Relativity in Fundamental Astronomy
Proceedings IAU Symposium No. 261, 2009
S. A. Klioner, P. K. Seidelman & M. H. Soffel, eds.

doi:10.1017/S174392130999072X

Modelling and simulation of the space mission MICROSCOPE

Stefanie Bremer[1], **Meike List**[1], **Hanns Selig**[1] **and Claus Lämmerzahl**[1]

[1]ZARM, University of Bremen,
Am Fallturm, 28359 Bremen, Germany
email: `bremer@zarm.uni-bremen.de`, `list@zarm.uni-bremen.de`,
`selig@zarm.uni-bremen.de`, `laemmerzahl@zarm.uni-bremen.de`

Abstract. The French space mission MICROSCOPE aims at testing the weak Equivalence Principle (EP) with an accuracy of 10^{-15}. The payload, which is developed and built by the French institute ONERA consists of two high-precision capacitive differential accelerometers. The detection of the test mass movement and their control is done via a complex electrode system. The German department ZARM is member of the MICROSCOPE performance team. In addition to drop tower tests, mission simulations and the preparation of the mission data evaluation are realized in close cooperation with the French partners CNES, ONERA and OCA. Therefore a comprehensive simulation of the real system including the science signal and all error sources is built for the development and testing of data reduction and data analysis algorithms to extract the EP violation signal. In this context the focus lays on the correct modeling of the environmental disturbances. Currently new effort to study the influence of the solar radiation and the Earth albedo to the MICROSCOPE mission scenario is underway.

Keywords. Gravitation, relativity

---

1. Introduction

The French MICROSCOPE mission is designed to test the weak Equivalence Principle (EP) with an accuracy of 10^{-15} (Touboul *et al.* (2001), Chhun *et al.* (2007)). For this purpose two high-precision capacitive differential accelerometers will be applied which are developed and built by the French institute ONERA. A drag-free satellite, that is produced by CNES, will carry out the experiment.

Free-fall tests at the Center of Applied Space Technology and Microgravity (ZARM) are used to study the instrument performance. In addition, the ZARM is also involved in the data evaluation of the MICROSCOPE mission. In this context a comprehensive simulation of the satellite and test mass dynamics is set up, including the instrument modelling and the influence of disturbances on the science signal. The simulation tool HPS will be presented and an overview about different modelling aspects will be given.

2. HPS: Structure and functionality

The High Performance Satellite Dynamics Simulator (HPS) is developed as cooperation project of the Center of Applied Space Technology and Microgravity (ZARM) and the DLR Institute of Space Systems. The software is based on the ZARM Drag-Free simulator (Scheithauer *et al.* (2002), Theil (2002)). It is a tool to support modelling and data analysis of missions that use so-called drag-free techniques. For this purpose the dynamics of a satellite that is equipped with up to four accelerometers each containing two test masses are modelled.

Figure 1. Illustration of shadow algorithm (left); Illumination example for MICROSCOPE radiator (right)

The development environment is Matlab/Simulink which provides the possibility to realize a modular design, i.e. all models can be developed and used separately. The core function calculates the states of the satellite and all test masses by numerical integration of the equations of motion. All effects that are based on the gravitational field are also considered within this main function. Forces and torques that act on the satellite or on its test masses are supplied as time-depending inputs. A multitude of coordinate systems are defined to take into account all technical entities like offsets and alignment errors.

3. Modeling of surface forces by means of finite elements

The correct modelling and understanding of the influence of external forces and torques on the satellite and test mass dynamics is important for the data reduction process. The forces and torques result from the interaction of the satellite with the space environment, basically solar radiation pressure, aerodynamic drag and Earth albedo.

In case of MICROSCOPE a detailed analysis of these effects is intended. The magnitude of all mentioned disturbance sources depends among other things on the satellite geometry and its surface properties. Standard approaches use a reference area for the force computation not taking into account e.g. shadowing. For MICROSCOPE a different procedure is set up, which will be exemplified for the computation of the solar radiation force. The general idea is based on the fact, that the magnitude of the resulting force is well known for a plate. Hence, it is possible to calculate the normalised force for each element of the discretized satellite surface (Wertz (1978), Cicek (2005)):

$$\mathbf{f}_\mathrm{i} = -A_\mathrm{i}[(1-c_\mathrm{si})\cdot\mathbf{e}_\mathrm{sun} + 2(c_\mathrm{si}\cos\alpha + \frac{1}{3}c_\mathrm{di})\cdot\mathbf{e}_\mathrm{N}]\cos\alpha \quad . \tag{3.1}$$

Here A_i is the area of the element i with the reflection coefficients for specular (c_si) and diffuse (c_di) reflexion. The sun vector $\mathbf{e}_\mathrm{sun}$ and the normal vector $\mathbf{e}_\mathrm{N}$ enclose the angle α.

