OPERATIONAL EXPERIENCE OF THE USE OF A GENERIC PRODUCT FOR COLLISION RISK ASSESSMENT ON GEOSTATIONARY ORBIT

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ABSTRACT

The risk of collision of a geostationary satellite with uncontrolled debris or other satellites is currently estimated to be above 1% over the 13 years of a mission lifetime and has increased an order of magnitude in the last decade. Many geostationary satellite operators have started to control this risk in the last few years.

GMV, a recognised leader in the field of Flight Dynamics, has a very extensive knowledge and broad base of experience in the field of space debris. This is due to its collaboration with the European Space Agency in this area over the last decade, as well as the development of customised solutions for operators such as EUTELSAT.

At the beginning of 2003, GMV was awarded a contract by New Skies Satellites, a leading communications satellite operator based in The Hague, (The Netherlands), for the development of a customised tool for detection of close approaches between their satellites and third-party objects. This tool uses the information provided by USSTRATCOM as two-line elements (TLEs) plus the operational data available for the operator's satellites. The tool has eventually evolved into a generic product called focusCloseAp, which is commercialised like a COTS product in different versions, to provide operators with a cost-efficient solution for collision risk assessment.

This paper presents the results of the experience obtained by New Skies Satellites while using focusCloseAp during the first year to obtain collision approach results automatically every night, the kind of problems encountered and the solutions that have been studied and / or applied. Some potential enhancements currently under consideration are also described.

After running the program for 5 operational satellites during 5 months, 38 actual encounters have been found, yielding a trend of 1.5 encounters per month and satellite. focusCloseAp presents a great flexibility in its use and allows the user to modify the satellite orbital and manoeuvre parameters very easily and re-run different analysis cases to check the effects of the proposed modifications. This feature has been exploited at New Skies Satellites to find out that there are various options for altering the encounter geometry quite considerably. They will be presented in this paper.

Moreover, when analysing the parameters altering the conjunction geometry, it has been found that a good planning of the operations is highly recommended to minimise the uncertainties. Differences between the planning and the actual operations can produce great variations of the geometry.

Finally, the continuous use of TLEs has led to the detection of several problems that will be described in the paper along with the solutions that have been considered. Issues like precision of TLE propagation, sudden updates of TLEs inconsistent with previous sets and others are discussed.

1. BACKGROUND ON COLLISSION AVOIDANCE

Since there is no natural method to clean the GEO orbit (as occurs for LEOs), the number of satellites and rocket upper stages has been continuously increasing along the years and it has been estimated to be over 800 at the moment. Additionally, recommendations for satellite removal have not been submitted until several years ago (by the IADC - Inter-Agency Space Debris Coordination Committee). The consequence is that the number of potential risks in GEO orbit is greater than it had been supposed: abandoned satellites, satellite explosions, failed satellites, objects in GTO (GEO Transfer Orbit), satellite relocations, etc.

The final estimated collision probability in the geostationary ring is above 1% over the 13 years of a mission lifetime [1]. Satellite operators have access to some solutions to predict collisions giving different precisions at different costs (obviously, a great precision is associated to a high cost). The solution given by

GMV, focusCloseAp, has demonstrated to be a very consistent and reliable solution at a low cost.

GMV S.A. (GMV) is a subsidiary of the holding group Grupo GMV, a privately owned company established in 1984 that provides engineering and expert support services to the aerospace, defense, transportation and telecommunications markets. Grupo GMV is involved in consultancy, design, development and integration of turn-key systems for advanced applications in these markets. GMV is a recognized leader in the Space and Defense sectors.

In particular, GMV has a very extensive knowledge and broad base of experience in the field of space debris from the projects developed for the ESA (European Space Agency) and different satellite operators such as EUTELSAT and New Skies Satellites.

New Skies Satellites is a leading communications satellite operator based in The Hague (The Netherlands) that owns and operates five geostationary communications satellites that offer high-power global coverage for the delivery of video, Internet, voice and data transmissions services around the world.

Under the development of a project for New Skies (during the beginning of 2003), the Cost-efficient, Generic Product for Collision Risk Assessment of Geostationary Satellites was generated. focusCloseAp has been widely used during the last year at New Skies, running the program automatically every night, and the results of such use are presented in this paper.

