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SIROM: LATEST DEVELOPMENTS.

AIR-BEARING TEST CAMPAIGN AS A CRUCIAL STEP FOR VALIDATING DOCKING APPLICABILITY.

CleanSpaceDays2024

Content

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Company vision

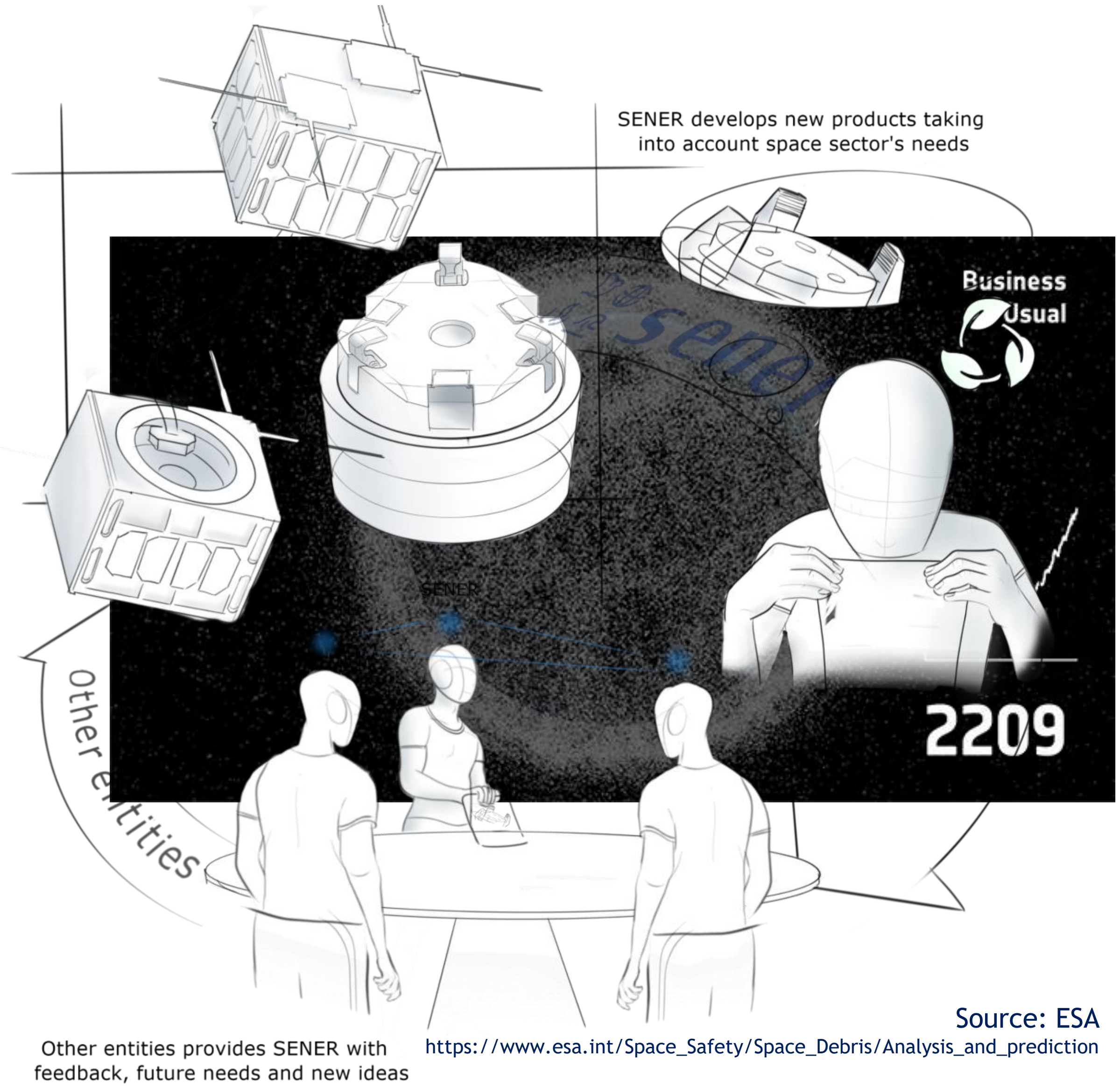
SENER Aeroespacial

SENER

Vision

In recent years, there has been a considerable increase in interest in the sustainable development of the space sector. Public awareness of the space debris problem within the context of future space logistics has significantly driven the development of solutions to address this critical issue.

SENER Aeroespacial is committed to playing a key role in addressing this challenge. The company is not only applying sustainable design principles in the selection of materials and processes but also enhancing the capabilities of its technological products that could be instrumental in the cleaning and prevention of space debris.



Source: ESA
https://www.esa.int/Space_Safety/Space_Debris/Analysis_and_prediction

Product Presentation

SIROM for ADRIOS

SIROM (Standard Interface for Robotic Manipulation)

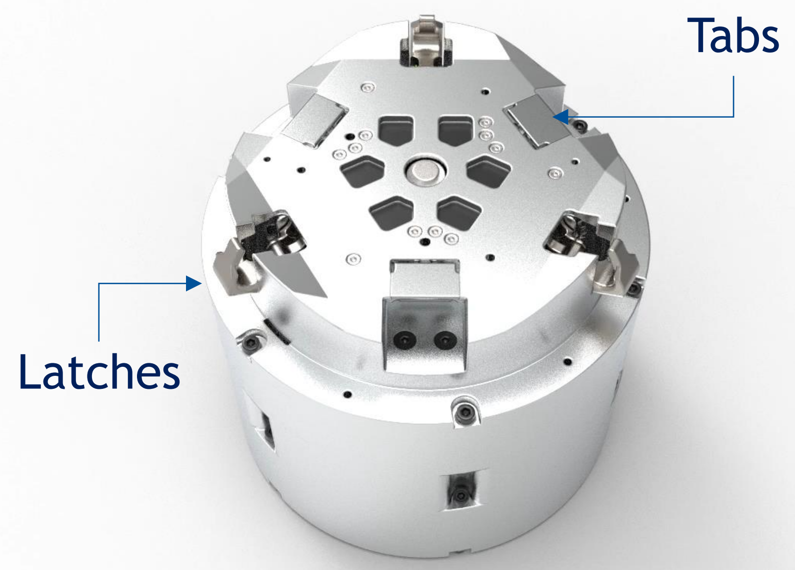
Product Description

GENERAL

- Origin: PERASPERA project (2016-19)
- Operation: Latching mechanism-based capture
- Transfer: Fluid/power/data
- Configurations: Active/Passive and Androgynous for electric versions
- Current projects: EROSS-IOD, ORU-BOAS, POC-1, ISAAC, EU-RISE, SPACE-USB

CAPTURE CAPABILITIES

- Latching system enables coupling between interfaces with a capture before contact
- Self-aligning capability using guiding petals



