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Recording the PHILAE Touchdown using CASSE: Laboratory Experiments

M. Knapmeyer (1), C. Faber (1), L. Witte (2), S. Schröder (2), J.-B. Tune (3), D. Möhlmann (1), W. Arnold (4), R. Roll (5), B. Chares (5), H.-H. Fischer (6), K.J. Seidensticker (1)

(1) DLR Institute of Planetary Research, Berlin Germany (martin.knapmeyer@dlr.de), (2) DLR Institute of Space Systems, Bremen, Germany, (3) Université Paris Diderot, Institut de Physique du Globe de Paris, (4) Saarland University, Department of Materials Science and Technology and 1. Physikalisches Institut, Göttingen University, Germany, (5) Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany, (6) DLR MUSC, Cologne, Germany

1. Introduction

The landing of Philae on comet 67P/Churyumov-Gerasimenko is scheduled for November 14, 2014. Its landing feet house the triaxial acceleration sensors of CASSE (Comet Acoustic Surface Sounding Experiment [1]) which will thus be the first sensors to be in mechanical contact with the cometary surface. It is planned that CASSE will be in listening mode to record the deceleration of the lander by the collision with the comet. The analysis of this data will not only support an engineering analysis of the landing process itself but also yield information about the mechanical properties of the comet's surface.

Here, we describe a series of controlled landings of a lander model. The tests were conducted in the Landing & Mobility Test Facility (LAMA) of the DLR Institute of Space Systems in Bremen, Germany, where an industrial robot can be programmed to move landers or rovers along predefined paths and under simulated low gravity (Figure 1).

Figure 1: The Philae lander model in the DLR LAMA facility, Bremen

2. Setup

We used a model of the lander body that contained a small flywheel (not used during our tests) and a cardanic joint that permitted triaxial rotations of the body underneath a carbon fiber mounting rod. This rod was connected via a spring suspension system to a 6-axis industrial standard robot. The orginal Philae body instrumentation was replaced by dummy masses in a way that the center of gravity fell into the center point of the cardanic joint.

The passive electric damping system that converts a relative motion of the body against the landing gear into electric energy is the same as on the spacecraft, as one goal of the measurement campaign was to obtain additional data on the inelastic behavior of the lander during touchdown.

The qualification model of the Philae landing gear was used in the tests. We are thus confident that its behavior is very similar to the version in flight. It consists of three legs manufactured of carbon fiber and metal joints. Attached to each leg is a foot with two soles and a mechanically driven ice screw to secure the lander on the comet (see [2] for details about *Philae*). The right one of these soles, if viewed from the outside towards the lander body, houses a Brüel & Kjaer DeltaTron 4506 triaxial piezoelectric accelerometer as used on the spacecraft. Orientation of the three axes was such that the X-axis of the accelerometer points downwards while the Y and Z axes are horizontal. This somewhat uncommon orientation is necessary due to the position of the electric connector on the 4506. Data was recorded at a sampling rate of 8.2 *kHz* for a duration of 2 *s*.

Touchdown measurements were conducted on three types of underground, with different velocities on each of them (Table 1). Landings with low velocities (to prevent destructive shocks) were carried out on the concrete floor of the LAMA to isolate the oscillatory behavior of the lander from that of the soil. Landings on fine-grained quartz sand (Wf34) and a Mars soil simulant (MSS-D) allow quantifying the changes due to interaction with the soil. These two materials were filled into three separate containers, one under each of the lander's feet.

Table 1: Model soils, touchdown velocities and peak accelerations

Material	Velocity [m/s]	Peak accel. [m/s^2]
Concrete	0.1, 0.2	200 ... 1200
MSSD	0.1, 0.2, 0.5, 0.8, 1.1	10 ... 700
WF34	0.1, 0.5, 1.1	8 ... 1000

The state of all feet after touchdown, including the depth into which the ice screws were drilled, was documented photographically. Selected touchdowns were filmed in high-speed video using a CASIO Exilim camera.

3. Preliminary Results

A phenomenological evaluation of high-speed videos supports the interpretation of the accelerometer data. The vertical component accelerograms of a landing on MSSD at 0.8 m/s (Figure 2) shows five discernible phases: A -Touchdown of foot 1, B - Touchdown of foot 2, C - First drilling phase of the ice screw of foot 1, D - Touchdown of foot 3, E - Second drilling phase of the ice screw of foot 1, ground contact of foot 3 ice screw.

The observed peak accelerations (Table 1) depend not only on landing velocity and soil material, but also on the delays between touchdowns of the individual feet. Phases C and E reflect a delayed answer of the foot 1 ice screw to the touchdown due to the sequential touchdown: in phase C, the ice screw drilled into the soil only a few millimeters during about 0.015 s, and in phase E, it drills about 5 cm in about 0.06 s. The other ice screws did not drill into the ground deeply during this touchdown.

The ringing signal visible on foot 3 between touchdowns of feet 2 and 3 has a dominating frequency of about 540 Hz and is thus close to the lowest eigenfrequency of the CASSE soles [3].

The accelerograms of feet 2 and 3 also show clear answers to the touchdowns of the preceeding feet.

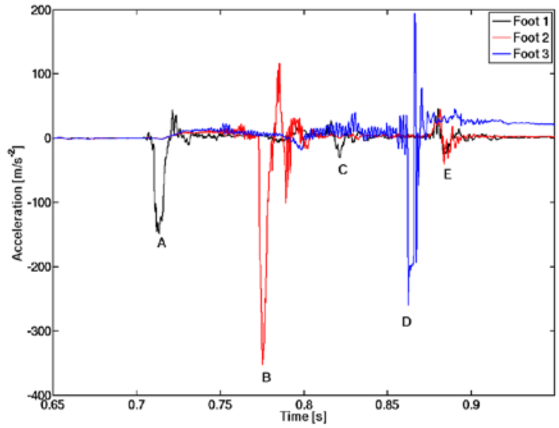

Figure 2: Example vertical component decelerations. Positive values signify acceleration *downwards*. The feet numbering in this touchdown corresponds to the sequence in which they touch ground. See text for a description of phases A to E.

4. Summary and Conclusions

We have conducted touchdown experiments under simulated low gravity, using the qualification model of the Philae landing gear and several combinations of soils and landing velocities. We demonstrate that CASSE data can support the reconstruction of Philae's landing on Churyumov-Gerasimenko.

References

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