COLLISION RISK ASSESSMENT FOR SPACECRAFT WITH CASS

Ma Chaowei, Huang Jianyu

Beijing Institute of Tracking and Telecommunications Technology

26 Beiqing Road，Haidian District, Beijing, CHINA. 100094

Email: machaowei@bittt.cn, huangjianyu@bittt.cn

ABSTRACT

Along with the rapid growth of the Earth orbital objects in recent years, the amount of the space debris is increasing faster than ever due to the increasing human space activities, which causes an increase in the risk of collision with operational satellites.

In order to provide technical supports for spacecraft's flight-safety assessment, BITTT has developed **CASS**, a software for conjunction assessment, orbit covariance analysis, collision probability calculation, and collision avoidance maneuver simulation. By which, BITTT continually analyzes operational satellites, high-risk collision analysis based on different kinds of orbit parameters.

This paper presents the composition, structure, and functions of **CASS**, and introduces BITTT's process for the identification and assessment of operational spacecraft, high-risk conjunction events. This paper consists of five parts, including the introduction, basic information of **CASS**, process overviews of collision assessment, examples of high risk analysis, and conclusions.

1. INTRODUCTION

In recent years, the amount of space debris is increasing faster than ever due to the increasing human space activities, the risk of collision with operational satellites is higher and higher as a result of the increasing density of space debris, which causes an important attention on spacecraft flight-safety from all space-fairing countries. NASA, ESA[1] and other organizations[2] are performing routine analysis for the upcoming conjunction events, collision risk assessment, and collision avoidance maneuvers for operational satellites. JSpOC continually provides the collision risk messages to space agencies, commercial organizations, and governments by e-mail or fax.

In order to provide technical support for spacecraft flight-safety assessment, **CASS**, Conjunction Assessment Tools for Spacecraft, has been developed by BITTT for conjunction assessment, orbit covariance analysis, collision probability calculation, and collision avoidance maneuver simulation. Routine analysis for China's spacecraft has been performed by BITTT with **CASS**, based on the TLE data downloaded from the space-track website (since January 2011), satellites precise ephemeris from owner/operators, and other orbit parameters. A 50 kilometers miss-distance threshold has been set to monitor the conjunction events for LEO objects, and 40 kilometers threshold for GEO objects. After that, most safety objects are eliminated and critical collision warning thresholds are set to filter high collision risk events. If the collision probability P is higher than 1:10,000, or if the identified miss-distance, $\triangle R$, is smaller than 1000m for LEO objects, and miss-distance, $\triangle R$, is smaller than 5000m for GEO objects, warning results are generated in text file. For more accurate analysis, telescopes for debris detecting research and pulse radars of satellite launch centers have been used to acquire tracking data and to determine the precise orbits of the suspected chaser objects. When the collision probability, or miss-distance, are still beyond the above given warning threshold for LEO and GEO objects, the avoidance maneuver is planned.

This paper consists of five parts, including the introduction, basic information of **CASS**, process overviews of collision assessment, examples of high risk analysis, and conclusions. We start with detailing the composition, structure, functions of **CASS** and briefly introducing the process for the identification and assessment of operational spacecraft high-risk conjunction events. Then, two recent conjunction events are illustrated: one events is YAOGAN 7(09069A) on 2010-Jul-12(UTC) with chaser object SL-14 Rocket(95046C), the other is CBERS 2B(07042A) on 2011-Apr-17(UTC) with chaser object SL-8(94038B). A summary concludes this paper.