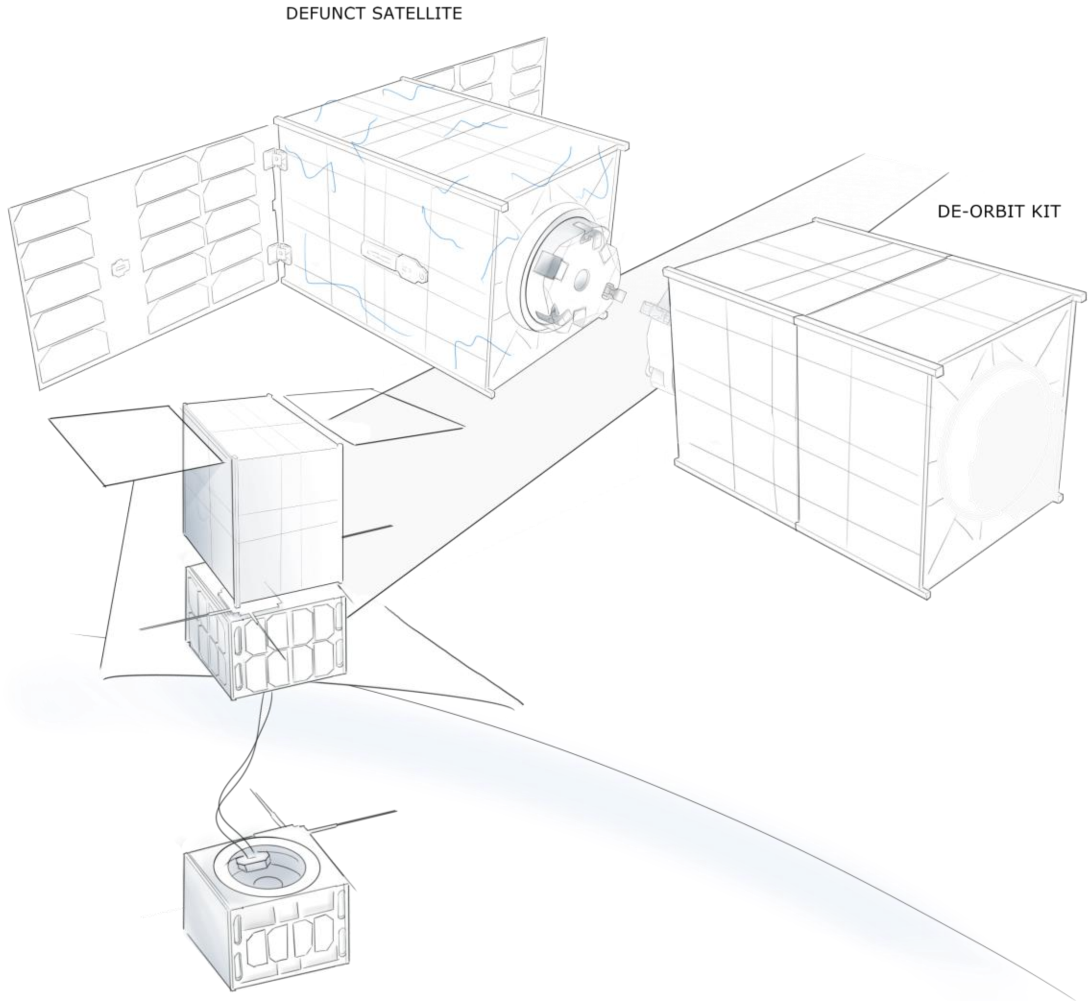
	SIROM D,E,F,G Active/Passive
Axial load traction	3KN
Bending	150Nm
Torsion	480Nm
Misalignment combined	x,y: +/-5mm z: +15mm
Maximum misalignment variables independently	x,y: +/-10mm pitch/roll/yaw +-5°

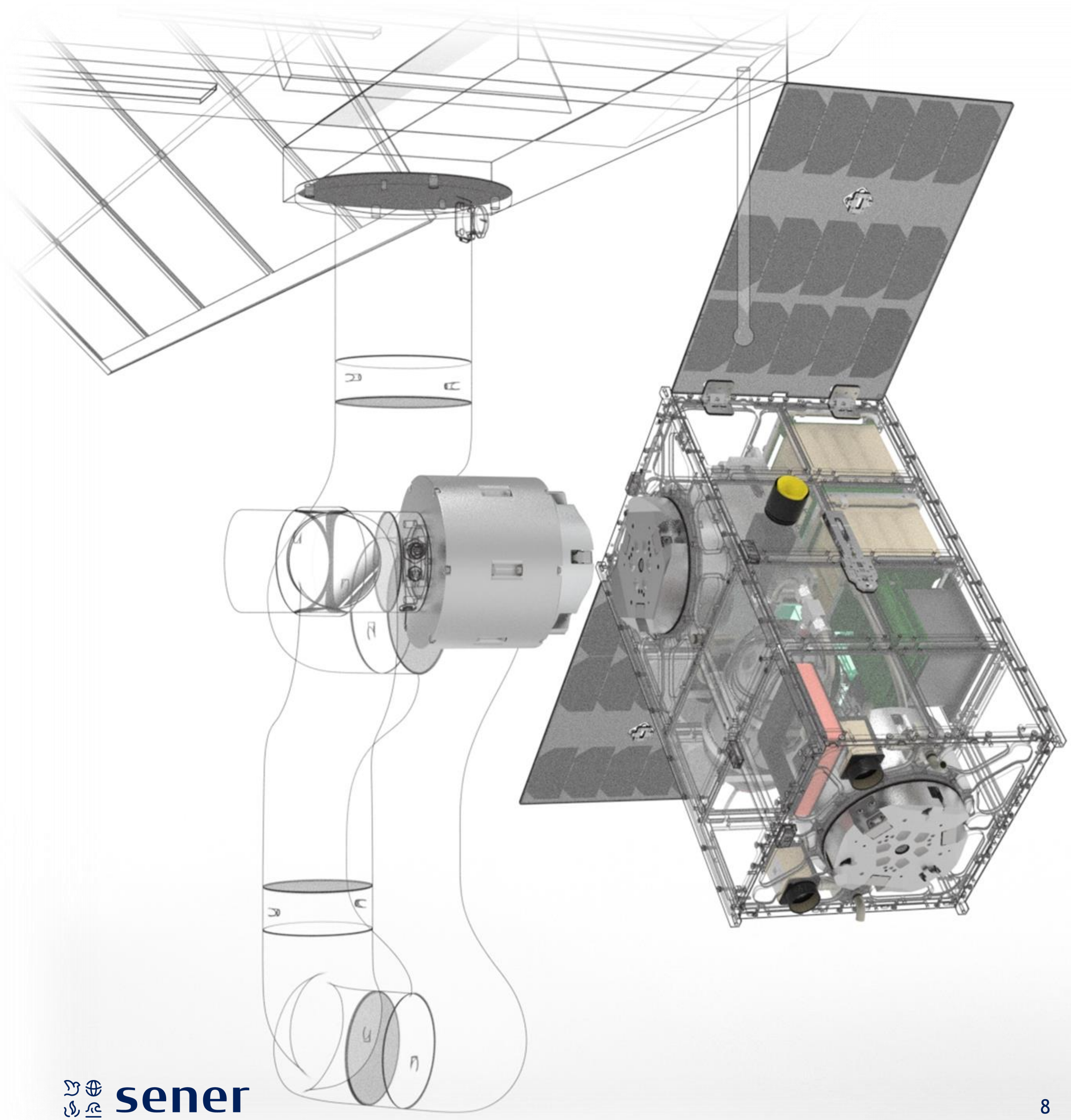
SIROM (Standard Interface for Robotic Manipulation)

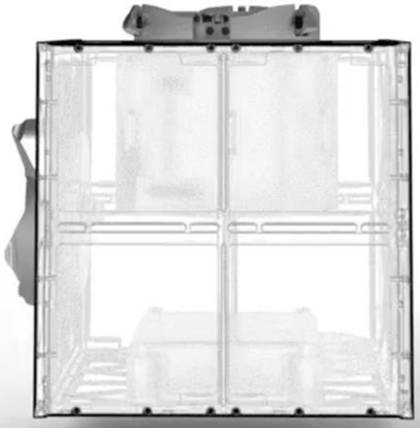
Space debris reduction

This mechanism's ability to mechanically connect devices presents a significant opportunity to prevent the increase of space debris by equipping clients with passive interfaces (I/Fs).

- Capture defunct satellites with a large vehicle intended to be deorbited
- Connect small deorbiting kits to defunct satellites







Use cases

SIROM versions and add-ons

OPERATION		HARD DOCKING		BERTHING		SMALL CARGO TRANSFER
Vehicle category		Small/ Light	Large/Heavy	Small/Light	Large/Heavy	By means of a single or moving 3-arm robot mounted on a vehicle
Vehicle mass		Chaser or target<500kg	Chaser and target<500kg	Chaser or target<500kg	Chaser and target >500kg	
Impact/Contact forces	Low relative velocity <15mm/s	Low impact forces	(*)High impact loads during the docking	Lowest restrictions during the capture due to robot's flexibility.	Low restriction during the capture	More stringent requirements as robot, cargo and struct. grows.
	High relative velocity >15mm/s	(*) Analysis required		(*)Robots can absorb more kinetic energy		(*)
Matting force requirements	Low thrust and aligned with the interface (MEO, GEO orbit change)	(1) Low mechanical loads once matted	(*)	(1)	(*)	(1)
	High thrust manoeuvres. (LEO)	(*)	(2) High loading capabilities required	(*)	(2)	(*)
Other Limitations		-Available space to allocate docking interfaces.		-Available space to allocate docking interfaces. -End effector manoeuvrability		

Use cases

Spotlight

SIROM APPLICABILITY FOR HARD DOCKING OPERATIONS

“”

Definition of computational models, tests and correlation.

