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VV16: The First VEGA Rideshare Mission Flight

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ABSTRACT

The SSMS (Small Spacecraft Mission Service) program is a new multi-launch concept for the Vega and Vega C launchers, thanks to a new modular dispenser for the Small Satellites Market. The Vega Proof of Concept (POC) flight using the SSMS hardware was developed in the context of ESA LLL Initiative (Light satellite, Low cost, launch opportunities) to provide solutions and services for the 1-400 kg mass class. The SSMS POC mission is foreseen to fly on VEGA VV16 flight on August 2020, following the last flight VV15 in July 2019.

The paper describes the lesson learned of this first rideshare mission flight due to late definition or evolution of the satellites aggregate. On one hand the missionization process needs to become more standardized and with increased genericity (ad-hoc margin policy) in order to cover the continuous changes. On the other hand, the satellites should try to adapt to the standardized SSMS interfaces to simplify and shorten the mission preparation time. Based on the accumulated experience of the previous flights, the development of the multi-Payload mission concept started from the analysis of the activities to fly a single payload mission adapted to the needs of multi payload rideshare missions.

Aggregation activities partially performed in Europe for the first time and completed in French Guiana, assembling, testing and integration into the Payload fairing, as well as relationships with clients and operators during the flight preparation campaign are not reported in this paper.

Vega SSMS first Mission carried 43 different satellites ranging from 1 to 150 Kg from more than 10 different operators; this milestone represents a major advancement towards the goal to provide access to space for Small Satellites

INTRODUCTION

SSMS

The SSMS (Small Spacecraft Mission Service) program is a new multi-launch concept for the Vega and Vega C launchers, thanks to a new modular dispenser for the Small Satellites Market.

The keywords for SSMS are

- **Standardization** of the dimensions and masses of the satellites, of the separation systems, of the interfaces and of the operational constraints,
- **Modularity** of the dispenser to fit a wide set of possible aggregates,

POC

The Vega Proof of Concept (POC) flight using the SSMS hardware was developed in the context of ESA LLL Initiative to provide solutions and services for the 1-400 kg mass class.

The POC mission is based on a dispenser configuration, FLEXI-3 complex enough to show all the possibilities of the concept. It includes 43 satellites divided into Microsats and Cubesats (one of the satellites includes 10 satellites to be separated after and thus total number is 52 satellites).

The POC mission will be accomplished in a multi-PL configuration aboard a VEGA launcher. After 15 flights, this launcher has already demonstrated a high flexibility in terms of missions (types of orbits: altitudes and inclinations; possibility of releasing several PL into different orbits; possibility of a wide range of maneuvers allowed in flights…).

This paper shows how the mission complexity has been addressed during the preparation phase, called Missionization. The experience of the previous 15 flights has been used. In the same time, new design tools and rules have been developed to deal with the specific features of SSMS missions. It is expected to have lessons learnt from this first SSMS mission to ease the Missionization of the future ones.

Map of this paper

This paper is organized as follows:

- We first present the configurations of the POC mission among the possible SSMS configurations. We also present the characteristics of the satellites and their separation systems

- We then present the design of the VEGA trajectory which have to respect a set of constraints. In the same section, we present the maneuvers programmed in the On-board SW to fulfill the SSMS mission.

- The next section is dedicated to the separation of the different satellites. The analysis shows the compliance of the system and of the mission design to the requirements of clearance, non-collision and non-contamination.

- The next section deals with the operational aspects at Kourou Guyana Space Center regarding the Assembling, Testing and Integration of the different passengers.

- The last section deals with the first preliminary results obtained after the flight.

CONFIGURATION

After reminding the general logic of SSMS system, we focus the presentation on the configuration to be launched with VEGA VV16 flight.

Architecture and Geometry

The SSMS system is based on different modules which can be adapted in different Smallsats accommodations configurations:

- HEX element: a structure composed of 6 panels. Each HEX element can accomodate up to 6 Smallsats of Class 2 or up to 12 Cubsats of 12U class.
- DECK: a circular platform, mounted on the HEX element
- Tower: a triangular element, used in FLEXI configuration, which facilitates the clearance of the satellites
- Central Column to support a bigger central PL

These modules can be combined to generate a set of configurations grouped into three families:

- HEX using only HEX elements;
- PLAT using HEX and DECK elements
- FLEXI using HEX and DECK elements plus a central column and towers.

