ROSPA, Cross Validation of the Platform-Art and ORBIT Test Facilities for Contact Dynamic Scenario Setup and Study

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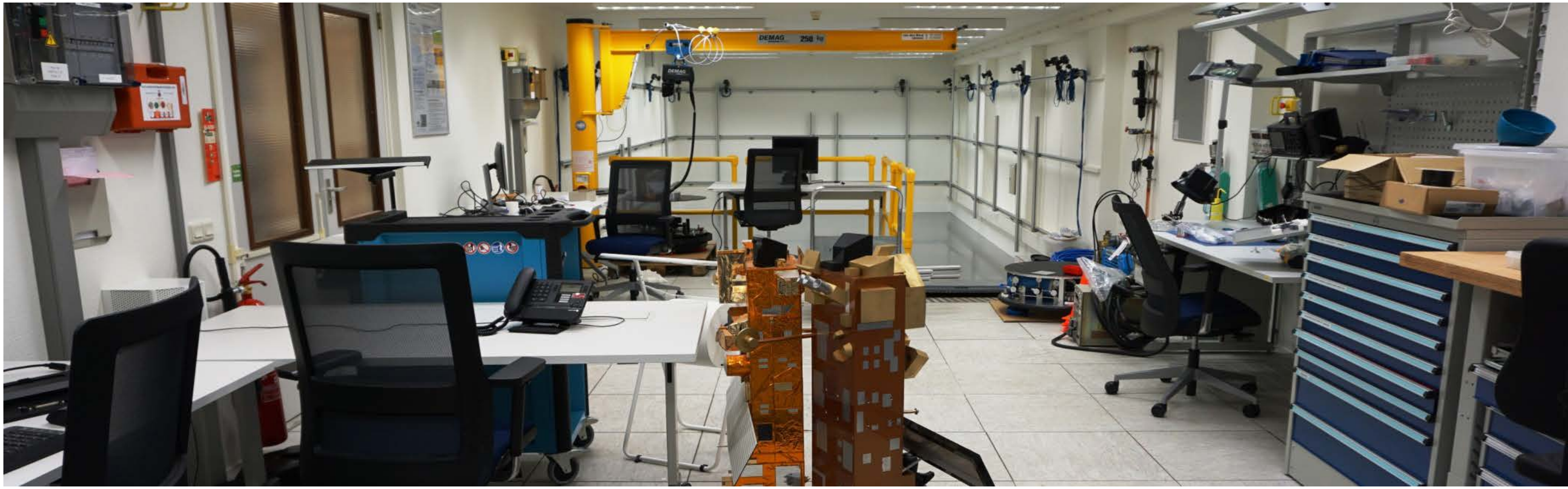
Cleanspace Industrial Days (23-27 May 2016)

European Space Agency

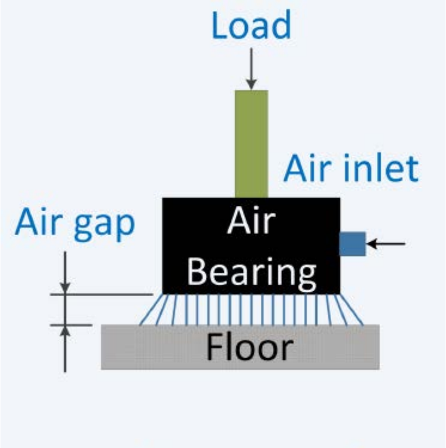
ORBITAL ROBOTICS LABORATORY



- Simulation of real contact dynamics for close-range rendezvous, docking, grabbing of free floating objects
- Landing and sampling on low-gravity bodies

  - ➢ Cleanspace project support (Active Debris Removal Technologies)

ORBIT - Orbit Robotics Bench for Integrated Technology

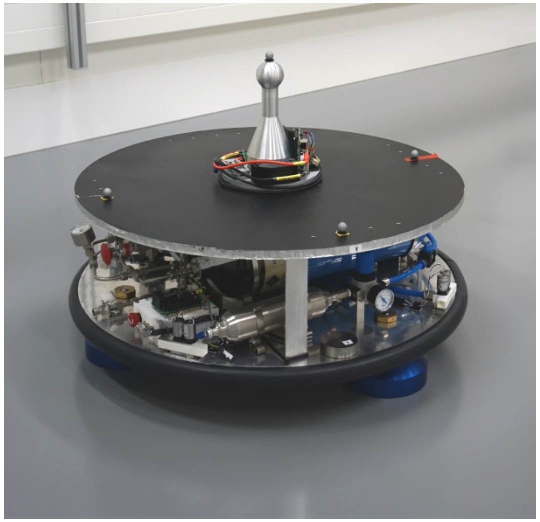


Air bearing working principle

- Extremely flat floor (0.8 (± 0.1) mm wrt to gravity)
- Targeted at “free floating” & realistic contact dynamics
- VICON Motion tracking system for ground truth
- Commissioned early 2015

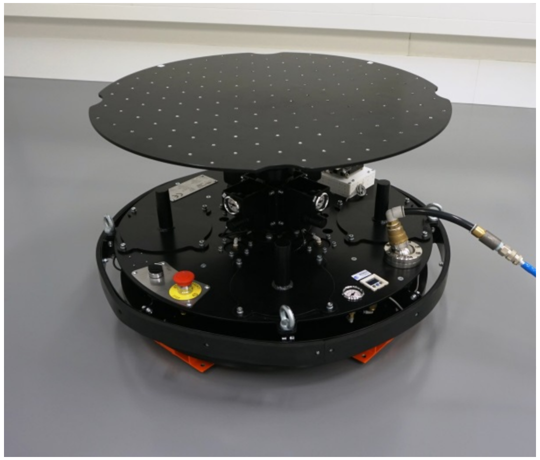
Air bearing platforms

- Three different air bearing platforms to float on the floor (independent, dependent air supply, different mass properties, common interface)



MANTIS

- Platform with independent air supply
- m = 25.82-27.55 kg
- MOI (around axis of symmetry) ≈ 1.6 kg/m2
- Eight experimental thrusters



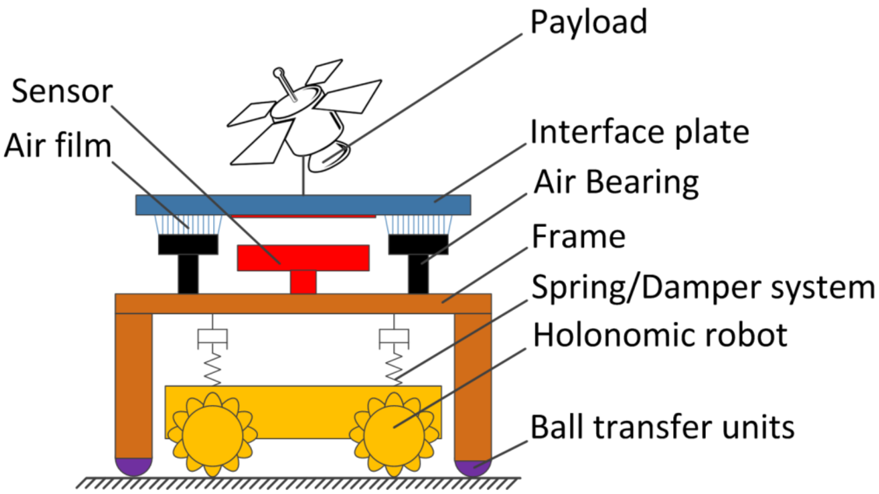
ACROBAT

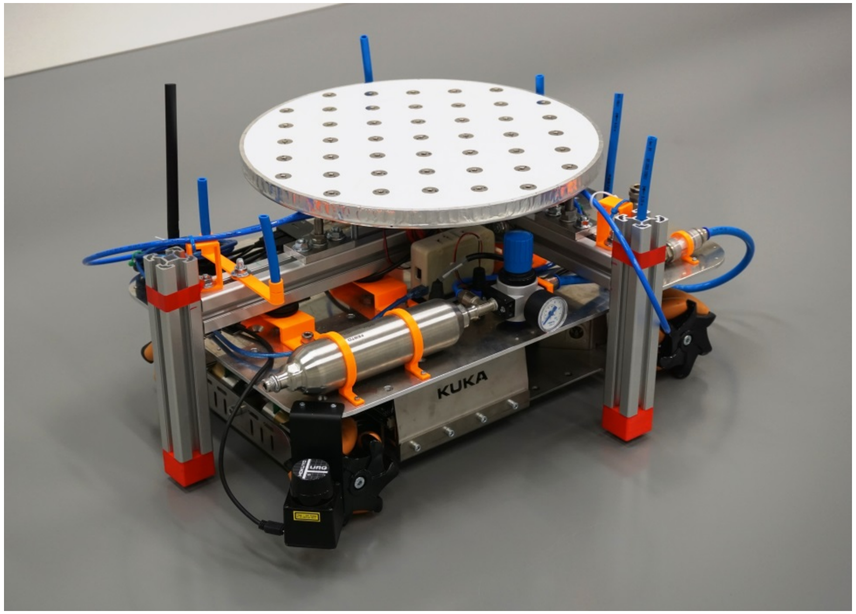
- Platform with continuous air supply
- m = 128.85 kg
- MOI (around axis of symmetry) = 8.154 kg/m2
- Possibility to extend with gym-type weights

Air bearing platform

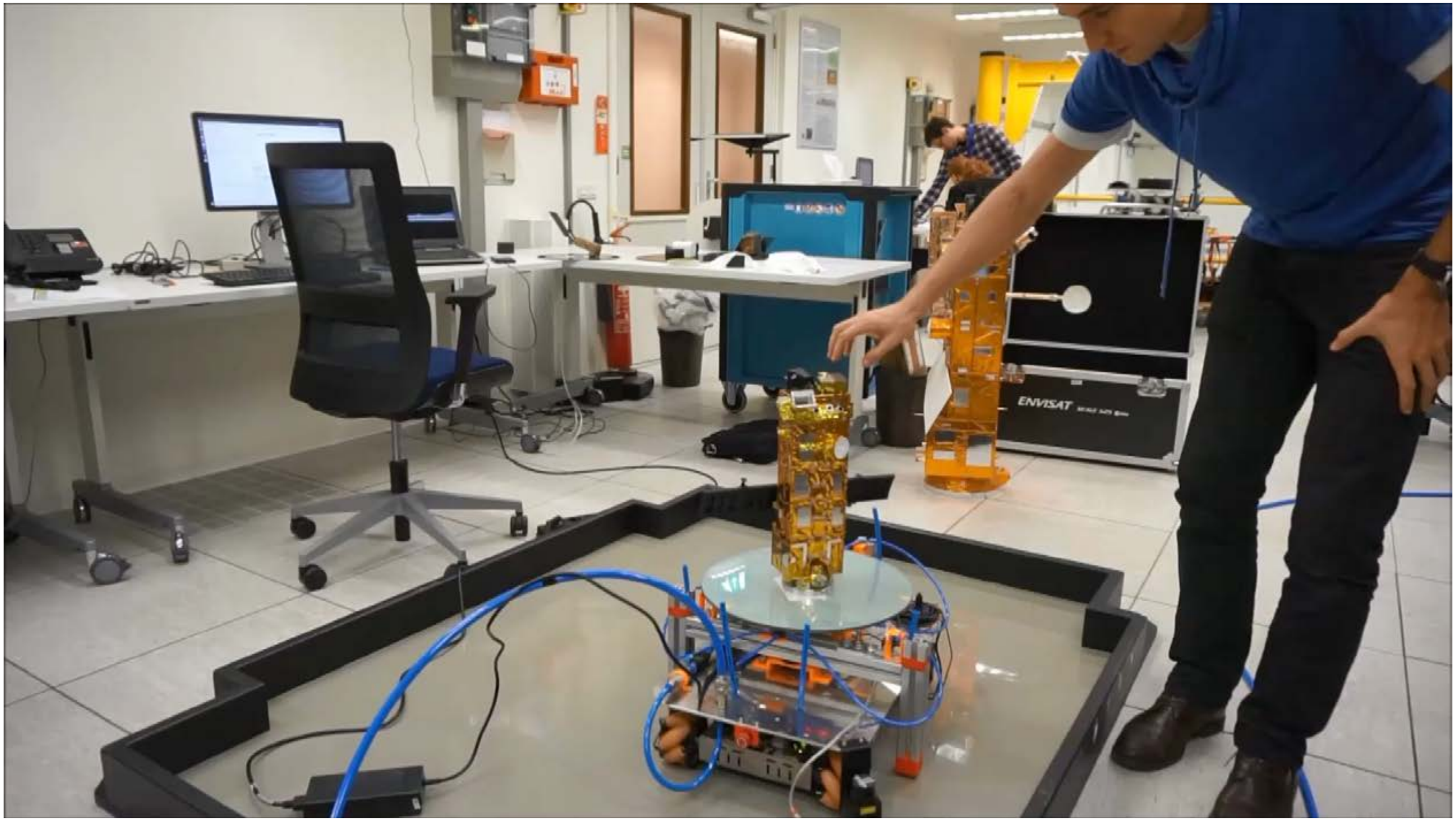
ROOTLESS

- In-house development
- Interface plate: m = 2.994 kg / MOI= 0.059 kg/m2
- Decoupling of payload mass/inertia from platform mass/inertia (testing of cubesats)
- (Introduction of artificial gravity)



