Validation methodology of the rendezvous and grasping manoeuvre on the planar air-bearing microgravity simulator

Karol Seweryn, Tomasz Rybus, Jakub Oleś, Kamil Tarenko

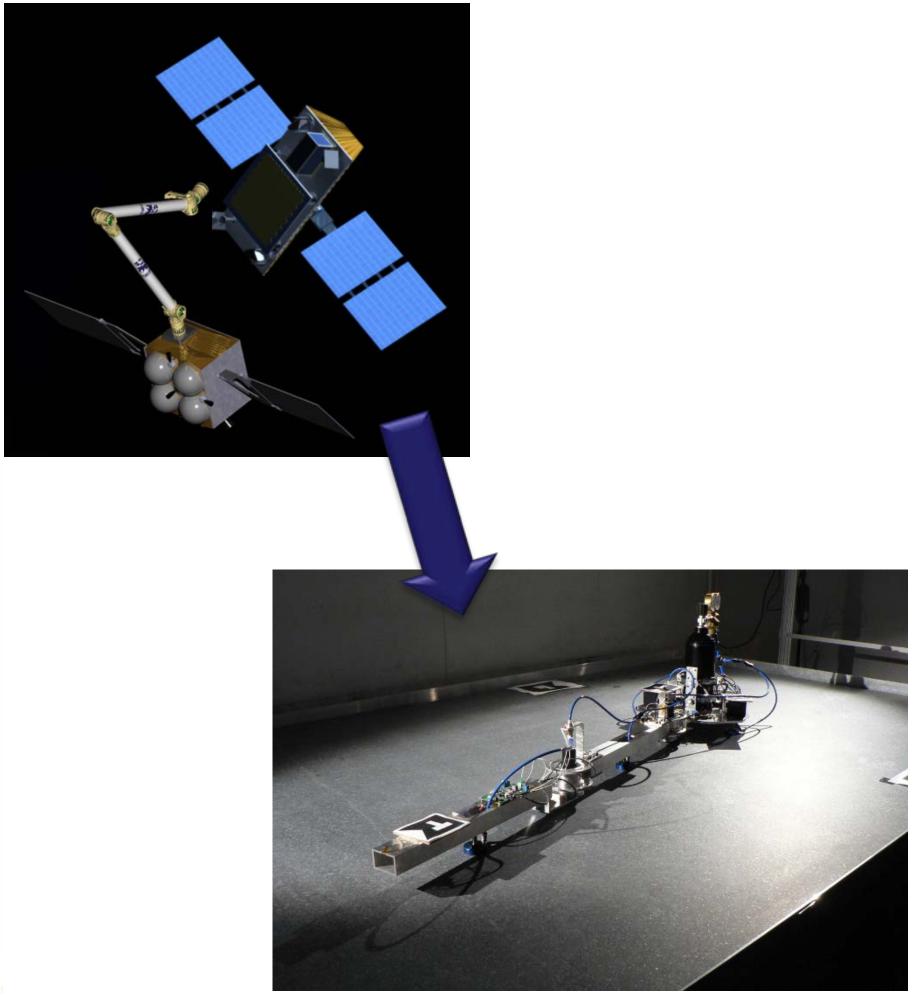
Space Research Centre of the Polish Academy of Sciences (CBK PAN)

Clean Space Industrial Days
24 – 26 October 2017

Outline

1. Planar air-bearing microgravity simulators.
2. Test facility at CBK PAN.
3. Proposed approach for validation of the rendezvoud and grasping.
4. Subsystems available at CBK PAN.
5. Results of experiments.
6. Summary.

Tests of robotic systems for planned ADR/OOS missions

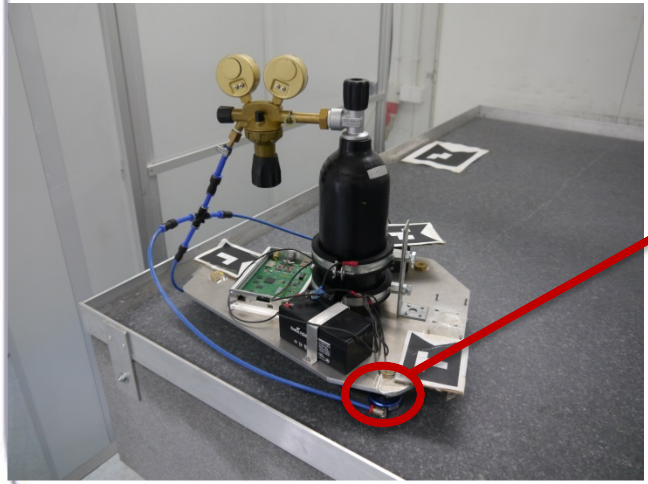


Orbital capture manoeuvre with a manipulator (artist concept) and planar air-bearing microgravity simulator at CBK.

- Microgravity is the aspect of space environment that is especially hard to be recreated on Earth.
- Microgravity test-bed is required for tests of robotic systems for ADR and OOS missions (e.g., manipulators, control algorithms).
- One possible approach is to use planar air-bearing microgravity simulators.

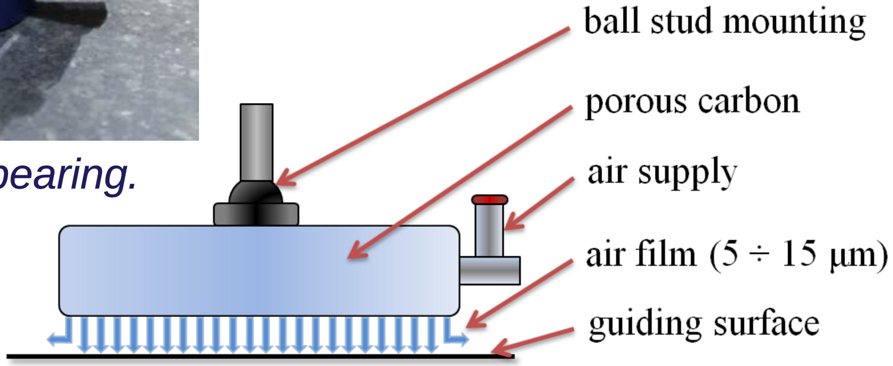
Planar air-bearing microgravity simulator 1/2

- Tested objects (e.g., satellite mock-up, manipulator) are mounted on planar air-bearings.
- Air-bearings provide an exceedingly low friction (friction coefficient around 10^{-5}) and allow almost frictionless motion on the table surface.



Satellite mock-up.

Planar air-bearing.



Schematic view of an air-bearing.

Planar air-bearing microgravity simulators 2/2

Advantages	Disadvantages
• Small disturbances: Residual gravity acceleration is around $10^{-3} \div 10^{-5}$ g. • Relatively long time of experiment: usually several minutes (up to 45 minutes). • Low costs of operations. • Many possible applications (not only in the field of space robotics).	• Motion limited to one plane only (simulation of microgravity conditions in two dimensions). • Limited size of the experimental area. • Tested systems must usually be scaled down. • Precise calibration required for free-floating experiments.

Scaling

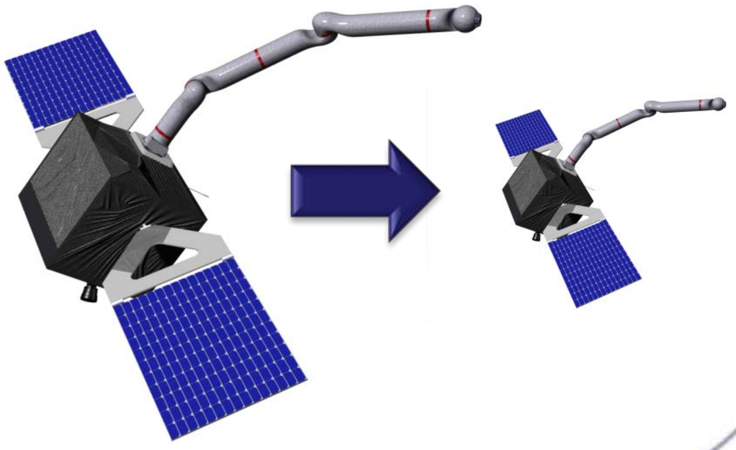
Objects must be scaled down due to limited area of the granite table and due to limits on maximal loads of air-bearings:

$$P_s = k^b \cdot P$$

where: P is value of a given parameter before scaling, P_s is the scaled value, k is the selected scaling factor, while b is the scaling exponent.

