Clean Space Industrial Days 2018:

Pre-Development of Clamping Mechanism for e.Deorbit mission

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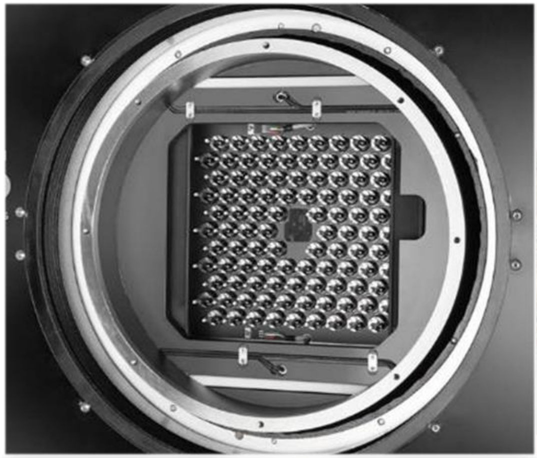
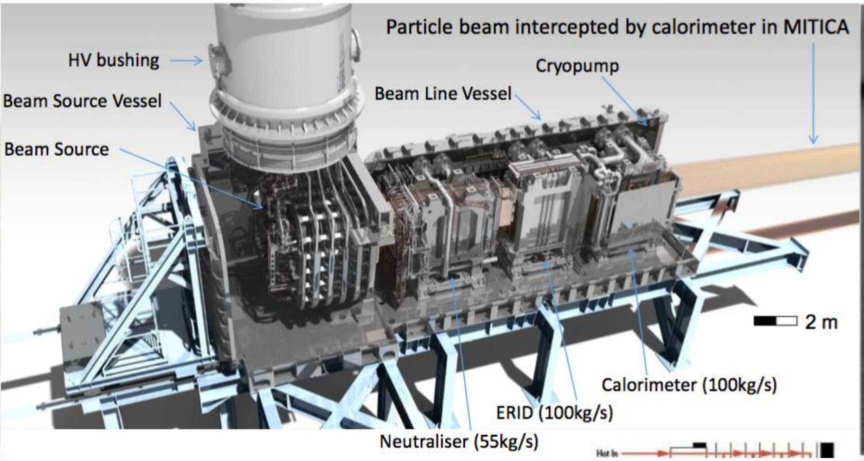
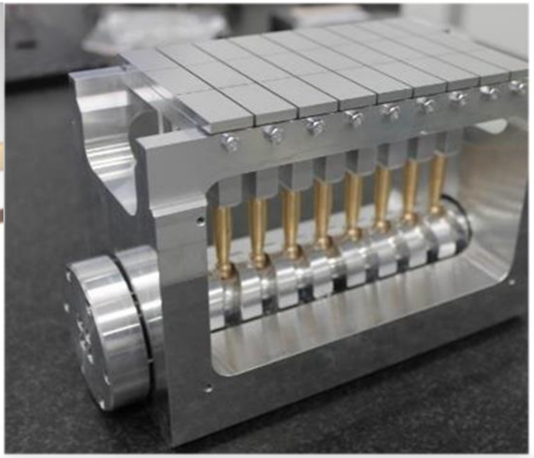
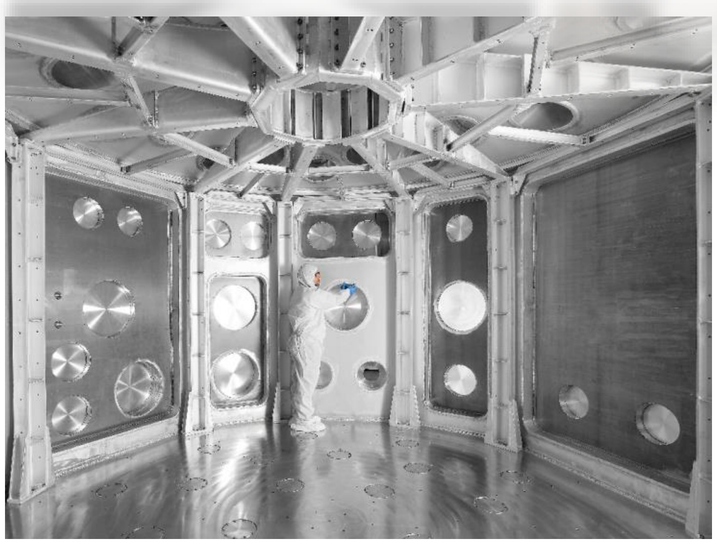
MARKETS

ASTROPHYSICS **ACCELERATORS** **FUSION** **SYNCHROTRONS** **NEUTRONS** **LASERS** **SPACE**









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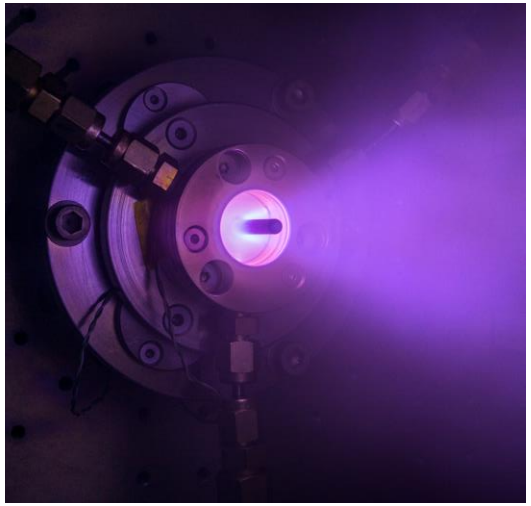
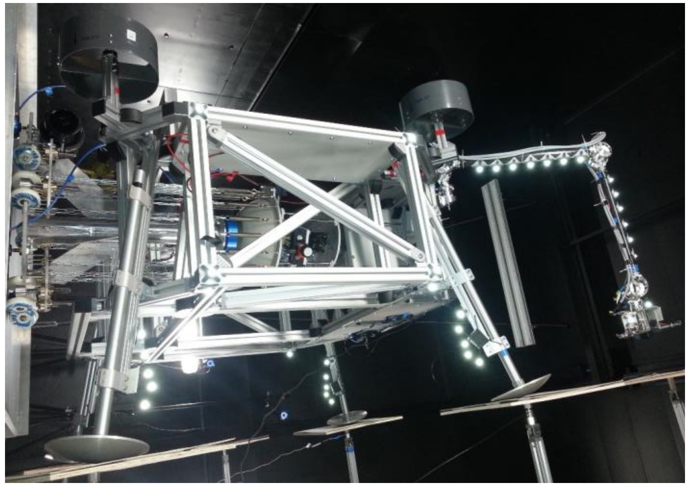
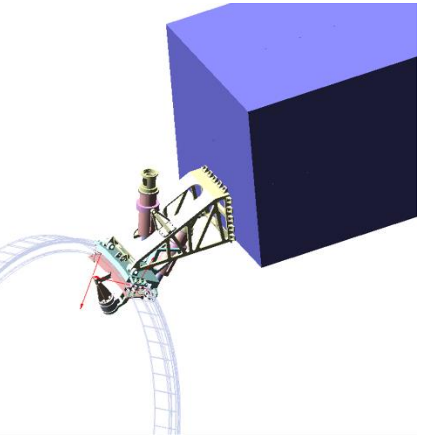
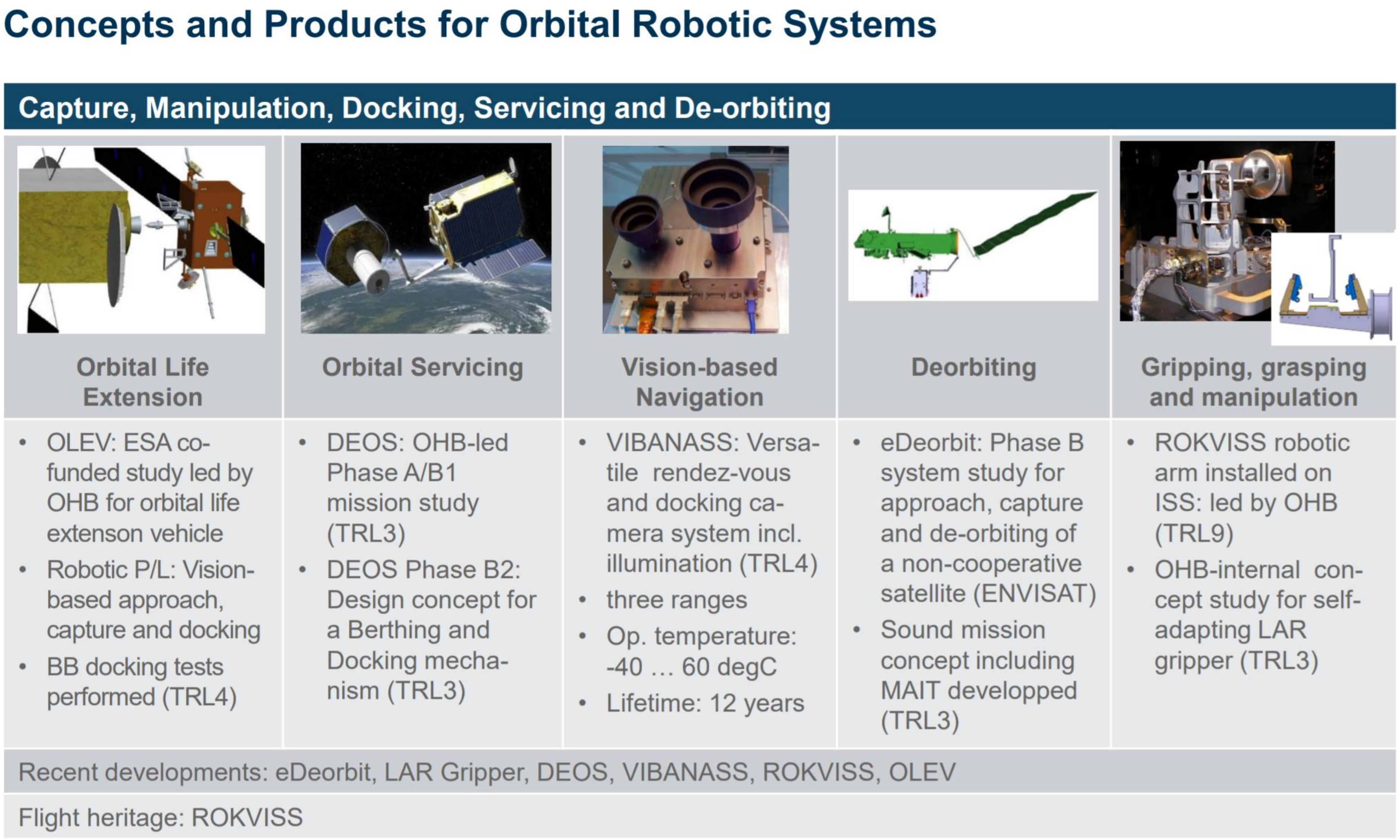
ELECTRIC PROPULSION | **EXPLORATION** | **EARTH OBSERVATION** | **SCIENCE** | **TELECOM** | **GROUND SUPPORT** | **IN-ORBIT SERVICING**

