Closeap: COLLISION PREDICTION AND AVOIDANCE SOFTWARE

GMV's ***Closeap*** COTS software is a software application for **conjunction detection**, **collision risk assessment** (CA) and **collision avoidance** (COLA) **manoeuvres** computation based on usual data sources used in SSA, such as satellite operational information (ephemerides and manoeuvre plans), orbital catalogues, conjunction data messages (CDMs) and two-line elements (TLEs). In addition to the previous capabilities, the software is able to generate interactive plots, summary tables, reports and CDM comparisons in order to display and summarize the most relevant results of the execution. It is based on the well-known and operationally proven ESA's NAPEOS technology, used in tens of missions and a wide variety of scenarios including Flight Dynamics (FD), Precise Orbit Determination (POD), Navigation (GNSS) and Space Surveillance and Tracking (SST).

Closeap has been proved under **stringent operational conditions** and for a wide set of customers including 30+ satellite operators and hundreds of satellites in all orbital regimes (LEO, MEO, GTO and GEO). Among many other uses, ***Closeap*** has been used for conjunction assessment and collision avoidance purposes at the Spanish SST Operations Centre (**S3TOC**, since 2017), the Greek SST Operations Centre (**GRNOC**, since 2023) and the military German SSA Centre (**WRLageZ**, since 2023). Additionally, ***Closeap*** is being used as part of the system ESA is currently developing for CA and COLA services in the frame of the Collision Risk Estimation and Automated Mitigation (**CREAM**, since 2021) cornerstone of its Space Safety Program (S2P).

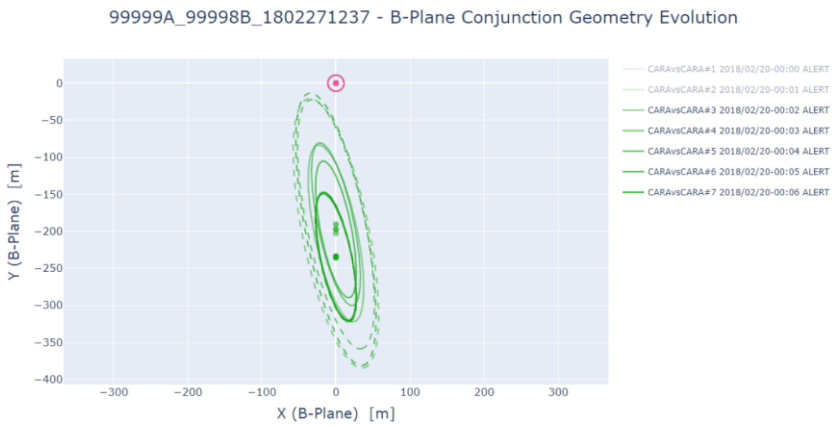

Figure 1. B-Plane Conjunction Geometry Evolution with *Closeap*

From an **interface** point of view, most of the execution-dependent information is passed to the software through clearly defined **file-based interfaces**. Moreover, the software has been designed to comply with standard interfaces (CCSDS OEM, OPM and CDM). In addition, it supports other formats like TLEs.

In **conjunction detection mode**, the software allows to perform **few-vs-few, few-vs-all and all-vs-all screening analyses** in order to detect close conjunctions over a user-defined time interval of analysis. These screening analyses are based on a series of very efficient filters with the aim of improving performance. In addition, the software is able to perform **Middle-Man analyses** where conjunctions reported in CDMs coming from an external SSA provider are re-evaluated using operational information for the primary satellites.

In **collision risk assessment mode**, the software extends the functionality of the conjunction detection mode in order to evaluate the collision risk of the detected/re-evaluated close conjunctions. Regarding the **Hard-Body Radius (HBR) computation** required to assess the probability of collision, the software can compute the HBR based on user-defined values, information available in the input files or external catalogues (e.g., ESA's DISCOS database or the Space-Track satellite catalogue). As for the **probability of collision computation**, the software offers several methods both for **short-term encounters** and **long-term encounters**. In order to deal with **covariance realism issues**, the software is also able to compute a **scaled probability of collision** based on user-defined or automatically computed ranges of **Kp-Ks scale factors** applied to the nominal covariances of the primary and secondary objects. As part of the collision risk assessment, the software can provide **predictions** about the **evolution of the probability of collision** in order to determine whether the risk of a given conjunction event is expected to stay, increase or disappear in the coming future.

