGA heritage, effectively the VEGA-C can be considered a new launcher system, integrating:
- two completely new 1st and 2nd stages, respectively from P80 to P120C, from Z23 to Z40;
- an enhanced liquid 4th stage with several new components and features;
- an improved avionics system, reducing recurring costs, increasing payload services, and replacing specific components obsolescence;
- an improved payload accommodation capability.

The launch vehicle configuration integrates a number of new enabling technologies developments, whose key features are reported hereafter.

VEGA-C Launcher System Avionics, Software, GNC

Significant technological improvements are under implementation in the field of avionics, software, GNC and TVC. More precisely:
- The TVC (Thrust Vector Control) development is focused on the evolution of the Electro-Mechanical Actuators and the Electrical Control Units in a simplex configuration adapted to withstand the more powerful P120C and Z40 stages. The high power demands are satisfied by the usage of
Thermal Batteries in similarity with ARIANE-6 configuration. Another important development concerns the TVC Lab which will simulate the mechanical, electrical and functional behaviour of the real hardware in the Hardware-in-the-Loop mock-up, thus introducing a major flexibility and simplification in the testing setup.

- The MFU (Multi-Functional Unit MKII) plays a central role within the avionics of the launcher as it carries out the main VEGA-C functions contributing to the achievement of the different type of missions, i.e. power distribution, pyrotechnical functions, ground (e.g. the management of the Safety Barriers), propulsion (actuation of the AVUM valves and RACS thrusters), communication among the different electrical equipments (by means of the 1553 protocol) and Payload, in particular by the introduction of non-pyrotechnics separation devices. The MKII configuration represents a modernization of the system, improving the versatility among the different VEGA-C missions and thus reducing sensibly the recurrent cost.

- The OBC (On-Board Computer) version is an important development introduced to solve the obsolescence of key components, while providing improved and optimized performances (usage of LEON2 processor combined with increased SRAM and EEPROM), adding further functionalities for testing and monitoring and improving the recurring cost of the unit.

- The GNC introduces new algorithms to improve the orbital flexibility in terms of AVUM and RACS boost capability, Payload releases in different orbital planes, management of coasting phases with further Collision Avoidance Maneuvers or the insertion of new time-driven managed events.

- The FPS (Flight Programme Software) will be updated to introduce the capability to command and control the new avionics previously described through the introduction of specific flight sequences. It will manage the new OBC-2 firmware services, introducing further mission timeline flexibility and improving the already high robustness of current VEGA software version.

- The new Telemetry Subsystem which increases the mission flexibility through a modular and scalable approach, with a fully configurable system of central and remote units allowing to improve the acquisition rate (including the usage of video cameras) and thus the observability of the launcher behaviour both on ground and flight phases. It resolves the telemetry losses during the non-visibility phases through an optimized mass memory capability, treating at the same time some obsolescence issues of current VEGA units. Finally, it contributes to the reduction of the recurring cost of the overall system.
VEGA-C Launcher System Propulsion, Structures, Pyros

Significant technological improvements are under implementation in the field of propulsion, structures, pyrotechniques. More precisely:

- The P120C solid rocket motor is the largest monolithic motor in composite case, featuring several improvements in its industrialization processes thanks to the synergies with ARIANE 6 where it is used as strap-on booster. The first P120C development model has been successfully hot fire tested in July 2018 at the SRM test bench (BEAP) in Kourou (French Guyana), now on its way for final qualification before VEGA-C maiden flight.

- The Zefiro 40 solid rocket motor is a new stage motor, completely manufactured at AVIO facilities in Italy, loaded with nearly 40 metric tons of solid propellant based on a new formulation specifically developed to improve performance. Also for Zefiro 40 several new technologies have been implemented to improve the structural performance and optimize the industrial processes to reduce the recurring cost (e.g. new pre-preg formulation for the composite case, automatic tape layup for the skirts, self-protected flexible joint, ultra light weight thermal protection). The validation of these improvements was achieved through a successful hot fire test conducted in March 2018 in Sardinia (Italy), where a new horizontal test bench was specifically developed.

- The composite interstage between the 2\textsuperscript{nd} and 3\textsuperscript{rd} stages provides a significant improvement in performance with respect to VEGA, with a new composite grid structure developed by AVIO in cooperation with CIRA (Italian Aerospace Research Center) based on a new processes of dry fibers winding on a rubber insert, followed by resin infusion. In comparison to the mechanical properties of aluminum, the structure provides similar longitudinal modulus of elasticity, higher longitudinal compressive strength and a mass density which is reduced almost by a factor of 2.

- The new AVUM+ Upper Stage, provides several improvements including: composite skin sandwich structure, increased propellant load and main engine re-ignition capabilities, giving more flexibility for multi-payload missions.

- The Enlarged Payload Fairing, to profit of the increased payload capability of VEGA-C for extending the market capture to larger LEO Earth Observation Satellites. Such new fairing is a composite structure with aluminium honeycomb...
core, featuring an external diameter of 3.3 meters and a total height of 9.3 m, implementing the out of autoclave curing to optimize the industrial processes and reduced delivery time and cost.

