DOI: 10.13009/EUCASS2019-987

Vega Space System

Stefano GALLUCCI, Roberto MANCINI**, Ettore SCARDECCHIA****
**AVIO S.p.A.*
Via Latina, snc - 00034 Colleferro (Roma) - Italy
stefano.gallucci@avio.com
*** AVIO S.p.A.*
roberto.mancini@avio.com
****AVIO S.p.A.*
ettore.scardecchia@avio.com

Abstract

The Vega Space System is flexible and customer oriented space system that unified in a single service the launch and an extended orbital service. The VSS offers a unified complete set of solutions and services for orbital exploitation and space transportation, including exploration missions, based on Vega family launch vehicles and on a set of specific modules (even of third party, as Space Rider's Re-entry Module), most of them existing or, to different extents, currently under development. The distinctive characteristic of the VSS is to define standard interfaces versus payloads and a kit approach to mission, which allows the lower cost for any mission.

1. Introduction

The LEO Market segment is booming and will keep on expanding, Avio is adapting products, services and solutions accordingly. The Vega Space System is a diversified portfolio of products, services and solutions that recurrently extend the space transportation service offered by the Vega launchers' family at competitive price.
It is conceived to provide to the PL an extended orbital experience in terms of :

- Accommodation, standard mechanical and electrical interfaces
- Electrical / Chemical additional propulsion for high DV demanding missions
- Extended orbital flight duration
- Bus Services: Power / Telemetry / TVC / AOCS
- Separation or De-orbiting with AOM

The modular approach of the VSS allows to configure the platform according to the customer's needs.
The main brick of the VSS is the ALEK (Avum Life Extension Kit) module that host the avionics necessary for orbital operations (Electric Power System, AOCS, TCS and TTC). It is declined in 3 versions depending on the installed power.

The platform is based on three basics configurations that can be completed with any adapter of the Vega family depending of the mission requirements:

- Standard Launch Vehicle configuration: the orbital segment is the AVUM / AVUM+
  - Can be fitted with any Payload Adapter/Dispenser present in the Vega family catalogue
  - Propellant load can be increased by the Extended Chemical Propulsion Module
- AVUM Orbital Module: it enhance the capabilities of AVUM+ extending its orbital lifetime
  - It is the Service Module of the Space Rider System
  - Can be fitted with any Payload Adapter/Dispenser present in the Vega family catalogue
  - Propellant load can be increased by the Extended Chemical Propulsion Module (ECPM)
- Vega Orbital Transfer Vehicle: based on the Electrical Propulsion Module (EPM) that dramatically increases the available DV
  - Can be fitted with any Payload Adapter/Dispenser present in the Vega family catalogue

DOI: 10.13009/EUCASS2019-987

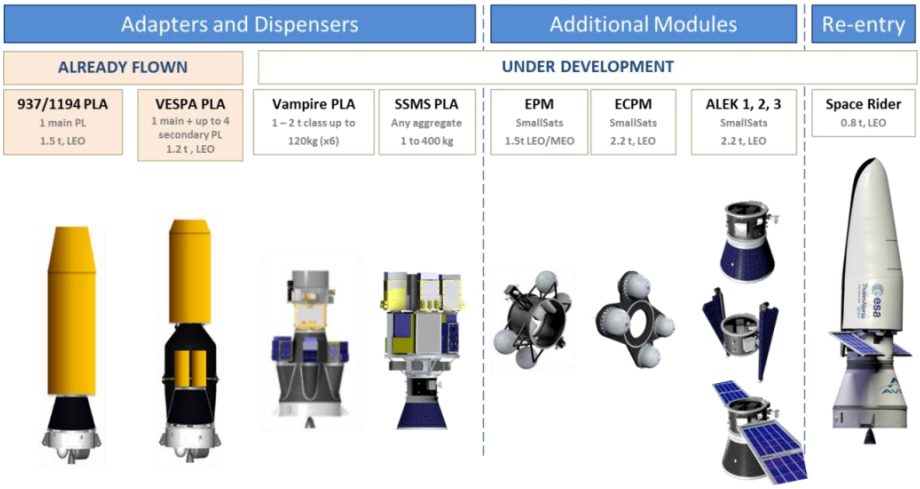


Figure 1: VSS overview

The Adapters already available for the Vega launchers are:

- the standard 937/1194mm adapters for single launches
- VESPA (VEga Secondary Payload Adapter) for double launches or 1 main Payload and up to 6 secondary Payloads
- Vampire for 1 main Payload and up to 6 Payloads
- SSMA (Small Spacecraft Mission Service) capable to separate multiple payloads from 1kg to 400kg
- Besides several dispensers for mini-satellite constellation deployment are in study.

