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Optimization of constellation jettisoning regards to short term collision risks

D.-DA.-A. Handschuh *, E. Bourgeois

CNES - Launcher Directorate, 52, Rue Jacques Hillairet, 75012 Paris, France

A B S T R A C T

The space debris problematic is directly linked to the in-orbit collision risk between artificial satellites. With the increase of the space constellation projects, a multiplication of multi-payload launches should occur. In the specific cases where many satellites are injected into orbit with the same launcher upper stage, all these objects will be placed on similar orbits, very close one from each other, at a specific moment where their control capabilities will be very limited. Under this hypothesis, it is up to the launcher operator to ensure that the simultaneous in-orbit injection is safe enough to guarantee the non-collision risk between all the objects under a ballistic hypothesis eventually considering appropriate uncertainties.

The purpose of the present study is to find optimized safe separation conditions to limit the in-orbit collision risk following the injection of many objects on very close orbits in a short-delay mission.

1. Introduction

The space debris problematic is nowadays no more discussed: it appears as an absolute need to limit their multiplication if we want to sustain a safe and efficient exploitation of the outer space. The first thing to do so is to prevent from any in-orbit collision between artificial satellites. In fact, in-orbit collision is the first step on the road to the Kessler Syndrome that we want absolutely to avoid.

Last few years, many private companies began to work on new orbital constellations very richly populated in satellites: OneWeb has announced a constellation of 648 satellites spread out in 18 orbital plans at an altitude of 1200 km and an inclination of 87.9° [1] and SpaceX has announced another constellation of 4425 satellites disseminated on 83 orbital plans with altitudes from 1110 km to 1325 km and inclinations from 53° to 81° [2]. Samsung [3], LeoSat Enterprises Inc. [4] or Telesat [5], have also expressed their interest for this kind of in-orbit constellations. All these constellations are based on the exploitation of small, cheap to produce and cheap to launch satellites. With such an economic scheme, the use of multiple launches (many satellites per launcher) seems to be a solution to focus on.

However, in this case of multiple launches, it is essential to be sure that there is no risk of collision between all the injected bodies in a short (i.e. few minutes after the jettisoning) or a mid-term (i.e. around the orbital period duration). In fact, by definition, all injected objects will have very close orbits one to each other because the propelled phase of the launch which is the main contributor to the orbit definition is common to all of them.

It has also to be noticed that during first moments or orbits following the release from the launcher, satellites may not be operational and specifically, they could be without any capacity to control their attitude. In particular, if the attitude control of the satellite is ensured by an electric propulsive system or magnetotorquers, it is likely that this system will need a certain time delay to be turned on and configured in-orbit before being operational. Therefore, satellites have to be injected on safe orbits from their injection point to ensure that, even strictly passive, there is no risk of collision with each other. This non-collision guarantee has to be given by the launch operator and ensured by mission analysis.

In this mission analysis, launch operator has to demonstrate that it is releasing all the embedded satellites on orbits sufficiently different to ensure that there will be no overlapping of the trajectories in an time horizon defined with the satellite operator. This time horizon's definition has to take into account the delay needed by the satellite operator to manage the attitude control system. This delay should become very long (and perhaps infinite) if the satellites do not include any attitude control system as it is commonly the case for cubesats.

On the 15th of February 2017, the PSLV Indian launcher broke the world's record of the number of satellites launched on one unique rocket: 104 satellites (the Indian satellite Cartosat-2D, 2 nano-sat class demonstrators [INS-1A and INS-1B] and 101 cubesats) [6]. Such a mission is exceptional but has to be treated with a particular caution regarding to the mission analysis.

The following article is presenting classical good practices that can be used by launch operators to assess the distancing between bodies when realizing a multiple launch. Then, after introducing what could be a

* Corresponding author.
E-mail addresses: David-Alexis.Handschuh@cnes.fr (D.-DA.-A. Handschuh), Eric.Bourgeois@cnes.fr (E. Bourgeois).

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classical launch mission for a constellation in-orbit deployment, the article presents the different solutions that a launcher has to ensure non-collisions between all its embedded payloads. After that, an optimization of the different separation directions is proposed to maximize the distancing between bodies simultaneously released. At last, an optimization of the overall multiple launch missions is proposed focusing on the maneuvers of the upper stage between each jettisoning.

2. Different ways to assess the non-collision risk

When jettisoning a satellite from a launcher, it will have to realize a set of maneuvers to reach its operational orbit. These maneuvers do not necessarily begin just after the satellite jettisoning. Therefore, some satellite could have operational constraints that implies to turn on progressively all the on-board systems involved in the attitude control, others can have visibility constraint or need to wait for the availability of the ground station before acting on their orbit, others can need to calibrate their orbital control system before using it in full operational way … De facto, waiting for all these constraints to be fulfilled, the satellite will remain freely uncontrolled on its ballistic initial orbit given by the launcher. That is why it is so important that the launch operator proposes to its clients a set of maneuvers during the orbital phase of the launch mission to differentiate the orbit of each injected object. A specific analysis has to be conducted to attest the efficiency of the sequence regarding to the collision risk between bodies.