VEGA-C Launch Base:
The VEGA-C Launch Base is conceived as an adaptation of the actual VEGA Launch Base, and includes:
- the Launch Complex, which in turn is composed of:
  o the Launch Complex Ground Proximity Means (LC-GPM), including the elements directly interfacing with the Launch Vehicle, e.g. the command and control bench, the fluid systems, the mechanical infrastructures, the LN3 application software, as for the present VEGA;
  o the Launch Complex Ground Support Means (LC-GSM), 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 centre (CCS);
- the Launch Range facilities and means, though not formally part of the Launch System, providing 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. These include CNES/CSG Technical Centre, Payload Preparation Facilities (EPCU), downrange stations for vehicle tracking, flight data acquisition and launch vehicle neutralization.

The Launch Base adaptation activities include a number of challenges to be addressed during the development, namely:
- the cohabitation with the concurrent VEGA operations, i.e. the capability to timely implement the adaptations for VEGA-C while the VEGA launch system is in full exploitation phase, successfully achieved through the identification and coordination of “slots” between VEGA launch campaigns, implying flexibility in the development lines to adapt with the evolving VEGA launch manifest. As an example, the installation in the mobile gantry of the new travelling crane capable of handling the heavier Z40 SRM was successfully performed under stringent planning constraints, including certification processes, avoiding any impact to VV12 launch campaign;
- the transition from the VEGA to the VEGA-C launch system exploitation, to be able within 2021 to have completed the VEGA ramp-down while in parallel achieved the VEGA-C ramp-up, with the objective to secure the “VEGA” launch manifest, implementing a high degree of operational, production, procurement, logistic and storage flexibility while keeping in full configuration control the two parallel launch systems;
- the operations optimization, implementing a number of modifications in the concept of operations for the VEGA-C launch system to achieve a significant reduction of the operational costs, and to keep the overall launch service cost competitive worldwide but at increased performances.
VEGA-C programme activities are progressing according to the planning towards the conclusion of the Phase-C, with a Critical Design Review planned by end-2018 and a maiden flight by end-2019.

III. SSMS

Forecasts for the next years suggest that the launch rate of small spacecraft will sensibly increase for Nano, Micro and Mini satellites, with the majority requiring LEO altitude placements. With the objective to fulfil such forthcoming market needs, the Small Spacecraft Mission Service (SSMS) was conceived as a spin-off of the VEGA developments, benefiting from VEGA-C higher performance and larger payload fairing, offering low cost ride-share opportunities for launch services of small spacecrafts into LEO.

More specifically, the SSMS objective is to develop dedicated hardware and launch preparation process, to enable the launch of multiple small spacecrafts at affordable costs. Therefore, two development lines have been set up in order to meet such objective, i.e.:

- the development of modular dispensers and adapters to assemble multiple configurations and aggregates of small satellites;
- the development of standardized and simplified qualification and integration processes.

The SSMS development activities are progressing according to the planning, targeting:

- a POC (Proof Of Concept) flight with VEGA by mid-2019, with the objective to verify the viability of the SSMS concept as a precursor for its use on the VEGA-C launch system;
- a flight with VEGA-C by end-2020, with the objective to fully qualifying the SSMS concept for the VEGA-C launch system.

With reference to the SSMS POC flight, the dispenser configuration will be the Flexi-3 shown herewith.

IV. SPACE RIDER

Building on the VEGA-IXV successful mission accomplished in February 2015, the objective of the Space Rider programme is to develop an affordable reusable European Space Transportation System integrated with the VEGA-C launch system, providing an orbital customisable/standardised platform for multiple space applications, able to perform in-orbit payloads operations, de-orbit, re-enter, land on ground, be relaunched after limited refurbishment, enabling European routine “access to”, “operation in”, and “return from” space.

In order to achieve such objective with the minimum development and recurring cost necessary and with the maximum payload capability possible, the Space Rider system implementing systematically technological synergies and commonalities between VEGA-C and IXV, being composed by the following two modules:

- the Orbital Service Module, a modified version of the VEGA-C AVUM+ to extend the orbital life-time;
- the Re-entry Module, a modified version of the IXV to integrate a MPCB (Multi Purpose Cargo Bay) with a payload volume capacity of 1.2 m3 and a mass capacity up to 800 kg, capable to land on ground and re-fly after a limited refurbishment.
More specifically, the Space Rider will perform in-orbit operations of ad-hoc combinations of several payloads into its MPCB, according to the following applications:

- **Free-Flyer applications:**
  - Micro-gravity experimentation;
  - Radiation exposure;

- **IOD/IOV of technologies for:**
  - Exploration;
  - Orbital infrastructures servicing;
  - Earth observation;
  - Earth science;
  - Telecommunication;
  - Re-entry;

- **In-Orbit applications:**
  - Earth monitoring;
  - Satellites inspection.

