SPACE DEBRIS CONJUNCTION RISK ASSESSMENT FOR THE ATV – JULES VERNE MISSION

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ABSTRACT

This paper focuses on the collision risk assessment, between ATV and space debris, managed in ATV-CC at CNES during phasing to docking and de-orbit phases. First, the methods and results of middle and short term mission analyses are detailed. The effects of the two fragmentation events which occurred shortly before and after the launch (the US ASAT on USA 193 and the natural fragmentation of the Russian satellite COSMOS 2421) have been evaluated using models and data from GRAVES and USSTRATCOM catalogues. The results showed a important impact on the foreseen conjunction rate. Second, the operational procedure of the conjunction management is described. The operational organization within ATV-CC teams and with the international partners is also presented. Then, a statement of the operational conjunction management is done, showing a good consistency level with the predictions. Eventually this led to 3 avoidance events (but only one avoidance maneuver).

INTRODUCTION

In early April 2008, the first ATV vehicle, Jules Verne, successfully docked to the International Space Station, becoming thus one of the ISS supply spaceships. The ATV spacecraft is designed and developed by Astrium Space Transportation as prime contractor for the European Space Agency (ESA). CNES (Centre National d'Etudes Spatiales) has developed the ATV Control Centre (ATV-CC) in Toulouse (France) under ESA contract and is responsible for the spacecraft operations. The ATV is dedicated to provide the crew with food and materials, to provide the ISS with propellant and water, to raise up the ISS by several reboosts, and eventually to unload the ISS waste for a final burning into the atmosphere. ESA's ATV is considered the most complex vehicle ever built in Europe, combining autonomous navigation capacities with strict human spacecraft safety requirements.

Because of the ever-increasing amount of orbital debris, it has been foreseen at the early beginning of the project that ATV-CC and NASA Johnson Space Center (JSC) would monitor close approaches between the ATV and objects from the USSTRATCOM catalogue. If a conjunction is detected and confirmed by a collision risk analysis, then an avoidance maneuver can be scheduled by ATV-CC. Within the stringent operational timeline, one particular attention had thus to be paid to the assessment of collision risks. This became even more true after the two successive fragmentation events which occurred respectively 18 days before (ASAT on USA193) and 10 days after (COSMOS 2421 natural fragmentation) the ATV launch.

The purpose of this paper is to present the collision risk assessment experience of ATV's Jules Verne mission, from the risk assessment method design, through the mission analysis and up to the operational results.

RISK CRITERION FOR CONJUNCTION DETECTION

CNES has some experience in the collision risk assessment as it has been daily monitoring the close approaches between orbital debris and the 15 LEO satellites under its control since mid-2007 [1]. The close approaches monitoring relies on the Two-Line Elements (TLE) from the USSTRATCOM catalogue and in-house collision risk assessment tools. These tools are based on probabilistic algorithms, such as real or maximum probability, and consider empirical statistical estimations of the TLE uncertainty. However, ATV mission had some specifics which prevented us to directly apply the same process :

- First, the collision assessment had to be performed after each orbit determination, which were performed in particular after each maneuver cycle. One can better assess the impact of this constraint knowing that around 50 ΔV have been done during the 3-week positioning phase : the collision risk assessment had to be computed very often.
- This stringent timeline also impacted the accessible screening window. No accurate prediction could be performed due to the continuous update of the trajectory design, so it was not realistic to screen more than a few hours ahead. Therefore we only had a 36-hour screening window, compared to the 7-day window used for the LEO satellites.
- In this context CNES had no way to anticipate the risks long in advance. Due to the short screening window, it was also impossible to ask for additional measurement data from the French military radars as it is often done for the LEO to improve our knowledge of the debris trajectory.
- Moreover any avoidance maneuver could have a strong impact on the mission, as the phasing trajectory was computed using specific optimization constraints and techniques.
- Eventually we always had in mind that human spacecraft safety requirements had to be considered, which led to a conservative risk assessment.

Due to these specifics, we had to implement a very short analysis and decision loop between the ATV-CC

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collision avoidance (CA) and maneuver teams, and also between CNES and NASA CA teams. This led to a definition of specific geometrical risk criterion to have a fast, conservative and robust risk assessment. We designed an exclusion area in the conjunction plane (plane perpendicular to the relative velocity of the objects and centered at the primary vehicle position): the criterion is thus adaptive to each conjunction geometry, contrarily to exclusion volumes that are defined in the vehicle local frame.

