UNIVERSITÀ
DEGLI STUDI
DI PADOVA

Integrated navigation and docking systems for small satellites

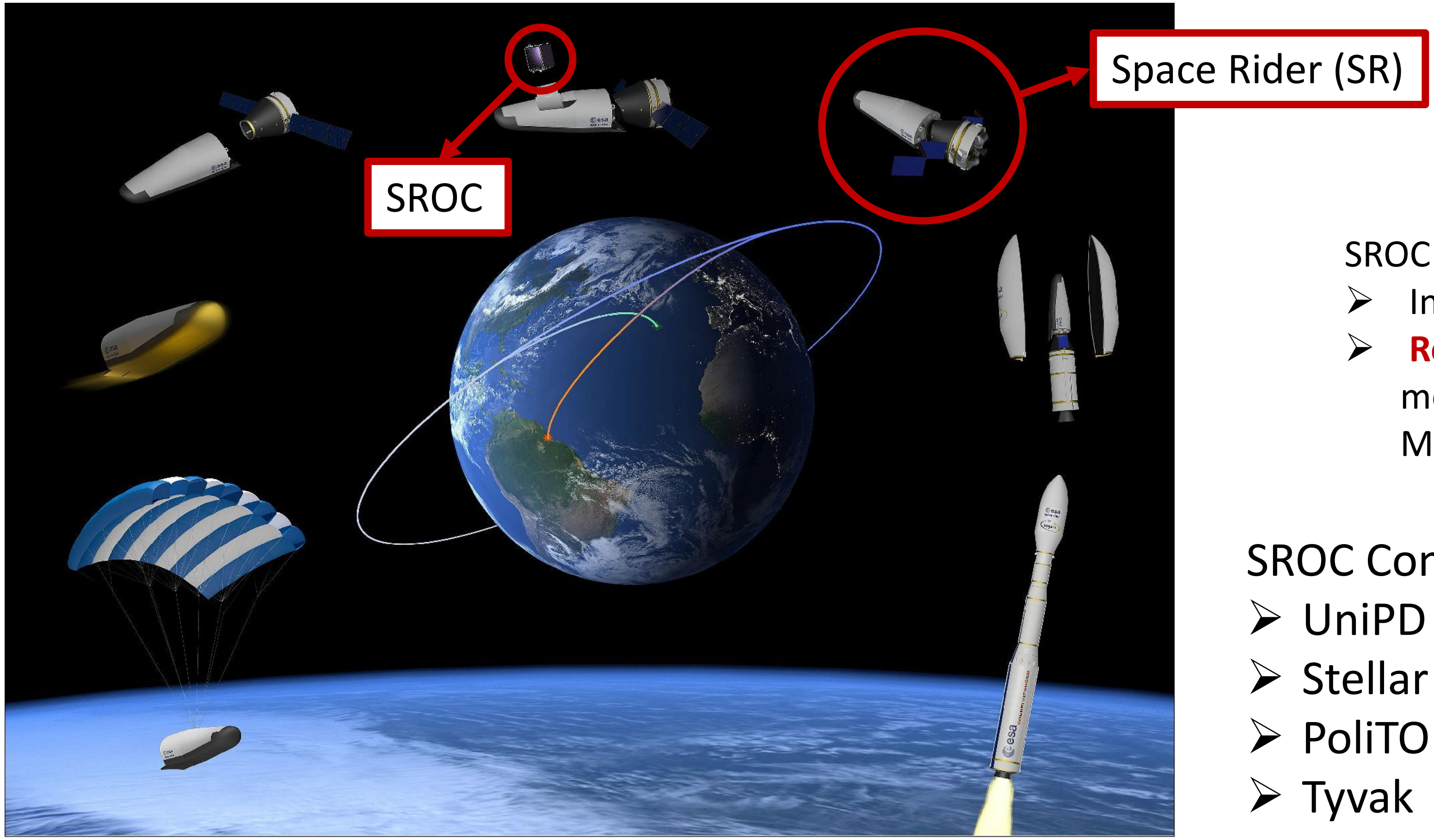
Martina Imperatrice - 39^{th} Cycle

Supervisor: Francesco Branz

Co-supervisor: Alessandro Francesconi

Admission to the 2^{nd} year - 9 October 2024

- Space Rider Observer Cube (SROC)