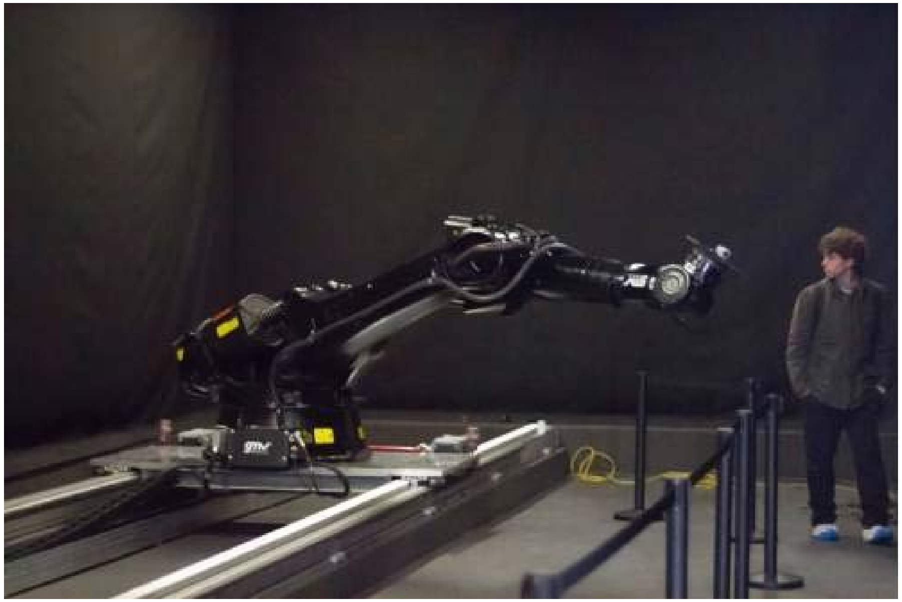


Air bearing platforms in action



platform-art© at GMV
Robotic arm facility

1. Robotic arm facility, located at GMV Madrid
2. Six Degree of Freedom simulation capability
3. Contact dynamic simulation through feedback loop (Sensing – Contact model – Actuation)



ROSPA, CROSSVALIDATION

1. Cross-validation of the ***ORBIT*** and the ***platform-art*** facilities as far as contact dynamic reproduction and investigation is concerned.

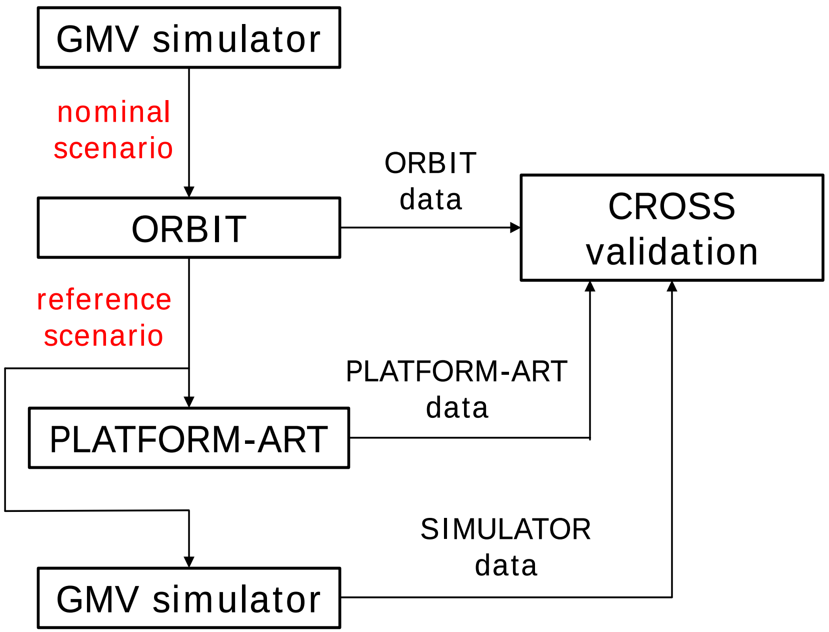
2. Generation of a database of representative images of a debris removal scenario, recreating several types of disturbances and effects that may occur in such a scenario (only in ***platform-art***).

3 DOF tests – Simple contact tests

Purpose: to evaluate the dynamic evolution during/after the contact between the chaser (Mitsubishi PA10) and the target (air-bearing platform/KUKA).

Testing procedure:

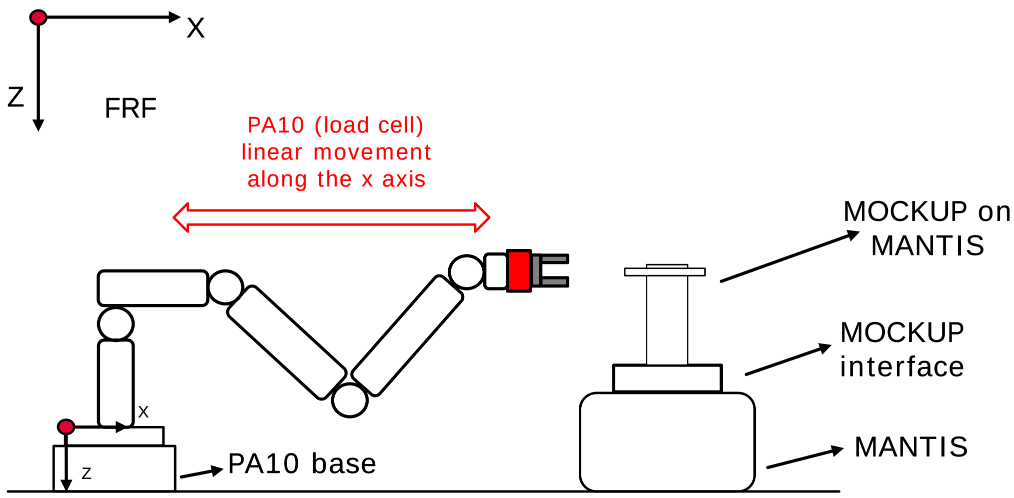
1. Nominal relative trajectory output of the scenario simulator developed at GMV.
2. Reference trajectory realised in ORBIT and to be adopted in platform-art.
3. Reference scenario recreated in the platform-art test bench (propagating back the contact condition for proper initialization).

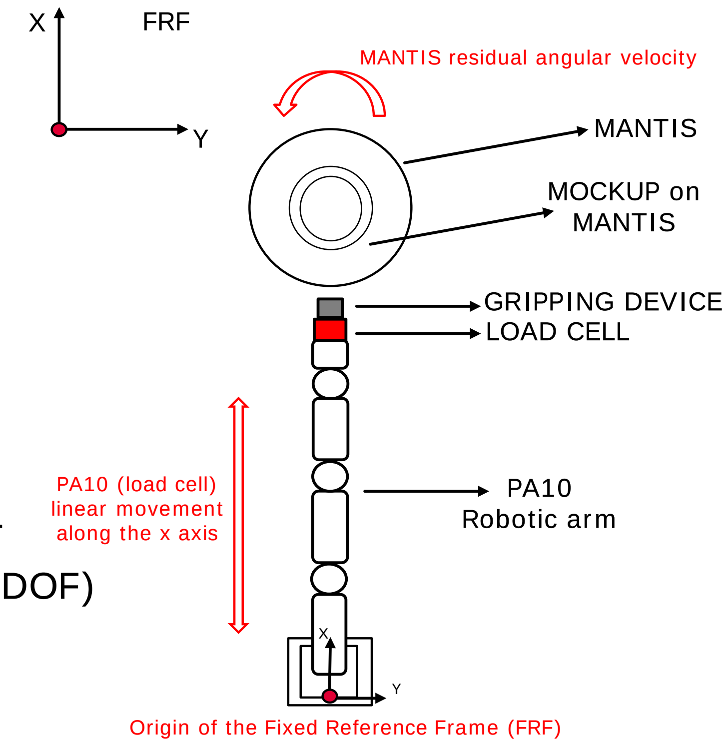


Tests adopted for the cross-validation

3 DOF tests – Gripping contact tests

Schematic description of the 3 DOF – Gripping contact tests





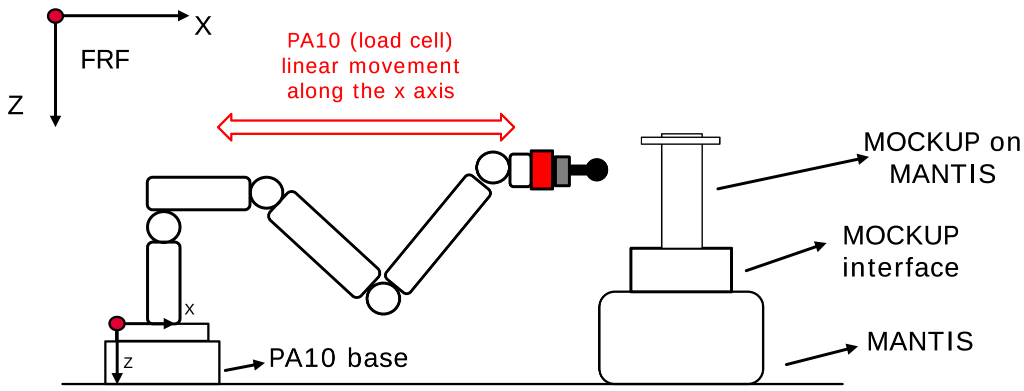
Purpose: to evaluate the dynamic evolution during/after the contact in a gripping scenario (3 DOF – ORBIT and 6 DOF)