Figure 2: Adapters and dispensers

The VSS can be configured also with third parties modules:

- the Space Rider System, that is built by the Avum Orbital Module and the Re-entry Module (TAS-I)
- the VIS (Vega In orbit Service), that is composed by the AOM and the Service Module (AVIO/SENER/MDA) + the robotics arm (MDA)

2.VSS Mission Scenario

The VSS enhances the mission perimeter of the Vega launchers allowing to add several services available to the customers.

DOI: 10.13009/EUCASS2019-987

- Multiple Payload Release:
  - Multiple spacecraft (rideshares or constellations) in the same orbit plane, but different true anomaly
  - Multiple spacecraft (rideshares or constellations) in different orbital planes
- Bus service for In Orbit Experimentation / Demonstration / Validation:
  - Capable to reach several orbit' inclinations and altitudes
- Payload return on Earth by means of the Space Rider Re-entry Module (TAS-I).
  - It allows to recover payload sent to orbit for experimentations, testing and validation
- Space Debris removal:
  - Removal in LEO by chemical propulsion module
  - Multiple orbit lowering in LEO to aloe faster natural decay by electrical propulsion module
  - Multiple removal from MEO to graveyard orbit by electrical propulsion module
  - Multiple removal from GEO to graveyard orbit by electrical propulsion module
- Space Tug:
  - LEO/MEO/GEO relocation and station keeping
  - LEO to MEO/GEO/GSO transfer and orbital insertion
  - GEO/GSO to LLO transfer and orbital insertion
  - LEO to LLO transfer and orbital insertion
- Servicing:
  - LEO/MEO/GEO inspection/refuelling

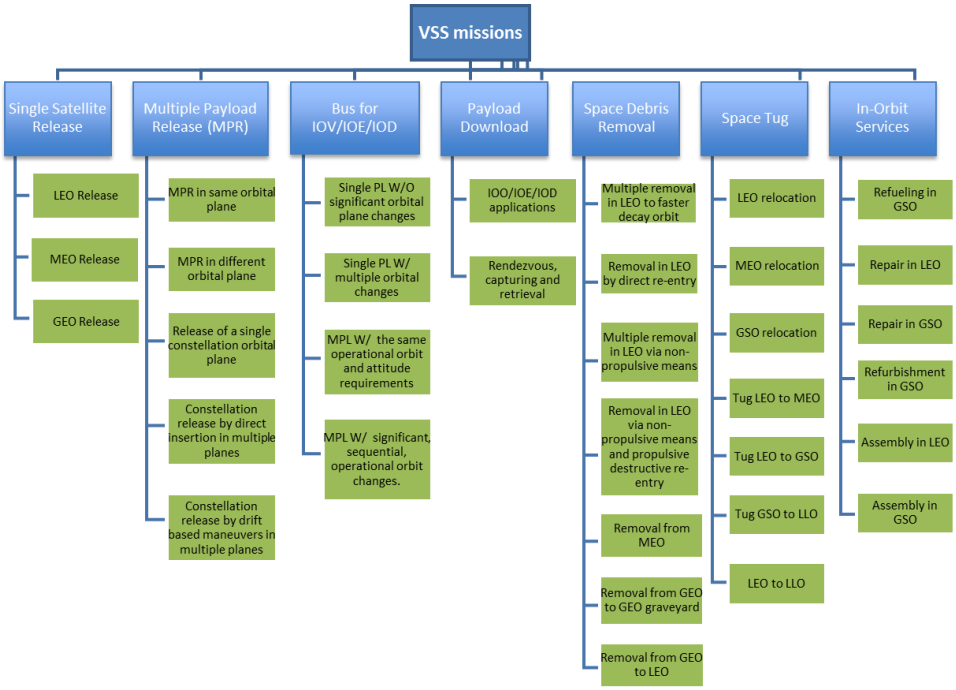


Figure 3: VSS Mission overview

2.ALEK Modules

The core of the VSS system is the ALEK module
ALEK is the AVIO's New Concept of scalable space module part of the Vega Space System.
It can perform all the typical functions of a spacecraft. Its architecture is mostly based on COTS for best cost effectiveness. The new developments are limited to Structures (ALEK cylinder, the OBDH and the Electric Power Subsystem. These new developments maximizes the use of existing European heritage and are based on consolidated technologies in order to reduce the development risks.