Test campaign and computational model correlation

AIR-BEARING test

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AIR-BEARING

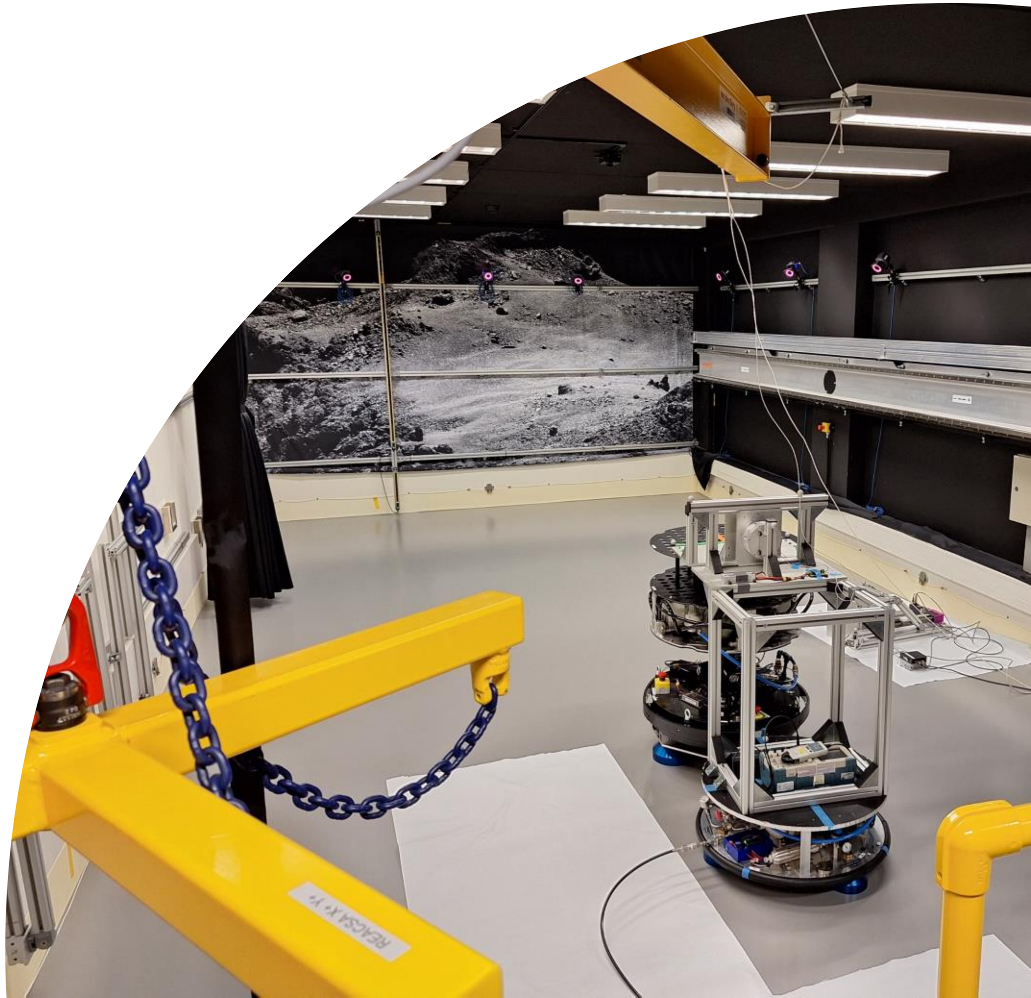
Objectives

1. **Offer physical proof to be used to validate the simulation models and verify SIROM applicability for hard docking operations**
2. Analyse the Capture Range in Three Degrees of Freedom (3DoF)
3. Conduct Multiple Trials with Low Perturbation on Trajectory
4. Explore the behaviour of the mechanism under different approach speed conditions
5. Gain insights into the dynamic performance of HES-based trigger integrated in SIROM, to ensure accurate and reliable performance.

Computational model

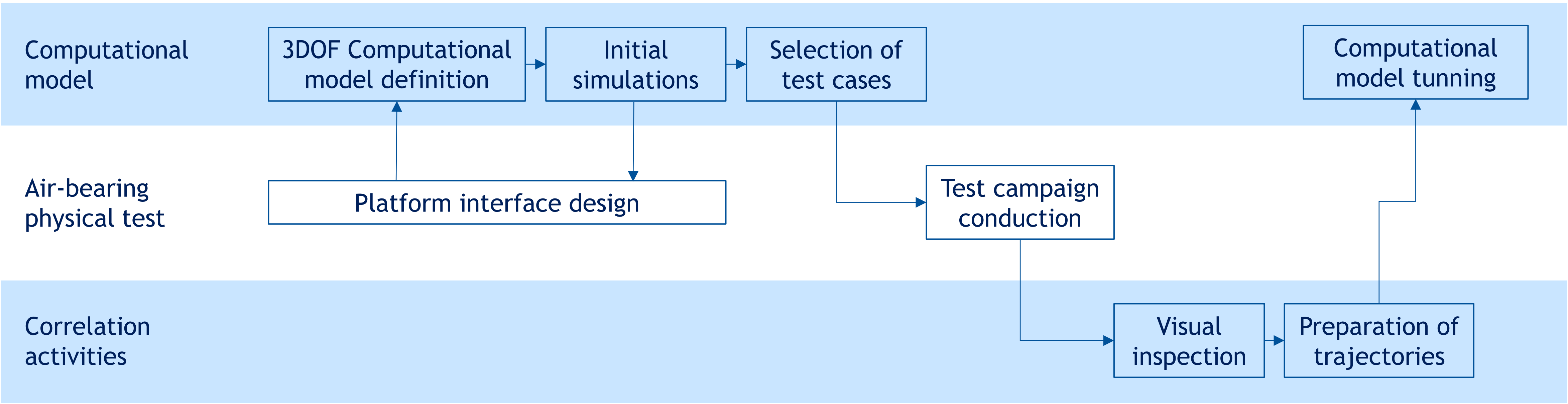
Air-bearing physical test

Correlation activities



AIR-BEARING

Procedure

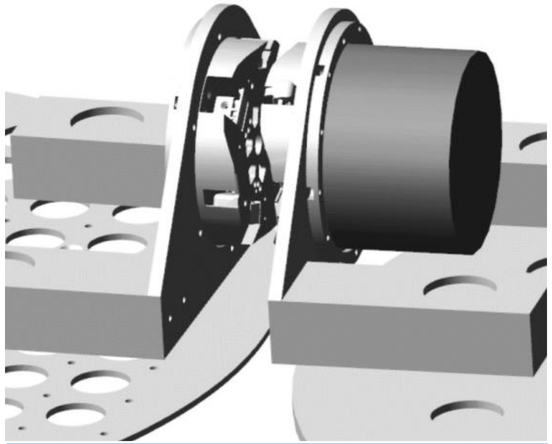


AIR-BEARING

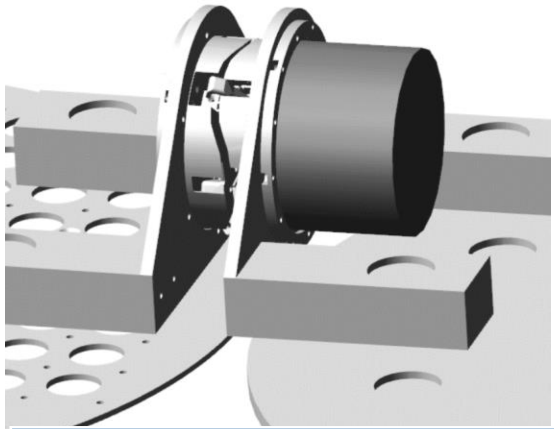
Computational model

Modelled in ADAMS, including the following adjustments:

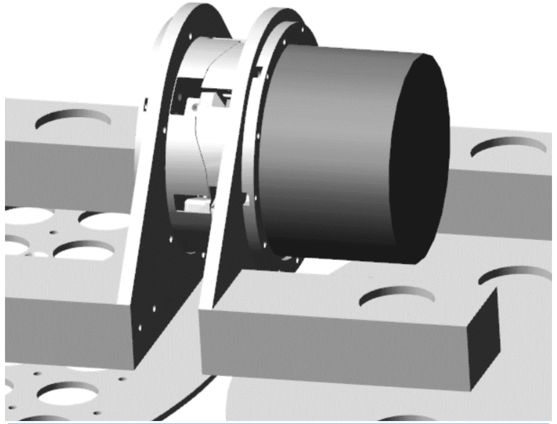
- Latches' mechanism replication to coincide with its practical motion.
- Relative positioning and orientation between platforms parametrization to enable a fast iterative approach.
- Platform properties inclusion (masses, CoG and inertial props)
- Contact definition between relevant components
- Maximum admissible torque limited
- 1 DOF representing the Z axis flexibility of the ejected vehicle
- (Optional) 1 DOF representing Fixed platform stiffness.