Leading player in Europe’s space business and in particular in the development of scientific payloads & instruments.

Specific experience directly related with this activity highlighted in the table:



Concepts and Products for Orbital Robotic Systems

Capture, Manipulation, Docking, Servicing and De-orbiting

Orbital Life Extension	Orbital Servicing	Vision-based Navigation	Deorbiting	Gripping, grasping and manipulation
• OLEV: ESA co-funded study led by OHB for orbital life extenson vehicle • Robotic P/L: Vision-based approach, capture and docking • BB docking tests performed (TRL4)	• DEOS: OHB-led Phase A/B1 mission study (TRL3) • DEOS Phase B2: Design concept for a Berthing and Docking mechanism (TRL3)	• VIBANASS: Versatile rendez-vous and docking camera system incl. illumination (TRL4) • three ranges • Op. temperature: -40 … 60 degC • Lifetime: 12 years	• eDeorbit: Phase B system study for approach, capture and de-orbiting of a non-cooperative satellite (ENVISAT) • Sound mission concept including MAIT developped (TRL3)	• ROKVISS robotic arm installed on ISS: led by OHB (TRL9) • OHB-internal concept study for self-adapting LAR gripper (TRL3)

Recent developments: eDeorbit, LAR Gripper, DEOS, VIBANASS, ROKVISS, OLEV

Flight heritage: ROKVISS

Activity background

- Several reference developments coming from different consortiums involved in e.Deorbit phases A & B1 studies:
  - **Grippers**
    - MDA
    - PIAP
    - OHB
  - **Clamping mechanisms**
    - MDA
    - SENER
  - ESA issued this **technology development** activity under TRP program with the following **scope**:
      - Design CLM for clamping at Envisat LAR
      - **Manufacture** & **test** a **BB** (up to TRL 4)
    - Proposal **lead by AVS** with the **collaboration** of **OHB** selected in open competition

AVS added value solutions

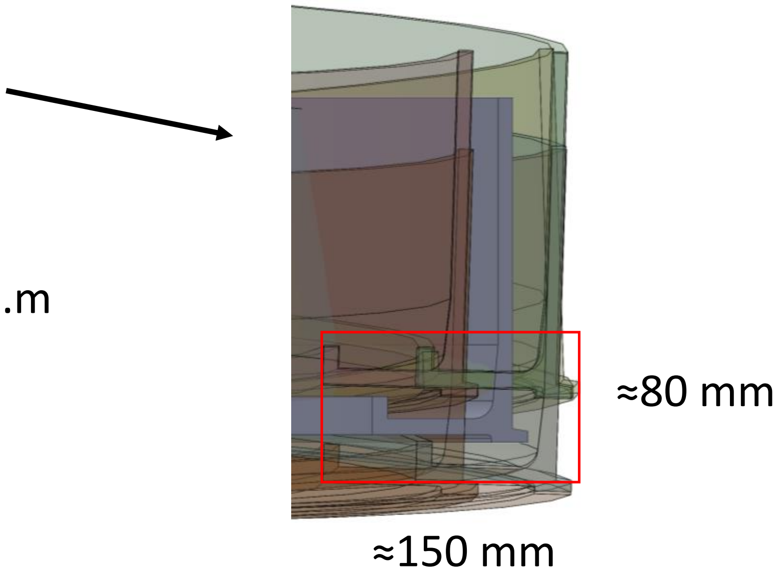
Activity coordination
Design & development
Manufacture & Assembly
Test

OHB

Internal customer role (system engineering & mission control)
Advice & relevant knowledge transfer