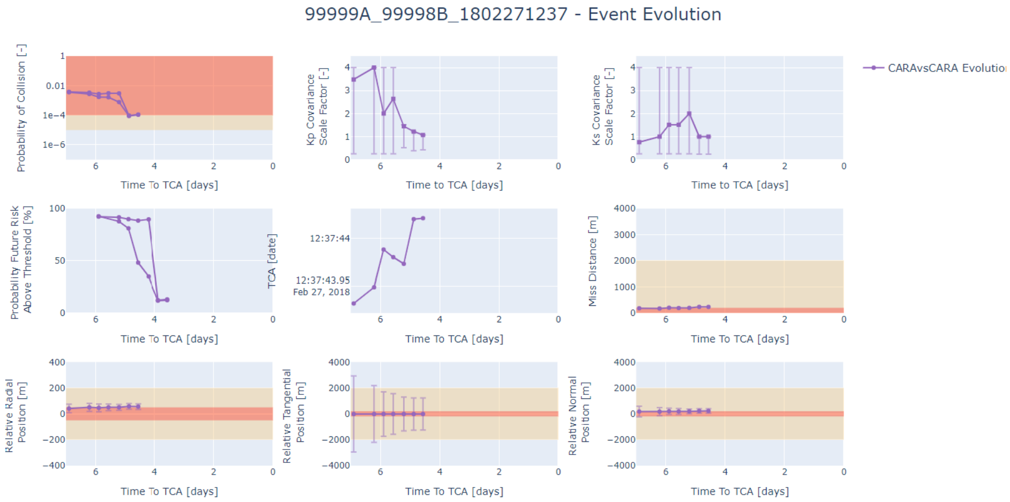

Figure 2. Conjunction Event Evolution with *Closeap*

In **collision avoidance manoeuvre optimization mode**, the software extends the functionality of the collision risk assessment mode in order to propose collision avoidance manoeuvres for those event whose risk level was high enough to require mitigation measures according to the user's preferences. Collision Avoidance Manoeuvres can be designed for impulsive and low-thrust platforms. The latter extend not only to platforms equipped with electrical thrusters, but also platforms with drag augmentation capabilities. ***Closeap*** is able to take into consideration manoeuvre plans taking place between the day of the analysis and the close encounter. If the existing manoeuvre plan cannot be modified to achieve a successful mitigation of the conjunction, a new manoeuvre will be designed. For electric satellites undergoing electric orbit raising or lowering activities involving continuous firing, a suitable shutdown of the thruster will be sought. Alternatively, for impulsive platforms, the strategy is to opt for a modification to the epoch or overall delta-V of an existing manoeuvre.

Closeap implements various design methods to achieve these features. On the one hand, a **parametrical analysis** in manoeuvre epoch and delta-V, assuming an along-track firing, usually the most efficient firing direction, for impulsive platforms, and in manoeuvre epoch and manoeuvre/shutdown duration for low-thrust platforms. On the other, several **optimisation processes**, in which not only manoeuvre epoch, delta-V/duration, but also the direction of firing becomes part of the optimisation, especially relevant for delayed manoeuvres to be executed in the last revolution before the encounter.

Closeap generates plots with the different possible manoeuvres that can be performed following the strategies mentioned above. A self-contained html file is generated with such plots that can be sent to the spacecraft operator for further analysis.

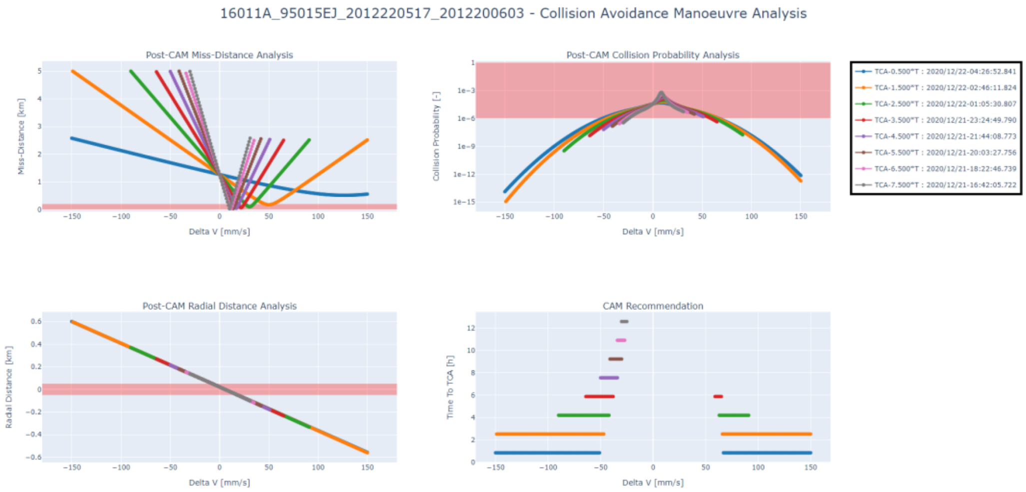

Figure 3. Collision Avoidance Manoeuvre Recommendation with *Closeap*