CLEAN SPACE INDUSTRIAL DAYS

HARMONISED SYSTEM STUDY ON INTERFACES AND STANDARDISA-TION OF FUEL TRANSFER (ASSIST)

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ASSIST

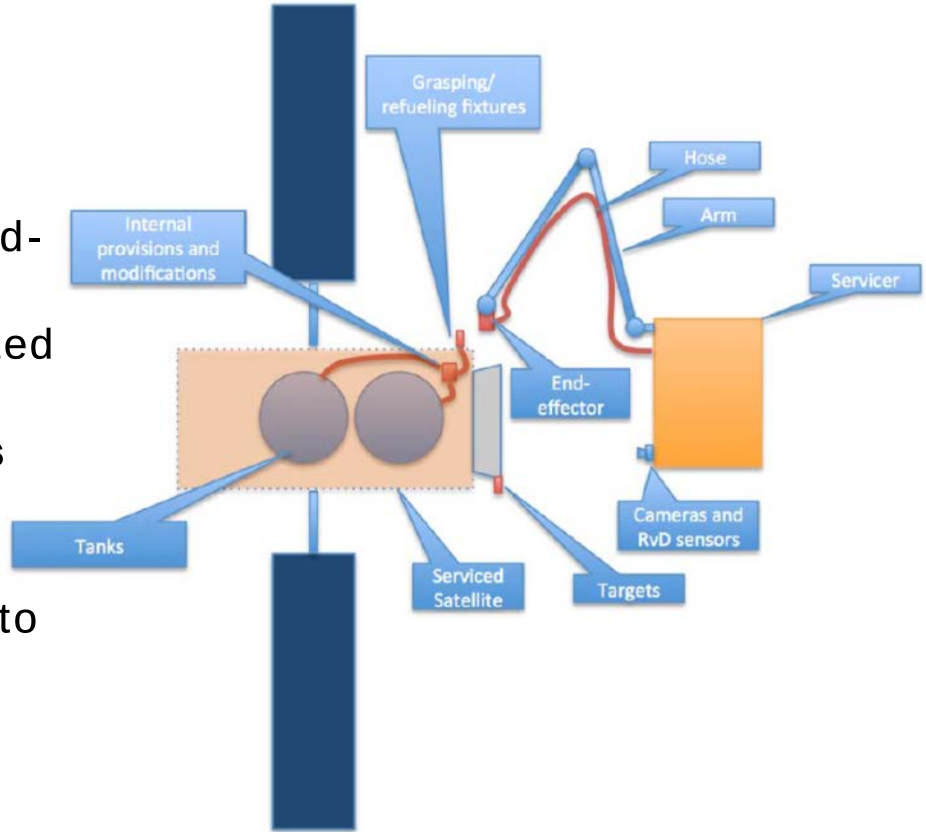
INNOVATING SOLUTIONS

ASSIST ACTIVITY: GOALS

*To **design** the **internal** and **external provisions** of a **servicing/refuelling** system for **GEO** satellites.*

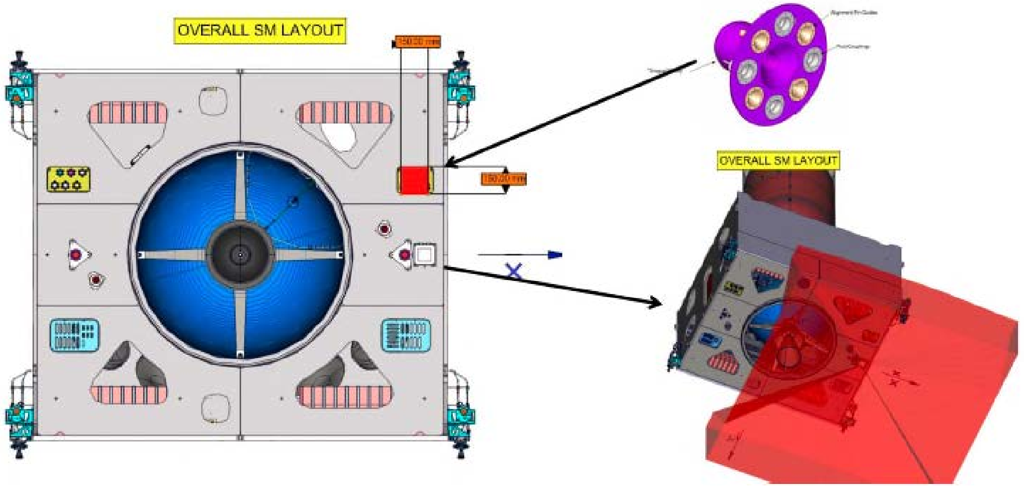
Taking into account:

- Minimum impact on **internal provisions** of GEO telecom satellites
- Minimum impact on **external provisions** for the servicing satellite
- **Flexibility** and **configurability** of end-effector/berthing fixture
- **End-effector** considered to be mounted at the tip of a robotic arm
- Identification of relative **rendez-vous sensors/markers**

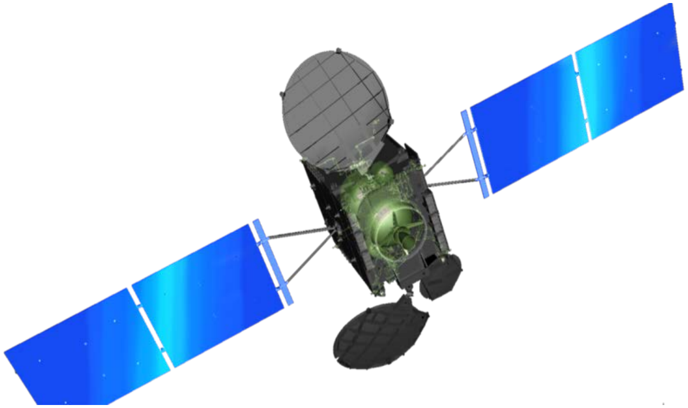


- Breadboard of the **berthing mechanism** to be tested under **environmental** and **dynamic** conditions
- Elaboration of a **refuelling standard** together with European LSI's.

GEO S/C CONFIGURATIONS: SPACEBUS TELECOM (TAS)



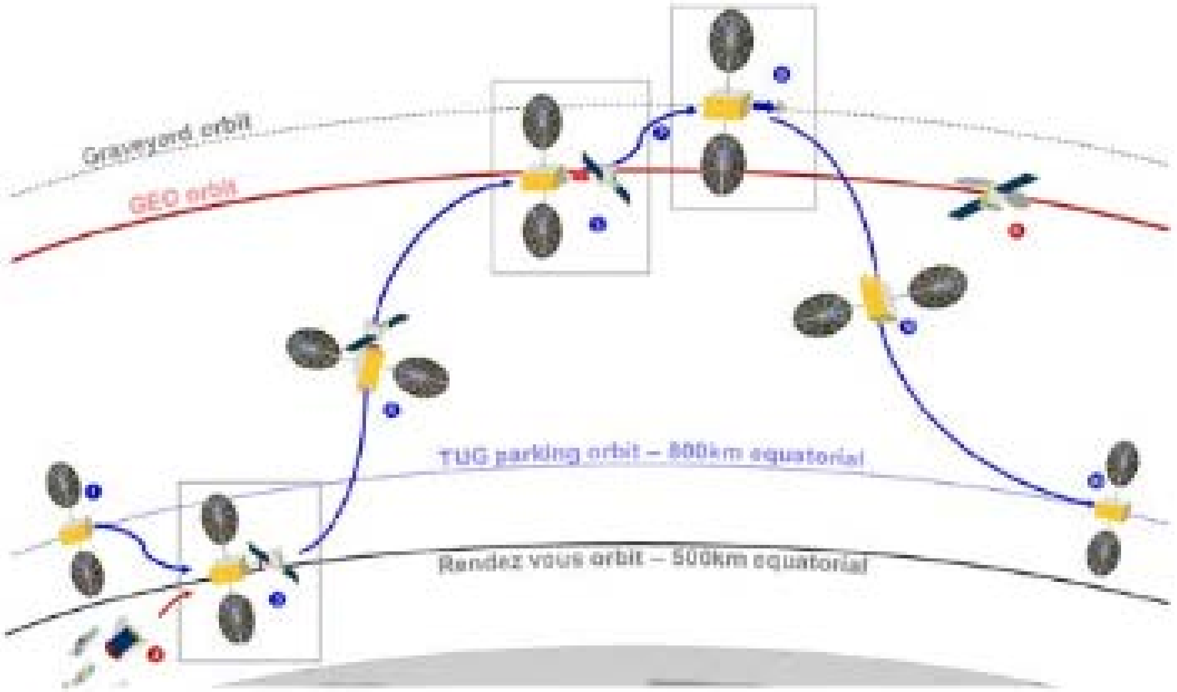
- Spacebus Telecom S/C (TAS):
  - 1000 kg of MON/MMH
  - 300 kg of Xenon.