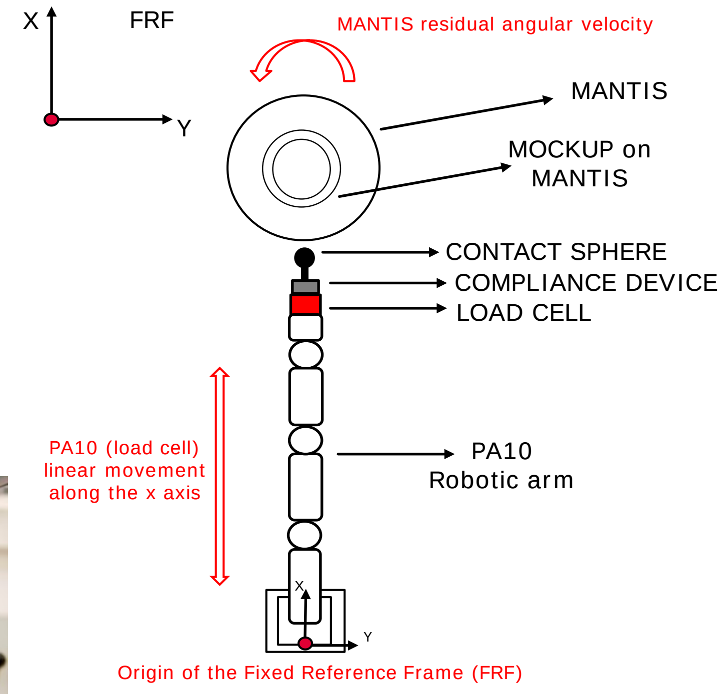
Not used for the cross-validation:

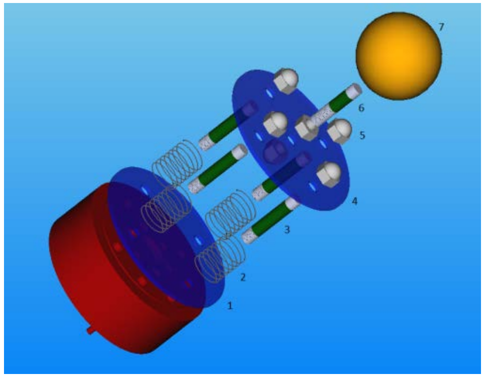
- **Required high detailed models and more sensors to close the loop in *platform-art*;**
- **Safety in the robotic facility to be carefully assessed.**

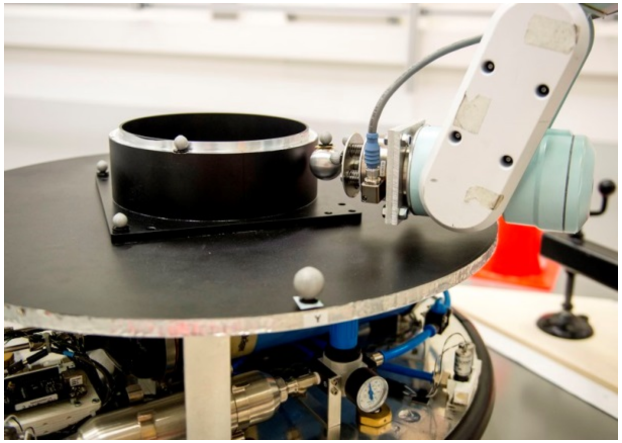
3 DOF tests – Simple contact tests

Schematic description of the 3 DOF – Simple contact tests









TEST Uncertainties

List of the tests uncertainties and comparison issues

ORBIT:
- Air-bearing free dynamic
- Measurements/calibration errors

Air-bearing model errors

PLATFORM-ART:
- Air-bearing model in the loop
- Measurements/calibration errors

Considered assumptions (especially 2D restriction)

Considered assumptions and closed loop with the load cell

SIMULATOR:
- Air-bearing model in the loop
- Considered assumptions

Contact test, example from ORBIT

Test report – 3DOF

71 Tests have been performed

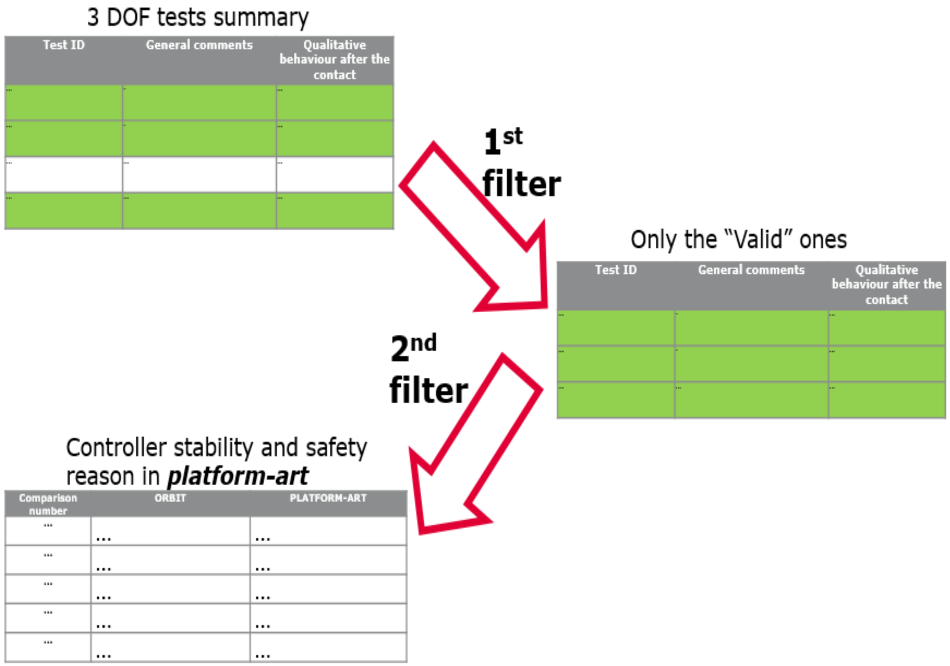
1st filter applied: Test validity

Selected FoM: the velocity vector in the XY FRF plane of the target just after the contact has a variation less than 10 % wrt the nominal value output of the contact models

2nd filter applied: Controller stability and safety constraints in *platform –art*

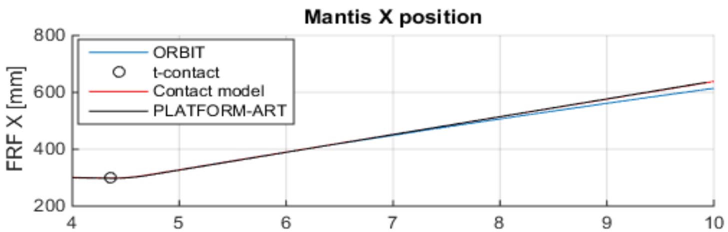
Instability contribution:
- High communication delay with the KUKA robotic arm
- High stiffness
- Low damping
- Low target mass

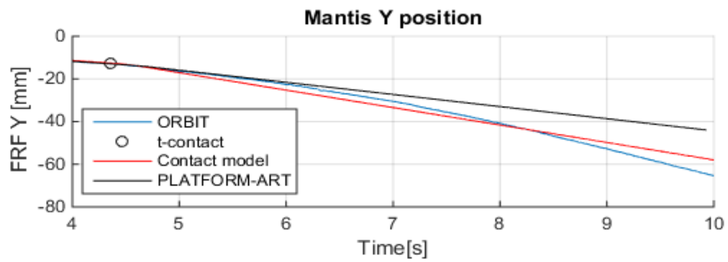
-> Tests at platform-ART performed in non-realtime (slowed down to compensate 12ms communication delay)

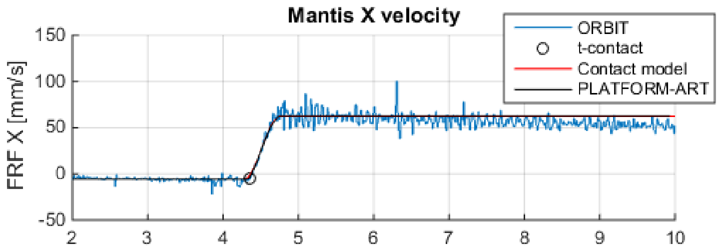


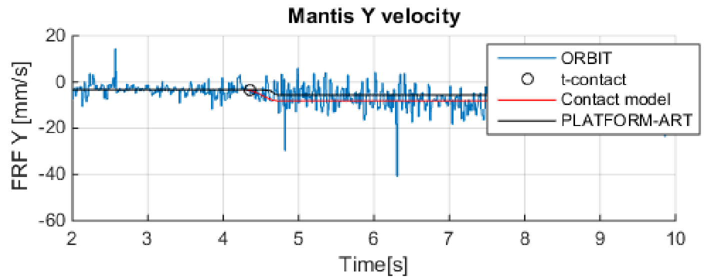
Comparison 1 - Mantis - 3 cm / s

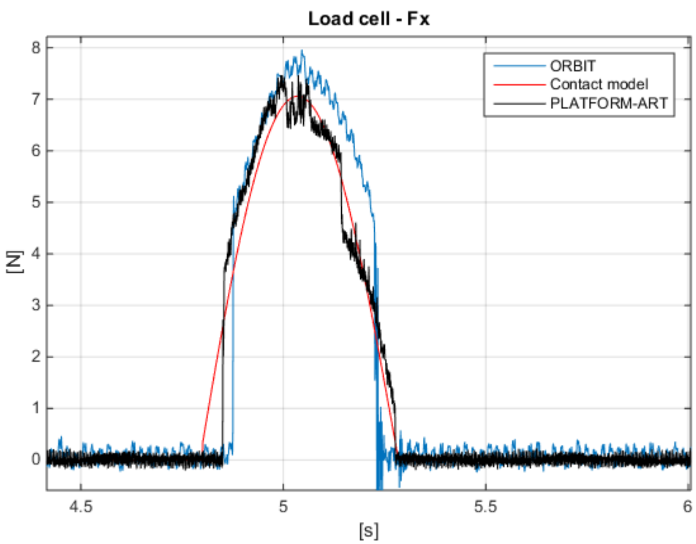
The dynamic evolution of the target during and after the contact









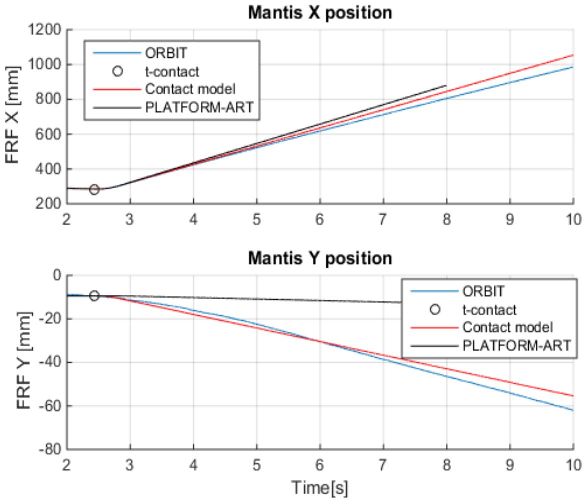


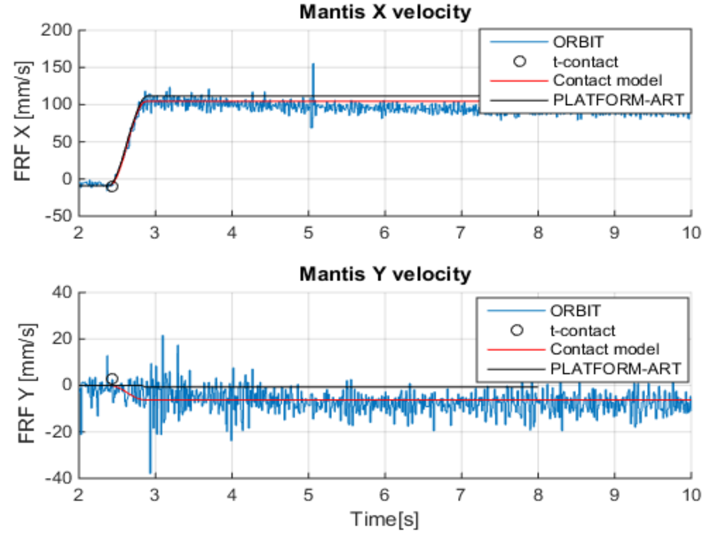
- After 5 seconds from t_contact, the divergence in position less than 5 cm