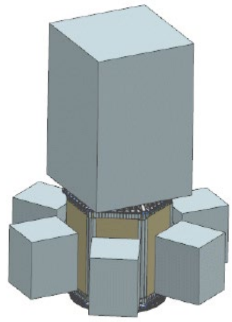

Figure 1: HEX-1

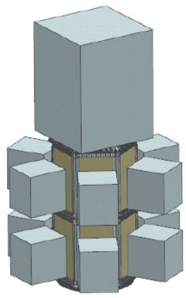

Figure 2: HEX-2

Configuration of POC mission

For this first POC mission, the SSMS dispenser is in the FLEXI-3 configuration with:

- 1 central bigger PL on the column (named D1P0). This configuration allows a PL with a mass up to 200kg and dimensions up to 800 x 800 x h 1000 mm.
- 6 microsatellites on the DECK (3 on the DECK itself and 3 put on 3 towers). The nomenclature is the following:
    - DECK1: D1P1, D1P2, D1P3 put on a tower. The satellites can have a mass up to 100 kg and dimensions till 500 x 500 x h 1000 mm.
    - DECK2: D2P1, D2P2, D2P3 for the 3 satellites on the DECK plan. The satellites can have a mass up to 250 kg and dimensions till 900 x 900 x h 1125 mm.
- satellites on the HEXA: 6 satellites up to 60 kg each with dimensions up to 600 x 600 x h 700 mm or 12 deployers for Cubesats. The nomenclature is
    - for upper part of the HEX surfaces: HU1, HU2, HU3, HU4, HU5, HU6

- for lower part of the HEX surfaces: HL1, HL2, HL3, HL4, HL5, HL6

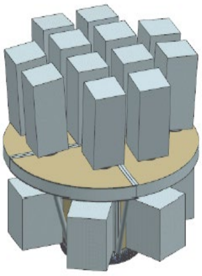

Figure 3: PLAT-1

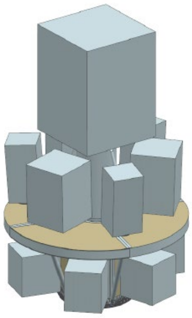

Figure 4: PLAT-2

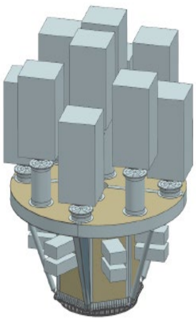

Figure 5: PLAT-3

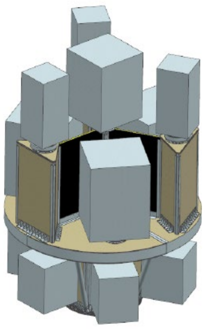

Figure 6: FLEXI-3 (POC config)

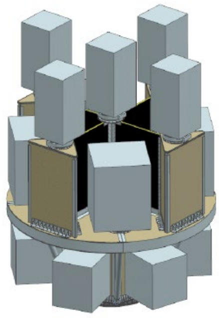

Figure 7: FLEXI-4

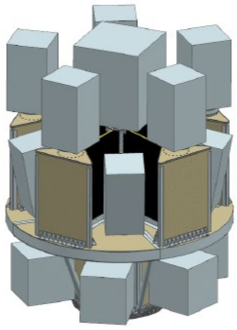

Figure 8: FLEXI-5

The SSMS POC is located on the VEGA adapter 1194. The following figure shows the different elements (adapter upon which a HEX element is located and upon it, a DECK with tower).

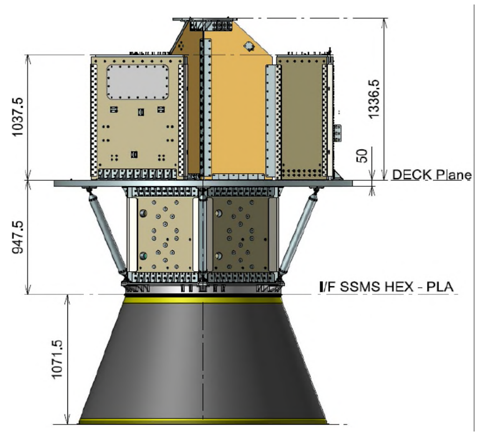

Figure 9: Adapter, HEX and DECK

The 43 PL are distributed according to the following locations, geometry and masses.

