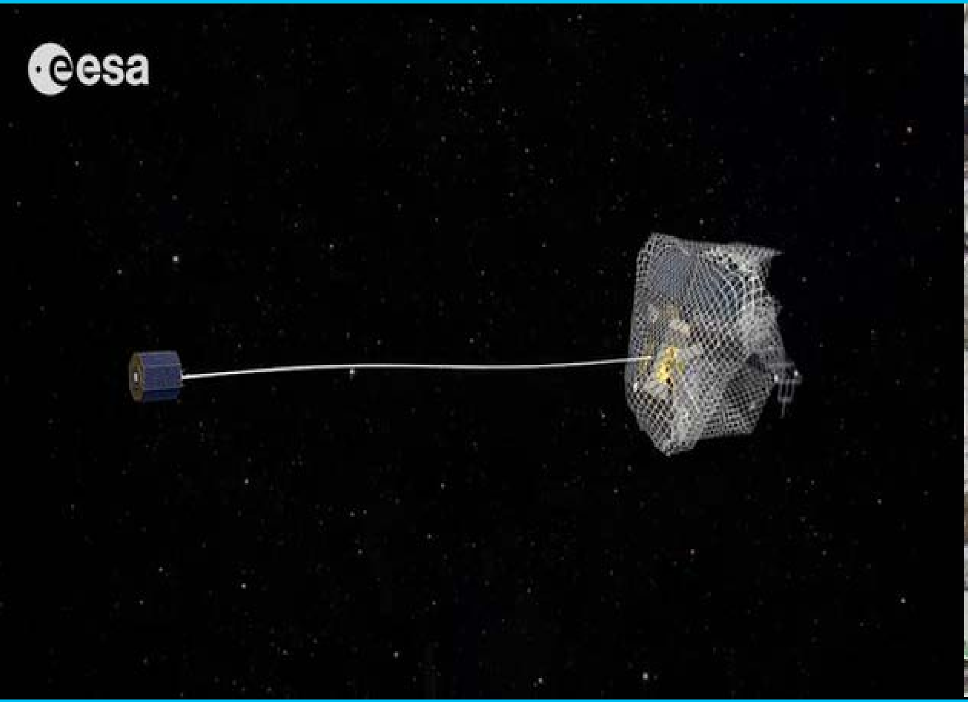
ISS Free Flying Experiment for Active Debris Removal

Cranfield UNIVERSITY

gmv INNOVATING SOLUTIONS



May 24, 2016

ESA Cleanspace Workshop

Project Introduction

- The objective of the study is to:
  - define requirements/constraints,
  - Highlight the limitations of free-flying experiments in ISS, and
  - create a test-plan,
- for a free flying ISS experiment that controls two spheres or cubes connected to each other by a tether, simulating the Target Stabilisation Phase and the Disposal phase of a debris captured by the e.deorbit mission using a net.

Task 1
Study ISS free flying experiment capabilities

→

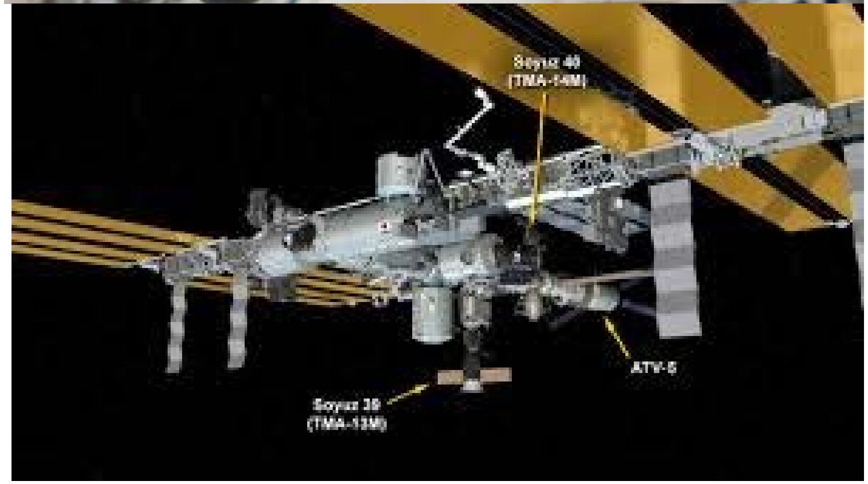
Task 2
Define the ISS free flying ADR experiment

→

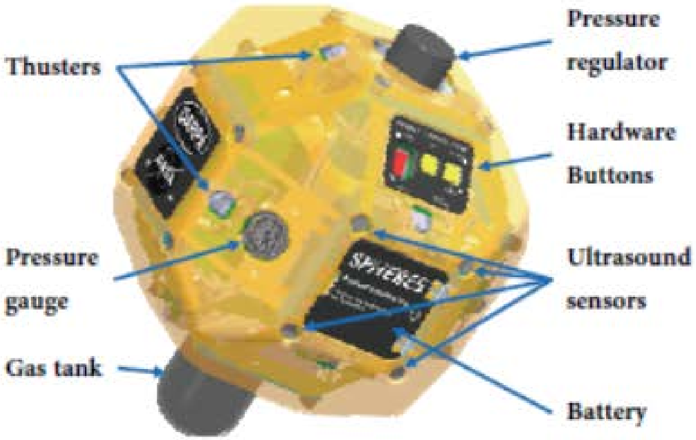
Task 3
Create a test plan and test requirements

Study ISS free flying experiment capabilities

- 6 month activity
- Study the capabilities of free flying ISS experiments already conducted
- Analyse constraints (e.g. limited space, short experiment duration, etc.), failures, deficiencies (resolution of accelerometers, etc.), relatively high MIB of thrusters etc., applicable to those experiments
- **Propose ADR free flying ISS experiments**
- **Use results for e.Deorbit mission**



SPHERES Specification



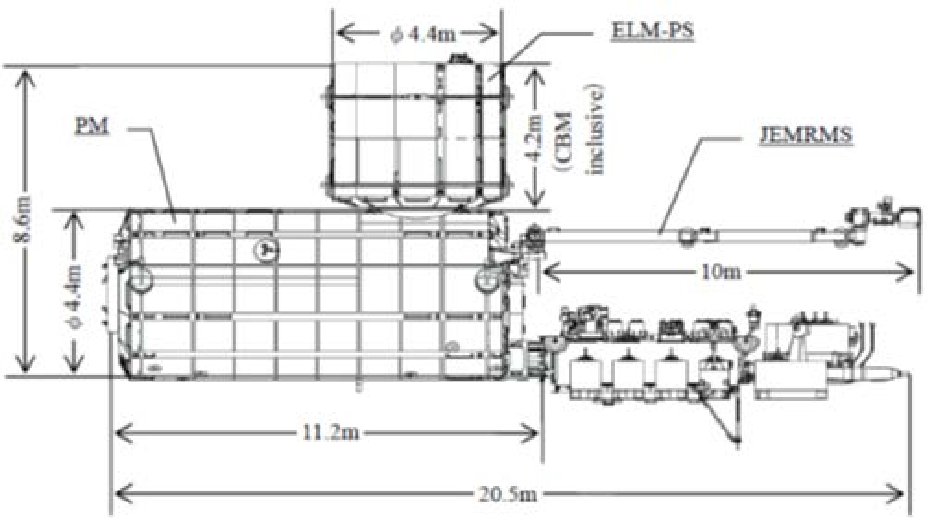
Property	Value
Diameter	$0.22m$
Mass (with tank and batteries)	$4.3kg$
Max linear acceleration	$0.17m/s^2$
Max angular acceleration	$3.5rad/s^2$
Power consumption	$13W$
Battery lifetime	$2h$