2. FOCUSCLOSEAP DESCRIPTION

focusCloseap is a product based on focusSuite infrastructure. focusSuite is an advanced off-the-shelf, multi-mission, multi-satellite flight dynamics solution for flight dynamics satellite control, developed by GMV. focusSuite provides full lifecycle flight dynamics operations support through a complete collection of flight-proven mission independent and mission specific functionality.

In particular, focusCloseAp allows automatic Collision Risk Assessment by generating every night a complete report of the predicted close approaches, which is sent to a configurable list of e-mail addresses. In this way, every morning, the user gets information of its satellites collision risks through the e-mail without any intervention.

Third-party objects orbital information is retrieved automatically from USSTRATCOM as TLEs (Two-Line Elements) and satellite orbital information is retrieved in specific user format.

New Skies satellite orbital data used by the program is retrieved automatically and is fully customized to the user requirements. In this way, the modification of the satellite data and the subsequent execution of the program is extremely easy. This capability has allowed to test different encounter situations as, for example, the analysis of the manoeuvres time or date modifications.

3. NUMBER OF OPERATIONAL ENCOUNTERS

The operational use of focusCloseAp has lead to the first values obtained (using this program) of a number of close approaches found in GEO orbit.

From previous studies (see [6]), the estimated number of encounters in GEO orbit for the population of active satellites against the entire threat population in that orbit is around 4364 during a year. If the total number of active satellites is 270, then this gives an average of 1.35 encounters per satellite each month.

In the previous study, an encounter is considered to take place when the closest distance during the approach is below 50 km.

For the study performed at New Skies, an encounter is considered to take place when an object comes inside an ellipsoid of 40 x 25 x 25 km (Tangential x Normal x Radial) around the satellite. The number of encounters detected using focusCloseAp is of 29 in 4 months, 38 in five months, 45 in six months and 65 in nine months for the five satellites of New Skies. All these values lead to a trend of 7.5 encounters, that is, 1.5 encounter per satellite and month. There is not enough time of study to assure that this is a real trend, but the values obtained seem to indicate it.

This is a mean value for all the satellites of New Skies. The number of encounters varies for the considered satellite depending on the distance to the Stable triaxiality equilibrium longitudes (at 75.1º E. and 245.7º E.). The reason for this is that many of the uncontrolled objects are oscillating around these two points, so the closer to this points, the higher the number of encounters is.

For example, the number of encounters detected for NSS-703 satellite, positioned at 57º E., during 9 months is 24 and the number of encounters for NSS-7 satellite, positioned at 338º E., for the same period is 3.

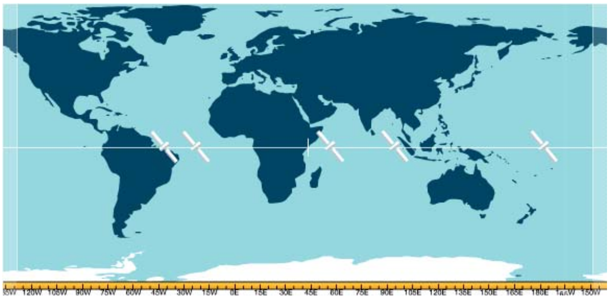

Fig 1: New Skies Satellites fleet

4. ENCOUNTER MODIFICATION AND OPERATIONAL PLANNING

Each time an encounter is predicted at New Skies with focusCloseap, the potential risk is analysed by means of the distances computed by the software. If a detected encounter is considered as a High Risk encounter, then there are two possibilities to avoid them:

- The first possibility is to modify the time of the EWSK (East West Station Keeping) manoeuvre within the same day. This will change the radial distance of the encounter but in general only by a few hundred metres.

- The second possibility is to change the date of the EWSK (or NSSK – North South Station Keeping) manoeuvre. This could change the longitude distance of the encounter minimum distance considerably (up to around 15 km).

The latter will produce in many cases the avoidance of the High Risk predicted encounter, though it is restricted in some specific ones when the manoeuvre has to be performed near a longitude deadband. The modification of the manoeuvre date could lead to a deadband violation, specially if the longitude window is small (as it is for New Skies, whose total longitude deadband is 73.6 km).

Different situations have been studied thanks to Closeap's customised interface for the satellite orbital data.