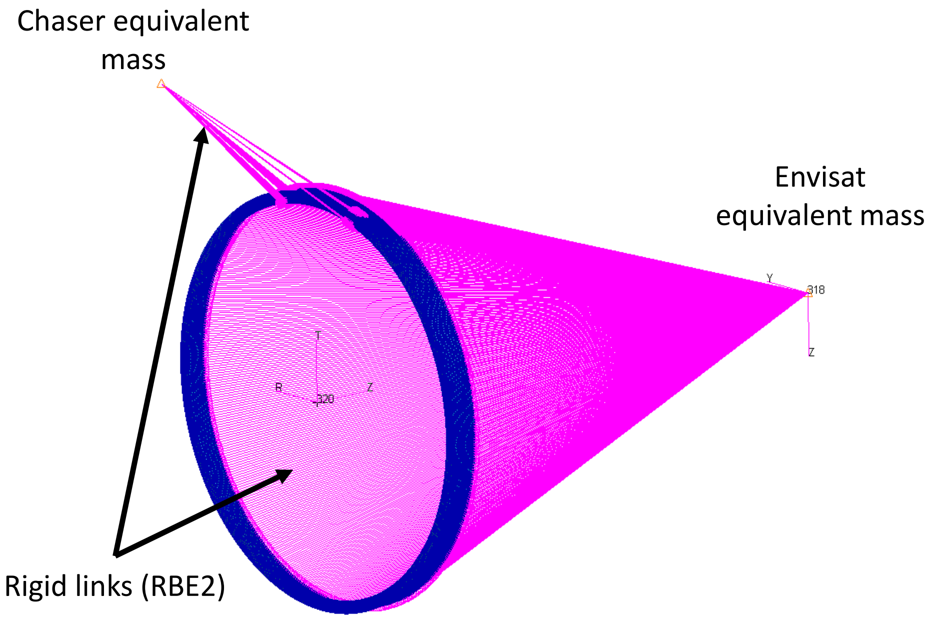
Main drivers

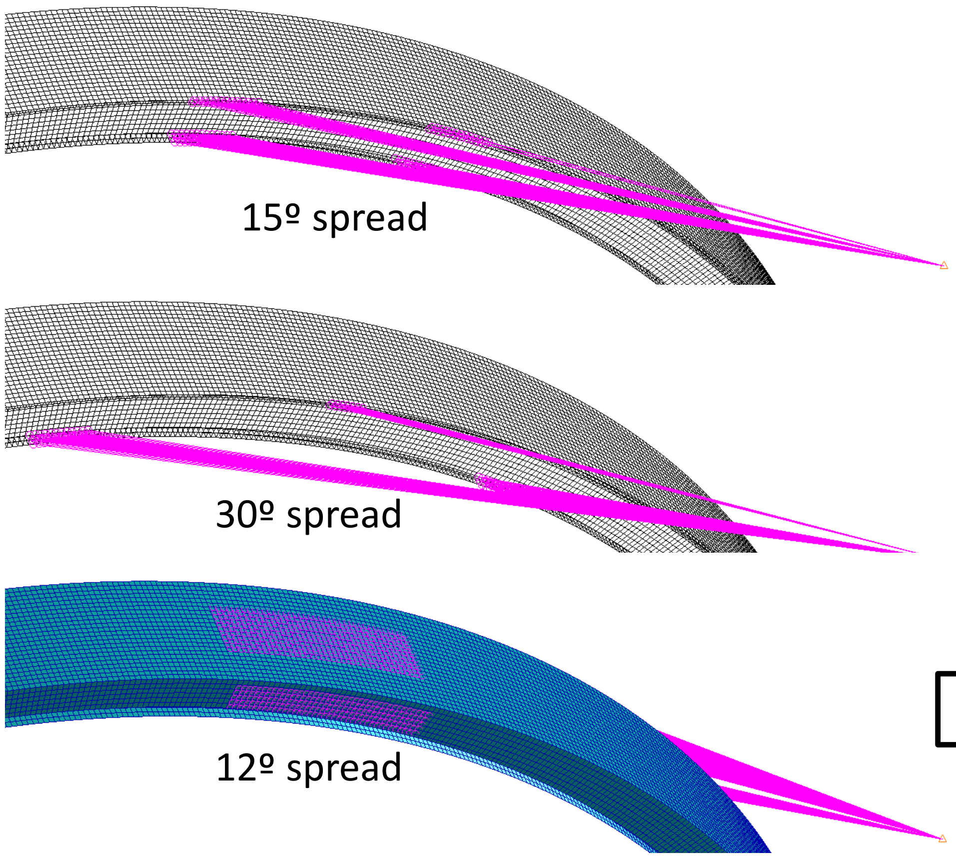
- Requirements ‘envelope’ from the different previous mission studies
  - Potential differences (e.g. different misalignment ranges, no friction brakes allowed)
    (And of course, differences with other ADR missions… $m_{Envisat}$≈7800 kg!)
- Main drivers:
  - ‘Grasping’ envelope
    - Residual misalignment ±25 mm & ±2.5º about a Point of Interest (POI)
  - ‘Grasping’ robotic arm reaction loads
    - 20 N & **80 N.m** about all three axes
  - De-orbit loads
    - Steady main resultant main thrust ≈1.7 kN & main torque ≈1.2 kN.m
    - ≈ **1.7** dynamic factor for **transient** loads
  - Stiffness required during de-orbiting
    - 1.5 Hz min. stack 1st eigenfrequency
    - Angular max. deflection 0.3 deg (static) / 0.65 deg (transient)
  - Adaptability to LAR status uncertainties
    - MMOD Dents (ø2mm)
    - LAR thermal range [-140, +140] ºC → thermal expansión & effect over strength (<50% at 140ºC!)
    - Manufacturing tolerances ISO2768-mK
    - Reflective metalized polymer tapes (up to 0.127mm thickness)
    - Degraded (peeled off, ripped, etc.) reflective tape parts
    - Unknown friction properties



Clamping region early assessment

- According to SoW, stack eigenfrequency to be calculated assuming Envisat & Chaser as rigid bodies.
- However, early simplified FE modal analysis showed that the LAR compliance drives the frequency and that clamping both axially & radially is required to reach the 1.5 Hz minimum stack eigenfrequency
  - Elastic LAR, rigidly constrained at edge (180 mm from the flange)
  - Envisat & Chaser equivalent lumped masses rigidly connected to the LAR (i.e. no CLM compliance contribution)





f_1= 0.76 Hz

f_1= 1.19 Hz

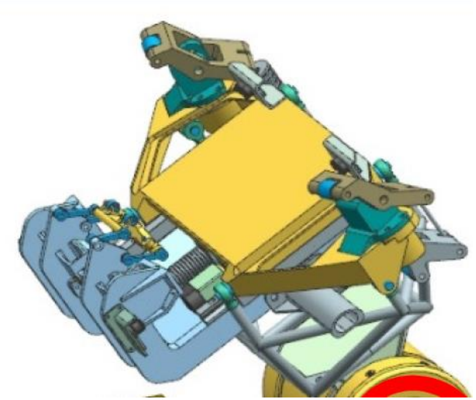
$\boxed{f_1\text{= 2 Hz}}$

Concept trade-off

- Several ‘grasping’ concepts considered for the concept selection
  - ESA emphasis in preliminary analysis support for the concepts

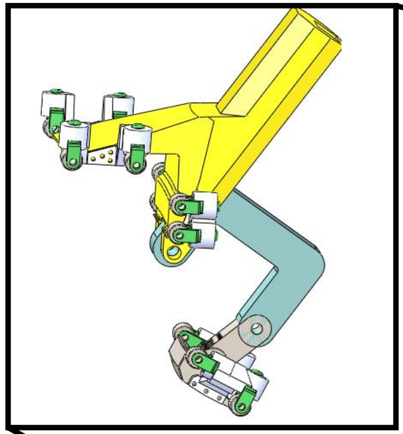
Criteria	Weight	Proposed metric
DoF actuated	20%	Max N DoF actuated / N DoF actuated
Joints	20%	Max N joints / N joints
Stiffness	30%	From 1 (worst) to 5 (best)
Mass	20%	From 1 (worst) to 5 (best)
Volume	10%	From 1 (worst) to 5 (best)