DOI: 10.13009/EUCASS2019-987

Figure 4: ALEK

The ALEK is composed basically by primary structure, a CFRP skins honeycomb cylinder of 1194mm radius with an upper separation flange (to eventually separate the PL or the RM), an aft flange interfacing with the EPM (electric propulsion module) or with the AVUM by the PLA-1194LEK, the attachment point for Solar Wings SAD and several Avionic units fixed on the cylinder:

- Power Conditioning and Distribution Unit
- On Board Data Handling unit
- AOCS
- Thermal Control system

The attitude control and orbital detection is performed on behalf of a set of sensors:

- 2 Star trackers
- 6 Sun Sensors
- 2 Magnetometers
- IMU+ GNSS

and associated actuators:

- 3 Magnetic torque rods
- 4 Reaction Wheels

The ALEK may be also equipped with an optional forward flange interfacing to Vega adapters (f.i. SSMS adapter, Constellation dispenser)

It can be configured in 3 versions, basically different for the Electric Power Subsystem:

- ALEK-1: 1kW
- ALEK-2: 4kW
- ALEK-3: 15kW

ALEK 1

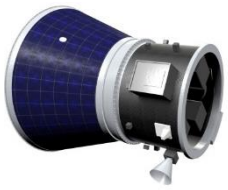


Figure 5: ALEK 1

ALEK 2

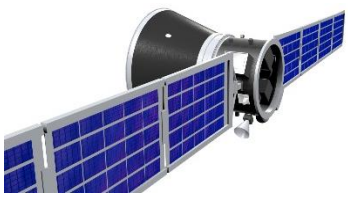


Figure 6: ALEK 2

DOI: 10.13009/EUCASS2019-987

ALEK 3

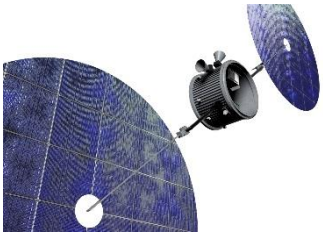


Figure 7: ALEK 3

3.Propulsive Modules

The VSS vehicle relies on both chemical and electrical propulsion:

- the AVUM+, the main chemical propulsion module of VSS, which propellant loading can be doubled by the ECPM
- the Electrical Propulsion Module, based on Hall Effect Thrusters

3.1 Chemical Propulsion

3.1.1 AVUM – Attitude Vernier Upper Module

The main propulsion module of the VSS is the AVUM+ stage. The fourth sage of VegaC, that guides the LV during the standard ascent phase. All its Subsystems are used also for the orbital operational phase. Only the launcher's On Board Computer is switched off after the ascent phase and the target orbit injection. During the Orbital Phase its function is replaced by On Board Data Handling of ALEK that takes the control also of the AVUM+ Subsystems:

- the Liquid Propulsion System and its Thrust Vector Control
- the Roll Attitude Control System
- Central Telemetry Unit.

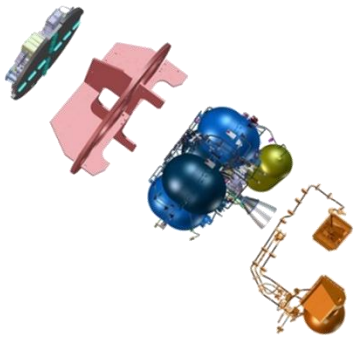


Figure 8: AVUM+

AVUM+ is the VegaC upper stage for orbital positioning and attitude control.
The AVUM+ stage consists of two different sections – one that hosts the propulsion system (APM: AVUM Propulsion Module), and the other which is devoted to the platform that houses the avionics (AAM: Avum Avionics Module).
The APM provides attitude and axial thrust control for the VegaC Launcher during the final stages of flight, in accordance with mission requirements. The current standard configuration includes a liquid bi-propellant system for primary manoeuvres which uses nitrogen tetroxide (NTO) as the oxidant and unsymmetrical dimethyl hydrazine (UDMH) as the fuel – both propelled by pressurised helium gas – and a monopropellant RACS for attitude control.