SROC will perform:

- Inspection of SR
- **Rendezvous and docking** through a docking mechanism with the MPCD located in the MPCB of Space Rider

SROC Consortium:

- UniPD
- Stellar Project

Development of the docking system **DOCKS**

- PoliTO
- Tyvak

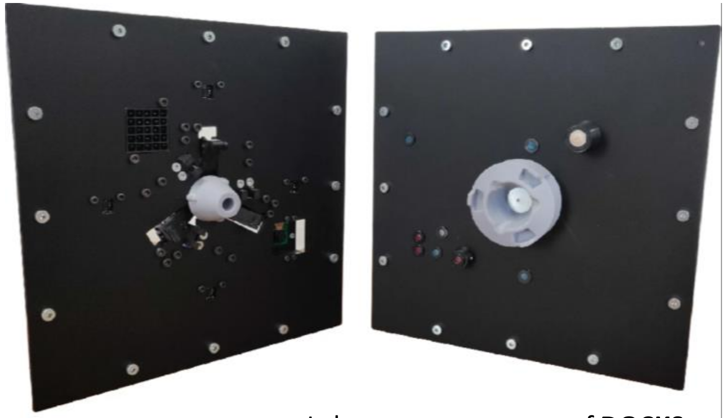
Development of SROC CubeSat

Doctoral work objective

- **Objective**: Development and testing of the BREADBOARD MODEL and the advanced MODELS of the docking system DOCKS:

1. Breadboard Model
2. Engineering Qualification Model (EQM)
3. Proto-Flight Model (PFM)

(2–3) with **Stellar Project** collaboration



Laboratory prototype of **DOCKS**

DOCKS Laboratory Prototype → **Space System (Ready to fly)**

DOCKS schedule

Last year schedule:

	First year												Second year												Third year											
	Nov.23	Dic.23	Jan.24	Feb.24	Mar.24	Apr.24	May.24	Jun.24	Jul.24	Aug.24	Sep.24	Oct.24	Nov.24	Dic.24	Jan.25	Feb.25	Mar.25	Apr.25	May.25	Jun.25	Jul.25	Aug.25	Sep.25	Oct.25	Nov.25	Dic.25	Jan.26	Feb.26	Mar.26	Apr.26	May.26	Jun.26	Jul.26	Aug.26	Sep.26	Oct.26
UniPD																																				
Stellar Project																																				
Period Abroad																																				
DOCKS Phases			B2						C										D																	
Model											EQM							PFM																		
DOCKS Milestones						PDR						CDR	MRR					SIR		TRR				QAR and FR												

Current schedule:

	First year												Second year												Third year											
	Nov.23	Dic.23	Jan.24	Feb.24	Mar.24	Apr.24	May.24	Jun.24	Jul.24	Aug.24	Sep.24	Oct.24	Nov.24	Dic.24	Jan.25	Feb.25	Mar.25	Apr.25	May.25	Jun.25	Jul.25	Aug.25	Sep.25	Oct.25	Nov.25	Dic.25	Jan.26	Feb.26	Mar.26	Apr.26	May.26	Jun.26	Jul.26	Aug.26	Sep.26	Oct.26
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Model																								EQM							PFM					
DOCKS Milestones								PDR																	CDR	MRR					SIR		TRR	QAR and FR		

First year activities

1. Selection of sensors and actuators compatible with vacuum and the expected temperatures in the operational scenario foreseen for the DOCKS docking system.

2. Design, setup, and execution of a test in a thermal-vacuum chamber to test the components selected in point 1.

3. Numerical simulations of the closure mechanism dynamics to evaluate the impact of friction and other dynamic phenomena (with software Adams View).

4. Multibody impact numerical simulations to support the design of a damper aimed at reducing impact loads during the docking maneuver between the two modules (with software Adams View).

5. Design and implementation of the experimental setup (preliminary phase) to validate the results of the simulation, using a floating module on a low-friction table.