The ATV exclusion area used by ATV-CC is oriented to roughly approximate the orientation of the projected relative error ellipsoid in the conjunction frame, without explicitly manipulating covariances. The idea is that the largest uncertainty errors are along ATV and object velocities, which is even more true for the considered altitude range (the main error contributor being the atmospheric drag). We then defined an ATV centered frame (C_1, C_2) in the conjunction plane as follows: C_2 is perpendicular to ATV and object velocity vectors, and C_1 is perpendicular to C_2. Thus projected along track errors are along C_1 (see Figure 1).

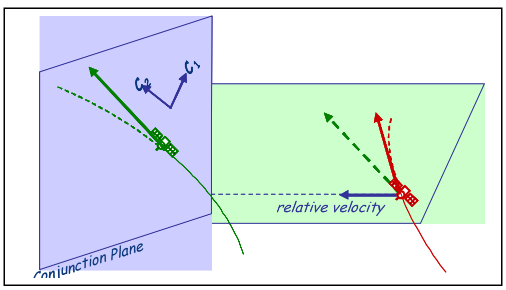

Figure 1 – Conjunction Frame definition

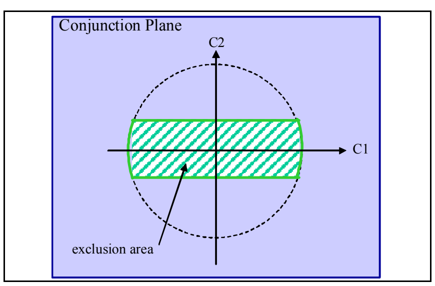

Figure 2 –Exclusion area definition

The exclusion area (see Figure 2) is then defined using 2 criteria: the 2D distance w.r.t ATV center of gravity and the distance w.r.t the C_2 axis.

There are two main differences compared to classical exclusion volumes defined in the vehicle local frame :
- this exclusion area is adaptive as the (C_1, C_2) conjunction frame is defined for each conjunction geometry,
- the time of conjunction factor is eliminated as the conjunction is projected in the conjunction plane.

The dimension of the ATV exclusion area are: d1=30km and d2=5km. They have been determined considering the observed dispersions for a set of debris relevant for ATV mission. Moreover these dimension are consistent with the NASA exclusion volume for ISS (±2km ±25km ±25km).
Some preliminary studies [2] have shown the relevance and efficiency of this exclusion area compared to classical exclusion volumes and to probabilistic methods.

Additional classical probability assessments were also computed (on CNES and NASA sides) to verify the risk evaluation. At CNES, two TLE accuracy models were used (both with a 10^{-5} threshold):
- in ATV-CC, covariances from ESA were considered (accuracy as a function of the orbit range)
- an additional computation was also performed using a statistical CNES model describing the TLE errors as a Gaussian Mixture Model (GMM).

MISSION ANALYSIS

Following this criterion design, mission analysis studies have been performed for the different phases of the mission.

Long term analysis

First, a long term evaluation has been done, more than one year before launch and jointly with the criterion design, in order to set the thresholds and to assess an average number of conjunction expected for the mission duration. The objective was to get a statistical estimation, as it was obviously not possible to predict accurately the risk level such a long time before launch. This estimation was however necessary to design the operational workload, and to insure that the operational timeline would be consistent with this quite unpredictable activity.

The predicted debris flux has been estimated using Monte Carlo simulations based on real TLE data. These results have then been compared to ESA's MASTER model estimation. This allowed us to get a rough estimate of the risk level depending on the considered altitude range (from 200 to 400km). It also gave us the opportunity to analyze more deeply the behavior of some particular objects which represent a large proportion of the overall close encounters: in average 30% of the conjunction were due to 2% of the debris involved in the close approaches.

Short and mid term analysis

A few weeks before launch, this estimation has been updated using current TLE data. This gave us a quantitative estimation of the risk based on different complementary scenario :
- first, we simulated ATV trajectories over 1 month at different altitude ranges (from 200km to 400km);
- then, once the operational trajectory has been defined (that is to say as soon as the launch date was known, and thus also the RAAN), we used the reference trajectory which had been computed for the negative chronology.

Eventually, shortly before and after launch, these studies have been updated again due to some unexpected fragmentation events.

Phasing to Rendezvous

A few weeks before launch, the simulations gave us a prediction of 2 to 6 close approaches to be expected up to docking, which was a quite low workload.
However two major fragmentation events significantly perturbed this prediction :

- 21st February 2008: destruction of the NRO satellite USA193. The ASAT occurred 18 days before the ATV launch, at 240km altitude, which was roughly the initial altitude of ATV.
- 14th March 2008: natural fragmentation of the Russian satellite COSMOS-2421. The satellite was orbiting at 400km altitude (that is to say close to the ISS altitude and to ATV final orbit), and the event occurred 5 days after the ATV launch.