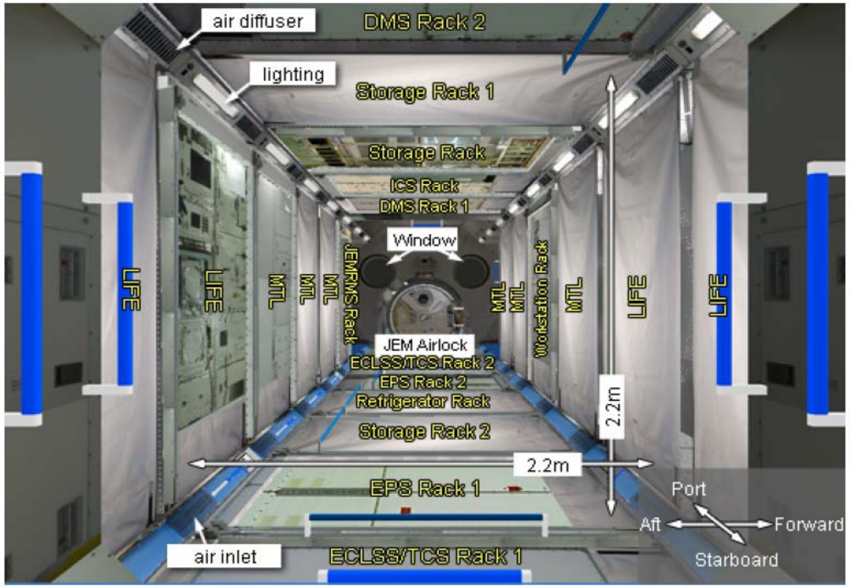
- SPHERES are football-sized nano-satellites, currently three aboard the ISS and on ground respectively
- The built-in navigation system consists of a custom pseudo-GPS based on ultrasound beacons and sensors.
- The beacons are located at the borders of the test volume such as the walls of the Japanese Experiment Module (JEM).
- The sensor fusion is done by an Extended Kalman Filter (EKF), reaching a precision in the vicinity of 10^{-3} m

Possible ISS/SPHERES tests for ADR

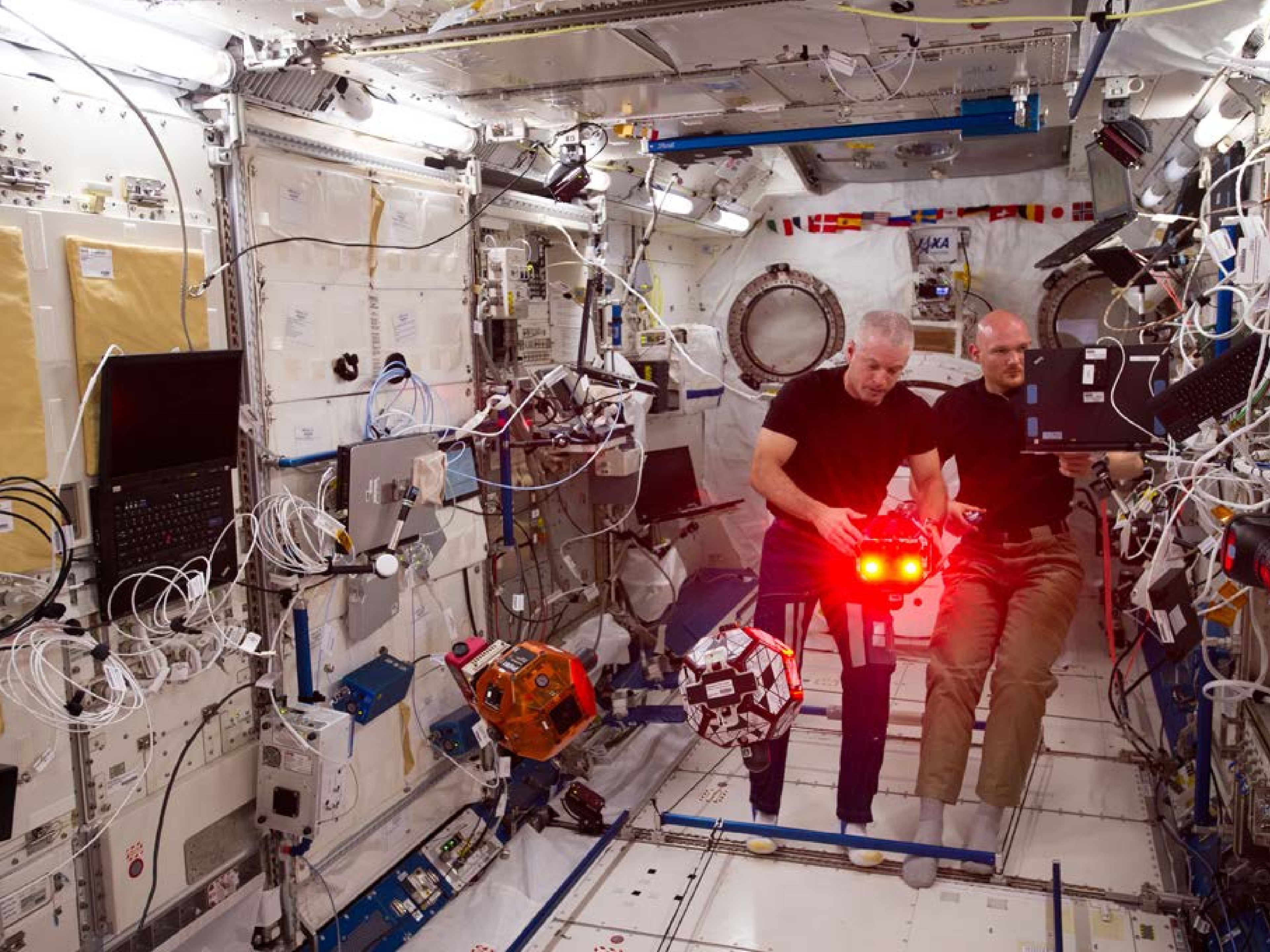
- Precision rendezvous-docking, close approach
- Sensor fusion
- Formation flying with debris (co-rotation)
- Capture of uncooperative targets (e.g. robotic arm, harpoon, net)
- Towing of debris with tether
- Target (debris) detection and characterisation (rotation rates, ranging)
- Enhancement of SPHERES with ADR related technology/sensors such as LIDAR sensors
- Tether experiments using SPHERES planned for 2016 on ISS

