

# CAESAR, FRENCH PROBATIVE PUBLIC SERVICE FOR IN-ORBIT COLLISION AVOIDANCE

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## ABSTRACT

This paper starts by describing the conjunction analysis which has to be performed using CSM data provided by JSpOC. This description not only demonstrates that Collision Avoidance is a 2-step process (close approach detection followed by risk evaluation for collision avoidance decision) but also leads to the conclusion that there is a need for Middle Man role.

After describing the Middle Man concept, it introduces the French response CAESAR and the need for collaborative work environment which is implied by Middle Man concept. It includes a description of the environment put in place for CAESAR (secure website and dedicated tools), the content of the service, the condition for the distribution of the CNES software JAC and the advantages for subscribers.

## 1 GENERAL CONTEXT

Because of the ever-increasing number of orbital debris, the possibility of a satellite collision with space debris or another satellite is becoming more and more likely. This phenomenon concerns all orbit altitude regime, particularly LEO but also MEO and GEO. Therefore CNES, the French Space Agency, in July 2007 settled an operational collision risk monitoring. After the first collision with an operational satellite in February 2009, major changes began in USA: JSpOC (Joint Space Operations Center from US Air Force) started to monitor collision risk for all the operational satellites and to send information messages describing close approach risks to operators worldwide. In July 2010, Conjunction Summary Messages (CSM) which are complete information to assess a collision alert, are made available for all by USSTRATCOM with a secured access on Space Track website. CNES operational Collision Avoidance process evolved to take into account access to CSM data. The evolutions of CNES process up until 2011 are described in [1].

## 2 CONJUNCTION ASSESSMENT WITH CSMs

Conjunction Summary Messages (CSM) are real satellite protection provided by JSpOC for all active satellites. They are made available on Emergency Criteria which are Time of Closest Approach (TCA) within 72 hours combined with for Low Earth Orbit (LEO) overall miss distance lower than 1km with radial miss distance lower than 200m and for higher orbits (GEO and MEO) overall miss distance lower than 10km. CSMs include: identification of the 2 objects, TCA and for each object position, velocity, dispersion and some orbit determination characteristics. Nevertheless, they are advisory and informational messages only and are not directly actionable: they don't provide a direct recommendation to perform an avoidance action and of course they cannot take into account the operational constraints of the asset.

Therefore, satellite Owner/Operators (O/O) must:

- evaluate the level of risk of the conjunction according to their own criteria;
- decide to perform or not an avoidance action, in other words detect among all conjunctions described with CSMs the High Interest Events (HIE);
- compute the avoidance action taking into account the operational constraints.

Conjunction Assessment using CSMs is not so easy to perform especially when a conjunction description is given through multiple CSMs. While each CSM provides a unique evaluation of the level of risk and can roughly easily lead to conclude if O/O criteria for avoidance actions are met, multiple CSMs do not always refine the description with consistent data. Each new CSM comes from a new Orbit Determination (OD) at JSpOC. Since OD is very sensitive to measurements (sensors distribution, dispersions, biases ...) and since realistic covariance is not easy to evaluate, successive OD are not always consistent. In such cases, it is not easy to evaluate if O/O criteria for avoidance action are met and which avoidance action should be chosen.

Conjunction Assessment using CSMs implies:

- consistency checks must be done using all CSMs;
- O/O must be ready 24/7 to perform the analysis with very short notice;
- Difference (if any) between CSMs must be explained : each CSM must be double checked and JSpOC OD for primary object must be compared with the O/O OD;
- Variation of dispersion should be analyzed: “realistic” dispersion inflation or reduction, on primary and on secondary object, can lead to very significant increase of the Probability of Collision (PoC). “Realistic” depends on the OD characteristics and relies on experience feedback. A low PoC conjunction can hide a very risky one.

After conjunction assessment, only very few CSMs lead to an avoidance action, but those HIE conjunctions must not be missed. In CNES experience, less than 5% of conjunctions are HIE conjunctions.

