Acta Astronautica ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at SciVerse ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Control system design of the Korean lunar lander demonstrator

Dong-Young Rew [a,*], Gwanghyeok Ju [a], Sangchul Lee [b], Kwangjin Kim [b], Sang-Wook Kang [a], Sang-Ryool Lee [a]

[a] Korea Aerospace Research Institute, 169-84 Gwahangno, Yuseong-gu, Daejeon 305-806, Republic of Korea
[b] Korea Aerospace University, 100 Hanggongdae-gil, Hwajeon-dong, Goyang, Gyeonggi 412-791, Republic of Korea

ARTICLE INFO

Article history:
Received 1 August 2012
Received in revised form
20 February 2013
Accepted 26 March 2013

Keywords:
Lunar lander
Landing demonstrator
Attitude control
Descending control
Thruster modulation

ABSTRACT

In preparation for the lunar exploration program scheduled to be launched during the early 2020s in Korea, a lunar lander demonstrator, which will be used for developing and demonstrating lunar landing technologies, is being developed. The control configuration of the lunar lander demonstrator is determined with the consideration of available technologies and flight requirements. It is suggested that altitude control be achieved by clustering five 200 N monopropellant thrusters and attitude control with eight 3 N thrusters. A control algorithm designed to follow a predefined trajectory is developed using quaternion feedback. Control system configuration and control logic are verified by using computer simulations. Simulation results show that a soft landing with a touch-down velocity of less than 3 m/s is achieved. Attitude control performance is also verified using computer simulations. The developed control configuration will be further tested by hardware in the loop simulations and ground based firing tests during the next phase of the study.

1. Introduction

A series of lunar exploration programs which consists of lunar orbiting and robotic lunar landing missions is planned in Korea during the 2020s. Korea Aerospace Research Institute (KARI) has experience in development and deployment of the Earth oriented mission satellites, but it has little experience in deep space mission spacecraft such as lunar explorers. KARI is doing conceptual design and is studying core technologies to prepare for those lunar exploration programs. It is also necessary to develop test beds prior to launching the official lunar exploration program for testing and validating new technologies related to the lunar explorer.

Planetary landing technologies are being developed with the aid of simulation environments. In Europe, Vision-Based Navigation Analysis Tool (VBNAT) [1], LIDAR-Based Navigation Analysis Tool (LBNAT) [2], and Precision Lander GNC Test Facility [3] were developed. In the United States, Mars entry, descent, and landing technologies are being developed with the aid of Dynamics Simulator for Entry, Descent, and Surface Landing (DSENDS) [4]. Besides computer based simulators or GNC test facilities, flight test vehicles are used for demonstrating technologies and space vehicle design. The Robotic Lander Prototype [5] and Morpheus project [6] are two examples.

KARI is developing a dynamic simulation environment for lunar mission guidance, navigation, control logic analysis, and processor/hardware in the loop simulation [7]. Actual verification of the design will be performed through ground based flight tests using a lunar lander demonstrator. The lunar lander demonstrator is being developed at KARI for testing newly developed thrusters and landing legs as well as guidance, navigation, and control logic.

In this paper, conceptual design results of the lunar lander explorer are briefly summarized to explain the relation between the actual lunar lander model and the

* Corresponding author. Tel.: +82 42 8703726; fax: +82 42 8703980.
E-mail addresses: dyrew@kari.re.kr, youngrew@hotmail.com (D.-Y. Rew).

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http://dx.doi.org/10.1016/j.actaastro.2013.03.023

demonstrator. Considerations and constraints for the control system design of the lunar lander demonstrator are discussed. Numbers, locations and directions of the thrusters for descending control and attitude control are determined by analysis and trade-off studies. Test flight scenario is defined and a control algorithm for the predefined flight trajectory is introduced. The proposed control system is verified with computer simulations by showing that the control design satisfies the requirements. Finally, a future plan for applying and verifying the control design is explained.

