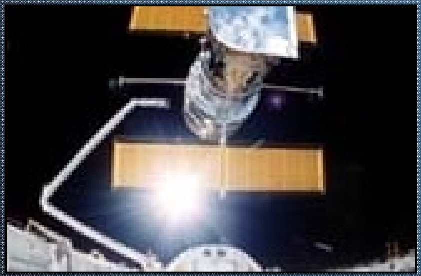
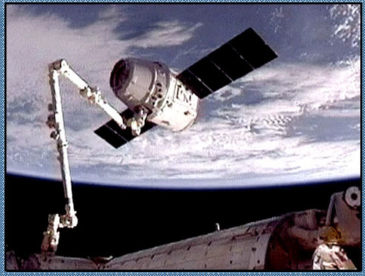


The LAR Capture Tool and the Clamping System: Mechanisms for the Capture and Berthing of Envisat

John Ratti, MDA

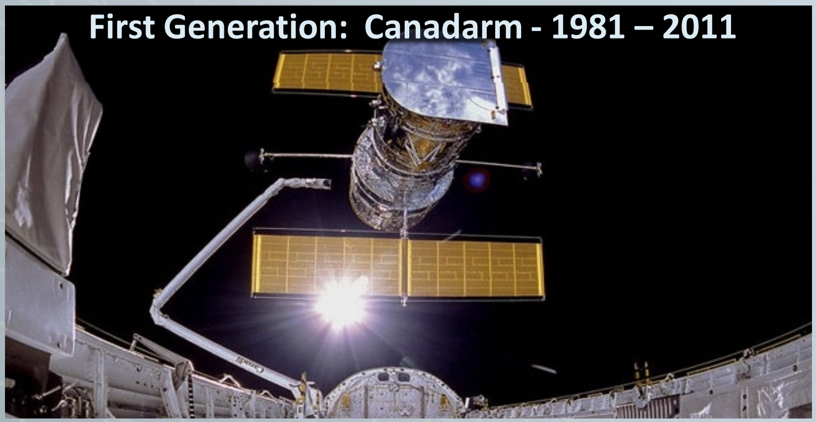
Clean Space Industrial Days (23-27 May 2016)

www.mdacorporation.com

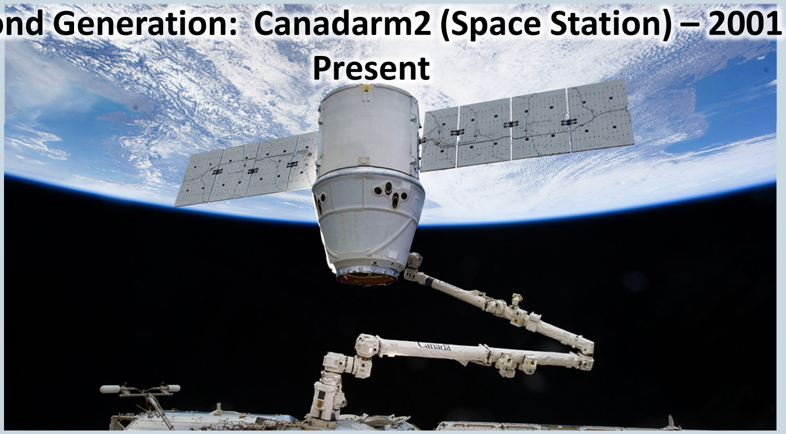
The LAR Capture Tool and the Clamping System

- Concept of Operations
- The LAR Tool Design Prototype
- Clamping System Design Concept
- Technology Roadmaps and Next Steps

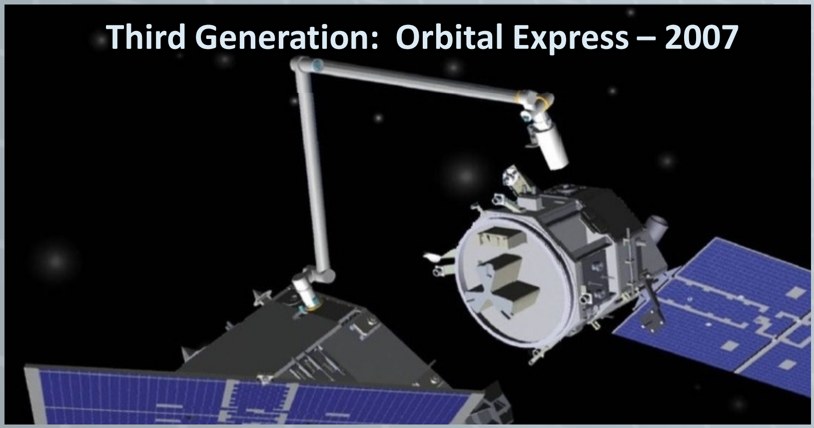
The first Step to Servicing or De-Orbiting is to Capture the Spacecraft: On-Orbit Robotic Capture History…..



Tele-Operated by an On-Board Astronaut



Tele-Operated by an Astronaut, Now also Ground Controlled. Increasing Level of Automated Response. Captures still Human in the Loop.



Full Autonomous Operation, Failure detection and abort modes. Still a Prepared Interface (Grapple Fixture / Target)

Mitigate latency, Full Autonomous Operation, Failure detection and abort modes. Unprepared interface, uncooperative or tumbling client

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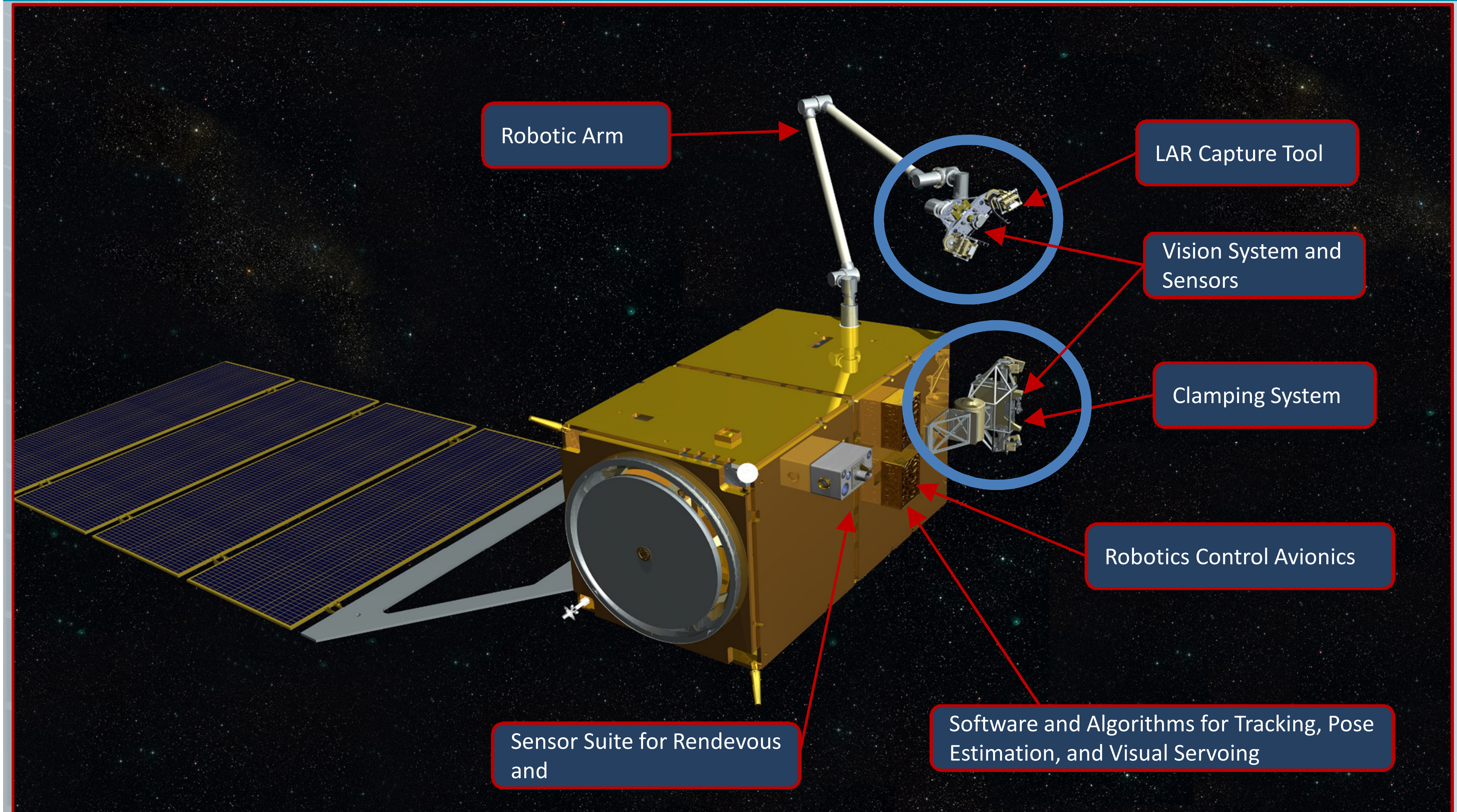
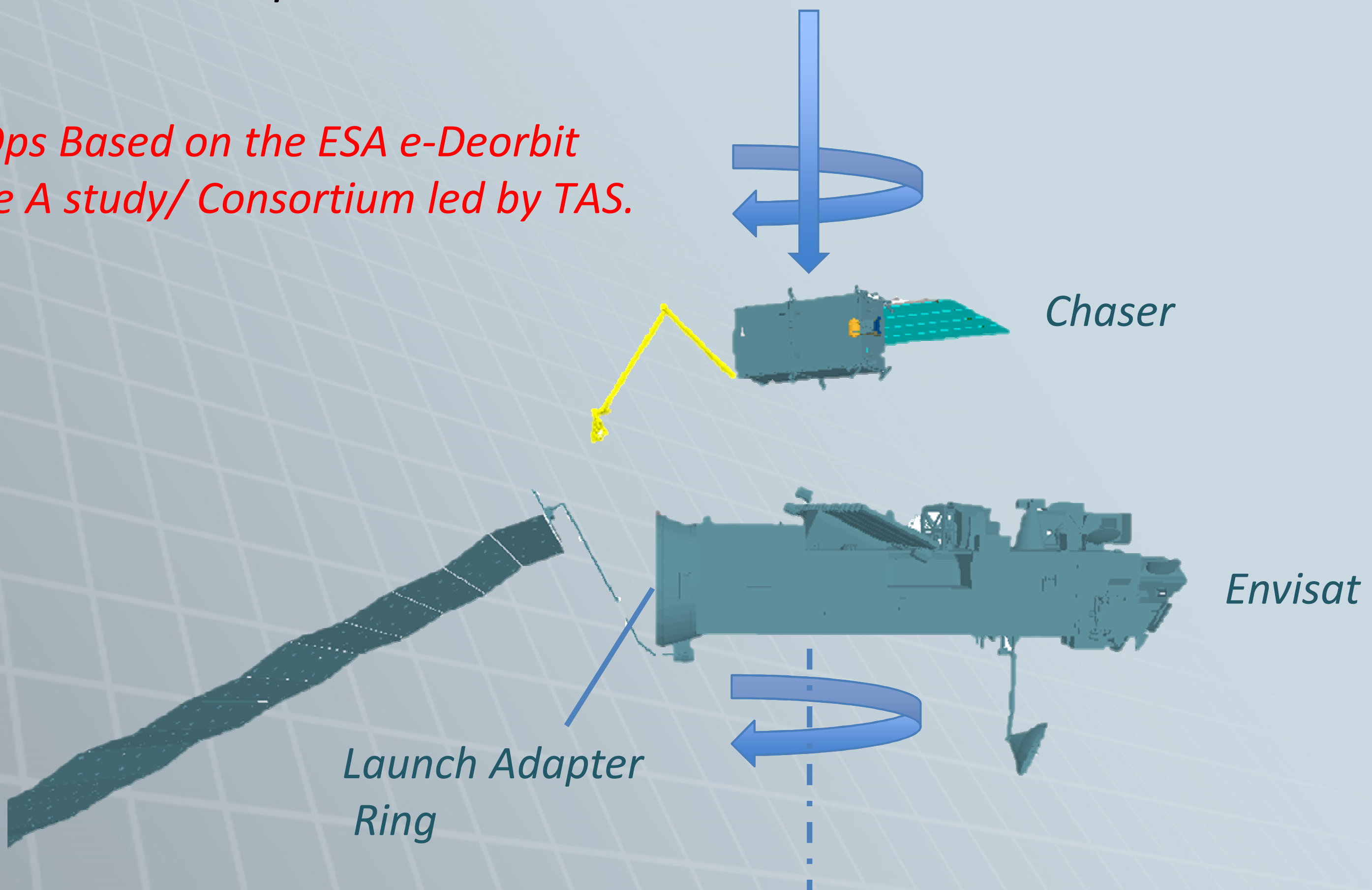
Capture and Berthing – The Robotics Hardware