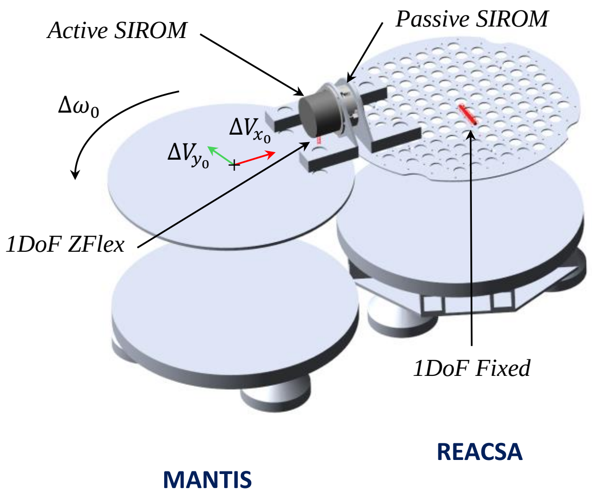
Step 1. ADAMS Air-bearing model before capture



Step 2. ADAMS Air-bearing model during capture

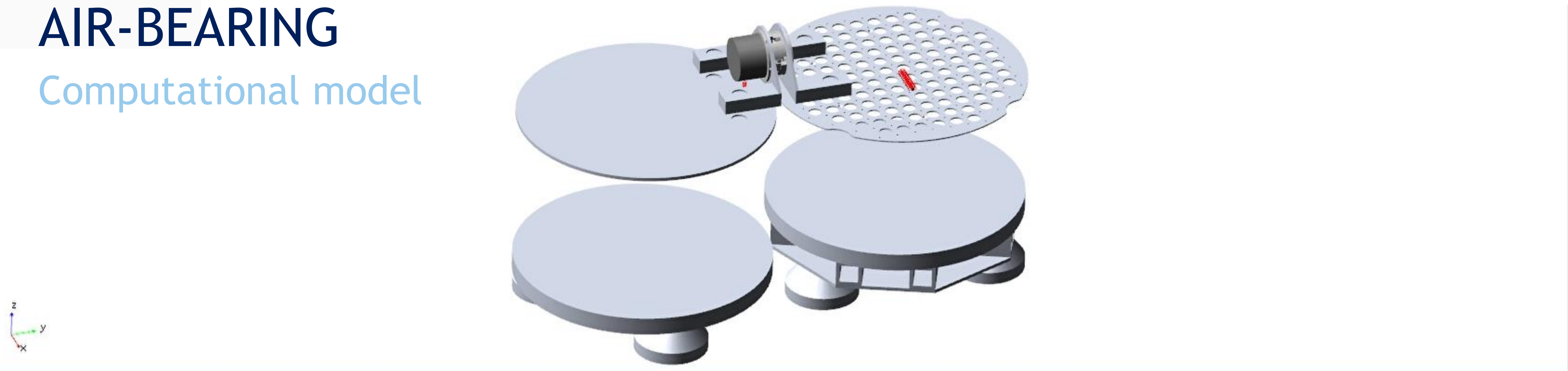


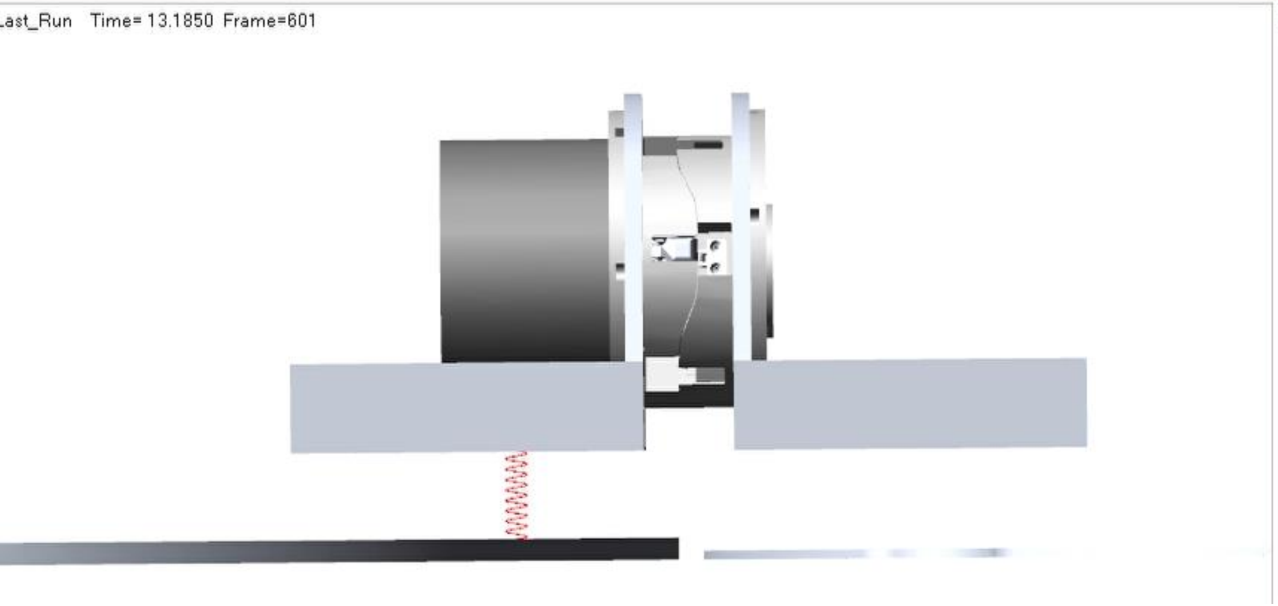
Step 3. ADAMS Air-bearing model after capture