Scaling exponents for selected physical quantities.

	Physical quantity	Scaling exponent
1	Length	1
2	Mass	3
3	Inertia	5
4	Velocity	0
5	Acceleration	-1

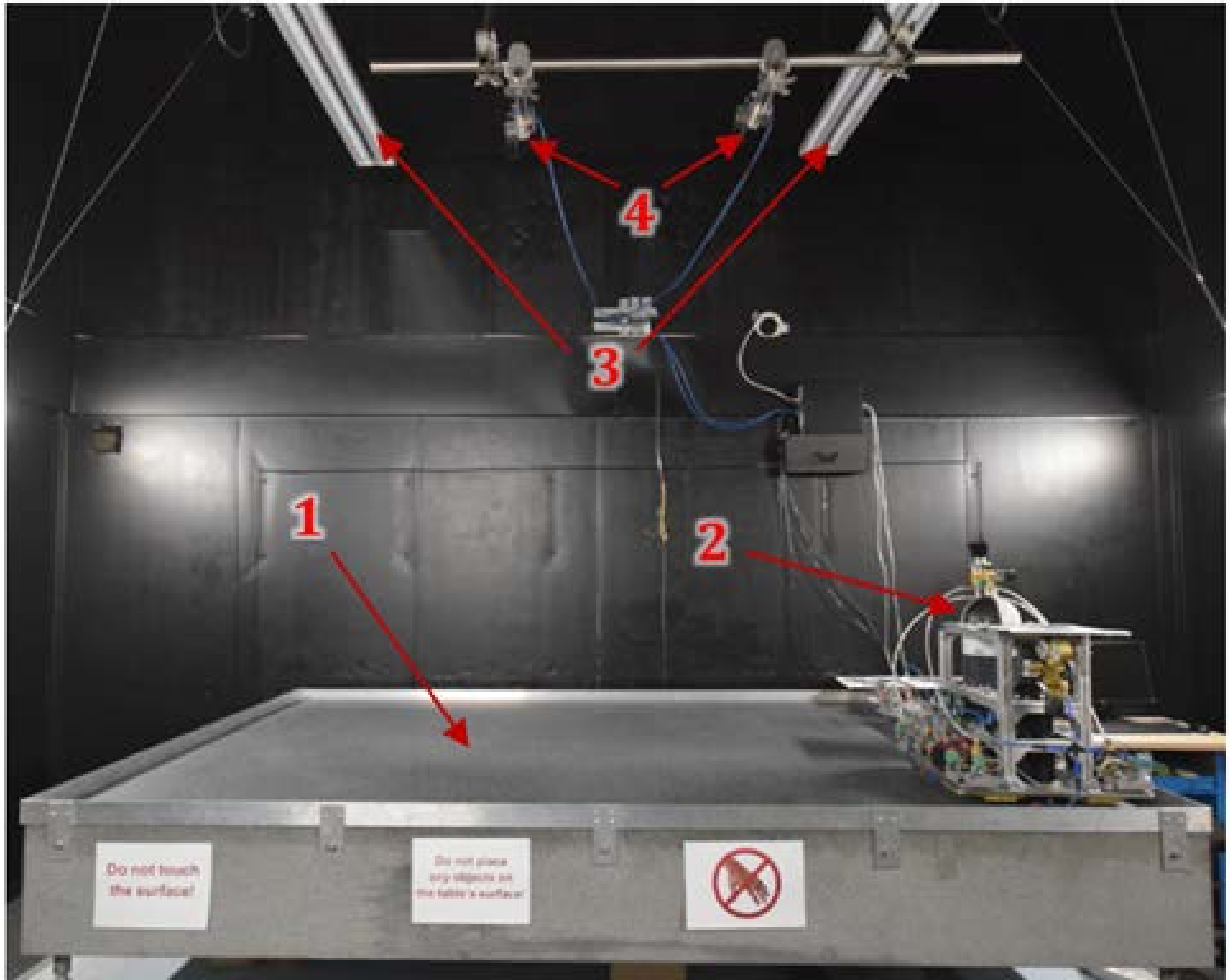


Air-bearing microgravity simulator at CBK PAN

- Test facility in use since 2012 (first presented at ASTRA 2013 conference).
- Major upgrade performed at the end of 2015.
- Used in various experiments connected with space robotics (but not only!).
- Test-bed based on 2*m* x 3*m* granite table (with celling 4*m* above the surface).

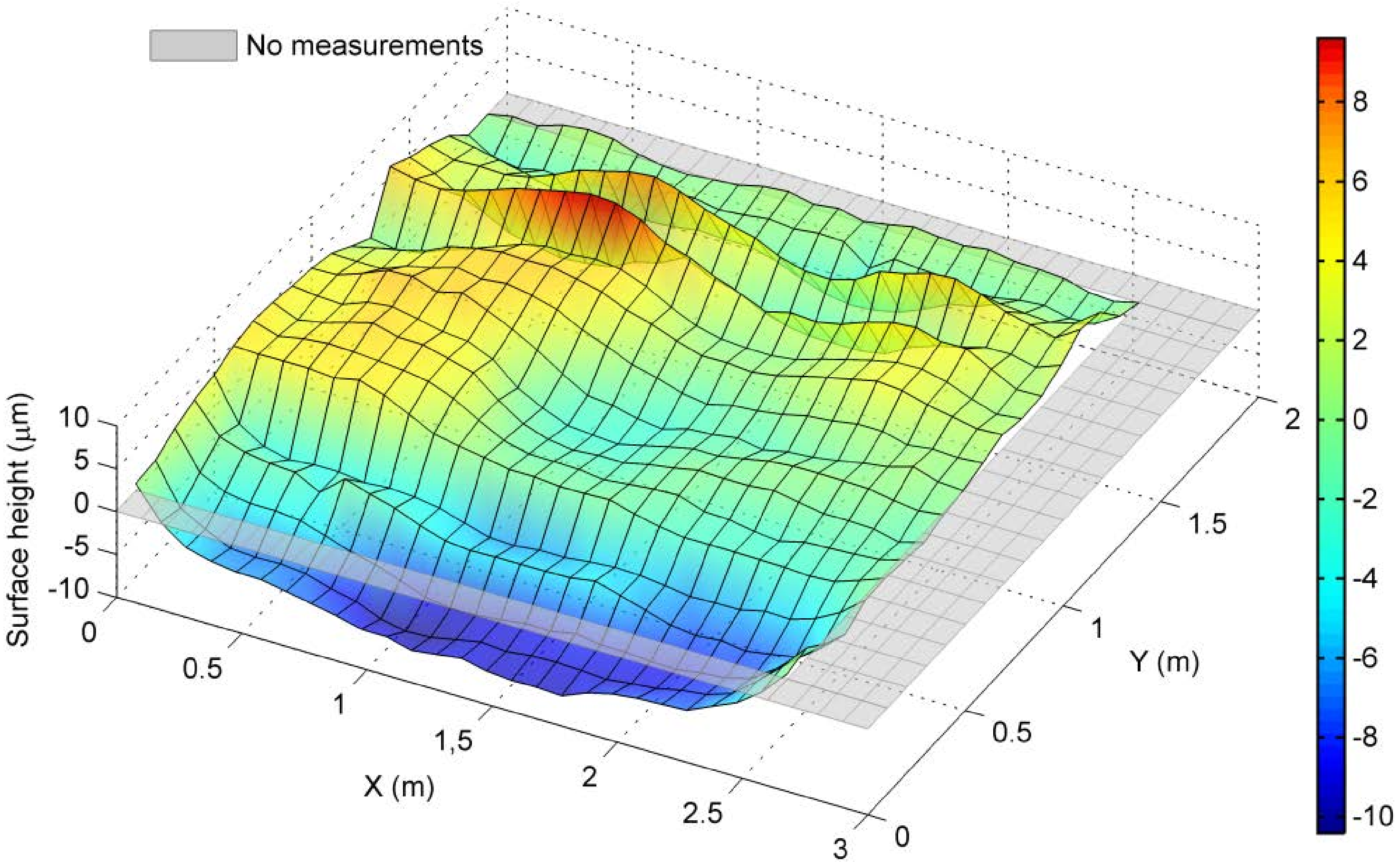
Granite table at CBK PAN.

Air-bearing microgravity simulator at CBK PAN



Testing facility: 1 – air-bearing table, 2 – space robot, 3 – illumination system, 4 – vision system cameras.