Table 1: PL for POC missions

Location	Sat names	Mass [kg]
D1P0	ATHENA	149.8
D1P1	NEMO HD	61.35
D1P2	UPMsat-2	45.5
D1P3	GHGsat	24.66
D2P1	ION	150
D2P2	NewSat	43.5
D2P3	ESAIL	113
HU1	TYVAK-1 LEFT TYVAK-1 RIGHT	36.5
HL1	FSSCAT-A FSSCAT-B	33.3
HU2	4 x SUPER DOVES	30.8
HL2	PICASSO + SIMBA + DIDO3 + TRISAT	24.1
HU3	AMICalSat	4
HL3	4 x SUPER DOVES	30.8
HU4	4 x SPIRES (Lxxxx)	32
HL4	2 x SUPER DIVES + SpaceBEE-1 + SpaceFlight-2	24.1
HU5	4 x SPIRES	32
HL5	NAPA1 + KEPLER	21.6
HU6	TTU100	2.9
HL6	4 x SUPER DOVES	30.8

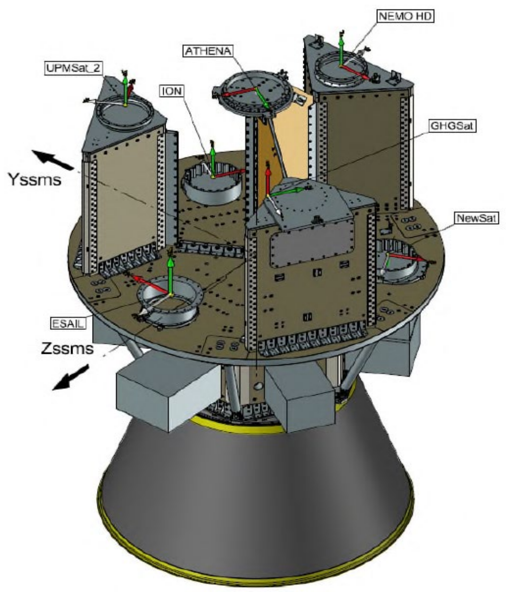

Figure 10: Adapter, HEX and DECK

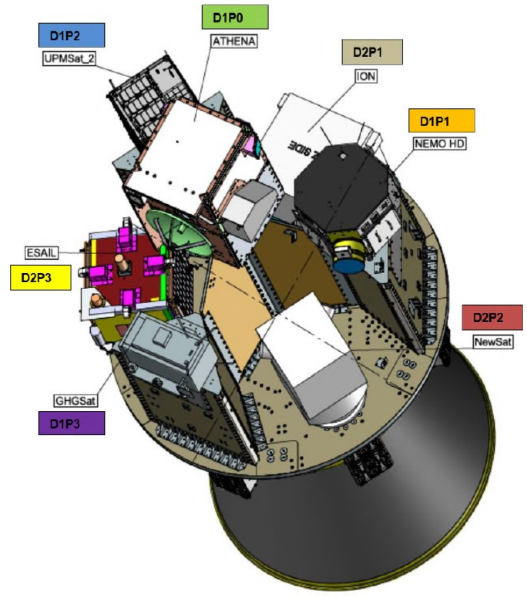

Figure 11: Adapter, HEX and DECK with the satellites

Separation

The separation of the Microsats on the Deck is performed thanks to classical devices: light bands with pushers, switches, connectors and springs characterized by their number and locations which can be selected, and consequently DV of separation.

Table 2: SEP devices for Microsats

Location	Sat names	
D1P0	ATHENA	MLB15''
D1P1	NEMO HD	MLB11.732''
D1P2	UPMsat-2	MLB13''
D1P3	GHGsat	Deployer*
D2P1	ION	MLB13''
D2P2	NewSat	MLB15''
D2P3	ESAIL	MLB15''

The MLB are types of light bands. The GHGsat is separated in a specific way thanks to a dedicated deployer, as a Cubesat.

The Cubesats in the HEX structure are separated thanks to deployer devices. Each deployer is characterized by the following quantities:

- Beginning of effective separation after doors' opening activation (from the moment of receiving the separation order by the sequencer to the instant of cubesat starts to move). Typical values range from 0.02s to 1s.