2. BASIC INFORMATION OF CASS

CASS is a tool package which consists of five independent software, including **CAOM** (Collision Assessment Operation Management), **CAA** (Close Approach Analysis), **CPC** (Collision Probability Calculation), **OCP** (Orbit Covariance Propagation), and **AMA** (Avoidance Maneuver Analysis). Each software, which can operate on the same workstation or different workstations, is controlled by **CAOM**, communicating with each other and exchanging information by unified interface. Fig. 1 shows the structure of the **CASS**.
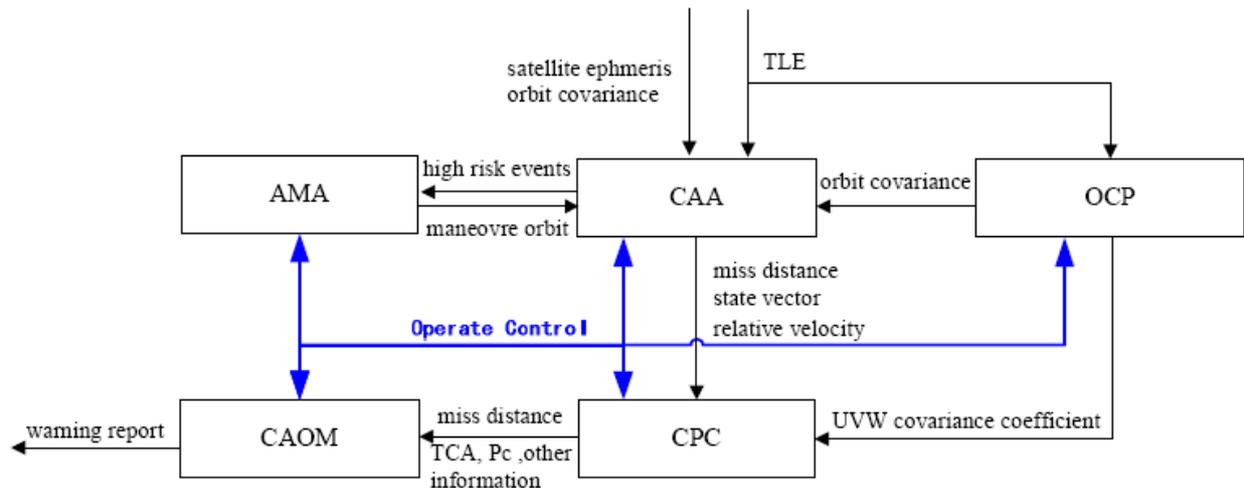

Fig. 1. The Structure of CASS

CAOM is the main control software, providing an advanced user interface and graphical display functions. Operations for the collision risk analysis starts from here, including parameter set, running control, conjunction calculation, results output, user management, database management, and so on.

CAA is the core software, providing conjunction analysis between space objects in different data types, including the satellite ephemeris, the TLE data, and other orbit parameters. **CAA** not only supports local calculation on the Windows OS in a single workstation, but also supports parallel calculation on the Linux OS in cluster servers. Based on the core calculating module, **CAA** can perform on-orbit conjunction analysis for catalogue space objects and launch window safety analysis for spacecraft which is going to fly, output information including the dangerous launch window, conjunction time, miss-distance, relative velocity, conjunction angle, UVW distance, J2000 state vectors, and so on, and provide basic conjunction information for subsequent probability calculation.

OCP is the basic software for collision risk assessment, providing state covariance of both the target satellite and the chaser object for probability calculation. It includes two modules: One is **SCCF**, State Covariance Coefficient Fitting module, which is used to generate the state covariance coefficient by polynomial fitting. The other is **SCG**, State Covariance Generating module, which is used to generate a UVW covariance by calculating a state covariance coefficient polynomial. Since the TLE determination error cannot be obtained, **SCCF** is mainly used to fit the TLE propagating

error coefficient by the Least Square Fitting method. During the process, a historical TLE catalogue is used to state the UVW covariance coefficients relative to the time and true anomaly angle. **SCG** provides different functions, not only the calculation of the TLE UVW propagation error, but also the satellite precise orbit error relative to TCA, time of closest approach, and other orbit parameters propagation errors relative to TCA. All information prepared by **OCP**, can be the inputs for probability calculation.

CPC is the most important software for collision risk assessment. Since collision probability is chosen for one of the warning judgment criteria, **CPC** is used to calculate the collision probability and the maximum probability of a given conjunction event, while conjunction information comes from **CAA** and the state covariance of the target and chaser objects comes from **OCP**. Some important information, including TCA, miss-distance, relative velocity, conjunction angle, UVW covariance, and J2000 state vectors, are picked out to calculate the collision probability at TCA.

AMA, used to support avoidance maneuver orbit determination, is still underway. It is designed to simulate the possible maneuver orbit to avoid high collision risk events. When miss-distance or collision probability are beyond the given thresholds, **AMA** receives the close conjunction information, generates maneuver orbit and returns it to **CAA**, and additional running to ensure that the maneuver orbit does not introduce other conjunction events. The results from **AMA** only provide the reference for O/O. The final maneuver orbit generation and decision should be made by O/O themselves.