Air-bearing microgravity simulator at CBK PAN

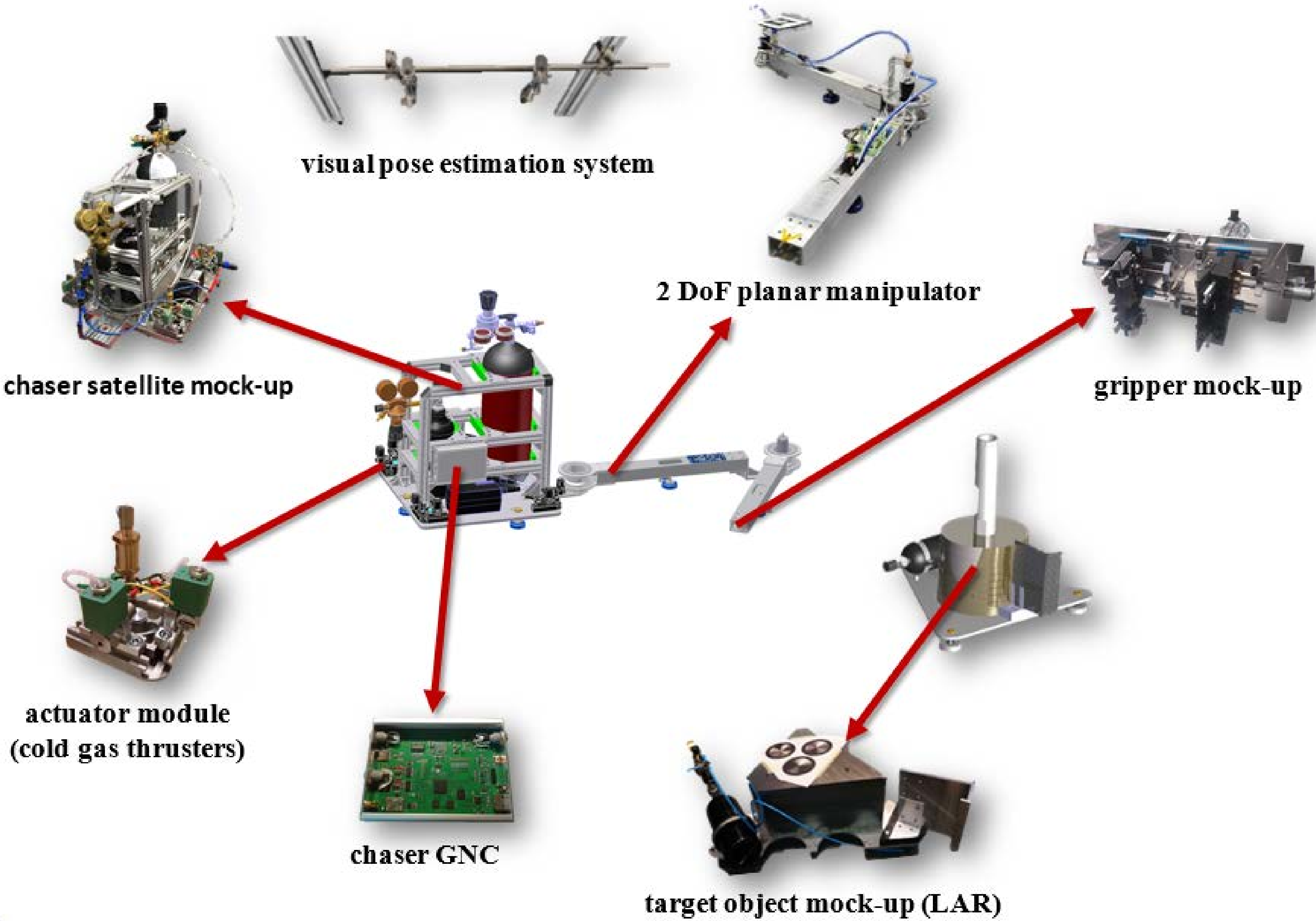


Topographic map of the granite table surface.

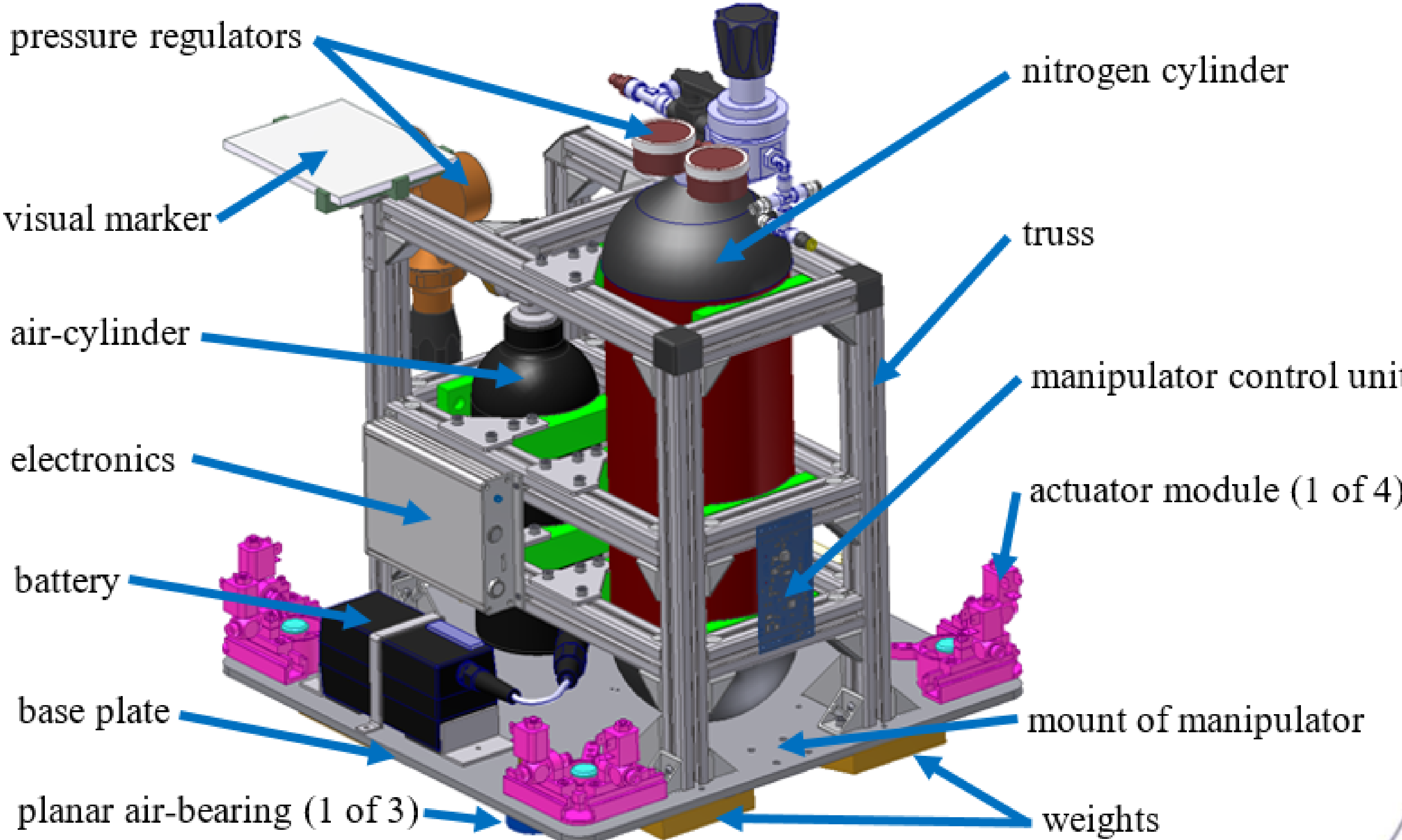
Approach for validation of the rendezvous and grasping

- Test facility at CBK allow to test all components that are crucial in the final phase of the capture manoeuvre, i.e., during fuel optimized approach to the target, arm transfer to delivery/acquisition point, capturing and detumbling.
- It is possible to performed full experiments with engineering models of all chaser subsystems, but it is also possible to test only selected subsystems (e.g., chaser GNC, gripper).
- The subsystems that are already available at CBK PAN can be used to substitute subsystems that are not selected for tests (e.g., mock-up of a dedicated gripper can be mounted on the simple 2 DoF manipulator that is already available).