ISS Modules/Testing

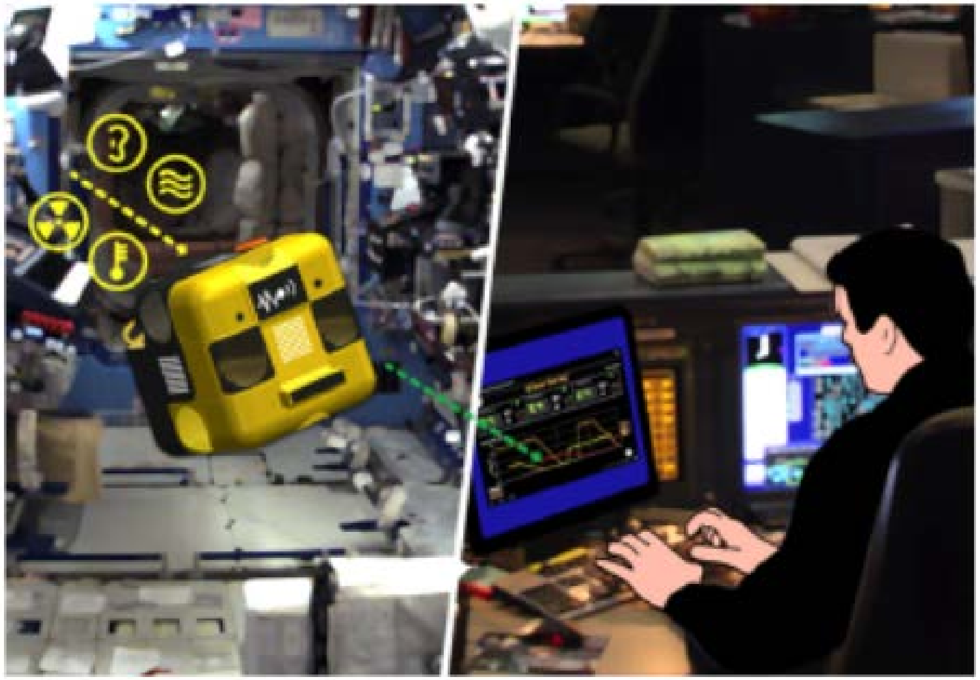


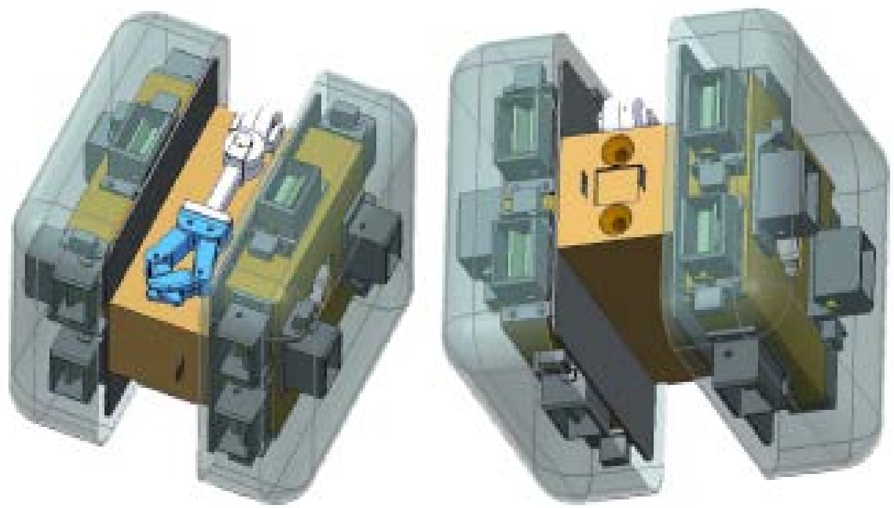


- The KIBO PM module is one of the largest volumes on ISS and the current volume set for SPHERES experiments is 2 m^3.
- Initial research and discussions with NASA/Ames which handles/manages ISS experiments indicates that the volume for experiments can potential increase to **more than 2 x 2 x 6 m (24 m^3) for a short ADR test campaign**


JAXA

SPHERES Follow-Up: Astrobee
A new free-flyer on ISS

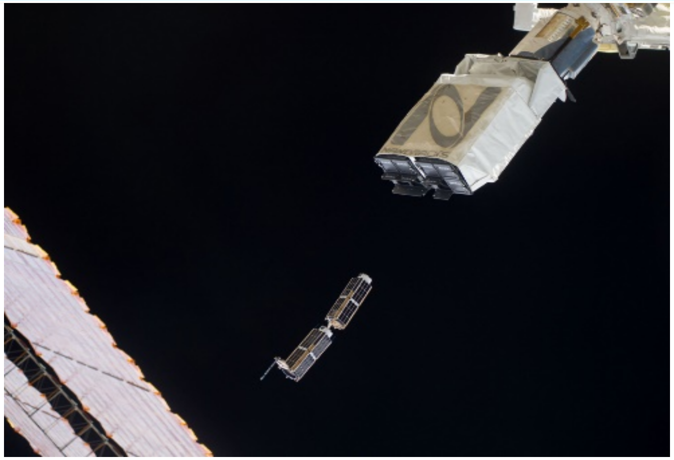




- Developed by NASA Ames, to be launched to ISS in 2017
- Better performance (attitude/position) than SPHERES
- Can be used for formation flying/ADR experiments
- Easy to adapt for ADR payloads: tethers, grippers, GNC modules

European Free-flyer technology

- The last decade has seen the design, manufacture, testing and successful operation of many nanosatellites or ‘cubesats’ with full 3-axis control, high accuracy pointing (sub-degree), propulsion capabilities (cold gas, colloid, MEMS) and with rendezvous and docking capabilities
- Off the shelf technologies exist which can be used to design a future ISS internal or external free-flyer set of cubesats which can perform experiments inside the ISS or in the vicinity of the ISS and return to the ISS/dock after the end of running experiments such as for ADR.