- Duration of effective separation from begin to SC clearance from Deployer (from the instant the Cubesat starts to move up to instant when it is completely outside the deployer). Typical values range from 0.2s to 0.6s
- ΔVsep amplitude. Typical values range from 0.9 to 1.5 m/s.
- Direction of separation = Half-cone around Z. Typical values range from ± 2 deg to ± 10 deg.

The deployers for each location in HEX element are

Table 3: SEP devices for Cubesats

Location	Sat names	
HU1	TYVAK-1 LEFT TYVAK-1 RIGHT	2x6U 6NLAS Tyvak deployer
HL1	FSSCAT-A FSSCAT-B	2x6U 6NLAS Tyvak deployer
HU2	4 x SUPER DOVES	4x3U Cubesats SuperDoves in QuadPack XL deployer
HL2	PICASSO + SIMBA + DIDO3 + TRISAT	4x3U Cubesats in QuadPack deployer
HU3	AMICalSat	1 x 2U + 1x1U CubeSats in ISIS ISIPOD deployer
HL3	4 x SUPER DOVES	4x3U Cubesats SuperDoves in QuadPack XL deployer
HU4	4 x SPIRES (Lxxxx)	4x3U Cubesats in PSL-P 4W deployer
HL4	2 x SUPER DIVES + SpaceBEE-1 + SpaceFlight-2	2x3U Cubesats SFL + 2x3U Cubesats SuperDoves in QuadPack XL
HU5	4 x SPIRES	4x3U Cubesats in PSL-P 4W deployer
HL5	NAPA1 + KEPLER	1x6U Cubesat and 2x3U CubeSats in QuadPack deployer
HU6	TTU100	1 x 2U + 1x1U CubeSats in ISIS ISIPOD deployer
HL6	4 x SUPER DOVES	4x3U Cubesats SuperDoves in QuadPack XL deployer

Some examples of deployers are provided hereafter:

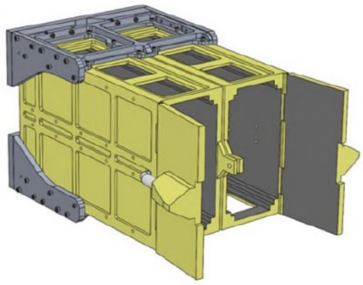

Figure 12: Deployer for HU1 & HL1

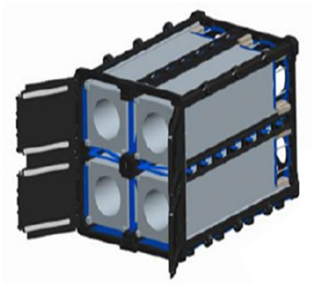

Figure 13: Deployer for HL3, HU2 & HL6

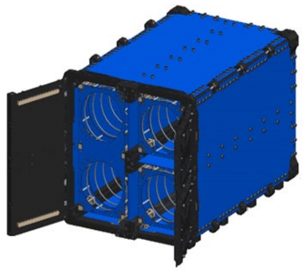

Figure 14: Deployer for HL5

TRAJECTORY AND MISSION DESIGN

Masses and Performances

The SSMS dispenser contains 43 satellites. The total mass of the PL to be separated is about 759 kg. The dispenser structure is to be considered as an additional inert mass of about 540 kg including the adapter 1194 (of 81 kg). The design of a mission must take into account the total mass to be put into orbit.

Typical performance maps are available to know what the launcher is able to put into orbit on a given inclination (in this case SSO) and possibly accepting a change of altitude in a multi-PL scheme. The POC mission is not critical in terms of performance even considering a de-orbiting boost at the end of the mission.

Trajectory optimization

To master the complexity (since each satellite cannot be put on a specific orbit), the PLs must be grouped into subsets to be released in given conditions. The VEGA On-board SW is able of performing till 5 Main Engine (AVUM) ignitions. This allows to release the PL on two circular orbits (2 boosts each) plus a last boost to de-orbit the launcher to fulfill the regulation on Space operations.

Between two AVUM boosts associated to each circular orbit, a long coasting phase (LCP1 and LCP2) of about half an orbit is performed. Being the attitude free in LCP, this degree of freedom is used to fulfill thermal constraints. For POC mission, a Barbeque mode of 2 deg/s is imposed.

The 7 microsatellites (ATHENA, NEMO-HD, UPMsat-2, GHGsat, ION, NewSat, ESAIL) on the upper part are released on the following quasi-circular orbit.

