UNITED NATIONS
Office for Outer Space Affairs

Promoting Space Sustainability

Collision avoidance

European Space Agency

25/02/2021

Implementation of the Guidelines for the Long-term Sustainability (LTS) of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space

Operational Case Studies

I. Short description of the outer space activity

When we look at the space debris environment, there are two perspectives related to performing collision avoidance activities. On one hand, operators want to avoid that the mission of their satellites is prematurely terminated by the impact with a piece of space debris. This could happen already for collisions with objects larger than 1 cm and it is estimated[1] that there are around 900000 objects larger than this size. Some of the objects are too small to be tracked from ground, but the larger ones (e.g. larger than 10 cm in Low Earth Orbit, LEO) are included in catalogues compiled and maintained by Space Surveillance Networks. This means that their position is know and its evolution can be predicted with an accepted level of confidence. As a result, the conjunctions with these objects can be monitored and avoided in case of a high risk of collision.

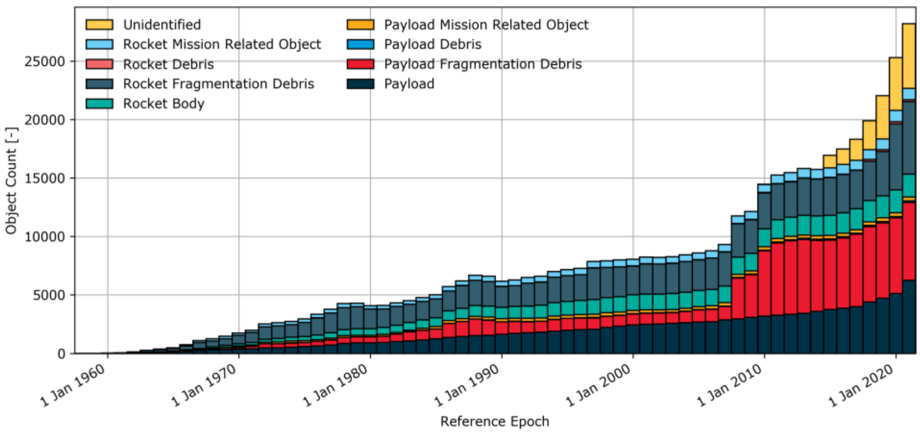

Figure 1. Tracked objects by category (as of end 2020).

[1] https://sdup.esoc.esa.int/discosweb/statistics/

By avoiding such conjunctions, one also limits the risk of new fragmentation events that have the potential of adding a considerable amount of objects to the environment. This is what occured, for example, in 2009, when the Iridium-33/Cosmos-2251 collision added more than 3000 fragments to the total count of objects tracked in catalogues (**Figure 1**).

For ESA performing collision avoidance activities means mainly taking care of around fifteen ESA-operated and third party missions in LEO plus additional spacecraft in other orbital regimes. We can see in **Figure 2** the distribution of these missions in altitude and how they overlap with the profile of a modelled debris spatial density. It appears that we operate several missions in proximity to the peak with the highest debris density.

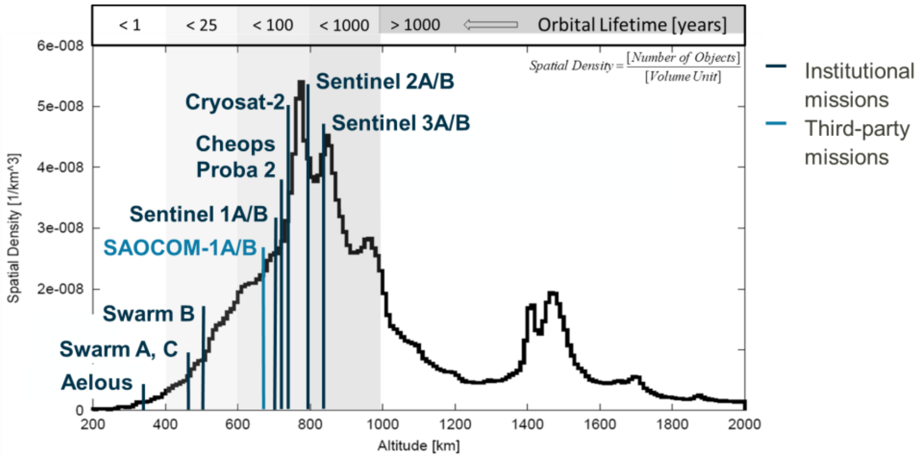

Figure 2. Distribution of the missions serviced by ESA collision avoidance activities.