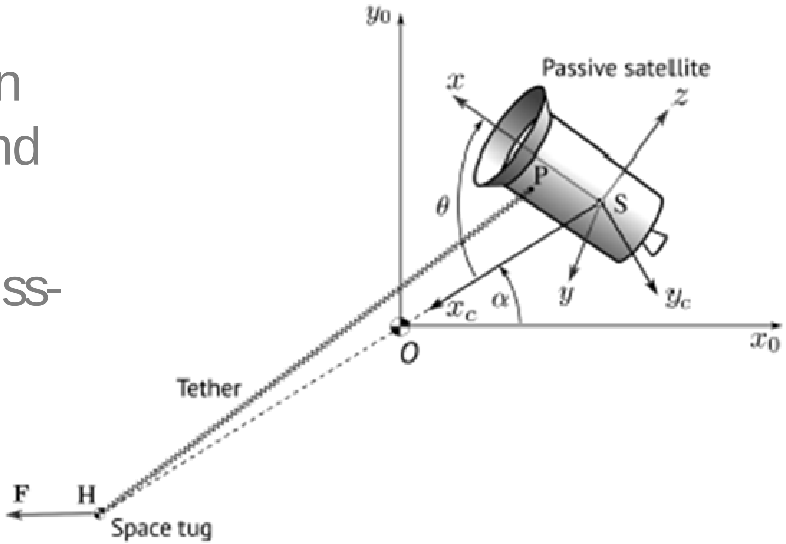


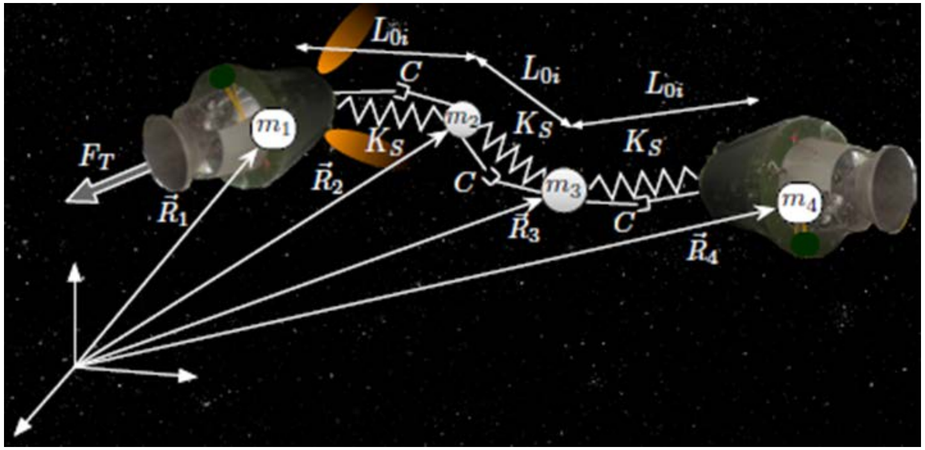
Free Flying ISS Experiment Constraints

- There are several constraints which need careful consideration when one wants to perform the free flyer experiments using the MIT SPHERES on-board the ISS:
  - SPHERES thruster capabilities
  - Limited space/volume available
  - Limited time available for the experiments/astronaut support
  - SPHERES navigation system performance
- Analysis of the constraints is supported with the simulation results showing their impact on the design of the experiments.
- A simple MATLAB/Simulink ISS/Spheres/ADR simulator has been developed to analyse the above constraints and to analyse/evaluate the possibility of realistic ADR experiments using SPHERES on the ISS

ADR Scenario:
Passive satellite/space tug Dynamics

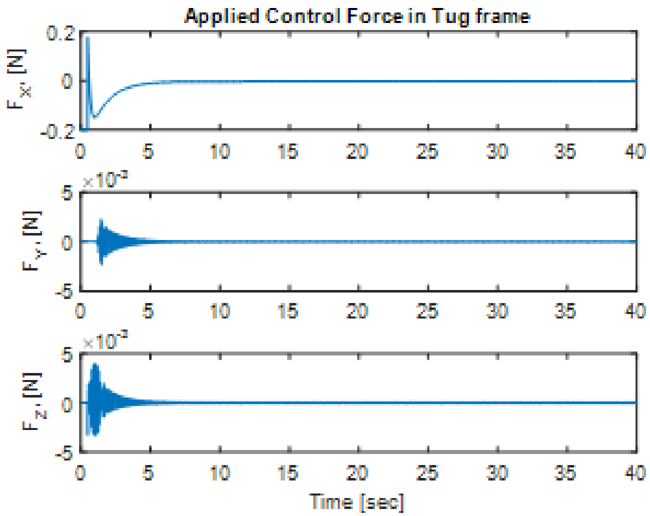
- Mission Concept: Once the tether is attached to the target, we fire the main thrusters to lower the orbit's perigee and speed up the atmospheric re-entry.
- Tether parameters (length, stiffness, cross-section, damping) influence on the dynamics when the *constant thrust* is applied have been investigated.
- Tether discretized into 2 point masses (3 links)
- Stiffness and damping included
- Tether force is 0 when there is slack



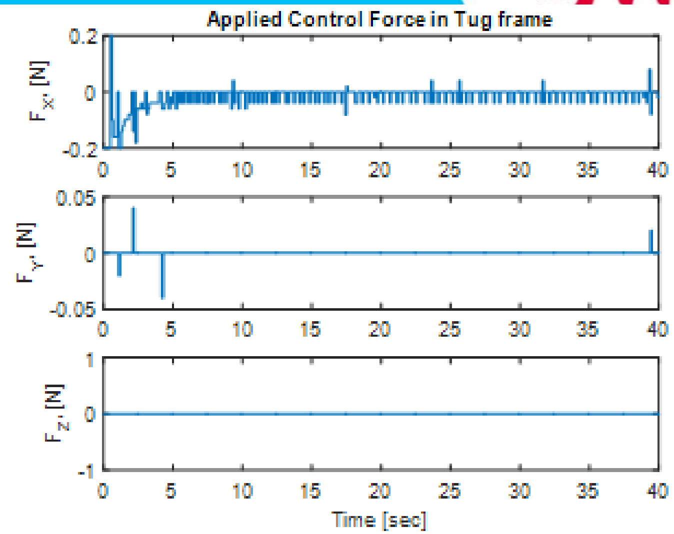


Thrust Limitation Simulation (i)

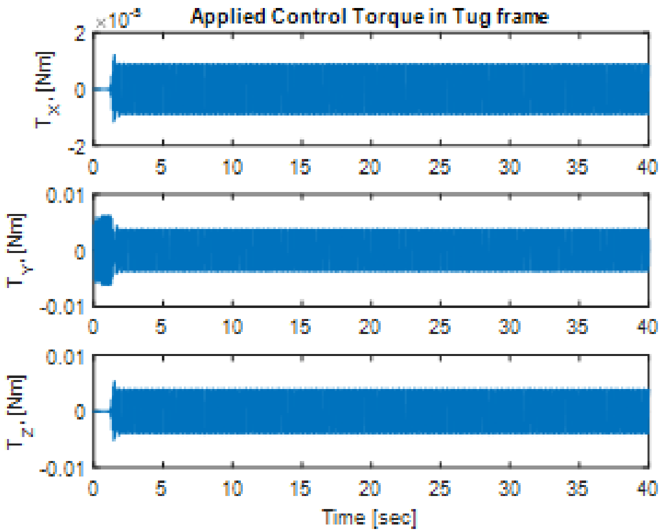
PWM and thrusters quiet time included in (b) and (d)