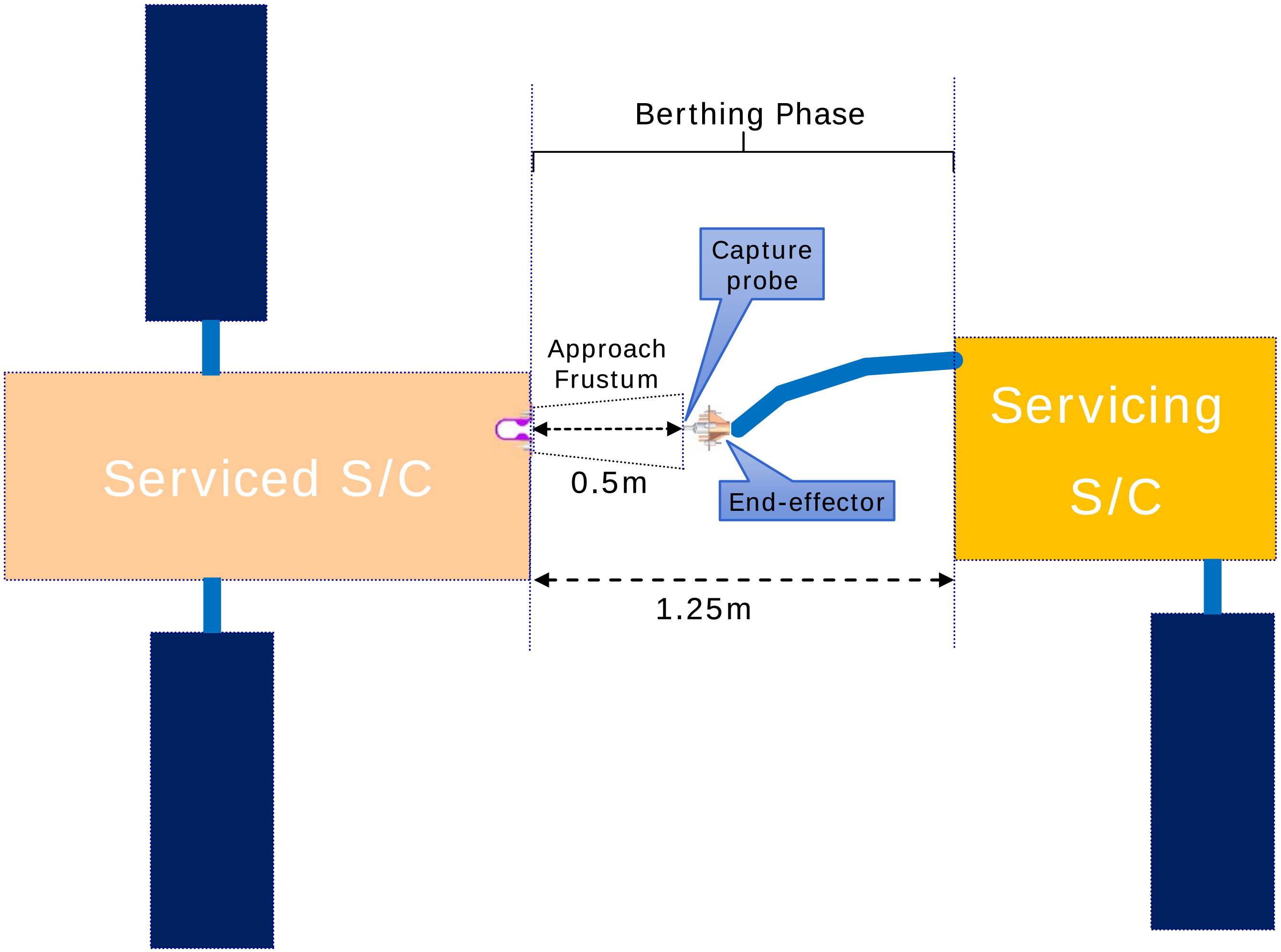
- Small telecom S/C (OHB):
  - 500 kg of MON/MMH (combined) for full chemical propulsion
  - 100 kg of MON/MMH (combined) plus 150 kg Xenon for hybrid
  - 200 kg full-electric propulsion (typically Xenon)

GEO S/C CONFIGURATIONS: SPACE TUG (AIRBUS DS)

- In-space resident multi-mission vehicle able to transfer payloads (Satellites or cargos) between low and high Earth orbits:
  - 200 kg of MON/MMH
  - 3000 kg of gas (Xenon)



ASSUMPTIONS: BERTHING PHASE (APPROACH FRUSTUM)



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ASSIST STANDARD

PROJECT GOALS AND ASSUMPTIONS

MECHANICAL DESIGN, RENDEZVOUS/BERTHING SENSORS AND MARKERS

SIMULATOR AND PRELIMINARY RESULTS

DYNAMIC AND ENVIRONMENTAL TEST SET-UP

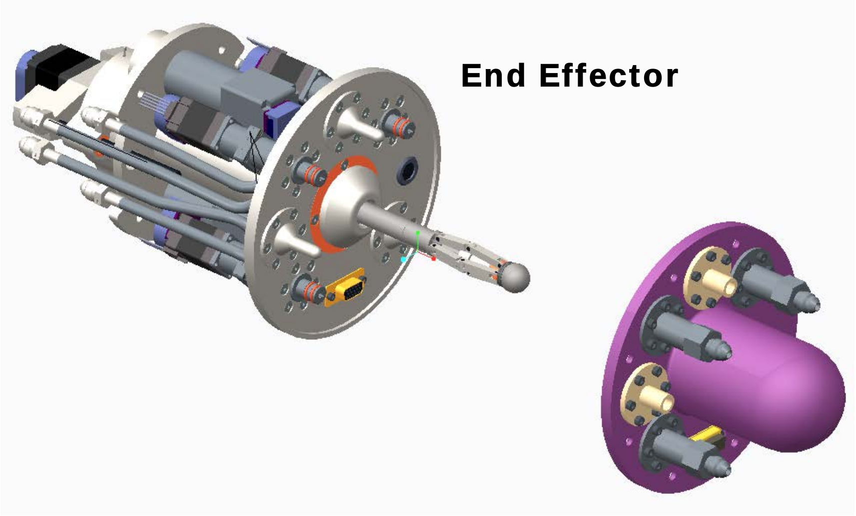
CONCLUSIONS

INNOVATING SOLUTIONS

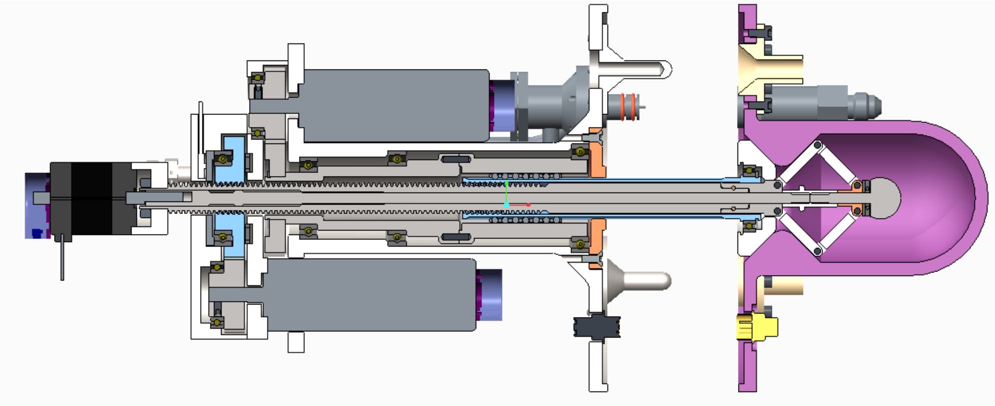
ASSIST DESIGN CONCEPT

ASSIST Design V1.6:

- Zero force capture and then clamping of the Client / Servicer around a central axis
- End effector capture probe pantograph expands inside client berthing fixture ‘drogue’
- Clamping collar provides a ‘hard dock’ before fluid planes are connected.
- Alignment pins centralise the system prior to mating the fluid couplings or electrical connector
- 3x fluid connections (MON, MMH, Xenon). One 9way electrical connector