Envisat Capture - Robotic Concept of Operation

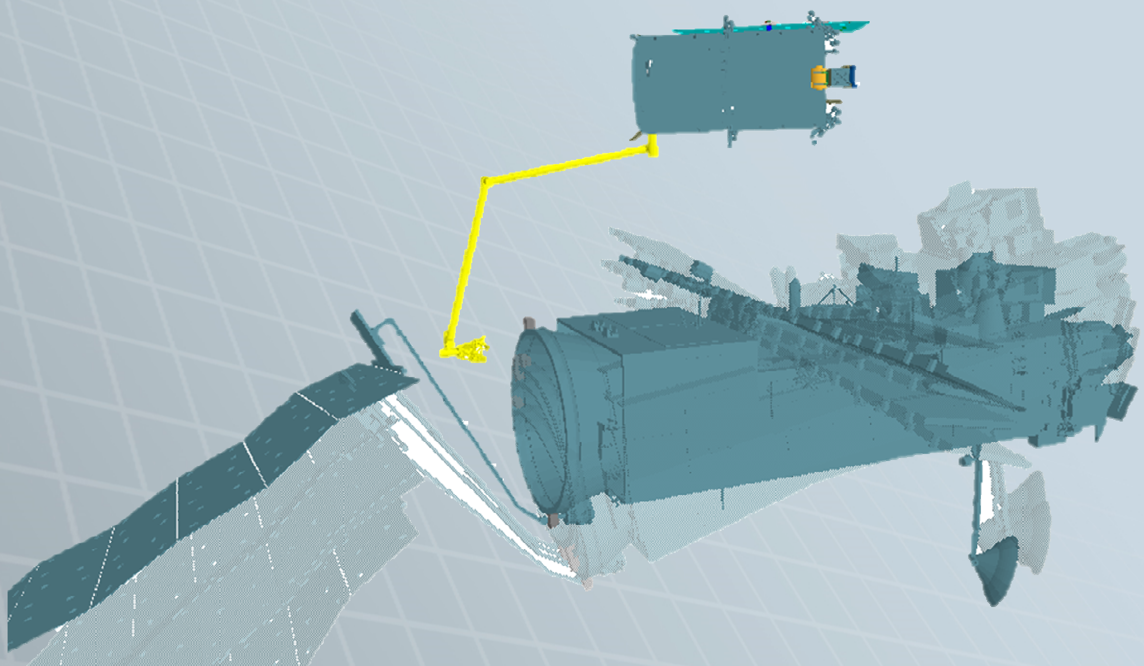
1. *Approach Envisat down its spin axis, hold at about 2 meters*
2. *Observe its spin and match rotation rates*

ConOps Based on the ESA e-Deorbit phase A study/ Consortium led by TAS.



Envisat Capture - Robotic Concept of Operation

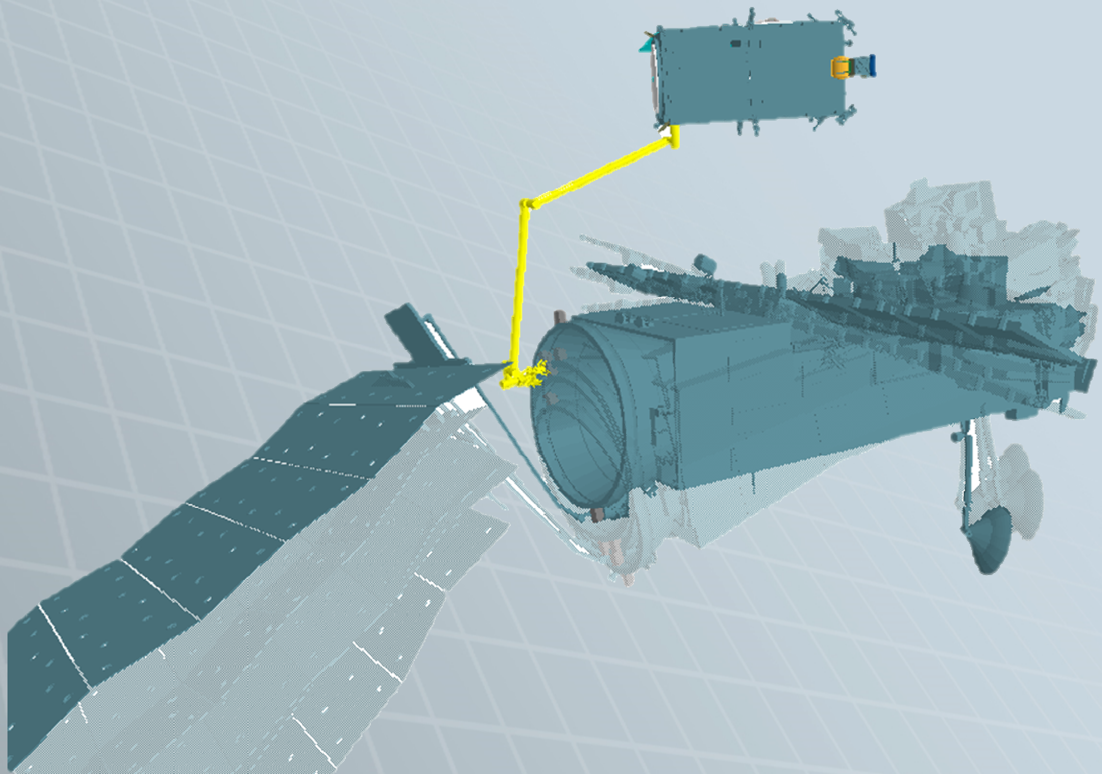
3. *Observe LAR precession, Move the arm to "Ready for Capture" position, 0.5 m above the LAR's closest precession point.*
4. *Wait for LAR to enter sensor's Field of View. Achieve sensor lock, track LAR until at closest precession*



With the chaser performing angular rate matching, due to precession and nutation, Envisat's motion will appear to the manipulator as a low frequency wobble (estimated 10 degree amplitude and 200s period)

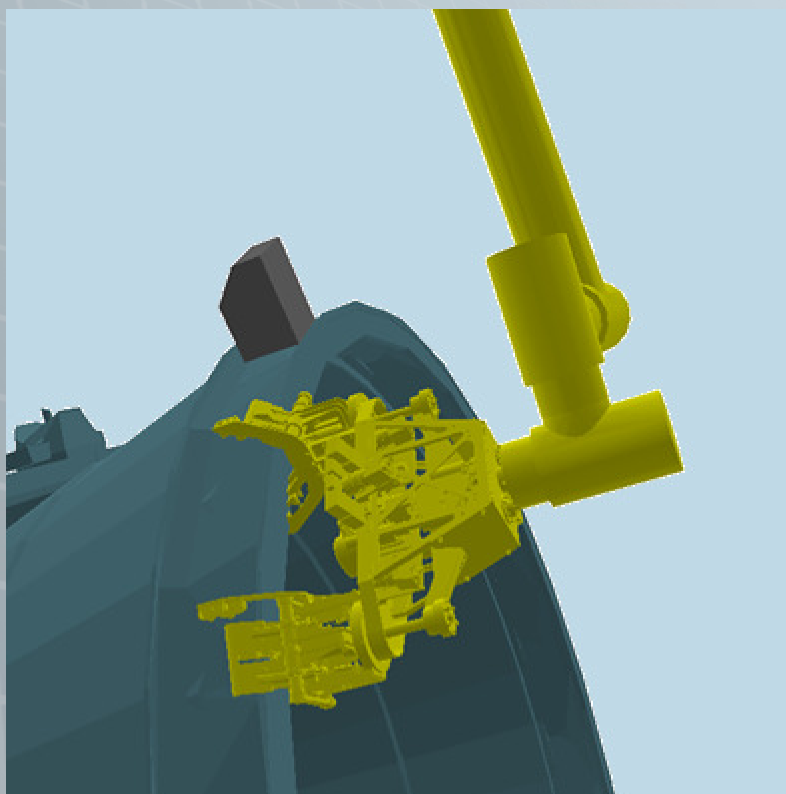
Envisat Capture - Robotic Concept of Operation