MDA adjustable spanner

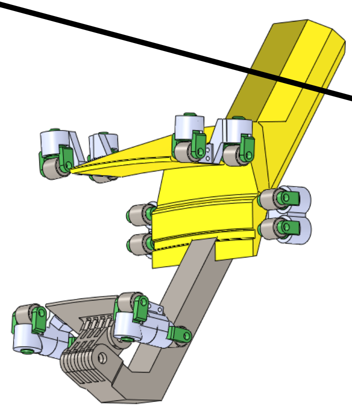


Credit: MDA

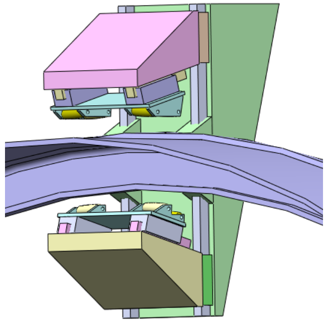
Rotary plier



Diagonal adjustable spanner

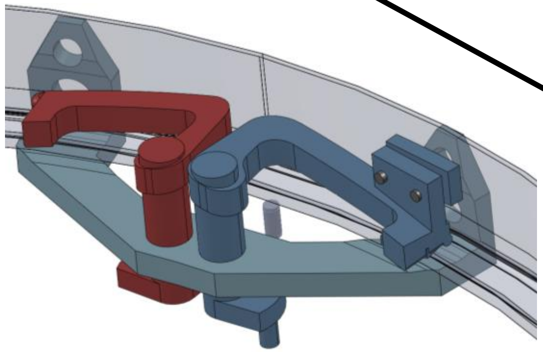


2-effect adjustable spanner

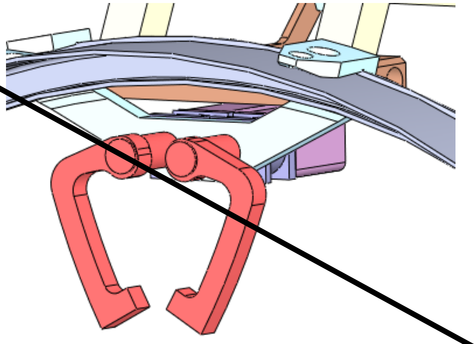


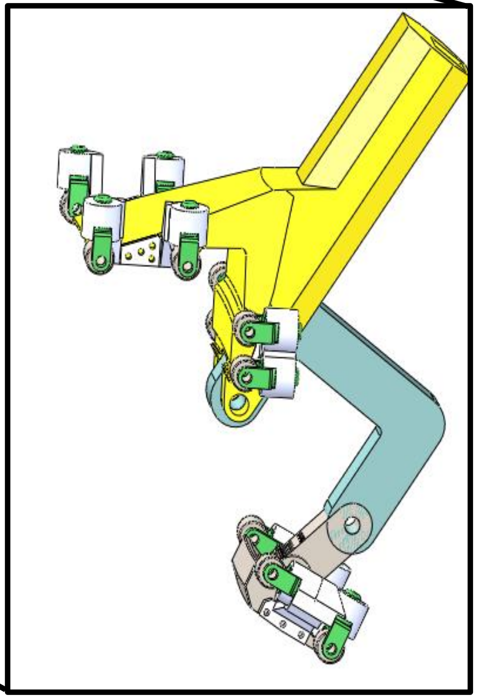
Based on OHB gripper concept

Spiral cam



Swing clamp

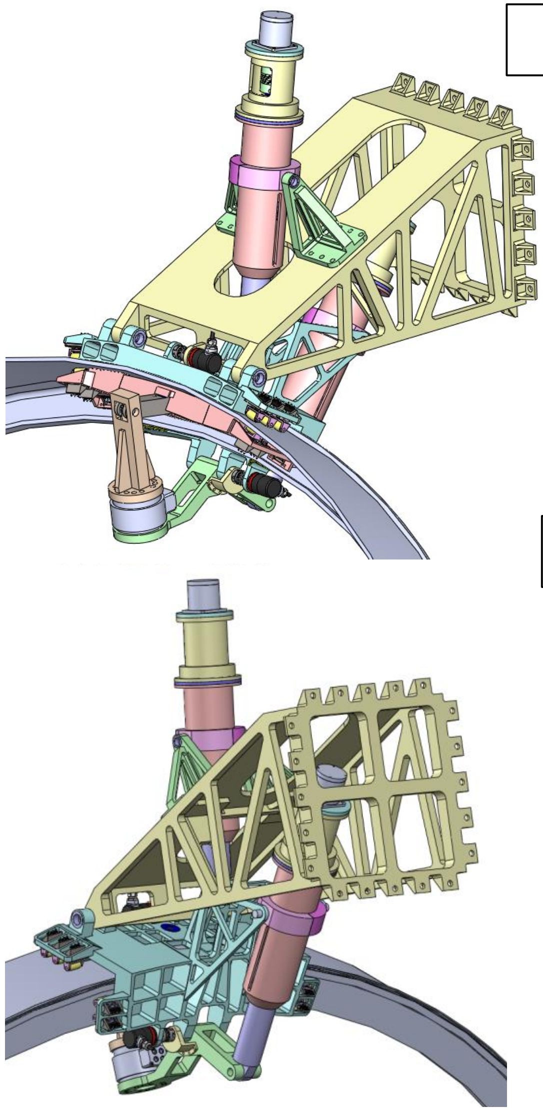




Final concept selection

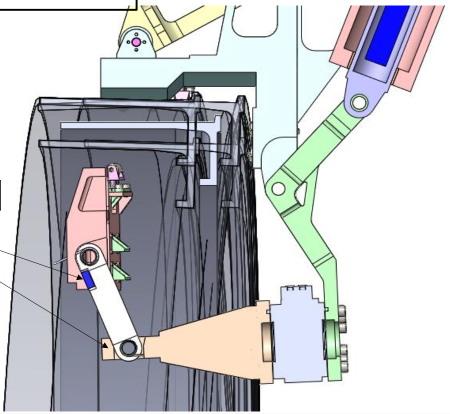
CLM Design

- The CLM has to accomplish several functionalities:



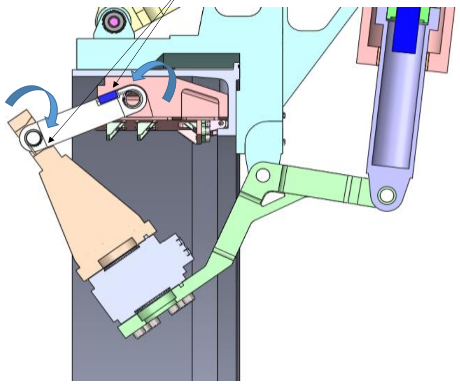
Grasping & clamping

Initial orientation hard stops



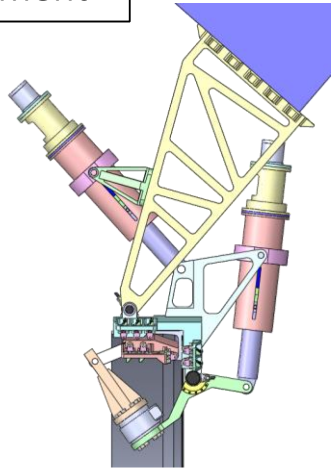
Opened arm configuration to start with the Grasping stage

Final orientation hard stops

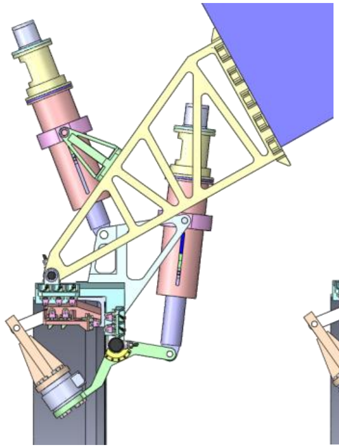


Closed arm configuration at clamping position

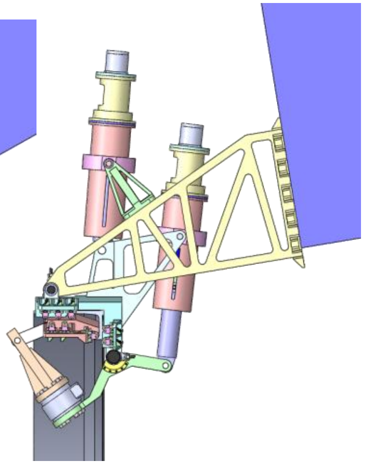
Alignment



Position +20º

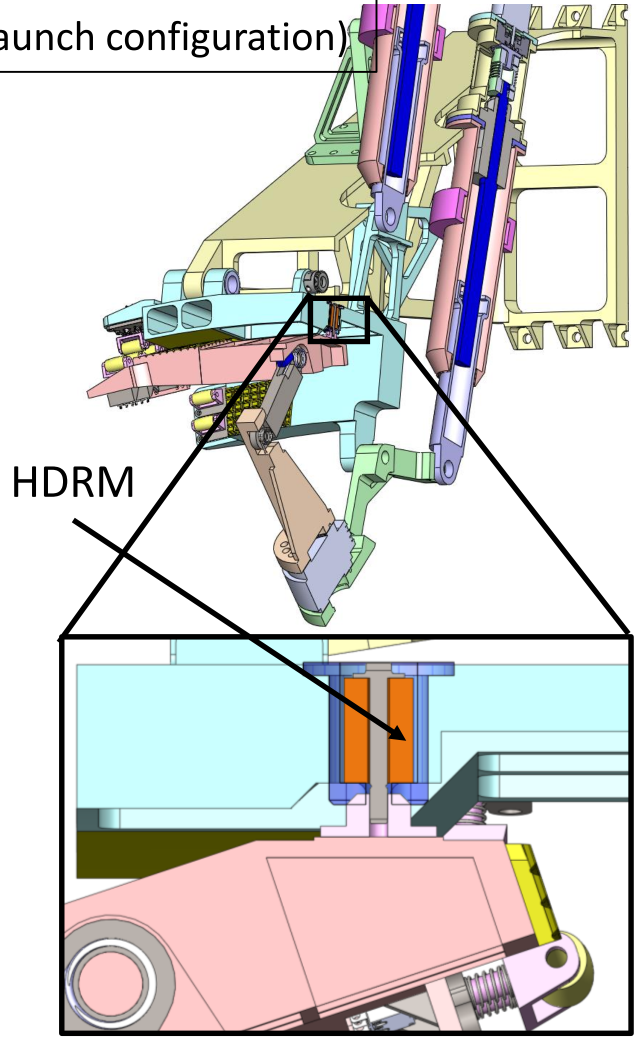


Nominal position (0º)