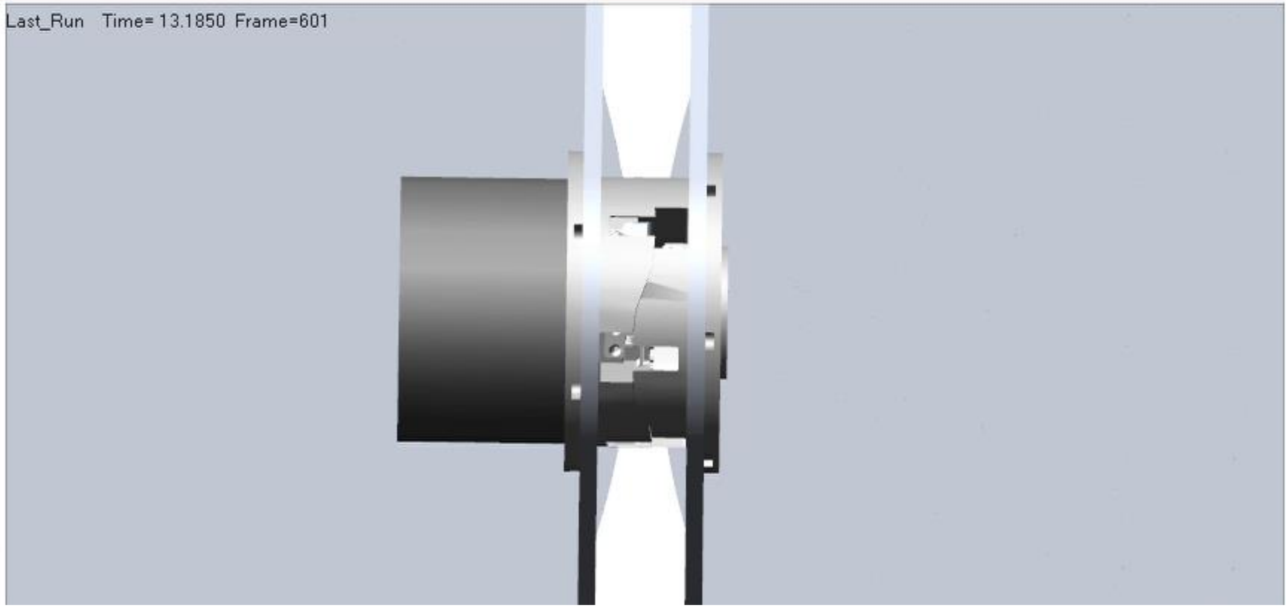


AIR-BEARING

Computational model





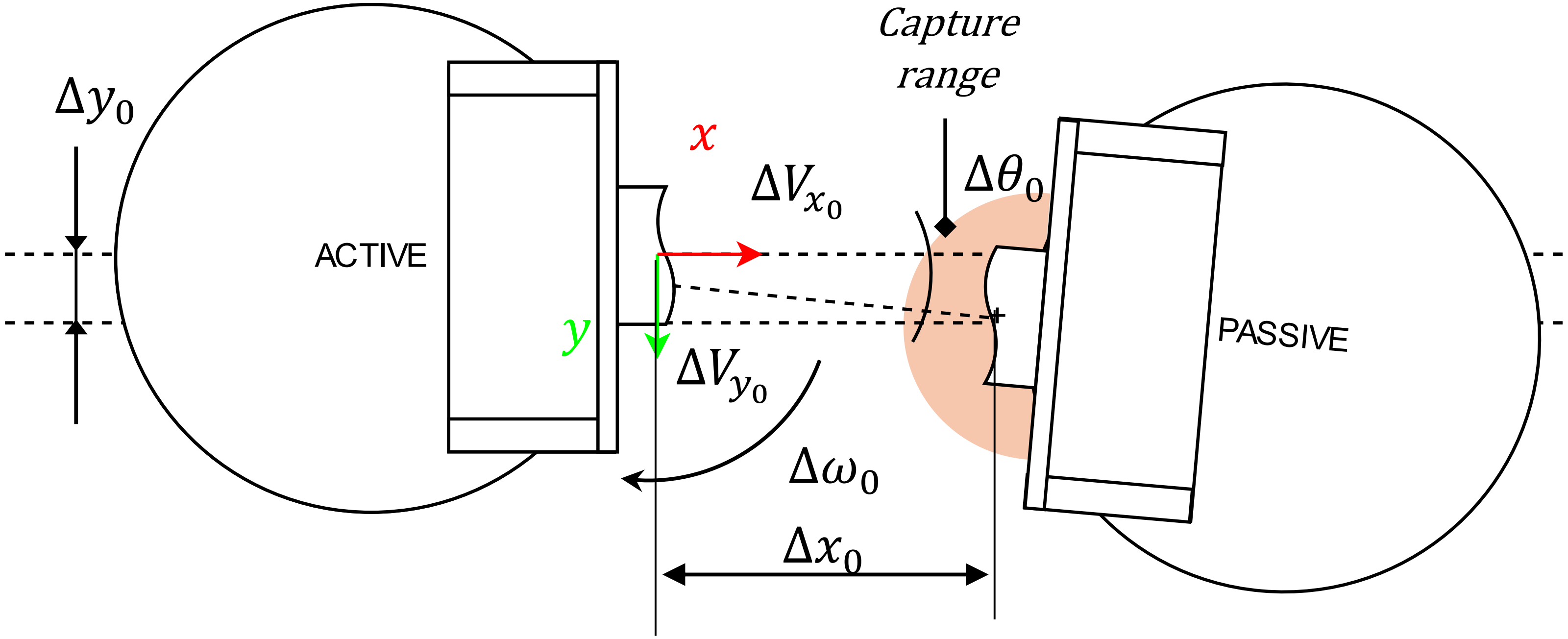


SIROM Air-bearing tests

Setup

- Radial misalignment
- Angular misalignment
- Axial velocity

- Residual radial velocity <5mm/s
- Residual angular velocity <0.2º/s



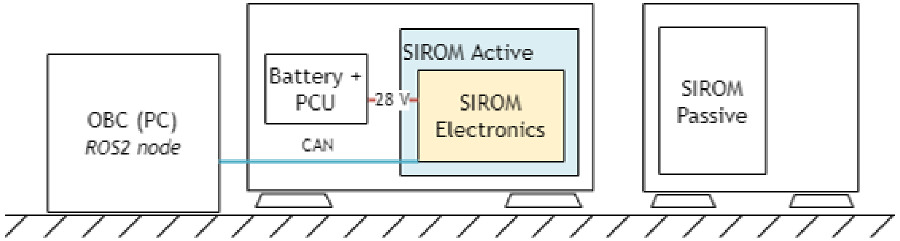
SIROM Air-bearing tests

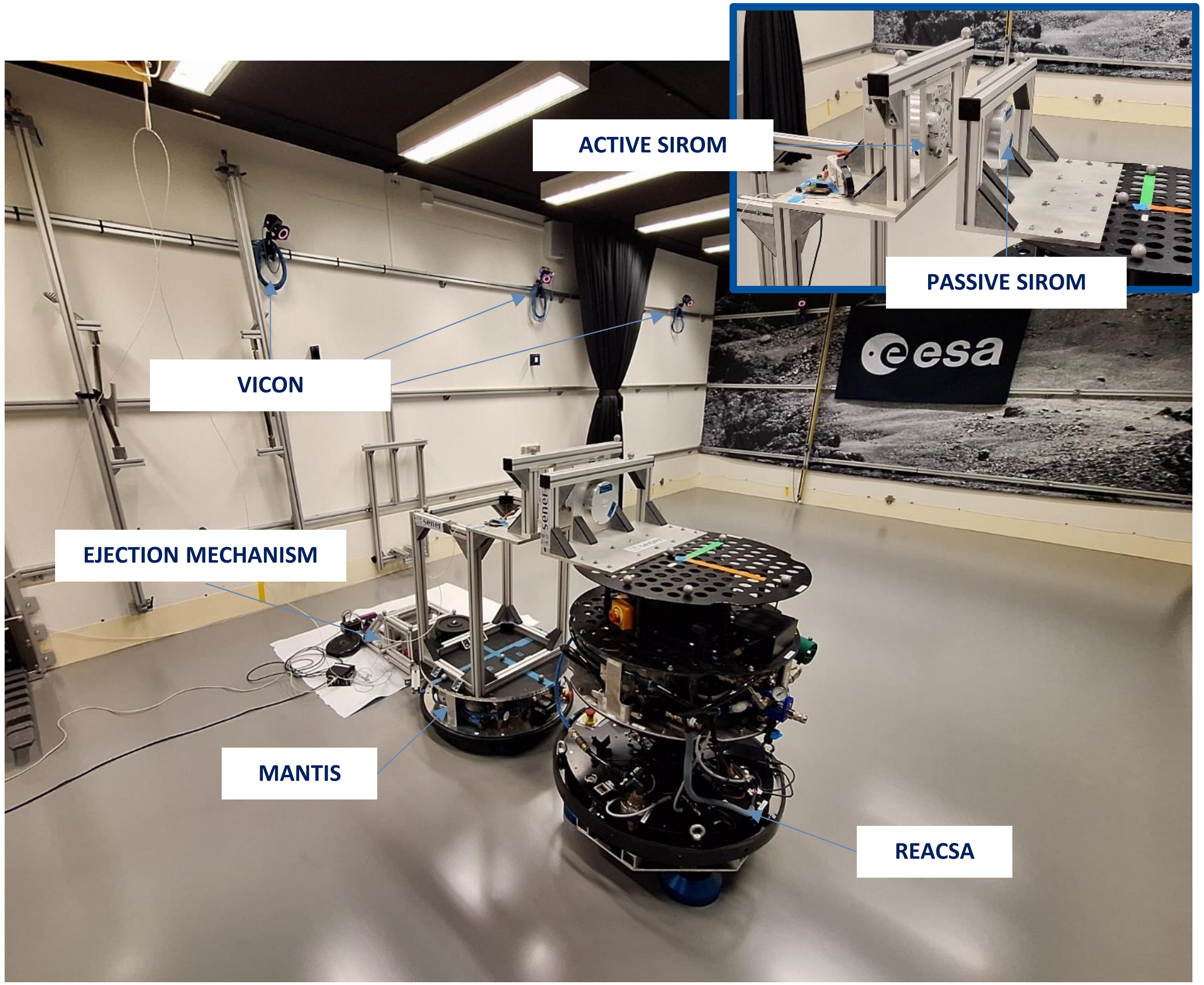
Setup

Test Campaign in ESA´s ORBITLAB (ORL) facilities:

	Originally agreed	Finally tested	Units
Cases quantity	114	183	[]
Trigger solution	VICON Hall optional	VICON and Hall	-
Trigger distance	10	6,8,10,12, 15,20, 22, 25	[mm]
Radial misalignment	-4 to +4	-15 to +15	[mm]
Angular misalignment	-3 to +3	-8 to +8	[degrees]
Velocity	5, 10	5, 10, 20, 30	[mm/s]

- Acceptance criteria: 3/3 latches correctly captured with a residual deviation lower than the admissible tolerance of mechanism.
- Cases where the capture is triggered by the VICON motion capture system, and the HES based trigger.
- Cases with both platforms floating and one fixed to a wall are launched.





SIROM Air-bearing tests

Setup

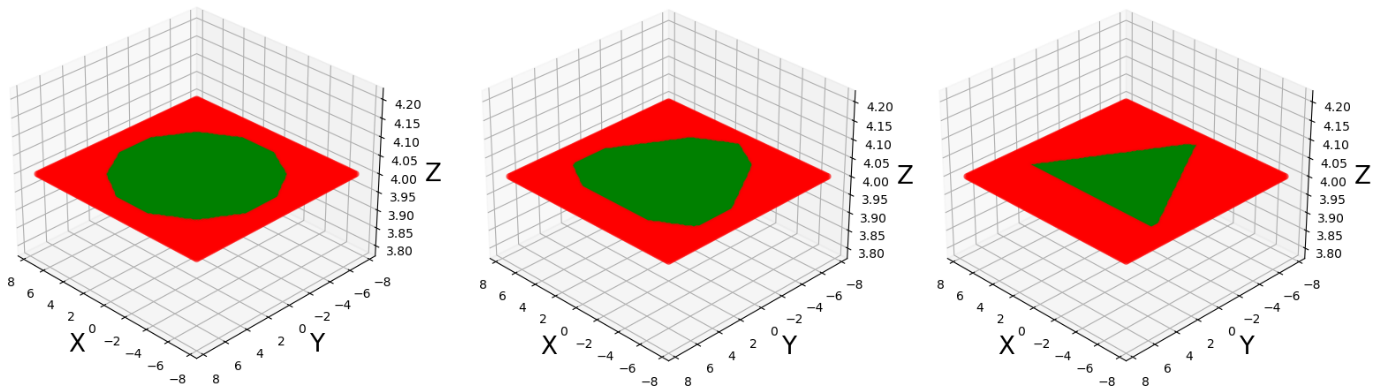
The air-bearing test explores one of the possible relative orientations with the flat plane.

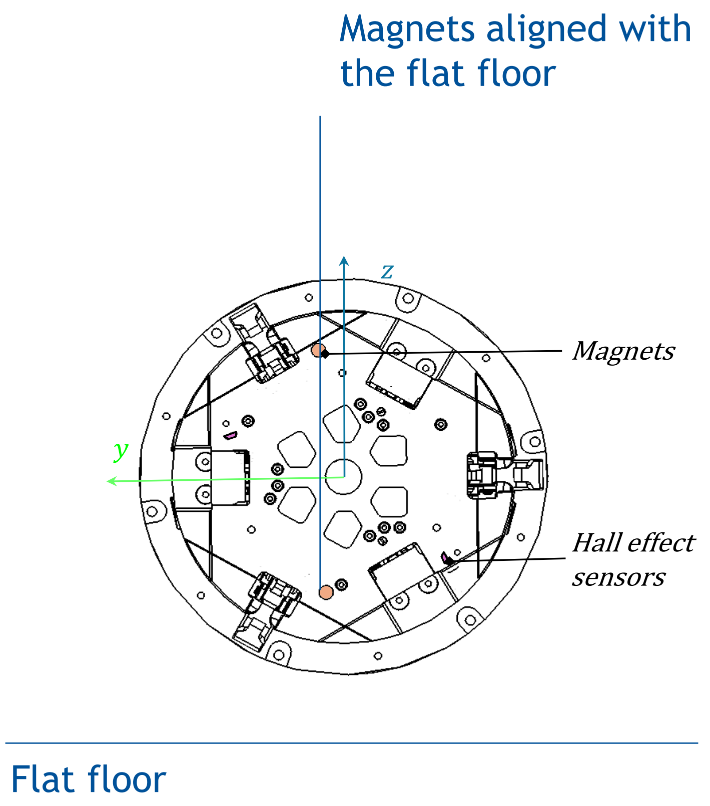
FOR RPY=0 Almost no influence

FOR RPY>1 Considerable influence

Capture range for different relative orientations obtained from a geometrical model(green= capture)

RPY = 0º. *RPY = 1º.* *RPY = 3º.*





SIROM Air-bearing tests

2 Setups

TEST 1-Case 10.4 Floating
(Good alignment / some drift)