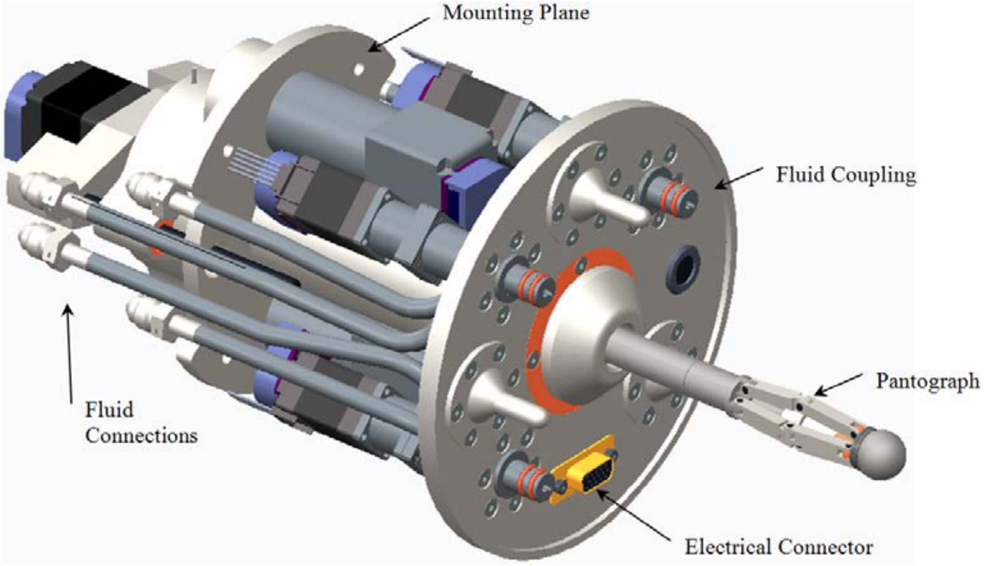
Berthing Fixture



ASSIST DESIGN: END-EFFECTOR

End Effector:

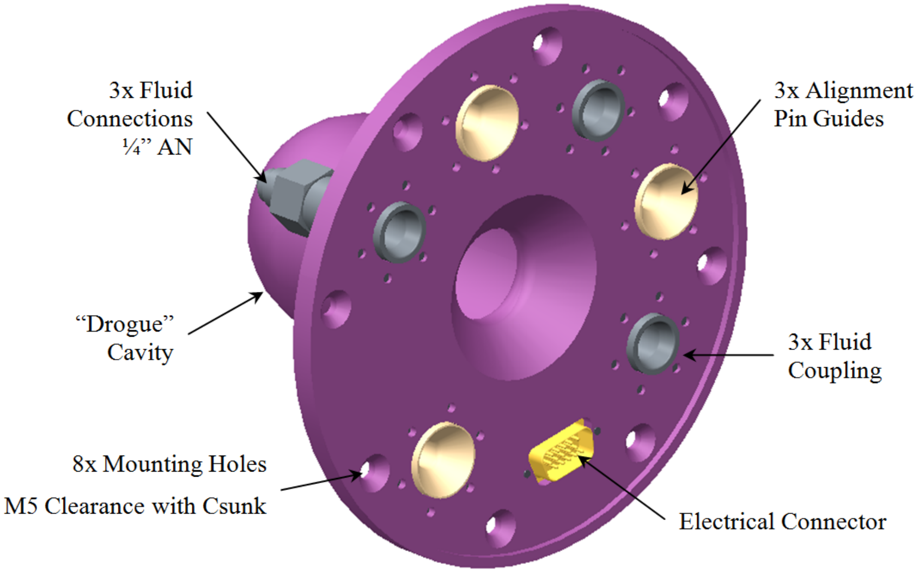
- Located on the servicer robotic arm
- Grasping mechanism which docks with the client
- Pantograph expands in the berthing fixture ‘drogue’
- 3x fluid couplings with actuation mechanism for the client valve
- ESA/SCC D sub connector
- Actuator position information is available through optical encoders



ASSIST DESIGN: BERTHING FIXTURE

Berthing Fixture:

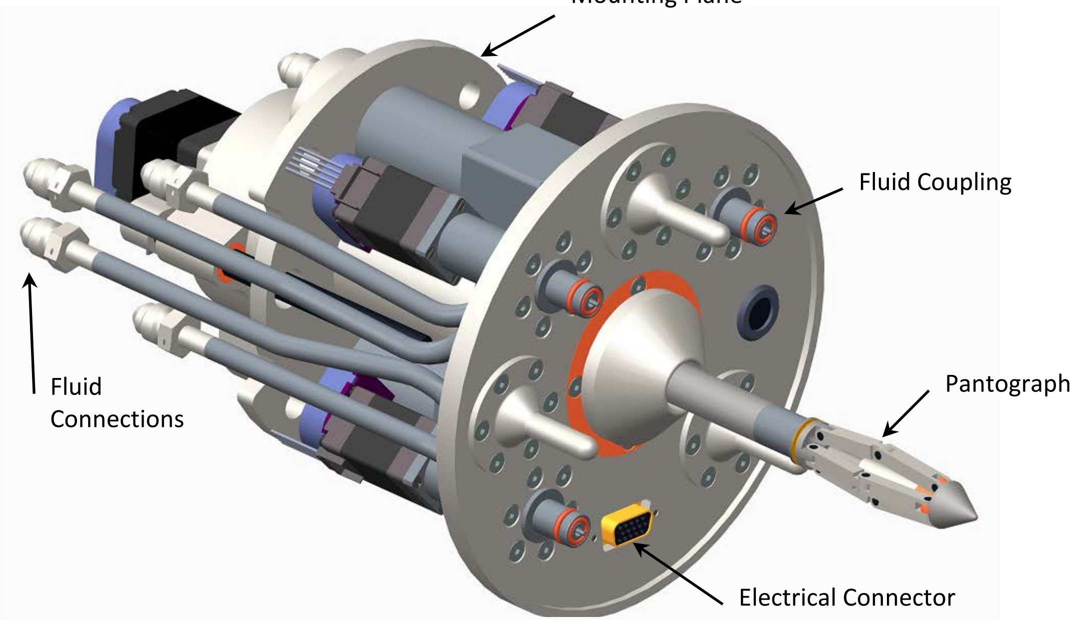
- Berthing fixture consists of a ‘drogue’ into which the capture probe is inserted.
- Mating fluid coupling has integral valves.
- Common to small GEO and large GEO platforms with the exception of the third fluid coupling used for Xenon which can be omitted for some platforms.
- Fluid plane has guides which receive the end effector alignment pins.
- Fluid coupling valves are aligned with end effector on assembly.



ASSIST DESIGN CONCEPT

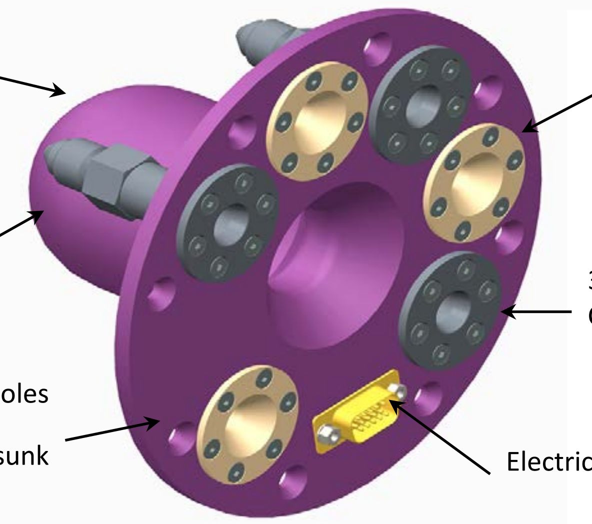
End Effector

- Grasping: pantograph expands in the berthing fixture 'drogue'
- 3x fluid couplings with actuation mechanism for the client valve; 1 ESA/SCC D sub connector