DOI: 10.13009/EUCASS2019-987

Total propellant load varies from 460 to 740 Kg, depending on configuration and mission. The AMM avionics module hosts the main components of the launch vehicle's avionic subsystem.

Table 1: AVUM+ characteristics

AVUM+ Main characteristics
AVUM Diameter 1.9 m
Propellant mass 740 Kg
Dry Mass 590 kg
Motor mass 16 kg
Average thrust of the main motor 2.5 kN
Specific impulse 314 s
Combustion time: 940s

No major changes are needed to adapt the AVUM+ to the longer orbital life, except for the Thermal Control System that has been redesigned in order to keep the LPS always in its operative temperature range also for critical attitudes. The rationale behind the whole AOM development has been to avoid any constraint coming from the housekeeping of the spacecraft toward the payloads operations.

The batteries of the AVUM+ are also used to power the ALEK's units and shall be recharged by the AOM Electric Power Subsystem.
The Central Telemetry Unit of the AVUM+ serves also the ALEK collecting its telemetry. During the Orbital Phase the telemetry is dispatched toward the RM that provides the downlink to Ground, while for the Re-entry Phase when the two module are separated the CTU is used to transmit the AOM telemetry to ground.

3.1.2 ECPM – Extended Chemical Propulsion Module

It is a plug-in module, providing additional chemical propellant and pressurizer for AVUM LPS. It re-uses most of elements of LPS (tanks, valves, fittings), installed over a structural platform connected to standard Payload Adapter with the goal to extend the LPS range
ECPM has been thought as a highly compact and stiff unit, optionally mountable between the payload adapter and the other VOTV modules. It is based on a 1194mm CFRP cylindrical structure with an upper separation flange (Clamping System LPSS1194 PL). It provides on reference conditions a delta-v up to 600 m/s.

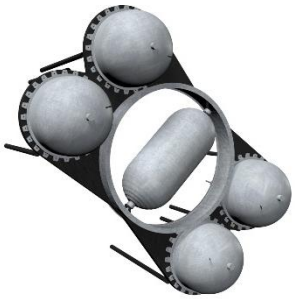


Figure 9: Extended Chemical Propulsion Module

It is mounted on the top of the PL adapter and can be used in the Hybrid configuration combined with EPM or as a standalone chemical propulsion additional module.

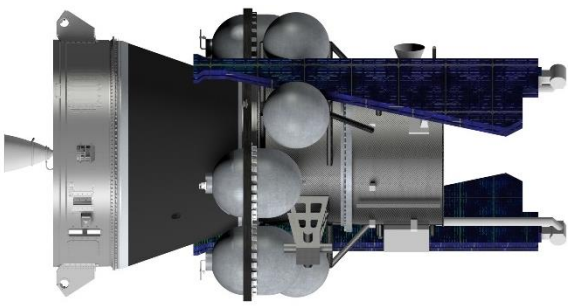


Figure 10: Hybrid Configuration

DOI: 10.13009/EUCASS2019-987

3.2 EPM - Electrical Propulsion Module

It is a plug-in module, providing large total impulse by electrical thrusters. The EPM is in charge of the sunlight orbit raising and relies on two 4.5 kW HET strings (PPU+XFC+HET), for a total propellant throughput in the order of 760 kg. It provides on reference conditions a delta-v up to 6600 m/s.
It includes thrusters, gimbal, TVC, tanks, fluidic, Reaction Control System and additional electrical power conditioning for propulsion.

The electric Propulsive Module is based on Hall Effect Thruster engine of the class of 5kW.
It can be configured with one or two engines for maximum customization and cost effectiveness.

It is based on a 1194mm CFRP cylindrical structure with a lower separation flange, carrying externally 4 Xenon Tanks and 2 RCT brackets, and internally, thruster assemblies.

Table 2: EPM characteristics

EPM Electric Engine	
Thrust [mN]	0.255
Average Acceleration [m/s^2]	1.1174 E-04
Isp [s]	1645.2

Figure 11: Electrical Propulsion Module

The high level product elements present in EPM are:

- Pressure Management Assy
- RCS
- Orbit Control System
- Thermal Control System

The propulsion S/S is composed of the Hall effect thrusters based OCS, the RCS thrusters and a common PMA.