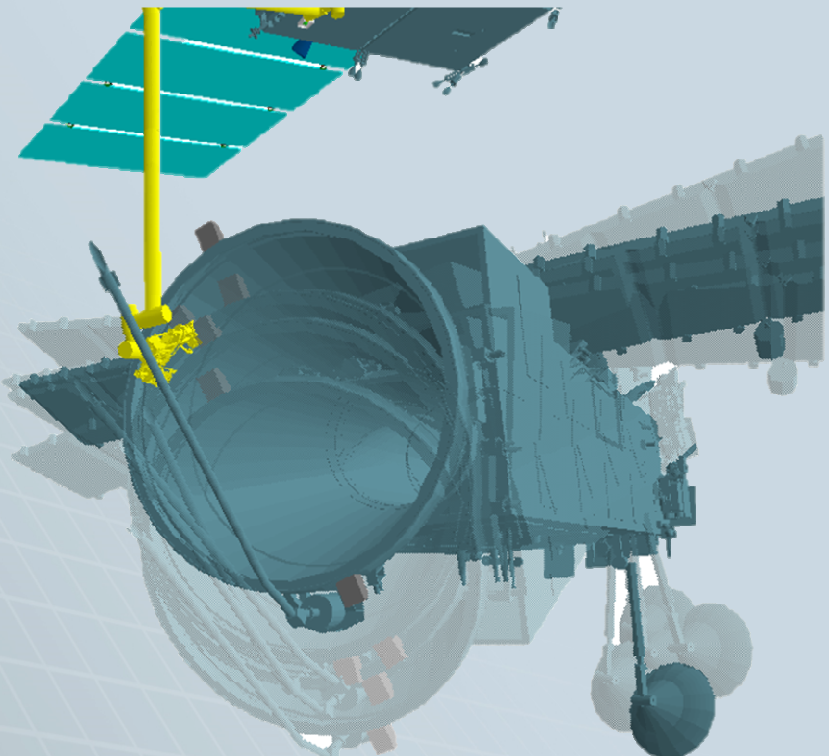
5. *Wait for "Go for Capture" command, then proceed with autonomous capture of LAR*
   - *Abort possible until contact is made*



Envisat Capture - Robotic Concept of Operation

6. *Autonomous Capture of Envisat's LAR with Tool*
7. *Remove relative rates between chaser and target*

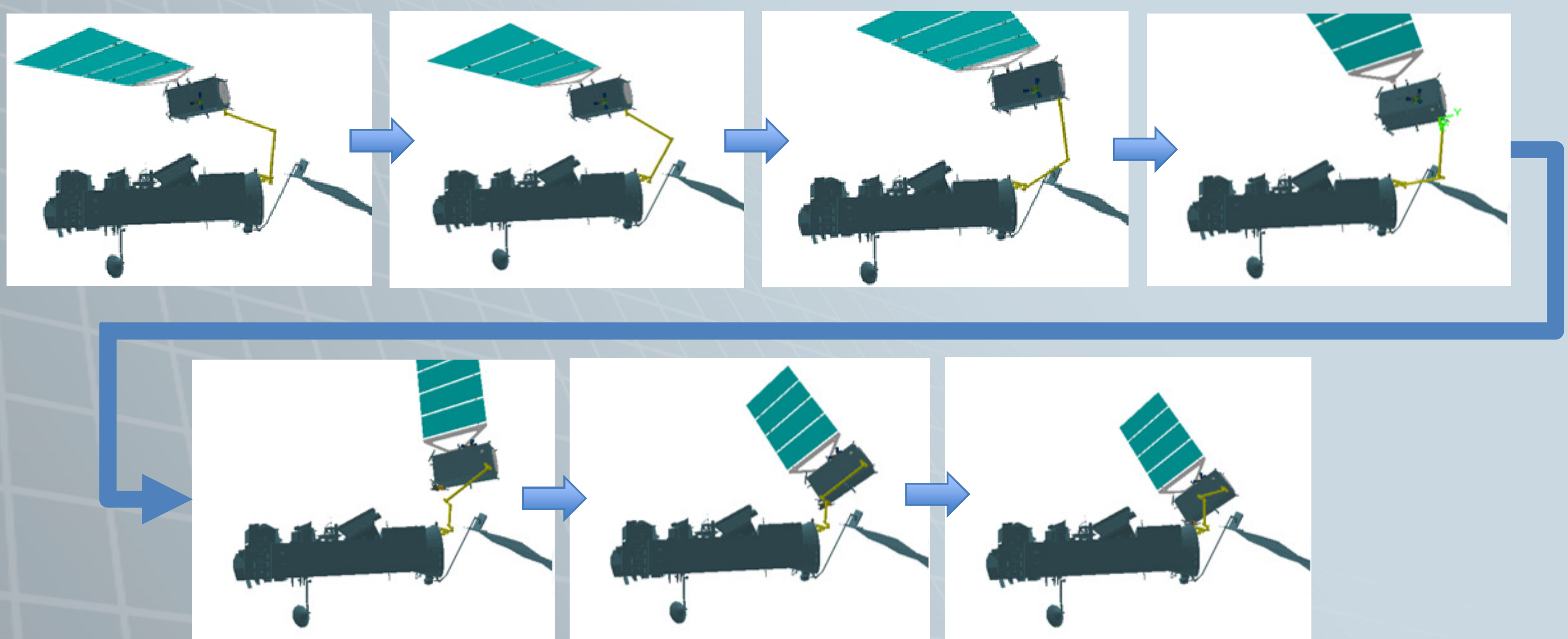




Envisat Berthing - Robotic Concept of Operation

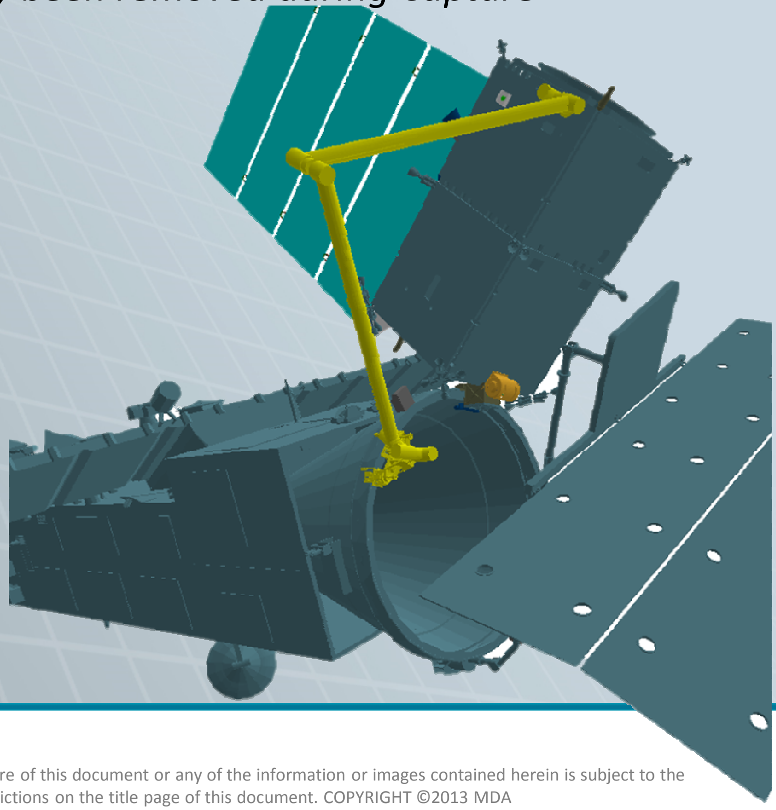
Berthing Commences once Envisat has been captured by the robotic arm

1. *Re-Position the Chaser using the Robotic Arm to bring the Clamping System to the Envisat LAR Ring*