Approach for validation of the rendezvous and grasping

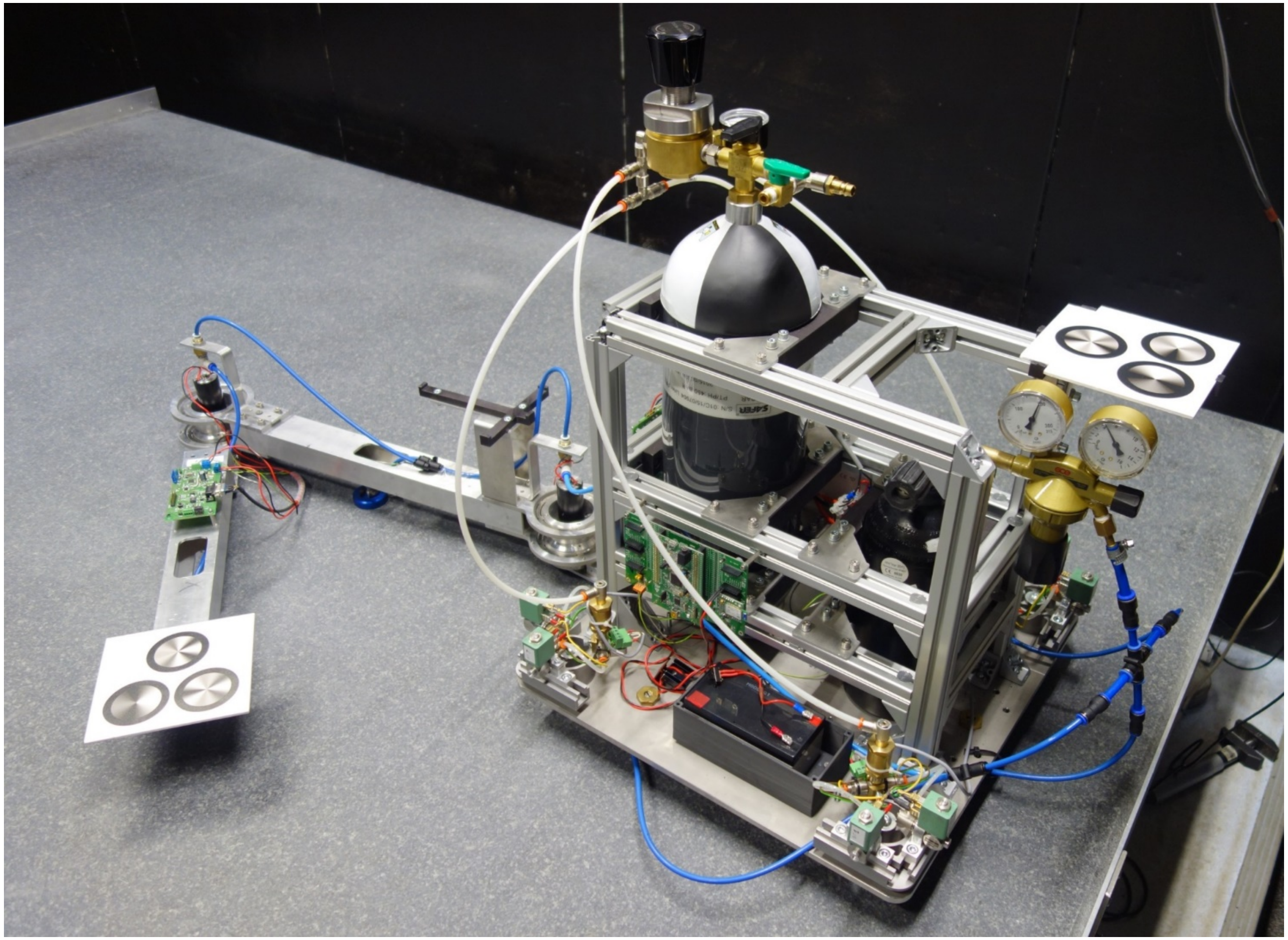


Subsystems available at CBK: chaser satellite mock-up



The schematic view of the chaser satellite mock-up.

Subsystems available at CBK: chaser satellite mock-up

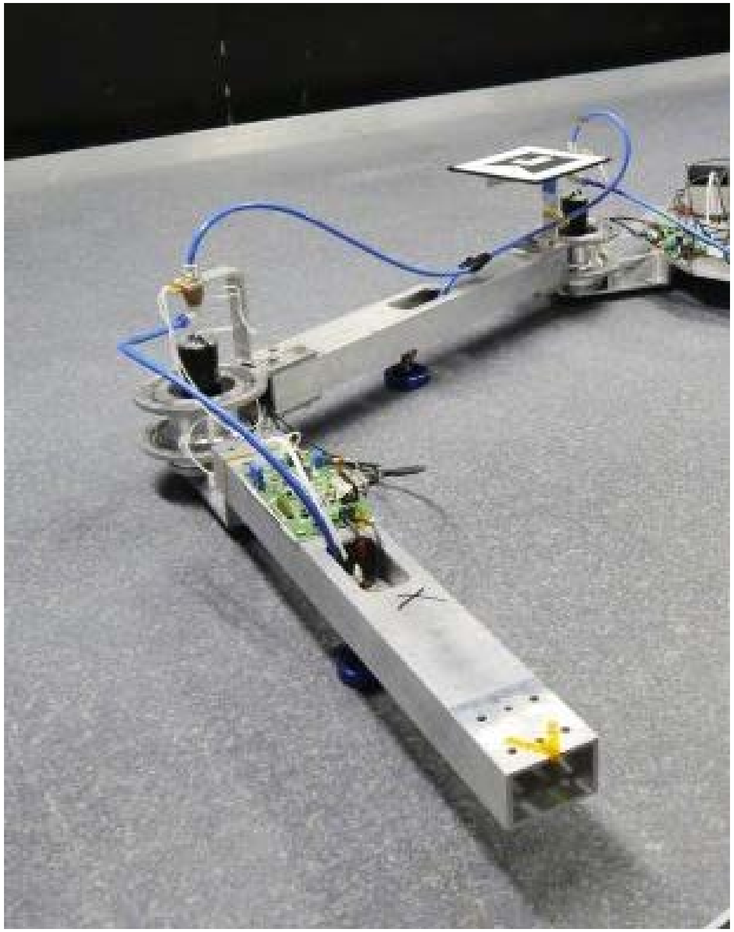


Picture of the chaser satellite mock-up with attached 2 DoF manipulator.

Subsystems available at CBK: 2 Dof planar manipulator

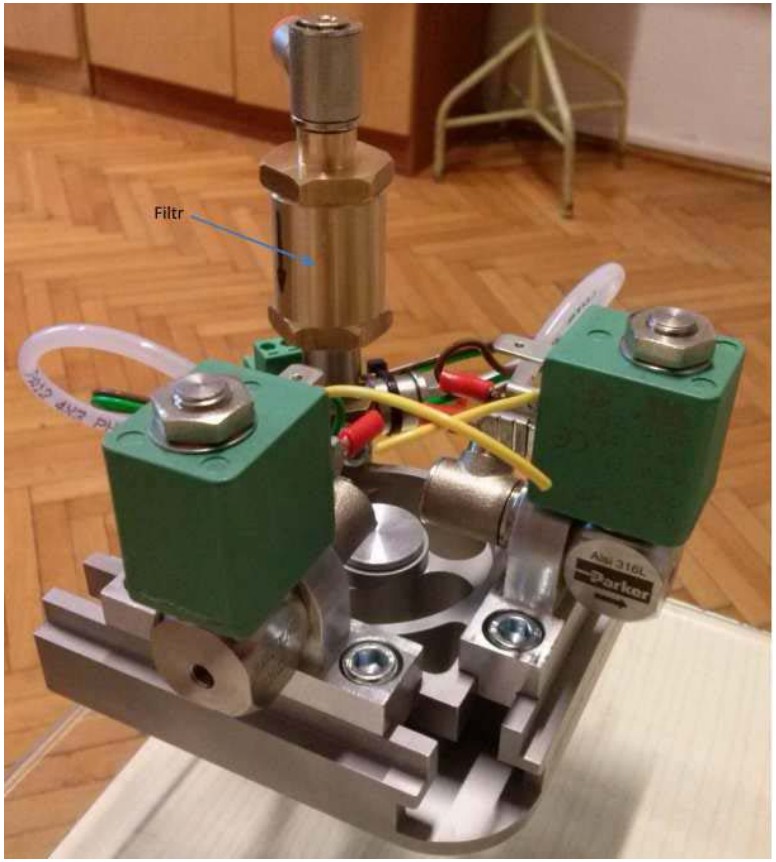
Geometrical and mass properties of the 2 Dof planar manipulator.