3. PROCESS OVERVIEWS OF COLLISION ASSESSMENT

Due to the large amount of space debris, the continual analysis of upcoming high-risk conjunction events for China's operational satellites is the routine activity of BITTT based on **CASS**. Satellites precise ephemeris and other orbit parameter data of space objects have been used to forecast the conjunction events. Since January 2011, the TLE catalogue data were added in the routine analysis. During the analysis, both miss-distance and collision probability are chosen to determine the high-risk events. The main process includes five steps: conjunction analysis, orbit error analysis, collision probability calculation, high risk events reconfirm, and warning report generation. The process flow is given in Fig. 2.
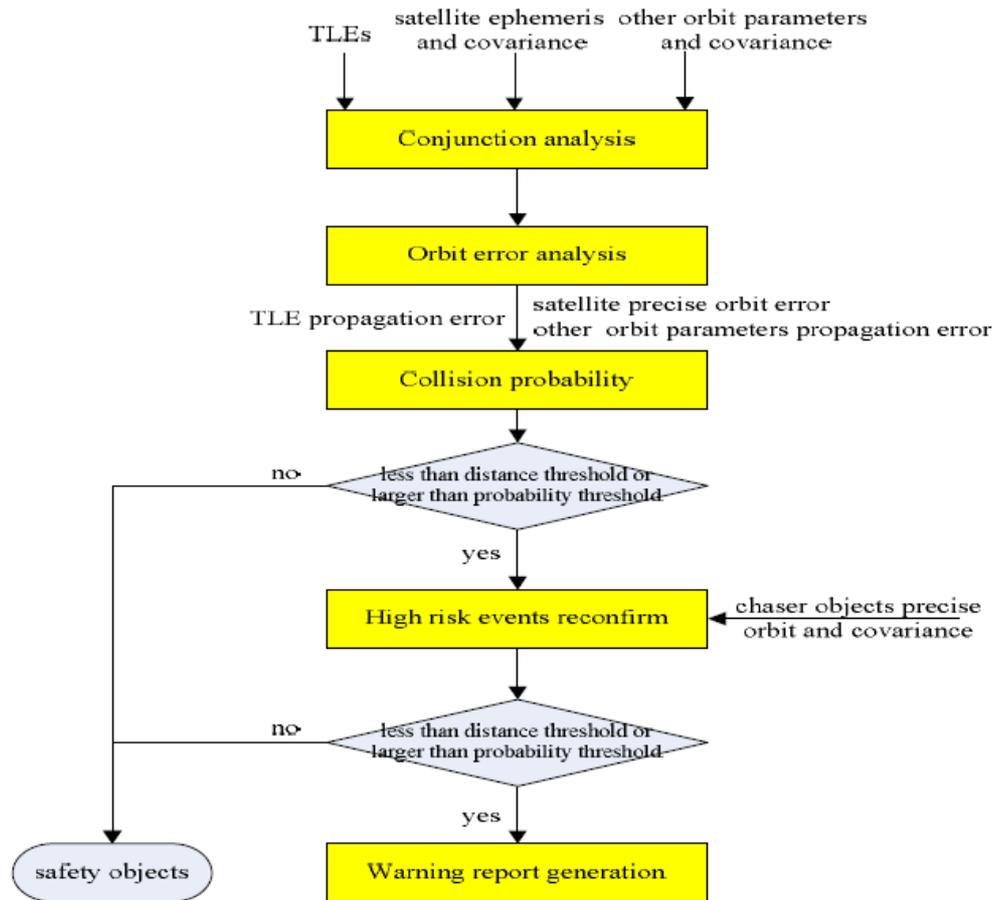
Fig. 2. Routine process flow for collision risk analysis

As shown in Fig. 2. when detecting new TLE data, satellite ephemeris, or other orbit parameters located at the default place, **CASS** starts to run and check the parameters set by **CAOM**, including start time, end time, warning threshold, running workstation or server. Afterwards, **CAA** starts and analyzes upcoming conjunction events for the next seven days between China's on-orbit satellites and other space objects. For those conjunction events and chaser objects, **OCP** starts to calculate the state covariance of target objects and chaser objects at TCA, and outputs UVW error to **CPC** for collision probability calculation. If the collision probability and miss-distance are beyond given thresholds, the acquisition of additional tracking data of the chaser object is put forward, and another high risk event reconfirmation will be made with the same process, as long as precise chaser objects are received. If the assessment of the collision risk is still higher than a given threshold, a warning report is generated and sent to the project manager to make a decision for avoidance maneuver.