The main problem with these events was the lack of data at the fragmentation date:

- One week before launch, 60 objects from USA 193 had been catalogued. This number had increased to 150 at the launch date.
- For COSMOS 2421, one week after the event, only 15 objects were present in the TLE catalogue, whereas this number reached almost 300 a few months later for the de-orbit phase.

As it was impossible to use TLE data to fully assess the risk increase, some additional simulations have been performed :

- The fragmentations have been simulated with CNES tool named CENDRE (which implements an adapted version of NASA fragmentation model EVOLVE). The results of the simulation have been compared with the few TLE data available both from NORAD and GRAVES (French military space surveillance radar) databases. The simulated debris clouds have been analyzed in term of lifetime and dispersions, to try to predict the short term evolution and the impact w.r.t the ATV trajectory.
- The risk prediction has been updated using all the available NORAD TLEs.

Figure 3 shows the Gabbard diagram for USA 193 case (for objects greater than 10cm), with a superposition of the available TLEs, both from NORAD and GRAVES catalogues. These data allowed us to validate our simulation. In the case of COSMOS 2421, we did not have enough relevant data to be able to fully validate our model.

In the case of USA193 (see Figure 4), the simulation showed that at the launch date, only 10% of the debris larger than 10cm were potentially still in orbit. Moreover, an analysis of the plane evolution of the debris cloud compared with the ATV showed a significant separation (see Figure 5): this induced that close approaches were foreseen “only” at the relative nodes during the positioning phase.

The same analysis has been done for COSMOS-2421: during the positioning phase, only 20% of the debris should have re-entered the atmosphere. The dispersion of the debris cloud was smaller than for USA 193 (due to the difference of dynamic of fragmentation) and we also had a good short term separation in planes.

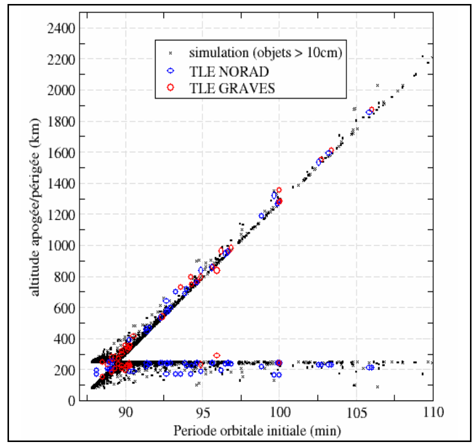

Figure 3 – Gabbard Diagrams for USA 193 ASAT

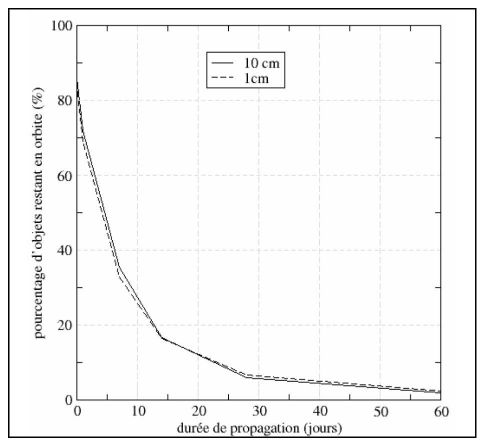

Figure 4 – USA 193 – Short term orbit lifetime

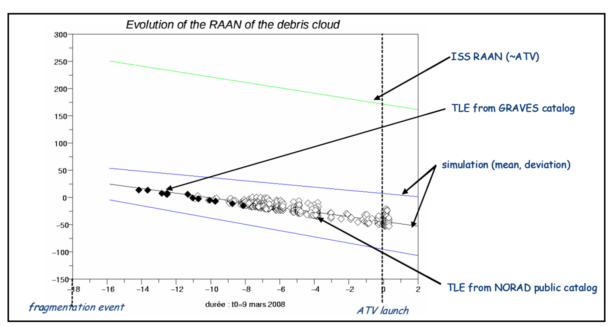

Figure 5 – USA 193 - Evolution of the RAAN

The update of the risks prediction showed an increase greater than 100% due to USA193 (15 alerts foreseen, instead of maximum 6 as initially predicted). No realistic prediction could be performed for COSMOS2421 due to the lack of data.