	Parameter	Link 1	Link 2
1	Mass [kg]	4.5	1.5
2	Moment of inertia [$kg \cdot m^2$]	0.32	0.049
3	Length [m]	0.619	0.6
4	Joint type	rotational	rotational



2 DoF planar manipulator.

Subsystems available at CBK: actuator module (thrusters)



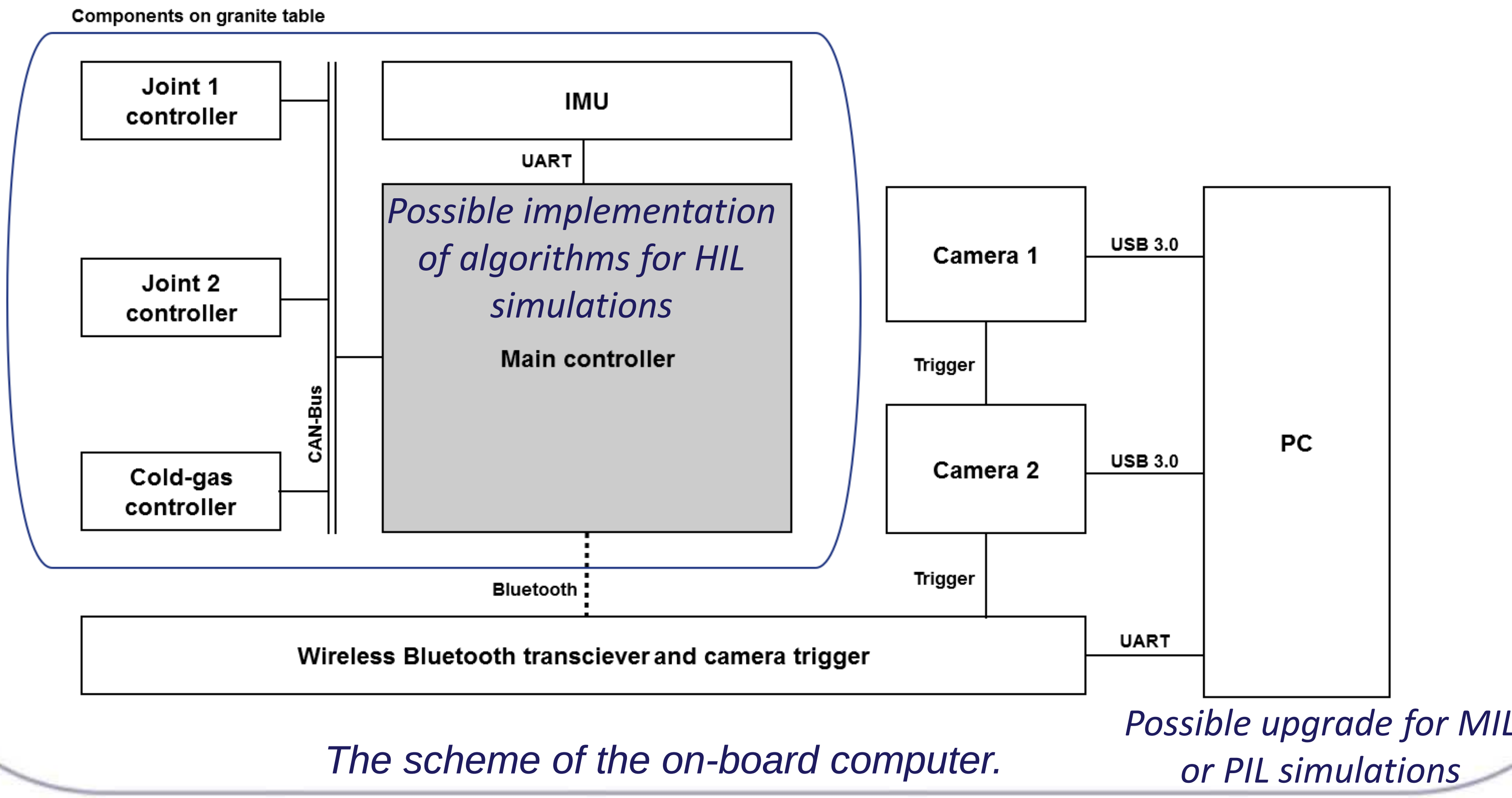
Pircture of the actuator module (2 cold gas thrusters)

Basic parameters of actuators.

	Parameter	Link 1
1	Number of thrusters	4 modules x 2 thrusters
2	Thrust [N]	0.846 N
3	Working medium	Nitrogen
4	Nominal chamber pressure [bar]	10
	Mass flow rate [g/s]	1.575

Subsystems available at CBK: on-board computer

- Control system for the manipulator and chaser can be implemented on the on-board computer.
- Processing unit is a high performance STM32F407 ARM®Cortex®-M4 32-bit core microcontroller. The main control loop lasts 10ms.

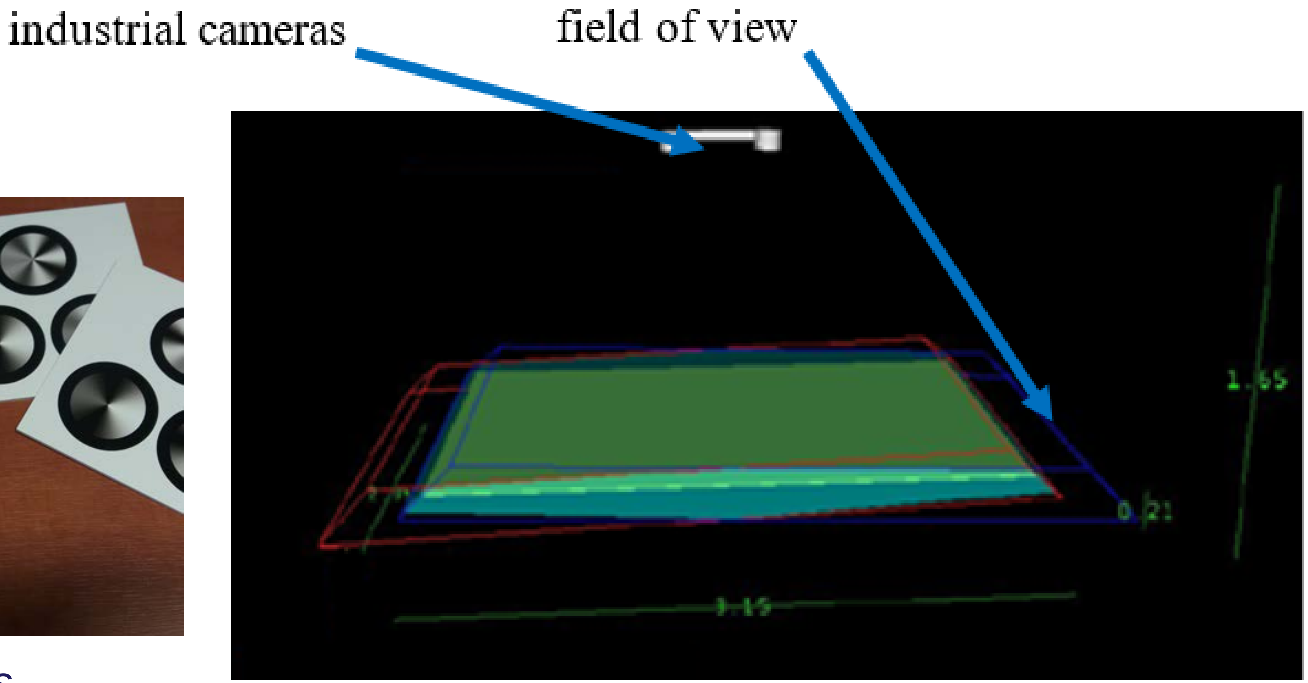


The scheme of the on-board computer.

Subsystems available at CBK: visual post estimation system

- Consists of three fast industrial cameras with 5MPx resolution and frequency up to 100Hz.
- Dedicated software for image recognition detects positions and orientations of visual markers (in the real time).
- High accuracy of measurements.

