IN-ORBIT COLLISION ANALYSIS FOR VEGA SECOND FLIGHT

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ABSTRACT

ELV, as prime contractor of the VEGA launcher, which operates in the protected LEO zone (up to 2000 km altitude), has to demonstrate that it abides by ESA debris mitigation rules, as well as by those imposed by the French Law on Space Operations (LOS).

After the full success of VEGA qualification flight, the second flight(VV02) will extend the qualification domain of the launcher to multi-payload missions, with the release of two satellites (Proba-V and VNRedSat-1) and one Cubesat (ESTCube-1) on different SSO orbits The multi-payload adapter, VESPA, also separates its upper part before the second payload release. This paper will present the results of the long-term analyses on in-orbit collision between these different bodies.

Typical duration of propagation requested by ELV customer is around 50 orbits, requiring a state-of-the-art simulator able to compute efficiently orbits disturbs, usually neglected in launcher trajectory optimization itself. To address the issue of in-orbit collision, ELV has therefore developed its own simulator, POLPO [1], a FORTRAN code which performs the long-term propagation of the released objects trajectories and computes the mutual distance between them.

The first part of the paper shall introduce the simulator itself, explaining the computation method chosen and briefly discussing the perturbing effects and their models taken into account in the tool, namely:

- gravity field modeling (zonal and tesseral harmonics)
- atmospheric model
- solar pressure
- third-body interaction

A second part will describe the application of the in-orbit collision analysis to the second flight mission. Main characteristics of the second flight will be introduced, as well as the dispersions considered for the Monte-Carlo analysis performed. The results of the long-term collision analysis between all the separated bodies will then be presented and discussed.

1. VEGA LAUNCH VEHICLE

Vega is a light launcher designed to lift small payloads in Low Earth Orbit (LEO). It is a four stage rocket, 30 m tall, 3 m in diameter and weighs 137 tons. The first three stages powered by Solid Rocket Motor engines (SRM), approx. 80, 23 and 9 tons, respectively. The engines were developed using innovative technologies, and this applies in particular to the casing, made of highly sophisticated carbon fibre composites. The upper stage of the Vega is a liquid propulsion module with multiple re-ignition capability. The first stage of the Vega uses the biggest, most powerful one-piece solid-fuel engine ever built, the P80 SRM. It is about 11 m tall, this stage is 3 m in diameter, weighs 95 tons and burns ca 88 tons of solid propellant in about 2 minutes. The P80 generates a 300 ton thrust. The second stage is powered by Zefiro 23 SRM. This is 7.5 m tall, it has a diameter of ca 2 m and weighs 26 tons, 24 of which is accounted for by the solid fuel that are burned in 80 seconds. The third stage is propelled by the Zefiro 9 SRM, it is 3.5 m tall and just less than 2 m in diameter and it weighs 10 tons and burns 9 tons of solid fuel in just two minutes. The fourth stage AVUM is powered by a pressure fed bi-propellant engine. It is accounted to refine the target orbital parameters, to compensate the typical scattering of solid propulsion engines, to control the attitude and the roll of the launcher and to point correctly the payload(s).

2. IN-ORBIT COLLISION ANALYSIS

The purpose of this work is to present the in-orbit collision (ICO) analysis conceived as part of the VEGA Mission Analysis. In the frame of system design activities, the IOC analysis is aimed to study possible in-orbit collisions among the bodies left in orbit at the end of mission.

Furthermore, since VEGA launch vehicle permits to perform both Single Payload and Multi Payload missions, ELV tools need to carry out studies in both scenarios.

Methodologies and results of this analysis are showed in this paper, in particular in the frame of the second flight [2].

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Actually in-orbit collision analysis is carried out by two proprietary tools: POLPO and SepaSim [3].

Both tools have been designed in order to easily interface with the trajectory simulators in ELV for VEGA Programme. Furthermore both codes have been cross-checked successfully with external tools. SepaSim is a six-degrees of freedom motion simulator. Actually it is used to carry out the analysis of transient phases and separations. A further development allowed its application for in-orbit collision studies in the short period too. Considering the range of missions, the tool is tuned to consider the prevalent effects at the altitude of interest (e.g. drag and Earth's oblateness effects).

Besides the principal disturbance effects in Low Earth Orbit, it can simulate the additional perturbations induced on the AVUM by the end-of-life space activities. This capability has been intensively used to simulate forces and couples due by the evacuation of remaining propellants at the end of the mission (i.e. the passivation process, mandatory activity to keep international space laws). It can be considered a tool for short-period analysis.

Figure. 1. VEGA LV at lift-off from French Guyana Space center (ESA)

3. POLPO

POLPO is a three-degrees of freedom orbital propagator [1]. It is an evolution of the previous tool and it used to perform analysis in the long term period. In fact some perturbation effects, considered negligible in SepaSim, needed to be taken into account, to avoid the loss of precision in long term analysis. Therefore, respect to SepaSim, it allows to simulate more disturbance effects. In fact is possible to take into account luni-solar perturbations. The detail of the gravitational field can be defined by the user selecting the order of zonal and tesseral harmonics to take into account. The solar pressure radiation can be modelled too, also detailing the body proprieties. For each body the proprieties of reflection and absorption of the photons can be assigned. The relevant equations are integrated by a 7th-8th order Runge-Kutta-Fehlberg scheme. An algorithm allows to automatically adapt the integration stepsize depending on the required integration tolerance. Furthermore POLPO can be used to estimate AVUM orbital lifetime too. This capability has been successfully crosschecked by external tools, DAS (developed by NASA) and STELA (developed by CNES). Results of the orbital propagations are compared with simulations in Satellite Tool Kit (STK). Furthermore University of Rome "La Sapienza" carried a campaign of validation by GEODYN [1]. Both testing campaigns closed successfully.