In any case, to predict an encounter long enough in advance and to be able to modify the manoeuvre characteristics and minimise the risk, the encounter prediction should remain consistent with the continuous TLE and satellite data updates (this is a good indication of program and data stability). And for that reason, a good planning of the operations is very important. In particular:

- EWSK manoeuvres should be known far in advance. In most cases, the estimation has to be known two weeks in advance.

- The performance parameters of the manoeuvres should be estimated with a high precision.

These previous are the main problems found during the operations preventing a good prediction of the encounter geometry. If the manoeuvre parameters are not known precisely and in advance, the predicted encounter may differ considerably from estimation to estimation.

5. STRANGE TLE EVENTS

The orbital data of the Third-party objects, as said previously, is generated from the TLEs provided by USSTRATCOM. In consequence, the prediction of the collision depends on the reliability of these TLE data.

During the operational use of focusCloseAp, some strange events have been found in the broadcasting of such TLE data. Some of them are related below:

- Sometimes, the TLE data for an specific object is updated for an epoch very close to the previous one (just a few seconds in some cases) with orbital elements very different from each other.

- It has been detected that in some specific cases, a new launched object had not been added to the catalogue after more than a month. That is, the new objects are added slowly to the catalogue.

- In one case, it was detected that the date of the new TLE file (one day after the previous update) was older than the date of the previous one.

- On one occasion, the TLE data for a New Skies satellite was updated three times in the same day, when there was no need from the satellite operations point of view for this to be the case (e.g. no large manoeuvres).

The previous notes show that there are a number of inconsistencies among TLE data that have to be taken into account when analysing the collision risk with Third-party objects. However, the cases related above are rare cases that do not appear frecuently.

But the worst experience with the TLE data provided by USSTRATCOM occurred when five close approaches to GOES-7 were detected in a period of 3 days with a radial separation below 2 km and GOES-7 was moving with a slow drift rate making longitude separation very difficult (even with the methods described above).

The TLE data for GOES-7 was a month older than the predicted conjunction date, and it was a difficult situation for the New Skies operations. One day later, the TLE data of the object was updated and it was found (after running focusCloseAp) that the GOES-7 had jumped in longitude by 1800 km, had already passed the

New Skies satellite and was now drifting slowly away from it.

The change of the orbital elements would have corresponded to an error in the original TLE drift rate of 0.1 deg/day although that increased drift rate was not visible in the new TLE element set (it is very unlikely that the slow down was caused by a manoeuvre).

From the previous strange TLE events, one might think that the TLE data is very unreliable. However, they are rare cases within a large amount of TLE data.

Additionally, at the moment an upgrade for focusCloseAp is being studied internally to perform an historical analysis of the TLE data and, in this way, detect the potential strange events by inspection of the TLE file used, warning to the user of such potential problems.

6. PROPAGATION IMPROVEMENT

The TLE data format contains information used to propagate the Third-party object orbit. But this information cannot be used directly by just any propagator, it has to be used with the SGP4, a Simplified General Perturbations model developed specifically for that purpose.

In particular, the SGP4 model is used to propagate the orbit of near Earth objects and the SDP4 model (a modification of the SGP4 for deep space) is used for objects in deep space (see [7]). So the propagator used to propagate objects near the GEO orbit is the SDP4.

It is well known that the SDP4 model included in [8] (which is the reference documentation for that models) contains a set of deficiencies. This propagator has been commonly used and these deficiencies have been discussed for a long time (see [9]).

Those deficiencies were corrected at GMV and the code of the SDP4 was correctly implemented and used in the initial version of the focusCloseAp software. However, the precision of the SDP4 implemented without bugs is not as good as desirable and GMV has added to focusCloseAp an important value, which is an algorithm (GMV Fitting Method) used to increase the accuracy of the propagation of the TLEs.

To test the capabilities of the new algorithm, a TLE was generated from a GEO satellite orbit. Comparison between the GEO orbit and the orbit generated from the TLE was performed both for the SDP4 propagator and for the GMV Fitting Method. The differences obtained in both cases after seven days of propagation can be seen in Table 1 in km.

The validity of this method is currently under analysis but it seems to improve considerably the propagation of the TLE. Additionally, it is intended to extend the algorithm to LEO objects (improving the SGP4 propagator, used for Low Earth Orbit objects).

