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Optimum Layout and Simulation of TT&C Antennas on Lunar Exploration Capsule

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Abstract. In the field of deep space exploration, to optimize the layout of TT&C antennas on space capsule, based on heat flux identification and TT&C condition analysis, we place the TT&C antennas shifted from the traditional position on vertical surface. So the TT&C antennas can avoid the high heat flux identification area due to the second cosmic velocity return of the space capsule. At the same time, known the orbit and the position of the ground station, we use STK to simulate the return phase to promise the TT&C antennas are used within their main lobe. The design method of TT&C antennas layout on deep space capsule is optimized, and is proved by the CE-5T project.

Keywords: Capsule · TT&C antenna · Layout · Simulation

1 Introduction

Up to the present in China, the spacecraft with the function of returning to the earth keeps the tradition of placing the two TT&C antennas exactly up to the sky and down to the earth. As the development of the deep space exploration, the satellite to the moon needs to return to the earth as well. Different from the former returning satellite and spaceship, this capsule comes back at the second cosmic velocity, the thermal environment is much worse, including high heat flux peak, high heat enthalpy, large heat up sum [1, 2]. What's more, the capsule will leap up after entering the atmosphere and enter again, the longer journey causes the heat accumulated to much higher temperature, which brings new requirement of heat insulation design of the antennas. Although the antenna has been redesigned due to the new thermal environment, it still can't bear the heat if being placed in the traditional position. At this time the problem is brought out, is the traditional position suitable for lunar exploration capsule? Is there a position which has better thermal environment as well as good communication condition? In this paper, a new position is found, and is proved to be effective by the successful flight of CE-5T satellite.

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2 Heat Flux Analysis

2.1 Simulation Results

Take the moon exploration project as an example, the capsule separates form the other part of the satellite at the height of 5000 km from the earth, and keep the flight until the height of 120 km to enter the atmosphere. Later it leaps out and enters the atmosphere again to reduce the speed. 12 points on the surface of the capsule are chosen to analyze the heat flux, including 3 points exactly down to the ground while flying (on the 0° line in the Fig. 1), 3 points shifted 30° aside from the 0° line, 3 points shifted 45° aside from the 0° line, 3 points shifted 60° aside from the 0° line. On each line, the 3 points have different heights as A, B, C shown in the Fig. 1.

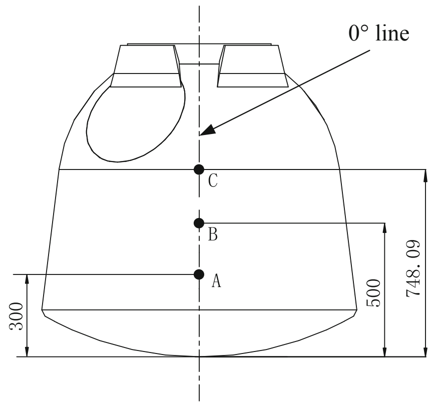

Fig. 1. Sketch map of the calculating point's position (Unit: mm)

Figures 2, 3 and 4 show the curve of the simulation results of the heat flux of each point. Time 0 in the figure refers to the time of entering at the height of 120 km.