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SIROM Air-bearing tests

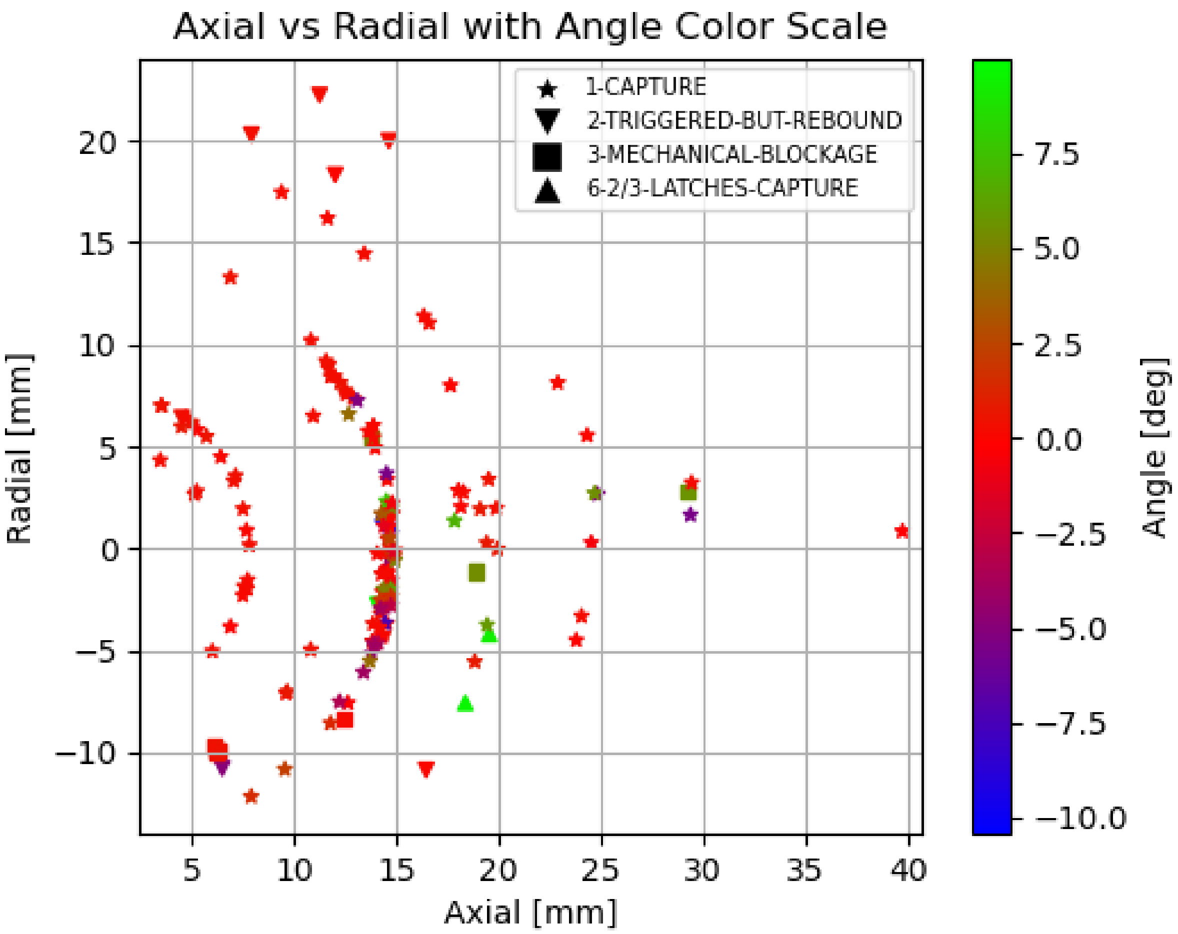
Results

- Originally expected capture range of +-6 mm and +/-3° worked effectively.
- SIROM can accommodate larger deviations from the ones presupposed from the initial geometrical models used to define the capture range.

Table .- Air-bearing test success rates

Range	Captured/Total cases	Capture rate [%]
< ±6 mm	96/100	96%
< ±10 mm	119/127	93.7%
< ±1°	92/97	94.9%
< ±3°	101/106	95.3%
< ±6 mm ∧ <±0.5°	54/55	98.2%
< ±10 mm ∧ <±0.5°	68/71	95.8%

Figure .- Air-bearing triggering conditions

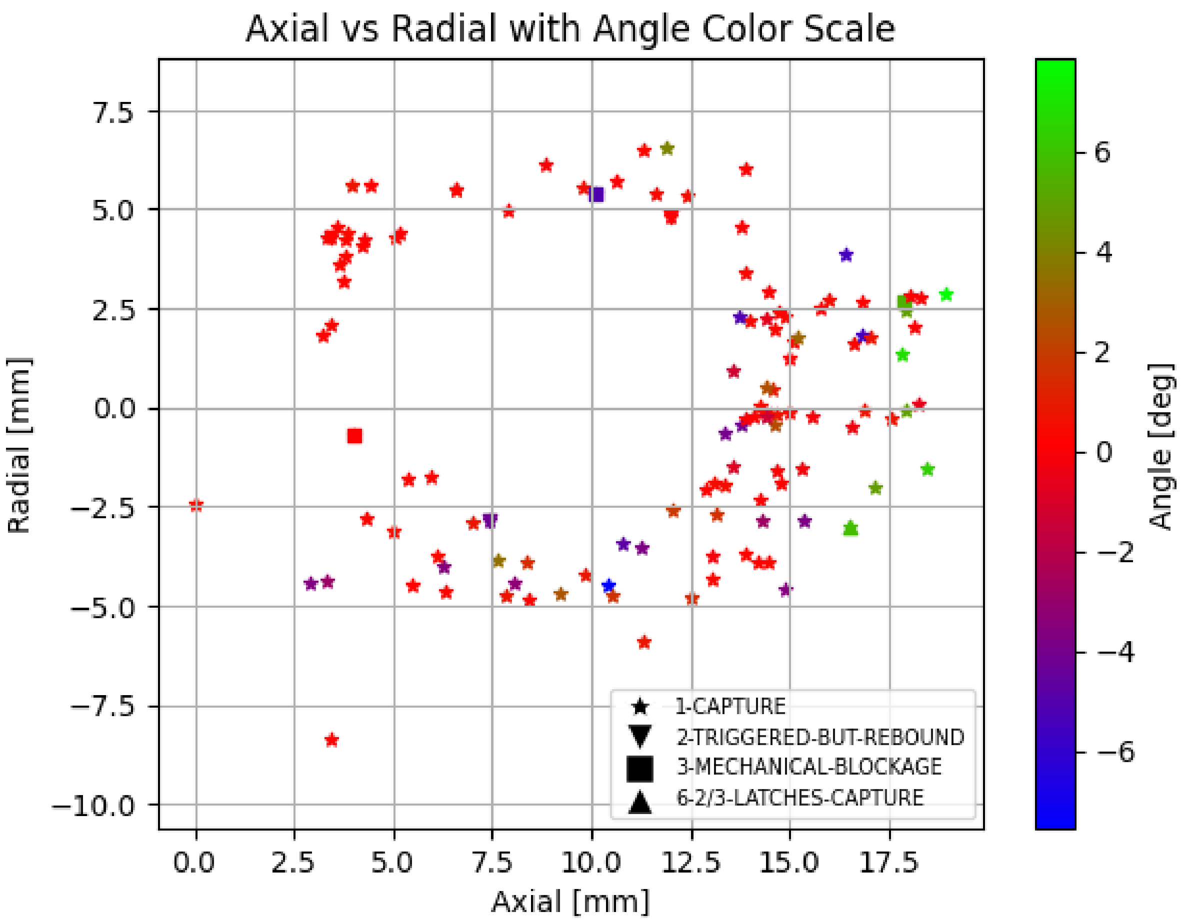


SIROM Air-bearing tests

Results

- Expected range of trigger was 13 to 15 mm .
- Divergent trajectories lead to delayed hall effect sensors activation:
  - Right Half of the graph: straight trajectories.
  - Left Half of the graph: lateral trajectories after rebound.
- 9 cases with conservative conditions and velocity 10 mm/s were performed using hall effect sensors trigger as capture trigger, with 100% of capture rate.

Figure .- Hall effect sensors trigger conditions



SIROM Air-bearing tests

Results

- Due to the orientation of SIROM with respect to the flat floor, SIROM allows for greater deviations with negative orientations.
- *It has to be noted that although SIROM can trigger the capture at almost 40mm axially, the first contact is produced closer than 13mm axially. (due to velocities up to 36mm/s).

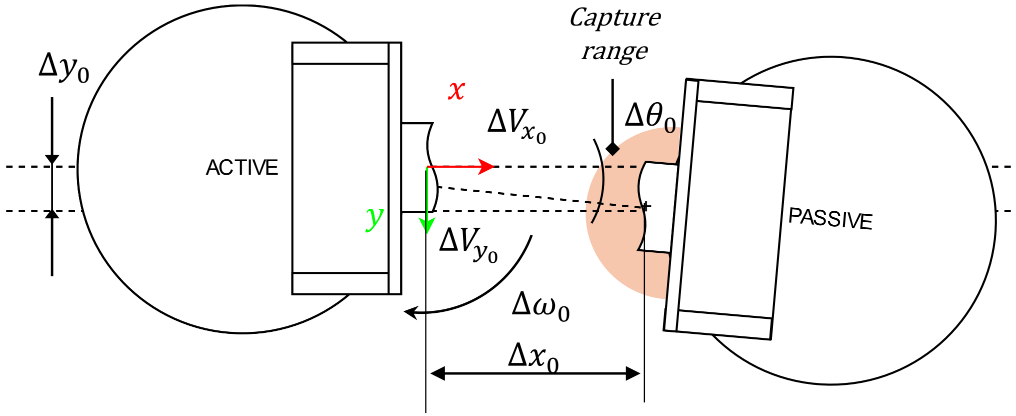
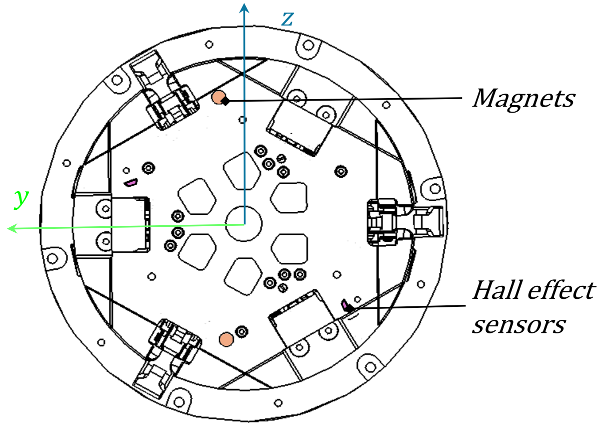


