Evaluation of landing success probability through landing dynamics simulation by Monte Carlo simulation with Kriging metamodel

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1. Introduction

For successful lunar exploration, structural integrity of lunar lander at the touch-down moment of landing has to be maintained, and posture stability without tip-over or sliding also be ensured. Therefore, the prediction of landing success probability of the lunar lander is an essential task for successful lunar exploration mission.

According to recent works, studies on the selection of safe landing sites have been carried out by using lunar surface information [1-2]. However, the accuracy of prediction was not so reliable because the landing success rate is determined using only information about the slope angle of the lunar surface.

In this work, a set of landing dynamic simulations on the virtual lunar surface considering soil characteristics is conducted and a kriging metamodel is created based on the results of simulation [3]. And the landing success probability is evaluated by conducting Monte Carlo simulations with kriging metamodel.

2. Lunar soil model based on finite element simulation

In this study, single-leg dropping test and analysis using properties of lunar soil simulant were carried out and the results were compared. However, as shown in Fig. 1, the magnitude of the first peak of simulation did not match with the test results, so the properties of soil model were modified as listed in Table 1. As a result, the magnitude of first peak is similar to the test results and post-landing behavior is physically reasonable. And two virtual lunar surfaces, as shown as Fig. 2, were created using calibrated properties.

3. Conditions of landing dynamics simulation

For landing dynamics simulation on virtual lunar surface, a simplified model of the lunar lander was created, as shown in Fig. 3. The landing analysis used the commercial program ABAQUS explicit. To realize the vertical touch-down speed 3m/sec on the lunar surface, a lunar lander model did a free fall analysis in a lunar gravitational gravity at a vertical distance of 2.752m from the virtual lunar surface.

Table 1 Properties of the modified soil model

	Elastic modulus [MPa]	Internal friction angle[°]	Cohesion [kPa]
Lunar soil simulant	15	33.6	2.45
Case 1	1.5	33.6	2.45
Case 2	1.5	20.0	0.5

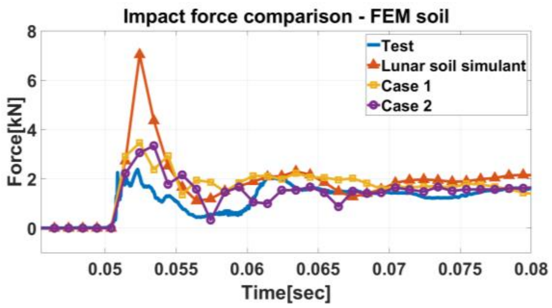
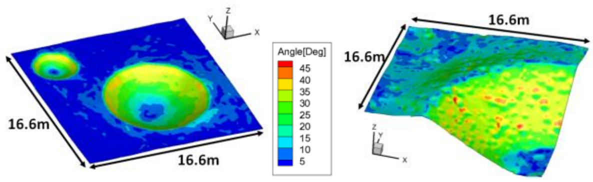
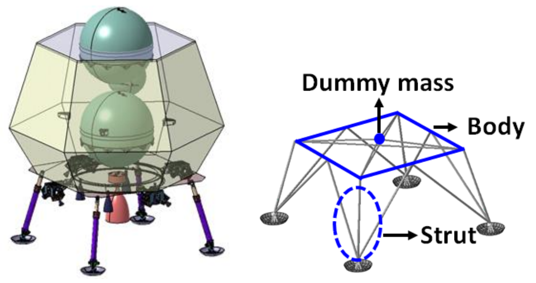


Fig.1 Comparison of impact force history on various lunar simulant models



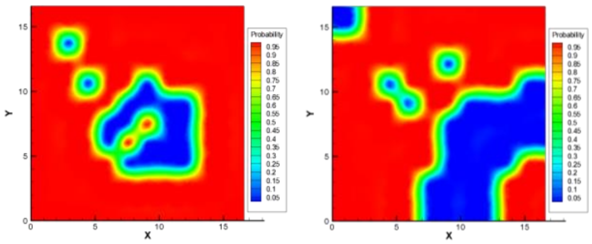
(a) Zone1 (b) Zone2
Fig.2 Tip-over angle



(a) CAD model (b) Analysis model
Fig.3 CAD & analysis model of the lunar lander

4. Monte Carlo simulation with Kriging metamodel

The landing dynamics simulation on the virtual lunar surface was conducted a total of 100 times at the sampling landing location. However an extensive landing dynamics simulation is not appropriate for Monte Carlo simulations because it requires tremendous computational cost for each simulation. Thus, we created a surrogated model based on kriging metamodel with results of landing dynamics simulation. Monte Carlo simulation with the kriging metamodel was conducted and the landing success probability of the lunar lander was predicted again, as shown in Fig. 4. As a results, the landing success rates were reevaluated as listed in Table 2.



(a) Zone1 (b) Zone2

Fig.4 Landing success probability by kriging metamodel

Table 2 Comparison of landing success probability

	Zone1 [%]	Zone2 [%]
Landing success prediction by slope angle	86.98	78.58
Landing dynamics simulation with one-hundred sample landing locations	85.07	70.73
Kriging prediction	83.31	69.01

5. Conclusion

In this work, the landing success probability of the lunar lander on the virtual lunar surfaces was predicted through the landing dynamics simulation with 100 sampling points of landing. Based on the results, a kriging metamodel was created. Thus a more reliable landing success probability was evaluated by conducting Monte Carlo simulation with the metamodel.

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