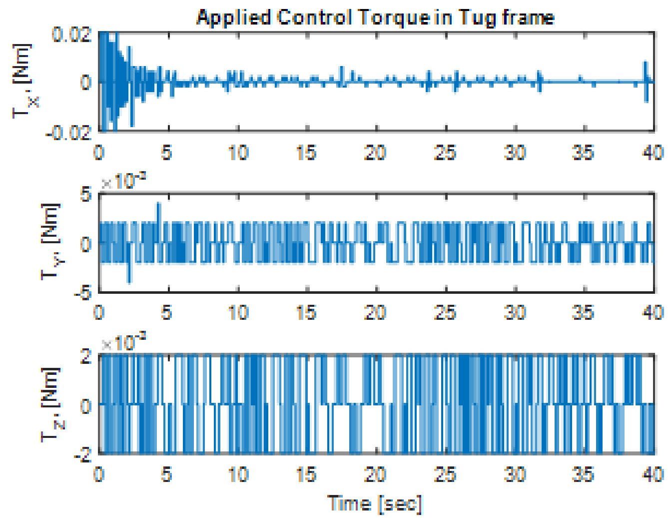
(a) No Thrust Limitations



(b) With Thrust Limitation



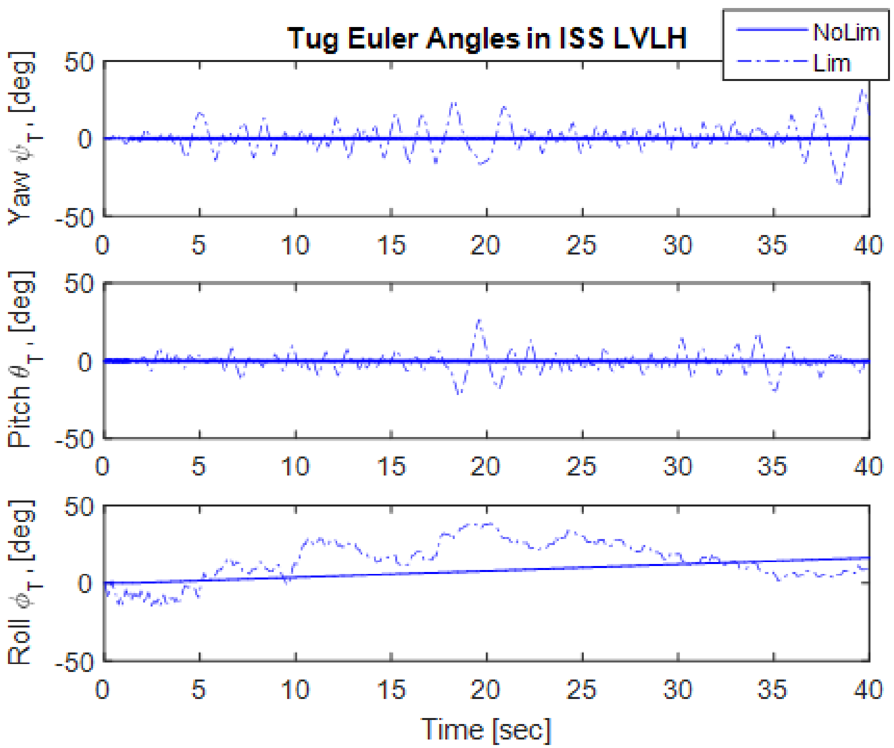
(c) No Thrust Limitations

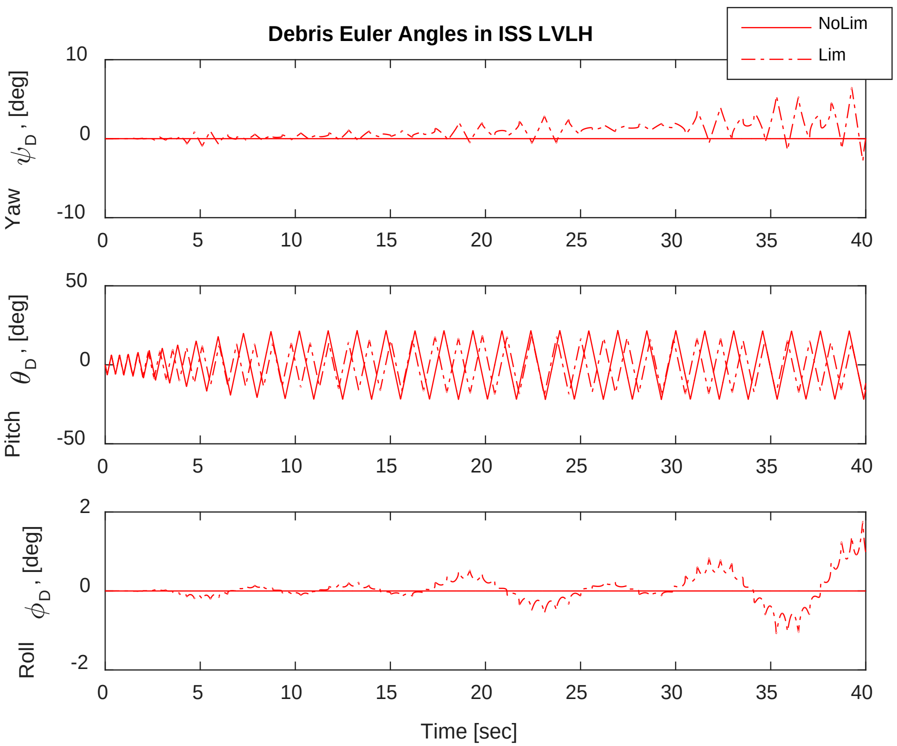


(d) With Thrust Limitation

Thrust Limitation Simulation (ii)

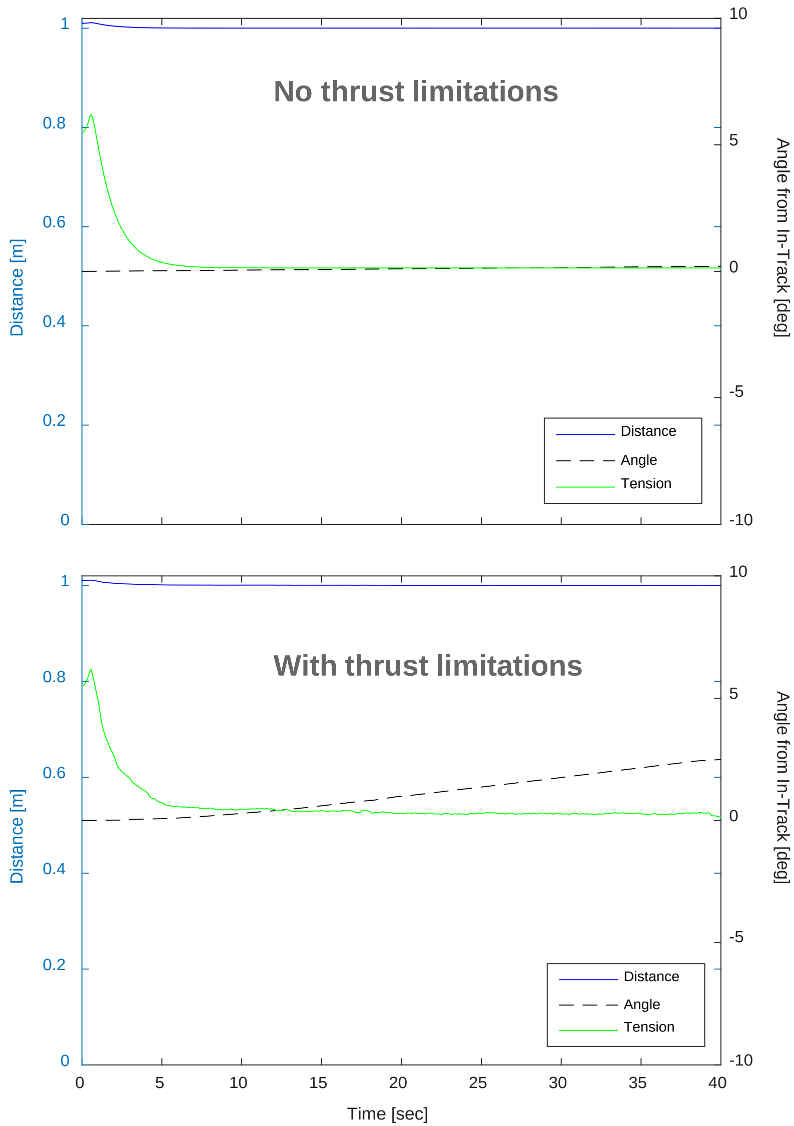
Attitude of the Tug and Debris in ISS frame