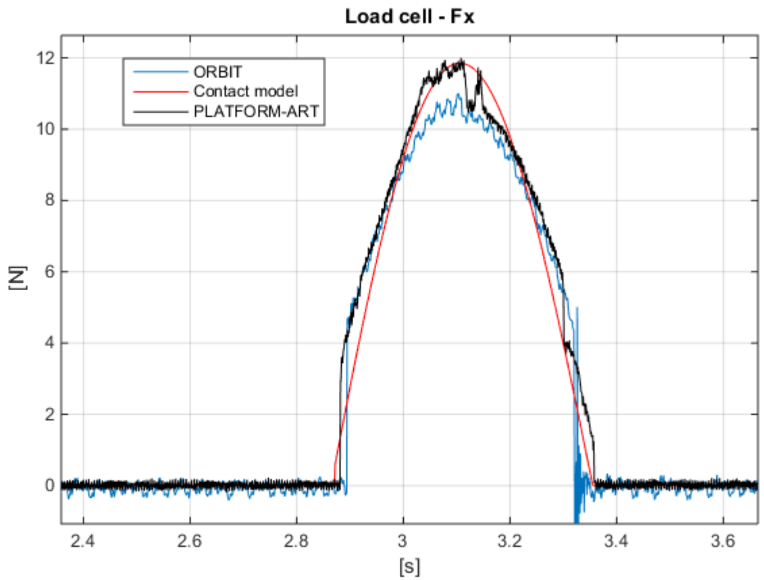
- Velocity vector error stays below 10% for more than 5 seconds

- Forces diverge less than 10%

Comparison 2 - Mantis - 5 cm / s







- After 5 seconds from t_contact, the divergence in position is less than 15 cm

- Velocity vector error stays below 10% for more than 5 seconds

- Forces divergence less than 10%

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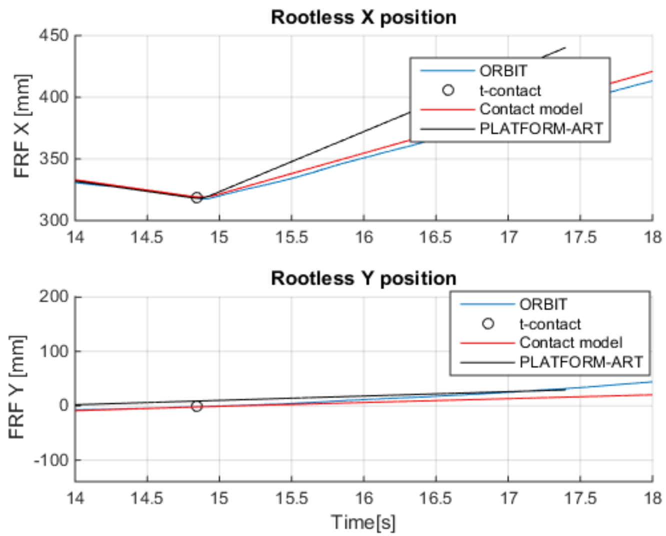
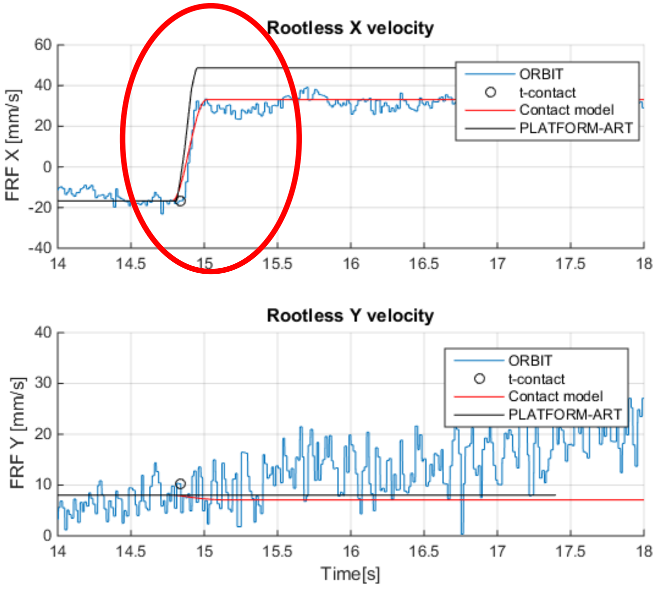
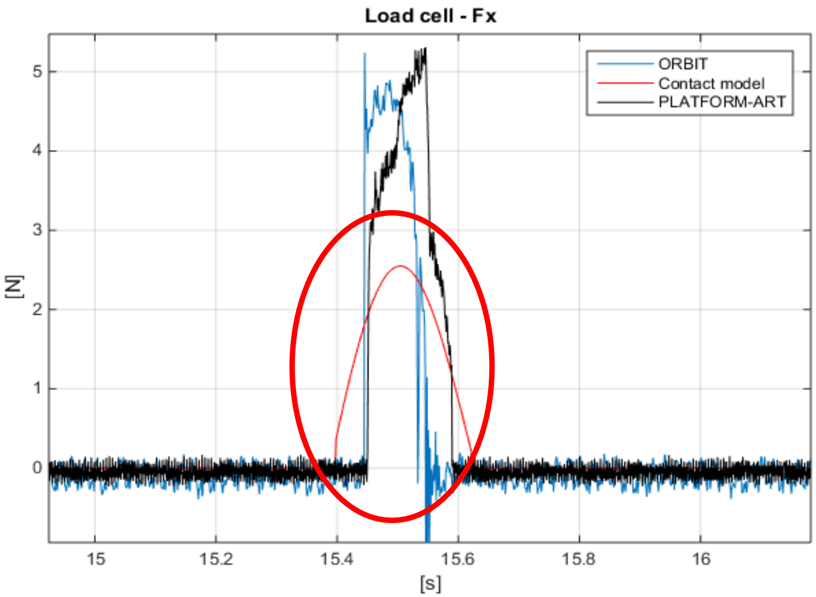
Comparison 3 - Rootless - 1 cm / s







platform-art error of 42% in the velocity vector just after the contact

Immediate divergence just after the contact (Y-FRF) at ORBIT

Forces divergence of about 100%, but similar between facilities

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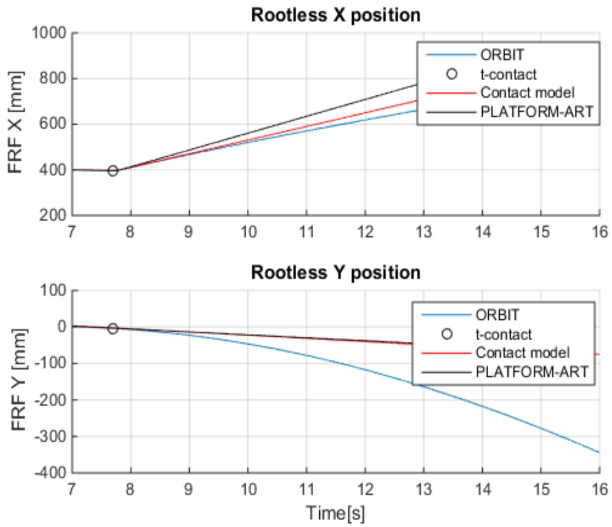
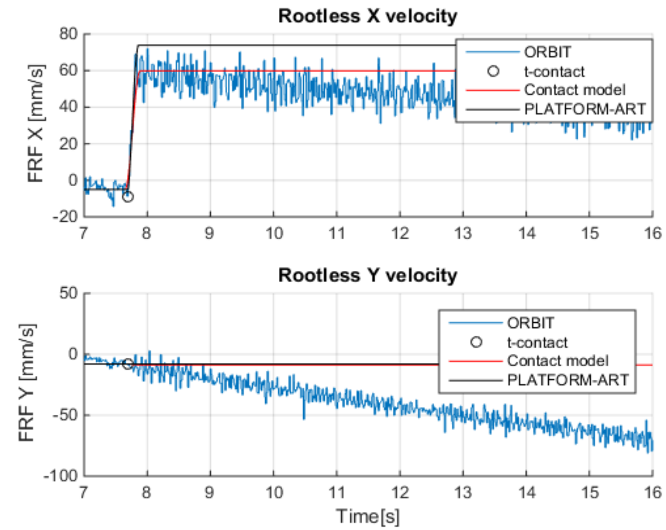
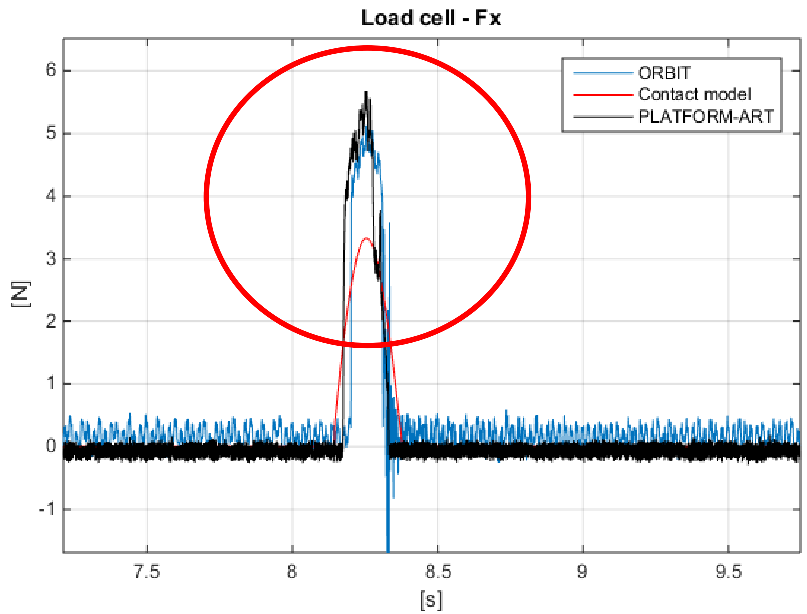
Comparison 4 Rootless- 3 cm / s





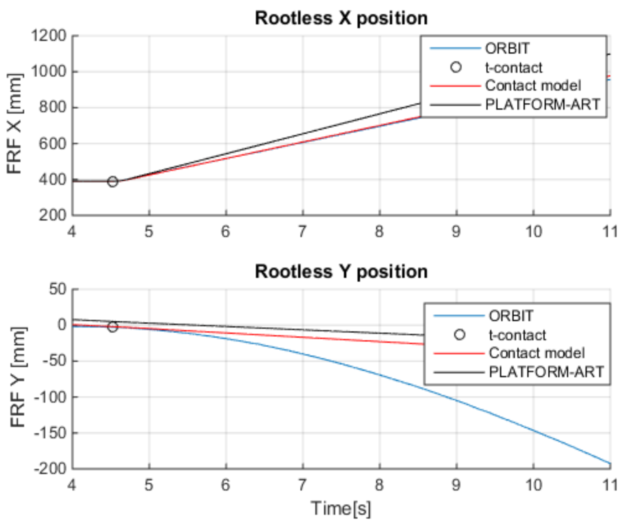


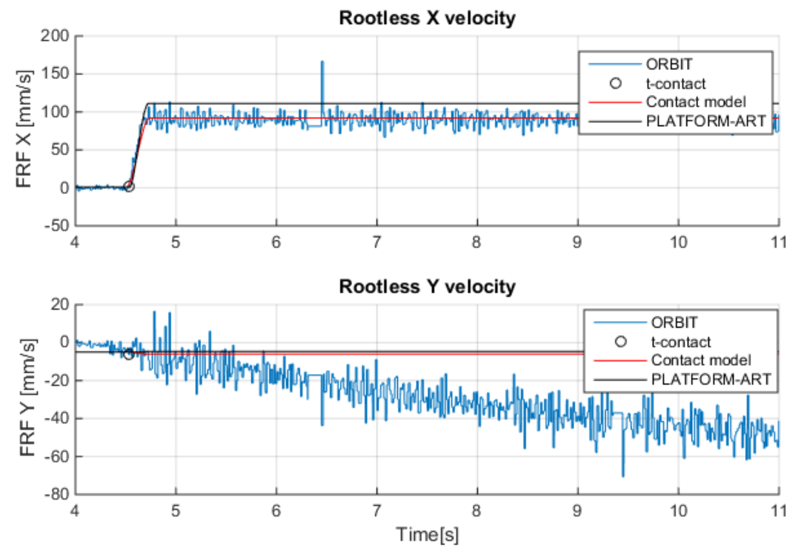
platform-art error of 23% in the velocity vector just after the contact