Table 1: SDP4/GMV Fitting Method comparison (km)

	SDP4	GMV's proprietary algorithm
Tangential	60	4
Normal	24	0.1
Radial	4	0.3

The results shown on the previous table indicate that the propagation method has been improved considerably. However, they represent only the error in the propagation using each of the methods, since the TLE used has been generated from a known satellite orbit.

It has to be highlighted that the improvement is in the propagation of the TLE, nothing can be done to improve the initial error contained in the TLE itself. The values in Table 1 must be taken as the improvement of the propagation by the GMV Fitting Method with respect to the direct use of the SDP4 theory.

Fig 2 and Fig 3 shows the differences obtained using the SDP4 propagator and the GMV Fitting Method in the Radial-Tangential plane for the same case as before. Take into account the different scales in these plots, while in Fig 2 the radial distance is of the order of 3 km, in Fig 3 is of the order of 300 m. And the same for the tangential distance.

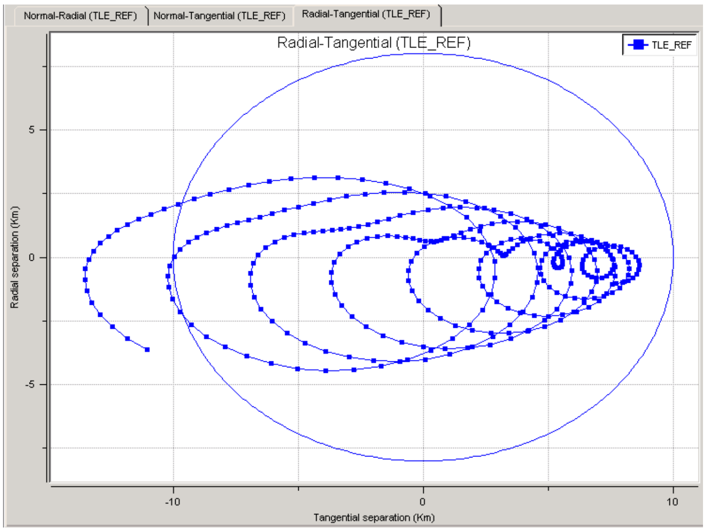

Fig 2: Radial-Tangential separation using SDP4

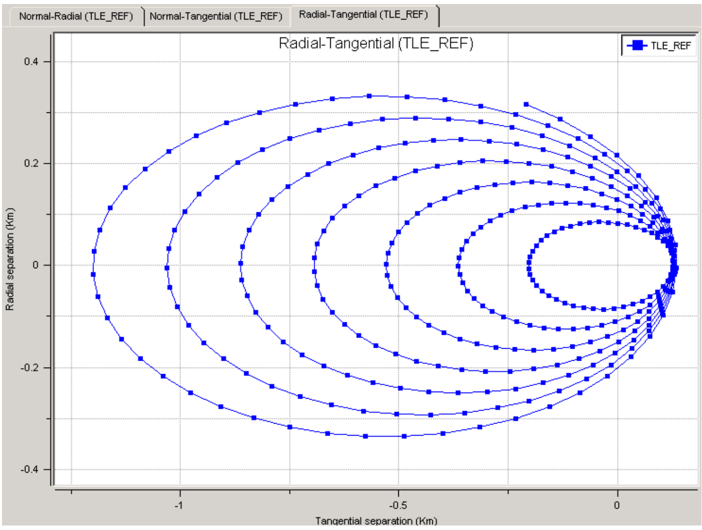

Fig 3: Radial-Tangential separation using GMV Fitting Method

7. CONCLUSIONS

The continuously growing number of uncontrolled objects in GEO orbit is increasing the risk of collision in this orbit and operators are considering the possibilities to reduce such risks.

After a complete year of continuous use of focusCloseAp, it has been noticed that it represents a cost-efficient, generic product for Collision Risk Assessment of geostationary satellites if a good operational planning is done, because it is very important to have a precise estimation of the collision encounters predicted.

TLE data and the propagator commonly used to generate the Third-party object orbit data are not as good as it is desirable, but focusCloseAp is being continuously improved to face up the these problems.

Finally, from the operational experience of its use, we have estimated that focusCloseAp reduces the probability of collision at least by a factor of 10.

8. REFERENCES

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