Transfer to de-orbit

A mission analysis was performed one month before the ATV undocking, in order to forecast the operational workload during the undocking and the transfer to de-orbit phases. This study included a computation of close approaches based on simulated ATV trajectories and an analysis of the evolution of FENGYUN 1C, COSMOS 2421 and USA 193 debris number in the database. The first objective of this study was to quantify the alerts number that operators would have to cope with, while the second objective was a simple way to check the level of potential danger from three major threats.

The first step was performed by computing close approaches using the same method as for the phasing to rendezvous phase. The results and analysis are detailed hereafter:

- An important workload was foreseen for the de-orbit phase. Indeed, the number of alerts reached 21 on geometric threshold for the trajectory at 290km. It reached almost 40 on the trajectory at 350km.
- No alert was raised for USA 193 debris and very few alerts for FENGYUN 1C debris. This result was important because a very big number of alerts had been generated during phasing to rendezvous phase with debris from USA 193.
- More than 75% of the alarms raised on probabilistic criteria concerned debris from COSMOS 2421. This last result had to be carefully considered because there were only few data available for these debris, which prevented us to have a correct estimation of their dispersion. So, probabilistic value of collision for these debris were not very reliable and might be overestimated.

Regarding these last results, it has been judged helpful to have a quick look on the debris density evolution in our TLE database for the destruction of FENGYUN 1C, USA 193, and the break-up of COSMOS 2421. Figure 6 represents the evolution of the number of debris contained in our daily database (fed by NORAD data) versus day-of-year. Dashed lines represent the number of debris flagged as “decayed” whereas the continuous lines are always-in-orbit debris (meaning “potential threats”). One must know that the debris flagged as “Decayed” are not kept in database forever. That’s why their number is decreasing with time.

It has also been interesting to focus on two time spans: the phasing to rendezvous phase (from day 70 to 95) and the simulation period of July (from day 185 to 210). During the first period, the plots gave justification to the fact that a lot of debris from USA 193 were on ATV trajectory. The debris from FENGYUN 1C were numerous but were at a higher altitude, so that they had not threatened ATV. Looking at the simulation time span and extrapolating these curves to September, this gave indication to quantify the number of close approaches caused by these 3 objects. The followings remarks could be assessed:

- No or very few alerts from USA 193 debris would have to be dealt with. Indeed, since the docking, a major part of these debris burnt during their re-entry.
- A heavy operational workload would be caused by the break up of the Russian satellite COSMOS2421. By the end of July, the number increased in our database

No change in the density of FENGYUN 1C debris since the phasing to rendezvous phase can be noticed. However, it could be expected that these debris would be more dangerous than during the phasing phase because their altitude could have decreased.

As a conclusion, this mission analysis prior to undocking highlighted the fact that an important number of close approaches would have to be handled during operations. Among these conjunctions, a non-negligible number of alarms could be raised with debris from COSMOS 2421, which would be difficult to analyze and the probabilistic approach was not reliable.