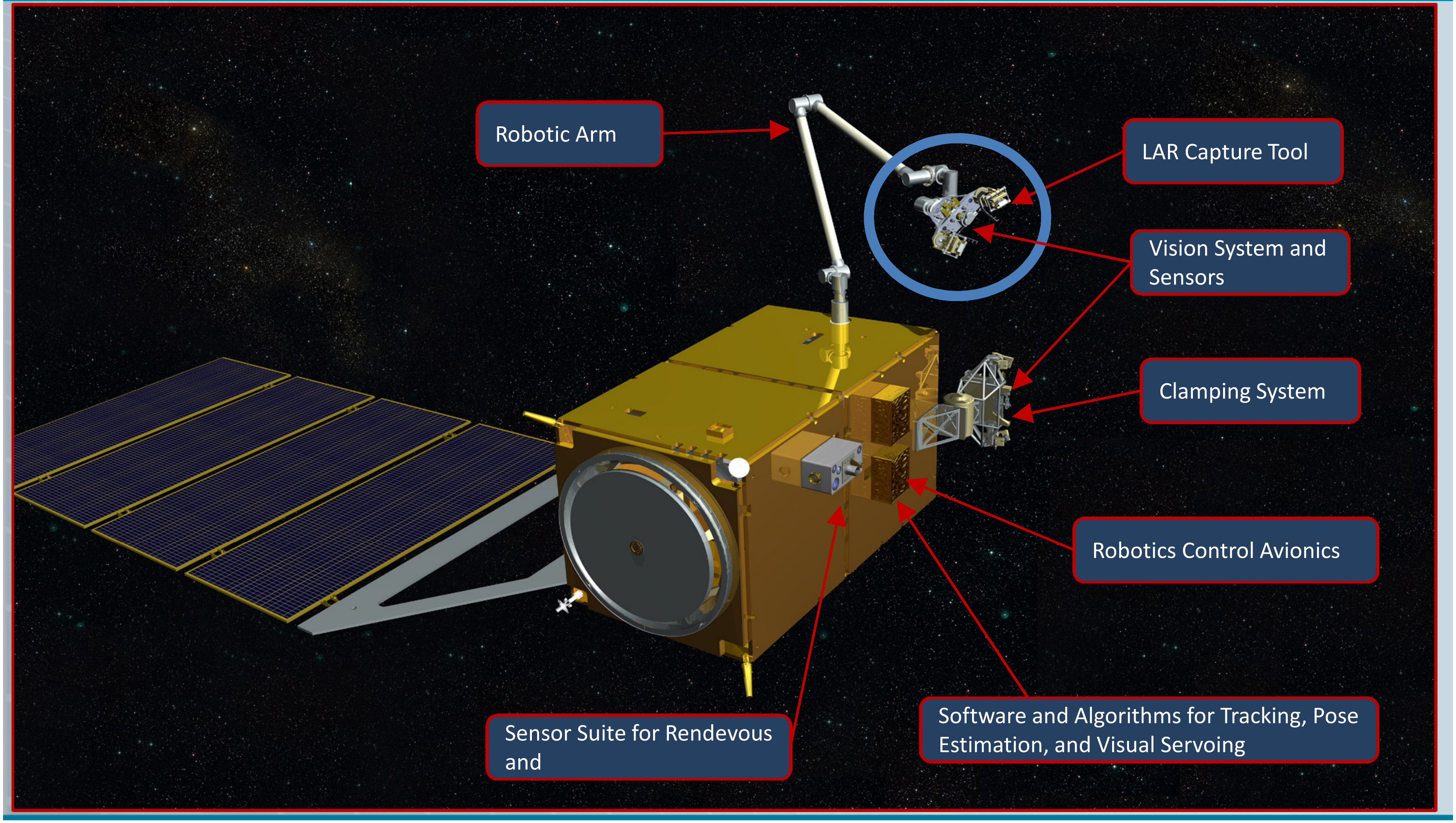


Envisat Berthing - Robotic Concept of Operation

2. *Align the Docking Clamp to LAR (includes a vision system)*
3. *The clamping mechanism is used to secure the Chaser to Envisat by clamping onto the LAR*
   - *Not time critical*
   - *Relative rates have already been removed during Capture*



The Launch Adapter Ring (LAR) Capture Tool



LAR Tool – Key Driving Requirements

The main requirements that drive the design of the LAR capture tool:

1) **LAR Compatibility:**
   - The ability of the tool to capture multiple styles of LARs
2) **Capture Loads:**
   - The expected loads that the tool must be able to withstand when captured
3) **Capture Time:**
   - The shorter the capture time, the less tracking of the LAR the arm and vision system need to do during capture, reducing arm length and increasing capture envelope.
4) **Capture Envelope:**
   - The misalignments that the tool must be able to allow and still be able to achieve capture
5) **Failure Detection and Recovery:**
   - The tool system must detect a failure or missed capture, and recover
   - Electrical / Sensor Redundancy
6) **The LAR Has no Vision Target:**
   - Tool must include sensors that allow for LAR location and pose to be determined (by a human or autonomously) under unpredictable lighting and with possible relative motion.

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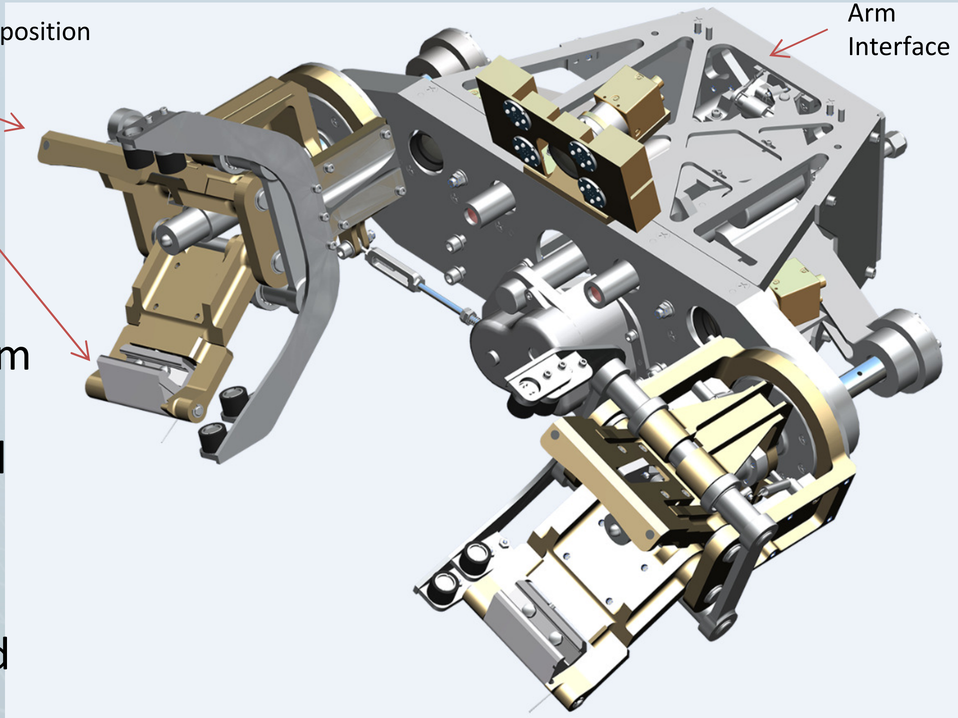
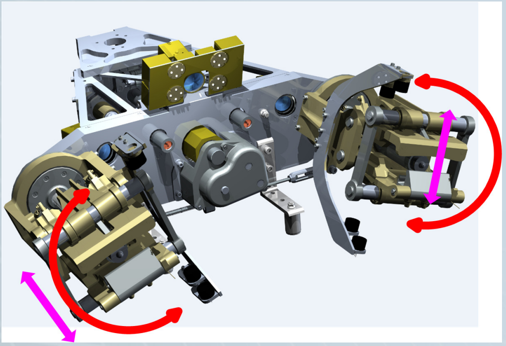
LAR Capture Tool Overview

The MDA design incorporates the following main features:

- Dual latch mechanism concept capable of accommodating variable diameter LARs - from 937mm diameter to a straight beam.
- Adaptive Jaw tips for rigid grasping of several LAR profiles (optional).
- Contactless sensors for determining when a LAR has entered the capture envelope of the tool as well as detecting a successful or failed capture attempt
- A two stage capture operation consisting of a fast acting (<0.5 second) soft capture and a slower (10.5 seconds) operation to seat and rigidize the LAR in the tool
- A solenoid and single motor drive performs the capture operation.

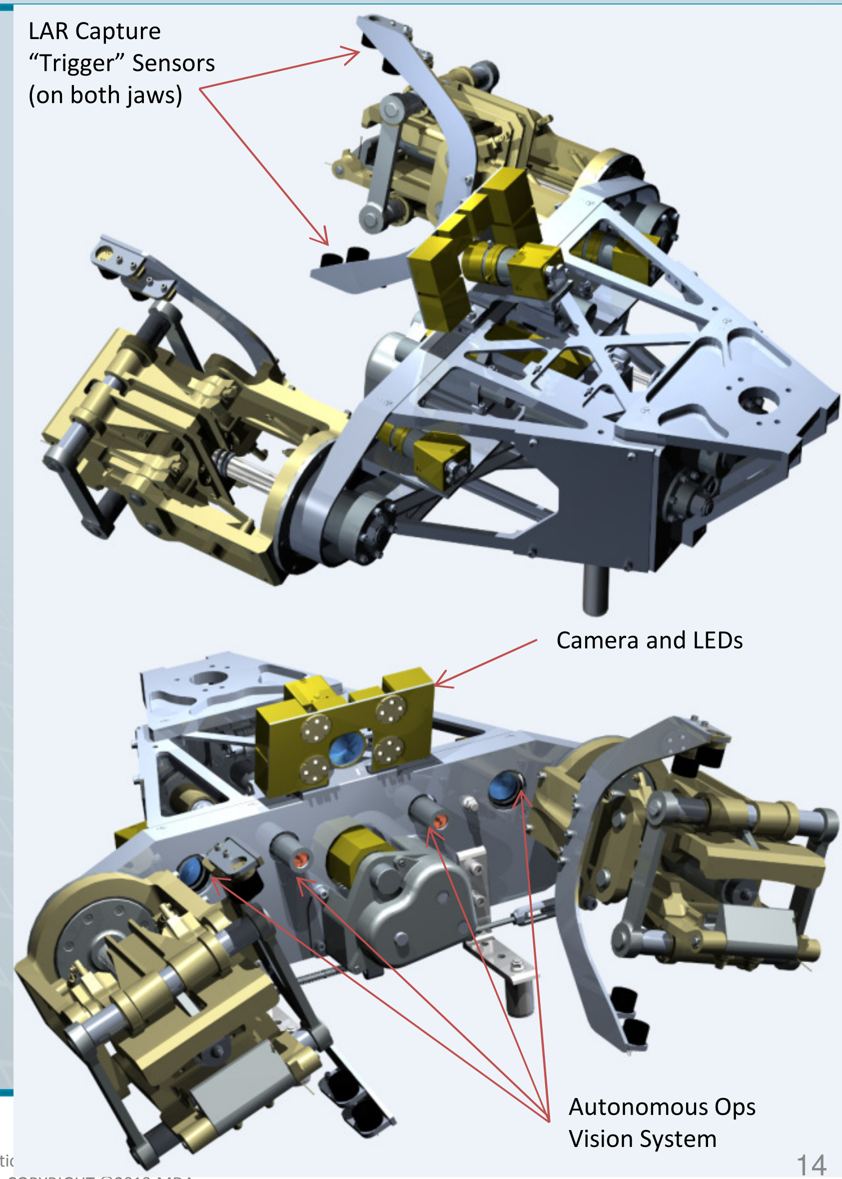




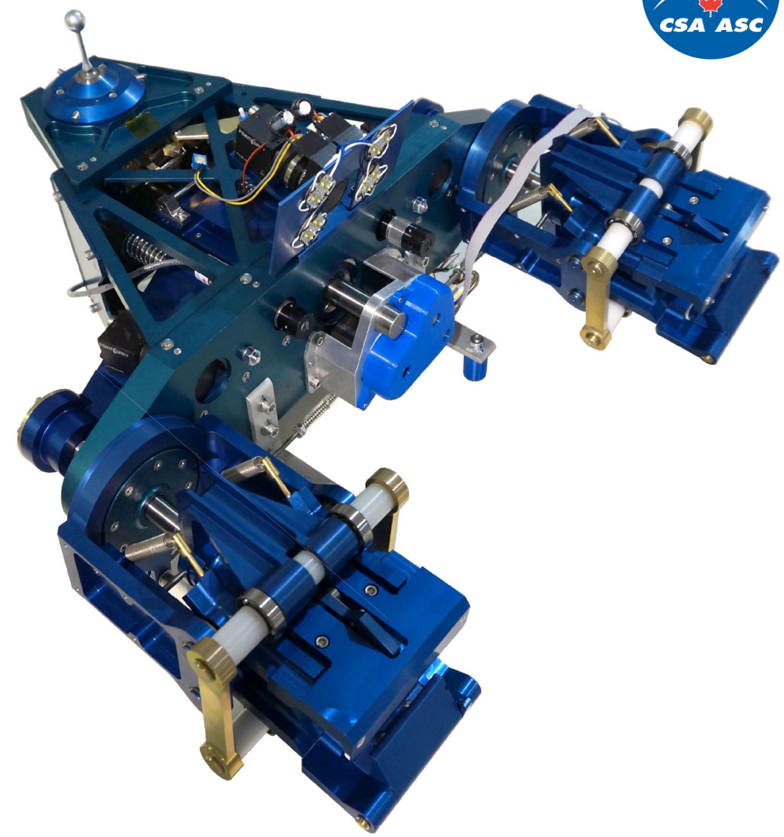
LAR Capture Tool Overview

The MDA design incorporates the following main features:

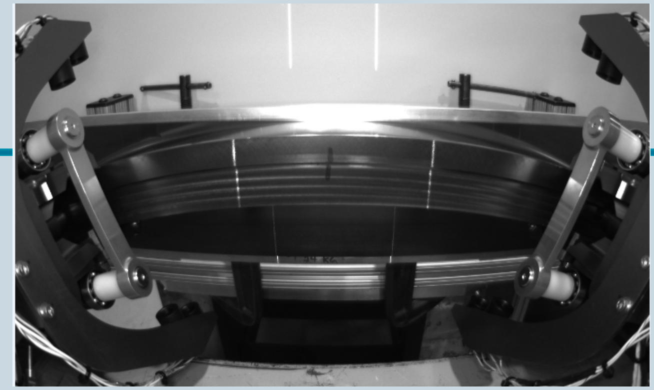
- Releasable, resettable
- Failure Mitigation: Dual-Wound motors, redundant sensors
- Compatible with arm capability and ops
- Camera with LED lights for situational awareness and human-in-the-loop operations
- Vision system for future autonomous operations
- Capture Envelope: ±22mm and ±2.4º misalignments in all axis simultaneously
- Clamping Force ~1000N vertical & 2000N axial
- Mass <15kg
- Load Capacity 200N.m in any axis
- US Patent Pending #61/987,860

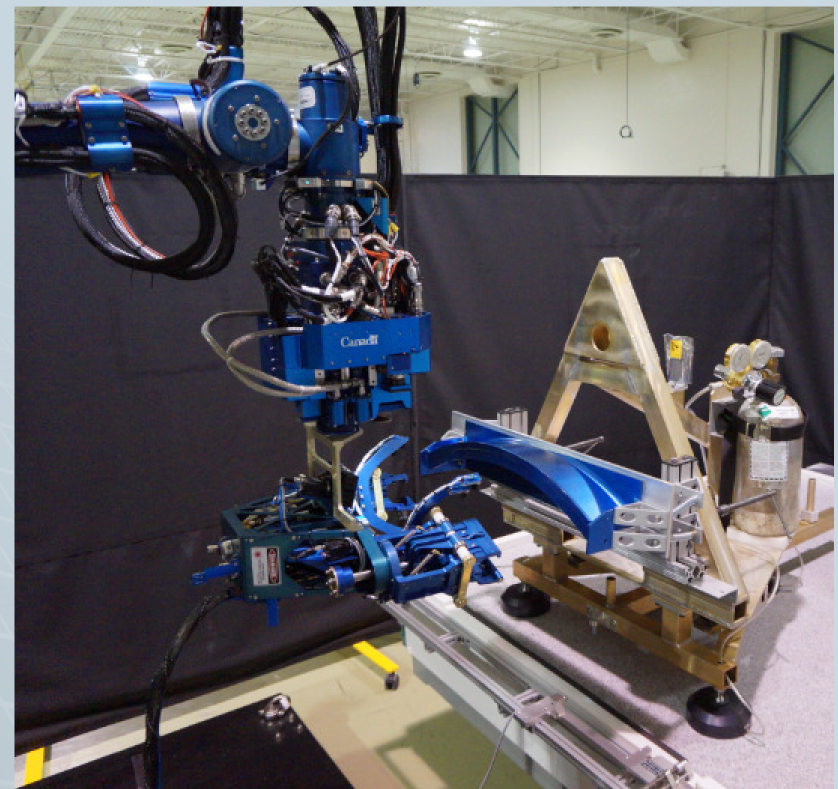


The LAR Tool EDU



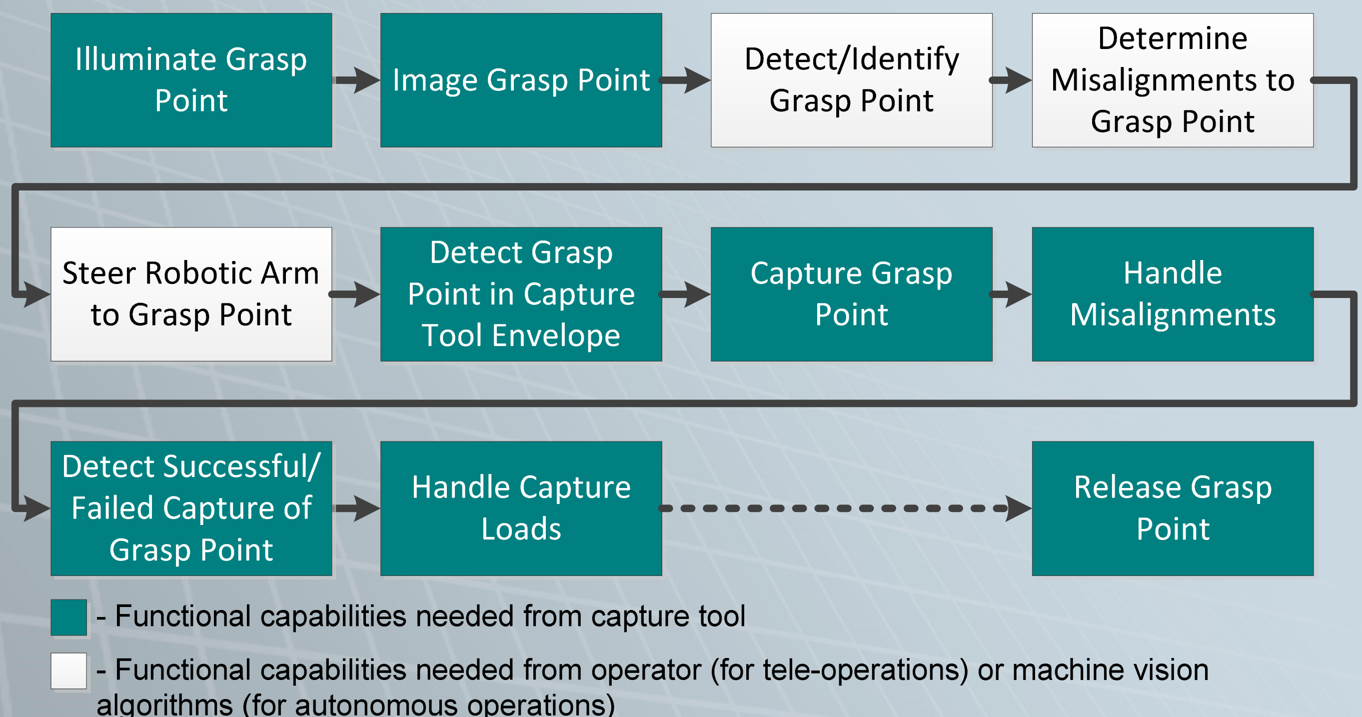
Launch Adapter Ring (LAR) Capture Tool
(US Patent Pending #61/987,860)