Conjunction Assessment is a 2 steps process:

- Step 1 : close approach detection

It requires the maintenance of a catalog of space objects. The catalog is the main source to perform screening and detect close approaches for active satellites. It produces conjunction messages to notify O/O of potential risky conjunctions.

Today, JSpOC is the single 24/7 global provider.

- Step 2 : risk evaluation for collision avoidance decision

It consists of the analysis of all available CSMs describing a conjunction with the capacity to do so 24/7. It produces an evaluation of the level of risk of the conjunction in order to detect HIE, alert and recommend avoidance action.

There is a need for few entities delivering to O/O Step 2 service; this is the Middle Man (MM) concept.

### 3 MIDDLE MAN CONCEPT

The Middle Man (MM) is in charge of risk evaluation for collision avoidance decision. The interface between provider of information messages describing detected close approaches and O/O evolves as described in Fig. 1.

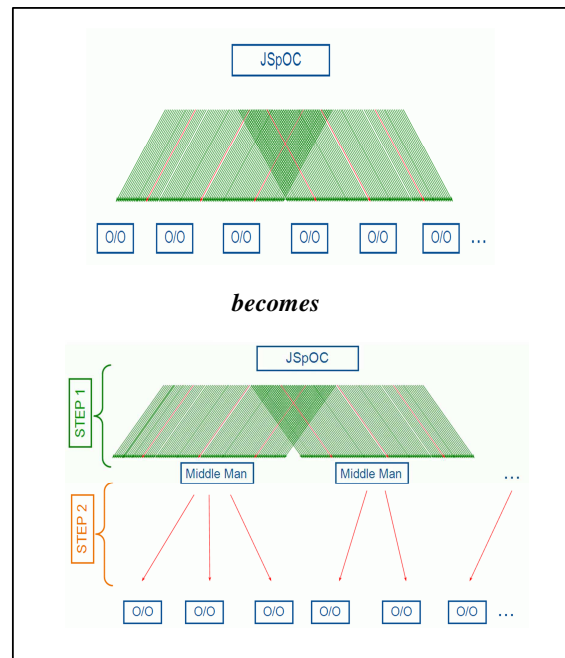


Fig.: 1 Interface evolution with Middle Man (MM).

In this organization, the satellite Owner/Operator (O/O) is only activated by MM for HIE, in other words when an avoidance action should be considered according to its own criteria (predefined with MM). MM is in charge of:

- Sending on daily basis O/O ephemeris to JSpOC;
- Analyzing all available CSMs;
- Finding the HIE conjunctions for which an avoidance action is needed according to O/O criteria;
- Sending collision alert to O/O in case of HIE;
- Providing elements to O/O in order to enable decision on an avoidance action;
- Supporting O/O to choose the avoidance action (to understand the level of the conjunction risk and to size the maneuver).

To enable fruitful dialogue between O/O and MM, a collaborative work environment between O/O and MM has to be established.

The collaborative work environment between O/O and MM has the following functions:

- Allow real time connections (phone, e-mail). The alert to O/O should be in close loop (acknowledgement of reception) and an interactive dialogue is necessary to ensure MM support;
- Ensure to share the same vision of the situation through the use of the same tool and secure exchange data means;
- Enable different levels of information visualization.

#### 4 CAESAR, THE FRENCH MIDDLE MAN

CAESAR stands for “Conjunction Analysis and Evaluation Service: Alert and Recommendations”. CAESAR is the French MM and a probative public service delivered by CNES for GNOSE (Groupement National Opérationnel de Surveillance de l’Espace); operational capacities of French defense and CNES are combined to create GNOSE.

For all Earth orbit regimes, CAESAR includes:

- Daily analysis of O/O ephemeris (with station-keeping maneuvers), data format transformation and sending to JSpOC;
- Analysis of all CSMs (24/7);

- Identification of HIE according to agreed criteria on PoC, uploading CNES CSM and JSpOC CSMs on CNES dedicated secure website SpOD, e-mail sending to alert O/O with phone confirmation;
- Support O/O in decision making thanks to JAC dedicated software.