An ESA Announcement of Opportunity for End-users was issued, receiving extraordinary feedback in terms of applications from different End-users communities. Despite the very short deadline for the submission of the payloads proposals 25 Notices of Intent were received from 11 different States, proposing 71 payloads, 79% originated by private companies and 21% by institutional organizations, 92% ready for a flight within the programme timeframe, all payload needs largely covered by vehicle capabilities.

The industrial activities are progressing according to the planning, with the system PDR planned to take place by the end of 2018 and the maiden flight expected by the end of 2021 and, in parallel, an ESA roadmap is in place for the consolidation of the various payloads aggregations with respect to the different Space Rider flights.

V. **VENUS**

VEnUS (VEGA Electrical nudge Upper Stage) objective is to extend the VEGA market base to provide orbit-to-orbit transfer to satellites of approximately 1 ton, for:

- Medium Earth Orbits, e.g. for constellation replacement services;
- Highly Elliptic Earth Orbits, Escape Orbits, e.g. for scientific/exploration applications;
- GEO, complementary to the GTO by orbit raising from LEO parking orbit.

In order to achieve such objective with the minimum development and recurring cost necessary, the main development line is based on a 16 kW Solar Electric
Propulsion Orbital Transfer Module, building on synergies with the Space Rider Orbital Service Module based on a modular design of the AVUM Life Extension Kit (ALEK) and a stepped approach:
- 1st Step, extending VEGA-C AVUM+ orbital lifetime in LEO, as Space Rider Orbital Service Module;
- 2nd Step, stretching the orbital capabilities up to orbit transfers, as VEnUS Orbital Transfer Module.

More in detail, VEnUS is integrated with VEGA-C on top of a reinforced version of the 1194mm diameter payload adapter, released into the VEGA-C parking orbit, consisting of two modules:

- The Electric Propulsion Module: a CFRP cylindrical structure with lower separation flanges providing impulse through internal electrical thrusters and including gimballing assembly, 4 external Xenon Tanks, 2 external cold gas RACS brackets, internal power conditioning for propulsion and fluidic control system;
- The AVUM Life Extension Kit: a CFRP cylindrical structure with upper separation flanges including power generation, conditioning and distribution to the P/L (16kW power Solar Arrays, stowing, deployment and orientation), extended Data Handling (Flight Software, GNC and TM/TC), Orbital Navigation and Attitude Control (Star/Sun Tracker, magneto-torquers and reaction wheels).

Today’s activities are progressing with the short-term focus on the identification and maturation of the enabling technologies, in particular the Solar Panels technology and the Power Systems, requiring significant reduction of recurring cost, with the objective to consolidate and finalise the system configuration by mid 2019 for further development. Therefore, a Technology Maturation Phase was started including a wide research of available solutions to reach the cost target, including concentrators technologies and flexible solar panel solutions.

VI. VEGA E
Consistently with the objectives set for the VEGA-C development, VEGA-E (VEGA Evolution) objective is aiming at a continuous improvement of VEGA competitiveness.

The following preparatory lines have been set up by the programme to achieve the challenging objective:
- the definition of a family of configurations, utilizing motors available or under full development in the frame of VEGA development (i.e. P120, P80, Z40, Z23, Z9, AVUM, Lox-Methane based VUS);
- the development of a new lox-methane propulsion engine for the upper stage;
- the identification and development of a number of new enabling Avionics and Mechanics technologies (e.g. 3D printing for parts reduction, H2O2 propulsion for roll and attitude control, Navigation Unit), increasing flexibility and performance at reduced operational costs.

More specifically, the definition of a family of configurations is currently focusing on two main configurations based on common building blocks:
- VEGA–E light, with performance of approximately 400Kg in LEO, integrating Z40 and VUS,
- VEGA–E heavy, with VEGA-C performance levels ensuring complementarity with Ariane 6 market, with reduced recurrent costs and improved versatility, integrating P120, Z40 and VUS.
The system configurations activities are progressing according to the planning, with the Launcher System Preliminary Requirements Review (PRR) planned before end-2018.

The development of the new lox-methane propulsion engine is targeting a thrust level of 10 tons, based on expander cycle, building on previous experience acquired during the Lyra Italian National Programme. The activity is focused on a new engine design concept, implementing new processes as 3D printing in order to reduce the number of engine parts, as well the cost of assembly, integration and testing. A subscale prototype of the 3D printed thrust chamber was successfully tested in July 2018, proving the feasibility of the proposed concept. Other prototypes are undergoing testing in 2018 and in 2019 a full scale TCA will be fired before the complete engine testing planned between end-2019 and beginning-2020.

VII. SYNTHESIS AND CONCLUSIONS
From both the technical and the programmatic perspectives, all products constituting the VEGA space transportation system are progressing according to the nominal planning of the activities, contributing to the consolidation of the widest VEGA fulfilment of the market needs, including:
- Access to LEO for payloads ranging from 1 kg to 2300 kg in the most competitive way;
- Orbital transfer from LEO, complementarily with other European solutions;
- Return from LEO, for a multitude of space applications.

A synoptic view of all VEGA development products application objectives, status and planning is provided here below.

VIII. ACKNOLEDGMENTS
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