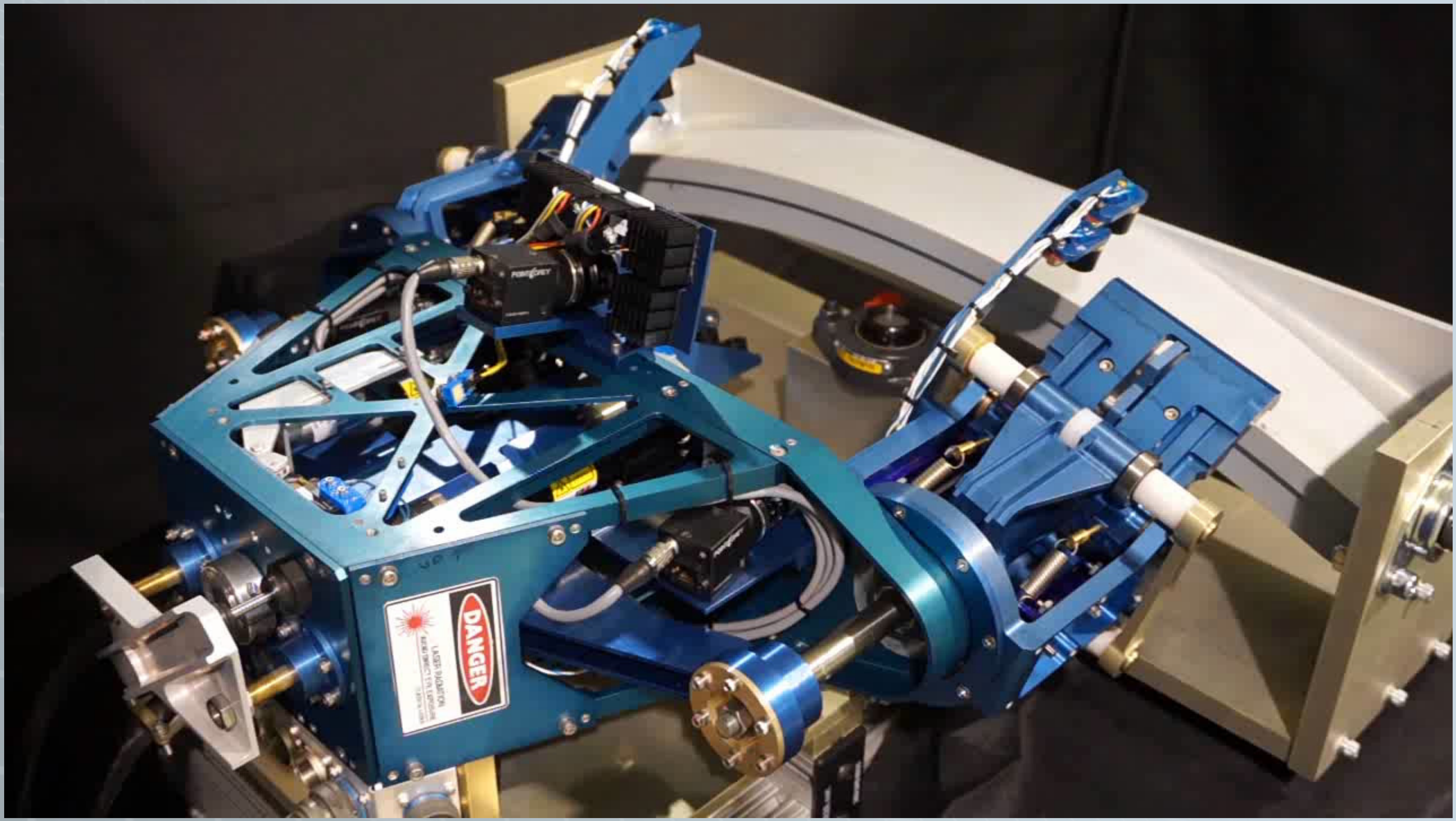


Tool Functional Flow of Operation

- High-level functions that the Launch Adapter Ring Capture Tool must provide as well as the functions that an arm operator (or machine vision system) must perform to support the tracking and alignment of the capture tool to the grasp point.



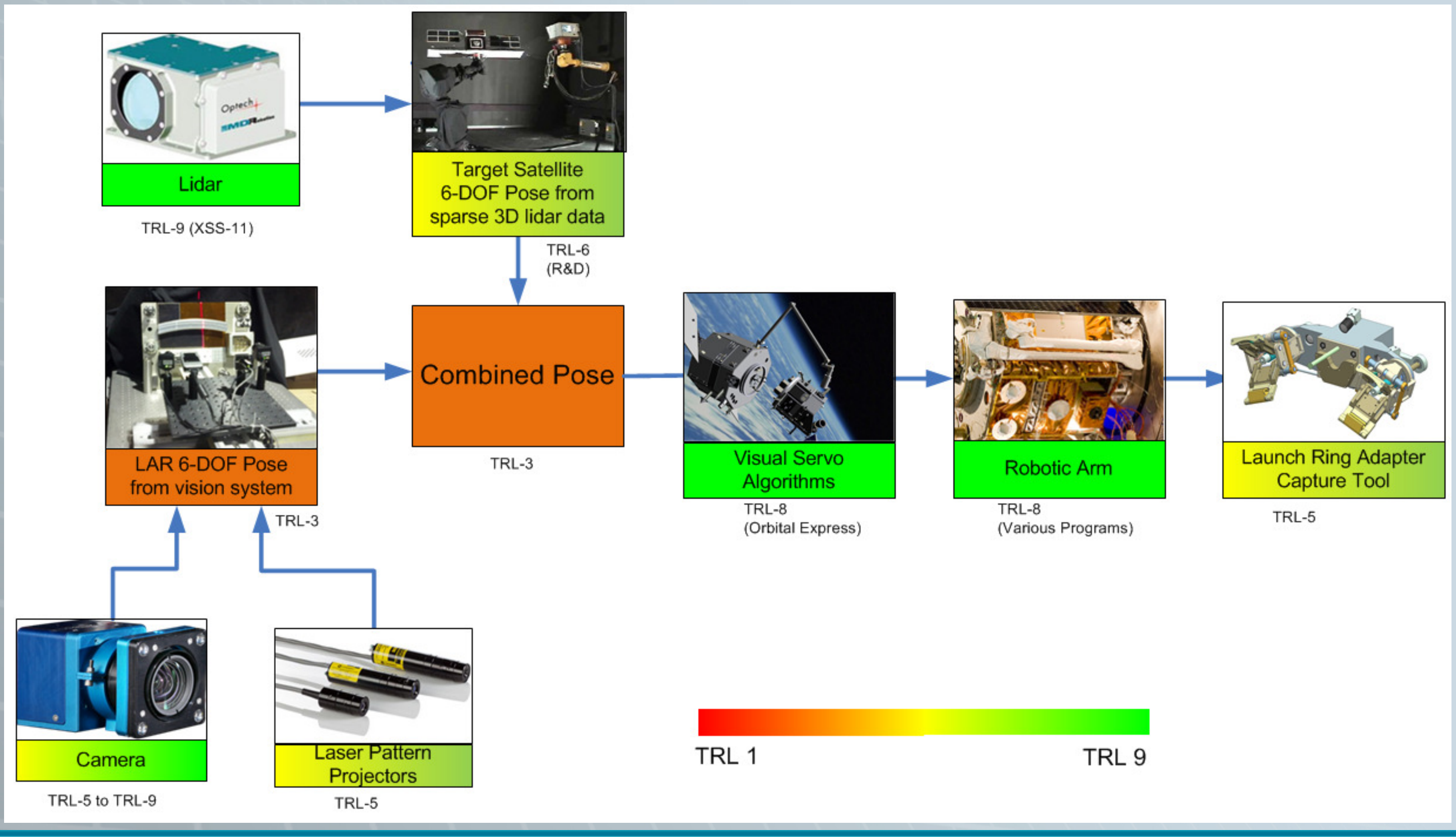
Capturing the LAR Ring



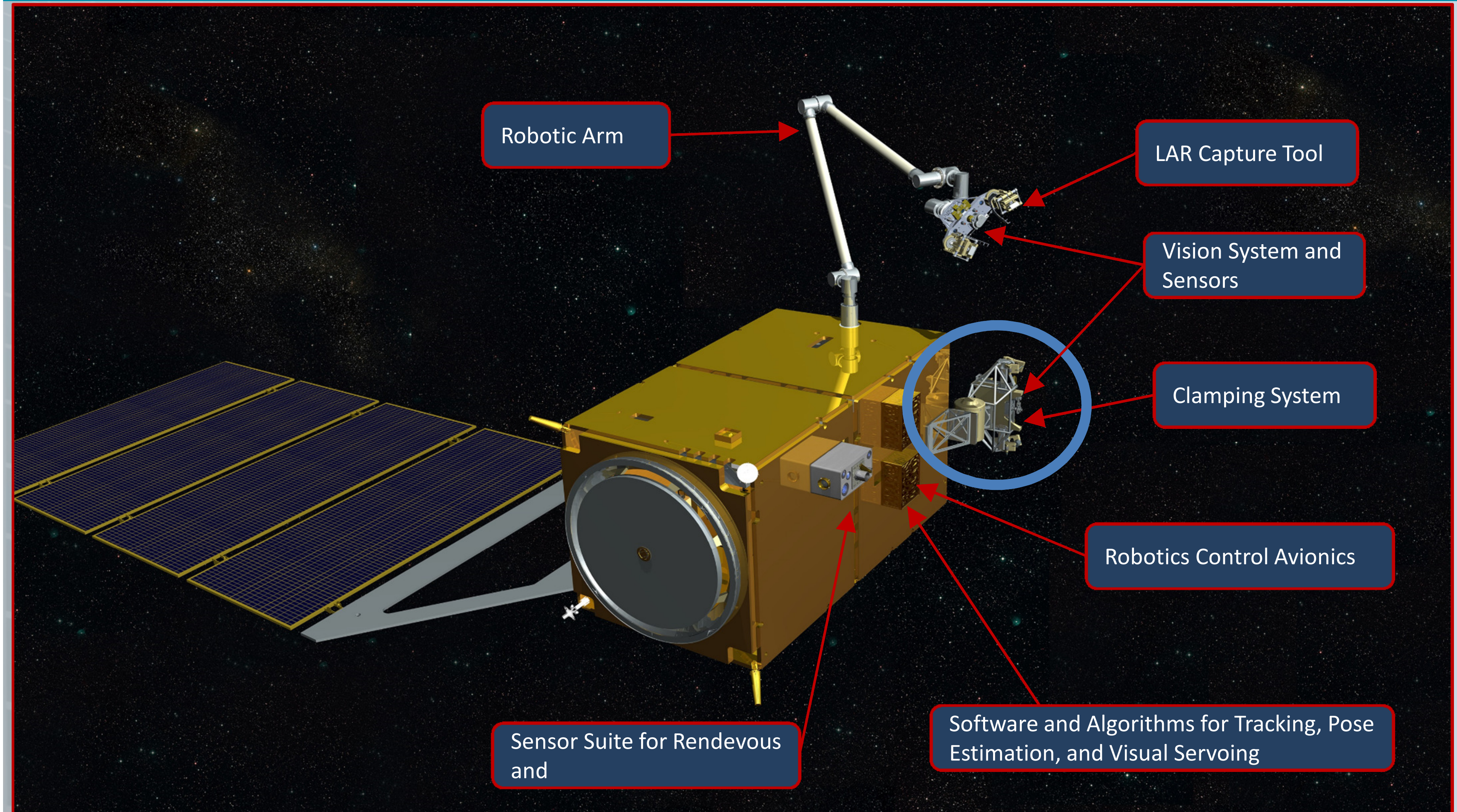
Capturing the LAR Ring

LAR Capture Tool Technology Roadmap

- Tool Development program with Canadian Space Agency completed in April 2015.
- Prototype tool has completed TRL-5 testing.
- Next step is advancement of the LAR vision system to TRL-4