For LEO orbits, CAESAR includes additional actions: when feasible, OD of the secondary object using available tracking means is performed for instance when uncertainties provided in JSpOC CSMs need to be confirmed or improved.

Fig. 2 shows the information flow of CAESAR from a high perspective.

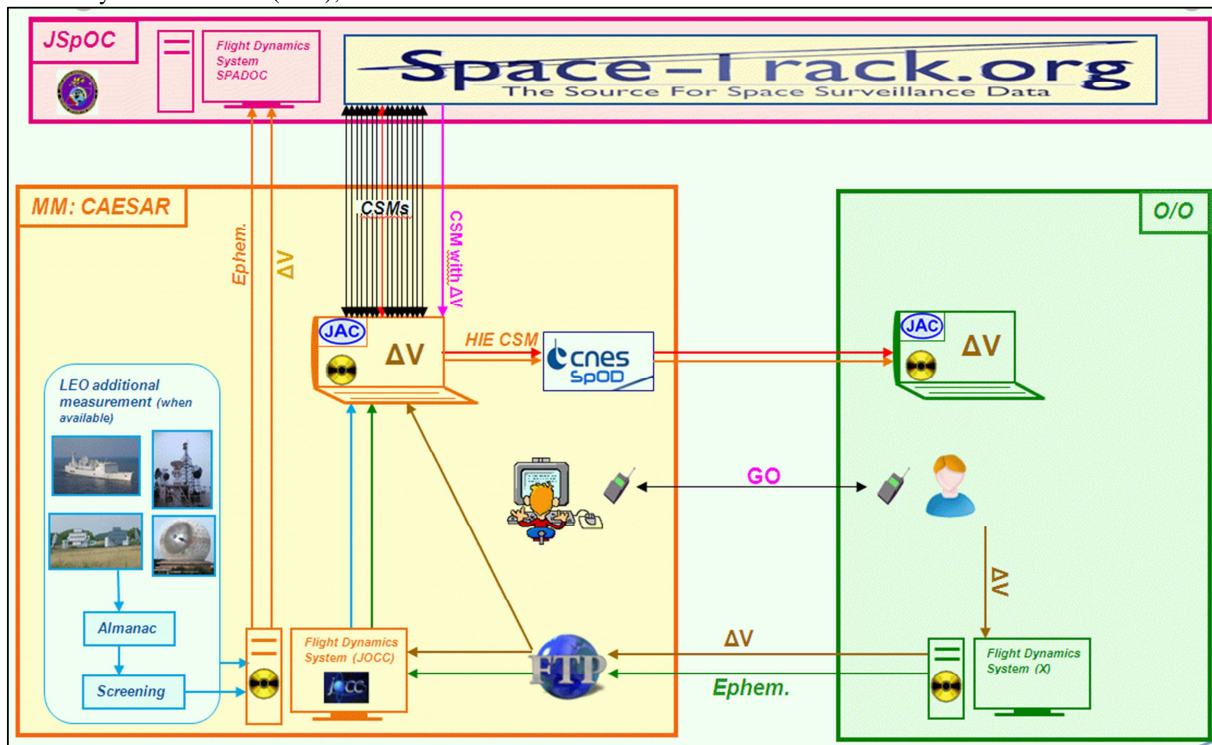


Fig. 2: Middle Man CAESAR

The Orbit Computation Center (OCC) from CNES Toulouse Space Center is the operational entity providing CAESAR. Before starting service delivery, the operational interface is defined between CNES/OCC and O/O. The operational interface defines satellites constraints, PoC threshold to alert O/O, O/O ephemeris format, and maneuvers plan format. CAESAR is mainly based on CNES capabilities. The use of other means (French Defense means, German TiRA radar) is not guaranteed. In any case, O/O remains responsible for the decision to perform or not an avoidance action.

