Analysis, Test and Simulation of Landing System Touchdown Dynamics

DLR – German Aerospace Center
Institute of Space Systems
Dep. Exploration Systems
Robert-Hooke-Str. 7
28359, Bremen
Germany
www.dlr.de/irs

Lars Witte, Robert Buchwald, Silvio Schröder, Tim van Zoest

lars.witte@dlr.de , robert.buchwald@dlr.de, silvio.schroeder@dlr.de, tim.zoest@dlr.de

10th International Planetary Probe Workshop San Jose State University, 17th - 21st June 2013

Introduction

Future exploration missions pose demanding requirements towards the access by vehicles to scientifically interesting sites on planetary surfaces. These stem particularly from the need of more flexibility in site selection, improved payload to vehicle mass ratios and higher mission success probabilities.
The Landing Technology group of the DLR Institute of Space Systems is focusing on the development and verification of experimental and analytical methods for the investigation of the touchdown dynamics of landing system, its capabilities the embedding into the landing site assessment. This poster outlines the test facility, simulation and analysis tools developed by the working group and used in recent landing missions.

System and Mission Context

Infusion of mission and system context information into the analysis scheme.

- Mission requirements,
- System requirements
- System Architecture Concept
- Reference Designs

ESA Lunar Lander ([1], Ph. A, B1)

Philae Lander ([2], Ph. E)

Mission involvements

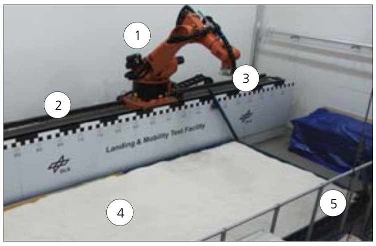
System Design

Syst. & Miss. Design

Mission Design

Landing & Mobility Test Facility

Core element for the experimental investigation is the Landing & Mobility Test Facility (LAMA), which allows touchdown testing under Earth gravity and under an apparently reduced gravitational environment using an active off-loading device [3]. The test article for investigation of legged landing systems is a modular Lander Engineering Model (LEM) designed by the Astrium ST (Bremen), representing today's European mission scenarios to the Moon and Mars such as the ESA Lunar Lander or the ESA Mars Precision Lander. Another test object recently under retesting is the Rosetta lander Philae representing a touch down system concept developed for small body landings.

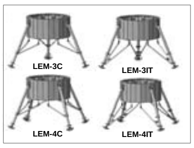


LAMA Infrastructure

1. 6-axis industrial robot system KR500 (500 kg load bearing capacity)
2. rail track system for horizontal movement (max. 2 m/s in every direction)
3. torque sensor on the hand flange for a sensor driven mode
4. 10 m x 4 m wide soil bin containing the planetary soil simulant
5. all elements are integrated into a test cell which provides the necessary infrastructure

Heritage

- System tests:
  - Lander Engineering Model (LEM) – Drop tests
  - Philae – coupled tests with weight offloading [7]
- Component tests:
  - Footpad-Soil Interaction [4]



Test Data, Verification

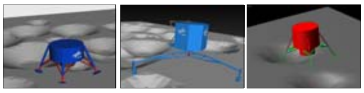
Test Prediction

Numerical Tools

Usually not all relevant environmental properties of the target landing site can be provided in one single and complete test, any verification approach has to be supported by adequate numerical analyses. Thus, another key topic for the verification of the touchdown performance of a landing system is the accurate analytical and numerical representation of the flight system, its touchdown conditions and the landing site. In this area the research focuses on the development of high fidelity engineering simulations of the vehicle-to-terrain/soil interaction [5].

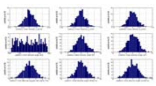
System Level Simulations

High-fidelity engineering simulators, based on multi-body dynamics software tools (MSC.Adams and SIMPACK), are available for multiple configurations. These configurations include 3 and 4 leg variants and comprising cantilever or inverted tripod gear kinematics. The models are parametrized and scalable. An upgraded model for the Rosetta lander Philae is currently under development.

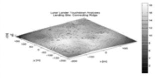


The Analysis Process

Stochastic pre-processing
Monte-Carlo method based parameter variation of touchdown conditions define the input parameter sets for the simulators.



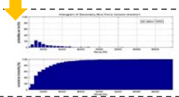
Environmental Context
Digital Terrain Models (DTM) from the landing site analysis are processed into simulator compatible terrain data files.