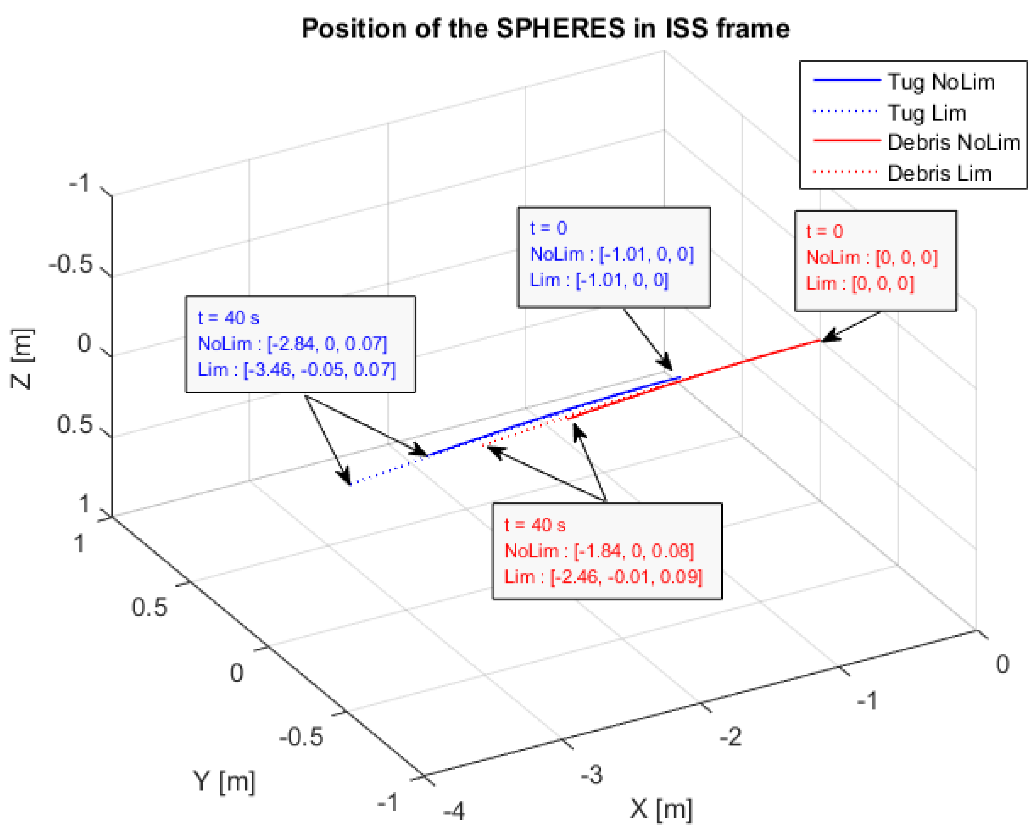




Thrust Limitation Simulation (iii)

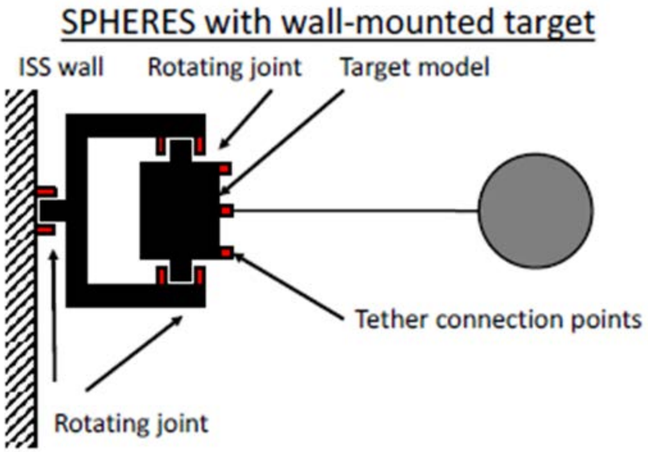
Relative distance, tension and global position in ISS frame





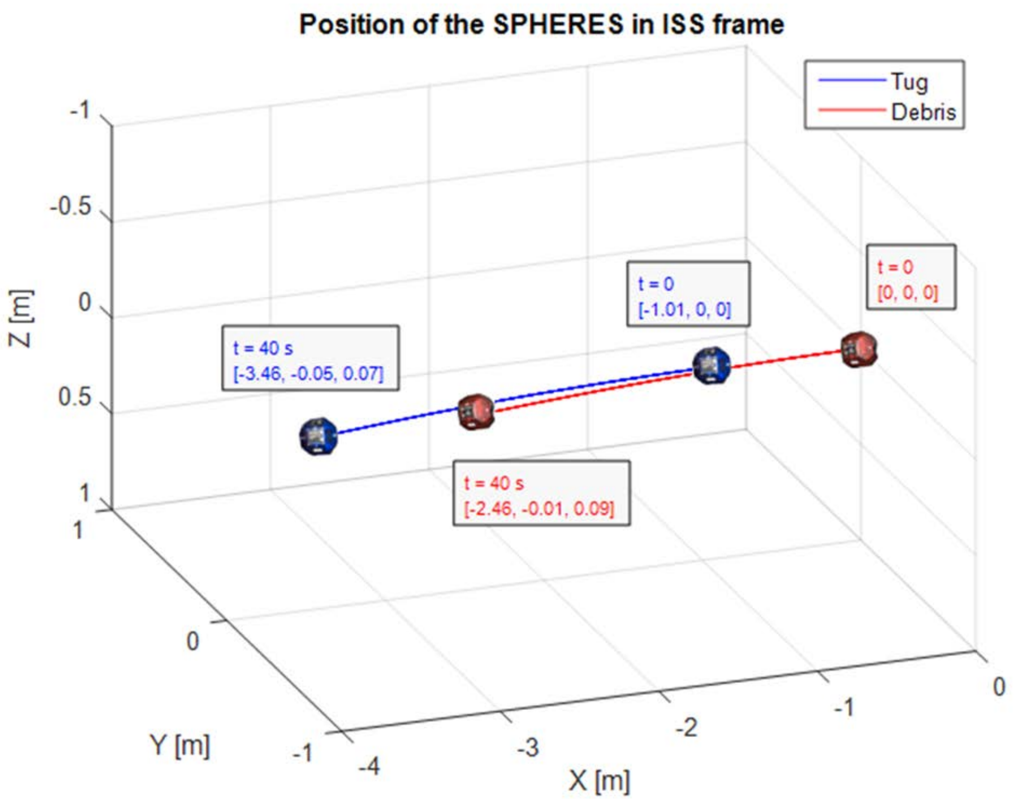
Limited Volume/Time Simulation

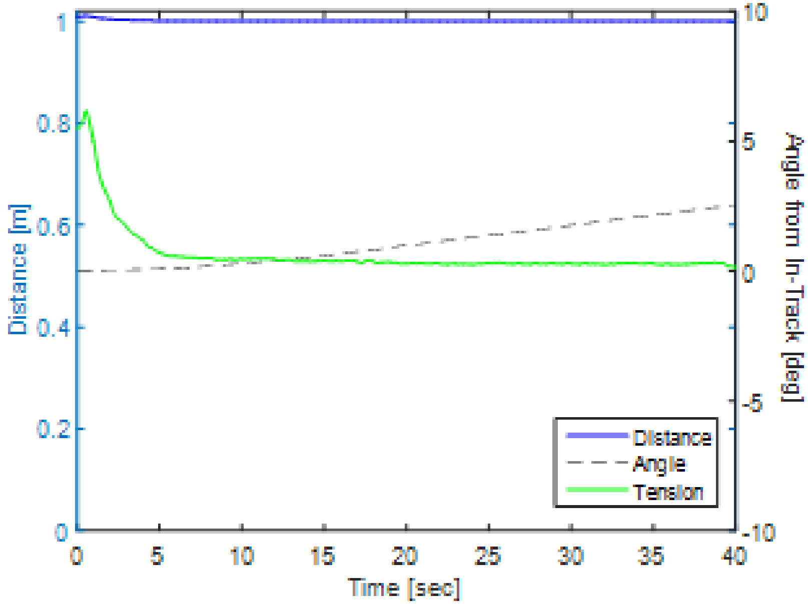
- SPHERES experiments are proposed to take place in the Japanese 'KIBO' module on the ISS.
- The current available volume is 2 m^3 with the potential to increase to 2 m x 2 m x 6 m (24 m^3).
- Using a larger volume is preferable, since it allows for better fidelity of the analysed scenario.
- When the limited space is of crucial importance, the tug SPHERE can be attached to the wall-mounted target SPHERE using a set of gimbals with active joints
- The target SPHERE can be given an initial attitude and angular rate with a very high level of precision and repeatability