Subscribers to CAESAR can rely on the recognized CNES expertise to analyze CSMs (on average 15 satellites to get the service since beginning of JSpOC

information messages delivery) and this expertise is sustained by the scaling factor. Subscribers do not have to develop the required specific skill which includes expertise and software, do not have to maintain an operational team with the capacity to handle CSMs 24/7 and do not have to adapt to specificities and evolutions of CSMs providers. To illustrate potential evolutions, CSM will be replaced by CDM. CDM (Conjunction Data Message) is a standard message under validation at CCSDS level and CDM will let choices to CDM providers. Subscribe to CAESAR lets to O/O the strategic choice of is residual risk level (O/O chooses the PoC threshold to get alerts from CAESAR).

Subscribers to CAESAR sign a contract with CNES and financially contribute to the exploitation effort.

## 5 COLLABORATIVE WORK ENVIRONMENT OF CAESAR

The collaborative work environment put in place to deliver CAESAR includes:

- SpOD: secure dedicated website (<https://spod.cnes.fr>);
- JAC: dedicated software to work with CSMs. JAC is distributed by CNES under a license. JAC has two levels, CAESAR subscribers have access to JAC Expert version distribution, JAC Basic distribution is open to anybody.

### 5.1 JAC: Java for Assessment of Conjunctions

JAC has been developed to help Operators to be aware of the reality of a conjunction described by CSMs, especially to detect potential inconsistencies as illustrated in Fig. 3 where 3 successive CSMs #1, #2 and #3 are not consistent (the three ellipses describing the combined uncertainties in the Collision Plane do not intersect).

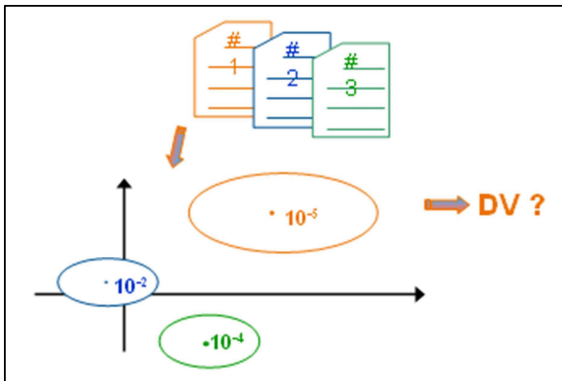


Fig. 3: In Collision Plane analysis with multiple CSMs.

JAC addresses the needs of teams responsible for managing in-orbit collision risks for one or many satellites. JAC is a modular software with two levels of use : Basic Modules and Expert Modules. JAC helps to retrieve and analyze close approach messages using CSM format by providing a synthetic vision of each close approach described by one or more CSMs. It helps the user to evaluate the level of risk according to its own criteria.

The main functions of JAC are listed below:

- JAC Basic Modules: to be aware of the situation.
  - o Automatic download of CSM from websites with secure password management
  - o Capacity to manage CSM from different providers
  - o Management of the downloaded CSM database

- o Visualization of the key data given by the different CSM related to each alert
- o Visualization of the evolution of those key data through tables, graphs, 3D animations
- o Capacity to copy/paste and edit CSM data to illustrate sensibility of key parameters
- o Capacity to use several pre-defined dispersions for each primary
- o Printable summary of analysis
- o Statistics on CSM in database

- JAC Expert Modules: to make and validate a decision.
  - o Several methods to compute probability of collision
  - o Threshold on the probability of collision is set by User
  - o Simulation of maneuvers on the satellite of interest to determine their effect in terms of mitigation of the identified risk

JAC takes into account the emergency characteristic of CSMs by making consistency checks (some CSM data can be computed from others) and management of two levels of inconsistency, warning and error. JAC addresses the need of operational tools such as possibility of multiple instances of JAC, robustness to Operator actions (some actions are deliberately not allowed) or batch mode (for instance to automate CSMs retrieval).

Today JAC works with CSMs, but JAC will be updated without delay as soon as CDM will be approved. JAC deals with Conjunction Messages (CM) currently CSM, next CDM.