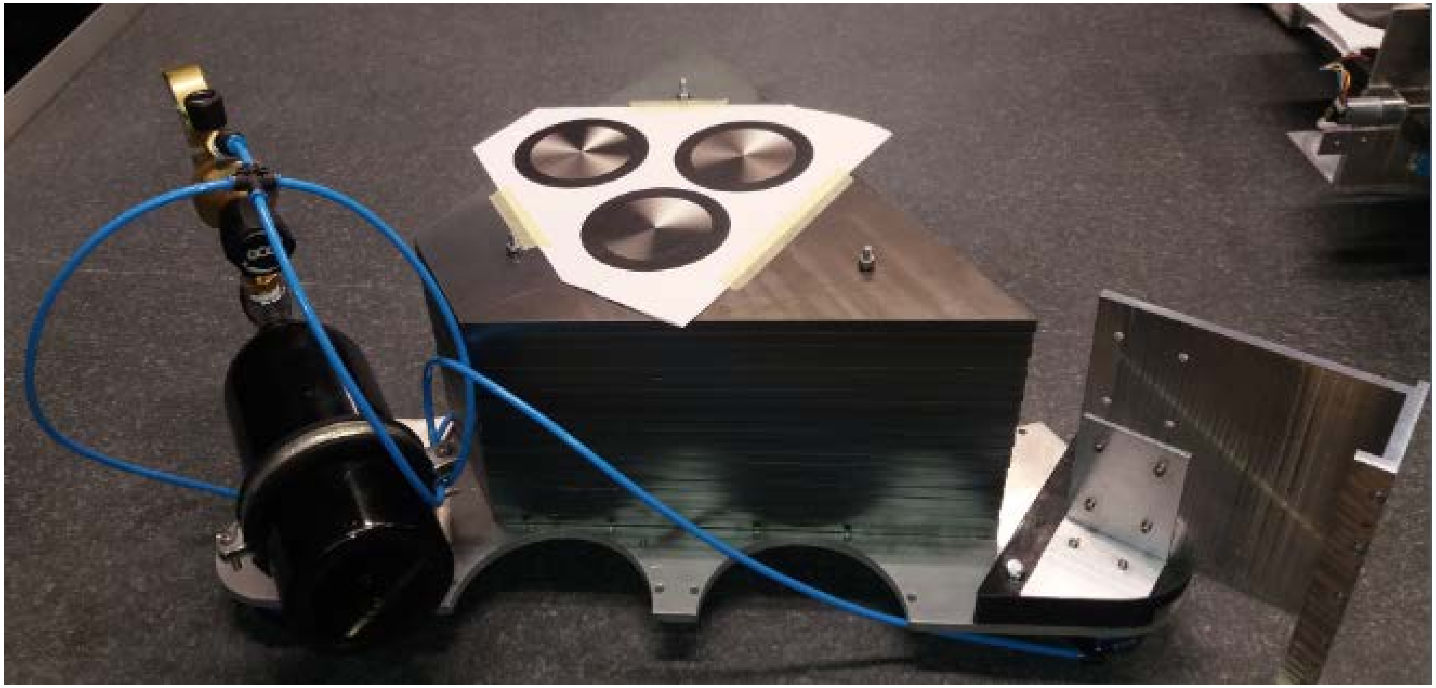
Visual markers.



Location of cameras with cameras field of view.

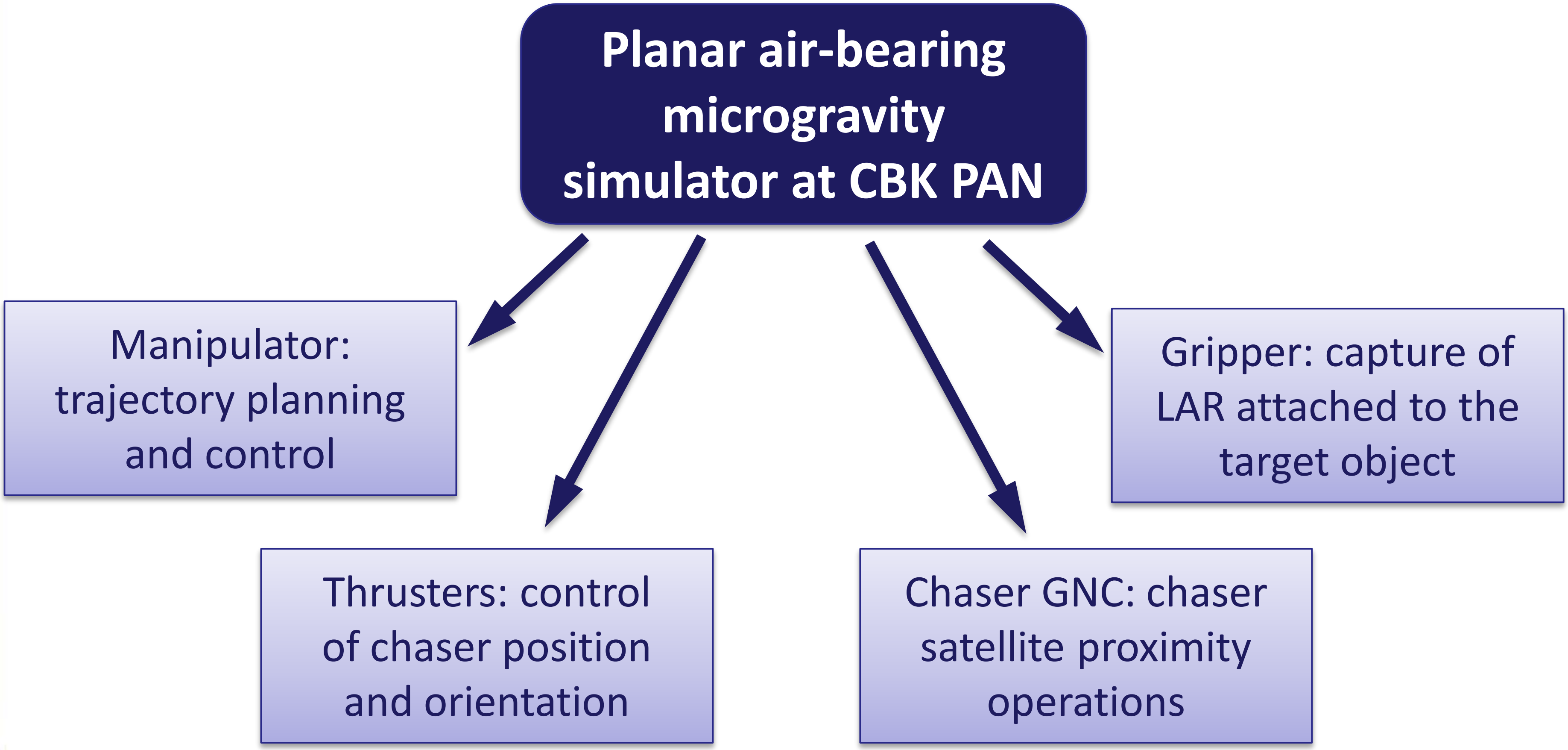
Subsystems available at CBK: target object mock-up