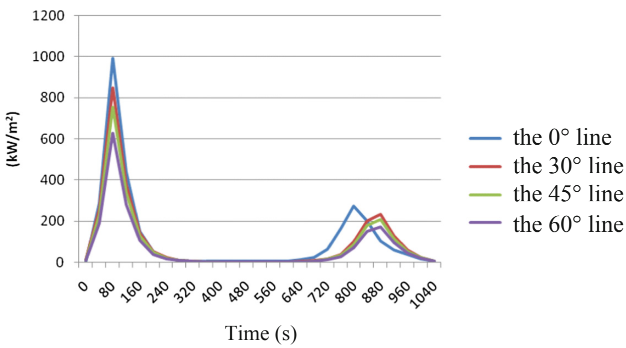

Fig. 2. Heat flux of point A

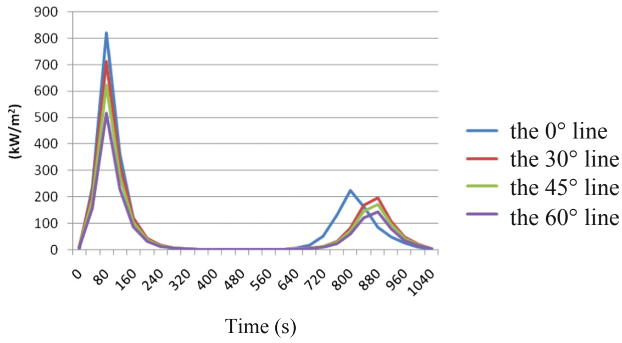

Fig. 3. Heat flux of point B

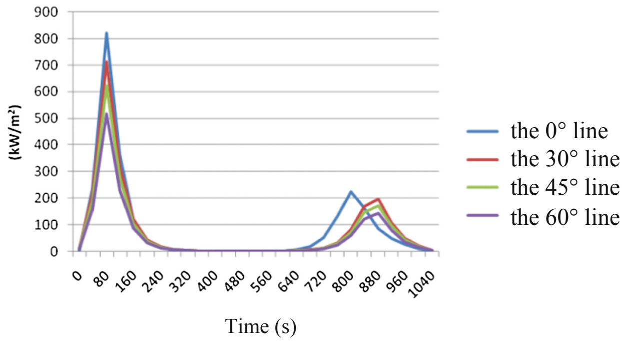

Fig. 4. Heat flux of point C

2.2 Data Analysis

Seen from the data above, the heat flux peak appears at 80 s after the entry. On the 0° line, the heat flux of A, B, C is 991.54, 820.89 and 820.42 kW/m^2, respectively. Compared to 223.5 kW/m^2 of the Shenzhou spaceship and 294.4 kW/m^2 of the former returning capsule, the value is much higher. On the 30° line, 45° line and 60° line, the heat flux reduces about 100, 200 and 300 kW/m^2, and it will keep reducing over 60° line. Although it's still higher than the Shenzhou spaceship and the former returning capsule, but the shift of the position would remarkably improve the thermal environment.

3 TT&C Condition Analysis

3.1 Qualitative Analysis

Figure 5 shows the journey of the capsule. The black curve is the projection of the journey, the direction is from the Australia to the west, through the Africa to China, and finally to Siziwangqi in China. It's easily to see from the figure that the four ground station of Namibia, Malindi, Karachi and Hetian are all coincidently under or on the left of the projection. In this situation, we can place the to-the-ground antenna shifted to the left side, and the to-the-sky antenna to the right side accordingly, so as to promise the TT&C antenna be used within its mainlobe.

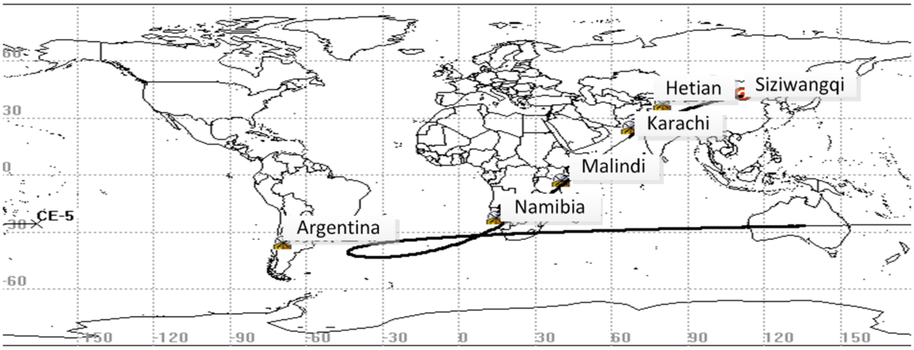

Fig. 5. The projection of the capsule journey

3.2 Quantitative Analysis

The TT&C condition is analyzed based on the actual attitude of the capsule during the entry.

Figures 6 and 7 show the angle between the capsule to the ground station and the point of the antenna VS time, under the situation of antenna being placed on the 0° line and the 45° line. The angle indicates the actual use of the antenna beam pattern [3]. If the angle is larger than 78°, then the line connecting the capsule and the ground station is outside the antenna beam lobe, which means the communication is processed using the interference region of the antenna, and the gain is too low to support the link. So the fundamental rule is to restrict the angle within 78° during the period when the capsule is in sight. The shade part of the figure indicates such period.