4. EXAMPLES OF HIGH RISK ANALYSIS

This section presents two examples of high risk analysis based on CASS. One is YAOGAN 7(09069A) with SL-14 Rocket(95046C), the other is CBERS 2B(07042A) with SL-8 Rocket(94038B).

4.1 The conjunction event between YAOGAN 7 with SL-14 Rocket

YAOGAN 7(SSN 36110, COSPAR 09069A), launched on 9 Dec 2009 by China, is a satellite operated in low Earth orbit($623 \times 661 \text{km} \times 97.9^\circ$). SL-14 R/B(SSN 23659, COSPAR 95046C),

launched on 31 Aug 1995 by Russia, is a rocket body remaining in low Earth orbit($622 \times 656 km \times 82.5^{\circ}$) with a cross-sectional area of 8.3m². The two orbits are in the same altitude.

The conjunction event involving the target object and SL-14 R/B as the chaser object was reconfirmed on 11 Jan 2011 by historical TLE data. When receiving a message from JSpOC on 12 Jul 2010, YAOGAN 7 ephemeris and tracking data and the precise orbit data of SL-14 R/B was demanded. Based on the historical TLE data downloaded from space-track website, it was found by CASS that there was indeed a high risk conjunction between the two objects at 2010-Jul-12 18:31:43(UTC), and an overall miss-distance of 356 meters, a radial miss distance of 60 meters and a collision probability of $3.6e^{-4}$ at longitude 32°, latitude 82°. Both the miss-distance and collision probability were beyond the thresholds.

By using the YAOGAN 7 satellite ephemeris and the acquired precise orbit of SL-14 R/B on 12 Jul 2010, the result changed with the collision probability of $2.9e^{-6}$ and miss distance of 534m. The miss-distance was still less than 1000m, otherwise, the collision probability was less than the threshold of 1:10,000. At that time, we paid attention to the conjunction event, but did not plan an avoidance maneuver. Fig. 3 is the historical results of the event calculated by using historical TLE data from 2010-Jul-6 to 2010-Jul-12. Fig. 4. is the results from three days after the conjunction event by using historical TLE data, which shows the distance of the two objects becoming larger and larger after TCA.
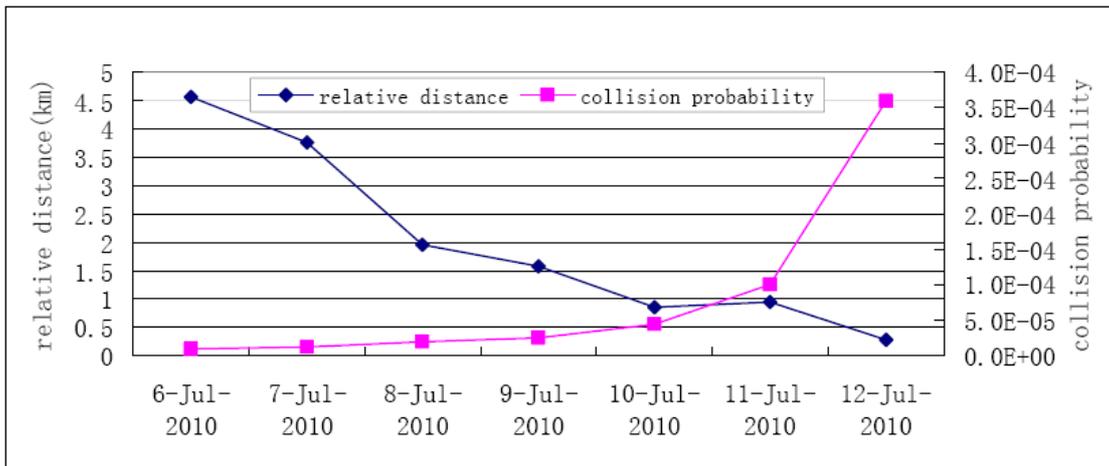