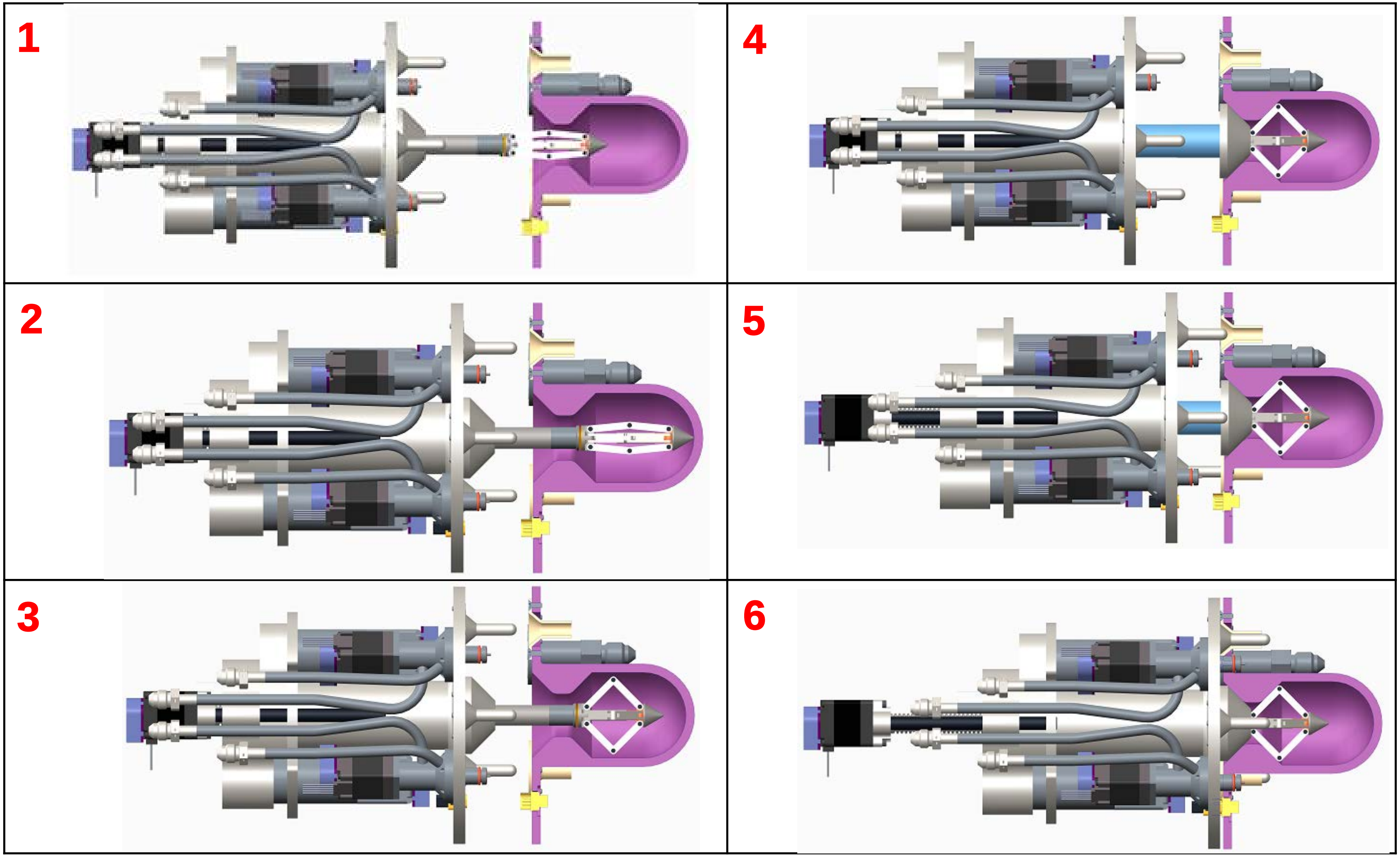


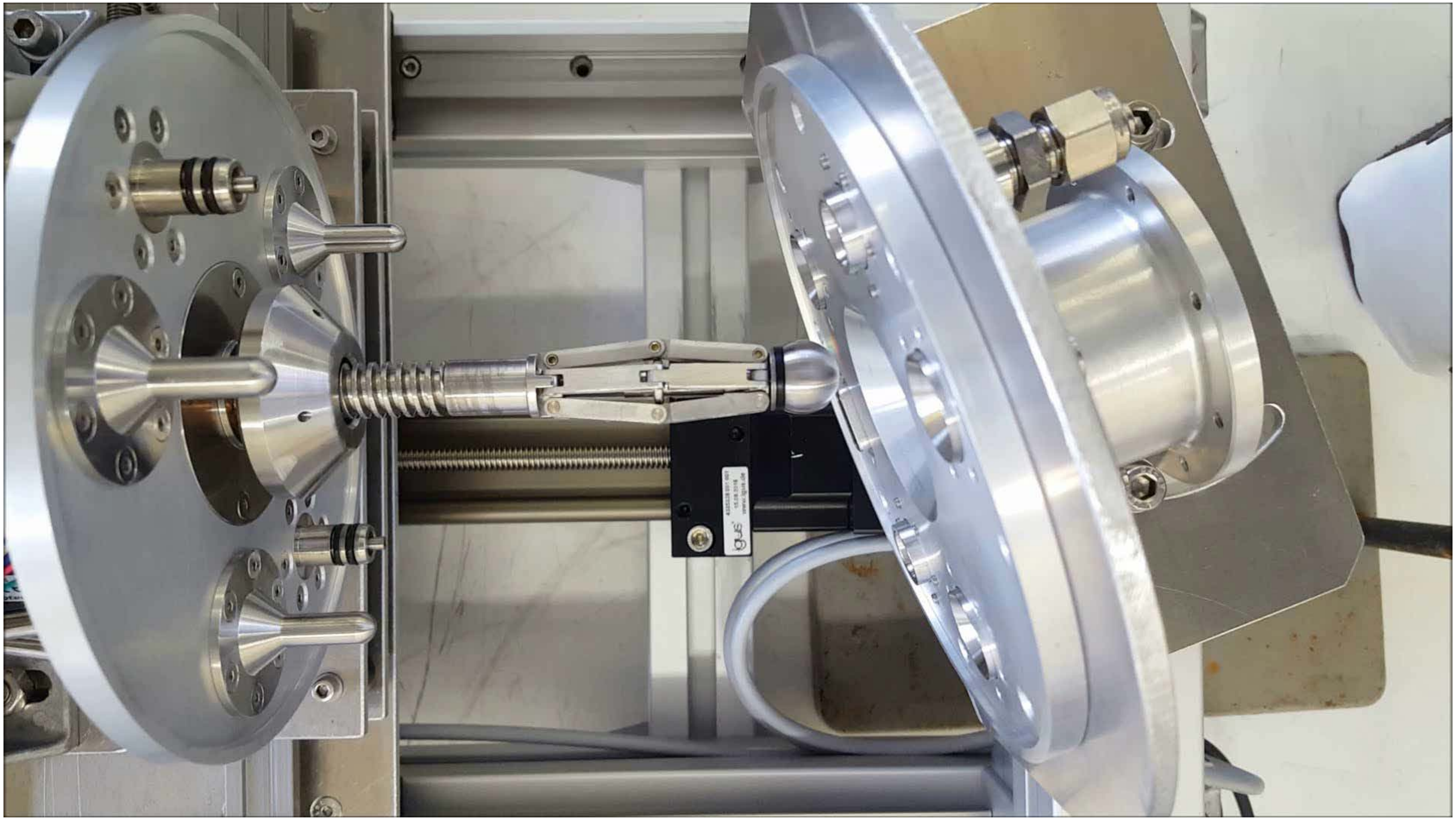
Berthing Fixture

- 'Drogue' cavity into which the capture probe is inserted
- Mating fluid coupling has integral valves
- Fluid plane has guides which receive the end effector alignment pins



ASSIST DOCKING PROCEDURE

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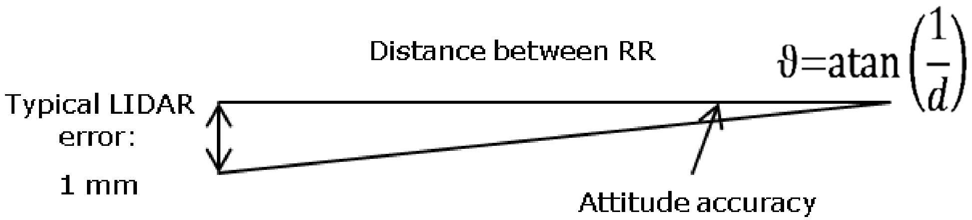
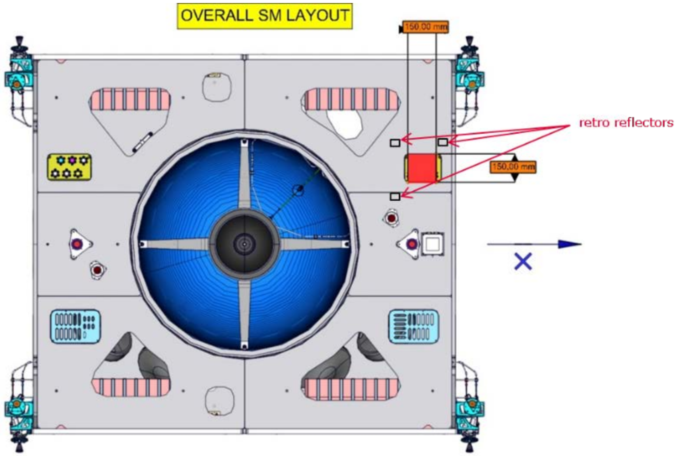
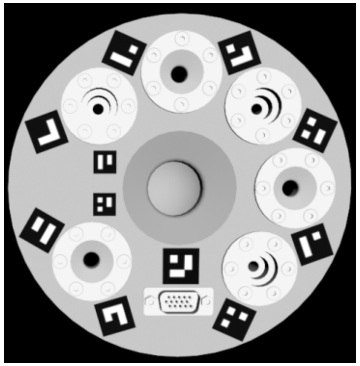
RENDEZVOUS SENSORS AND MARKERS