For Namibia station in Fig. 6, the insight period starts before the capsule separation and ends 14 min later. During the 14 min the angle gradually decrease from 66° to 20°, then increase up to 55°. In other words, it's always within 78°. As to the station of Malindi, during the 14 min of insight period, the angle gradually decrease from 78° to 31°, then increase up to 74°, also within 78°.

The analysis above is when the antenna is placed exactly down to the earth as traditional way. We can get the conclusion that the TT&C condition is good, although the thermal environment is too strict. To solve this, the following analysis is processed with the antenna placed on the 45° line, as shown in Fig. 7.

For Namibia station in Fig. 7, the insight period starts before the capsule separation and ends 14 min later. During the 14 min the angle gradually decrease from 72° to 35°, then increase up to 58°. As to the station of Malindi, during the 12 min of insight period, the angle gradually decrease from 78° to 31°, then increase up to 78°, also within 78°.

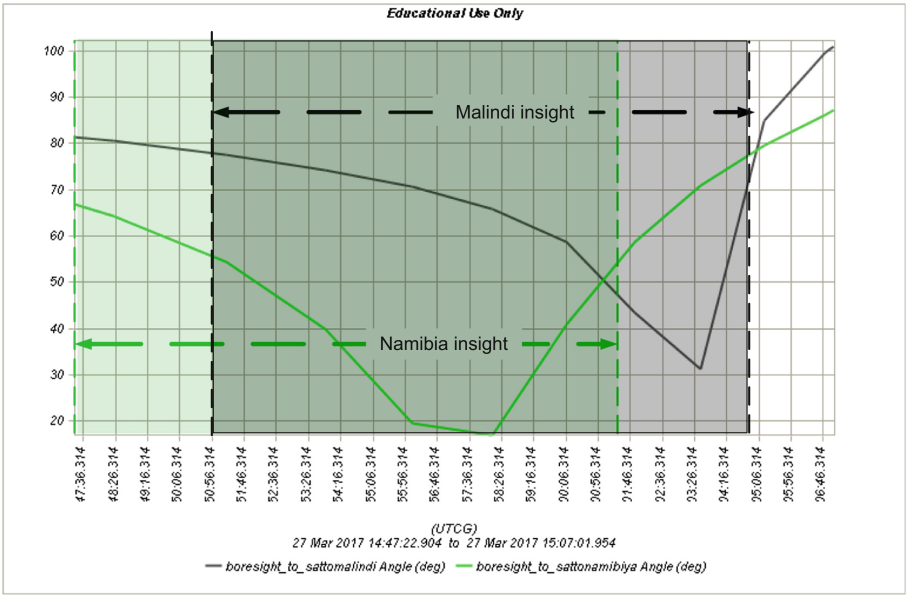

Fig. 6. The angle between the capsule to the ground station and the point of the antenna VS time (the antenna is placed on the 0° line, separation to first entry)