If JAC provides a friendly synthesis for conjunctions described with CSMs, JAC does not replace the required expertise to perform complete analysis up to avoidance action decision, it helps the analysis. JAC does not either provide direct recommendations for avoidance actions; it helps to choose avoidance actions. Of course, JAC does not replace dialogue; it optimizes dialogue with CSM or MM providers.

JAC is in Java, therefore JAC is naturally available on various platforms (Windows, Solaris, Linux, MacOS,...). JAC is accessible on SpOD website. JAC is distributed by CNES after signature of a license:

- JAC Basic Modules are distributed by CNES for free;
- JAC Expert Modules are distributed with CAESAR.

The main conditions of the license to be signed:

- Free use of Basic/ Expert Modules of JAC software
- Non-exclusive license for one year

- LICENSEE is allowed neither to modify, adapt nor change JAC
- Login/password for dedicated CNES website (SpOD) will be sent to the email address of the LICENSEE
- LICENSEE is not allowed to grant sub-licenses of JAC
- The license is not transferable in whatever form
- CNES is liable neither for errors nor for anomalies that may occur after delivery of JAC and has no obligation to correct potential deficiencies whatsoever.

JAC email contact : jac@cnes.fr.

- Conjunction analysis with JAC Basic in Fig. 4 :
  - o each CM of the selected conjunction is independently analyzed (one per line)
  - o changes are immediately taken into account
  - o for primary and secondary, visualization of dispersions of selected CM (to check consistency between OD solutions, 2D and 3D)
  - o collision plane visualization, 2D and 3D
  - o summary file available
- PoC sensibility analysis and Delta-V choice with JAC Expert in Fig. 5:
  - o PoC sensibility to dispersion variation
  - o Delta-V choice

Fig. 4 and Fig.5 display some examples of JAC screens, either JAC Basic or JAC Expert ones.