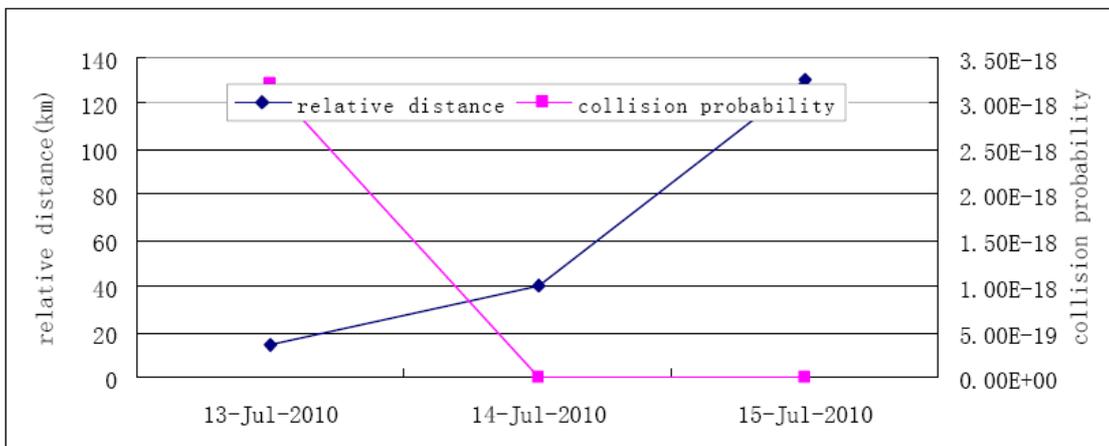Fig. 3 Historical results of the event between YAOGAN7 and SL-14 R/B

Fig. 4 The results of three days after the conjunction event between YAOGAN7 and SL-14 R/B

4.2 The conjunction event between CBERS 2B with SL-8 Rocket

Another conjunction event involving CBERS 2B(SSN 32062, COSPAR 07042A) as target object and SL-8 R/B(SSN 23432, COSPAR 94038B) as chaser object was found in routine analysis on 17 Apr 2011. Based on the TLE data and satellite's precise ephemeris, it was forecast that there is a high risk conjunction between the two objects at 2011-Apr-22 04:29:13(UTC) with an overall miss-distance of 654 meters. From 18 Apr until 21 Apr, the high risk event was still on the top of the warning result. The miss-distance became 76m on 21 Apr 2011, and collision probability became $1.9e^{-3}$. Fig. 5 is the result of the miss distance and collision probability calculated in five days.
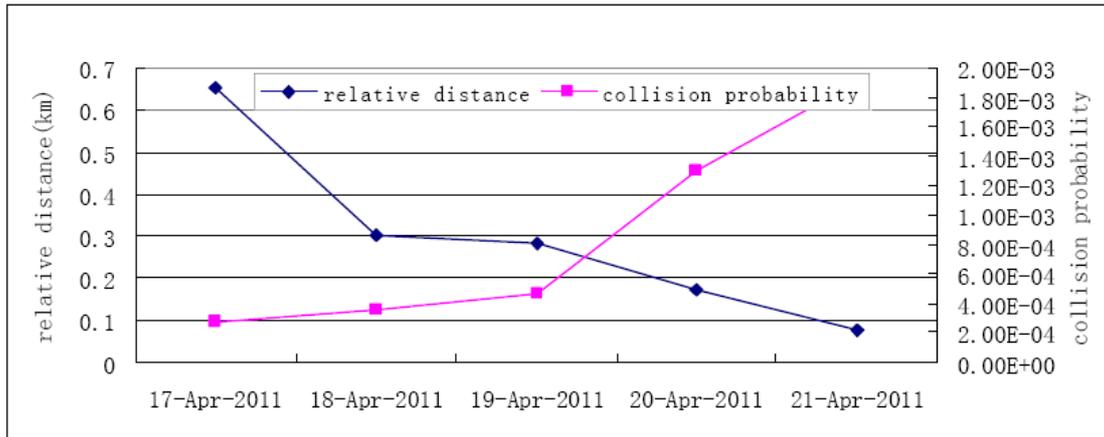

Fig. 5 Five days results of the event between CBERS 2B and SL-8 R/B

5. CONCLUSIONS

This paper presents the composition, structure, and functions of CASS, developed by BITTT, and briefly introduces the process for the identification and assessment of operational spacecraft high-risk conjunction events. The examples of YAOGAN 7 and CBERS 2B were used to illustrate the process effect with CASS. Further work has been planned to upgrade the CASS package, including collision probability calculation for overtake conjunction and collision confidence assessment, and to finish the test of AMA.

References

[1] T. Flohrer, H. Krag and H. Klinkrad. "ESA's process for the identification and assessment of high-risk conjunction events," *Adv. Space Res*. 44, 2009, pp.355-363.

[2] A.B. Jenkin, G.E. Peterson. "Collision risk management in geosynchronous orbit," **Adv. Space Res**. 34, 2004, pp.1188-1192.