Digital Integration of Landing Dynamics Analysis of the Lunar Lander

Jian-Zhong Ding[1], Chun-Jie Wang[1,2], and Jia-Jun Wang[1]
[1]School of Mechanical Engineering & Automation, Beihang University, Beijing, China.
[2]State Key Laboratory of Virtual Reality Technology and Systems, Beihang University, Beijing, China.
Email: jianzhongd@buaa.edu.cn.com, wangcj@buaa.edu.cn, wangjiajun1990@126.com

***Abstract*—Large amount of simulation work should be done to predict the landing performance of a specific lunar lander before it really lands on the moon and this kind of work is repetitive .To reduce the time consumed and improve the efficiency of analysis, an application of digital integration is discussed in this paper. The proposed integration consists of one module for parametric modeling, one module for landing dynamics analysis, one module for reliability analysis and one module for database management. The creation of a parameterized landing model in the modeling module was discussed in detail seeing that it is the key to realizing the automated integration. Using the method of integrating, the simulation process of the lunar landing was standardized, the design experience was accumulated, and meanwhile, the automation of the simulation process was realized.**

***Index Terms*—digital integration, lunar landing, parametric modeling, dynamics analysis**

I. Introduction

The dynamics analysis of the lunar landing is crucial to verify a successful soft-landing on the moon [1], [2]. Currently, researchers have devoted great efforts to the computer-aided landing dynamics analysis and great achievements have been got on modeling [3]-[5], stability analysis [1]-[7], reliability analysis [8], [9], and structural optimization [10]. Based on the design requirements, which must satisfy the structural, mechanical, and landing performance of the vehicle, the simulation of the lunar landing should be conducted repeatedly. Therefore, the process of simulation of lunar landing dynamics analysis is completely integrated for the purpose to improve the efficiency.

The use of digital integration contributes to the realization of automation. In the integrated module for parametric modeling of the lunar lander, a widely used lunar lander with the configuration of a four-legged landing gear is parameterized. Using independent parameters, the model can be easily created. In the module for dynamics analysis, the initial landing conditions for lunar landing are set and the touching down simulation is run, besides, the landing performance of the lander is shown in figures. In the module for reliability analysis, an approach of Mento Carlo is introduced. Consequently, the failure rate is calculated. In the last module for database, the data of the simulation process is recorded.

II. General Description of Lunar Lander

The present lunar lander (Fig. 1) consists of a main body and a subsystem of landing gear [1].

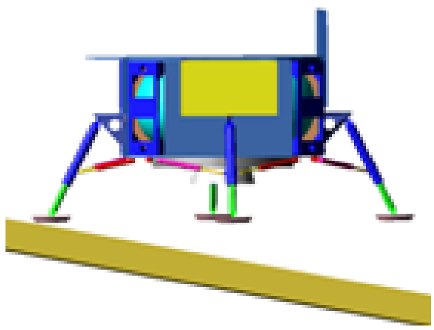

Figure 1. The model of lunar lander

The main body of the lunar lander consists of fuel container, lunar rover container, solar battery board and some others components for navigation and lunar exploration. The four-legged landing gear subsystem is the most crucial assembly of the lunar lander. Four legs of the subsystem are symmetrically distributed around the main body and each leg consists of one primary strut having one pad and two secondary struts supporting the primary strut. The landing gear must provide sufficient energy-absorption capability and adequate vehicle stability when the lunar lander lands on the moon.

III. Designofthe Digital Intergration

A. Module for Modeling

In this module, the model used for landing dynamics analysis is created. This module is the foundation of the others. To create a model, the lunar lander needs to be parameterized beforehand. The geometric structure of the main body is concerned little in dynamics analysis. All that matters are the mass property. Therefore, using parameters including the mass, location of the barycenter and the moments of inertia, the main body is fully described. The main task of parameterization is to parameterize the landing gear. The performance of the

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landing gear is critical to estimate the stability of the soft-landing. Its parameterization work should be done in two aspects: to parameterize the structure and to parameterize the mechanical properties.

The structure is parameterized by independent parameters, as shown in Fig. 2. Using the independent parameters defined in Fig. 2, the other parameters of the configuration can be calculated automatically in this module.