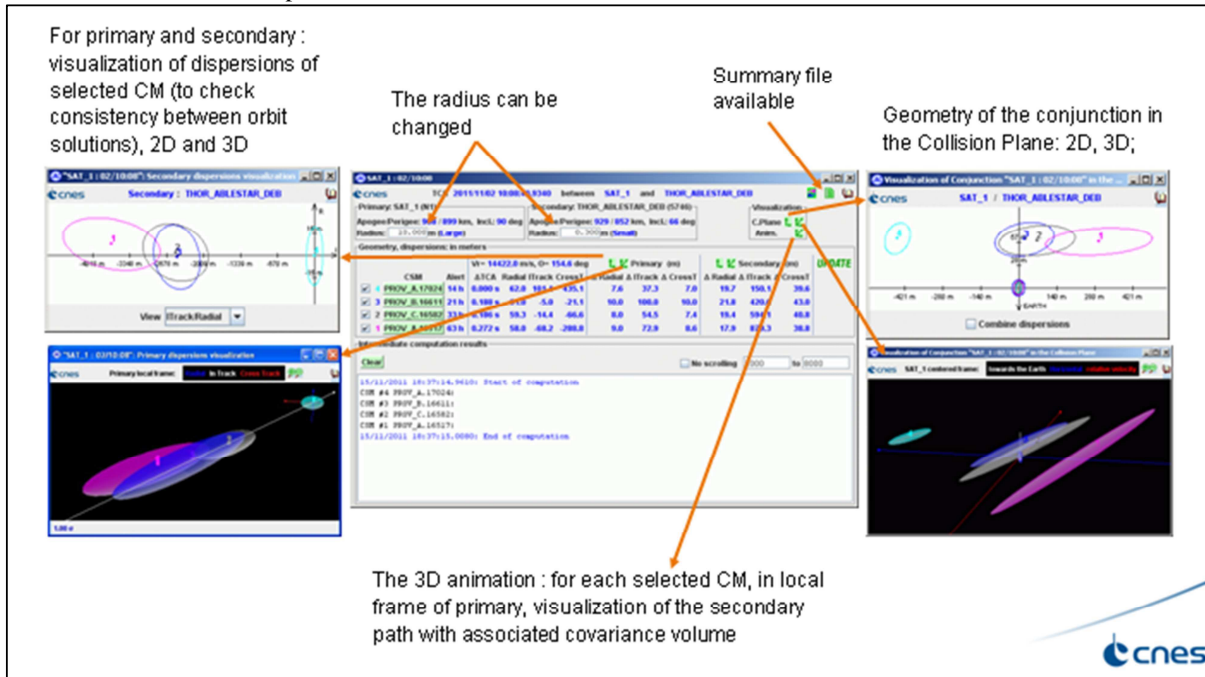


Fig. 4: Some JAC Basic screens

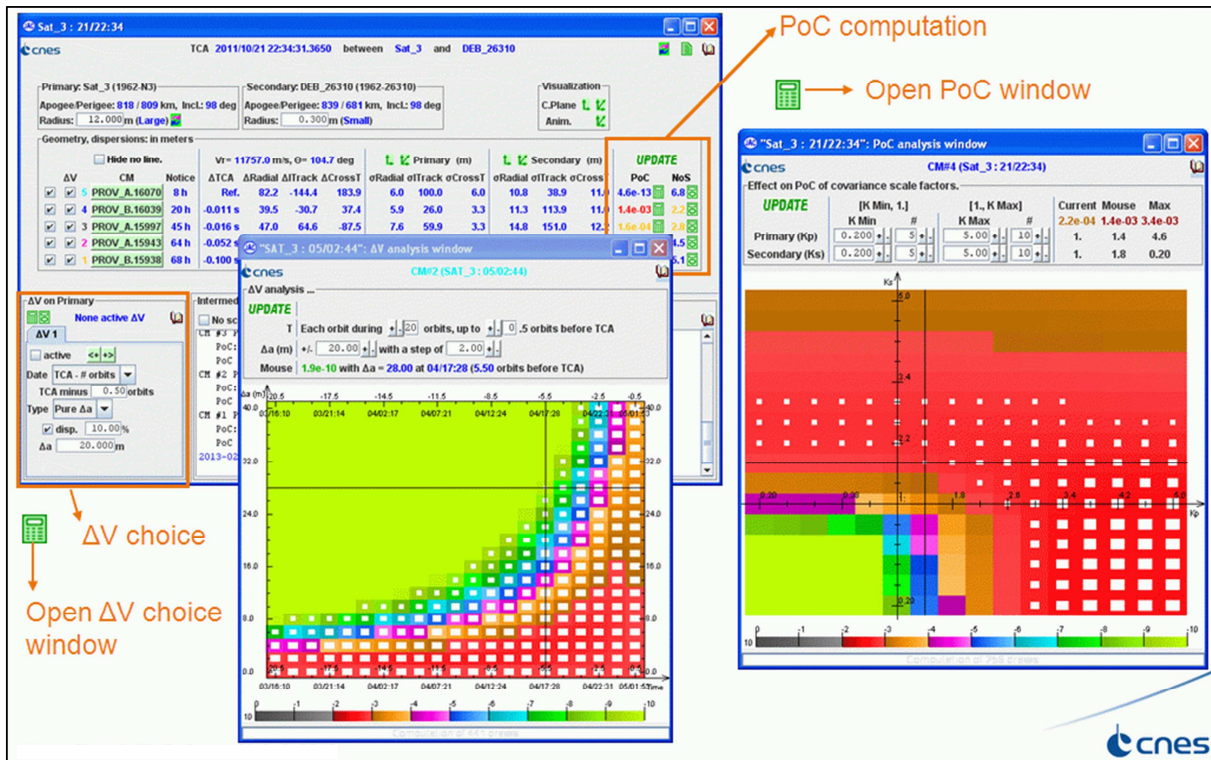


Fig. 5: Some JAC Expert screens

## 5.2 SpOD : Space Operational Data

SpOD is the CNES secure web server: <https://spod.cnes.fr>. Login and password are required to access data. SpOD has a responsive Web design, the resolution is adapted to Smartphone. SpOD fulfills two tasks for CAESAR:

- Sharing the results of the analysis performed by MM CAESAR with O/O to facilitate dialogue;
- Distributing JAC software versions.