Position -20º

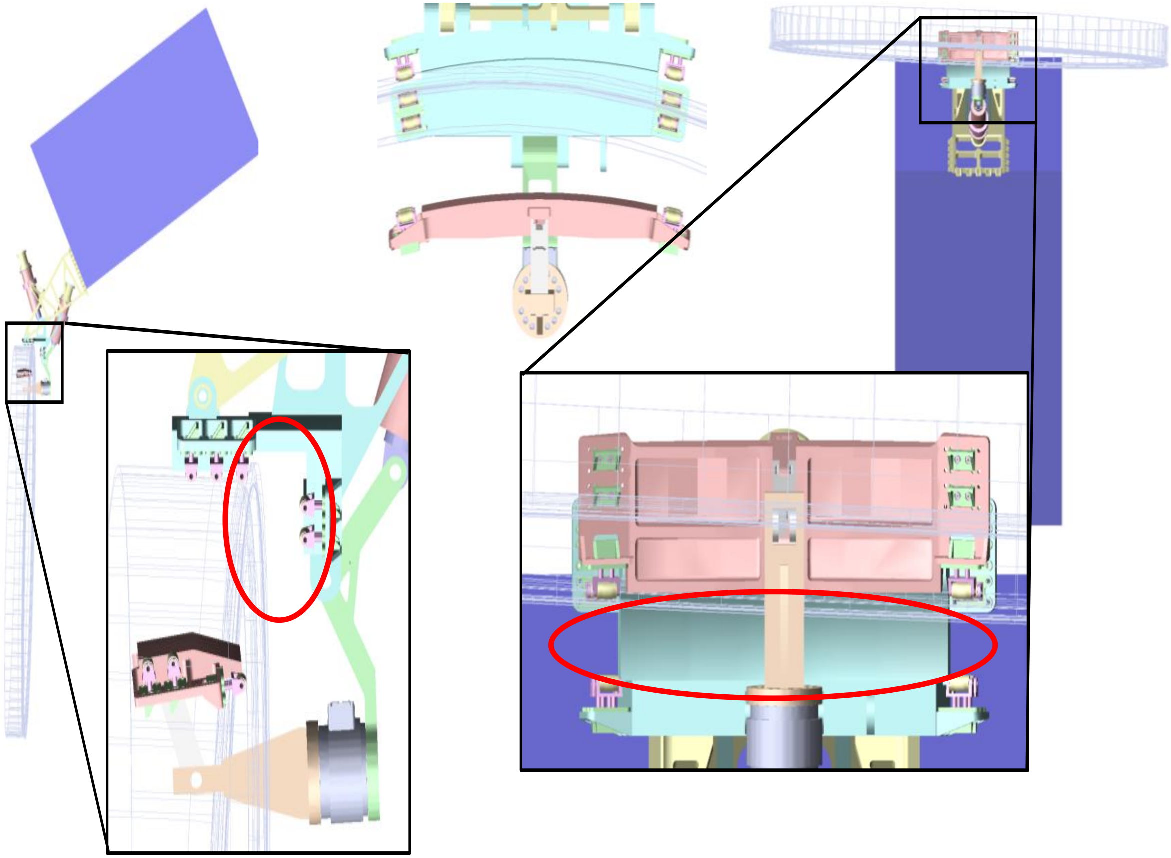
Get to orbit! (launch configuration)



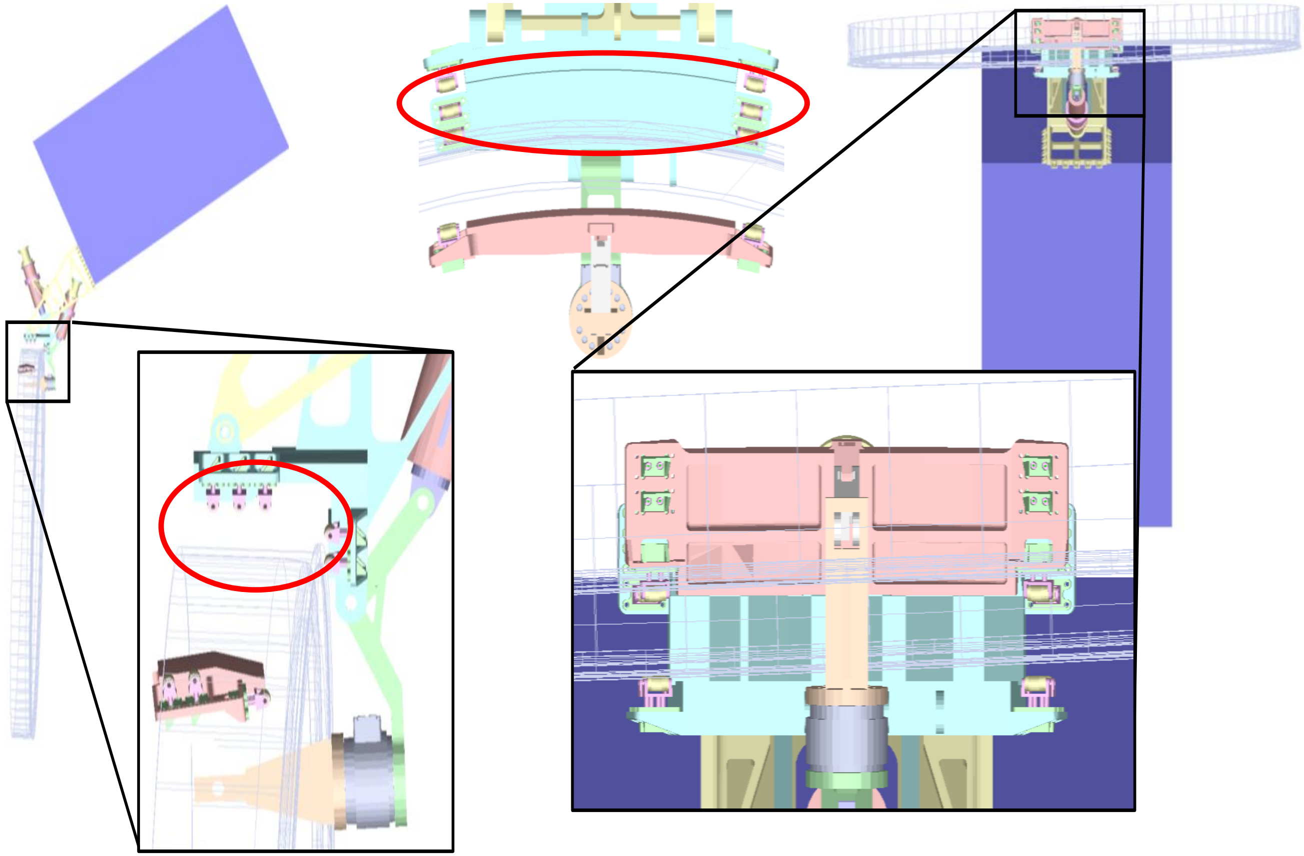
Dealing with LAR uncertainties I

- CLM grasping kinematics has to cover potential LAR residual misalignments
  - ± 25mm in every axis
  - ± 2.5 deg about every axis