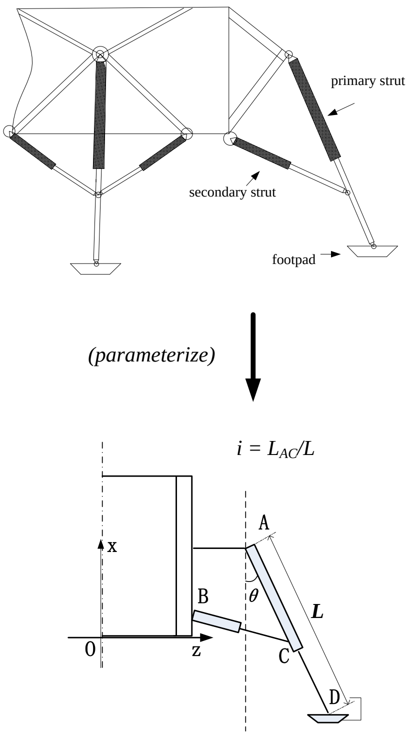
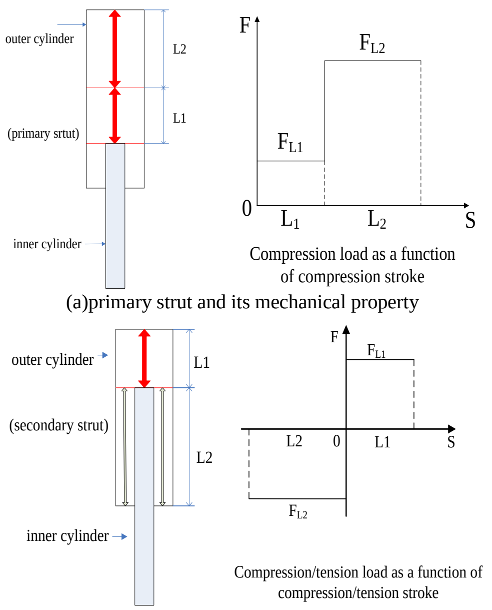


Figure 2. Parameterization of the landing gear

In Fig. 2, point A, point B, point C and point D represent the centers of the connecting hinge respectively.



(a)primary strut and its mechanical property

(b) secondary strut and its mechanical property

Figure 3. Parameterization of the primary and secondary strut

The primary strut on each landing-gear leg assembly consists of a lower inner cylinder that fits into an upper outer cylinder to provide compression stroking at touchdown. The secondary struts also have an outer and inner cylinder, however, they are capable of both tension and compression stroking [1]. Their mechanical properties can be described by loads as function of strokes (Fig. 3).

The parameters of the lunar soil are of vital importance in impact dynamics analysis at touchdown. The mechanical properties of the lunar soil are expressed in the contact model of footpads and lunar soil. The subsystem is simplified to a nonlinear spring-damp model and Coulomb friction model, which represent the normal forces and tangential forces respectively [8]. The kernel formula of this nonlinear spring-damp model is shown in Eq. (1).

$$F_n = K\delta^e + C\dot{\delta} \tag{1}$$

where parameter K, e and C represents the stiffness coefficient, nonlinear exponent and damping coefficient relevant to the deformation δ, and F_n represents the compact force between the footpad and the lunar soil.

The formula used in Coulomb friction model is shown in Eq. (2).

$$F_f = \mu F_n \tag{2}$$

where μ represents the friction coefficient and F_f represents the friction force.

In this module, once the independent parameters are assigned with values, a model of lunar lander for dynamics analysis will be created automatically and it will be used in other modules.

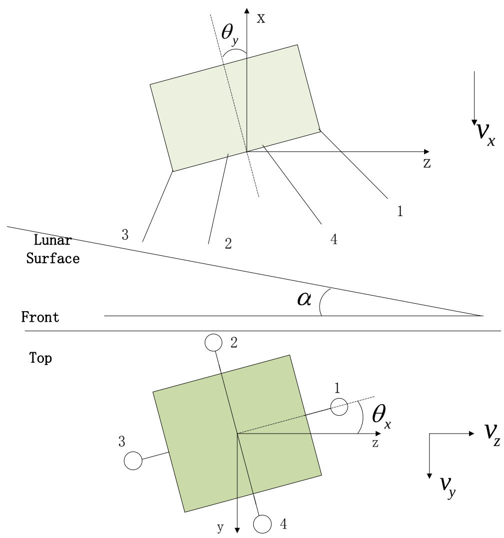


Figure 4. Landing conditions

B. Module for Dynamics Analysis

The parameterized model of the lander is introduced into dynamics analysis. Before running the simulation, the landing conditions should be set. Similarly, the conditions are parameterized. The initial landing conditions consist of instant velocities and angular velocities of the lander at touchdown, the slope angle of the lunar surface, the posture angles of the vehicle and the coefficient of friction between the footpads and the lunar soil [8].