Simulation
Example ADAMS View / Insight Experiment:
- Touchdown conditions, landing site properties
- Lander design parameter

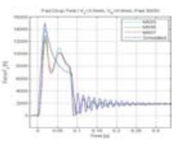
User output requests
- Transformed forces, Measures and sensors
- Design objectives

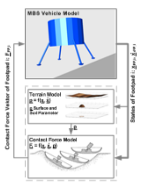
Stochastic post-processing
Statistics on the simulation result data assigns probability of compliance figures to design performance indicators.



Component Level Simulations

A contact-force-law for footpad to terrain interaction is implemented and validated. It basically describes the momentum transfer, drag from soil displacement and the soils elastic-plastic properties.





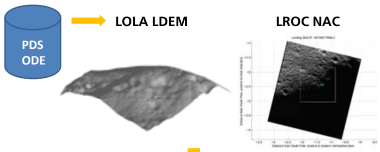
Terrain Model

Ldg. Gear Constraints

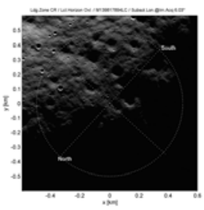
Landing Site Analysis Tools

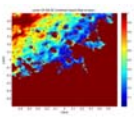
The landing site characterization and assessment (contributed to ESA's Lunar Lander mission study, [6]) focuses on the development of landing site assessment methods and tools to provide terrain models for engineering simulations (both touchdown dynamics and/or hazard detection & avoidance simulations). In return landing system performance limits are mapped onto cartographic landing site representations to support the landing safety assessment.
To achieve that task several processing and analysis steps are applied to remote sensing data from the LRO mission. The process flow and its main steps and outputs are shown below.

Down-selection of LRO raw data used as input to the surface hazard analysis process.

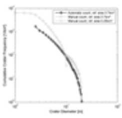


- Processing of the LRO LDEM GDR data products into slope information.
- Image registration and processing of LRO NAC image data products.
- Shadow hazards and boulder/crater hazards.

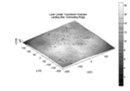




The hazard map provides information on the hazard magnitude at a surface position within the landing zone. It combines the three surface properties slope, roughness and shadow into a single metric. The hazard magnitude HM of pixel (i, j) is determined by the ratio of the respective property to its specified limit. The interpretation of the metric is that a value of 1 means the associated surface position is outside the specified limits. A value of less than 1 means compliance, however with the degree to which the particular surface position compares to the out-of-spec limit.



Development of software for automatic detection of hazardous terrain features has been started at DLR Institute of Space Systems, in order to speed-up the feature detection process and to collect extensive statistics [6].
The automatic feature detection follows a two-step approach applying image processing techniques to the LRO NAC image data. The first step makes use of texture filters to segment the image and outline potential features. The second processing step classifies the potential features as crater or boulder by exploiting their characteristic bright/dark pattern.



Terrain data is processed and formatted into files compatible with high-fidelity engineering simulations (both touchdown dynamics and hazard detection & avoidance). The terrain model can represent either the actual landing site candidate, can be fully generic representing a defined statistical property or hybrid (e.g. real DEM with statistical crater/boulder coverage).

References

[1] A. Pradier et.al., The First European Lunar Lander And The ESA-DLR Approach To Its Development, Proceedings of the International Astronautical Congress, IAC-10.A3.2B.8, Prague, 2010
[2] S. Ulamec, J. Biele, Surface elements and landing strategies for small bodies missions – Philae and beyond, Advances in Space Research, Vol. 44, pp. 847-858, 2009
[3] L. Witte et.al, A Vehicle Dynamics Test Facility For Planetary Surface Mobility, Proceedings of the 11th European Conference on Spacecraft Structures, Materials & Mechanical Testing , Toulouse, 2009
[4] S. Schröder et.al., Footpad-Terrain Interaction Tests with the Robotic Landing and Mobility Test Facility LAMA, Proceedings of the 62th International Astronautical Congress, IAC-11.A5.1.9, 2011
[5] L. Witte et.al, Touchdown Dynamics and Terrain Interaction of Planetary Lander, 1st ESA Workshop on Multibody Dynamics for Space Applications, ESTEC, 2010
[6] D. De Rosa et al., Characterisation of potential landing sites for the European Space Agency's Lunar Lander project. Planetary and Space Science (2012), doi:10.1016/j.pss.2012.08.002
[7] L. Witte et.al, Philae-Lander Touchdown Dynamics Revisited – Tests For The Upcoming Landing Preparations, Proceedings of the 10th International Planetary Probe Workshop, San Jose, 2013