6. Participation in seminars and courses offered by the PhD program on topics related to the research activity.

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From prototype to DOCKS-Mec BB

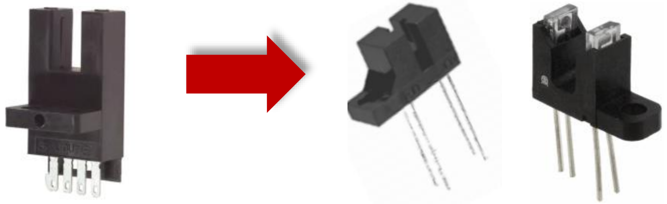
DOCKS Mechanical Breadboard

Laboratory prototype of DOCKS

1. Sensors and actuators upgrade

1. Selection of sensors and actuators compatible with vacuum and the expected temperatures in the operational scenario foreseen for the DOCKS docking system.

Acknowledgment sensors



Omron EE-SX673 → Optek OPB 820 and OPB 825

Phototransistors / IR LED

Osram SFH309FA — SFH4544

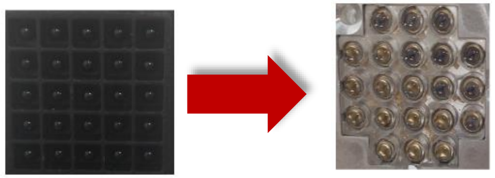
Optek OP800B — OP133

Vishay VEMT2520X01 — VSMY2850GX01

Actuator

Faulhaber Motor AM2224
and Encoder Faulhaber PE22-120

Matrix sensor



Osram SFH309FA → Optek OP800B

ToFs

Pololu Vl6180x — DF Robot Vl6180x

Visible LED

APEM
Q8F5BXXB12E and
Q8F5BXXHR12E

2. Vacuum chamber test

2. Design, setup, and execution of a test in a thermal-vacuum chamber to test the components selected in point 1.

Test parameters

Results:

3. Claw simulations

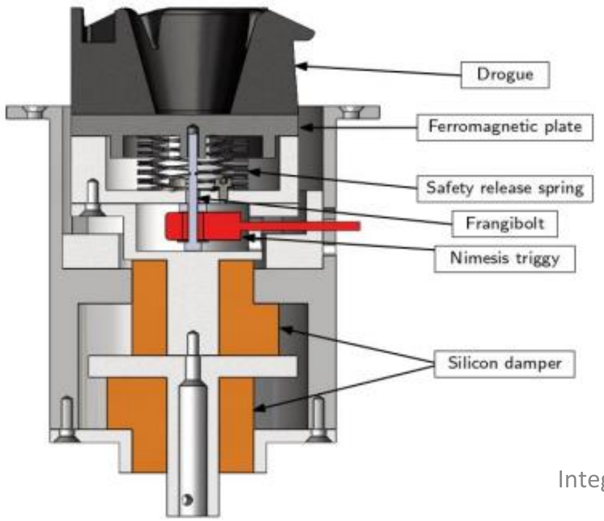
3. Numerical simulations of the closure mechanism dynamics to evaluate the impact of friction and other dynamic phenomena (with **software Adams View**).

4.1 Impact simulations

4. Multibody impact numerical simulations to support the design of a damper aimed at reducing impact loads during the docking maneuver between the two modules (with **software Adams View**).

Objectives:

1. Impact loads analysis to define the silicon elements stiffness
2. Define the misalignment tolerated by DOCKS.
3. Evaluate the impacts and misalignment tolerated obtained increasing the drogue degrees of freedom.

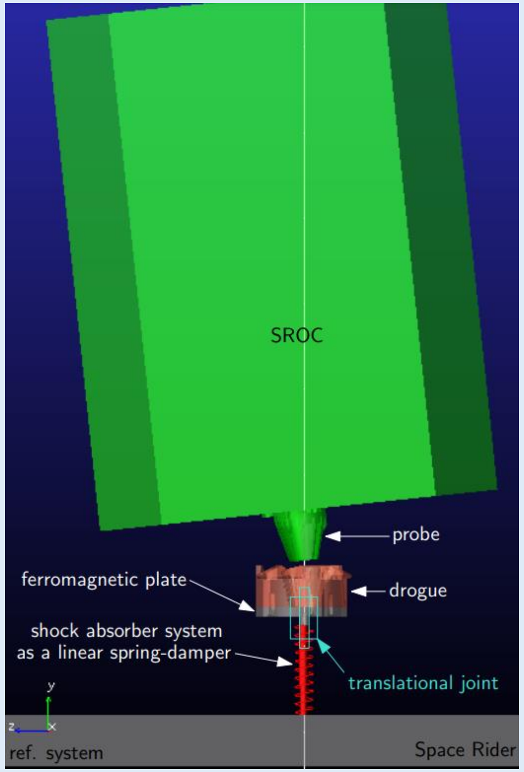


Hypotesis: the damping system is modelled as a linear spring-damper, and the drogue can move only in the vertical direction (throught the use of a translational joint)

