The Evaluation Methods of Collision
Between Space Debris and Spacecraft

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[Abstract]: With the rapid development of space technology, more and more spacecraft have been launched into space, at the same time, the number of space debris increased dramatically, the probability of collision between space debris and spacecraft arise accordingly. To evaluate the collision effect, some evaluation methods should be studied. The paper introduces some evaluation methods according to different collision modes by analyzing tracking data obtained by measurement equipment. Relevant evaluation standards are given according to different collision degrees.

Keywords: space debris, spacecraft, collision evaluation

1. Introduction
With the rapid development of space technology, more and more spacecraft have been launched into space, at the same time, the number of space debris increased dramatically, the probability of collision between space debris and spacecraft arise accordingly. In July 1996, the CERISE satellite of France collided with Ariana Rocket at the gravity pole, the upper part was broken, and the attitude control system was destroyed. Two collision targets were first recorded by the surveillance system. The window of the Mir Space Station was destroyed by space debris, the ability to take high quality photos of earth surface was affected. Moreover, it can be found on a recycled satellite that the satellite surface has been injected by some debris with the diameter of several millimeter.

Currently, to obtain the status of spacecraft, two tracking methods are used, including orbit measurements and remote sensing measurements. For orbit measurements, range, elevation, azimuth and range rate can be tracked. For remote sensing measurements, some parameters such as temperature, pressure and so on can be obtained by ground equipment. Some spacecrafts equipped with GPS receiver, the GPS position data can be received to determine the position of spacecraft, and collision effect can be evaluated directly.

To evaluate the collision effect, some evaluation methods should be studied. The paper introduces some evaluation methods according to different collision modes by analyzing tracking data obtained by measurement equipment. Relevant evaluation standards are given according to different collision degrees.

2 Evaluation methods
The evaluation of collisions can be classified into three kinds according to the time efficiency: real time evaluation, near real time evaluation, and post evaluation. According to the data source, the evaluation can be classified as a remote signal evaluation, tracking data evaluation, relative range evaluation, post
precise orbit evaluation, angular momentum evaluation, and tracking station steering evaluation. Among these methods, the first three methods are real time or near real time, the last three methods are post evaluation.

2.1 Remote signal evaluation

A tracking station can obtain a remote signal from those spacecraft which work normally. So the status of the remote signal near collision time can be watched by the space tracking network. Especially in the events, such as the installation on the space station, the meeting of spaceship and satellite, and so on, usually surveillance information for a specific part can be sent to the tracking station in the form of a remote signal. The space expert can diagnose the collision effects by analyzing this information. For other events, if a remote signal changes abnormally at the theoretical collision time, the collision affair can be affirmed. The following criterion can be used to determine whether the collision occurs.

1) if the remote signal is normal before the theoretical collision time, but after that time, the remote signal can’t be received any longer, we can ensure that the collision did happen, and the spacecraft are destroyed totally and it can’t work any more.

2) If the remote signal can still downlink after the theoretical collision time, but some signals are abnormal, a light collision can be affirmed, and the spacecraft can only work partly.

3) If there is no clear change after the theoretical collision time, the other factors should be taken into account to determine the collision.

2.2 Tracking data evaluation

If there are tracking data before and after the theoretical collision time, the curves of error which represent the difference between observation and calculated value (in short O-C value) can be drawn. In other words, we can compare the tracking data with the predicted data with a precise trajectory. If the tracking data vary abnormally, the collision accident can be assured. According to the conservation of momentum law, if two spacecraft hit together, their velocity will vary about hundred meters per second. If collision happens in the same direction, their velocity will vary a little. Moreover, if tracking data can’t be received abruptly, the collision can be affirmed. Charts 1-4 illustrate spacecraft tracking data varying curves with the velocity variation of 20 meters per second. It is found that, with the instantaneous change of velocity, the diversity between the tracking value and calculated value will become more distinct. Though range, azimuth, and elevation can’t vary instantaneous, their trend will vary differently from the original path and the O-C value will exceed the scheduled value. The scheduled value can be determined with the predicted data before the theoretical collision time. After the time, if O-C value increases dramatically and succeeding value, the collision can be thought to happen. For LEO satellites, if their prediction error can reach 300 meters, predicted range error is about 40 meters, angular error is about 50 arc second, added in system error and random error from tracking equipment, the values of range, azimuth and elevation can be 2000 meters, 400 arc seconds, 400 arc seconds, respectively. If the varying velocity is 20 meters per second, after 200 seconds, the tracking date will exceed these values. If the varying velocity is bigger, the time will be shorter.
2.3 Relative range evaluation
During the collision process, we can determine the position of space debris and the spacecraft with tracking data or satellite equipped GPS receiver. A value of relative range needs to be set in advance. If the relative range is smaller than the value, the possibility of collision is bigger. If the spacecraft position can be obtained by surface station instantaneously, the position of space debris can be predicted with historical tracking data. The value of relative range should take into account the orbit error of the spacecraft and space debris. If the error of space debris is 100 meters, the error of spacecraft is 50 meters, the value of relative range is the sum of both errors, 150 meters. If the relative range is bigger than 150 meters, the other factors should be considered to affirm the collision.

