MMX Rover MECSS - Separation from the Mothership: Multibody Simulation Analysis of the Ejection

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1 Introduction

The CNES and DLR space agencies provide a rover to the JAXA MMX sample return mission to Phobos, a moon of Mars [4, 5, 6, 7]. The MMX rover will be the first attempt of wheeled locomotion in milli gravity [1, 3]. Laboratory experiments to test the proper functioning of the rover are only partially possible because of the very different conditions on Phobos compared to Earth. This is why computer simulations take a very important role in the development and analysis process [2]. For example, for the separation of the rover from the mothership as will be related in the following. The spacecraft will descend to around 50 m above the surface and eject the rover, from there the rover will fall on the surface. DLR provides a device for the mothership called *MECSS* (**M**echanical and **E**lectrical **C**hassis **S**upport **S**ystem) through which power and communication will be supplied during cruise. The MECSS further features a mechanism to safely separate the rover from the mothership. As the rover must not interfere with the mothership after separation, a minimum and maximum separation velocity, a maximum tumbling rate and a pyramidal volume must be kept by the rover in proximity of the mothership. A Monte Carlo analysis and an in-depth analysis with more detail of selected samples is conducted in order to have a statistically sound statement about the separation safety for rover and mothership.

2 Simulation Model

The MMX mothership and rover are rigid and inert masses. Mass and inertia of the mothership are fixed; mass, inertia and center of mass of the rover are variable within known bounds. Inertia and mass center about the three principal axes as well as mass are seven values varied in the Monte Carlo analysis.
The MECSS model is more complex and exists in two versions, one with simplifications for Monte Carlo analyses with a large number of samples and one with more detail for more in-depth investigations of a reduced number of parameter values. In the simplified model, the rover is either clompetely locked to the MECSS or free. In the detailed model, there are four hold down and release mechanisms that allow a little movement of the rover while attached. Additionally they don't open exactly at the same time but after a random delay. The push-off mechanism is also not entirely rigid in the detailed simulation model.
The MECSS model evolved through the phases, steadily incorporating more known parameter values, narrowing down the search space. Some parameters varied in the first Monte Carlo iterations, such as friction, became fixed in the latest iteration, as confirmed by measurement. Other parameters initially varied, like the direction of gravity, were removed because they had no measurable impact on the results.

3 Results

The simplified model is used for a Monte Carlo analysis with 100000 samples with 10 uncertain parameter values. The values are chosen uniformly between the known bounds. Separation direction is x, direction of the wheels is y, direction of driving is z.
Figure 1 shows the velocities and angular velocities of the rover relative to the MECSS 1 s after ejection. The box plots show the median (orange line in the middle), the 1 σ region as box, the 3 σ region as lines and outliers, if present, as circles. The requirements to meet are marked with horizontal yellow lines.

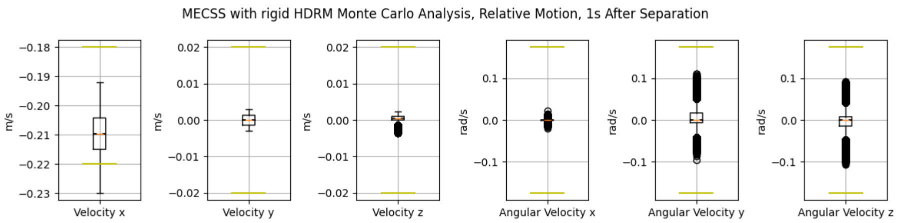

Figure 1: MECSS Monte Carlo Result Overview

While the requirements on the tumbling are met, the requirement of ejection velocity is met only within a $\sim 2\,\sigma$ region, whereas the lateral motions are small enough with good margin.
In fig. 2 the red lines span the allocated separation volume that the rover must not leave. Left is a heat map of the rover location, not only the center of mass is considered but the cuboid envelope. The large yellow portion in the middle is passed through by all samples. The borders going gradually over green to blue show that fewer samples pass through these points with the cuboid envelope. Right are 100 samples randomly selected from the 100 000 simulation samples. The rover cuboid envelope is shown for every 100 ms for the simulation time of 5 s. The allocated volume is never left by any sample.

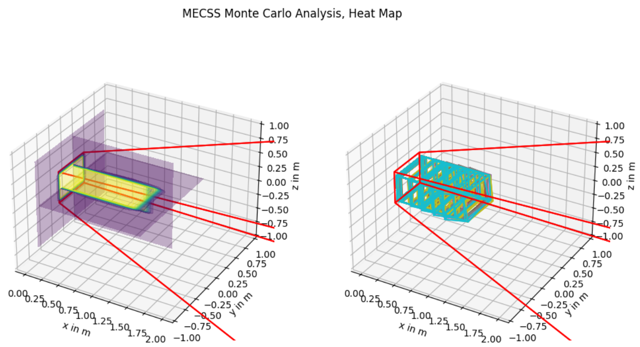

Figure 2: MECSS Monte Carlo Result: allocated volume (red), heat map (left), a few samples (right)

The simulation model for the Monte Carlo analysis above has many simplifications. Having more detail, such as nonideal HDRMs that don't completely lock any movement when closed, slows down the simulation speed much. Thus, a complete Monte Carlo analysis with all 100 000 samples is not possible in reasonable time on normal office hardware. Instead, a reduced number of samples, randomly selected, are simulated with the detailed MECSS model. In short, these simulations confirm that the separation of rover and mothership is safe within a $\sim 2\,\sigma$ region. The final paper will report about this more advanced model in detail as well as relate the latest results.

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