Parameter	Nominal
a : Semi-Major Axis (km)	6893.137
e : Eccentricity	0.0012
i : Inclination (deg)	97.4585
ω : Argument of Perigee (deg)	90
LTDN	10:30:00

Figure 15: First target orbit

It is a Sun Synchronous Orbit (SSO) characterized by the parameter LTDN (= Local Time at Descending Node). The first orbit is reached after the end of the second AVUM boost of circularization (event called FC14). The first orbit is a 509 km x 530 km.

After two successive AVUM boosts, a second quasi-circular orbit is reached at the end of the circularization boost (event called FC19). This orbit corresponds to the first Cubesat separation. It is distant from the first orbit by 15 km on the altitude. The orbit of the first Cubesat is a 525 km x 545 km.

Parameter	Nominal
a : Semi-Major Axis (km)	6908.137
e : Eccentricity	0.0012
i : Inclination (deg)	97.5158
ω : Argument of Perigee (deg)	90

Figure 16: Second target orbit

Maneuver design and timeline

This main canvass is made more complex by using other degrees of freedom:

- The PL release times and the separation DV (in norm and direction)
- The boosts allowed by the thrusters of the RACS system (Roll and Attitude Control System). The longitudinal thrusters can be used to perform boost to distance the PL and practically reach different, though very close, orbits.

The separation logic for the 7 upper Microsatellites is the following:

- FC14: ATHENA is released
- FC14 + 1.5s: NEMO-HD and UPMSAT-2 are released
- FC14 + 3.5s: GHGsat is released in a transversal direction (having a specific deployer as for Cubesat)
- FC14 + 510s: RACS boost of 2.2 m/s is performed
- FC14 + 580s: NewSat and ESAIL are released
- FC14 + 580.08s: ION is released

The intermediate RACS boost allows the non-collision of the satellites by putting the last three ones on a slightly different orbit.

The separation logic for the 36 Cubesats is not detailed here. But the point is that the release is commanded by the SSMS sequencer with a time step of 5s (sometimes two Cubesats are released at the same instant) starting from the event FC19. This timeline is defined inside the Avionics (through two sequencers) not inside the On-board SW which only defines the FC19 event. The last separation occurs 160s after FC19.

During this long separation phase of 160s, the attitude control is kept by the RACS thrusters (for Cubesats, the possible contamination by thrusters is not a constraint). To keep control allows to ensure a good spacing of the PL and to guarantee non collision. The longitudinal axis of the launcher is oriented towards the out of orbit axis, allowing a separation of all the Cubesats in the orbital plan.

In addition, the attitude control kept during the 160s makes the design more robust to a last-minute change of mission: if a PL is removed or exchanged, unbalance of global center of mass may occur inducing possible disturbances at separations.

The choice of the 160s allocated to separate the Cubesats is the result of a trade-off: it should be as long as possible to avoid collisions between Cubesats but as short as possible to be compatible with visibility constraints.