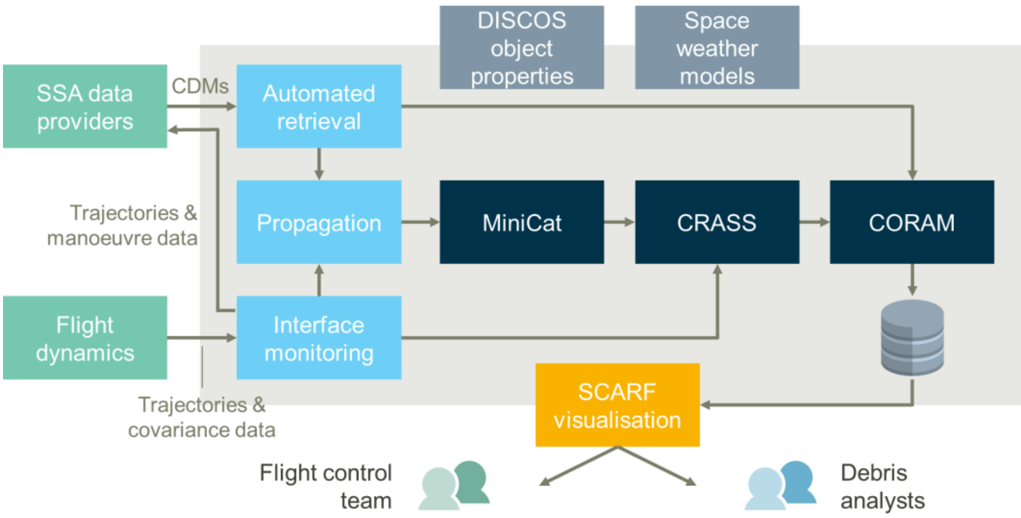

Figure 3. Schematics of ESA Collision Avoidance process.

The custody of these missions is performed through the process[2] in **Figure 3**. The process is fed by two main sources: on one hand, the surveillance networks provide us with orbital data on space objects in the proximity of our missions, and, on the other hand, flight dynamics teams provide updated information on the trajectories, uncertainties, and planned manoeuvres of our satellites. This data is automatically retrieved and processed to identify high-risk events, and the results related to the screened conjunctions is stored in a database to allow for further statistical analysis. The data is also available through a web-based interface, both to the debris analysts and to the flight control team, so that it can be used to monitor the evolution of risks, and to make informed decision on when and how to manoeuvre.

The processing of the data is largely automated, but monitored by a debris analyst that will alert the flight control team in case of high risk and support the design of avoidance manoeuvres. For a satellite like one of Sentinels, such a manoeuvre is performed roughly every four months - per satellite. On average once a month – per satellite - the predicted collision probability is exceeds an agreed threshold to inform the flight control team. **Figure 4** show some statistics on the total number of alerts and manoeuvre in the recent years.

Each of these executed manoeuvres has a cost. The cost is not only the fuel spent as the manoeuvres tend to be small. The real cost becomes obvious when we consider cases where for a fifteen-second manoeuvre, we had to interrupt the spacecraft operation for eight hours, meaning an outage of data for the scientists and users working with the satellite.

In addition, this system of monitoring and alerts requires a team of experts available 24 hours/day and also this comes with a significant cost, and it results in a not negligible effort for the team as the process of designing and implementing a manoeuvre still involves several manual processes and checks.

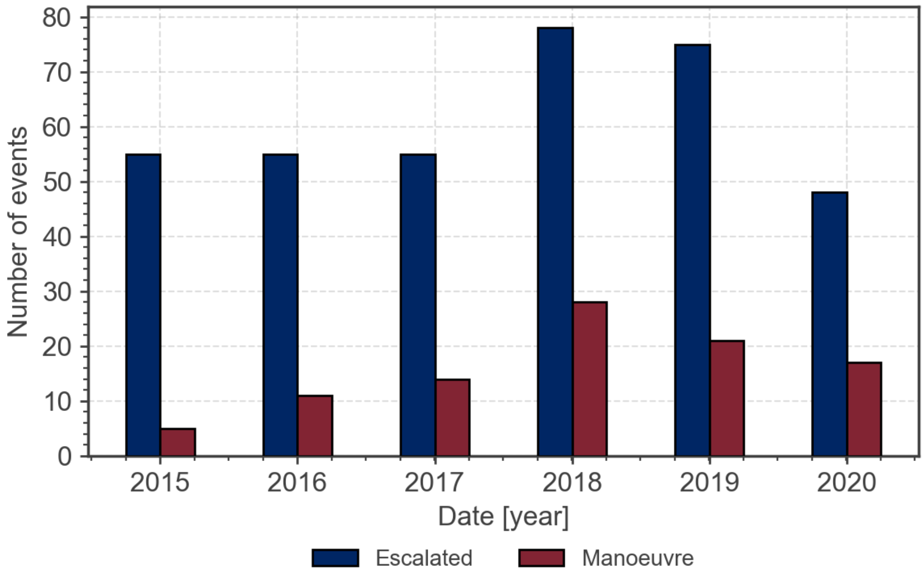

Figure 4. Total number of alerts and manoeuvres performed under ESA Collision Avoidance activities.