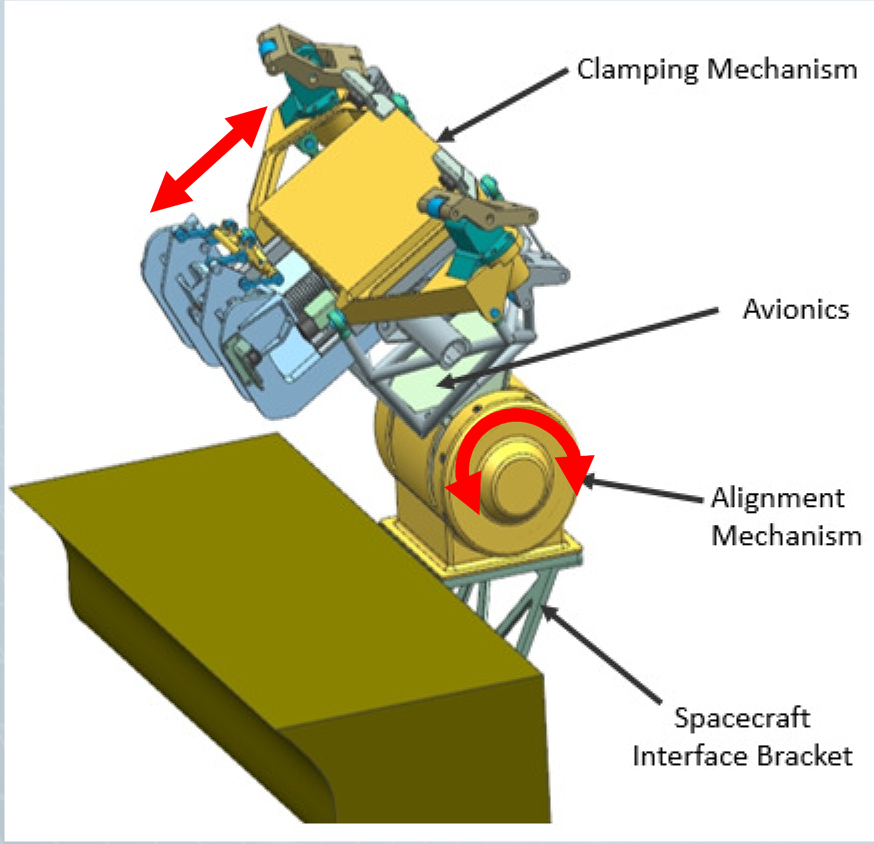
The Clamping System



Clamping System

The Clamping Subsystem in the e.deorbit chaser provides three primary functions for the mission:

- **Secure ENVISAT** to the chaser by grasping onto a segment of ENVISAT's launch adapter ring (LAR).
- **Adjust the relative orientation** of the chaser with respect to ENVISAT to support the alignment of the chaser's main engine thrust vector through the center of mass (CoM) of ENVISAT.
- **Provide Structural strength and rigidity** during Chaser maneuvering and de-orbit engine firings



Clamping System Driving Requirements

Stiffness of connection between Envisat and Chaser:

- Stiffness is a function of the arc length over which the clamp secures to.
- A stiff interface is key for Attitude Control System performance.

Maneuvering Loads:

- Steady state and transient loads during attitude control and de-orbit burns drive the size of the clamp.

Alignment Accuracy:

- Alignment mechanism must point the de-orbit thrust accurately through the Center of Mass of the mated spacecraft stack.

Compatibility with Arm and System Performance:

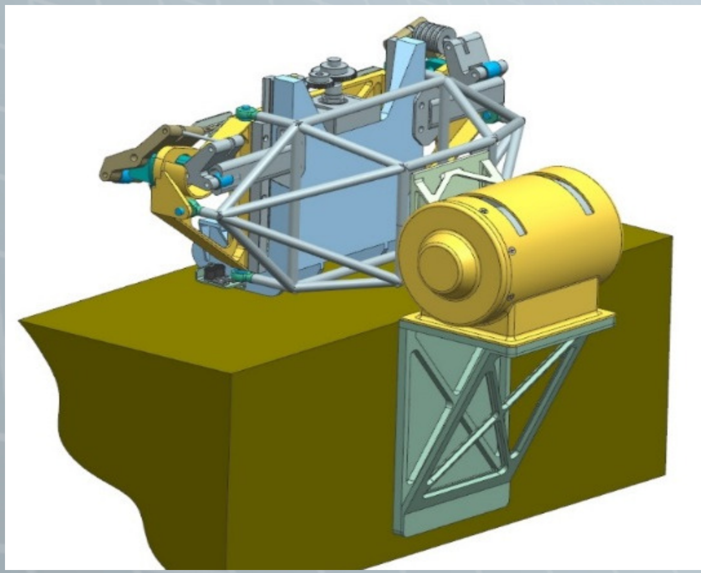
- Capture envelope and operation of Clamp do not drive the arm and system requirements

Failure Detection and Recovery:

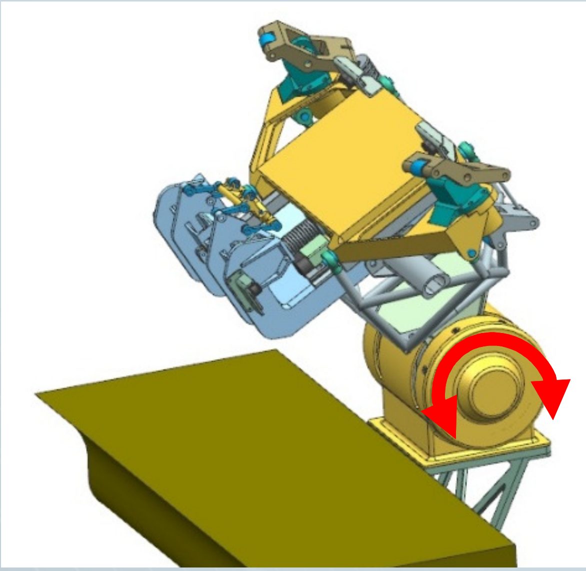
- The tool system must detect a failure or missed capture, and recover
- Electrical / Sensor Redundancy

Alignment Mechanism Design

- The alignment mechanism is based on existing engineering development unit joints.
  - Drive train consists of a harmonic-drive, planetary gear head, and a DC motor
  - Friction brake on motor maintains mechanism position when not being commanded
  - Absolute position sensor on output provides pointing telemetry with 0.005° resolution