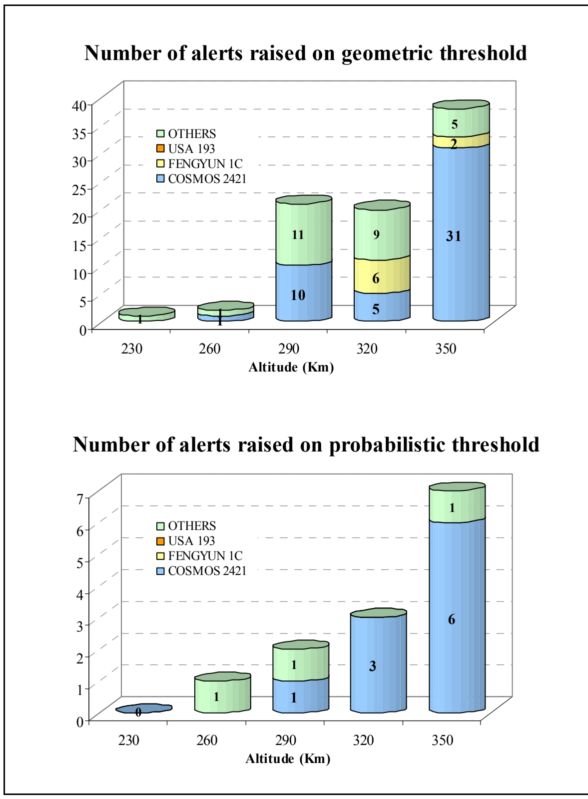

Figure 6 – Simulation results : number of alarms

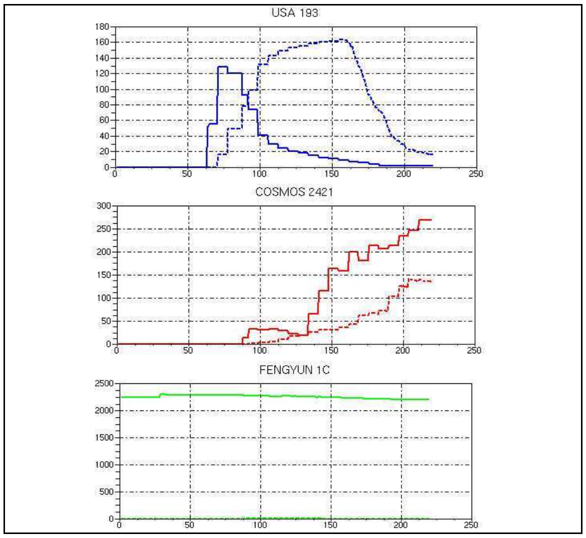

Figure 7 – Evolution of the number of catalogued debris from the breakup events

OPERATIONS

Organization

Besides operational tasks performed by operators in ATV-CC, space debris conjunction risk assessment for the Jules Verne mission was particular because it involves support from Trajectory Operations Officer (TOPO) of Mission Control Centre – Houston. Furthermore, a CNES shadow team was on-call in case of a collision risk to provide additional analysis with different means. Each entity had its own specific role inside the organization of operations, that is depicted in Figure 8.

The Flight Dynamics sub-System (FDS) of the ATV-CC is, among others, in charge of the determination and the prediction of ATV trajectory. For various purposes, FDS broadcasts data related to the trajectory: ephemeris, maneuver plan, GPS ground filtered state vector, etc to ISS international partners. Within the framework of collision risks, ATV predicted trajectory and covariance are also shared, insuring the consistency between each entity computations.

FDS assesses the collision risks using the public NORAD TLE catalogue. As already explained, the exclusion area to detect the conjunctions is defined in the conjunction plan. The collision probability is computed using an ESA model for debris covariance (pre-fixed covariance by orbit ranges). FDS is also responsible to compute the avoidance strategy and to propose it to TOPO for clearance with regards to debris.

The CNES shadow team can be called by FDS leader when a collision risk is detected. The objective is to provide a complementary computation of collision probability based on CNES debris covariance model [3].

TOPO makes a computation similar to FDS but with its own debris database and the possibility to activate a debris tracking with USSTRATCOM support. Moreover, one can notice that the detection criterion is slightly different: TOPO uses a box (expressed in the vehicle local frame) similar to ISS management of collision risks.

Each time a risk is identified or updated, FDS and TOPO exchange the debris conjunction characteristics through Format #7 conjunction messages. This file contains in particular the debris identification, the conjunction time, its geometry (relative state vector), the collision probability, as well as ATV and debris absolute state vectors. Therefore, besides its role in the crosschecking process, it allows TOPO to provide FDS the debris position updates; for instance after a close monitoring of a debris that raised an alarm.

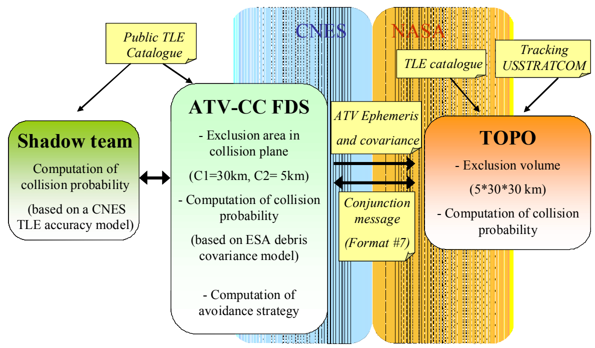

Figure 8 - Organization of Operations for Jules Verne mission

Procedure

As a consequence of this organization, a coordination of tasks between ATV-CC and NASA operators is required and a dedicated Operational Interface Procedure (OIP) was set up during the operation preparation. This OIP provides guidelines for the joint management of collision risks, especially the data files exchanges and the chain of actions to make a decision to perform or not a Debris Avoidance Maneuver (DAM). This article's scope is not to detail the procedure but only to show the main principles.

During free-flight phases (such as phasing), collision risks with space debris are assessed each time a new ATV trajectory is estimated from an orbit determination, in particular after each maneuver cycle. Since this risk assessment is made in parallel at the ATV-CC and by TOPO, FDS must broadcast their predicted ATV ephemeris as soon as possible. The screening window, i.e. the scanned portion of ATV trajectory, is defined for 36 hours. We will see later in the next paragraph more details about this screening window and its subset called the "period to be cleared".

