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## **PS05**

## 異なる車輪形状を有する四輪小型月面探査機の横滑り評価

# **Evaluation of skidding of a small four-wheeled lunar** rover with different shaped wheels

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#### 1. Introduction

In recent years, the lunar exploration in the space development has again attracted attention. The lunar exploration is necessary to unravel the solar origin and use moon resources. In order to conduct this exploration smoothly, the necessity of small lunar exploration rovers increases, which are capable of autonomous driving. When they drive on the moon, the soft ground formed by the lunar fine sand called Regolith causes wheels used for rovers to slip. When climbing the slope such as craters, wheels can sink into the soft ground and become inoperative called stuck. When crossing the slope, a slip called side skid occurs and can cause the lowering of exploration efficiency by taking rovers off the target path. It also can cause rovers to become inescapable because the wheel is buried into the sol1<sup>1</sup>. We have developed small lunar rovers with special shaped wheels<sup>2</sup> such as an ellipse wheel and a 3blade wheel that is able to climb the slope of 30 degrees. However, effects of these special shaped wheels on the side skid have not been evaluated. Therefore, this paper reveals the slope crossing performance of the small lunar rover with specifically shaped wheels.

### 2. Design and experimental method for small lunar rover

### 2.1. Design of a small lunar rover

**Figure. 1** shows a small four-wheeled lunar rover used in this experiment. The sizes of the main body are 230 mm in length, 90 mm in width, and 73.5 mm in height and the total weight is 2 kg placing a weight.

**Figure. 2** shows wheels attached to the main body. A circular wheel has a diameter of 110 mm, and an ellipse wheel has a major axis of 110 mm and a minor axis of 66 mm. A 3blade wheel is inscribed in a circular with a diameter of 110 mm and a blade radius of curvature of 27.5 mm. Each wheel is designed with 15 lugs of 10 mm high and 3 mm thick. The width of wheels is set to 30 mm.

## 2.2. Road test track

**Figure. 3** shows a test site. The size of test site is 1820 mm long, 450 mm wide and 308 mm high. The ground environment is set with a mixture of silica sand No. 5 (Takeori Kogyo Sho) with a particle size of 0.3 to 0.8 mm

and silica sand No. 6 (Takeori Kogyo Sho) with a particle size of 0.2 to 0.3 mm, at a ratio of 1:1.

#### 2.3. Cross-slope test

The slope traverse test is conducted as shown in **Figure. 4(a)**. The slope angle conditions are 5  $^{\circ}$ , 10  $^{\circ}$ , and 15  $^{\circ}$ . The installation condition of the small lunar rover is 100 mm from the outer side of the test site above the slope to the inner side of the wheel above the slope. The power consumption and travel time of the small lunar rover are measured for 500 mm of travel. **Figure. 4(b)** shows the location of the measurement of the amount of skidding. The horizontal distance from the outer side of the test site above the slope to the inside of the ruts formed by the front wheels above the slope is measured. The amount of skid is calculated by dividing the difference between the measured value and the installation distance of 100 mm by the value of cos (slope angle). The motor speed is set at 10 rpm and driven by a 12 V regulated power supply.

## 2.4. Measurement of wheel settlement relative to the ground

Measure the amount of wheel settlement and the lateral area of the settlement when traversing a 15° slope. The amount of wheel settlement relative to the ground is calculated by measuring the distance from the center of each wheel to the ground using ImageJ<sup>3</sup>). Furthermore, the measured values and the drawing data of each wheel are used to measure the area of settlement of each wheel.

#### 3. Experimental results and discussion

#### 3.1 Comparison of energy consumption and running time

**Figure. 5** shows the power consumption of each wheel. The circular wheel consumes the least amount of energy at each inclination angle. It has a larger circumference than the other wheel shapes, which shorten the running time, and this is thought to reduce the power consumption. In the wheel shapes except the circular wheel, it is thought to increase the amount of power consumption because of the extra torque generated in the motor which caused the vehicle body to move up and down.

#### 3.2 Relationship between the amount of skidding and settlement of each wheel

**Figure. 6** shows the amount of skid for each wheel. When comparing the ellipse wheel and the circular wheel, the ellipse wheel has a smaller amount of skid at slope angle of 5°. However, there is no difference in the amount of skid at slope angle of 10° and 15°. When comparing the 3blade wheel and the circular wheel, the 3blade wheel has a smaller amount of skidding at all slope angles.

**Figure.** 7 shows the amount of sinkage and the lateral area of the sinking part for each wheel. Comparing the ellipse wheel and the circular wheel, there is no significant difference in the mean values of the amount of sinkage and the lateral area of the sinking part of both wheels. The 3blade wheel sinks not only the lugs but also the wheel itself during soil scraping. Therefore, the amount of sinkage and the lateral area of the sinking part were the largest among the wheel shapes compared.

**Figure. 8** shows how skidding occurs. Skidding occurs when the downward force due to the wheel's own weight exceeds the support force from the soil, causing the soil to collapse. The bearing force immediately before the soil collapses is called the passive earth pressure, which is defined in Rankine's theory<sup>3</sup> of earth pressure by Equation (1).

$$P = \frac{1}{2}rH^2\tan^2\left(45^\circ + \frac{\phi}{2}\right) \quad (N/m^2) \tag{1}$$

Therefore, it is considered possible to increase the passive earth pressure and obtain high bearing capacity by increasing the amount of settlement H into the soil. It is also considered effective to increase the lateral area of settlement to reduce the pressure on the soil to less than the passive earth pressure.

The ellipse wheel does not differ from the average values of settlement and lateral area of settlement of the circular wheel. Therefore, there is no difference in the total amount of support force received from the soil during the measurement time, suggesting that the ellipse wheel is not effective in suppressing sideslip at high slopes. The 3blade wheel has the largest settlement and the largest lateral area of settlement among the wheels compared. Therefore, it is considered that the support force is increased by decreasing the pressure on the soil while increasing the passive soil pressure, and that the wheel is effective in preventing sideslip even at high slopes. These results are based on Equation (1) and show Rankine's soil pressure theory is appropriate.

## 4. Conclusion

The findings of this study are as follows.

- When traversing a slope, the circular wheel can run with the lowest power consumption and in the shortest time. This may be due to the fact that the circumference of the circular wheel is the largest and no torque loss occurs due to the vertical motion of the vehicle body.
- 2) The 3blade wheel is more effective than other wheels in suppressing skidding. This is because the wheel itself also sinks when the 3blade wheel scrapes the soil, and both the amount of sinkage and the lateral area of the sinking part are larger.
- 3) When traversing a slope, the greater the amount of settlement of the wheel relative to the ground and the lateral area of the settlement, the higher the support from the soil and the more effective the control of skidding.



Figure 1. Small four-wheeled lunar rover used in this experiment



(a) Circular wheel (b) Ellipse wheel (c) 3blade wheel Figure 2. Shape of each wheel



Figure 3. Test site



Figure 4. Schematic diagram of a cross-slope test



Figure 5. Power consumption and running time (N=5, mean ± S.D.)



Figure 6. Amount of skid  $(N=5, mean \pm S.D.)$ 



Figure 7. Amount of sinkage and the lateral area of sinkage for each wheel



Figure 8. Mechanism of skidding

## 5. References

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