The correct derivation of the illumination conditions is divided into two parts. The identification of all elements that are exposed to the sun is the first step. In a second step, the position of the middle node of the visible elements is compared against each other to ascertain which element is shaded by another one (cf. figure 1 (left)). Figure 1 (right) shows the baseplate of the satellite with the payload's radiator which is prepared for the investigation of the Earth albedo influence. The total force is derived as the sum over all visible elements multiplied by the solar pressure.

4. Modelling of MICROSCOPE payload

Great effort is done to model the MICROSCOPE payload T-SAGE (Twin Space Accelerometer for Gravitation Experimentation). This instrument, developed and built at the French institute ONERA (Guiu (2007)), is composed of two differential accelerometers equipped with two test masses each. The so-called reference sensor contains test masses of the same platinum alloy whereas the test masses of the second accelerometer are made of different material to derive the science signal. The sensor dynamics are

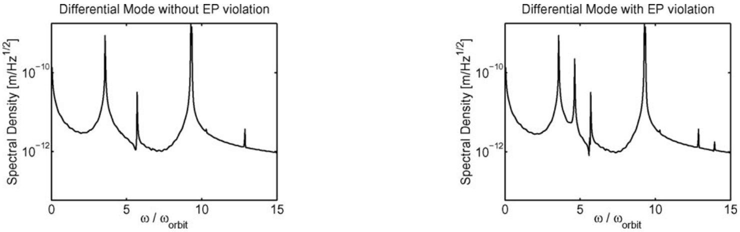

Figure 2. Results for simplified ansatz: Without EP violation (left); With EP violation (right)

linearized in a first approach, i.e. no coupling between the degrees of freedom are considered. The exact test mass position is detected via 18 electrodes. According to the HPS philosophy the sensor dynamics are coded in C and are available for the simulation in the Matlab/Simulink environment via an s-function.

5. Modelling of MICROSCOPE mission: Simplified Ansatz

A simplified ansatz is used to demonstrate an analysis method for the MICROSCOPE mission (Theil (2002)). In this case the satellite follows a circular orbit and rotates with a constant angular velocity with respect to the inertial frame. The test mass motion is constrained to the sensitive x-axis. The satellite and test mass coupling is modelled in terms of a spring-mass system. A spherical potential of the Earth is assumed. Figure 2 shows the results for this approach, on the left hand side without EP violation and on the right with EP violation. Here an additional peak appears at $\omega_{\text{orbit}} + \omega_{\text{spin}} = 4.6\,\omega_{\text{orbit}}$. It can be clearly distinguished from the peaks due to the spin frequency at $3.6\,\omega_{\text{orbit}}$ and the effect due to the gravity gradient at $9.2\,\omega_{\text{orbit}}$. The implementation of other disturbance effects and their detection is underway.

Acknowledgements

The authors like to thank our colleagues from the DLR Institute of Space Systems, in particular Stephan Theil and Hansjörg Dittus. Additionally we like to thank our colleagues from ONERA and from Observatoire de la Cote d'Azur, especially Pierre Touboul, Manuel Rodrigues, Bernard Foulon, Vincent Josselin, Ratana Chhun and Gilles Métris for their support. This work is supported by the German Space Agency of DLR with funds of the BMWi (FKZ 50 OY 0801).

References

Scheithauer, S. & Theil, S. 2002, *Generic Drag-Free Simulator, AIAA Modeling and Simulation Conference, Monterey, California*

Theil, S. 2002, *Satellite and Test Mass Dynamics Modeling and Observation for Drag-free Satellite Control of the STEP Mission, PhD thesis, Department of Production Engineering, University of Bremen*

Touboul, P. & Rodrigues, M. 2001, *Class. Quantum Grav.*, 18, 2487-98

Chhun, R., Hudson, D., Flinoise, P., Rodrigues, M., Touboul, P., & Foulon, B. 2007, *Acta Astronautica*, 60, 873-879

Cicek, M. 2005, *Entwicklung und Validierung einer Methode zur Berechnung der Oberflächenkräfte auf Satelliten, Master Thesis, Hochschule Reutlingen*

Guiu, É. 2007 *Étalonnage de la mission spatiale MICROSCOPE: optimisation des performances, PhD Thesis, École Centrale de Nantes et l'Université de Nantes*

Wertz, J. R. 1978, *Spacecraft Attitude Determination and Control, Kluwer Academic Publishers, Dordrecht, The Netherlands*