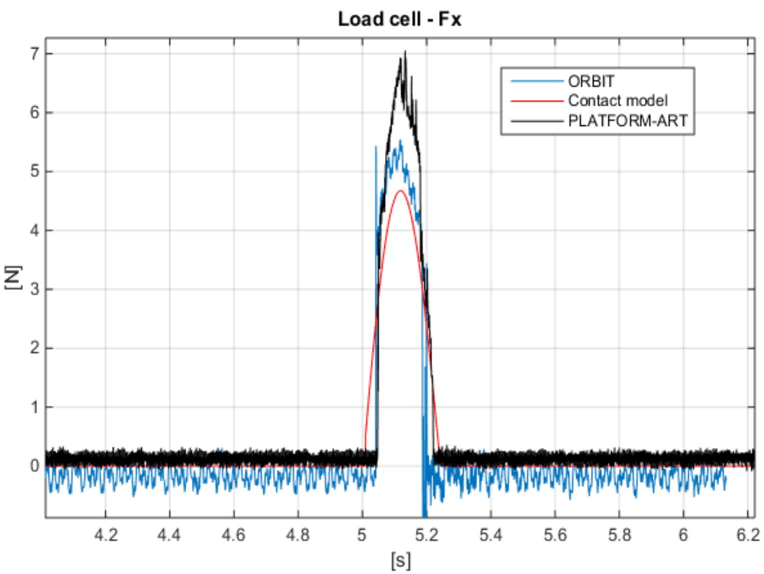
Immediate divergence just after the contact (Y-FRF) at ORBIT

Forces divergence of about 60%, but similar between facilities

Comparison 5 Rootless - 5 cm / s







platform-art error of 17% in the velocity just after the contact

ORBIT immediate divergence just after the contact (Y-FRF)

Forces divergence of about 30% between facilities and closer to contact models

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Conclusions – During the contact

The cross-validation is considered to be valid (FoM: target velocity vector in the XY FRF plane has an error of less than 10 % wrt the nominal value) respecting the following:

- ***platform-art*** HW: KUKA and PA10 robotic arms;
- ORBIT air-bearing platform: Mantis (mass of 30 kg) at velocities of 3 cm/s and 5 cm/s;
- Complementary HW described in TN1, with the FT sensor saving data at 1000 Hz and a set of four spring of 333 N/m;
- Usage of the developed 1DoF contact model, neglecting friction due to the contact on the contact surfaces/points;
- No real-time tests in platform-art (slowing down the 1000 Hz simulator by a factor of 12) in order to compensate for the delay of communication with the KUKA robotic arm.

With these limitations, platform-art is able to reproduce the contact dynamic from ORBIT with a velocity vector error of less than 10%.

Conclusions – after the contact

The after contact trajectory evolution was validated using the nominal trajectory coming from the mathematical model.

On platform-art, the after contact trajectory shows no divergence.

The Mantis platforms shows on average a velocity vector error of;

- velocity vector error of 10 % occurs after 5.1 s at an impact speed of 3 cm/s;
- velocity vector error of 10 % occurs after 5.5 s at an impact speed of 5 cm/s;
- velocity vector error of 10 % occurs after 7.0 s at an impact speed of 10 cm/s.

The Rootless platforms shows on average a velocity vector error of;

- velocity vector error of 10 % occurs after 2.2 s at an impact speed of 1 cm/s;
- velocity vector error of 10 % occurs after 2.4 s at an impact speed of 3 cm/s;
- velocity vector error of 10 % occurs after 4.8 s at an impact speed of 5 cm/s.

The higher the velocity the longer the ORBIT trajectory will be close to the contact model one (at low velocity regimes the collateral forces on the floor are not negligible wrt the contact forces)

Lesson learnt

During the experiment preparation and execution the team from GMV and from ESA/ESTEC acquired valuable know-how of the contact dynamic and how to perform this kind of experiments in an air-bearing and in a robotic facility.

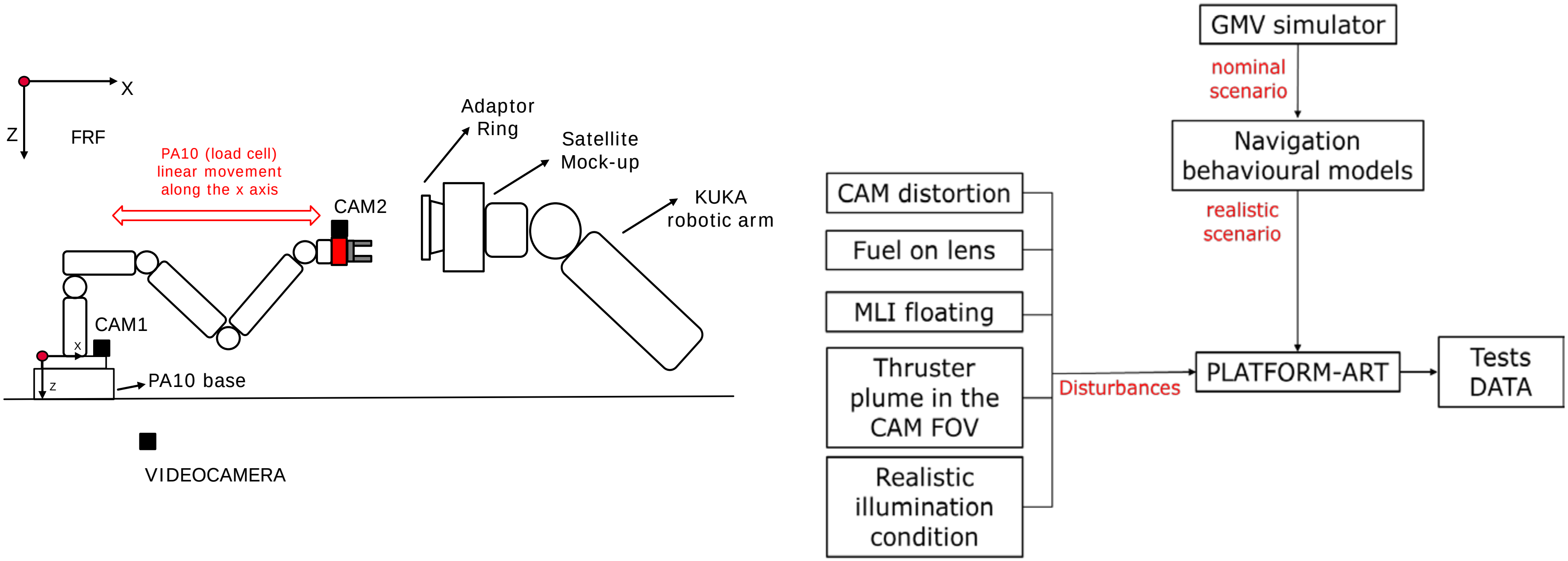
Here below are listed the suggestions to take into account for future works in the same scope of this activity:

- **Clearly define the scenario**, so to be able to choose the facility that most suite the specific needs. In general, if the same experiment can be repeated in both of them it would improve the robustness of the results;
- **Properly select the type / number / locations of sensors** to be included in the loop according to what has to be measured for closed loop or investigation purposes;
- In case a **simulation model** is required, adapt its level of detail and complexity to the specific scenario;
- Focus on a limited number of defined test and repeat those several times, so to have a **Monte Carlo approach** in a problem that in general has a lot of variables.

The 3 DOF gripping tests have not been part of the cross-validation. More detailed contact models and more sensors (i.e. extensometer on the gripping fingers) required to close the loop. Agreed to be out of the budget of the activity.

Creation of a image dataset for close range spacecraft-spacecraft interaction

Schematic description of the 6 DOF



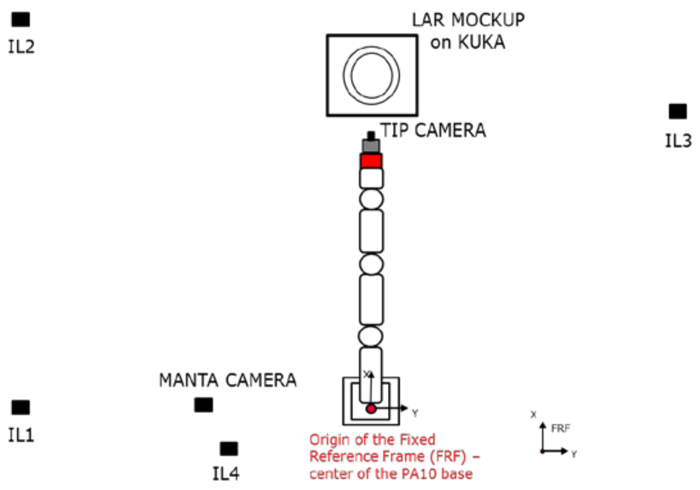
Cameras:

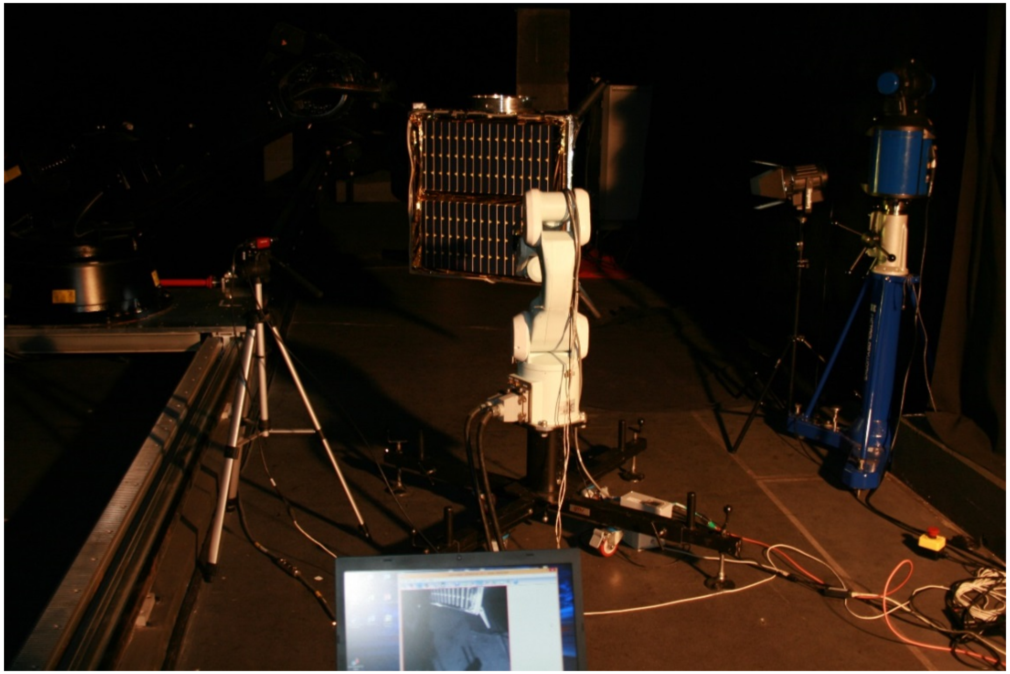
1. CAM1: MANTA camera, space representative (database of images);
2. CAM2: uEye camera, tip camera (Gripping confirmation);
3. VIDEOCAMERA: recording experiments.