The OCS is in charge of the Orbit Rising during the sunlight and relies on one or two 4.5 kW HET strings (PPU+XFC+HET), for a total propellant throughput greater than 700 kg.
Thrusters are positioned on the EPM lower plate and mounted on gimbals for closed-loop attitude control. Two independent gimbals are required in order to provide torque around the z axis.
RCS is composed by Cold Gas Reaction Control System Thrusters, equipped by a simple solenoid valve, arranged into two set of four thrusters positioned on two booms.

4.Adapters & Dispensers

4.1 Vampire

It is the standard VegaC adapter, it is highly configurable and allows both single and multi-payload missions.

DOI: 10.13009/EUCASS2019-987

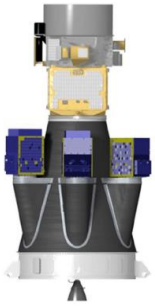


Figure 12: Vampire adapter in multi-payload configuration

- Enables access to space for Medium Satellites: Single Payload configuration
- Enable Access to space for Small Satellites: piggyback
- Increasing the LV filling factor reduces the cost per launch

4.2 SSMS

The SSMS (Small Spacecraft Mission Service) is a modular structure able to carry satellites of class from 1kg to 400kg

The new importance gained by the constellations, as well as of satellites of given intermediate masses, pushed AVIO to consider the development and the recurrent exploitation

It allows multiple satellites separation as well IOD/IOT/IOV taking advantage of long orbital duration missions and the Bus services available to the payloads

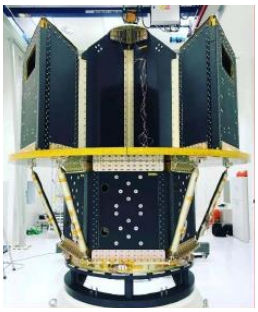


Figure 13: SSMS

The system is based on different modules defined in order to be adaptable to different Smallsats accommodation configurations. Combining the modules, it can be possible to achieve several configurations, each one of them allowing the accommodation of different aggregates of satellites.

Generally the adapter can accommodate:

- Up to 12x 12U cubesat
- Up to 9x Micro and Mini satellites in the upper section

4.3 Constellation Dispenser

To enhance the service and to meet the request of flexible multiple satellite dispenser optimized for constellation deployment it has been introduced the Mast Constellation Dispenser. It is a configurable mast that can host several satellite of the same constellation, on the bottom it has a standard 1994mm flange to interface with the ALEK.

Figure 14 : Mast dispenser

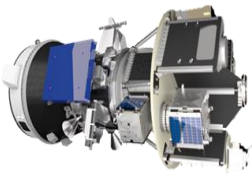
DOI: 10.13009/EUCASS2019-987

5. VSS Configurations

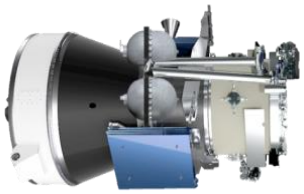
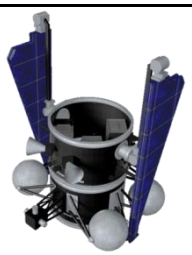
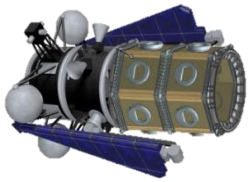
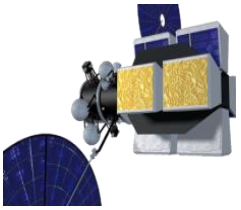
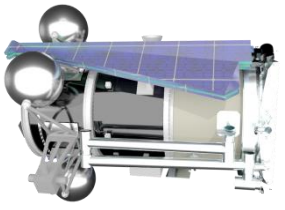
Several vehicles can be assembled to accomplish several missions.
The main vehicles are the AOM (Avum Orbital Module), the VOTV (Vega Orbital Transfer Vehicle) and the VIS (Vega In orbit Servicing).
On the basis of these basic modules several vehicles can be configured adding different adapters or dispensers.