- Selected scanning LIDAR with the use of retro-reflectors (long-range targets):
  - Very reliable and accurate (guarantees GEO sat integrity)
  - Simplifies RVD strategy (not constrained by illumination condition)
- Set of 3 retro reflectors (foils of about 50x30 mm) consisting of a large number of miniature corner cubes retro reflectors (light and thin)
- Attitude estimation (0.28 deg) at short range:

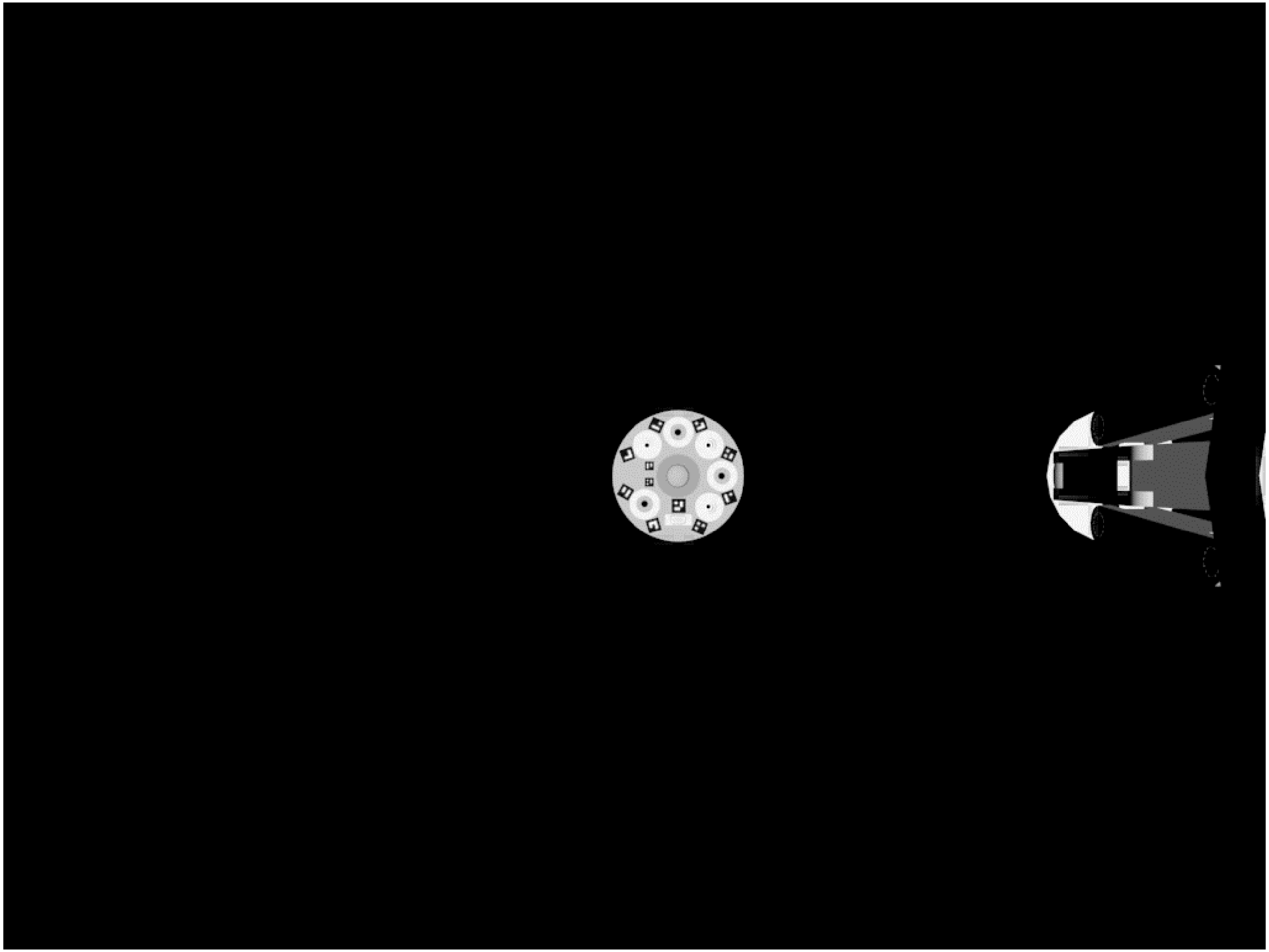




- Proposing visual servoing for the last approach phase (1.25m down to 0.5m)
  – Chosen simpler (yet robust) design based in 2D fiducial makers (ArUco library)
  – More markers allow for better robustness in case of shadows or occlusions
- Two sets of differently sized markers (2cm for farther distances, 1cm for closer distances)



BERTHING PHASE: VISUAL SERVOING



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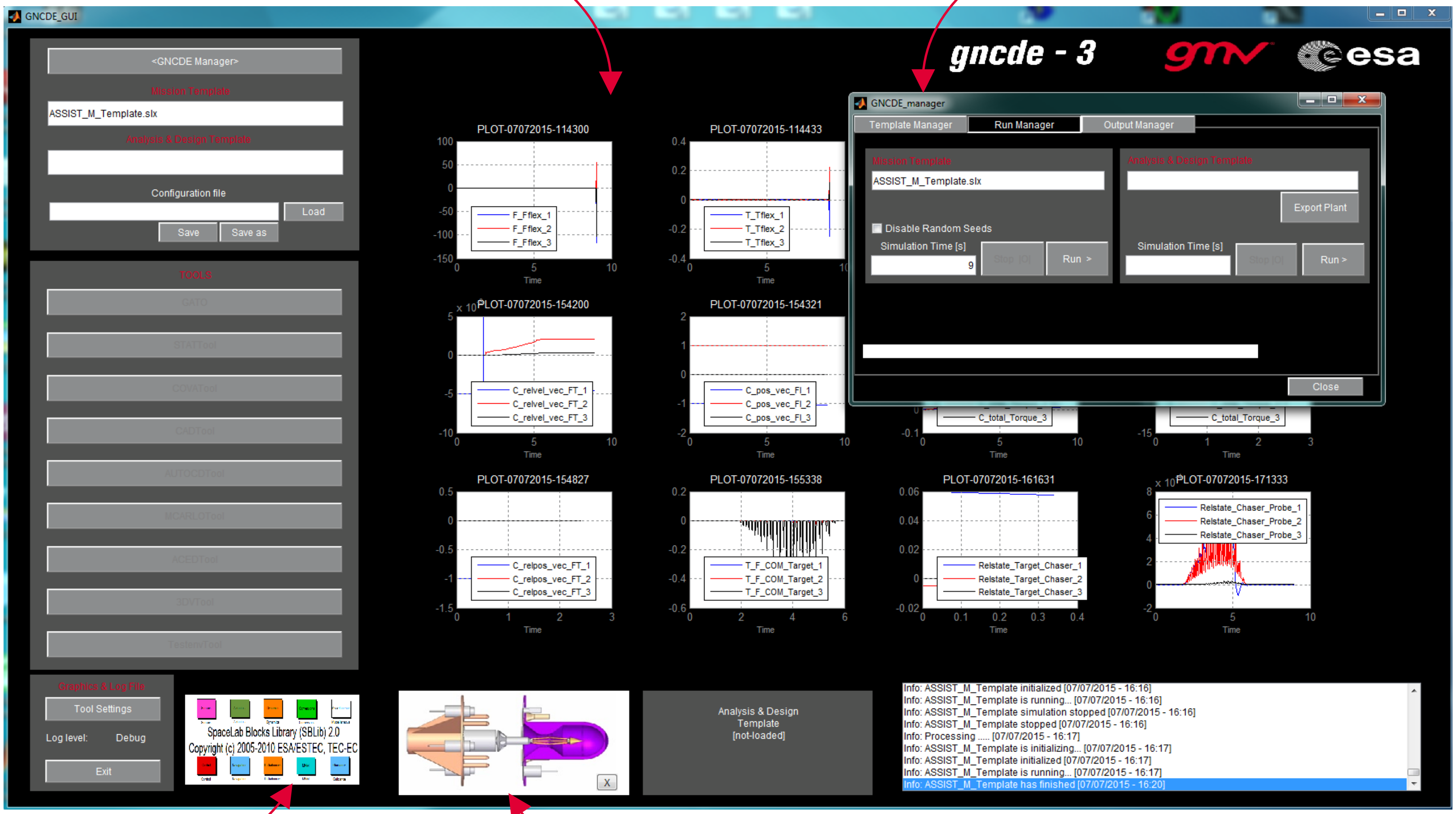
gmv® INNOVATING SOLUTIONS