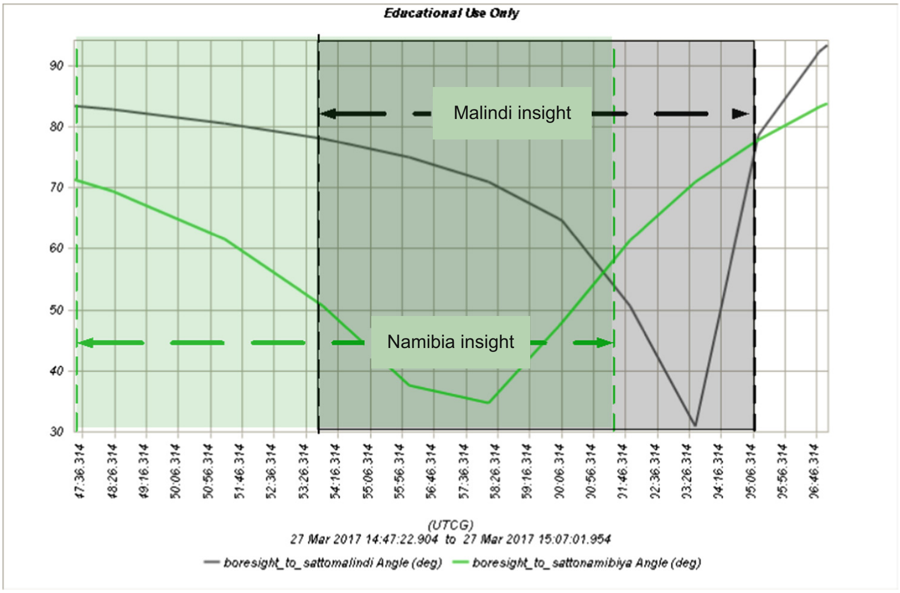

Fig. 7. The angle between the capsule to the ground station and the point of the antenna VS time (the antenna is placed on the 45° line, separation to first entry)

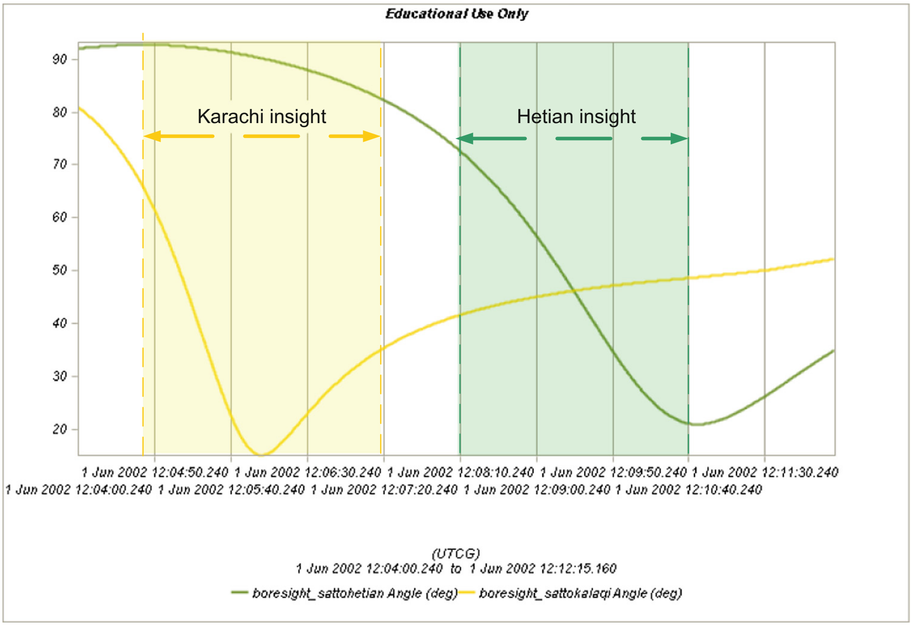

Fig. 8. The angle between the capsule to the ground station and the point of the antenna VS time (the antenna is placed on the 45° line, leap out period)

From the two analyses, the link is always with the main lobe of the antenna. For Namibia station, the TT&C condition is similar. For Malindi station, the insight period is 160 s shorter. But it is due to the delay of the start, at that time Namibia station is already insight, the total time of the two stations keeps the same. So the shift of the antenna does not influence the communication.

After the entry is the continuous blackout, and then comes the leap out period. During this period, under the situation of shifting to 45° of the antenna position, the angle is show in Fig. 8. It can be seen that the angle is less than 78° for both Karachi and Hetian station. The TT&C communication is not affected by the shifting of the antenna.

4 Practical Resolution

Above is the analysis and simulation under ideal condition. Putting into practice, other factors should be considered such as the antenna view, the layout of the capsule and the position of other antennas and umbrella cabin, etc. At last, the TT&C antennas are placed on the 115° line and 295° line, respectively, which is near the side of the capsule. This shift greatly improved the thermal environment of the antenna. The heat flux requirements of the two points are 592 and 300 kW/m2, much lower than before. Figures 9 and 10 show the position sketch map of the capsule and the ground station. The angle illustrates the angle between the capsule to the ground station and the point of the antenna in Figs. 6, 7 and 8.