2. Conceptual design of lunar lander

One of the major constraints for a Korean lunar mission is that the lunar orbiter and lander are to be launched by the Korean launch vehicle, KSLV-2. According to the outcome of a recent feasibility study for the Korean launch vehicle, KSLV-2 will be designed to have the capability to insert a 1.5 t class spacecraft into a sun-synchronous orbit at an altitude of 700 km and 98° inclination. For a low Earth orbit satellite, its capability is increased up to 2.6 t at an altitude of 300 km and an 80° inclination. The spacecraft's mass, after trans-lunar injection (TLI) maneuver, is estimated at 550 kg if a circular orbit of 300 km altitude is used as a parking orbit and a solid kick motor with specific impulse of 287 s is used for the TLI maneuver. [8].

Considering technical and strategic issues, preliminary specifications for the orbiter and lander as summarized in Table 1 have been derived from the early phase study:

Fig. 1 shows the resulting lunar lander shape from the conceptual design. The lunar lander model is modular, and modules will be combined based on the mission. Some modules will be shared with the lunar orbiter.

A major premise of structure subsystem design in the present study is to design the modular bus platform with compatibility between the orbiter and the lander. Modular design with compatibility enables minimal cost and time in realizing various missions. Structure subsystem requirements of the lunar lander driven by the mission requirements of the system are shown in Table 2.

The propulsion system includes flow control components such as propellant tank, pressurant tank, pressure regulator, propellant and pressurant filter, latching valves, thruster valves and lines. Tank size was selected considering the modular structure design. For the lunar lander, two groups of thrusters are used. The first thruster cluster is for descending control which is used for lunar orbit injection, deorbit maneuver, braking, and powered descent. The other thruster group is for attitude control during all phases. Descending control thrusters should provide large enough thrust level for deceleration and soft landing in lunar gravity. Considering the available technology, a single thruster is designed to have a thrust level of 220 N in vacuum conditions and they are clustered to provide a maximum thrust level of 1100 N. Attitude control thrusters will have a 5 N thrust level in vacuum conditions. The capability and reliability of the 5 N thrusters have been proved from successes in the Korea Multi-Purpose Satellite (KOMPSAT) programs. Table 3 shows the proposed configuration of the propulsion system of the lunar lander.

Table 1
Design specifications for the lunar orbiter and lander [9]..

	Orbiter	Lander
Mission lifetime	1 year	3 month (TBD)
Wet mass (kg)	550	550
Payload mass (kg)	TBD	TBD
Propellant	Mono	Mono
Stabilization type	3-axis	3-axis
Launch vehicle	KSLV-2	KSLV-2
Mission orbit		
Type	Polar Orbit	N/A
Altitude (km)	100	N/A
Inclination (deg)	90	N/A
Eccentricity	0	N/A
Landing site	N/A	Near side (TBD)

3. Control configuration design of lunar lander demonstrator

Lunar lander demonstrator is a technology demonstration model for lunar landing mission. This demonstrator is a flight test vehicle in the ground condition. The total mass of the ground based lunar lander demonstration model is determined by the strength of gravity on the Moon which is 1/6 that of Earth's. As the conceptual lunar lander model has a wet mass of 550 kg, we limit the initial mass of the demonstrator to less than 100 kg including fuel. The lunar lander demonstrator will be used as a test bed for guidance, navigation, and control technology such as accurate and soft landing, hazard detection and avoidance. It will be also used as a test bed for testing landing structures and landing mechanisms including shock absorption devices. Tip-over stability will be tested by using the demonstrator at the touchdown phase. Thruster clustering and controlling technology with newly developed thrusters will also be tested using this lunar lander demonstrator.

The dimensions and components of the lunar lander demonstrator are shown in Fig. 2. The external dimensions of the demonstrator are similar to the lander conceptual model, but a smaller sized fuel tank is used to reduce the mass. The components include five 200 N Descending Control Thrusters (DCTs), eight 3 N Attitude Control Thrusters (ACTs), an Onboard Computer (OBC), an Electric Power System (EPS), and a Telemetry Telecommand (TTC) module. Four landing legs include impact absorption mechanisms using aluminum honeycomb struts. We use thrust levels of 200 N and 3 N considering the thrust level decrement in the ambient conditions compared with the vacuum condition.

Changes from the lunar lander conceptual design model to the demonstrator model are summarized in Fig. 3.

3.1. Control configuration design requirements

We start the design of the guidance, navigation, and control by selecting hardware components for the navigation sensor and control actuator. Navigation sensors are