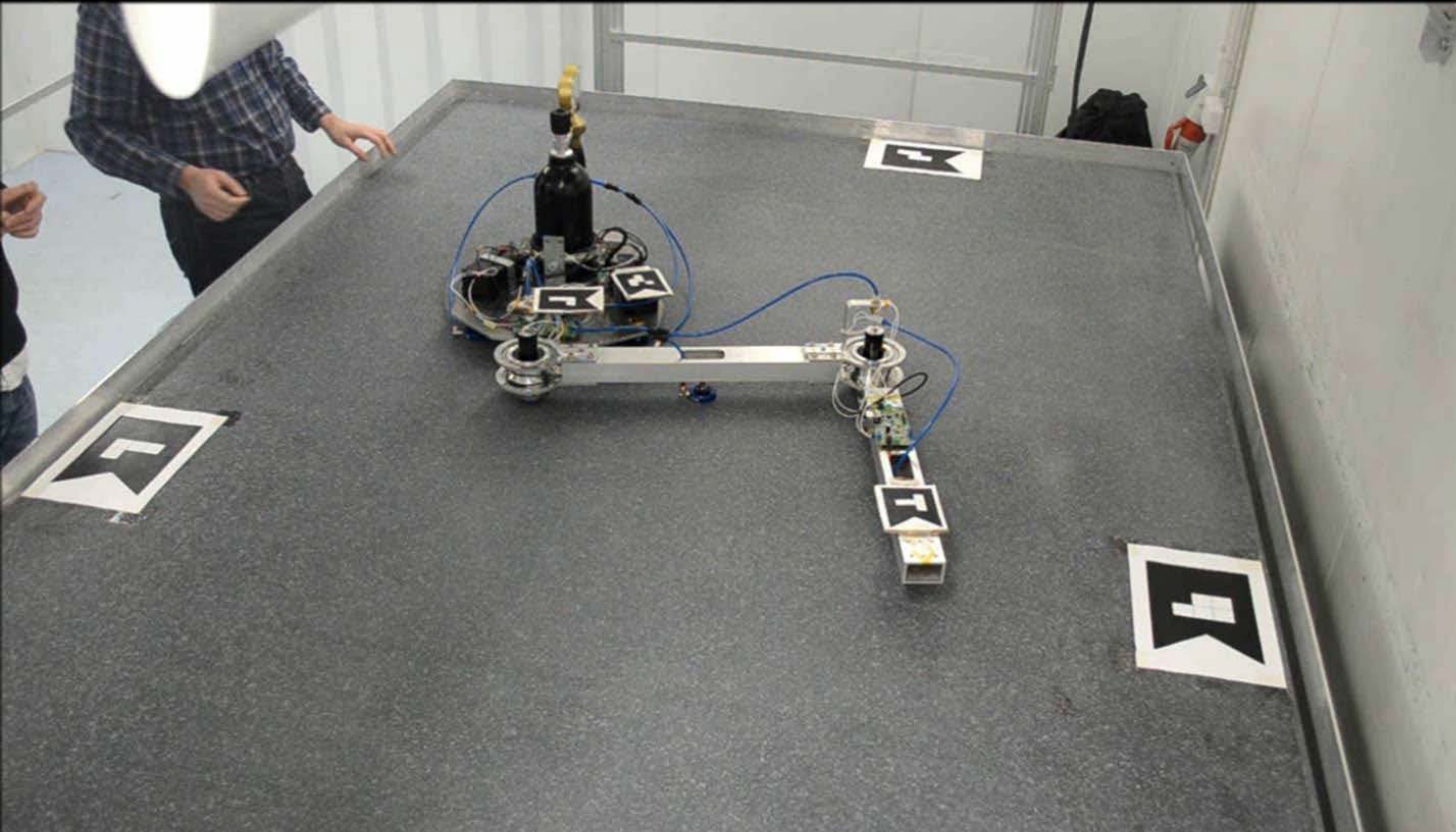
- Adjustable mass and inertia.
- Possibility to mount LAR mock-up.
- No control of the target mock-up (just a free-floating behaviour).



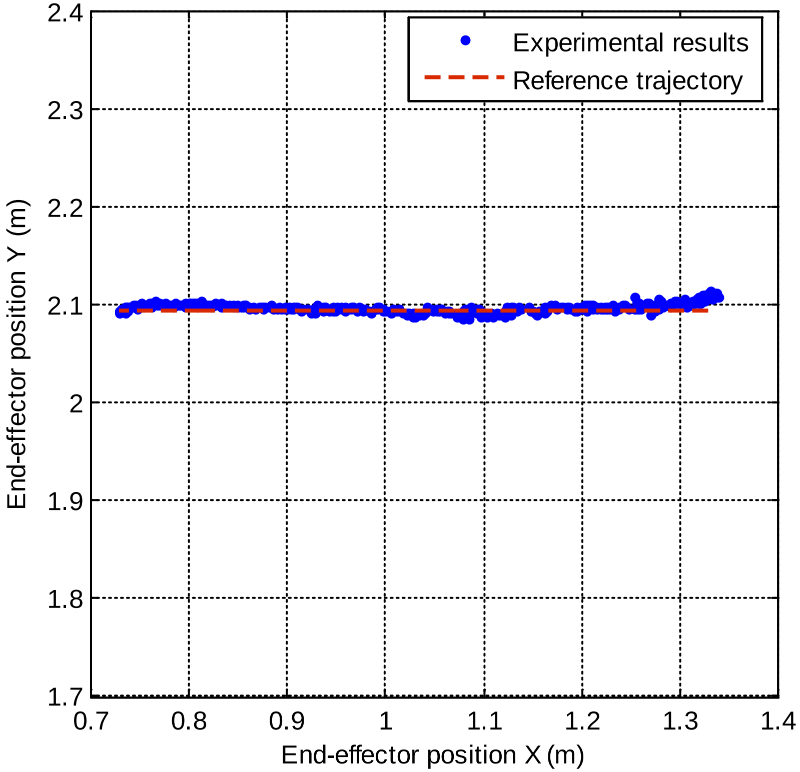
Picture of the target object mock-up.