2.4 Angular momentum evaluation
The angular momentum represents the energy of a spacecraft orbit, angular momentum is a constant value for a specific eclipse orbit. If space debris collides with the spacecraft, the energy of the spacecraft will change consequentially. The initial orbit can be calculated with the range and angle data tracked by radar, and a varying curve $H'$ of angular momentum magnitude $|\vec{h}|$ and the direction curve $\vec{L}'$ of $\vec{h}$. $\vec{h}$ is the angular momentum of the spacecraft relative to the Earth center, equal to the vector product of vector $\vec{r}$ and vector $\vec{v}$, $\vec{h}$ is parallel with space orbit plane. The magnitude and direction of angular momentum $\vec{h}$ are constant theoretically. After drawing the $H'$ and $L'$ curve, noticing their variation before and after theoretical collision time, the collision can be identified. The initial moment of variation can be regarded as the actual time of collision.
Charts 5-6 are $H'$ and $L'$ curve, and the variation of spacecraft velocity is 20 meters per second.
2.5 Post precise orbit evaluation

The tracking data after a theoretical collision time can be used to determine the precise orbit of the spacecraft. By comparing the orbit with the precise orbit before the theoretical collision time, the possibility of collision can be concluded. If three of \(a, e, i, \sigma, \Omega\) exceed the orbit determination error, the collision can be identified. Moreover, all tracking data, including those after the theoretical time, can be used to determine one orbit of the spacecraft, if the tracking data after the theoretical time have been eliminated, the collision can be identified too.

2.6 Tracking station steering evaluation

The tracking prediction can be made with the orbit before collision time. After the collision time, if the spacecraft can be tracked any longer, or predicted data is different from real tracking data, clearly the spacecraft is not running in the original orbit due to the collision. Assuming that the velocity of the spacecraft varies 10 meters per second, the station can’t observe the spacecraft in the next pass according to the previous steering prediction. So some equipment can be arranged to track the spacecraft with the previous steering, the others are arranged to track the spacecraft with steering data calculated with the initial orbit after the theoretical time, this method can ensure that the spacecraft can be captured again and it’s orbit can be determined within 24 hours.

3 Comprehensive evaluation of collision

Different collision rules can be used in the different procedures and different collision degrees. The following three criteria can be used in the collision between spacecraft and space debris.

3.1 Criterion for no collision

If the space debris doesn’t collide with the spacecraft, the criterion could be these: the remote signal is normal; there is no jump of the velocity of the space debris and spacecraft; the relative range of spacecraft and space debris is bigger than range value; there exists no abnormity with the tracking data O-C value; the orbital angular momentum is normal; the orbit elements before and after the collision time are similar; the surface station can track spacecraft normally.

3.2 Criterion for light collision

Light collision means the velocity of the spacecraft change a little due to the collision with space debris, its attitude change more or less, but the spacecraft still works. The criterion could be these: the spacecraft can still downlink remote signal, but some signals are abnormal; the velocity of spacecraft vary more or less; the relative range of the spacecraft and
space debris is less than the range value; the tracking data O-C value varies clearly; angular momentum varies clearly; the orbit elements after the theoretical time change a lot; the error is big when equipment tracks the spacecraft with the original steering prediction.

3.3 Criterion for severe collision

Severe collision means the space debris hit spacecraft heavily, the spacecraft is broken or its attitude and orbit changed a lot. It can’t work at all. The criteria could be these: Suddenly the remote signal disappears. The real time trajectory varies abnormally, cooperative radar can’t receive measurement data any longer; the relative range of space debris and spacecraft is less than the value; angular momentum varies clearly; the orbit elements after the theoretical time changed a lot; the equipment can’t track the spacecraft with the original steering prediction.

Reference
[1] An Jia Xin, the new progress of space debris research, international space, 1998,01.