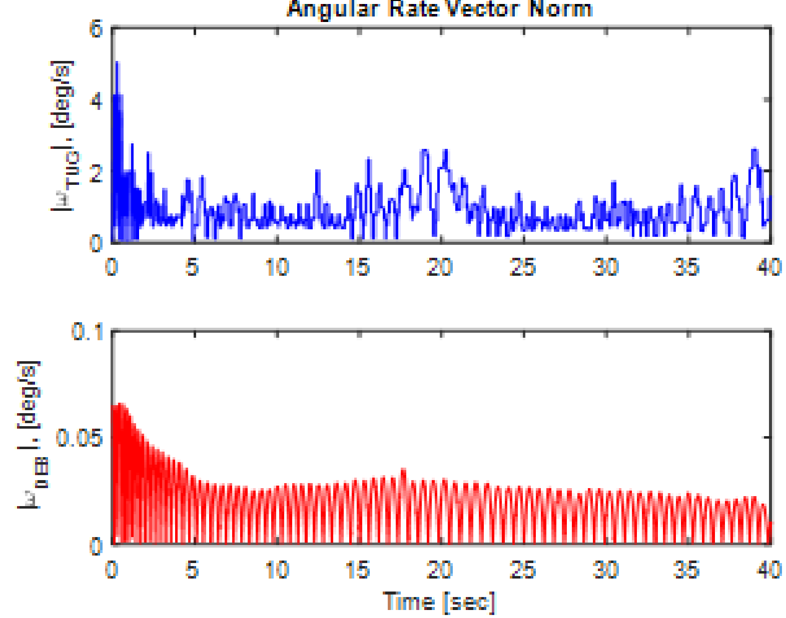
Limited Volume/Time Simulation
Stabilisation after de-orbit burn

- Initial attitude and angular rates of the tug and debris were assumed to be 0 in the ISS frame and initial tether elongation was equal to 1%, which corresponds to 1cm.
- Initially, a step input of 0.2 N was applied for 0.5 s and afterwards relative distance control and attitude stabilisation were performed.
- **This scenario can simulate the stabilisation of the system after the main engine cut-off following the de-orbit burn.** The test was run for 40 s.
- During the stabilisation phase, the nominal thrust is 0.2 N, which results in the nominal force and torque equal 0.2 N and 0.02 Nm, respectively

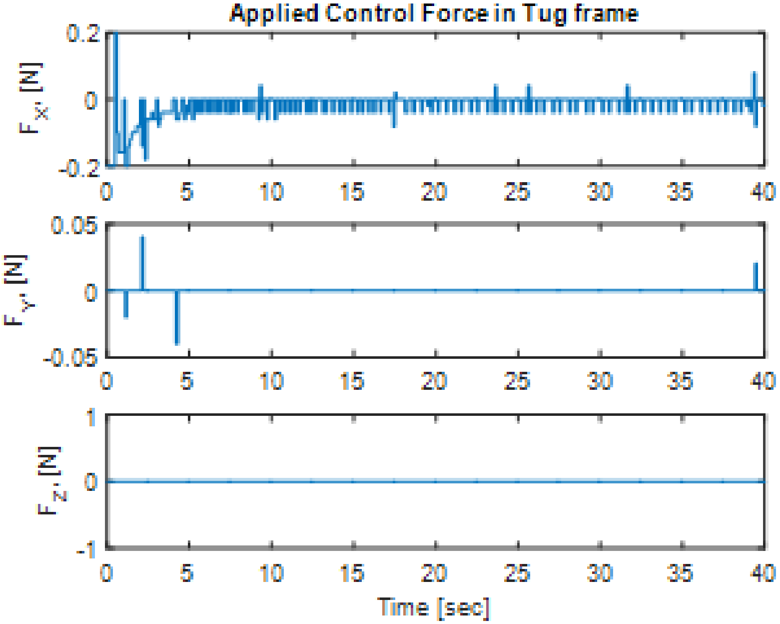




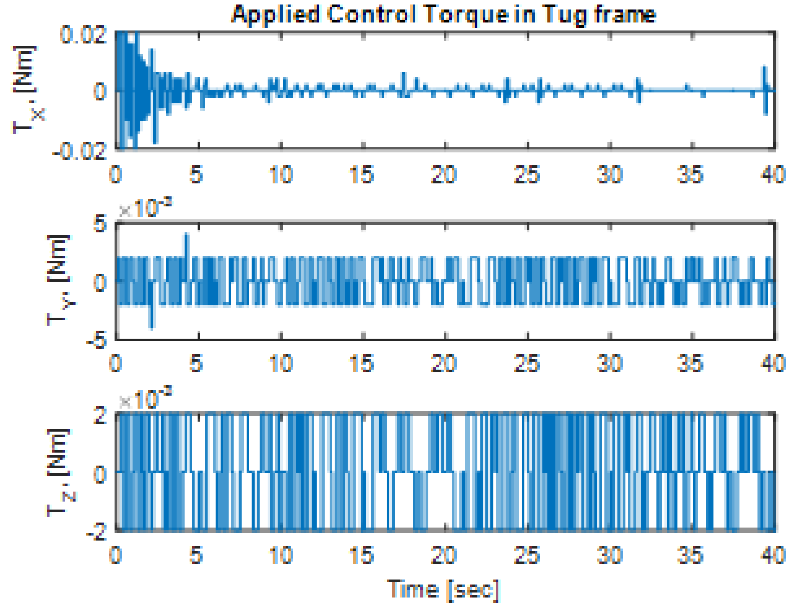
(a) Relative Distance and Tether Tension