The assessment process consists of two main steps: the detection of potential risk(s) among the whole debris catalogue, thanks to a geometrical exclusion criterion;

and then, a deeper analysis of identified conjunction(s), which tries to characterize the risk level and the necessity to trigger a DAM:

- If a conjunction is detected either by FDS or TOPO, in other words if a debris crosses their respective geometrical threshold during the scanned period, FDS or TOPO raise an alert and exchange format #7 conjunction messages to crosscheck the risk. Once the risk is confirmed by both entities (which should be the case because TOPO and FDS use the same input data), TOPO initiates a tracking of the concerned debris with USSTRATCOM support. The available time before conjunction is employed to get more accurate position information.
- Strictly following the procedure, an avoidance strategy must be decided if the collision probability exceeds the threshold (10^{-5}). Since NASA has the best information about debris position accuracy and receives ATV covariance delivered by FDS, the probability computed by TOPO is the reference one and the primary criterion to take the decision. However, especially if this probability is not available or not reliable, it is necessary to rely on other elements to get to a final decision. Geometry of the conjunction, statistical analysis of shadow team, analysis of the evolution of risk can thus be taken into account.

During Jules Verne mission, TOPO happened to be unable to provide their support because of the hurricane Ike, making ATV-CC deal with a collision risk on their own. This conjunction led to a DAM as detailed later in this article. Besides this exceptional event that provoked a complete loss of TOPO support, other situations may lead to unreliable probabilities. The probability is based on the covariance of both ATV and debris, and if one of them cannot be estimated or presents great values (e.g. after a maneuver for the ATV), the probability result cannot be trusted.

At last, if the risk seems dangerous, FDS considers an avoidance strategy which can be either an addition of a DAM or a modification of existing maneuver plan. Updated maneuver plan is then sent to TOPO for clearance before execution.

Obviously, anytime the risk is ruled out, the procedure is stopped. Moreover, a risk detected in the screening window is considered differently depending on when the collision would occur. This leads to the notion of the "period to be cleared": a risk detected near enough in the screening window (i.e. inside the period to be cleared) requires an immediate decision to build an avoidance strategy, whereas for a risk far enough, one can wait for next ATV orbit determination and/or updated debris information.

Figure 9 shows an example of timeline for screening window and period to be cleared.

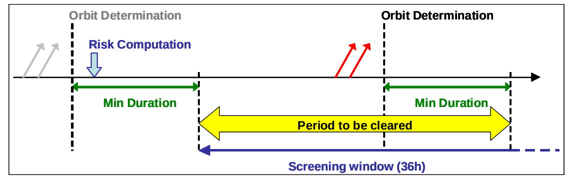

Figure 9 - Example of timeline for risk assessment

The timeline depends on what is called here the "MinDuration" which is the estimated minimum duration required to detect a risk and to build an avoidance strategy. Typically, it is not necessary to compute collision risks during this period as lack of time to react. It must be covered by preceding computation. Hence, screening window and period to be cleared start at last ATV orbit determination + MinDuration. But the period to be cleared ends at next orbit determination + MinDuration while screening window lasts 36 hours. For information, an ATV orbit determination is performed at least every 24 hours in free-drift.

Tools

There are two main tools employed by ATV-CC operators to perform collision risk assessment:
(beside the file exchange function): T-ARC and RAMDAM.

T-ARC is part of the FDS-ATV software in ATV-CC. As the central operational tool for collision risk assessment with space debris, its purpose is to compute the risks by confronting the ATV trajectory with debris position data (from TLE catalog or format #7 message). For each conjunction identified that matches the filter parameters, it generates outputs for the risk analysis: identification of debris, time of the closest approach, conjunction geometry, probability of collision (with ESA debris covariance model), etc.

RAMDAM, which stands for Risk AssessMent for Debris Avoidance Maneuver, is chained with T-ARC results and aims to offer an assistance for the risk analysis thanks to graphical representations. RAMDAN plots the risk identified by T-ARC in the conjunction plan and it also estimates the impact of defined type of maneuvers on the conjunction (effect on C_1 and C_2 axes). This last main function provides abacuses to initiate the avoidance strategy computation. An example of RAMDAM plots is given afterwards.