Experiments performed on the microgravity simulator

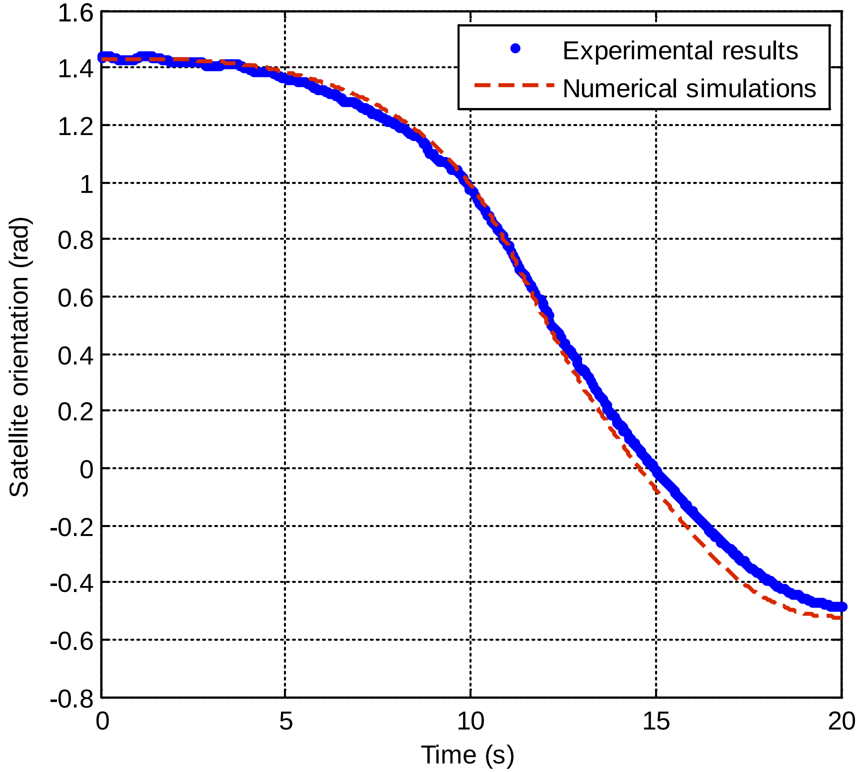




Results of experiments: manipulator trajectory planning



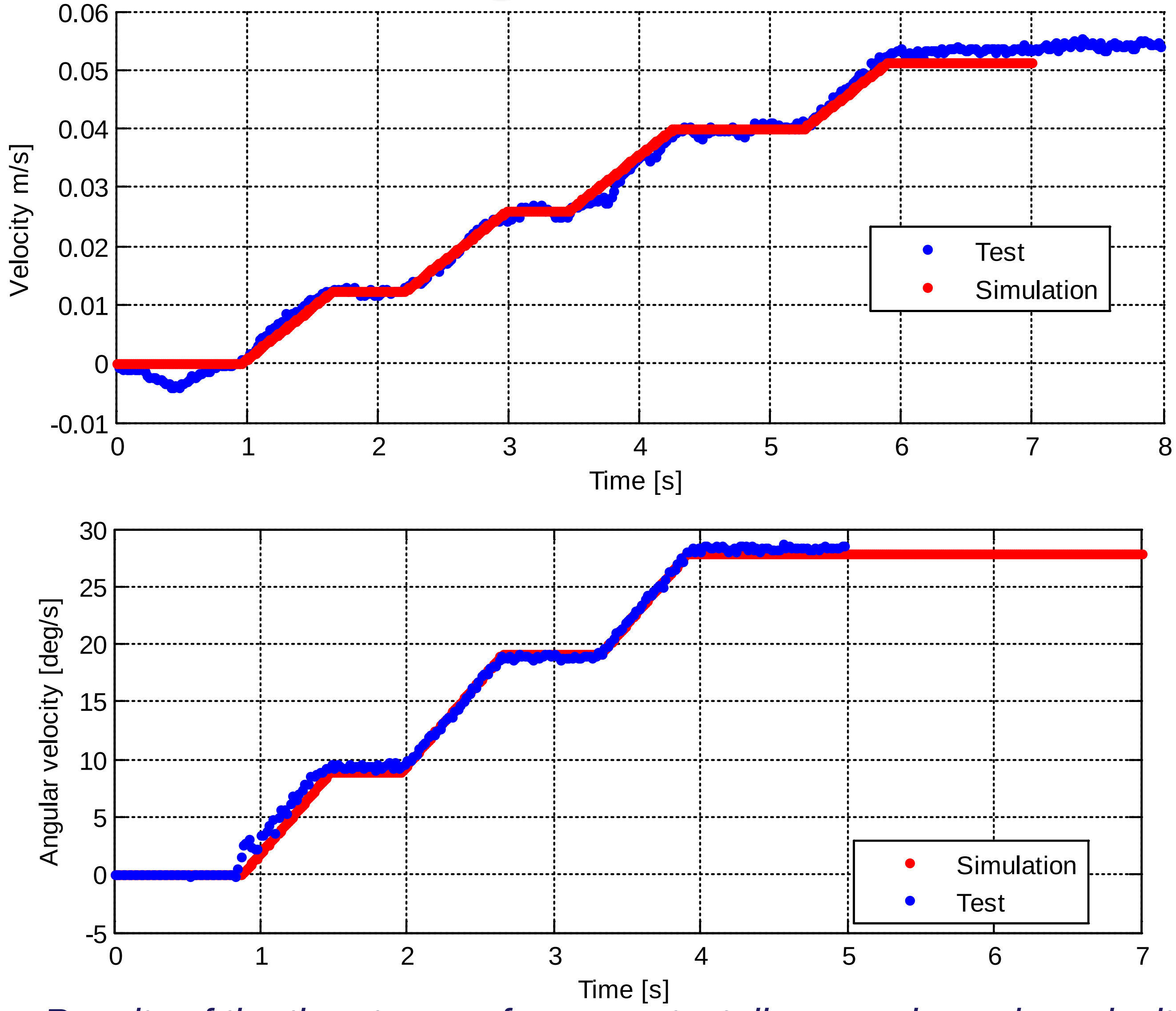
Comparison between the reference end-effector trajectory and end-effector position measured during the experiment.



Comparison between the satellite orientation obtained from numerical simulations and orientation of manipulator base measured during the experiment.

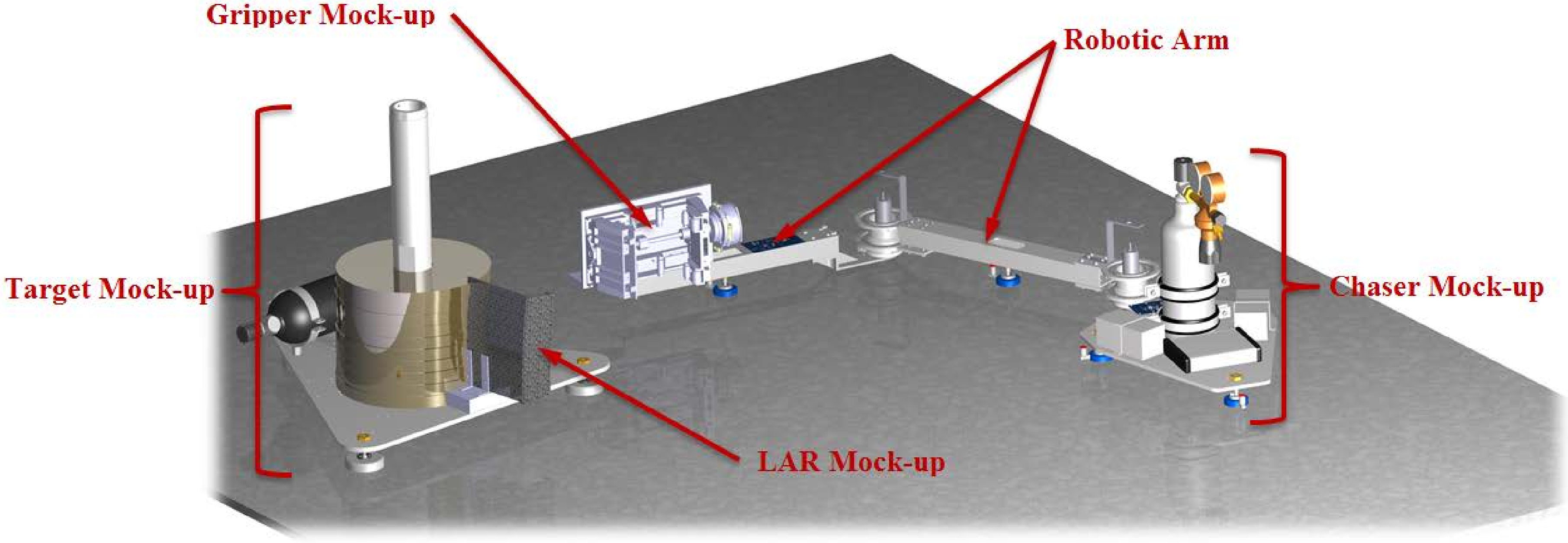
Results of experiments: cold-gas thrusters

Results of experiments: cold-gas thrusters



Results of the thrusters performance test: linear and angular velocity.

Results of experiments: gripper (e.Deorbit capture)

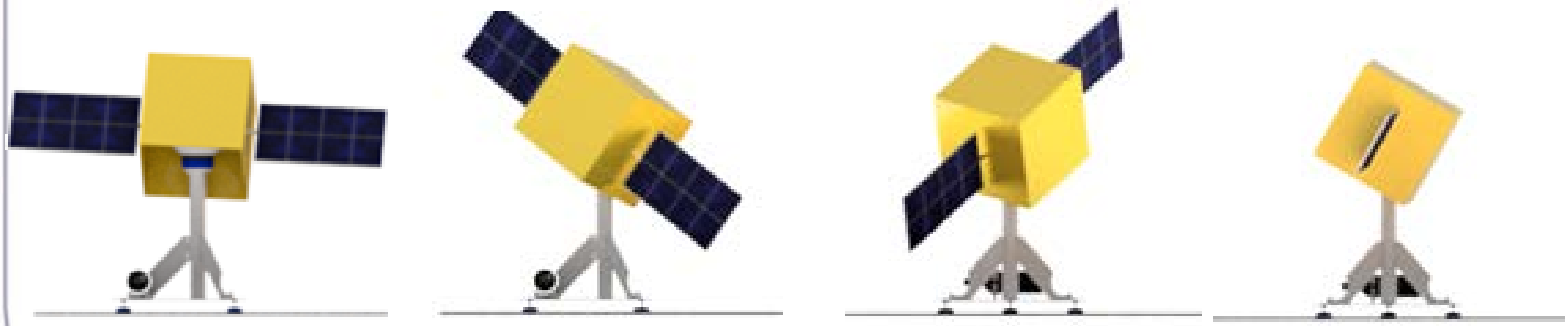


Experimental test set-up on the planar air-bearing microgravity simulator with chaser and target mock-ups.

Results of experiments: gripper (e.Deorbit capture)

Planned upgrades and experiments

- Experiments with flexible joints of the manipulator.
- Additional rotational joint (3 DoF redundant manipulator).
- 5 DoF set-up for tests of satellite GNC (based on the test set-up from SAMPLER project).



The different positions of satellite mock-up achieved by using the spherical air-bearing.

Summary

- The planar air-bearing microgravity simulator at CBK PAN can be used for validation of various subsystems developed for the planned OOS and ADR missions.
- This test facility was succesfully used in various projects, including two projects funded by ESA: SAMPLER and e.Deorbit Phase B1.
- All subsystems that are crucial in the final phase of the capture manoeuvre can be tested on the planar air-bearing microgravity simulator at CBK.
- Subsystems that are already available at CBK PAN can be used to substitute subsystems that are not selected for tests.

Thank you
for your attention!

ACKNOWLEDGMENTS
This study was partially supported by the Polish National Science Centre under research grant 2015/17/B/ST7/03995.