Sample misaligned position 1

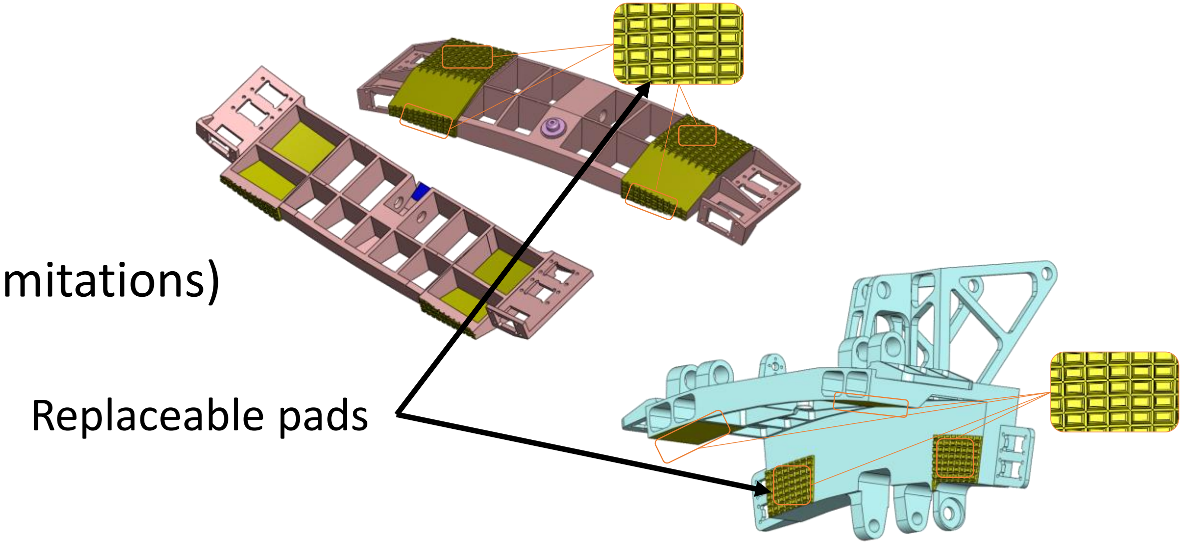


Sample misaligned position 2



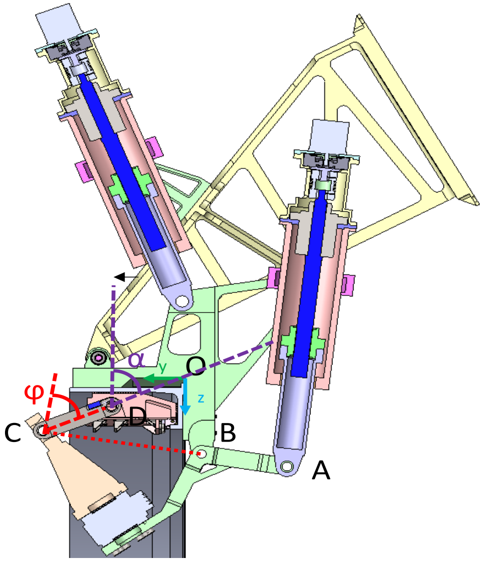
Dealing with LAR uncertainties II

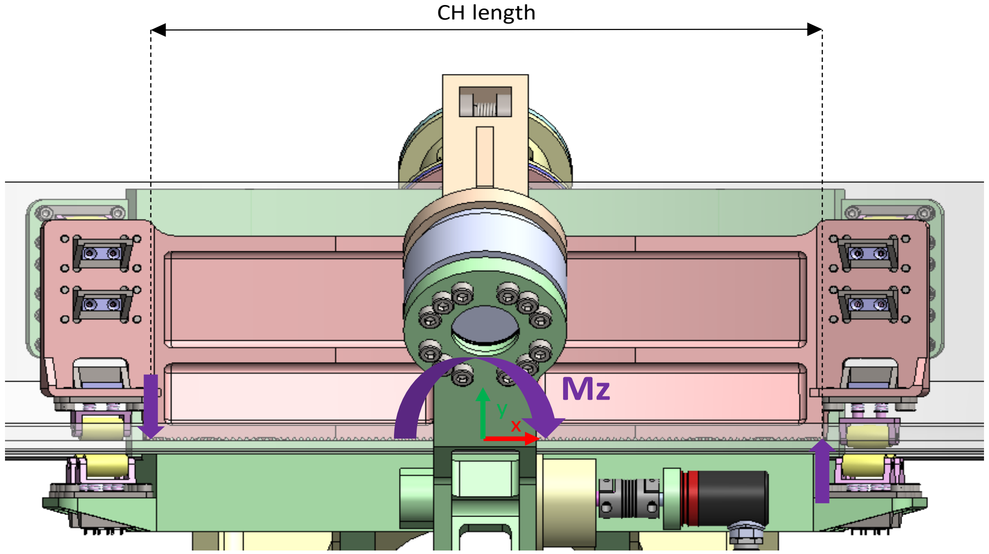
- LAR status is unknown
    - Geometrical variations due to tolerances & thermal gradients
        - Pivots at the contact part (Clamping Hand) to allow compensation of axial & radial geometry variation
        - Curvature variation will change the lines of contact
            - Smaller effect (<0.4% curvature change) → to be compensated by elastic deformation
    - Unknown friction properties
        - Retractable rollers provided to minimise friction contribution during misalignment compensation
    - Potential MMOD damage
        - Discrete contact regions at CH & MF parts
        - Different patterns to be analysed and tested if suitable at the contact regions
            - Sample approaches:
                - 'fakir mattress'
                - 'elastic keyboard'
                - 'soft pad'
                    - E.g. PTFE (potential stiffness limitations)

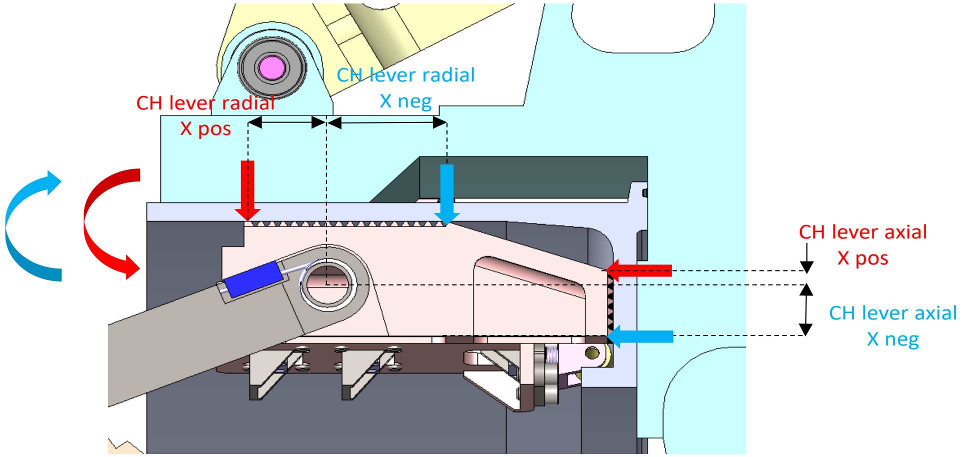


Dealing with RA reactions

- Leverage required to compensate Robotic arm reaction torque & forces
  - Main contribution to resistive efforts in actual configuration







Torque around Z		
CH length	400	[mm]
Axial force	200	[N]

Torque around X		
CH lever radial xpos	30	[mm]
CH lever axial xpos	5.7	[mm]
CH lever radial xneg	42.36	[mm]
CH lever axial xneg	20	[mm]
Rrad_x_extremes	1008.39	[N]
Rax_x_extremes	2487.42	[N]
Resultant _extremes	**2684.05**	**[N]**

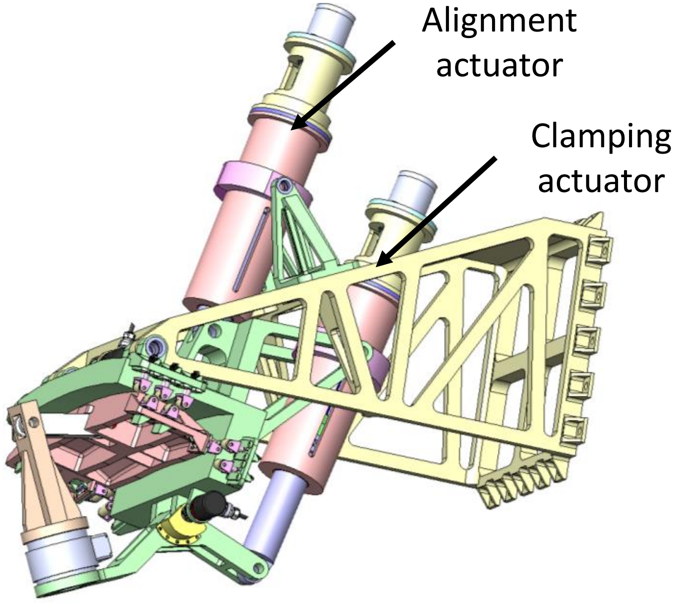
Currently under optimisation!

Actuators

- Baseline: custom linear actuator
  - Specific requirements limiting applicability of COTS or other space applications heritage (TVGs)
    - High stiffness required
    - No backlash allowed
    - No friction breaks allowed
    - High unpowered detent torque required
    - Additional friction de-rating (affecting potential non-backdrivability)
  - Detailed ECSS motorisation margin calculation performed
    - Tailored to each actuator
    - Efficencies as lossess (based on ESA AMDC course formulation).
    - Alignment examples (alignment operation & detent):

$$T_{\min\_hold} = MF\left[\underbrace{\left[\underbrace{\left[\frac{1.25}{MF}\left(m_L\left(\frac{p_h}{2\pi}\right)\overset{\alpha_{sp}=\alpha_G=\alpha_M/i}{\frac{\propto_M}{i}}\right)+K_R T_{R\_ext\_brngs}\right]}_{\text{External loads reflected at the spindle}}\left(1+\underbrace{K_{sp}\left(\frac{1}{\eta_{sp}}-1\right)}_{\text{Spindle efficiency as losses}}\right)+\frac{1.25}{MF}I_{sp}\frac{\propto_M}{i}+K_R T_{pr\_sp\_nut}+K_R T_{sp\_sup\_brng}\right]}_{\text{Loads at the spindle}}\left(\frac{1+\underbrace{K_G\left(\frac{1}{\eta_G}-1\right)}_{\text{Gearbox efficiency as losses}}}{i}\right)+\frac{1.25}{MF}\left(I_G+I_M+I_{brake}\right)\propto_M+K_M T_{brake}\right]$$