The quantities which best describe the performance of the lunar landing are computed as part of the dynamics analysis. They are given as follows [9]:

(1)Clearance-This is defined as the distance between the lunar surface and the bottom of the lunar lander.

(2)Strut strokes-These are the amount of compression and extension stroking experienced by any of the struts.

(3)Joint loads-These are the loads in the connection joints.

(4)Stability distance-This is a quantitative measure to judge whether the lunar lander turns over or not.

These quantities are shown in figures after each simulation. Here shows some figures.

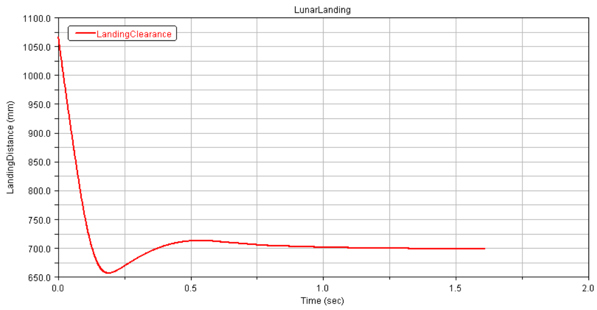


Figure 5. Landing Clearance

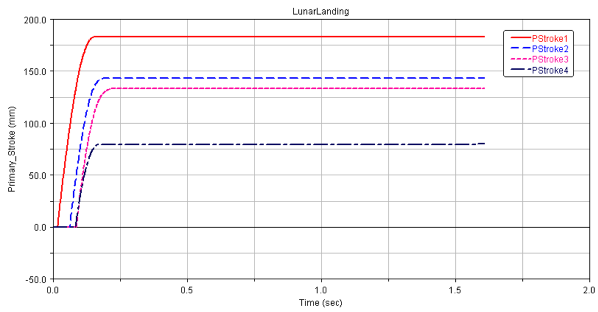


Figure 6. Landing stroke of each leg

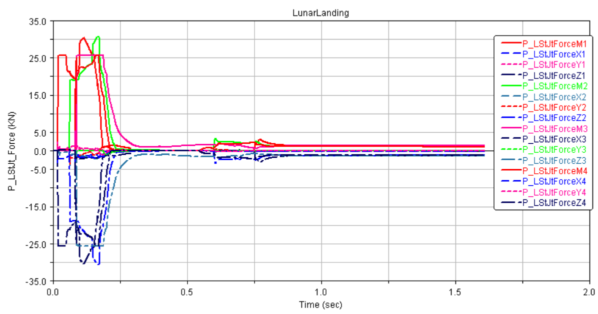


Figure 7. Joint loads between primary struts and main body

The curve in Fig. 8 shows the stability distance to judge whether the lunar lander turns over. The toppling distance is the distance between the rigid-vehicle center of mass and a plane parallel to the gravity vector that passes through two adjacent landing gear footpads. If the center of mass is within an enclosure by the four planes, then the landing is considered to be stable.

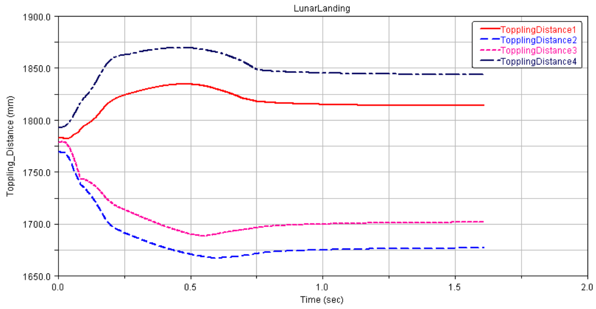


Figure 8. Toppling Distance

The model used in the simulation, the inputs of the initial landing conditions and their corresponding results will be record in the database.

C. Module for Reliability Analysis

An optimum design of the lunar lander with the highest reliability must be obtained. Therefore, a module designed to compute the reliability of a lunar lander is discussed.

As described above, the major requirements of a lunar lander are that the clearance, the strut strokes, the joint loads and the stability distance be constrained within established limits. This quaternion of opposing requirements forms a highly challenging design problem. The initial landing conditions vary, that is, all of which can hardly be fully-considered in the simulation. Consequently, an approach of Mento Carlo analysis is introduced in this module.