ENVIRONMENT

Output plots

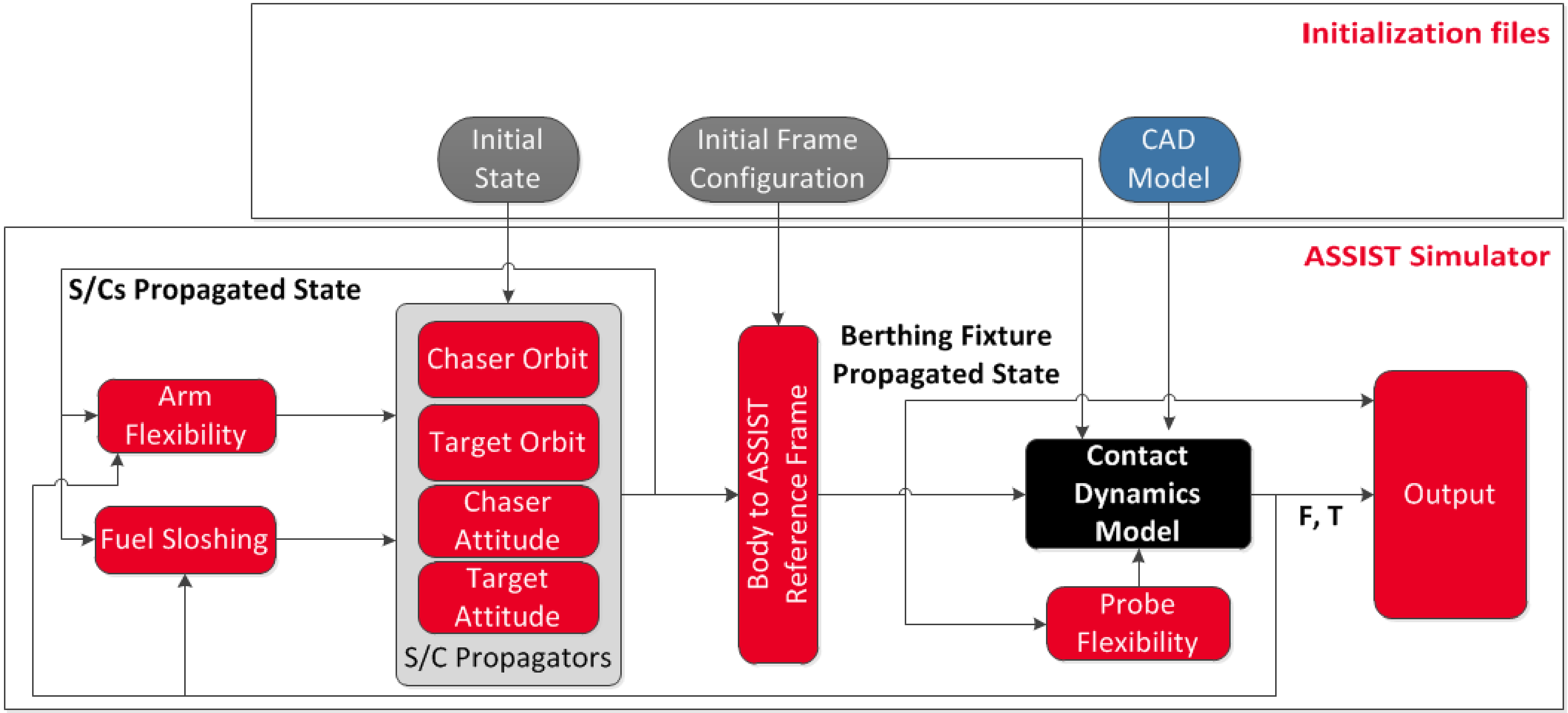
Template/Run/Output manager



Libraries

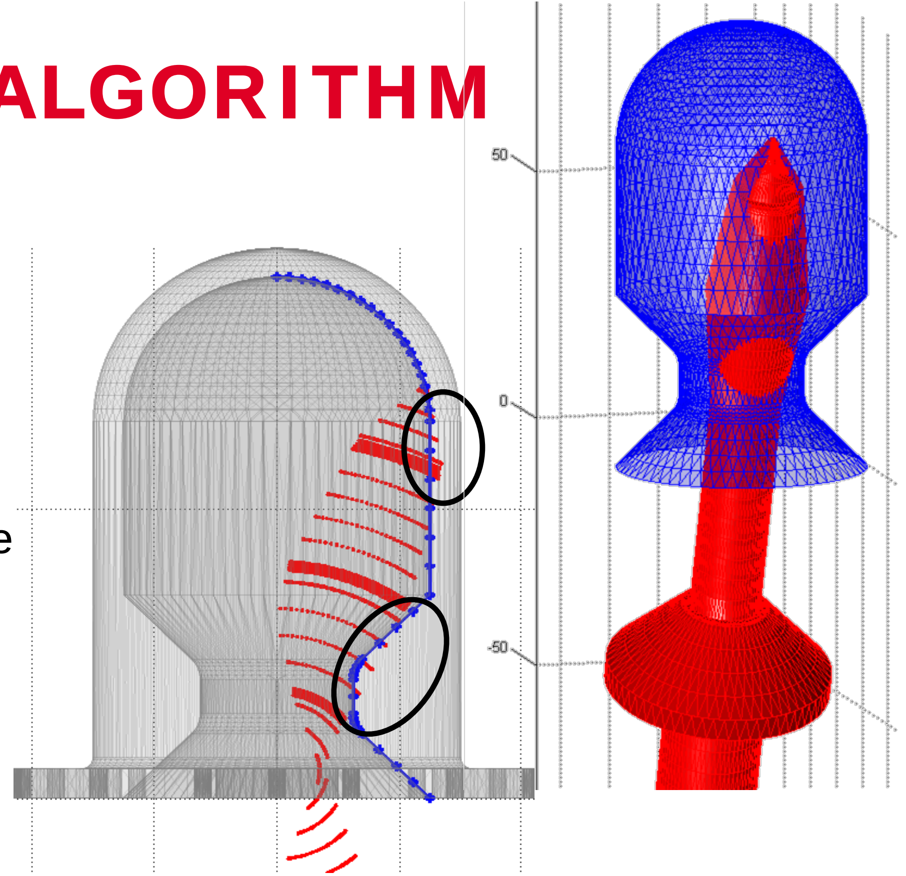
ASSIST Template loaded

SIMULATOR ARCHITECTURE



- Main components:
  - Disturbances
  - S/Cs propagation
  - Reference Frames manager
  - Contact Dynamics Model
  - Output storage
  - Open loop simulation (no control in the loop)
- Main modelled effects:
  - Fuel sloshing
  - Robotic arm flexibility
  - First impact damping

CONTACT DYNAMICS ALGORITHM



- Express point cloud vertex coordinates in the profile.
- 3D → 2D mapping of point cloud (Cartesian to cylindrical coordinates)
- Contact detection:
  Point cloud vertices inside/outside profile
- Contact points (the corresponding surface facets) form the contact patch in 3D.