[2] K.Merz et al, Current Collision Avoidance service by ESA's Space Debris Office, 7th European Conference on Space Debris, 2017, https://conference.sdo.esoc.esa.int/proceedings/sdc7/paper/1017/SDC7-paper1017.pdf

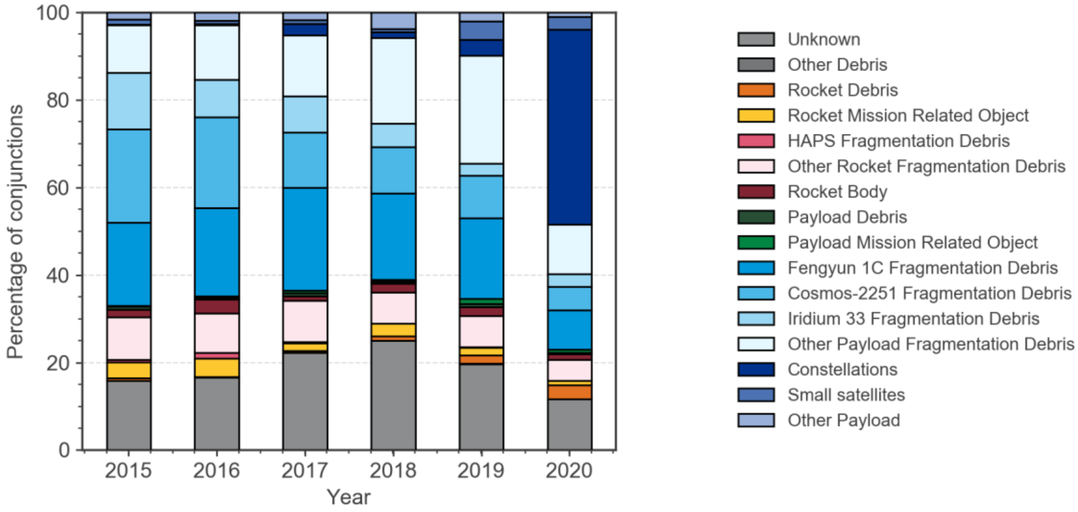

Figure 5. Statistics on secondary objects for events with collision probability > 10^{-6}.

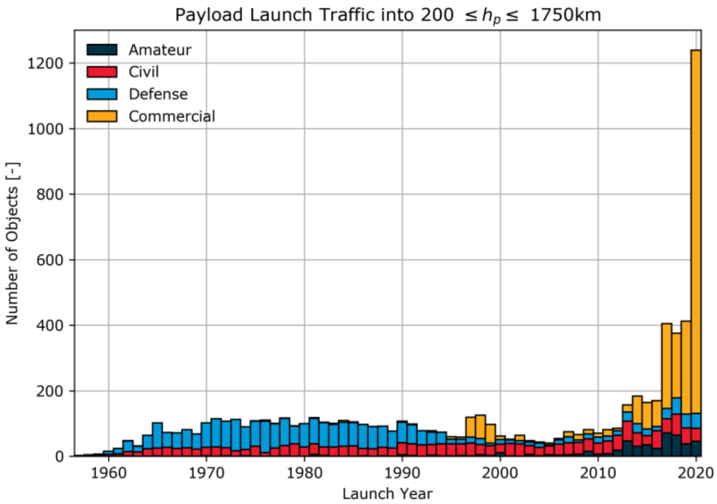

Figure 6. Number of satellites inserted in Low Earth Orbit by launch year.

