Deep Space Exploration Strategy Based on Distant Retrograde Orbits Space Station

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Abstract: To improve the utilization rate of DRO, reduce the cost of human lunar and human mars exploration mission, and exploit space between earth and moon, this paper studied human lunar and mars exploration flight modes based on DRO space station. Firstly, the mission profile of human lunar and mars exploration flight mode based on DRO space station is analyzed by comparing with the direct round-trip lunar flight mode. The human lunar and mars exploration mission can be decoupled into the human space transportation mission and the lunar or mars landing mission by the DRO space station. Then, a flight mode evaluation model is established to analyze and evaluate quantitatively the advantages and disadvantages of the flight modes based on the DRO space station. The evaluation results show that the flight mode based on the DRO space station is a optimal flight mode.

1. Introduction

There are many ways to realize manned lunar-landing or manned landing on Mars. The design of flight mode is one of the key issues that must be solved in the implementation of manned lunar-landing or manned landing on Mars. Manned landing on the moon or landing on Mars flight mode refers to the way that the aircraft is divided into different cabins to complete different orbital changes, and then rendezvous and assemble at a certain position or orbit in space. Different flight modes determine the mass scale of the aircraft, rocket carrying capacity, mission reliability, and engineering development and implementation risks.

For manned landing on the moon, according to whether rendezvous and docking at the lunar orbit or near-Earth orbit, the flight plan can be basically divided into three categories: Lunar orbit rendezvous and docking, Near-Earth orbit rendezvous and docking, Lunar orbit and Near-Earth orbit rendezvous and docking. Among them, the Apollo moon landing plan in the United States adopted the first plan, and the constellation plan adopted the third plan in the early demonstration. Judging from the current technical conditions of China, due to the limitation of carrying capacity, it is quite difficult to realize the first flight plan like the Apollo plan. Therefore, choosing a manned lunar-landing plan suitable for the current technological development of China is a topic that needs urgent research.[1-2]

The DRO(Distant Retrograde Orbits) space station is a long-time running manned space facility.[3] It can be used as a departure and return base for manned lunar exploration vehicles. In addition, the DRO space station can provide fuel supplements for the aircraft in orbit, thereby reducing the scale of the aircraft's entry into space, reducing the capacity requirements of launch vehicles, and reducing the difficulty of launch vehicle development. The use of DRO space station for manned missions to the moon can effectively develop and utilize the Earth-Moon space economic circle; at the same time, it increases the flexibility of lunar missions and reduces the cost of a single lunar mission. NASA, ESA
and Chinese scientists have all proposed the use of different orbital space stations for manned lunar-landing, including the use of Low-Earth orbit space stations, Earth-Moon L1 space stations, and Moon orbit space stations.\[4\]

2. Manned lunar-landing Based on DRO Space Station

2.1. Advantages of Manned Lunar-landing Based on DRO Space Station\[5,6\]

Compared with low-Earth orbit, the DRO orbital environment has good lighting conditions and stable thermal environment. There are currently no man-made spacecraft near the DRO orbit, no artificial or naturally formed space debris, and fewer surrounding micro meteors. These advantages are conducive for DRO space station long-term continuous operation in the earth and moon space. At the same time, the DRO space station is far away from the earth's radiation belt and is basically unaffected by it. It is just that the earth's far magnetic tail periodically sweeps, which can reduce the probability of spacecraft accidents to a certain extent.

The launch windows of different moon landing methods are different. If we use the moon orbital rendezvous and docking method, refer to the earth and moon motion and the lighting conditions of the landing site, the launch window is about 14 days. Landing on the moon based on DRO space station has obvious advantages. If you do not consider other constraints such as TT&C and communication, landing sites, theoretically launching a spacecraft heading to DRO orbit from any position on the earth will have one opportunity per day, which greatly shortens the mission period, that is, the spacecraft assembled through multiple launches can be assembled quickly.

