A SINGLE-WHEEL TESTBED FOR REGOLITH SCIENCE STUDIES.

L. Passoni[1], G. Imhof[1], C. Sunday[1,2], M. Bassas[1], A. Sournac[1] and N. Murdoch[1]. [1]Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-SUPAERO), Toulouse, France (laura.passoni@student.isae-supaero.fr, gerald-alois-omar.imhof@student.isae-supaero.fr), [2]Université Côte d'Azur, Observatoire de la Côte d'Azur, Centre National de la Recherche Scientifique (CNRS), Laboratoire Lagrange, Nice, France.

Introduction: In 2024, the Japanese Aerospace Exploration Agency (JAXA) plans to launch the Martian Moons eXploration (MMX) mission to the two Martian satellites, Phobos and Deimos [1]. One objective of the mission is to study the origin of these bodies. To help achieve that goal, instruments will be used to collect more information about their surfaces, which are likely covered by fine-grained regolith [2]. The surface conditions of Phobos are similar to a large asteroid, presenting a challenge for in-situ exploration. In particular, the milli-gravity environment will make landing and operating surface rovers very difficult.

During the MMX mission, the French and German space agencies (CNES and DLR) will send a rover to the surface of Phobos. The MMX rover, weighing about 25 kg, will be the first wheeled rover on a small-body and will serve as a scout for the spacecraft's other lander [3]. The rover will be equipped with two WheelCams pointed at the left wheels for studying wheel-regolith interactions in low-gravity conditions [4]. Specifically, the front WheelCam will study the interaction between the wheel and the soil, while the rear one will observe the track left by the wheel.

In this work, we present the design of single-wheel testbed that can be used to conduct regolith science studies similar to those that the MMX rover might perform. The testbed will be used to help interpret 'WheelCam-like' images and, with the aid of the testbed's sensors, will be used to validate image analysis techniques for calculating performance parameters like wheel sinkage and slip.

Parameters of interest: Before designing the ISAE single-wheel testbed, we conducted an extensive survey of vehicle performance metrics and their applicability to planetary rovers. Wheel sinkage and slip are two parameters that can be determined from image analysis, so the single-wheel testbed was designed in order to observe these specific behaviors.

Wheel slip is essentially the loss of traction and is a phenomenon that can occur primarily on loose soil. The slip ratio i is defined by [5] and [6] as follows,

$$i = 1 - v/(\omega r)$$

where v is the linear translational velocity of the wheel, ω the angular velocity and r its radius. i can assume values between 0, when there is no slip, and 1, where there is full blockage of the wheel.

Wheel sinkage is defined as the distance that the wheel penetrates into the surface material at any given moment. The authors in [7] calculate wheel sinkage z as

$$z = r(1 - cos\theta_c)$$

where θ_c is the contact angle between the bottom of the wheel and the surface and r is the radius of the wheel.

Testbed design: The main objective of the ISAE single-wheel testbed is to recreate scenes that the MMX rover might observe with the WheelCams. Then, the testbed images and sensors will be used to estimate and measure wheel sinkage and slip on different types of surface materials.

Overall, the testbed is 1.34 m in length, 0.66 m in width and 0.65 m in height. The wheel is 214 mm in diameter and is fabricated using a 3D printer. The container that holds the surface material is 1.14 m long and is divided into sections so that the wheel can traverse different materials during the same test. The CAD design of the testbed can be seen in Fig.1

The testbed structure has two degrees of freedom so that the wheel can move in the vertical and horizontal directions. The wheel is rotated using a 12V DC brushed motor with a torque rating of 9 Nm and is controlled to a constant rotational speed. A high-ratio gearhead (1526:1) is used to reach the small translational velocities we desire for testing (1 - 4 mm.s^{-1}).

Various sensors are implemented in order to measure wheel sinkage and slip. First, an encoder on the motor measures the wheel's rotational speed. Then, a laser sensor is used to measure the wheel's horizontal displacement, while a linear magnetic displacement sensor is used to measure the wheel's vertical displacement. The scene is observed using two CMOS sensor cameras with a resolution of 1936x1216 pixels and maximum frame rate of 161 fps. The cameras are mounted so that they move with the wheel, where one camera looks at the front of the wheel and the other observes the back. Finally, a counter weight can be used to modify the vertical load of the wheel.

Limitations: Since planetary rovers operate in reduced-gravity environments, recreating such conditions in the testbed would be interesting. However, low-gravity testing is not within the scope of this project. Experiments carried out in zero-g show that there is a linear evolution of slippage and sinkage between 1G and micro-gravity [8], suggesting that observations made in Earth gravity can still be applicable to low-gravity conditions.

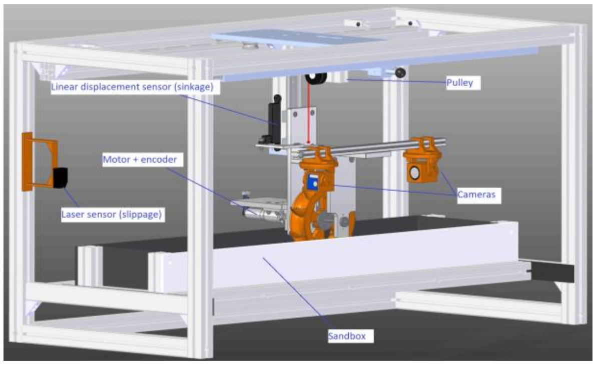

Fig. 1. CAD design of the ISAE single-wheel testbed

Future work: Here, we present the design of a testbed that can be used to study the dynamics of wheel-regolith interactions via image analysis. The mechanical and electrical integration of the testbed is still in progress, but once assembled, we will demonstrate how to use the testbeds cameras and sensors to estimate wheel sinkage and slip. First, images of the rover's wheels will be acquired and processed. Then, the measurements obtained through visual techniques will be compared with the additional sensors' measurements. This will allow us to validate the first experimental results for the sinkage and slippage detection methods.

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