RESULTS FROM THE JULES VERNE MISSION

Phasing to Rendezvous

Figure 10 shows a summary of alerts number handled at ATV-CC during the positioning phase, depending on their origin (detected by ATV-CC or TOPO) and on the object involved in the conjunctions (debris from USA193, COSMOS-2421, or other bodies). It shall be noted that some objects raised more than one alarm because they present recurring conjunctions with ATV. The alerts detected by ATV-CC were all confirmed by

TOPO. However some alerts were only detected by TOPO because those objects were not available in the NORAD public catalogue. It can be seen that the total amount of alerts is consistent with the prediction (16 operational alerts compared to 15 predicted), and that the majority were due to USA193 debris.

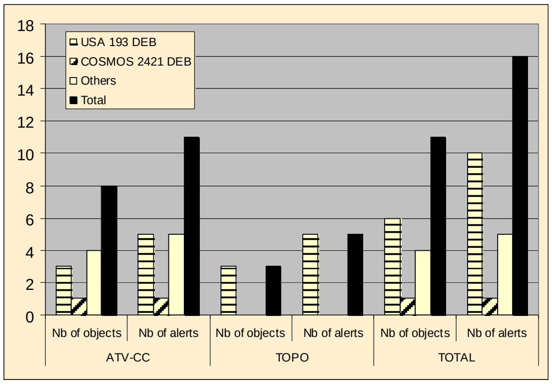

Figure 10 – Repartition of the alerts during phasing

The main problem during this phase was the handling of the numerous conjunctions due to USA193 (and in a second order COSMOS2421) debris, for which no statistical information could be computed to estimate the TLE uncertainty and thus to compute meaningful probability.

However for some other cases, we had a sufficient knowledge of the TLE uncertainty to make a probability computation. Figure 12 and Figure 12 show the conjunction with object 26475 (Delta 2 rocket body) : the TLE errors are plotted in the conjunction plane, the conjunction occurred at 11:47 on the 18th March, with a miss distance of 25km (C_1) and 2.8km (C_2). This example is interesting to show the very large dispersions which can be observed at the ATV altitude range: about 90km along C1 and 2km along C_2, which is to be scaled by a factor of at least 10 to get comparable figures in LEO. Due to this large dispersion, the probability of collision was very low (10^{-8}) and thus this risk has been considered as not critical both by CNES and NASA CA teams.

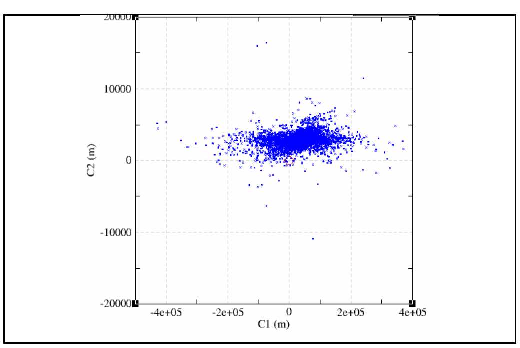

Figure 11 - Conjunction with object 26475

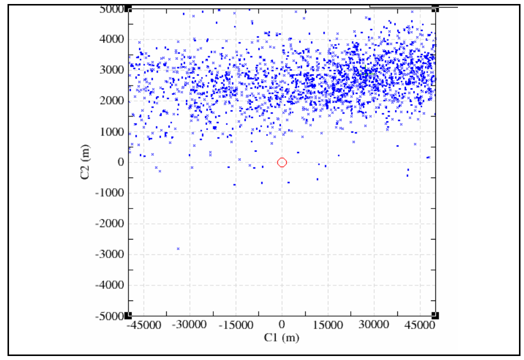

Figure 12 – Conjunction with object 26475 (Zoom)

Eventually, during the positioning phase, the collision assessment led to only two slight changes of the nominal maneuver strategy at the early beginning of the mission (use of a pre-computed backup strategy).

Transfer to de-orbit

After 5 months of attached phase, ATV undocked from the ISS on 5th September 2008. The de-orbit ended by the re-entry of the ATV spacecraft above the south Pacific Ocean on 29th September 2008. From collision risk assessment point of view, the transfer to de-orbit was conducted in a very unfavourable context. Indeed, on the ISS, there had been more collision conjunctions during the last 3 months than during the last 2 years! So, an important number of alerts was expected during re-entry operations.