The approach of Mento Carlo bases on random sampling and it is of high precision [8], [9]. The only things need to be done in this module are to determine the distributions of the landing conditions and to determine a precision coefficient before running the simulations. The number of simulation attempts is closely related with the precision coefficient. After adequate times of simulation, a statistical result is obtained to reveal the landing reliability. Operations in this module generally work as followed:

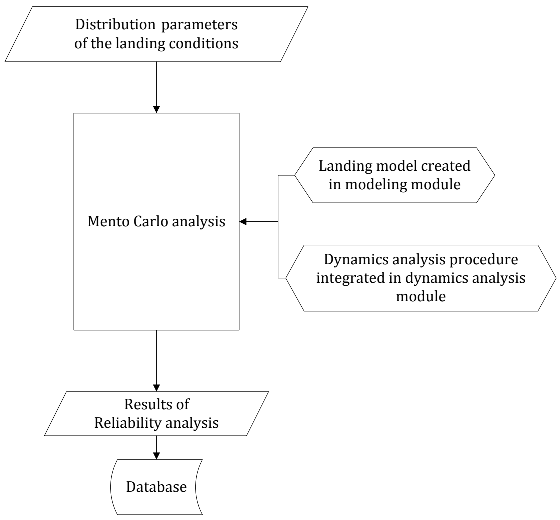


Figure 9. Flow chart of the reliability analysis

In the digital integrated system, the model simulated in this module for reliability analysis is created in the modeling module. The simulations are run in dynamics analysis module. Similarly, the results are record in the database.

D. Module for Database

This module is designed to record the every model created in modeling module together with its corresponding analysis results. In this module, the results of considerable amount of simulations are compared to determine an optimum design of the lunar lander. Besides, some factors that significantly affect the landing performance are detected and the design experience of the lunar landing gear is accumulated.

The structure of the database is shown in Fig. 6.

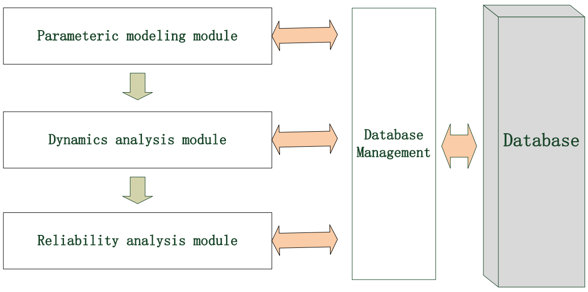


Figure 10. Structure of the database

IV. Realization of the Digital Integration

A software platform is introduced to realize the digital integration of the landing dynamics analysis of the lunar lander. It integrates all the modules mentioned above .The frame of the platform is shown in Fig. 11.

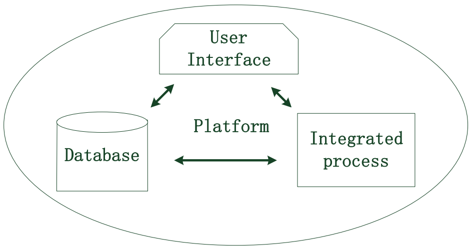


Figure 11. Frame of the platform

V. Conclusion

The digital integration of the landing dynamics analysis of the lunar lander was discussed in this paper. The function design of each module in the integration was described in detail. By means of integration, great improvements were achieved in efficiency, simplification and standardization.

The integration of the process of modeling, dynamics analysis and reliability analysis had been realized. Then the process of optimization can be considered for a further integration

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Jian-zhong Ding, born in Shangdong Province, China in 1991, received a bachelor's degree of Mechanical Engineering at School of Mechanical Engineering & Petroleum Storage and Transportation Engineering, Chinese University of Petroleum, Beijing, China in 2013.And now he is a doctoral students of Mechanical Engineering in Beihang University, Beijing, China, majoring in dynamics simulation and digital integration.

Chun-jie Wang, born in Liaoning Province, China in 1978, received a bachelor's degree of Mechanical Engineering in Liaoning Project Technology University in 1982,received a doctor's degree in Engineering in Beihang University, Beijing, China in 1997.Now she is a doctoral supervisor in Beihang University, majoring in CAD/CAE and simulation technology.

Jia-jun Wang, born in Hebei Province, China in 1990, received a bachelor's degree of Mechanical Engineering in Beihang University, Beijing, China in 2012. Now he is a postgraduate in Mechanical Engineering in Beihang University, majoring in mechanical design and simulation.