1. Evaluate impact loads and limit approach velocity during the docking manoeuvre, varying
   a) $k_s = [1 \div 1000]$ N/mm and $v = [2.5, 5, 7.5, 10, 50]$ mm/s.
   b) $m_{SROC} = [16 \div 26]$ kg and $v = [2.5, 5, 7.5, 10, 50]$ mm/s.

Results 1:
At spring stiffness $k_s = 50\ N/mm$ and approach velocity of $5\ mm/s$, the minimum of the impact force is obtained ($< 40\ N$)

2. Tolerated misalignments



Fixed values:

$m_{SROC} = 24kg$

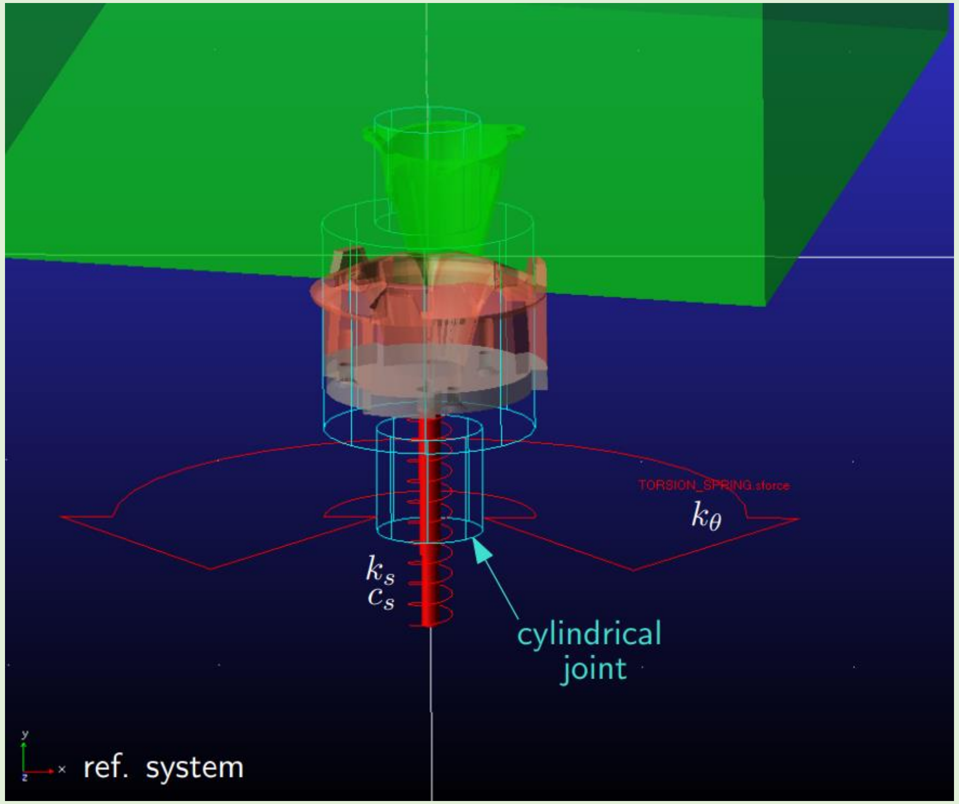
$k_s = 50\ N/mm$

$v_{SROC} = 5\ mm/s$

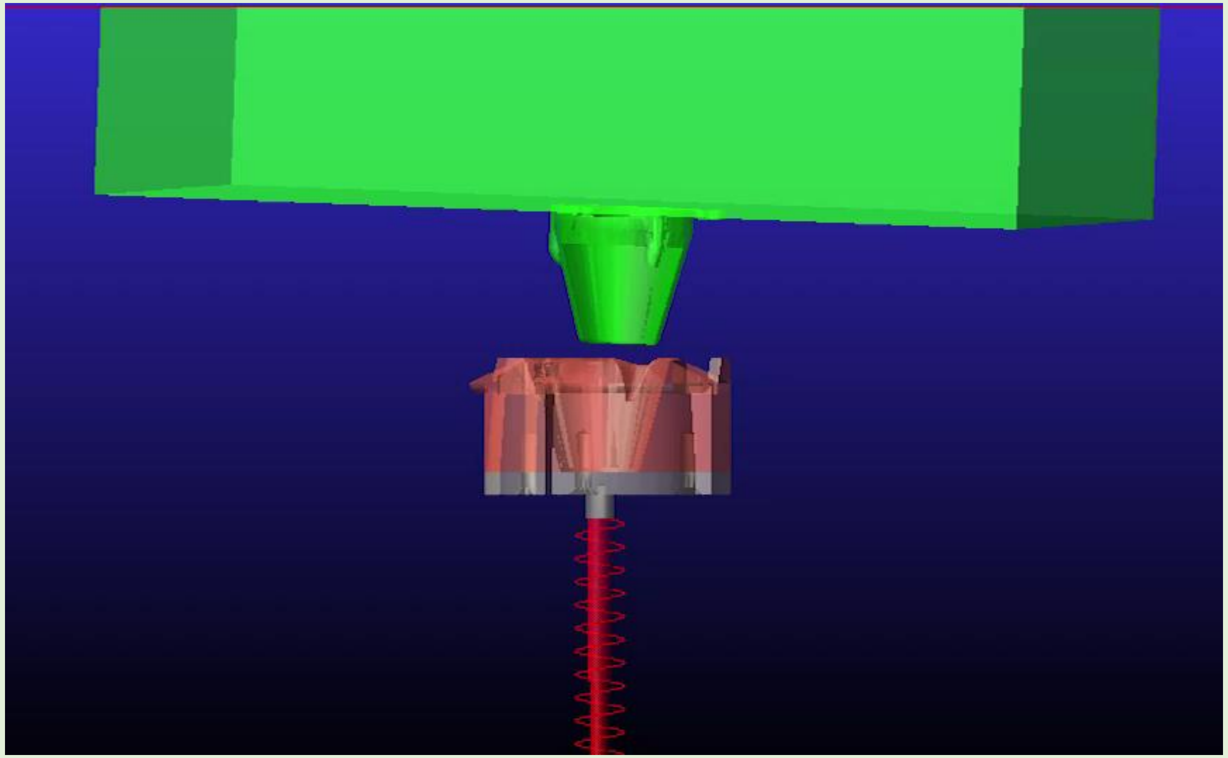
Results 2:

Type	Misalignment
Linear (x – z plane)	8 mm
Angular (x or z axis)	10 deg
Combined (linear + angular)	± 6 mm, ± 5 deg

3.1 Drogue with 2 DoF

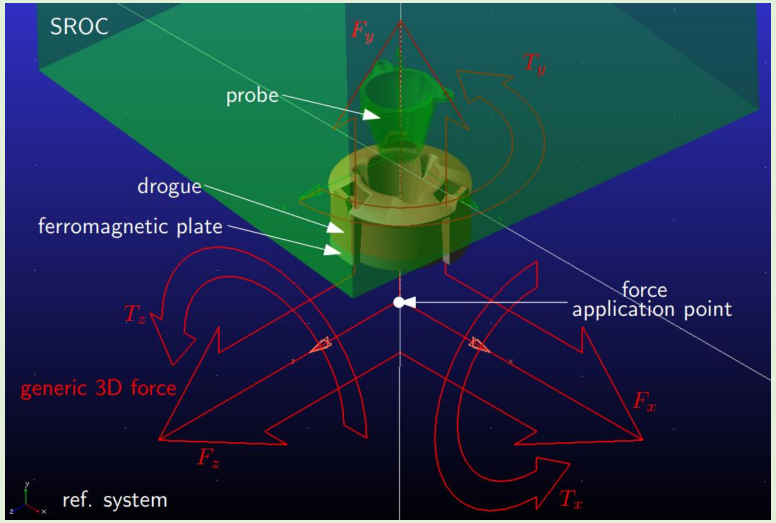


Video parameters
- Misalignments:
  - 6 mm
  - 2deg@x, 1deg@z, 2deg@y
- Approach vel. 5 mm/s