The latitude of lunar surface we can arrive using the traditional lunar landing method is limited by the orbital inclination, that is, the lunar landing latitude is not greater than its orbital inclination, which is not conducive to a full lunar survey. The DRO orbital surface is basically in the orbital surface of the moon orbiting the earth. The spacecraft operating in DRO can observe the whole moon in a small field of view, covering most of the front and back of the moon. The moon landing from DRO space station can support full lunar landing missions, that is, reaching any latitude of the moon's surface, or returning to the DRO space station from any latitude of the moon's surface, and the speed increment of reaching any latitude of the moon's surface is almost the same. In this way, not only can the difficulty of mission design be reduced, but also the detection range of the moon surface can be expanded without consuming more fuel.

When performing exploration missions, emergency situations such as engine failure, solar flares, and insufficient fuel often occur in the DRO-lunar surface and the Earth-DRO segment, and the DRO space station can effectively provide short-term settlement for astronauts. Since the speed increment required to return to the DRO from the lunar surface is small, in the event of engine failure or other accidents that cause the mission to be suspended, the spacecraft can return to the DRO first for some inspection and maintenance tasks, and then return to the earth under the premise of ensuring safety.

The DRO space station can operate stably in the earth-moon space for a long time, and keeping in a bounded space without the maintenance of orbit control, and will not fly to the earth or the moon. The long-term stability of DRO makes it an option to deploy long-term spacecraft in DRO. In contrast, the Lagrange point orbit is unstable and requires orbital maneuver maintenance; GEO generally requires fixed-point maintenance; LEOs below 500 kilometers require orbital altitude maintenance. Deploying spacecraft in DRO can achieve long-term stable flight without orbital maintenance control in the true sense.

2.2. Manned Lunar-landing Mission Based on DRO Space Station

For the manned lunar-landing flight mode based on the DRO space station, it is assumed that the DRO space station is already in operation, the spaceport and the lunar lander have been sent to the designated orbit, and the flight process starts from the launch of the manned spacecraft. Go to the moon and return to the earth. The mission profile is shown in Figure 1.\[7\]
Using DRO as a transfer station to explore the lunar, manned-landing lunar missions can be divided into two parts: manned missions to and from the earth and missions to the moon. The manned missions to and from the earth refers to the round-trip mission of the manned spacecraft between the earth and the DRO space station; the lunar landing mission refers to the round-trip mission between the DRO space station and the moon surface. The DRO space station can provide astronauts with a resident platform, and can eliminate the mission cycle constraint. After arriving at the DRO space station, astronauts can wait for a suitable moon landing window on the DRO space station before proceeding to the moon. Astronauts can use the DRO space station to return to the moon multiple times. Similarly, after completing the mission to the moon and returning to the DRO space station, astronauts can also wait for a suitable Earth reentry window before returning to Earth. Therefore, the DRO space station decomposes manned space-to-earth missions and moon landing missions, increasing the flexibility of the entire manned moon landing mission, while improving mission reliability and personnel safety.

The lunar-landing flight plan based on the DRO space station is shown in Figure 2. The manned spacecraft and the lunar lander are directly sent into the Earth-Moon Transfer Orbit (LTO), and finally enter the DRO by leveraging the lunar gravity. The manned spacecraft and the lunar lander transfer people and cargo through the long-orbit spaceport. Two days are reserved for the rendezvous and docking of the manned spacecraft and the spaceport during the voyage to the moon.
When the manned spacecraft and the lunar lander enter the DRO orbit from LEO, they apply a velocity pulse at perigee, lunar turning, and DRO cut, respectively, at 3280m/s, 170m/s, and 130m/s. In this process, the lunar gravity can help the spacecraft save a lot of fuel consumption. After the moon landing mission is finished, the manned spacecraft can return to the earth directly from the lunar surface, and return to the surface of the earth through atmospheric reentry to achieve aerodynamic deceleration; it can also return to the DRO for refueling and land on the moon again, and from DRO after the completion of multiple lunar missions Return to earth.