4. VV02 Mission

This paragraph presents some features of the VEGA second flight, with particular attention to the problem of the risk of in-orbit collision after the end of the mission. A detailed analysis of the results cannot be report in this frame, but some typical charts are showed as example.

4.1. A summary of the mission

The second flight will be the first multipayloads mission for VEGA and it will test new capabilities. After two boosts of AVUM, stagger by a ballistic phase, Proba-V is released in a 812 x 828 km orbit, with inclination 98.730 deg. After a contamination and collision avidance manoeuvre (CCAM), AVUM peforms its 3rd firing to low the perigee the altitude. In the resulting orbit VESPA Upper Part is released. Therefore the first satellite and part of the payload adapter are coplnara and they share the same apogee altitude. After the second ballistic phase, the last stage fires again near the perigee to the transfer orbit. This manoeuvre insert the LV in the VNRedSat-1 target orbit, a 657 x 670 km. During this boost the LV changes its orbital inclination reaching 98.138 deg, thus VESPA Upper Part and VNRedSat-1 are not coplanar. Anyway the perigee of the payload adapter is at the same altitude of the second payload. After the second CCAM manoeuvre ESTCubeSat-1 is released. Since the CCAM manoeuvre delivers a littler ΔV than an AVUM boost, the cubesat final orbit is very similar to the VNRedsat-1 one. After a coasting phase, the last boost injects the launch vehicle in a re-entry trajectory with a splashing point in the South Pacific Ocean [2].

4.2. Methodologies and results

Since the last stage is planned to re-enter into the atmosphere during the first orbit, this mission did not need SepaSim analyses. As reported in the previous paragraph, several orbital parameters of the released bodies are similar. Because of this mission characteristic, in the frame of the final analysis the hereafter in-orbit collision studies were needed:

- Proba-V – VESPA Upper part
- VESPA Upper part – VNRedSat-1
- VESPA Upper part – ESTCube-1
- VNRedSat-1 – ESTCube-1

Even though the standard analyses are based on 50 orbits, the most critical cases are been studied in a period of 5 years.

The Fig.2 shows a typical example of output of this analysis. In fact the mutual distances among the released bodies is the main figure of merit to check

The analysis shows well known periodic trend with different frequencies [3]. In the frame of VV02 analyses no risk of collision occurs in the nominal scenario.

Besides the nominal case, a Montecarlo campaign has been carried out, linked up to dispersed trajectories of the relevant simulators. In fact the corporate six degree of freedom tool provided the ephemerides of the released body for each case of its own Montecarlo campaign.

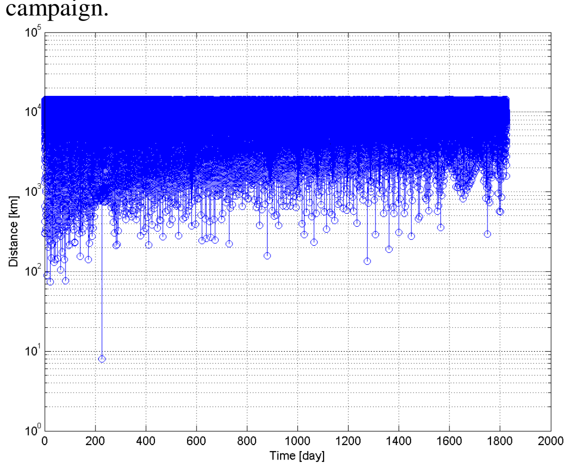

Figure. 2. Typical chart of mutual distance between two bodies in a nominal analysis.

POLPO Montecarlo [2], an evolution of the standard version, applies further scattering on the mass and aerodynamic proprieties of the bodies, in the frame of a multidisciplinary activity. Fig. 3 shows the typical results of a Montecarlo campaign involving two bodies. The chart reports a superimposition of the whole batch of the campaign.

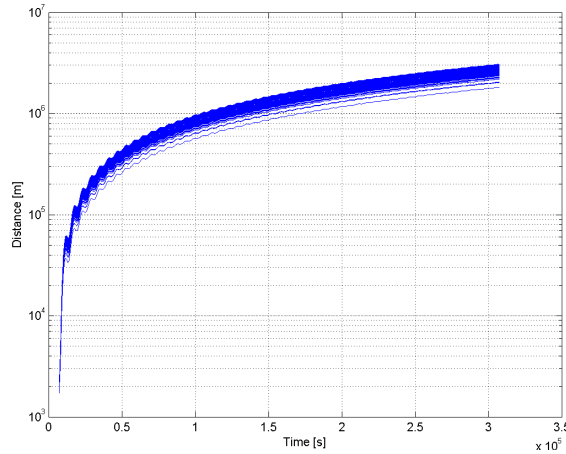

Figure. 3 Superimposition of runs composing a Montecarlo batch.

Therefore this activity demonstrated no risk of collision occurs both in the nominal trajectories and in the dispersed trajectories [3].

5. CONCLUSION

The in-orbit collision analyses of long-term period takes their own place inside the frame of the final mission analysis review. In fact both customer and safety authorities require no risk of collision, and consequently debris generation, occurs after the launch vehicle flight. Therefore a detailed study has been carried out for the VEGA second flight by ELV, the prime contractor of the launch vehicle. Furthermore ELV had to fit out its internal tools with new features to meet the customer requests. All analyses demonstrated no risk of collision occurs among the released bodies.

6. REFERENCE

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