Thus, the Ariane 5 user's manual [7] and the Vega user's manual [8], both edited by Arianespace, the European launch operator, include in the mission analysis the distancing evaluation between all injected bodies: "for each mission, Arianespace will verify that the distances between separated spacecraft and launch vehicle are sufficient to avoid any risk of collision and, if necessary, the separation system will be adequately tuned". To allow Arianespace to conduct this analysis, the User's Manuals are asking the satellite operator to give its flight plan description (in particular all maneuvers aiming at modifying the orbit or the attitude of the spacecraft during the firsts hours following the launch). Otherwise, Arianespace will realize its distancing evaluation considering the satellite purely ballistic.

Many techniques could be implemented to check this non-collision risk:

- One can try to inject each body on a different orbit. As an example, orbits might be differentiated through different perigee/apogee altitude, or inclination modification;
- In many cases, if orbits asked by the clients are very close one from each other, short term distancing might be implemented using the attitude control system of the upper stage between two jettisoning. Orbits will be marginally modified but distancing between bodies could be ensured. In such a case, it could be interesting to produce a statistical dedicated study to validate the lack of collision risk.
- Sometimes, it can be showed that distance between bodies is always increasing, or at last, during a certain time. In this particular case, no collision can occur.
- If the infinite increase of distance is too hard to demonstrate, it is maybe possible to show that the distance will increase monotonically till a certain safe distance and then, bodies will never come closer than this distance again.
- …

Choice of a strategy to demonstrate the safe situation should be made regarding to the mission, the involved satellites, the number of satellites, the targeted orbits, etc …

In the particular case of the injection into orbit of many satellites simultaneously, as it could be the case when deploying a constellation, it suits to realize a collision risk assessment between all bodies two by two on a dedicated time horizon that could be quite long. Indeed, if there are many payloads to inject, the launcher's mission could be unusually long. The analysis will have to cover no less than all the payloads' jettisoning till the upper stage's end of life maneuver (such as potential deorbitation and, at least, passivation). It could be really recommended to proceed with this analysis during, at least, one complete orbital period following the last jettisoning. Potentially, it could be asked by the satellites operator to spread the study longer depending on its needs.

3. A typical launcher mission to deploy a constellation

All the announced constellations [1–5] that have been presented yet evoke hundreds or even thousands satellites operating in LEO (i.e. less than 2000 km of altitude). Looking more precisely on the specific example of the OneWeb envisaged constellation [1], it appears that:

The overall network of satellite would be deployed thanks to 2 types of launchers carrying either 32 or 2 payloads. The targeted orbit is not the operating one but would be at a lower altitude (around 450–475 km for the injection compared to an operational altitude of 1200 km). The upper stage of the launcher will be deorbited just after the end of the deployment of all its embedded clients. Thus, the upper stage will not interfere with the just injected group of satellite. At least, the upper stage has to be considered in the distancing study till its atmospheric re-entry.

It is also announced that the satellites will fly up till there operational altitude following spiral orbits using low-thrust Hall Effect ion engine. This means that the embedded attitude and orbit control systems of each satellite won't be functioning directly after the jettisoning. Indeed, these particular electrical propulsive systems need a certain time to be activated.

With such hypothesis, it is a need that every orbit where a satellite of the constellation is released is intrinsically safe enough with regard to the collision risk problematic.

Moreover, always considering these assumptions, the way up of each satellite till its operational position inside the constellation will last many weeks. Thus, it can be supposed that it won't be problematic to slightly modify the initial orbit of each satellite to guarantee the absence of collision risk. The initial added perturbation to fulfill this requirement will be easily compensated during the long ascent phase till the operational position.

It is also known that Arianespace asked to RUAG to develop a specific payload dispenser to realize the OneWeb mission [9–11]. This dispenser should be able to carry into space and to release in orbit 32 satellites in one shot. It will be organized in four tiers of eight satellites equally split all around the dispenser.

4. Available means to ensure the non-collision

As previously said, the launch operator has the responsibility to ensure the absence of risk of collision at short or mid-term between all the injected objects via a multiple launch. To do so, the launch operator has different devices:

- The main engine of the upper stage
- The attitude and orbit control system of the upper stage
- The separation system of each satellite from the launcher
- The dispenser, if any, on which all the payloads are attached.

4.1. The main engine of the upper stage

If the main engine of the upper stage is re-ignitable, as it is on the Fregat upper stage of the Soyuz, it is possible to release every satellite on different orbit. These more or less important orbital modifications can be realized regarding to the functional capacity of the upper stage and its engine on one hand and regarding to the asked performance to the launcher on the other hand.

Thus, as an example, during the first flight of the European Vega launcher held in 2012 [12], the main payload "LARES" has been injected