- Contact pressure:

$$\sigma = \left(K s_n + D v_n\right); \quad \begin{cases} K = \dfrac{1-\nu}{(1-\nu)(1-2\nu)} \cdot \dfrac{E}{b} \\ D = D_0 \cdot T\left(s_n\right) \cdot H\left(v_n\right) \end{cases}$$

- Shear stress (regularized Coulomb friction)

$$\tau = \mu\sigma = \begin{cases} \mu_0 \sigma; & \left|v_t\right| > \left|v_0\right|; \\ \mu_0 \dfrac{v_t}{v_0} \sigma; & \left|v_t\right| \le \left|v_0\right|; \end{cases}$$

- Specific cloud point contact force:

$$\mathbf{f} = \sigma \mathbf{n} + \tau \mathbf{t}; \quad \left\|\mathbf{n}\right\| = \left\|\mathbf{t}\right\| = 1$$

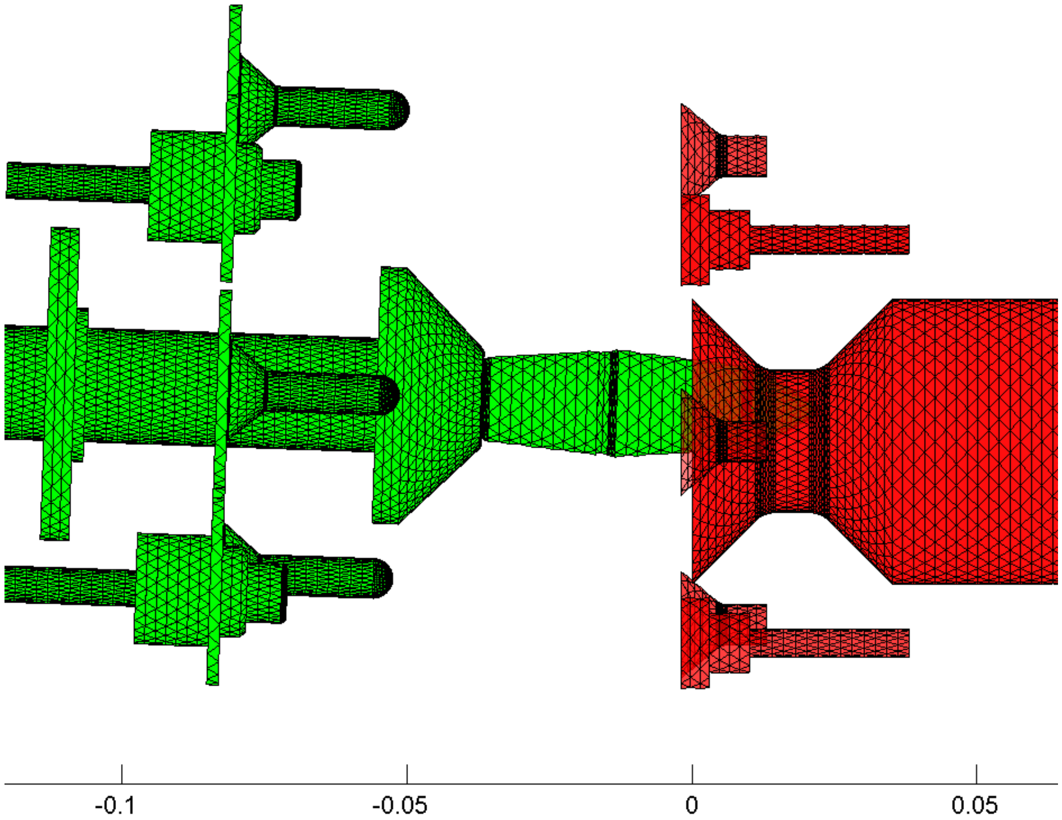
- Force / torque applied to the contact surface:

$$\mathbf{F} = \sum_{i=1}^{n} \Delta A_i \mathbf{f}_i;$$

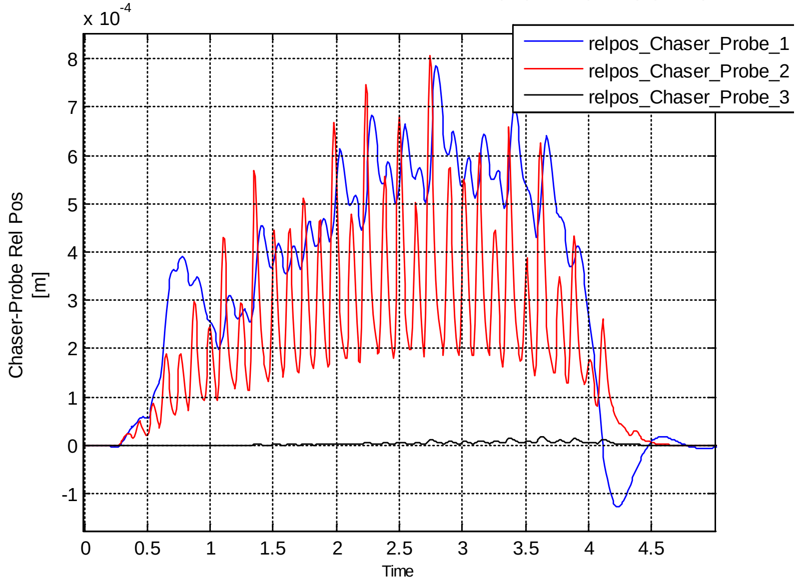
$$\mathbf{T} = \sum_{i=1}^{n} \Delta A_i \left(\mathbf{r}_i \times \mathbf{f}_i\right);$$

SIMULATION RESULTS

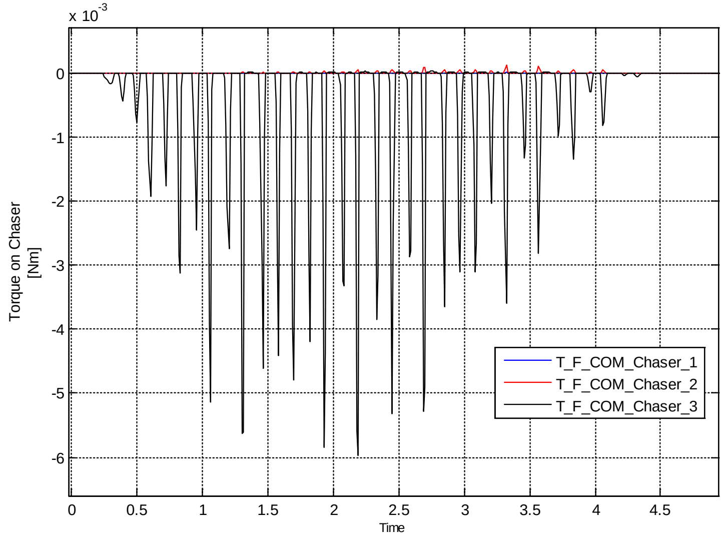
Misalignment: 1 cm on plane X-Y, 4º between boresight axes