For each HIE, CAESAR team uploads on SpOD with JAC all the CSMs (CSMs from JSpOC and CSM created during the analysis of the conjunction). O/O automatically gets an email notification and can download them with JAC.

JAC can be downloaded from SpOD and provides with the MD5 the possibility to check the integrity of the current JAC version.

## 6 PERSPECTIVE FOR NEAR FUTURE

Space Environment protection concerns everyone and is the interest of all. In this scheme, USA delivers CSMs which are the best available data to mitigate in-orbit collisions.

Each actor of the two steps of Conjunction Assessment process is working for improvements with Space Environment protection as main goal.

- For Step1 (detection of close approaches), JSpOC is working to widen its operational capacity in order to propose automated screenings using O/O ephemeris.
- For Step2 (risk evaluation for collision avoidance decision), few entities should play Middle Man role, such as the French probative public service CAESAR.

Since July 2012, CAESAR, the French Middle Man service, is ready to take into account satellites not controlled at CNES. The first entity who became subscriber to CAESAR is ASTRUM for Spot6 and future Spot7 satellites. The objective is to increase the number of subscribers to CAESAR in priority with satellites with a French interest, then for European interests in order to contribute to Space Environment protection. CAESAR requires a collaborative work environment, it relies on :

- A secure website SpOD to exchange data and distribute JAC versions;
- A dedicated tool JAC to work with CSMs.

JAC software helps to work with CSMs by providing friendly visualizations of the geometry of conjunctions and helping the evaluation of the risk level. CNES

distributes JAC Basic Modules for free after signature of a license. CNES distributes JAC Expert Modules with CAESAR as part of the collaborative work environment between O/O and CAESAR team.

## 7 ACKNOWLEDGEMENTS

The French status achieved for Collision Avoidance presented in this paper relies on contributions from GNOSE team but also CIE and CNES support for French side and on very fruitful international exchanges.

## 8 ABBREVIATIONS AND ACRONYMS

**CAESAR:** Conjunction Analysis and Evaluation Service, Alert and Recommendations. This probative public service is available since July 2012, delivered by CNES for GNOSE.

**CDAOA:** Commandement de la Défense Aérienne et des Opérations Aériennes, Air Defense and Air Operations Command from French Air Force.

**CDM:** Conjunction Data Message, standard message prepared by CCSDS.

**CIE:** Commandement Interarmées de l'Espace, French Joint Space Command.

**CNES:** Centre National d'Etudes Spatiales, French Space Agency.

**Collision Plane:** plane perpendicular to relative velocity, at TCA.

**CSM:** Conjunction Summary Message, information data message spontaneously provided by JSpOC for identified close approaches.

**HIE:** High Interest Event, close approach for which an avoidance action is considered.

**JAC:** Java for Assessment of Conjunctions, software distributed by CNES (jac@cnes.fr).

**JSpOC:** Joint Space Operations Center, US Air Force.

**GEO**

**GNOSE:** Groupement National Opérationnel de Surveillance de l'Espace, Dual French Space Surveillance Operations Center consisting of Space Surveillance Division of CDAOA and CAESAR team from CNES.

**LEO:** Low Earth orbit

**MM:** Middle Man, concept being defined in the article.

**O/O:** Owner / Operator

**OCC:** orbit Computation Center, operational CNES center delivering CAESAR

**OD:** Orbit Determination

**PoC:** Probability of Collision

**SpOD:** Space Operations Data, secure webserver to exchange data between CAESAR team and subscribers.

**TCA:** Time of Closest Approach.

## 9 REFERENCES

[1] Laporte F., "Adaptations to changes in Collision Avoidance Operations at CNES for in-orbit satellites", June 2011 European Space Surveillance Conference, Madrid.