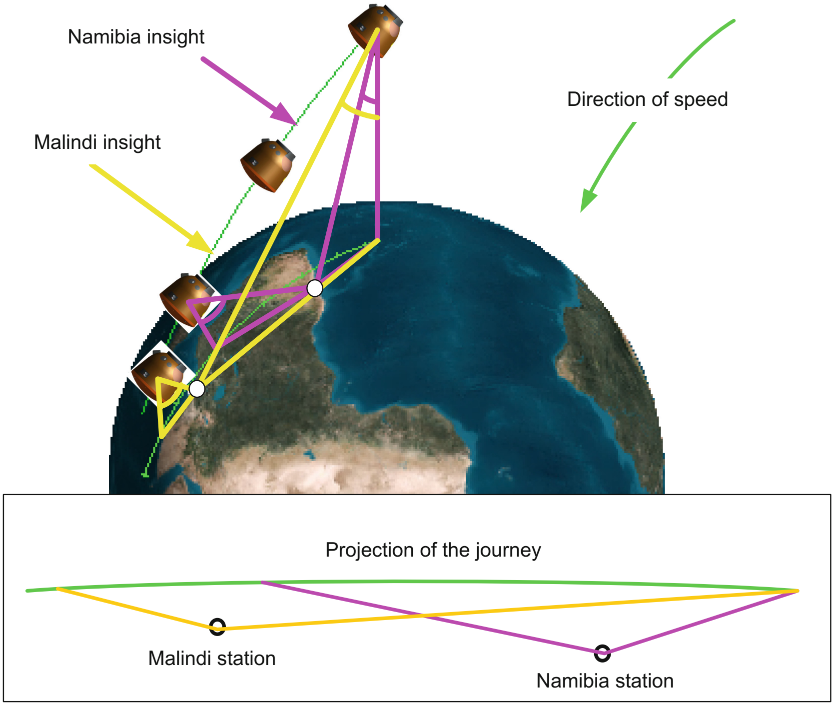

Fig. 9. The position sketch map of the capsule and the ground station (separation to first entry)

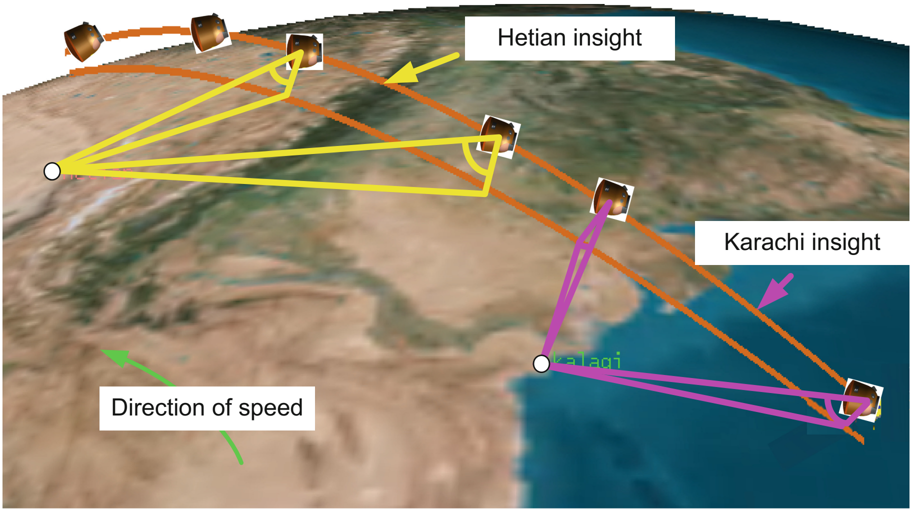

Fig. 10. The position sketch map of the capsule and the ground station (leap out period)

5 Conclusion

Considering both the TT&C link and thermal environment, based on the orbit and the position of ground station, this resolution keeps the link within the main lobe of the antenna and avoids the strict heat area on 0° line. Compared to traditional layout plan, the confliction between the antenna heat endurance and the high heat flux due to the second cosmic velocity is solved.

In the fight of CE-5T satellite in Oct. 2014 [4], the TT&C link was just good after capsule separation, and the antennas endured the burn at the position, which proved the resolution to be effective. The change of the antennas' position performed successfully.

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