Test report – 6DOF

PROCEDURE:

- Preparing the set-up
- Calibration using FARO laser tracker
- Implementing the relative trajectory to KUKA (both translation and attitude)
- Setting up the parameters of the MANTA camera





Test report – 6DOF – IL1

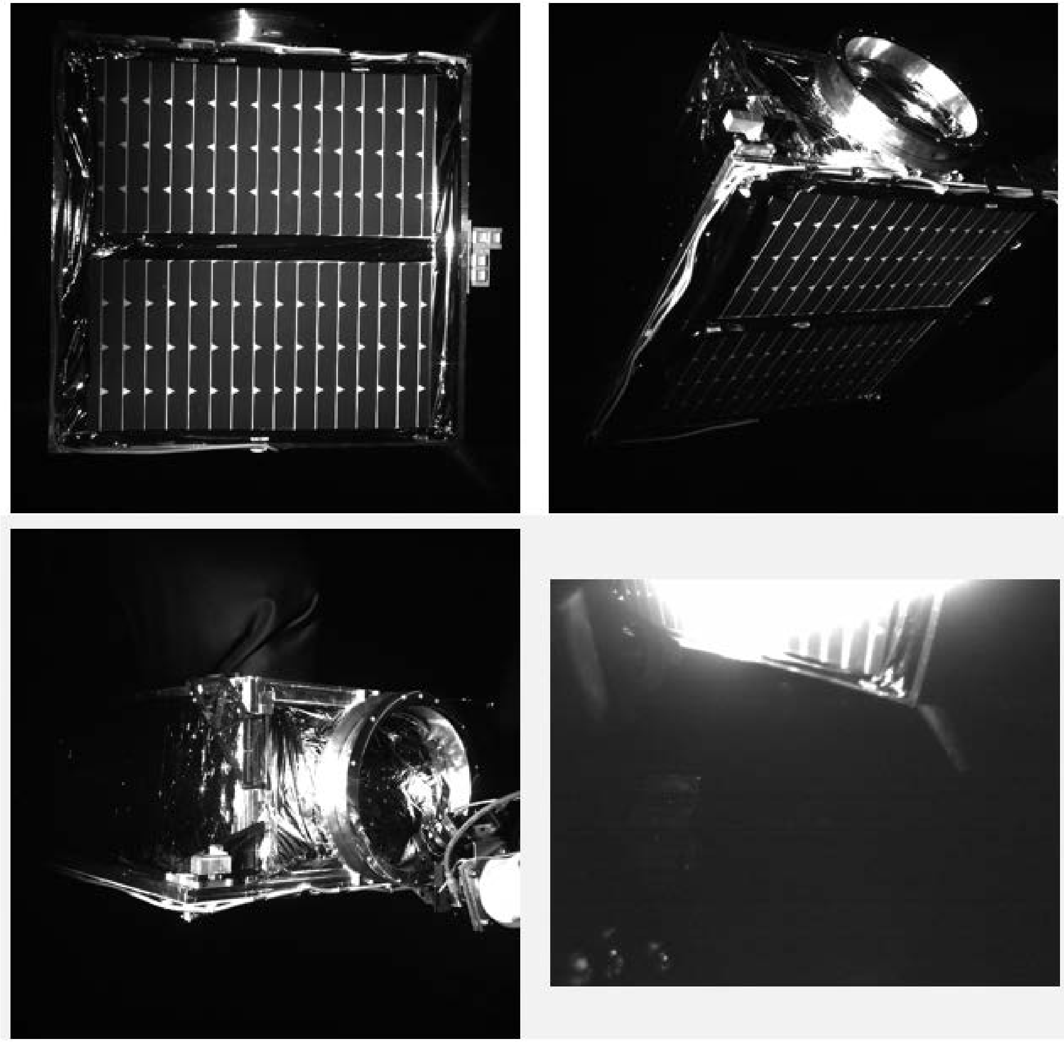


Figure 8-7: Manta (up-left 1/150, up-right 80/150, bottom-left 136/150) and uEye (bottom-right) in PLT-6DOF-GRI-IL1-042-D

Phase angle of around 45 degrees

- Good visibility of the target
- LAR visibility needs to be assessed further

Test report – 6DOF – IL2

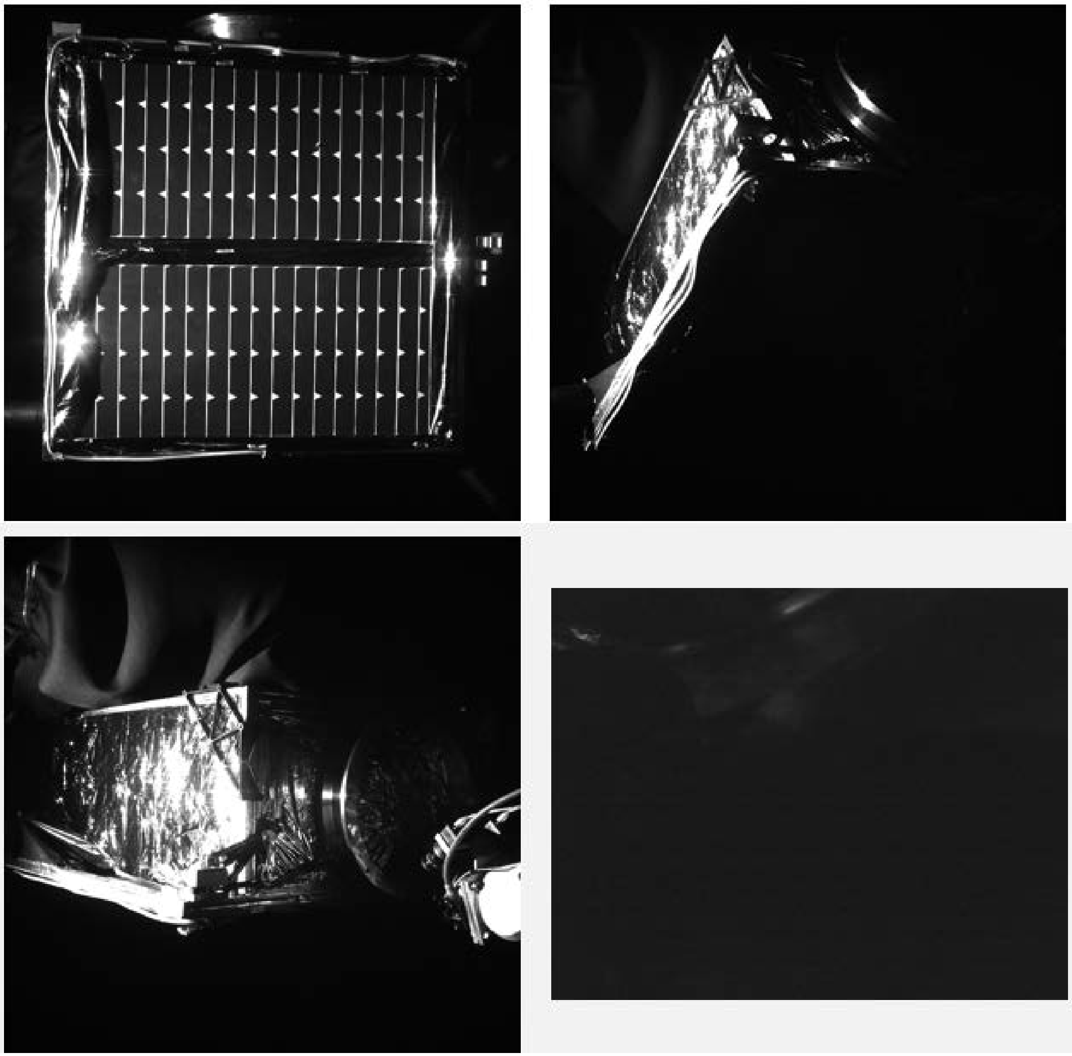


Figure 8-8: Manta (up-left 1/150, up-right 80/150, bottom-left 136/150) and uEye (bottom-right) in PLT-6DOF-GRI-IL2-043-D

Phase angle of around 90 degrees

- Limit case for image processing
- Bad visibility of the LAR for gripping confirmation

Test report – 6DOF – IL3

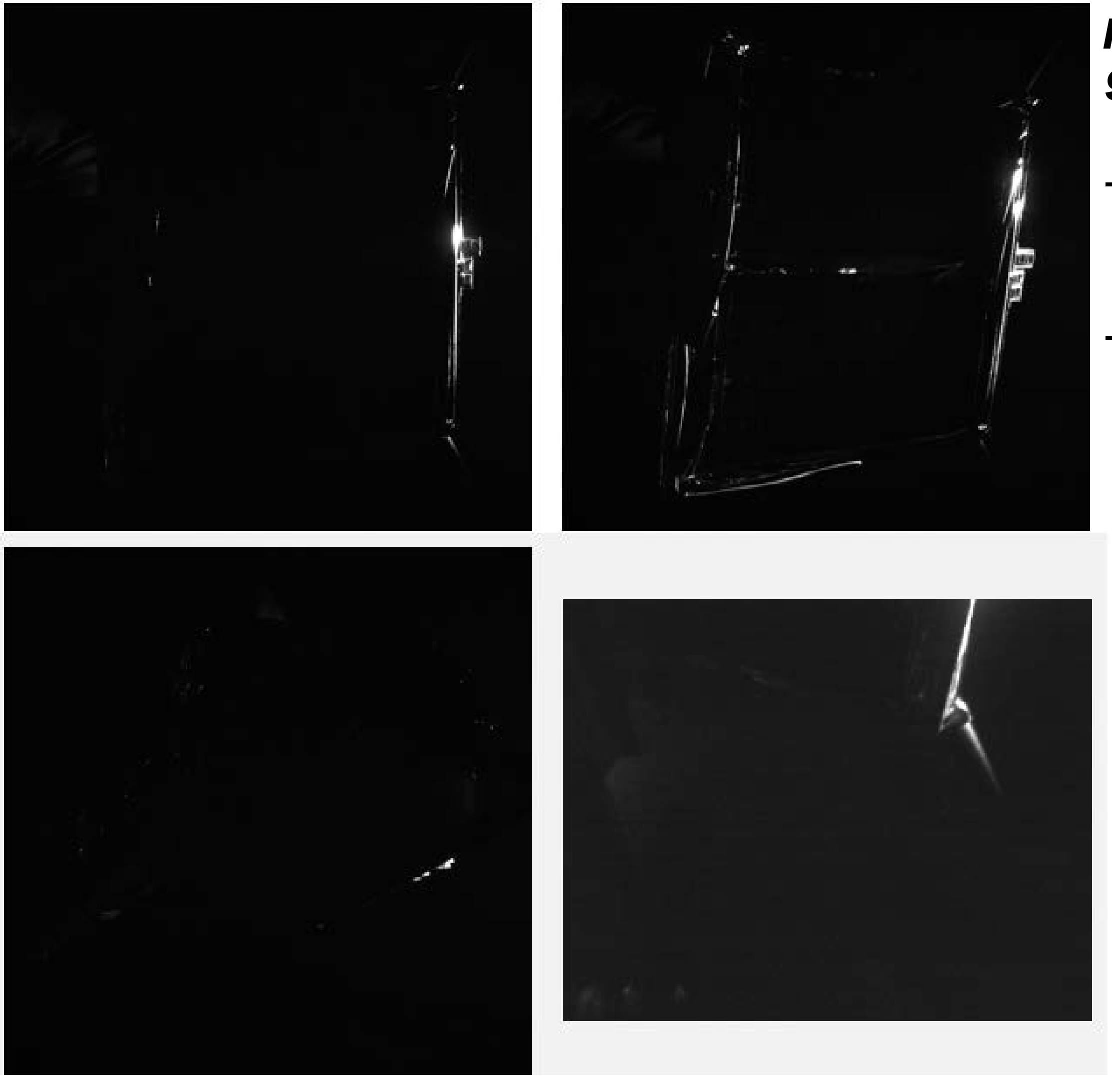


Figure 8-9: Manta (up-left 28/150, up-right 40/150, bottom-left 98/150) and uEye (bottom-right) in PLT-6DOF-GRI-IL3-044-D