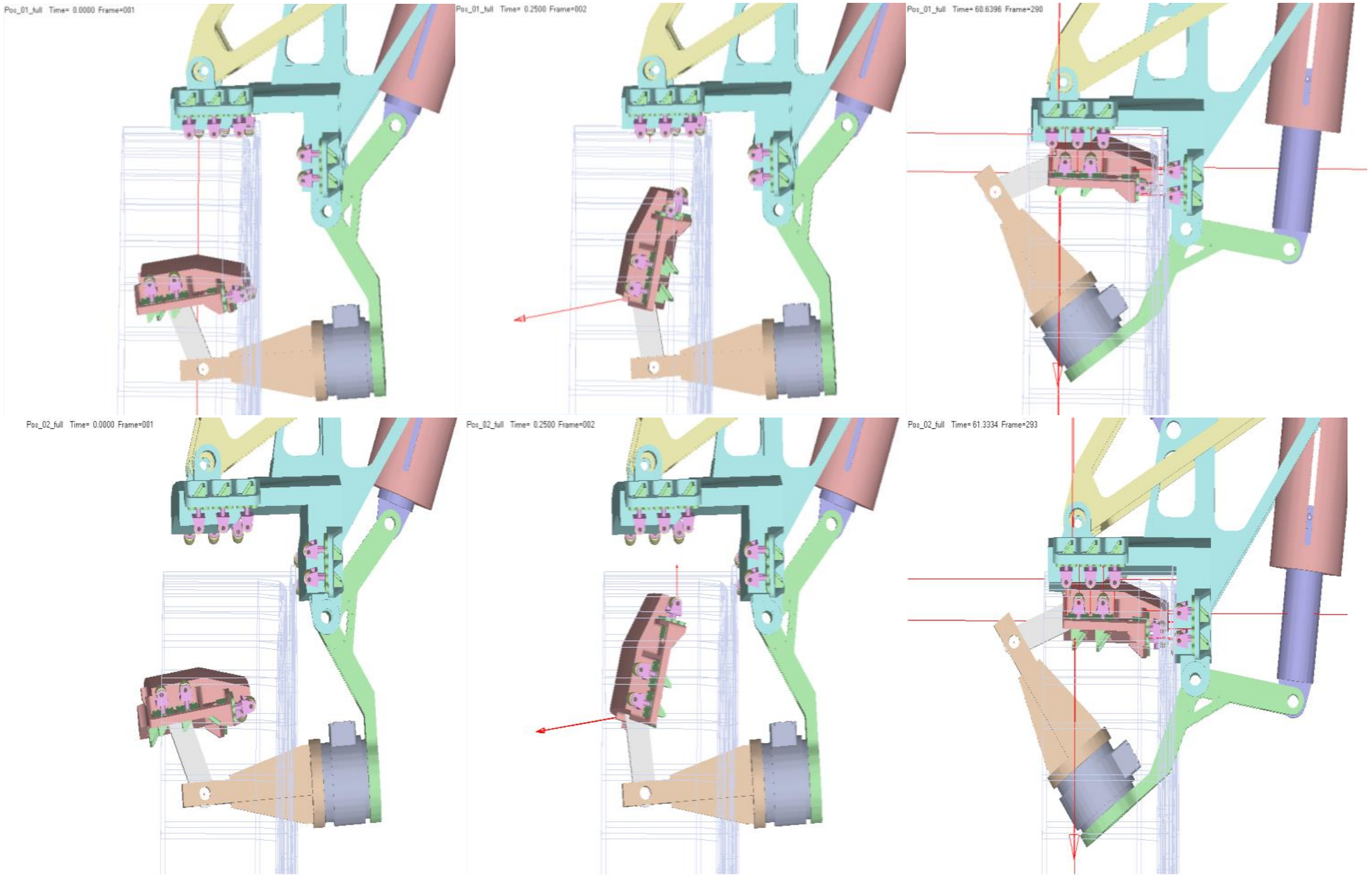
$$T_{detent\_min} = K_M\left[\left(MF\,K_I\left(F\frac{p_h}{2\pi}\right)\eta'_{derated}-\left[\frac{1}{K_R}T_{R\_ext\_bearing}+\frac{1}{K_R}T_{pr}+\frac{1}{K_R}T_{pr\_sp\_brng}\right]\left(1+\frac{1}{K_G}\left(1-\eta_G\right)\right)\right)\frac{1}{i}-\frac{1}{K_M}T_{brake}\right]$$



- Grasping/clamping actuation time (requirement: 20s) to be improved as part of the overall optimisation

CLM MB analysis

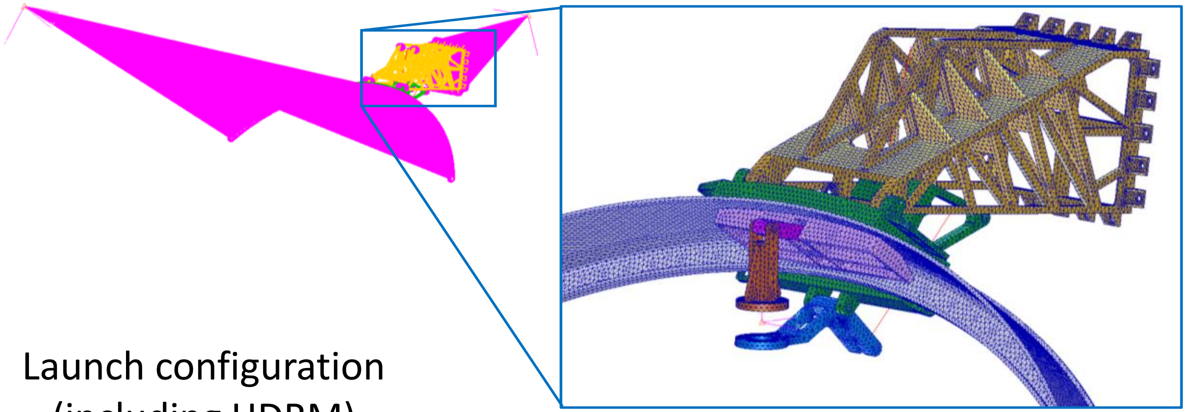
- Grasping & clamping functionalities simulated by MB analysis including
  - Inertial effects
  - Robotic arm reaction torques
  - Retractable roller spring forces
  - Contact (including contact friction)



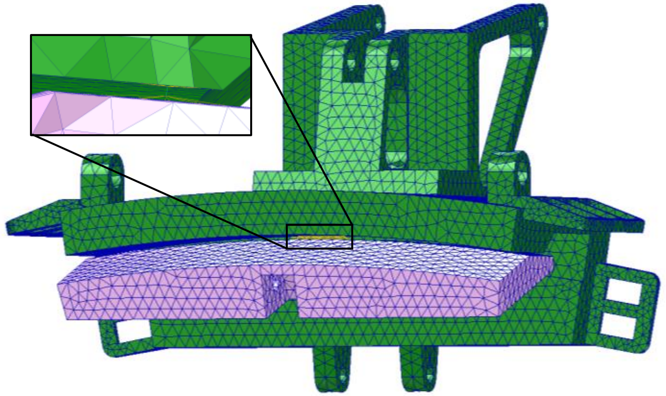
CLM FE analysis

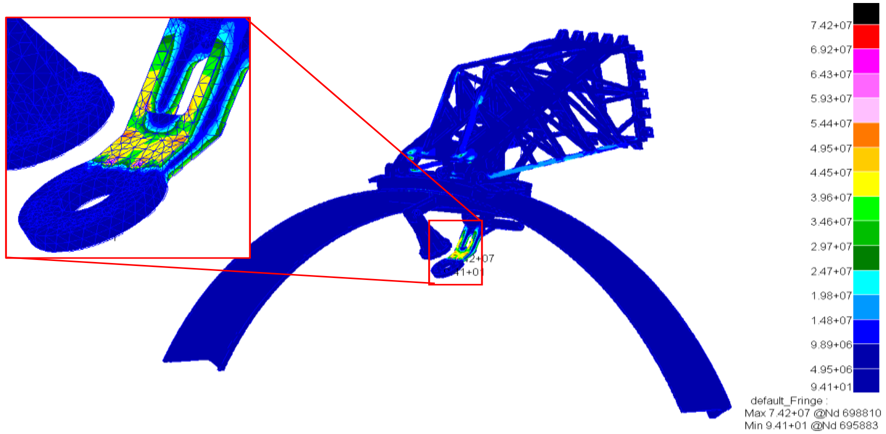
- De-orbiting & launch scenarios analysed by means of FE model
  - Nastran SOL 400 used (sequential analysis preload + modal / preload + de-orbiting)
    - Including also thermal range to assess effect on dimensional variation

Stack model - Several configurations (+20º/0º/-20º)