3. Manned Mars-landing Based on DRO Space Station

The DRO space station can be used as a propellant replenishment station during a manned landing on Mars, reducing the initial mass of a low-Earth orbit departure. Assuming that a transportation mission needs to be performed before the manned mission to pre-deploy the residence, compare the difference between propellant refill in DRO and not in DRO orbit. The Mars mission plan is as follows:

Option 1: The spacecraft is directly transferred from the earth to Mars;
Option 2: Replenish oxygen at the DRO far-orbiting spaceport: the spacecraft departs from the earth to the far-orbiting spaceport, refills oxygen at the far-orbiting spaceport propellant replenishment station, and then goes to Mars;
Option 3: Replenish hydrogen and oxygen at the DRO long-orbit spaceport: the spacecraft departs from the earth to the long-orbit spaceport, refills hydrogen and oxygen at the long-orbit spaceport propellant replenishment station, and then heads to Mars;

Calculate the required ∆V and flight time to Mars based on the assumed parameters and rocket equations. Assuming that the Earth-Mars rendezvous time is 2035-2036, it is launched with a rocket similar to the US SLS, and a chemical engine with a specific impulse of 450s is used as the propulsion system. The propellant replenishment time is assumed to take 10 days. Give the ratio of the weight to LEO and the weight to low Martian orbit (LMO):

| Start | Arrive | ∆V (km/s) | Flight time (days) |
|-------|--------|-----------|--------------------|
| LEO   | LMO    | 5.76      | 202                |
| LEO   | DRO    | 3.82      | 6                  |
| DRO   | LMO    | 3.29      | 206                |

| scenario | The ratio of the weight to LEO to the weight to low Mars orbit (LMO) | Flight time (days) | Number of rocket launches |
|----------|-------------------------------------------------|--------------------|--------------------------|
| scenario 1 | 13.09                                           | 202                | 5                        |
| scenario 2 | 10.56                                           | 222                | 4                        |
| scenario 3 | 8.43                                            | 222                | 3                        |

The results show that because Mars is far away from the earth, the far-orbiting spaceport can provide necessary propellant for part or all of the journey to Mars, thereby effectively reducing the mass of propellant launched from the earth and the size and mass of its storage tanks. Therefore, the same payload mass can be launched to Mars with fewer or smaller rockets. Under the above circumstances, the total mass of the spacecraft can be reduced by more than 35%, and the number of launches can therefore be reduced from five to three, thus greatly saving launch costs and time.

Figure 3 shows an example of the use of a far-orbiting spaceport as a DRO propellant replenishment station and Moon In-Situ Resource Utilization (ISRU) in a Mars mission. The first launch was a manned mission, transporting ISRU units to the surface of the moon and transporting
propellant supplement equipment to DRO. During ISRU operations, astronauts need to maintain ISRU devices and perform scientific missions on the lunar surface at the same time. After ISRU propellant is generated, the propellant obtained is delivered to DRO's far-orbit spaceport, and then the astronauts return to Earth. At the same time, the Mars transport mission was launched at LEO, stopped at the far-orbiting spaceport to add propellant, and then went to Mars to complete the transport mission (for example, pre-deploy a survival base for future manned missions, etc.).

![Fig 3 Concept of Operations (ConOps) for an example scenario of using DRO (Icon Credit:NASA, ULA)](image)

4. Conclusion
The DRO space station will provide a new model and path for manned deep space exploration. In the process of manned landing on the moon, the DRO space station and the lunar base complement each other. In the early stage, DRO space station can be used as a transit station for the construction of lunar base. Providing astronauts with living conditions and residency conditions. After the completion of the lunar base, lunar base can provide necessary materials for the DRO space station, such as fuel and some materials needed by astronauts and support subsequent manned missions to Mars. In the manned mission to Mars, the DRO space station can provide fuel for manned spacecraft through the use of lunar resources, thereby saving ground launch quality and greatly reducing the cost of landing on Mars. Overall, the DRO space station will play an important role in the process of human landing on other celestial bodies in the solar system.

Acknowledgments
This work was supported by Key Research Program of the Chinese Academy of Sciences, Grant NO. ZDEW-KT-2019-1.

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