Phase angle of more than 90 degrees

- Target eclipses the source of light
- No visibility of the LAR for gripping confirmation

Test report – 6DOF – IL4

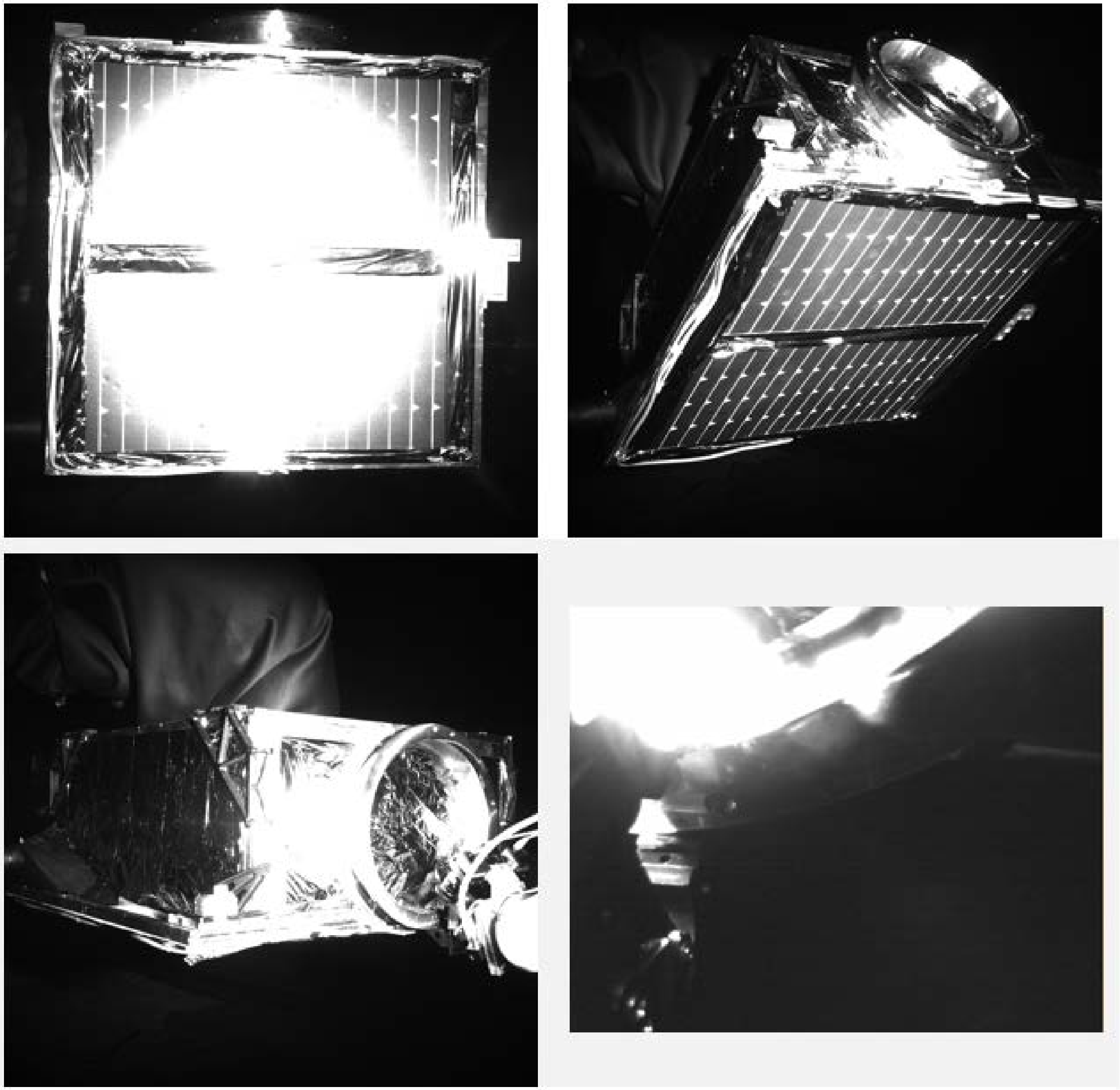


Figure 8-10: Manta (up-left 1/150, up-right 80/150, bottom-left 136/150) and uEye (bottom-right) in PLT-6DOF-GRI-IL4-045-D

Light source behind the chaser

- Overexposure of the satellite
- Overexposure of parts of the LAR on the gripper camera
- (platform-art robotic arm is visible)

Test report – 6DOF – FOL

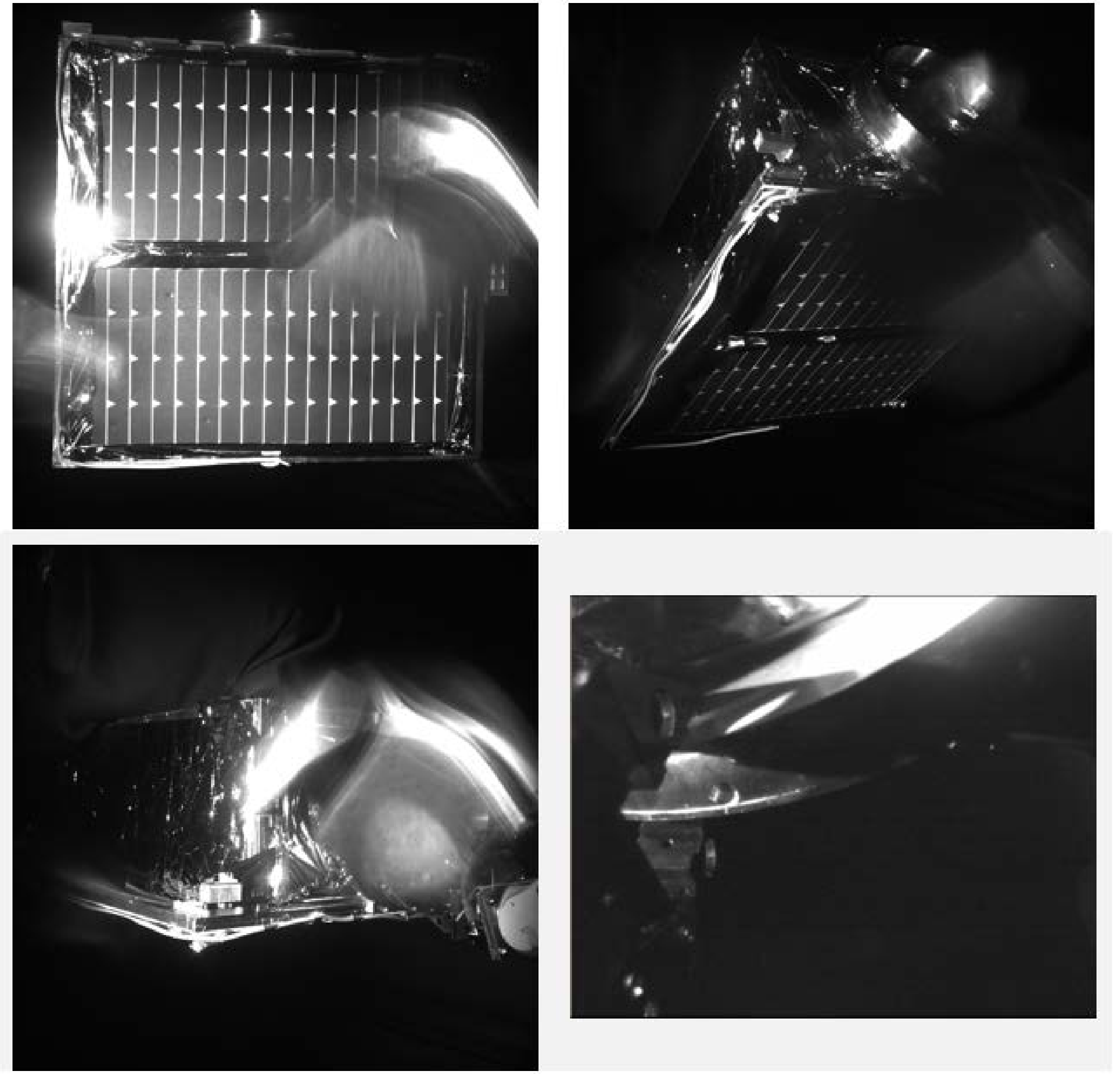


Figure 8-4: Manta (up-left 1/150, up-right 80/150, bottom-left 136/150) and uEye (bottom-right) in PLT-6DOF-GRI-FOL-039-D