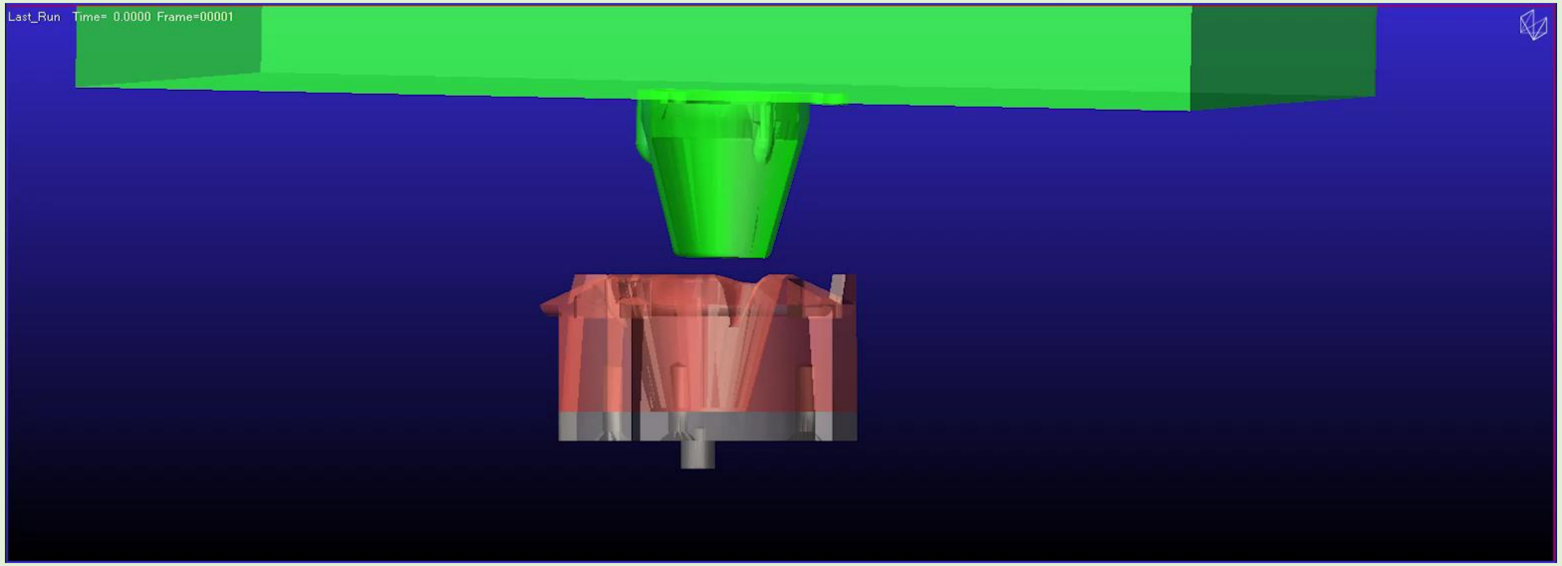
<u>Results 3.1</u>: results from 1 and 2 confirmed

3.2 Drogue with 6 DoF



$$F_x = -k_x \cdot x - c_x \cdot \dot{x}$$
$$F_y = -k_y \cdot y - c_y \cdot \dot{y}$$
$$F_z = -k_z \cdot z - c_z \cdot \dot{z}$$
$$T_x = -k_{T_x} \cdot \alpha_x - c_{T_x} \cdot \dot{\omega}_x$$
$$T_y = -k_{T_y} \cdot \alpha_y - c_{T_y} \cdot \dot{\omega}_y$$
$$T_z = -k_{T_z} \cdot \alpha_z - c_{T_z} \cdot \dot{\omega}_z$$

Video parameters
- Misalignments:
  - 6 mm
  - 2deg @ x,z
- Approach vel. 5 mm/s



Results 3.2: results from 1 and 2 confirmed

5.1 Preliminary test

5. Design and implementation of the experimental setup (preliminary phase) to validate the results of the simulation, using a floating module on a low-friction table.

5.2 Test results

Future work

1. Improve the dynamic testing
    a) Reliable
    b) Repeatable
    c) Structural stiffening

2. Measurement of exchanged loads and comparison with simulations

3. Performance of navigation algorithm tests

4. Continue with the development of DOCKS advanced models

Thanks for your attention

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