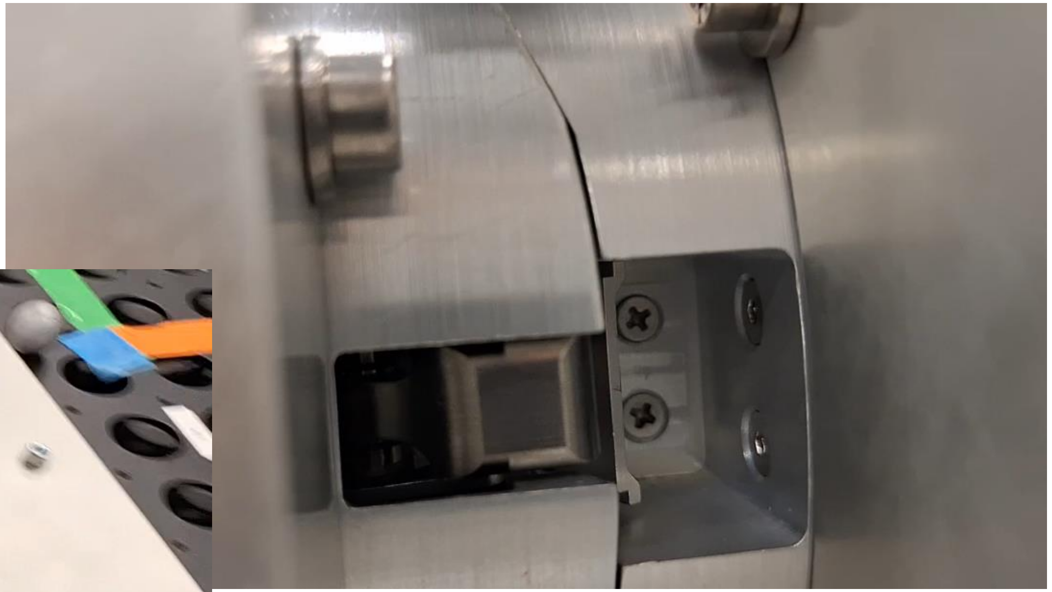
Table .- Trigger conditions

	Independent Values	Combined Values	Failure Limit Case
Δx [mm]	-39.7*	-13.1	-13.8
Δy [mm]	17.5	7.3	5.4
Δθ [deg]	-7.5	-5.2	5.1
Δvx [mm/s]	36.1	8.9	6.4
Δvy [mm/s]	-13.3	-2.8	-5.6
Δω [deg/s]	-0.1	0.1	-0.1



SIROM Air-bearing tests

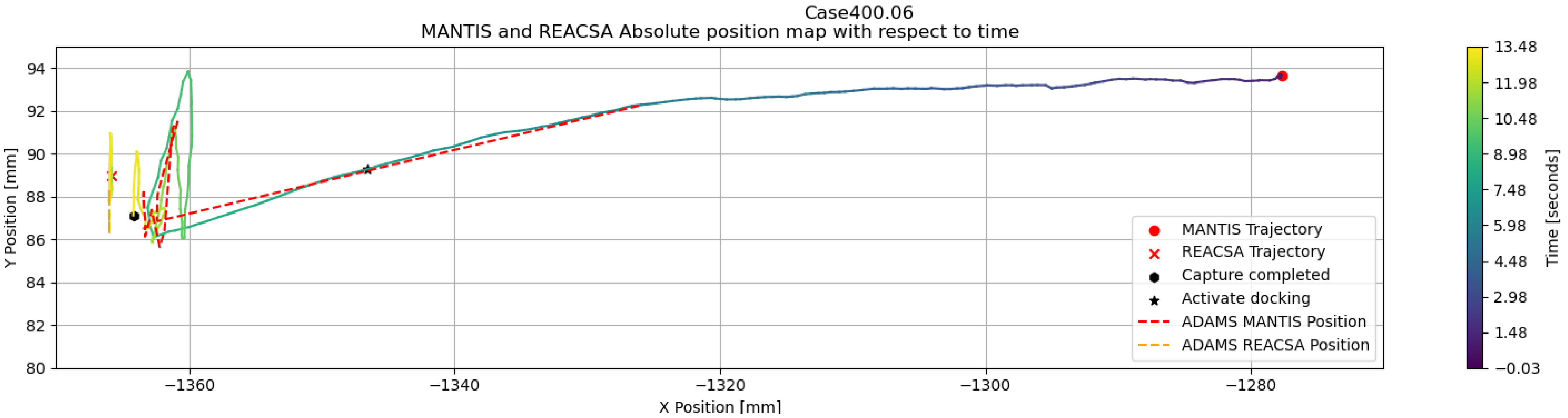
Results



SIROM Air-bearing tests

Correlation

- After visual observation of the trajectories, some are selected to linearize and correlate.
- Significant correlation success was achieved, accurately replicating trajectory changes post-rebound.
- Computational models exhibit stiffer behaviour than reality.



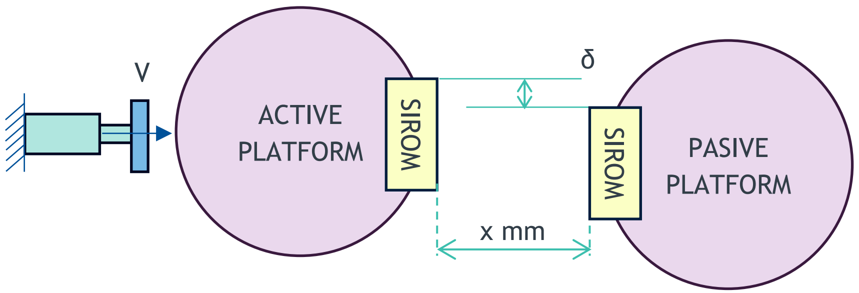
What´s next ?

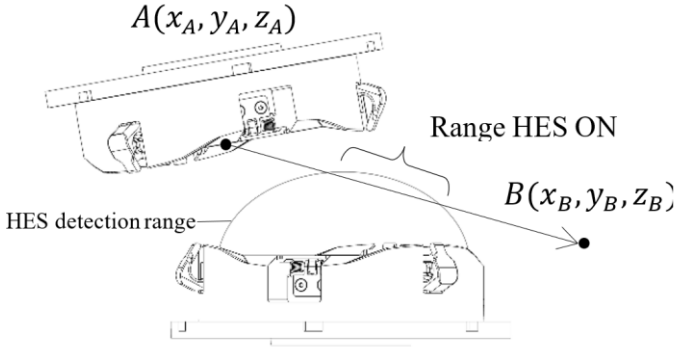
LESSONS LEARNED & CONCLUSIONS

Lessons Learned

- Air-bearing facilities are tremendously helpful to understand the dynamic behavior of a capture mechanism.
- Limitations
  - Acquisition systems error (order of 0.x mm)
  - Flat floor planarity results in irregular trajectories
  - Difficulty to repeat the exact same case.
- Therefore, repeat 3-4 times to observe the repeatability of the divergences on the trajectory.
- The capture problem is a dynamic problem. Being in a certain spot might not be deterministic of a successful capture, the trajectory might be too divergent.

It is a Montecarlo campaign!





Conclusions

The capture functionality common to SIROM families E, F and G in a 3DoF scenario was successfully tested.

- Within the baseline capture envelope of SIROM (±6mm and ±1.5º combinedly evaluated), a success rate of 98.55%
    - Next step: improve the tunning of the 3DOF and export to 6DOF models

The flexible tab offers a non-destructive solution for highly misaligned cases

- After the test campaign SIROM (183 cases) was functional.

The hall effect sensors serve as a capture trigger but understand the problem as static

- The performance during the test was successful in most of the cases.
    - Next step: Stewart platform additional tests to iterate on possible magnet sizes and positions. Still limited to static.

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