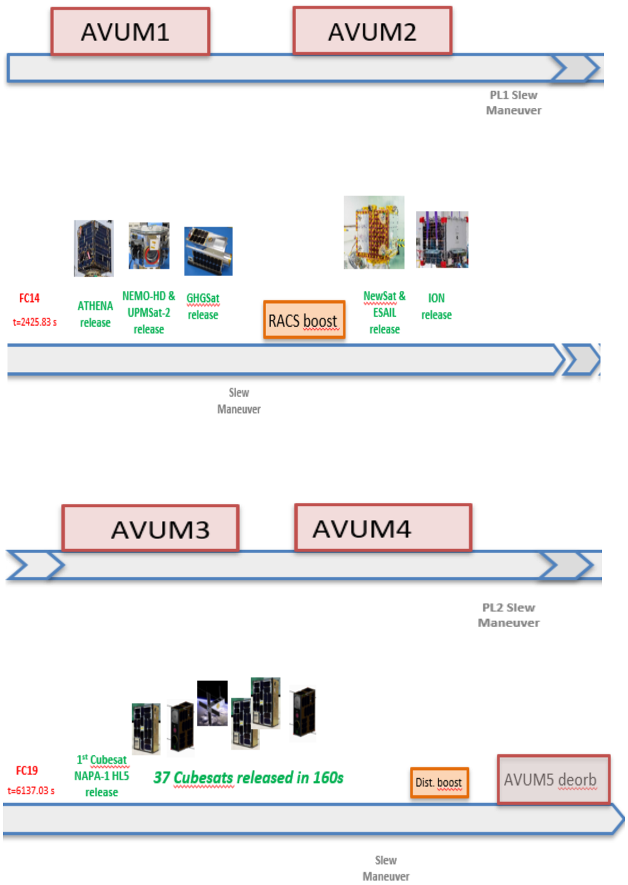

Figure 17: Timeline in orbital phase

De-orbiting boost

After the last Cubesat separation, a RACS boost of 12 m/s is commanded in the Out-Of-Plane direction. It is the best way to avoid possible collisions with the set of Cubesats. After a short waiting phase, the de-orbiting boost is commanded by Main Engine ignition (named AVUM5 boost). The visibility from Ground stations is also a constraint for this sequence.

Flight parameters

Examples of flight variables are provided hereafter (ground track and altitude profile) where the boosts phases are indicated. The AVUM3 and AVUM4 boosts are so short that their position is indicated by their names more than by the red dots of propelled phases.