In the following table a summary of the possible vehicle and missions is reported

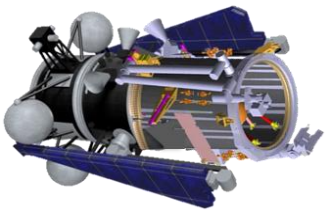
Table 3: VSS vehicles

	Vehicle	Components				Configuration
		Module				
Chemical Propulsion	AVUM++	AVUM+	ECPM			
	SRS	AVUM+	ALEK-2	RM		
	SMS+	AVUM+	ALEK-2	SSMS		
	VIS	AVUM+	ALEK-2	SM		

DOI: 10.13009/EUCASS2019-987

	Vehicle	Components					Configuration
		Module					
	VIS+	AVUM+	ECPM	ALEK-2	SM		
Electrical Propulsion	VOTV	EPM	ALEK-3				
	SMSS++	EPM	ALEK-3	SSMS			
	CD	EPM	ALEK-3	CD			
	VIS+	EPM	ALEK-3	SM			

DOI: 10.13009/EUCASS2019-987

	Vehicle	Components					Configuration
		Module					
	VIS++	EPM	ALEK-3	SM-2			
Hybrid Propulsion	CD-Hyb	AVUM+	ECPM	EPM	ALEK-3	CD	

6.AOM – AVUM Orbital Module

The AOM is a complex spacecraft made by:

- AVUM+ (as is from VegaC with minor adapting)
- ALEK Assy
  - PLA1194-LEK (VG-1194 conical adapter modified for Space Rider)
  - ALEK (AVUM Life Extension Kit)

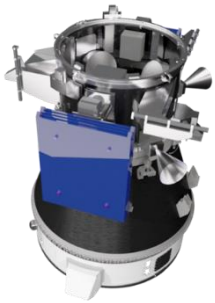


Figure 15: AOM with SAW in stowed configuration

AVUM+ is the 4th stage of VEGA-C LV, it has minor modification in order to implement the Thermal Control System (TCS) managed by the ALEK.

The ALEK module is the version 2 (ALEK2) of the VSS ALEK family. The ALEK module hosts the avionics dedicated to the Orbital Phase Operations and the Power S/S.

In order to properly connect AVUM+ with ALEK a modified version of VG-1194 PLA has been developed

DOI: 10.13009/EUCASS2019-987

AOM main characteristics:

- High efficiency Solar Generator for up to 3.6kW of installed power (up to 2kW deliverable to RM)
- Multiple Attitude Control Actuators for wide range of manoeuvres
- Reaction wheels for smooths and precise manoeuvres
- Chemical RACS for fast manoeuvres and small scale orbit control
- Magnetic rod for smooth and continuous perturbation counteracting
- Orbital Control based on well proven Vega's 4th stage Liquid Propulsion System
- Complete Navigation's sensors suite for high accuracy performances
    - Star Trackers
    - Magnetometers
    - Inertial Unit
    - GNSS
- Powerful On Board Data Handling system properly designed for orbital operations

Maximum reuse of VegaC 4th stage for cost and development schedule optimization.

7.VOTV -Vega Orbital Transfer Vehicle

The Vega Orbital Transfer Vehicle is a newly developed fully autonomous 15kW electrical propulsion powered modular space-tug that further strengthen and expand the current Vega-C position on the market in the short and medium term by allowing Vega-C and its evolutions Vega-E to serve MEO, GEO and interplanetary orbits. Additional mission objectives as debris removal, satellite servicing, GEO satellites life extension and satellite de-orbiting are possible with the excess capacity of VOTV or as a main mission.

VOTV can be thought as the fifth stage of the launcher, that is connected to the VEGA mechanical and electrical I/Fs, while carrying atop the P/L satellite that will be injected into orbit, to which VOTV provide a set of mechanical and electrical I/Fs as well.

The VOTV mission can be summarized as follows:
1. VEGA-C injects into a LEO parking orbit the upper composite formed by VOTV plus the P/L
2. VOTV is commissioned and starts providing to the P/L (kept in safe and stowed mode) survival power and a datalink for P/L housekeeping data monitoring
3. VOTV starts the orbit transfer by means of a low thrust orbit raising manoeuvre. GNC functions, as well as telemetry and attitude control are executed autonomously by the module avionics for the achievement of payload final orbit
4. VOTV releases the P/L into its final orbit, performs an avoidance manoeuver, a disposal manoeuver (de-orbiting or re-boost to graveyard, depending on the target orbit), then passivates.

The VOTV System is made of two different modules:

- ALEK-3: ALEK is a modular plug-in module, providing:
- additional functions to Vega
- services vs. Payloads.

