Study on space environment safety based on satellite collision

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Abstract. In order to avoid collision with SpaceX's Starlink44 satellite, the European space agency (ESA) said on September 2, 2019 that it fired the thrusters of the Aeolus satellite to avoid collision. In this paper, the collision probability of two space objects is analyzed. In addition, considering the crowded space environment in the future, the number of collisions in a certain period of time was simulated. Meanwhile, compared with the number of possible collisions within 365 days of the existing space target and the number of possible collisions after the addition of Starlink satellite group. The result shows that the future space environment will be much more crowded than expected. On this basis, some reasonable suggestions are put forward for the future space development to ensure the safety and reliability of the future space.

1. Introduction
With more and more countries paying attention to the space field, the space technology has entered the era of rapid development. The introduction of more and more innovative concepts and the application of cutting-edge technologies have made the space field show extraordinary development and changing with each passing day. In 2018, the Federal Communications Commission (FCC)’s approval of SpaceX's application to build a new generation of Internet constellation is kicking off the competition for space resources in low-orbit space.

On May 25, 2019, the SpaceX falcon 9 rocket was launched from station 40 at cape canaveral air force base in Florida, sending the first 60 members of Starlink's fleet of broadband satellites into orbit successfully. In less than four months of operation, the European space agency (ESA) responded positively to warnings of collisions brought in by Starlink satellite, firing Aeolus's thrusters to avoid collision. And ESA says this is the first time the agency has to move a satellite to avoid a space collision. In contrast, SpaceX, which manages the Starlink constellation and claims that each satellite has its own collision avoidance capabilities, has not mentioned the incident.

2. Collision event simulation
For collision warning problem, common early warning methods include BOX area method and the collision probability method [1], the collision probability method using the near distance, time of approach and the information such as track error covariance, calculated the collision probability, to determine the collision probability between two space objects, this method forecast more accurate, as accepted by the national space agency [2].NASA classified the probability threshold for evasive maneuvers as yellow, with a value of 10-5, and red, with a value of 10-4.

One of the main stars of the event, the Aeolus satellite, is a probe satellite belonging to the European Space Agency (ESA). It runs in a sun-synchronous orbit at an altitude of about 400 km and takes about 1.5 hours in orbit once. Considering that the Aeolus maneuver took place at half a lap from the expected
collision, the evasive operation should be within one hour before the expected collision. According to the calculations of experts from the space debris group of the ESA, the collision avoidance method is determined to be height separated, that is, by giving a velocity impulse to the Aeolus satellite, the orbital altitude of the satellite is increased, and the altitude difference between the satellite and Starlink44 is staggered to complete the avoidance. According to an emailed statement from Aeolus' operations team and SpaceX, "information was finally exchanged between the two sides on August 28, when the probability of collision was only within the range of 2.2e-5", which was within the safe range and not necessary for maneuver compared to the evasive threshold of 1e-4. However, the U.S. military space transportation updated the probability, said it would increase to 1.69 e-3, which greatly exceeded NASA red threshold 10-4, to avoid collision, The ESA maneuvered the Aeolus satellite within an hour before expected collision, using boosters carried by the satellite to increase its orbit by about 350 meters to reduce the probability of collision.

Figure 1 shows the change of collision probability in the whole process. After simulation calculation, the collision probability decreases to the safe range after the orbit height increases by about 350 meters, which is in the safe range.

Figure 1. Change in collision probability between two objects

3. Space collision inference simulation
The current space objects are mainly located in low earth orbit (LEO) and geostationary orbit (GEO), which will still be developed and utilized in the future, so the space environment will be extremely crowded there [3].

In this paper, the number of collisions in a certain period of time is used to describe the crowding degree of the space environment. Obtain the approach information and error covariance matrix of the space target, the joint error ellipsoid and the complex can be formed according to the two targets, and the collision probability is calculated by projection into the encounter coordinate system. When the collision probability between the two space targets is higher than the collision threshold (10^-4), it is denoted as a possible collision.