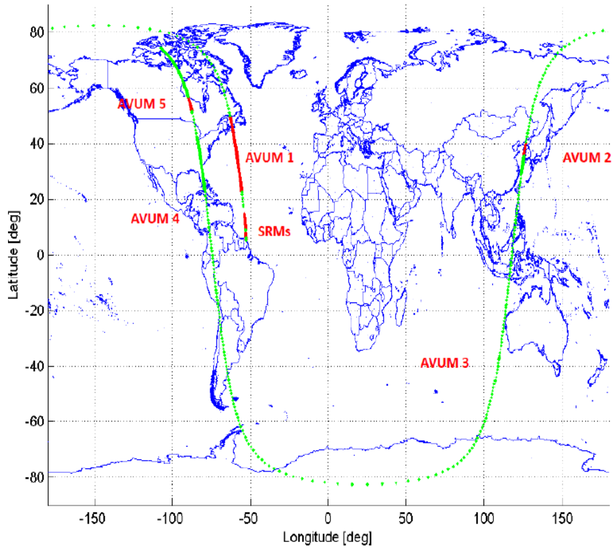

Figure 18: Ground track

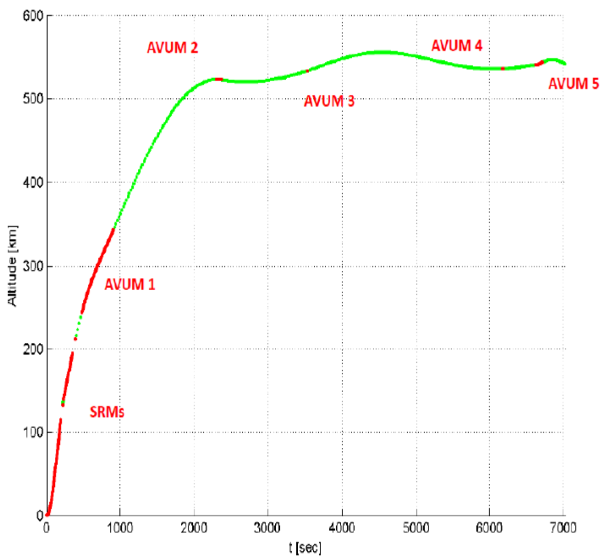

Figure 19: Altitude profile

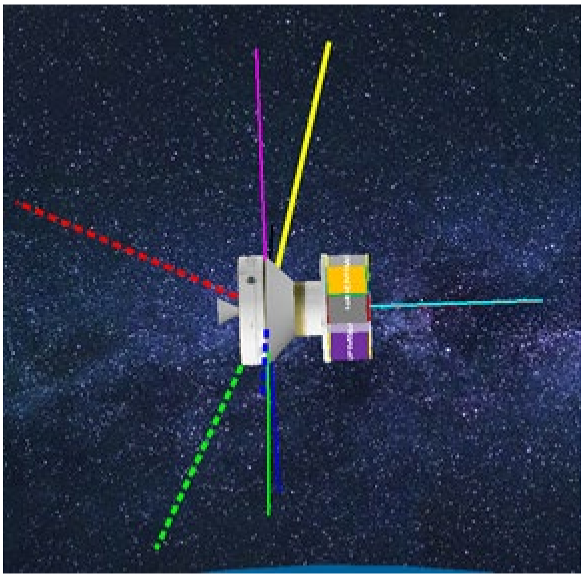

Figure 20: Attitude just before ATHENA release

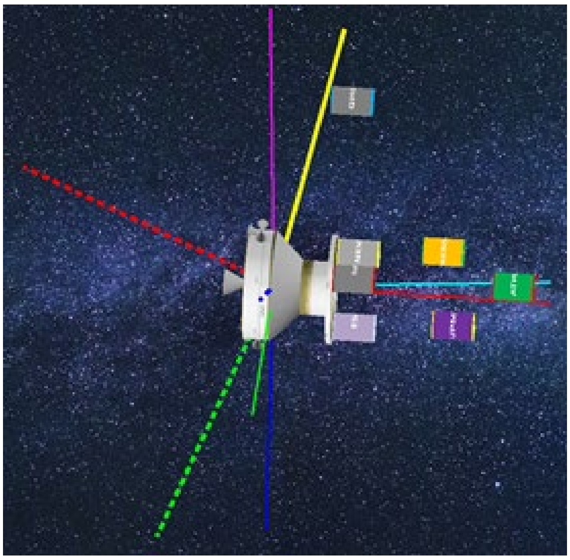

Figure 21: Attitude 10s after ATHENA release

SEPARATION STUDIES

The separation studies cover several activities depending on the horizon to be considered:

At very short-term, clearance analysis is done to be sure that no collision is found between each PL and the launcher on one hand and with all the PL separated so far on the other hand

At mid-term, it is to be shown that no collision is found after 1.5 orbit.

Clearance (very short term)

The clearance analysis is based on the 3D-geometry of the different satellites, especially the Microsats. A set of critical points are defined a priori on these satellites.

The non-collision is demonstrated by Monte-Carlo simulations.

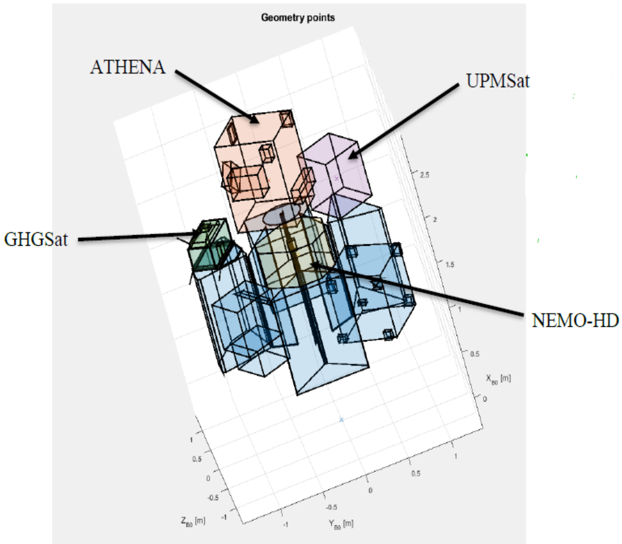

Figure 22: Geometry for clearance analysis

Short-term and Mid-term collisions

In the short-term and mid-term analysis, the satellites are modelled as mass points.

The risk of collision is presented in orbital frame and in relative wrt launch vehicle position. As an illustration, the following figures show the evolution of the different Microsats and the Cubesats after their respective separation.

In addition to these figures, matrices of inter-distances (with the worst values computed over a set of Monte-Carlo runs) is computed to demonstrate the compliance in terms of non-collision requirements.

For Microsats (and not for Cubesats), the non-contamination by RACS thrusters as well as Main Engine plume during the boost is also demonstrated.

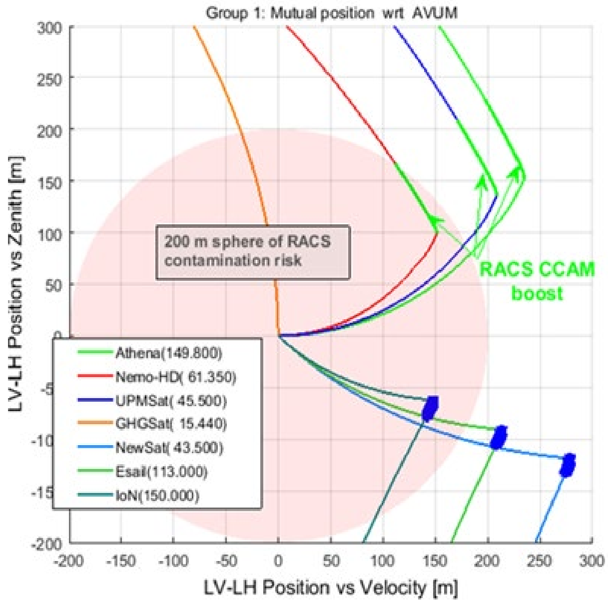

Figure 23: Short term relative motion (Microsats)

