SCIENCE CHINA
Technological Sciences

October 2010 Vol.53 No.10: 2691–2698
doi: 10.1007/s11431-010-4092-3

Review on abort trajectory for manned lunar landing mission

XI XiaoNing[1], HUANG WenDe[2*] & WANG Wei[2,3]

[1] *College of Mechatronics Engineering and Automation, National University of Defense Technology, Changsha 410073, China;*
[2] *College of Aerospace and Material Engineering, National University of Defense Technology, Changsha 410073, China;*
[3] *School of Surveying and Spatial Information System, University of New South Wales, Sydney, NSW 2052, Australia*

Received May 19, 2010; accepted July 16, 2010

Abort trajectory is a passage that ensures the astronauts to return safely to the earth when an emergency occurs. Firstly, the essential elements of mission abort are analyzed entirely based on summarizing the existing studies. Then, abort trajectory requirement and rational selection for different flight phases of typical manned lunar mission are discussed specifically. Considering a trade-off between the two primary constrains of an abort, the return time of flight and energy requirement, a general optimizing method for mission abort is proposed. Finally, some suggestions are given for China's future manned lunar landing mission.

manned lunar landing, mission abort, trajectory design, free return trajectory

Citation: Xi X N, Huang W D, Wang W. Review on abort trajectory for manned lunar landing mission. Sci China Tech Sci, 2010, 53: 2691–2698, doi: 10.1007/s11431-010-4092-3

1 Introduction

The safety of astronauts is always of dominant importance, though the major objectives of the manned lunar landing mission are to land the astronauts to the moon, explore the surface, and return safely to the earth. This safety requirement demands an abort and a safe return when an emergency occurs. However, it is difficult to send another spacecraft to save the spacecraft in the emergency, because it is flying away from the earth either on the way to the moon or too far from the earth when arriving at the moon. Consequently, the safe return can only rely on the spacecraft itself to transfer the trajectory onto an abort trajectory. Since the trajectory design is an upper work of the mission design [1], the abort capability should be considered in the design of manned landing mission trajectory. That is, abort trajectory should be designed before a manned landing mission is initialized.

Although the abort is usually not carried out, the design of abort trajectory is as important as the normal mission trajectory, especially in the sense of ensuring the safety of astronauts. American scholars have studied the abort for manned lunar mission as many as the normal mission [2–15], which will be described in detail below. After the CE-1 was successfully implemented, China's manned lunar landing program will also be accomplished consequentially in the near future. In this paper, we review the experience of the manned lunar landing mission, as well as summarize ourselves long-term research in this area, especially the studies on the mission trajectory design for manned lunar landing, abort trajectory design and launch window since the year of 2008 [16–17].

In this review, the mission abort studies of America's Apollo program are described in the next section. Then the essential elements of abort, which include the failures that result in an abort, the abort trajectory that returns the crew to the earth, thrust system that realizes the abort, navigation

*Corresponding author (email: nn_hwd@126.com)

and guidance system, and life support system, are analyzed. To that end, the requirements of an abort and the rational selection of the abort trajectory are mainly discussed during various flight phases of the mission. In addition, the two primary constraints of abort, the time of flight and energy requirement, are discussed. In order to make a trade-off between time of flight and energy requirement, an optimum method that uses multi-impulse abort is proposed. Lastly, suggestions of abort research are given for China's future manned lunar landing mission.

2 Review of American research on mission abort for the Apollo program

For the problem of abort for lunar landing mission, the America's scholars have made a lot of analysis and design. Among these studies, Hyle [2] summarized the abort planning of Apollo. Babb [4] proposed a method that used the lunar module of Apollo as the "lifeboat" when an emergency occurred in 1969, like the situation of Apollo 13 launched in Apr. 1970. Anselmo [5] studied the translunar and lunar orbit abort trajectory for Apollo 14. These studies promoted the early exploration of the moon.