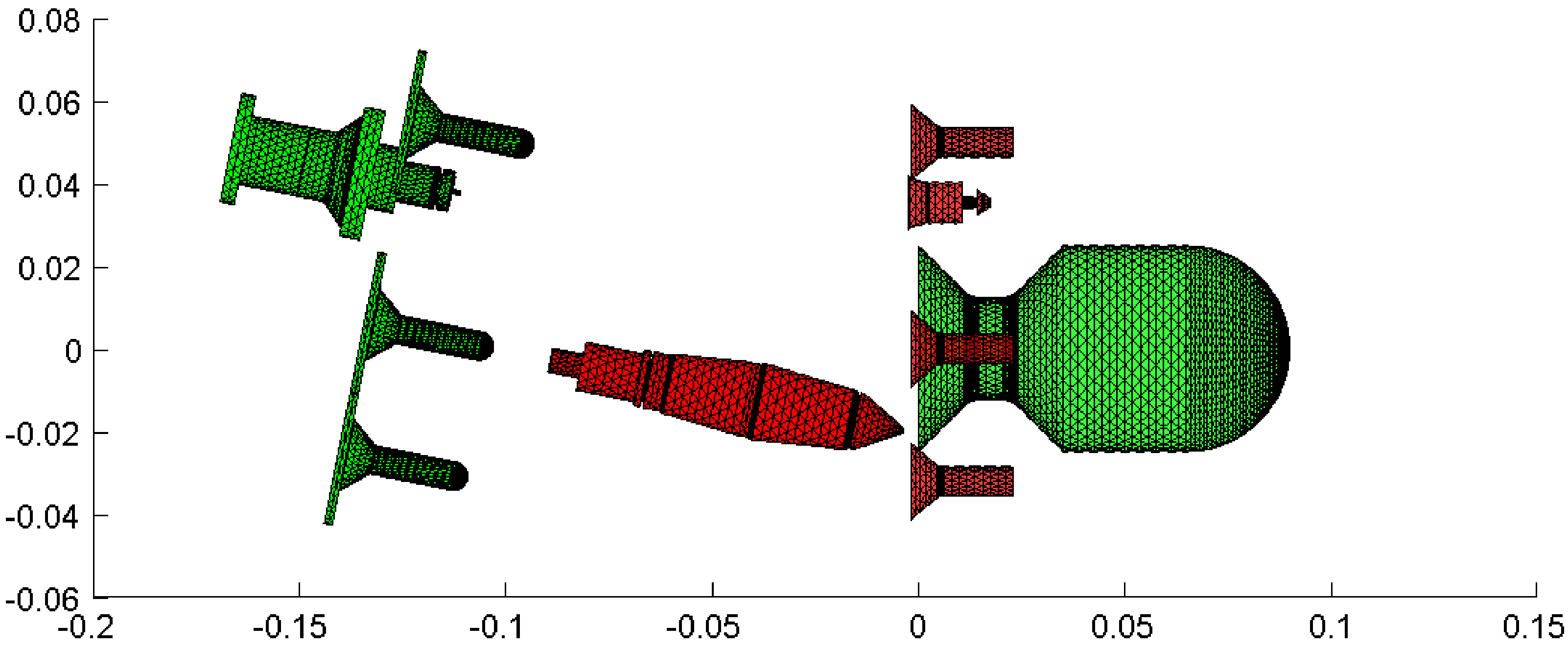
Probe-Chaser Relative Position



Torque on Chaser COM T_{max} ~ 6e-3 [Nm]



SIMULATION RESULTS



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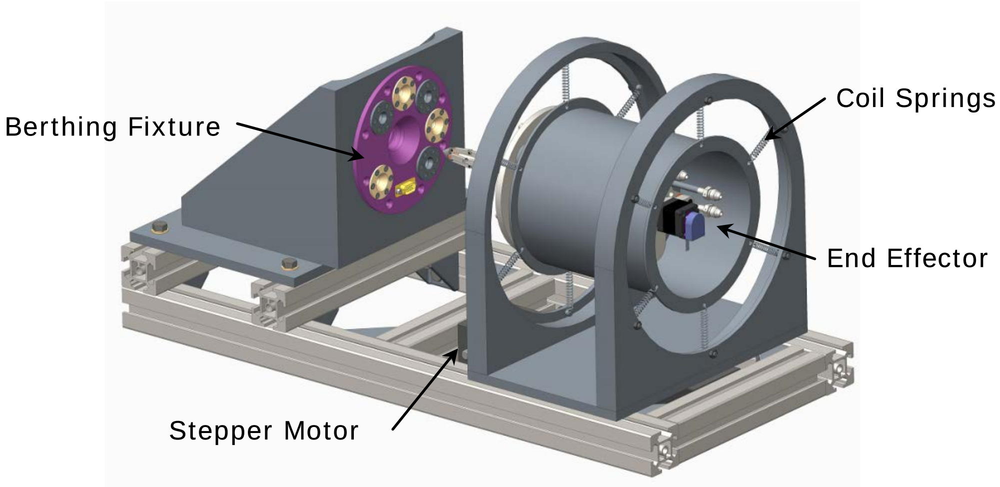
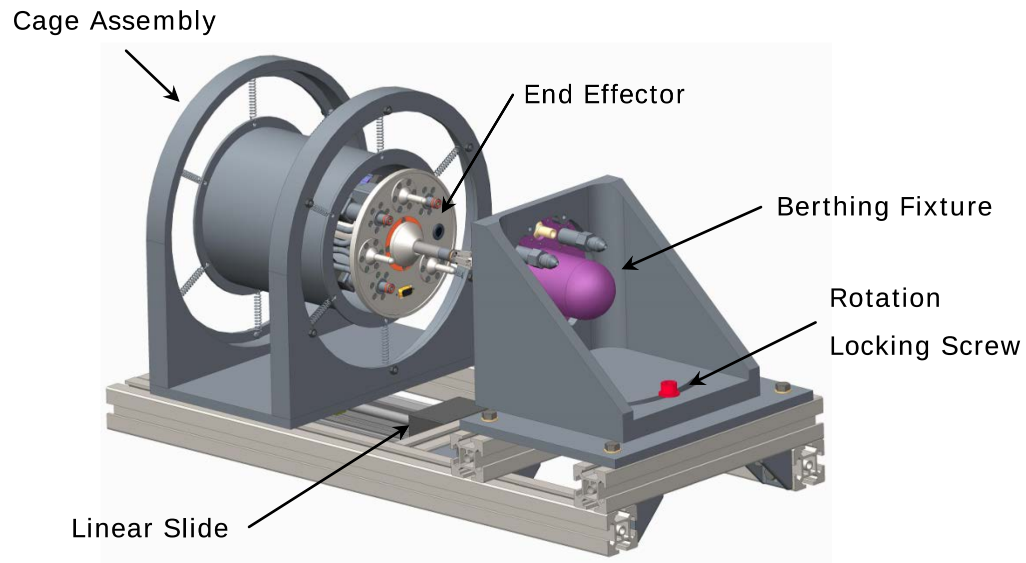
ENVIRONMENTAL TEST SETUP (Moog)

- Thermal vacuum chamber:
  - Electrical continuity, leakage and flow rate tests at temperature extremes.
  - Vacuum < 1E-3mbar
  - Temperature range 5°C to 50°C
  - Liquid and gas transfer

- Misalignements:
  - Rotational offset up to 20º
  - Lateral offset up to ±20mm

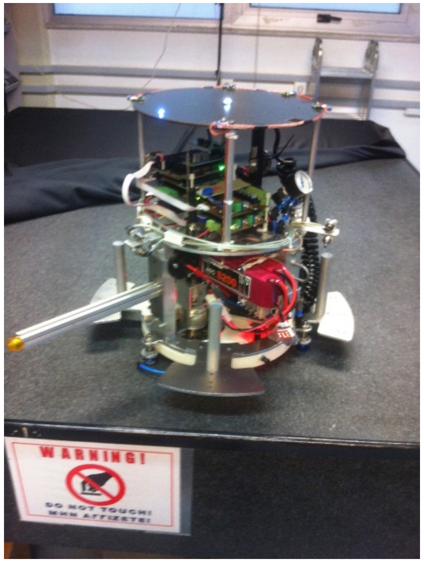
- During the berthing procedure, when the fluid plane transfers to the berthing fixture it moves axially on the spring cage assembly.



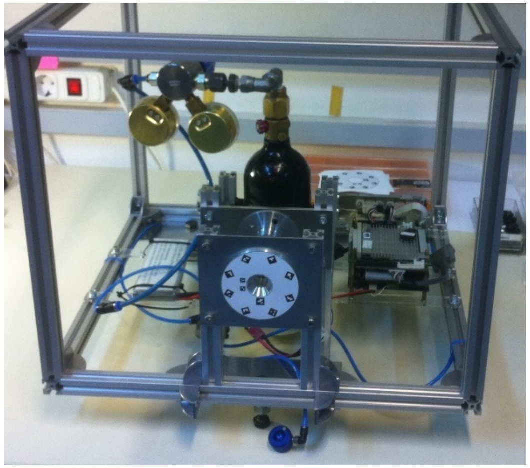


DYNAMIC TEST SETUP (NTUA CSL)

- **Air-bearing table:**
  - Low roughness (5μm) granite table (2.2m x 1.8m)
  - Localization through Phasespace mocap system



- **Upgrade of Servicing System (Chaser):**
  - External dimensions 500mm diameter using a metallic circular extension
  - PC104 board and camera on probe
  - End effector base prepared for breadboard and force sensor



- **New Serviced robot (Target):**
  - Height 430mm; square footprint with adjustable width 400-700mm
  - Dead weight to achieve up to 24kg
  - 25 mm diameter flat Air Bearings

PRELIMINARY DYNAMIC TESTS

- Stiff Springs, Central Impact

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- **ASSIST is an incoming European refuelling standard (end of 2016) :**
  - Agreed by major European LSI’s (OHB, TAS, ADS)
  - Including mechanical/fluid/electrical design of end-effector and berthing fixture
  - Developped an accurate kinematic and dynamic simulator to support its design and validation
  - On-going extensive verification and validation testing:
    - Air-bearing table (NTUA CSL)
    - Vacuum chamber with fluid transfer (MOOG)

Thank you

for your attention!

The ASSIST Team

INNOVATING SOLUTIONS