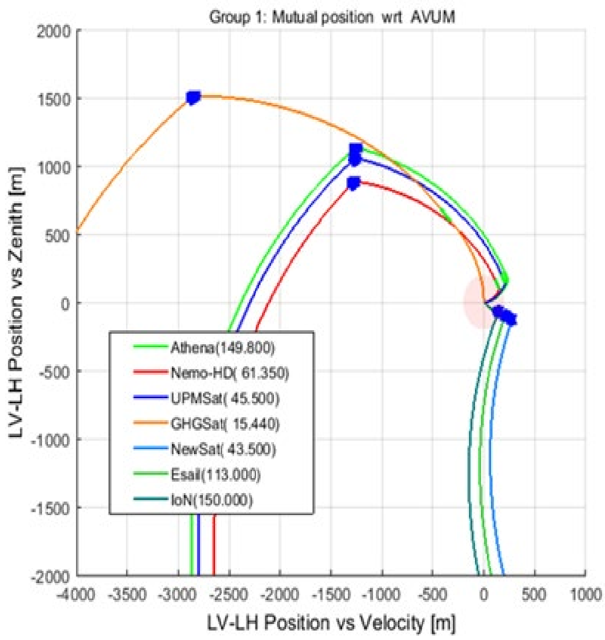

Figure 24: Mid-term relative motion (Microsats)

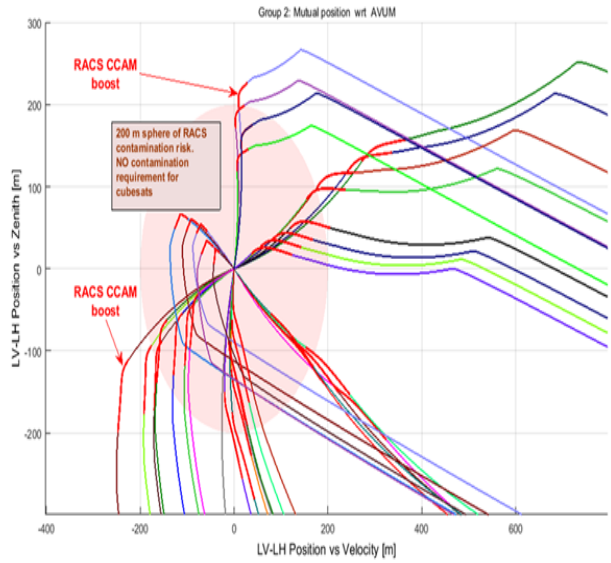

Figure 25: Mid-term relative motion (Cubesats)

The close distance between 1st and 2nd orbit (15 km of altitude) does not present a specific collision risk. Even if the worst case injection accuracy has the same order of magnitude (15 km on semi-major axis), it has been shown that statistically, the scattered cases with highest altitude at end of 1st boost are correlated with the cases of highest altitude at end of 2nd boost (and not with the cases of lowest altitude for which a risk of orbits intersection could occur).

CONCLUSION

The SSMS POC to be flown on VEGA is a complex mission: the FLEXI-3 dispenser allows the separation of 43 satellites grouped into subsets: 7 Microsats separated in two subsets on a quasi-circular orbit and then 36 Cubesats separated in a short phase of 160s on a second quasi-circular orbit.

The mission design is shown compliant to the requirements (propellant budget, injection accuracy, probability of non-collision and non-contamination, safety rules). Several specific problems have been solved while doing the Missionization and can be capitalized as rules for the future SSMS activities. The Missionization tools have been updated and adapted to deal with such a complexity (such as the computation of non-collision between dozens of PL).

The POC mission is to be flown with VEGA launcher and its GNC algorithms inside the On-Board SW. For VEGA-C, the GNC algorithms are made more flexible (more AVUM boost and thus more target orbits) which will be exploited for enlarge the range of SSMS missions.