In particular, it provides: power generation conditioning and distribution to P/L and other modules, extended Data Handling, Orbital Navigation and Attitude Control, Thermal Control, evolved interfaces to P/L for an orbital duration up to 12 months. The ALEK-3 version is designed for VOTV with the goal of producing 15KW of power.

EPM: It is a plug-in module, providing large total impulse by electrical thrusters. The EPM is in charge of the sunlight orbit raising and relies on two 4.5 kW HET strings (PPU+XFC+HET), for a total propellant throughput in the order of 760 kg. It provides on reference conditions a delta-v up to 6600 m/s. It includes thrusters, gimbal, TVC, tanks, fluidic, Reaction Control System and additional electrical power conditioning for propulsion.

VOTV Flight Segment includes also the necessary Ground Support Equipment (GSE), foreseen for the assembly, integration, testing, handling, transportation, and refurbishment of the two elements and of the integrated stack-up.

VOTV Ground Segment includes:

- The Mission Control Center (MCC)

DOI: 10.13009/EUCASS2019-987

- The Ground Stations
- The Logistics and Transportation facilities

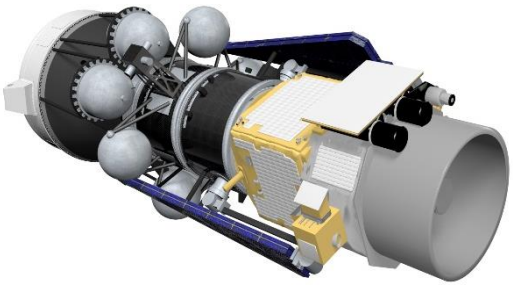


Figure 16: Vega Orbital Transfer Vehicle

8.In Orbit Servicing, the VIS

The Vega In Orbit Service (VIS) has the primary mission to remove space debris and spent satellites relying on an affordable cost. Its secondary mission includes the possibility to perform servicing activities to other spacecraft, in order to extend their lifetime.

The Vega In Orbit Service (VIS) vehicle is composed of:

- AOM (AVUM+ + PLA + ALEK2) that is providing the survival services:
  - Propulsion
  - Power
  - TT&C
  - AOCS
  - Data handling
  - Service Module (SM) that is providing all the relevant equipment for the rendezvous and capture:
    - the robotic elements (robotic arm and clamping mechanism)
    - fine ACS thrusters
    - the proximity sensors and GNC

Figure 17: Vega In-orbit Service (VIS)

The VIS for Debris Removal has two baseline mission scenarios:

- “1 P/L up, 1 debris down”: VIS (AOM + SM + PL) is launched by Vega C into the P/L orbit, deploys the P/L and then transfers to the debris orbit. Subsequently, it rendezvouses and captures the debris and finally destructively deorbits with it
- “Dedicated debris removal mission”: VIS (AOM + SM) is launched by Vega C into the debris orbit, rendezvous and captures the debris and finally destructively deorbits with it. For heavy debris can be also fitted with ECPM to deliver extra DV necessary to remove and splash down huge debris.

DOI: 10.13009/EUCASS2019-987

The VIS can also be fitted for Heavy Debris removal with the ECPM (extended chemical propulsion module) that increase the available DV on board.

Extend missions includes the Spacecraft's servicing scenarios:
Refuelling
Repositioning and transfer to precise orbit slot
Station keeping

9.Conclusions

The VSS is the answer to the exponential growth experienced by the demand of LEO enhanced services. A unique Space Transport System that allows the injection in orbit of several kind of launch configurations from single payloads to multiple spacecraft release relying on the whole catalogue of Vega's adapter and dispensers. Furthermore, several enhanced in-orbit services are made available, by using the VSS modules that can be configured together to assemble the platform bus that meet the customers' requirements. Hence, the extended orbital lifetime allowed by the VSS platforms introduce in the market a new variety of services for IOD/IOV/IOT, constellation deployment and multi-payloads injections. The introduction of the propulsive modules that increase the available DV extends significantly the Vega family mission range and its flexibility.
Third party module compatibility further enlarge the field of application of the VSS, like the In-orbit Servicing (VIS) or the Space Rider System(SRS).

References

[1] Wiley j. Larson, James R. Wertz. 1999. Space Mission Analysis and design. 3rd edition. *Kluwer Academic Publishers*.
[2] Michael D. Griffin, James R. French. 2004. Space Vehicle design. 2nd edition. *AIAA Education Series*.