Recently, Beksinski [6] and Adam [7] of the University of Maryland have studied the abort for lunar mission and Marian mission, respectively. The former compares the abort trajectory of Apollo program with that of the crew exploration vehicle (CEV) developed for NASA's "constellation program". Although Adam's study is about the Marian landing mission, it still has the reference value for lunar mission.

Relative to the theoretical analysis and design of the studies mentioned above, the successful save of the Apollo 13, which was referred to as "a successful failure", is an illustrious accomplishment among the history of human deep space exploration. The Apollo 13 mission has been aborted after an explosion happened when the Apollo was 205000 miles away from the earth. Obviously, the objective of Apollo 13 was returning the crew to the earth safely. Therefore, a midcourse correction was carried out, which consequently transferred the trajectory of Apollo 13 onto a free return trajectory (circumlunar then return to earth automatically). In addition, an acceleration maneuver and several midcourse corrections were executed sequentially to ensure a splashed down in the Pacific. The process of the rescue of Apollo 13 is illustrated in Figure 1.

Although the Apollo 13 was not a successful lunar mission, it was a successful abort experiment for manned lunar landing in the sense of abort. The successful rescue of Apollo 13 practically reflected the extreme importance of the abort trajectory.

3 Essential elements of an abort

When an emergency occurs during a lunar mission, the mission has to abort, then the crew will be returned to the earth, or an alternative mission with low ambitious objective will be selected. Therefore, the essential elements of an abort should include such elements as failure causing an abort, abort trajectory i.e. a passage to the earth, thrust systems realizing the abort, navigation and guidance system assistance, and life support system. These essential elements will be described below.

3.1 Classification of failures

The contingencies during manned lunar mission can be mainly classified into three types. The first type of contingencies comprises the system failures. It means that there may be some original design errors in software or hardware of the spacecraft system or the ground system. The second type of contingencies concerns the health or life safety of the crew. It means that something endangers the lives of the astronauts, such as a serious illness that cannot be cured onboard. The third type of contingencies consists of the operational malfunctions, such as the astronauts mistaken

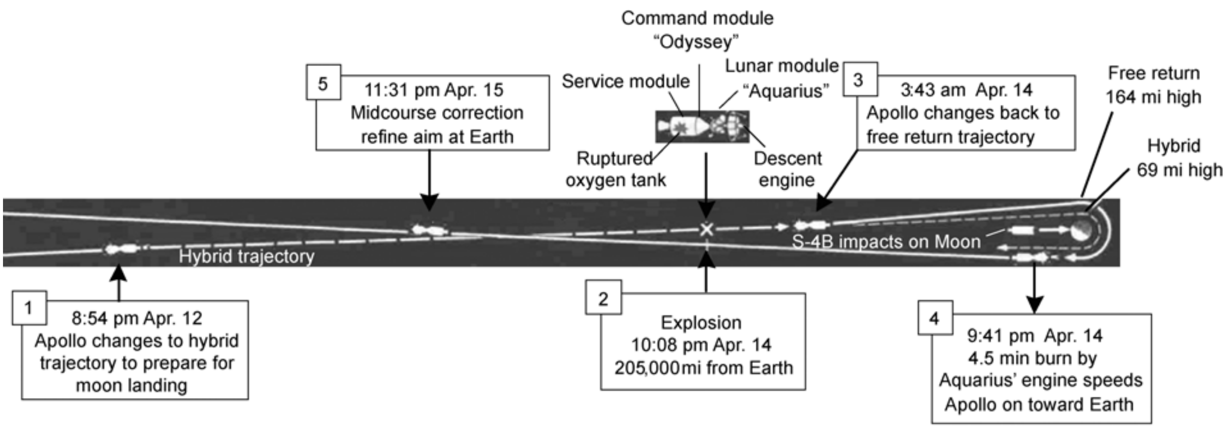

Figure 1 Sketch of the Apollo 13's abort and return process after an explosion [8].