As all data from the conjunction process is stored in a database we can analyse the conjunctions experienced by our satellites, for example, by checking which kind of objects they encounter, as shown in **Figure 5**. What we see is that fragments from the two large breakup events in 2007 (Fengyun-1C) and 2009 (Cosmos/Iridium) have represented for several years around half of the conjunctions with collision probability above 10^{-6}. In the last year, a new trend is emerging, with more conjunctions involving intact (and sometimes operational) satellites. This change can be related directly to the drastic increase in the number of satellites launched in Low Earth Orbit shown in **Figure 6.**

How can operators deal with this increase in traffic? High-risk events and manoeuvre design still rely on interaction among experts and human intervention is the process. Therefore, a natural evolution is to consider how the overall process can be made more automated, especially supporting decision taking. Several activities in this direction are being implemented as part of ESA Space Safety Programme including, among others, the analysis of historical data for model training and the investigation in coordination mechanisms[3].

[3] T. Flohrer et al, Update on ESA's Space Safety Programme and its Cornerstone on Collision Avoidance, AMOS, 2020. https://amostech.com/TechnicalPapers/2020/SSA-SDA/Flohrer.pdf

II. Connection with the LTS Guidelines

In the past, the issue of collision avoidance was only marginally covered by debris mitigation guidelines. More recently, both technical standards (such as ISO 24113) and the UN LTS guidelines (with Guideline B4) directly address this aspect of space operations and space debris mitigation.

Besides the direct relationship between collision assessment and Guideline B4, several additional guidelines are connected to collision avoidance activities. For example, data exchanges (internally and externally) are carried out applying standard data formats, in line with Guideline B2. These data exchanges cover not only incoming information on secondary objects, but also our own updates on the satellites' and on planned manoeuvres, in line with Guideline B1.

An important data source of the process is our DISCOS database, where we store information on space objects such as, for example, their dimensions. Besides curating the data collection, we also provide access to it worldwide, in line again with Guideline B1. Currently, we have around 500 users that access DISCOS through its web-interface4 and further support several users that directly incorporate DISCOS data in their pipeline for collision avoidance activities.

Decisions on whether to perform a collision avoidance manoeuvre are based on the comparison with mission-specific reaction thresholds. Such thresholds are defined through the analysis of how a certain level of collision probability translates into risk mitigation. We use this approach also to assess how many collision avoidance manoeuvres a mission should expect during its lifetime. In this way, already during the design phase, one can estimate the amount of fuel needed for such future operations. As in the case for DISCOS, the tools and the methodologies used for such assessment during mission design are freely available from our website5 and we currently have around 3000 users of our related software suite (DRAMA). We see this in line with the guideline C2 i.e. a practical way of sharing experience related to space debris mitigation activities.

Performing collision avoidance manoeuvres is communicated often in social media, which is an occasion to increase awareness on space activities and specifically on sustainable operations, in line with the guideline C4.

To support research in sustainable operations, in line with guideline D1, we have organised in 2019 an open competition for researchers to test whether machine-learning methods can be used to predict which conjunctions will result in high-risk events6. The competition has also been an occasion to publish an anonymised version of the data set that we have collected during our operational activity[7].

[4] https://discosweb.esoc.esa.int/
[5] https://sdup.esoc.esa.int/drama/
[6] https://kelvins.esa.int/collision-avoidance-challenge/
[7] https://zenodo.org/record/4463683#.YC1emmhKi71

III. Lessons learned

The wide adoption of standard data formats is fundamental for the scalability of operations, which is important considering the imminent evolution in the traffic to LEO. In this aspect, the Consultative Committee for Space Data Systems (CCSDS) Conjunction Data Messages (CDMs) represent a positive example of how standardisation can work and support operators. Before the standard was established through the CCSDS, related data was shared via email among data providers and known operators. In the 2000' the US took the lead in organising a series of workshops in different regions to understand which information operators needs for using their conjunction data. This was then translated into a first draft of the CDM format, which was then formalised in a publicly and freely available standard and today is largely adopted by operators. Such standardisation processes involving large communities efficiently is particularly relevant now that we are moving away from single sources for SSA data, with the emergence of multiple institutional and commercial data providers. Working with increased data sets, different levels of more comprehensive, accurate, and timely data will drive the need to invest into automation of decision process and also overall coordination among operators through machine interfaces.

Storing the outcome of the conjunction assessments in a database allows further statistics that enable reflecting on the evolution of the environment and space operations. However, this type of analysis is shared only rarely.

The proportion of collision manoeuvres performed to avoid operational satellites is increasing. In this case, coordination is required to check the manoeuvrability status and whether any collision avoidance plan is in place also on the other side. Currently, this is done via emails or calls, but more efficient coordination mechanisms would be needed in a scenario with thousands additional operational satellites. A first (and comparably easy to achieve) step to ease the coordination among operators is to promote data sharing, for example for what concerns the manoeuvrability of an object and its predicted ephemerides.