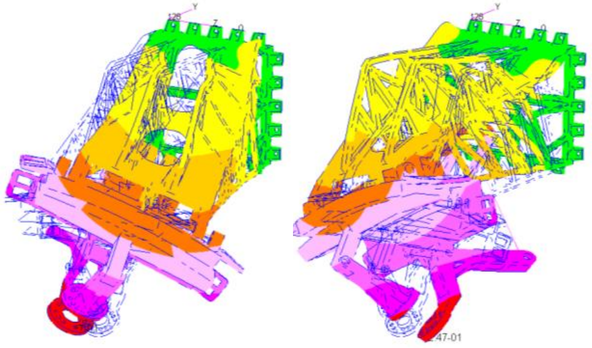


Launch configuration (including HDRM)





-20º alignment
De-orbiting loads
VM stress

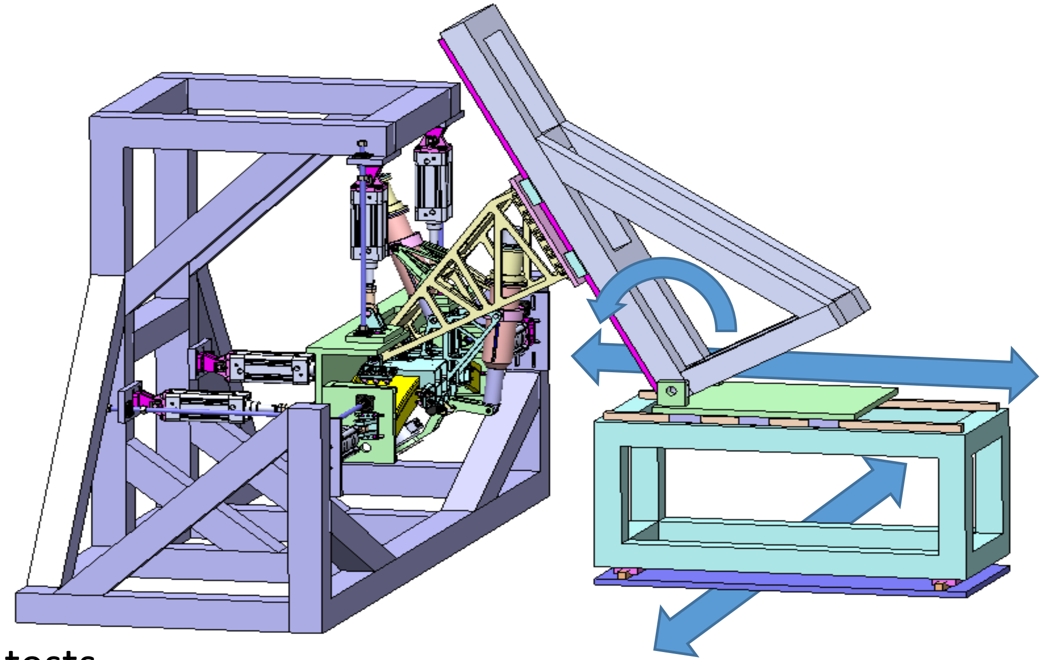


Launch configuration 1st eigenfrequency: 42 Hz (driven by RTF stiffness)

General performance in line with the requirements
Improvement areas identified and under implementation along with overall optimisation

Test setup I

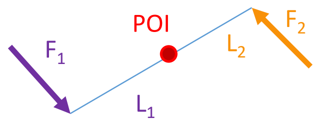
- Almost a project on its own… Challenging requirements:
    - Grasping & clamping performance testing: the setup has to be able to provide
        - Controlled constant loads…
        - From misaligned positions…
        - Allowing compensation of the misalignments…
        - … within budget!
    - De-orbit performance testing:
        - Larger loads (from 80 N.m to ≈1.7 kN.m)
        - Alignment configurations

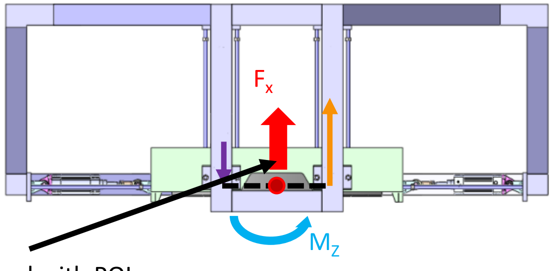


- Test setup design:
    - System based on linear actuators
    - Provisions for different alignment angles
        - ‘fixed’ after alignment operation for the grasping & clamping tests
    - Position & orientation of the LAR dummy sections by setting adjustable mechanical stops
        - Pre-calculated by analysis for the positions to be tested
    - Equivalent efforts generation at the LAR dummy by setting the forces at the linear actuators
        - Combinations of torque & force can be achieved by adjusting the pairs
        - Potential limitations in simulation inertial loads

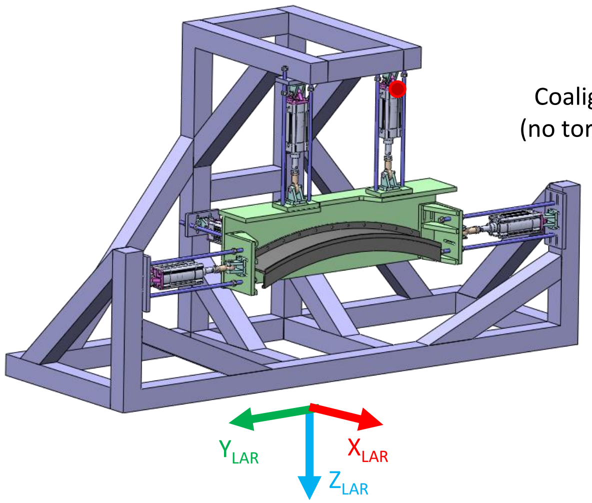
Test setup II

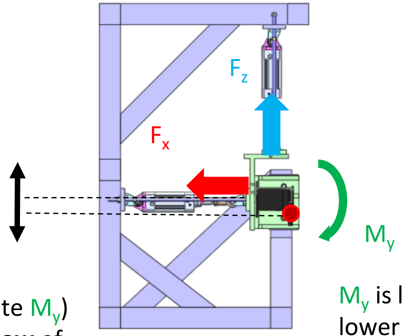
- Working principle: force settings at each pair of cylinders generates:
  - Required resultant force in the plane $F_{req}=F_1-F_2$
  - Required torque $M_{req}=F_1L_1+F_2L_2$ orientation depending on the alignment/offset w.r.t POI
  - Multiple possibilities; the following scheme is the preliminary setting:



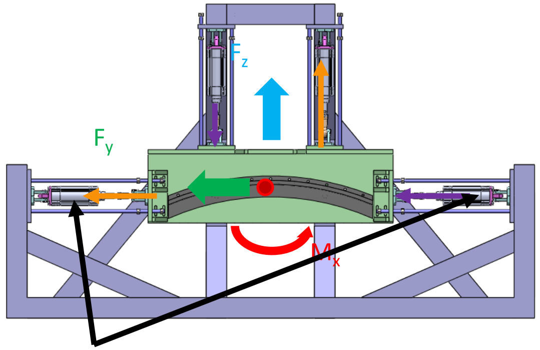


Coaligned with POI
(no torque generated)



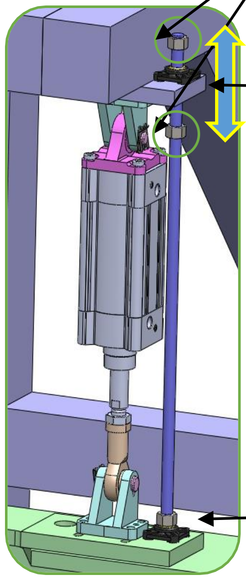


Adjustable distance (to regulate M_y)
And/or use of an **additional row** of
actuators (if the leverage goes too high)



Coaligned with POI
(no torque generated)

M_y is likely the highest torque→ using these actuators allows for lower demands on the structure (compared, for instance, with using the vertical cylinders)



Axial stroke limits
(adjustable)

Spherical bearing 02
3 rotations and axial
displacement allowed

Spherical bearing 01
(3 rotations)

Conclusions

- Clamping mechanism pre-development activity for e.Deorbit mission on-going
  - **TRP** activity lead by AVS with the collaboration of OHB
  - Not the typical ADR scenario (≈7800 kg)… but serves as a ‘worst case’ from the ADR **CLM** perspective
  - High complexity of the task due to uncertainties regarding LAR status & high structural capacity required
  - Design & MAIT of **breadboard** up to **TRL 4**

- Valuable **lessons** to be learned (particularly in difficult to simulate issues as MMOD, etc.) testing, with potential application to other ADR & IOS missions

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Thank you for your attention!

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