(b) Angular Rates



(c) Applied Control Force

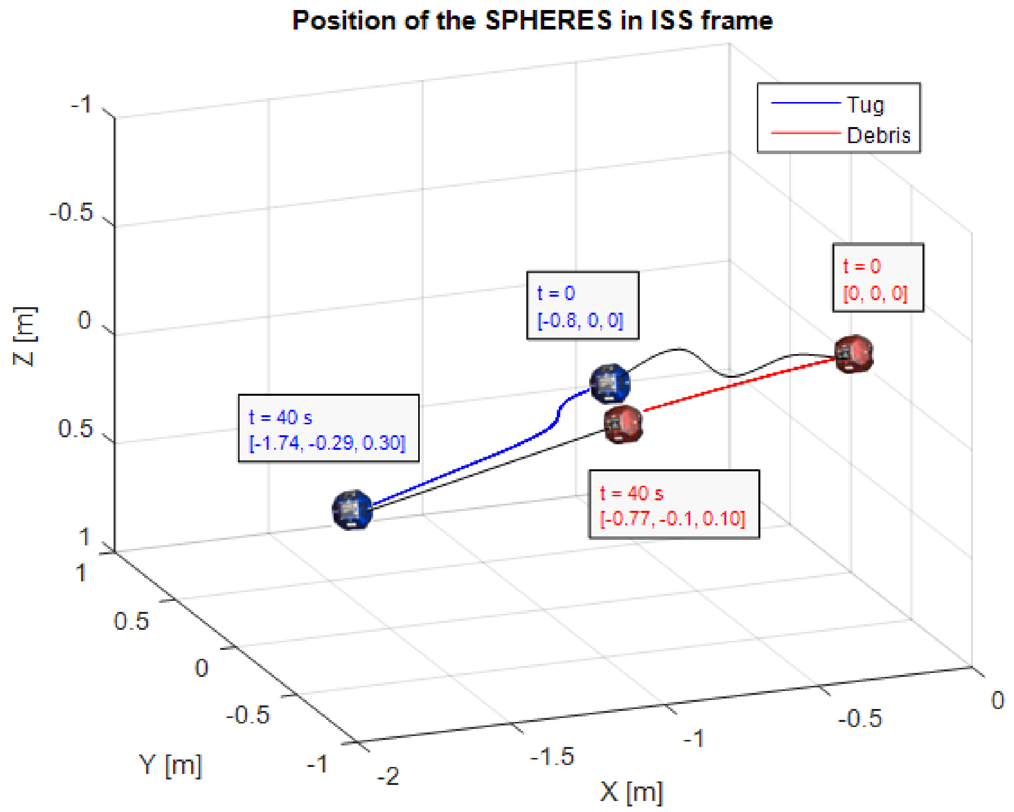


(d) Applied Control Torque

Simulation
SPHERES case with tether slack

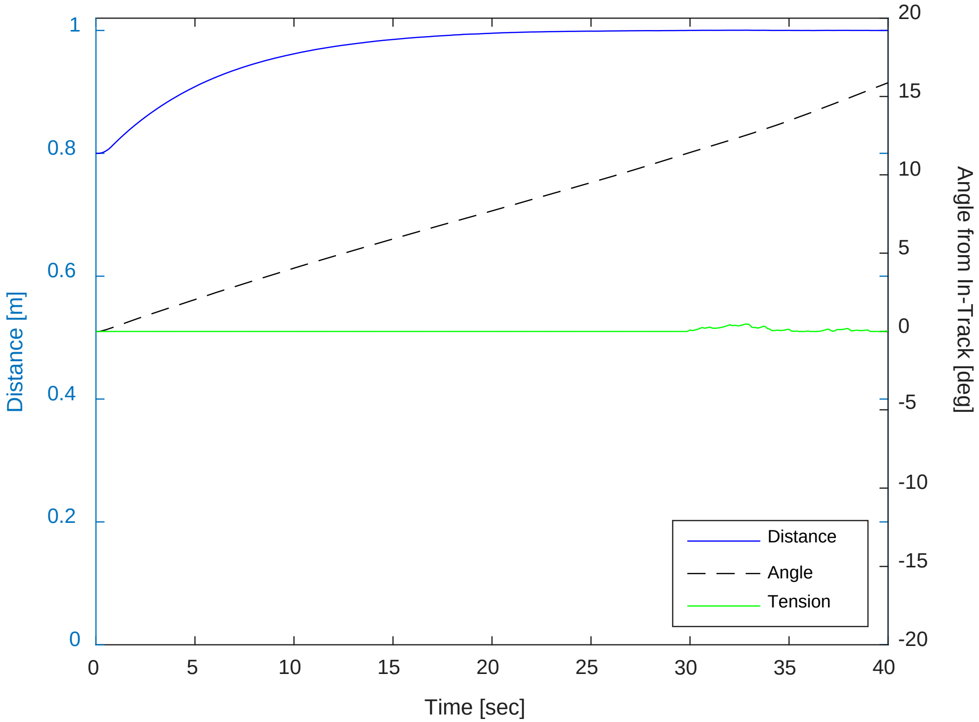
- SPHERES case with tether slack

Tug Mass	4.4 kg
Tug Inertia	diag[0.025, 0.023, 0.022] kg m^2
Debris Mass	4.4 kg
Debris Inertia	diag[0.025, 0.023, 0.022] kg m^2
Tether Length L_0	1 m Equal space between masses
E	0.01 GPa
Tether Diameter	1 mm
Tether Density	920 kg/m^3
C	0 kg/s
Starting Altitude	400 km (circular)

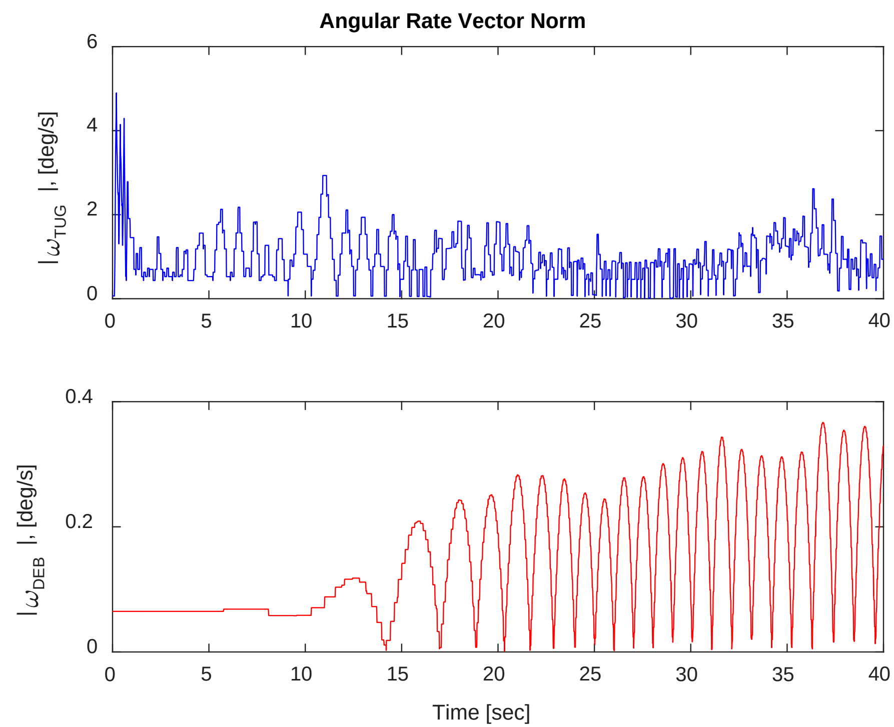


Simulation
SPHERES case with tether slack

Relative Distance & Angle from In-Track



Angular Rate Norms



Project Current status - Findings

- Project shows already, that realistic, practical ADR experiments can help ADR research and e.Deorbit mission design
- ISS SPHERES experiments with existing hardware can provide useful ADR tether dynamics/mission information and help ADR technology development at low cost and with a quick turn around (months)

Project Current status – Next Steps

- The next on-going steps consist in
  - Scaling of e.deorbit mission parameters to the SPHERES experiment
  - Definition of SPHERES test scenarios, including test objectives, set-up and hardware and software configuration

Thank you!

- For more information contact:
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