The above collision deduction judgment could be made for all space objects, and the total number of possible collisions of space objects within 365 days is obtained, as shown in FIG 2. With time goes on, the number of possible collisions also increases. The orbit of the existing cataloged low orbit space objects observed and published by space-track website is deduced and simulated, and the number of possible collisions of the existing cataloged low orbit space objects within 365 days is obtained. According to the parameters of the Starlink low orbit satellite group published by SpaceX (see table 1), the simulation time is assumed to be in 2027, when it will complete the deployment of 11,927 low orbit satellites. With the completion of the networking of nearly 12,000 satellites, the total number of near-
earth space targets increases rapidly, and the number of possible collisions also increases rapidly. It is conceivable that when the number of collisions is small, manual operation can be used to give the satellite maneuver instruction to evade, but when the number of spacecraft is increasing and the number of collisions is increasing rapidly, manual operation to evade satellites one by one becomes more and more impractical. The space environment will become more dangerous in the future, and it will be difficult for spacecraft to work properly without adequate collision avoidance technology as guarantee.

Table 1. SpaceX’s announced plans for the Starlink launch

| Orbit height (km) | Number of satellites | Orbital inclination | Initial completion time | Full completion time |
|-------------------|----------------------|---------------------|------------------------|---------------------|
| 550~1110          | 3184                 | 53                  | 2024.3                 | 2027.3              |
| 1130~1325         | 1225                 | 70~80               | 2024.3                 | 2027.3              |
| 335~345           | 7518                 | 42~53               | 2024.11                | 2027.11             |

Figure 2. collision times of low orbit space objects in 365 days

4. Inspiration from space development
In the context of the development on space science and technology, space congestion has become an unavoidable topic. To solve the problem of space congestion, we should not give up eating for fear of choking.

First, the operation of the spacecraft needs to have a mature avoidance system as a guarantee. Under the condition that the spacecraft has not been evading autonomously it is necessary for the ground personnel to forecast its orbit and regulate its attitude and orbit when it is in danger at the present stage, so as to ensure the safety of the space operation environment.

Secondly, every satellite should be carefully considered from design, production to launch. In the design, integrated loads should be used to concentrate various functions on a satellite platform, solid space materials should be used, and ideal satellite orbital position should be selected...These measures can not only reduce the launch cost, but also reduce the number of satellites, saving space resources.

Accordingly, international space regulations should restrict the launch of large, region-intensive satellite communities. Influenced by the characteristics of orbit and the functions of satellites, the space objects are mainly focused on low earth orbit and synchronous orbit, so there are much risks in this area. Collisions between spacecraft are prone to occur, and once the collision occurs, the space debris is extremely likely to have a secondary collision, causing a chain reaction and great impacts on space security.

In addition, using higher capacity of CPU and chip as the foundation, can gradually change some
processing control from ground station to space-based. On one hand can reduce the workload of stations, on the other hand also shortened the "get information - processing - instructions" the process of time, improve the flexibility of case of emergency.

At the same time, with the continuous development of science and technology, spacecraft intelligent avoidance can judge the risk of collision, and according to different collision types and collision probabilities, ensuring not to interfere with other spacecraft while doing avoiding operations. Surge in the number of space target, it's hard for every human to do avoiding manipulation, need these satellites could have autonomous avoidance capacity, sensing the collision risk with calculation arithmetic unit. It is also need to have avoiding power plant – like satellite's "eyes", "brains" and "legs", to ensure the safety in space environment.

In the case of Starlink, it would be a feat if SpaceX's 12,000 low-orbit satellites had all the features listed above and were able to operate safely for themselves and the space environment. Otherwise, it would be a disaster for earth.

5. Conclusions
The development of heavy launch vehicle and rocket launch recovery has greatly reduced the cost of launching spacecraft, but at the same time, the future space environment is bound to become increasingly crowded. The US federal communications commission has approved SpaceX to launch two sets of satellites for Starlink: a set of 4,409 satellites and another set of 7,518 satellites, which is a very large number compared to the current space environment -- only 1,459 satellites are currently orbiting the earth (excluding space junk, space debris and other targets).

For Starlink, CEO Elon Musk has claimed that each Starlink satellites have their own independent space debris tracking system, the use of information transmission from the ground and space debris threaten data can realize automatic avoidance of space debris and the other functions. But in this crash, Starlink44 did not maneuver, ESA officials told Forbes. "Based on the situation, we notified SpaceX, but the company replied that they were not planning to take action. That leaves us to take action."

Even without SpaceX's Starlink programme , the future of space security is grim: Boeing proposes a network of 1,396 to 2,956 satellites; Amazon also submitted an application to build a satellite cluster of 3,236 satellites. It would be irresponsible for the FCC to approve all of them without adequate safeguards for space security.

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