Fuel on lens

- Blurred spots in the camera field of view

Test report – 6DOF – MLI

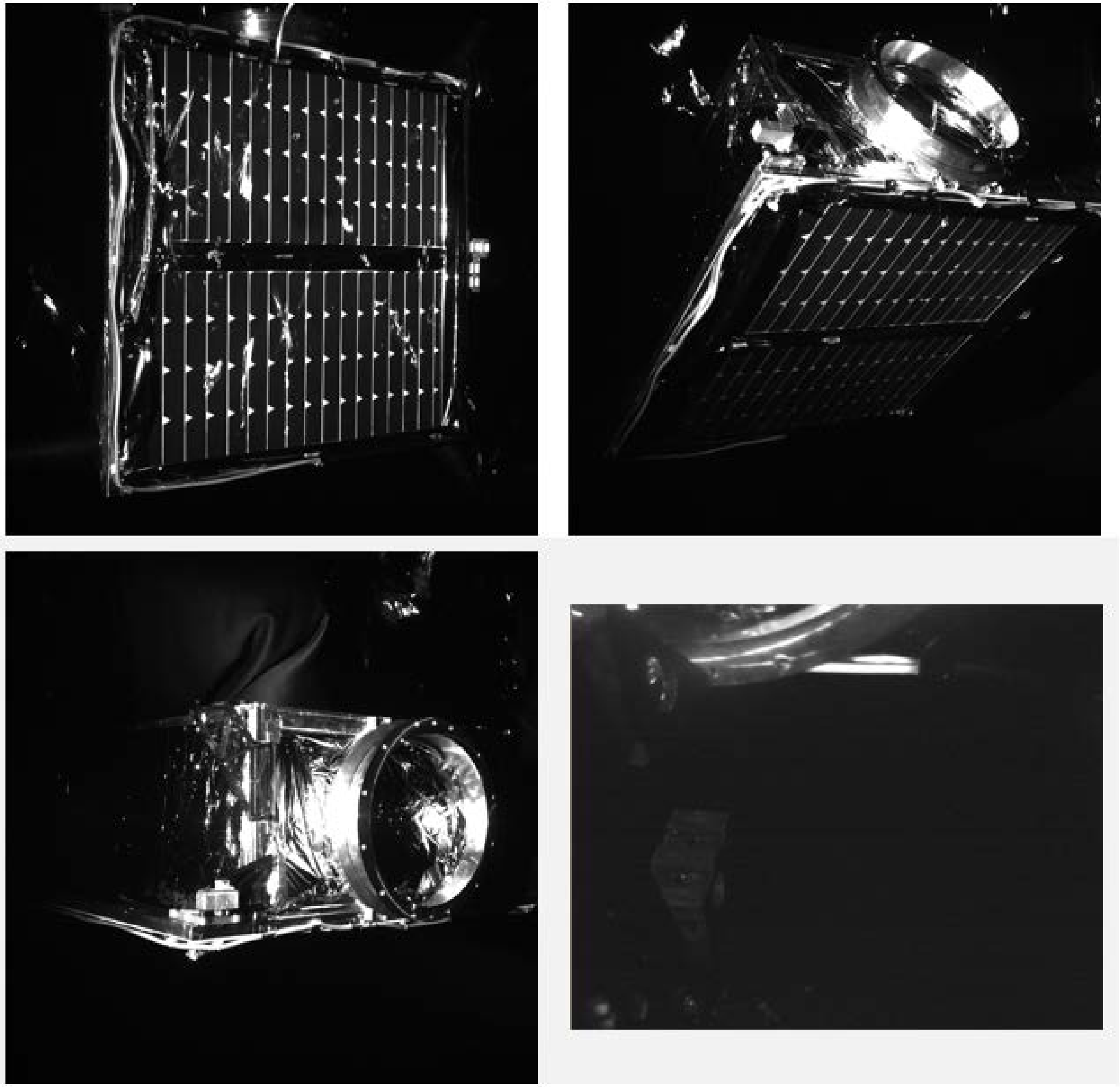


Figure 8-5: Manta (up-left 27/150, up-right 81/150, bottom-left 121/150) and uEye (bottom-right) in PLT-6DOF-GRI-MLI-040-D

Floating pieces of MLI around the target

- Sudden reflective spots in the camera field of view

Test report – 6DOF – PLU

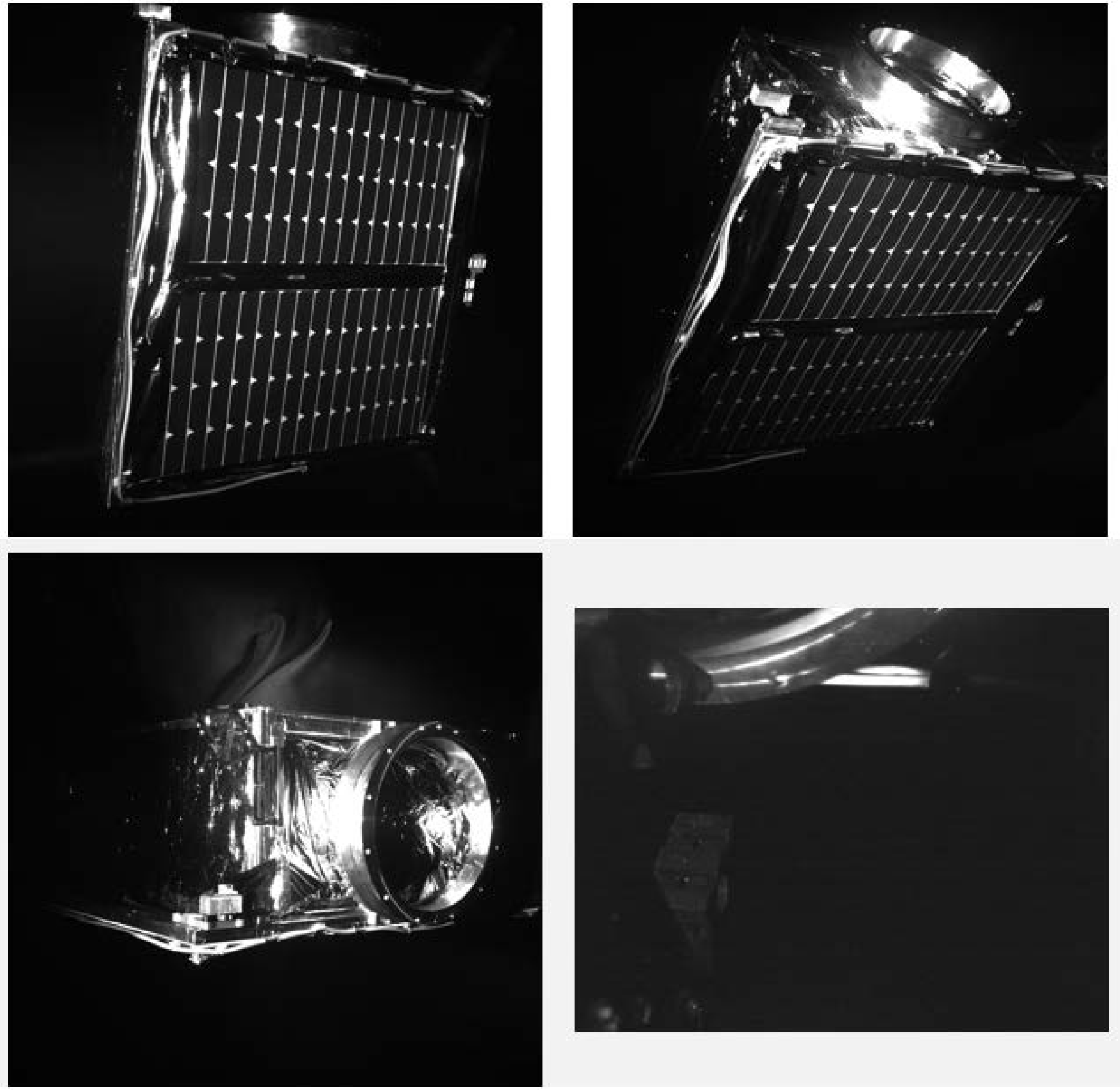


Figure 8-6: Manta (up-left 41/150, up-right 73/150, bottom-left 123/150) and uEye (bottom-right) in PLT-6DOF-GRI-PLU-041-D

Plume in the FoV

- Sudden brightness change because of reflecting particles

Test report – 6DOF – FOL–MLI–PLU–IL2

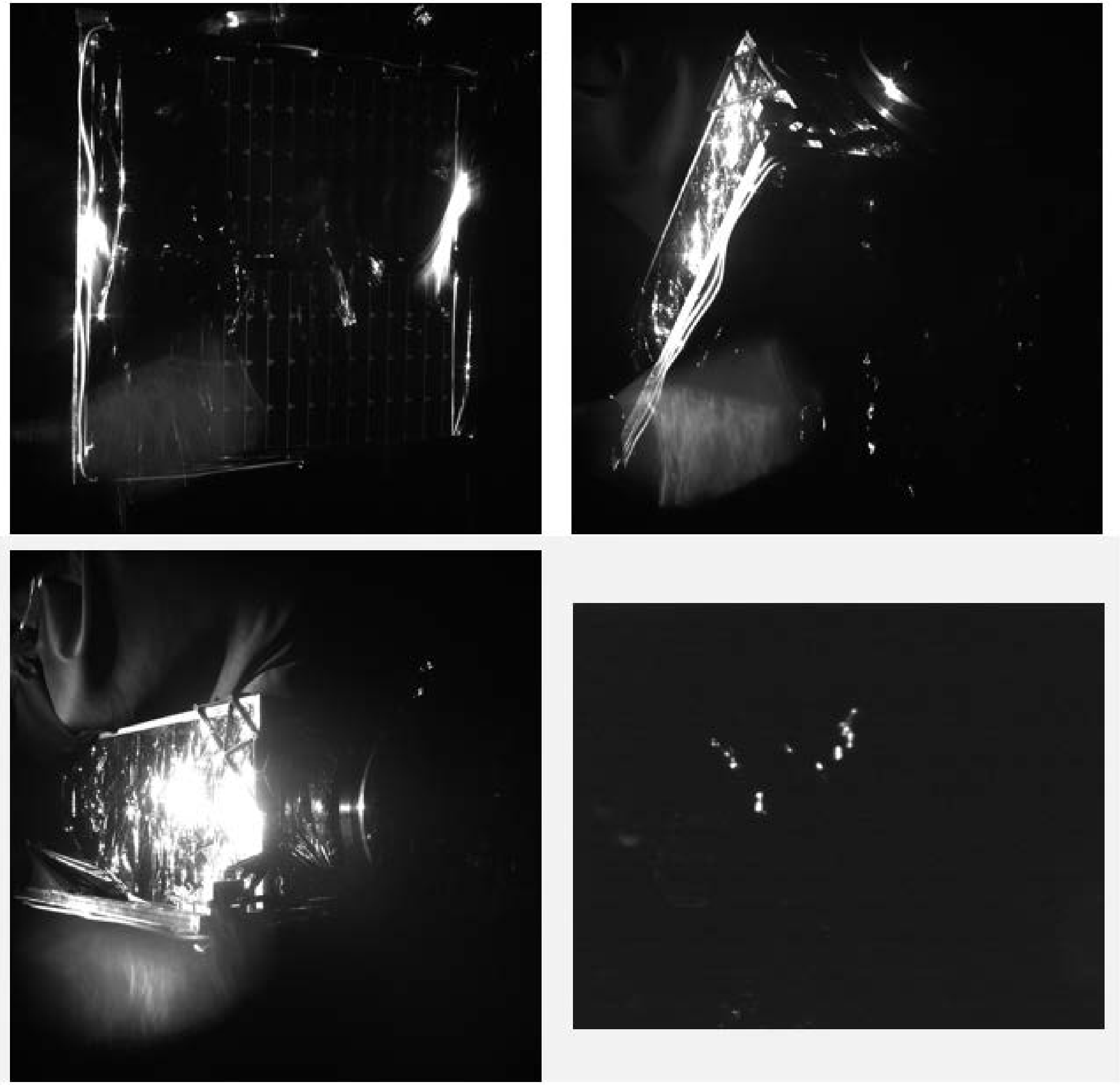


Figure 8-11: Manta (up-left 14/150, up-right 76/150, bottom-left 119/150) and uEye (bottom-right) in PLT-6DOF-GRI-FOL-MLI-PLU-IL2-046-D

Phase angle 90 degrees

Fuel on camera lens

Pieces of floating MLI

Plume in the FoV

Thank you for the attention! Questions?

References:

- Hendrik Kolvenbach and Kjetil Wormnes. A Facility for Experiments on Free Floating Contact Dynamics. In *13th Symposium on Advanced Space Technologies in Robotics and Automation (ASTRA)*, 2015.

- Hendrik Kolvenbach, Kjetil Wormnes. Recent Developments on ORBIT, a 3-DOF Free Floating Contact Dynamics Testbed. In *13th International Symposium on Artificial Intelligence, Robotics and Automation in Space (i-SAIRAS)*, Beijing, China, 2016. (submitted)

- Jakub Tomasek, Hendrik Kolvenbach, Marco Pagnamenta, and Kjetil Wormnes. A robotic testbed for low-gravity simulation. In *13th International Symposium on Artificial Intelligence, Robotics and Automation in Space (i-SAIRAS)*, Beijing, China, 2016. (submitted)

- Andrea Pellacani and Hendrik Kolvenbach. Rospa, cross-validation of the platform-art and orbit test facilities for contact dynamic scenario setup and study. In *6th International Conference on Astrodynamics Tools and Techniques*, ESA/ESOC, 2016.