The following plot shows the number of alerts raised during the 24 days of de-orbit operations :

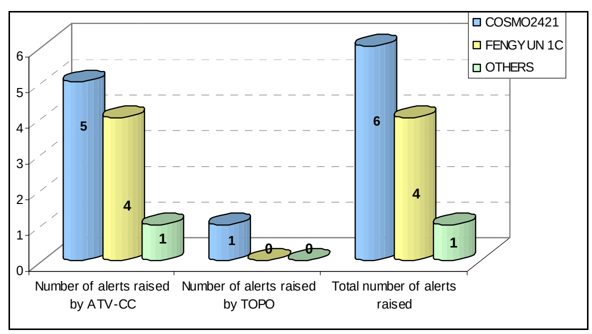

Figure 13 – Repartition of the alerts raised during de-orbit phase

This summary is in good agreement with predictions made in the frame of mission analysis. A great number of alerts were raised with debris from COSMOS 2421 and from FENGYUN 1C. No alert with debris from USA 193 was raised as predicted.

Among these alerts, one alert led to a DAM (Debris Avoidance Manoeuvre) performed on 11th September 2008 at 21:20 to move away from a debris of COSMOS 2421 (TLE number 33257). This debris caused 3 alerts on 3 successive orbits with some relative distances along C2 axis of about 500m.

Conjunction date	Miss distance	C1 (km)	C2(km)
12/09/2008 04h04m10	20,33 km	20,32	-0,45
12/09/2008 05h35m32	1,65 km	-1,57	-0,49
12/09/2008 07h06m55	24,09 km	-24,09	-0,49

Tab. 1 Conjunctions characteristics for ATV/33257 close approach during de-orbit

However, this object had been catalogued recently, and NORAD database was not populated enough so that an analysis of the covariance of these TLE could not be possible. Therefore no probability of collision could have been computed. In addition, hurricane Ike prevented any support or data exchange with TOPO/MCC-H, that's why ATV-CC took the decision to perform a DAM.

Coping with successive close approaches with the same debris, a separation along the C1 axis would not have been judicious, thereby a separation along the C2 axis was aimed with an along-track manoeuvre. With the characteristics of this close approach, RAMDAM compute the following level curves representing the effect of an along track manoeuvre on the miss distances along the C2 axis (post manoeuvre miss distances are labelled on the level curves) :

It shows that an along-track manoeuvre of more than 1.5m/s, nT/2 minutes before the conjunction could put ATV far from the debris of about 5km and avoid the three conjunctions. Finally, a DAM of -1.7m/s was performed.

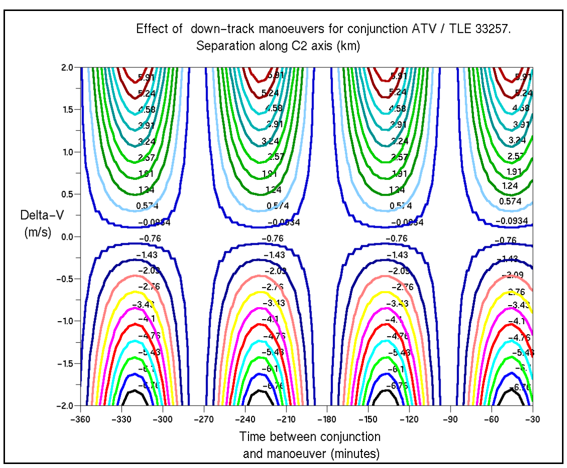

Figure 14 – Maneuver design (RAMDAM plot)

As a conclusion, the analysis made on July, 2 months before departure from the station, has been useful to quantify the operational workload and identify the most dangerous objects. As expected, in operations, the alerts were numerous, and one led to a DAM few days before re-entry.

CONCLUSION AND PERSPECTIVES

The ATV Jules Verne mission had to deal with an unexpectedly high level of collision risks due to two major fragmentation events which occurred at the same range of altitude shortly before and after launch. However the efficient analysis procedure implemented at ATV-CC and CNES, and also the collaboration with NASA CA team allowed us to manage this activity without disturbing the stringent operational timeline. Eventually this led to only 3 avoidance events (2 slight changes in the nominal strategy before docking, and one avoidance maneuver before re-entry). This experience will be useful to prepare the following ATV missions, hoping however for a less perturbed debris environment.

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NOMENCLATURE

ASAT	Anti Satellite
ATV	Automated Transfer Vehicle
ATV-CC	ATV-Control Center
CA	Collision Assessment
CNES	Centre National d'Etudes Spatiales
DAM	Debris Avoidance Maneuver
ESA	European Space Agency
FDS	Flight Dynamic Sub-system
GRAVES	Grand Réseau Adapté à la Veille Spatiale
JSC	Johnson Space Center
LEO	Low Earth Orbit
NORAD	North American Aerospace Defense Command
OIP	Operational Interface Procedure
RAAN	Right Ascension of the Ascending Node
TCA	Time of Closest Approach
TLE	Two-Lines Elements
TOPO	Trajectory Operation Officer

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