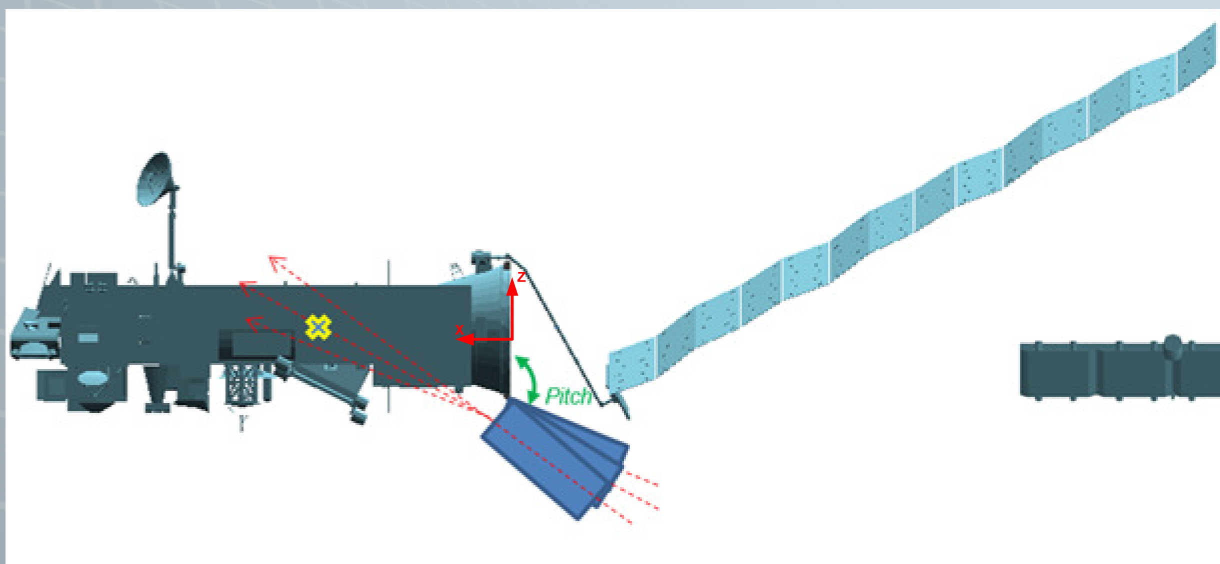
Stowed Position, for Launch

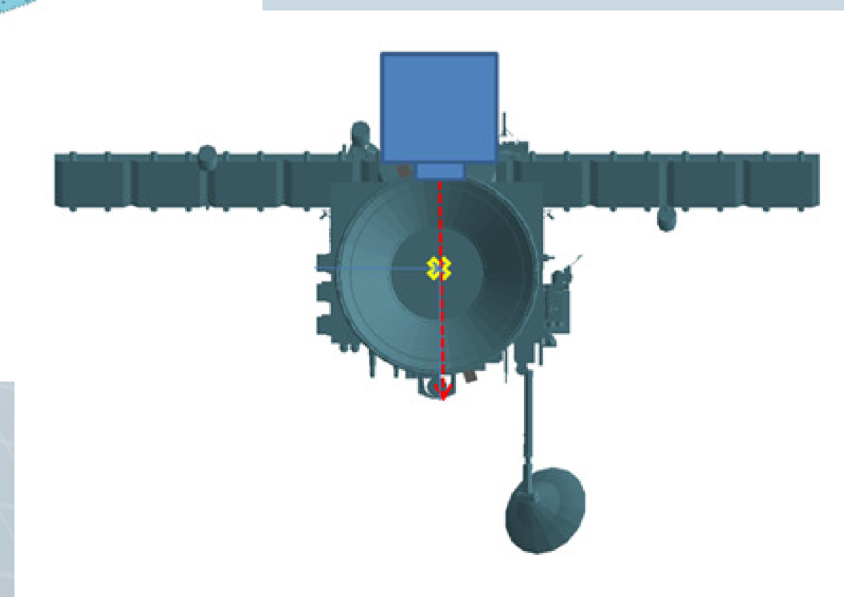


Operational Position, for aligning the Chaser with Envisat

Alignment Mechanism Design

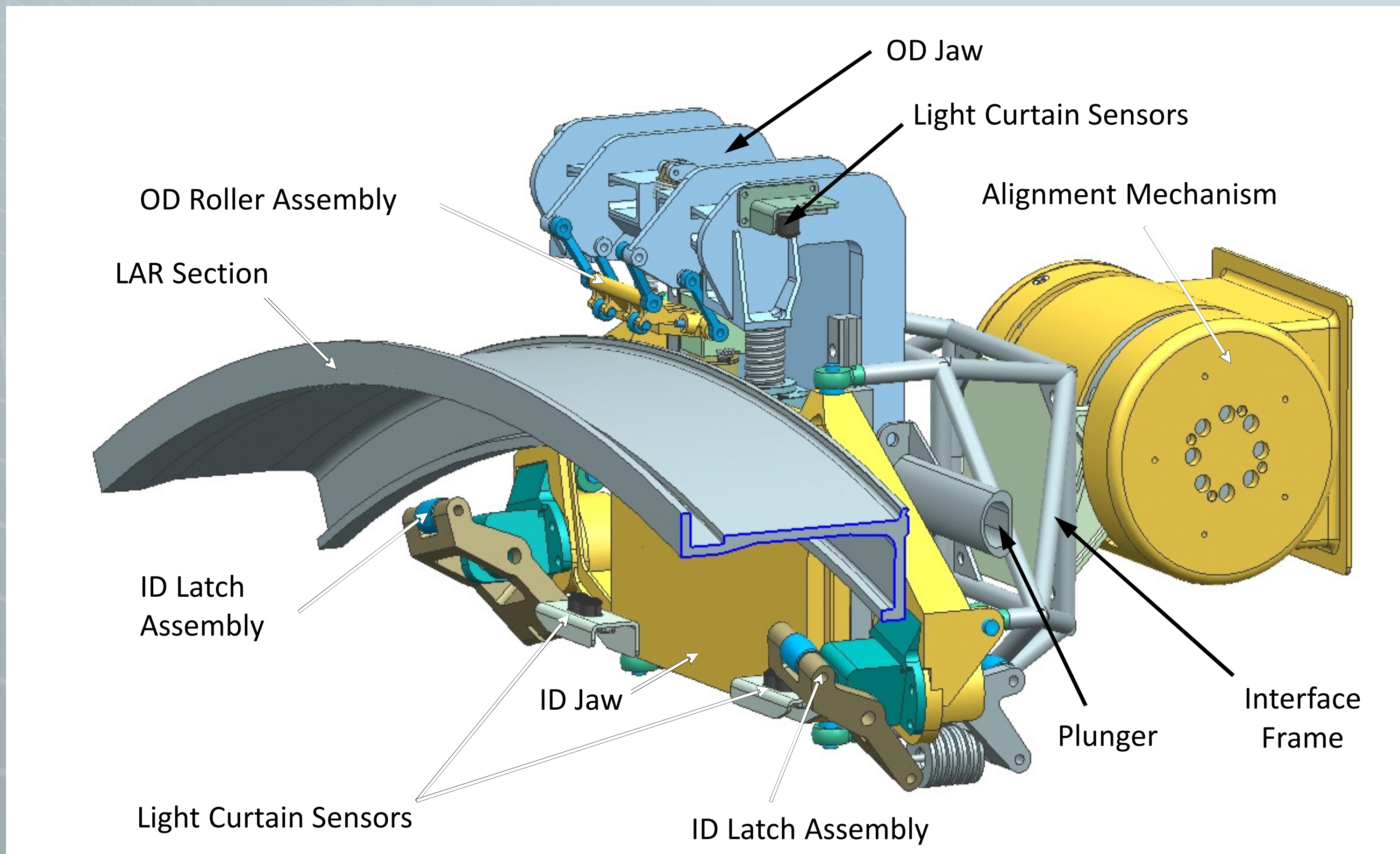
- The alignment mechanism is the rotary “pitch” degree of freedom between the clamping mechanism and the chaser and is used to align the chaser thrust vector with the combined Envisat / Chaser center of mass.





- Since we don’t know exactly where Envisat’s C of G is, the alignment mechanism compensates.

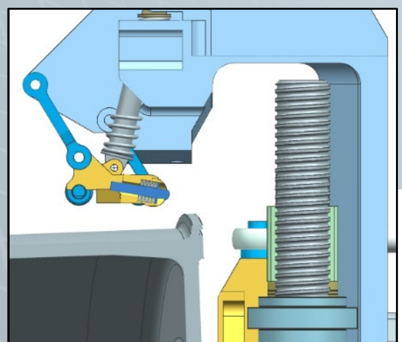
Clamping Mechanism Overview

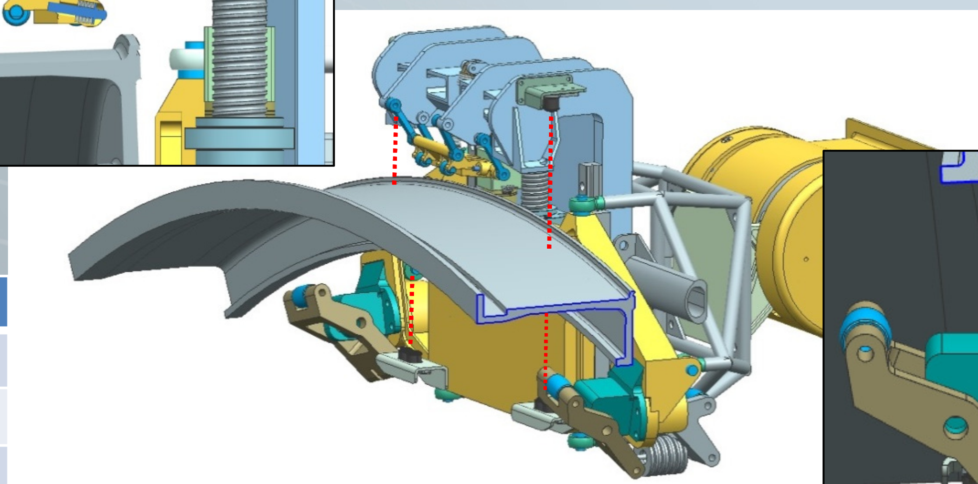


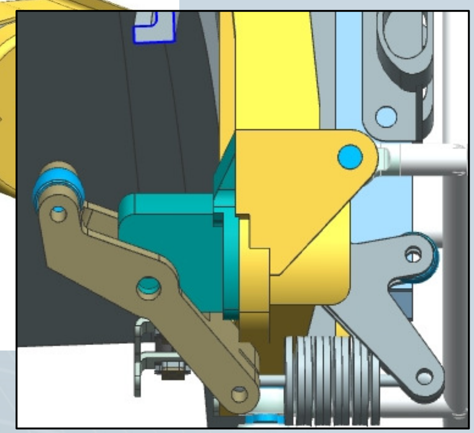
- Capture Envelope: +/- 21 mm in all axes, +/- 2 deg about any axis
- Clamping Preload: 10,000 N

Clamping Sequence

Light Curtain Sensors detect when robotic arm has aligned ENVISAT's LAR within capture envelope of clamping mechanism and command autonomous capture



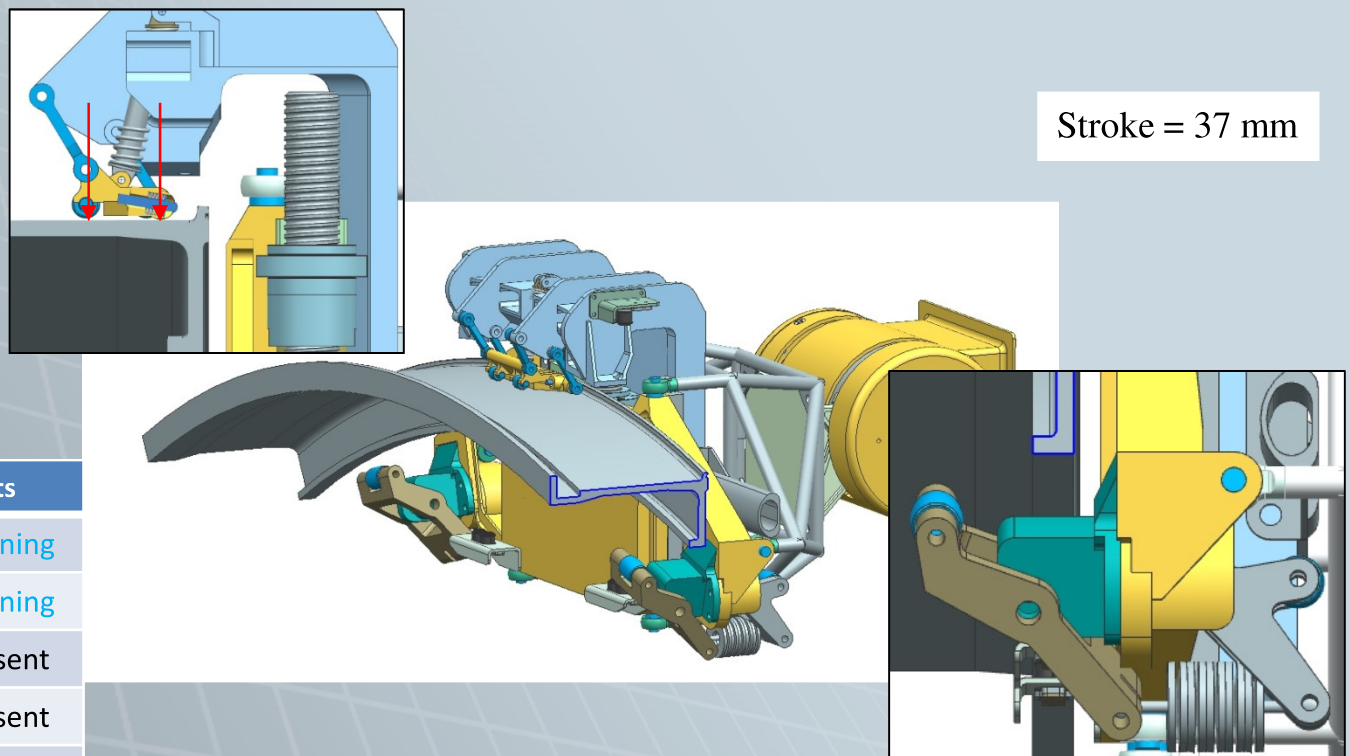




Misalignments	
Vertical	Present
Roll	Present
Axial	Present
Yaw	Present
Pitch	Present

Jaws Fully Open

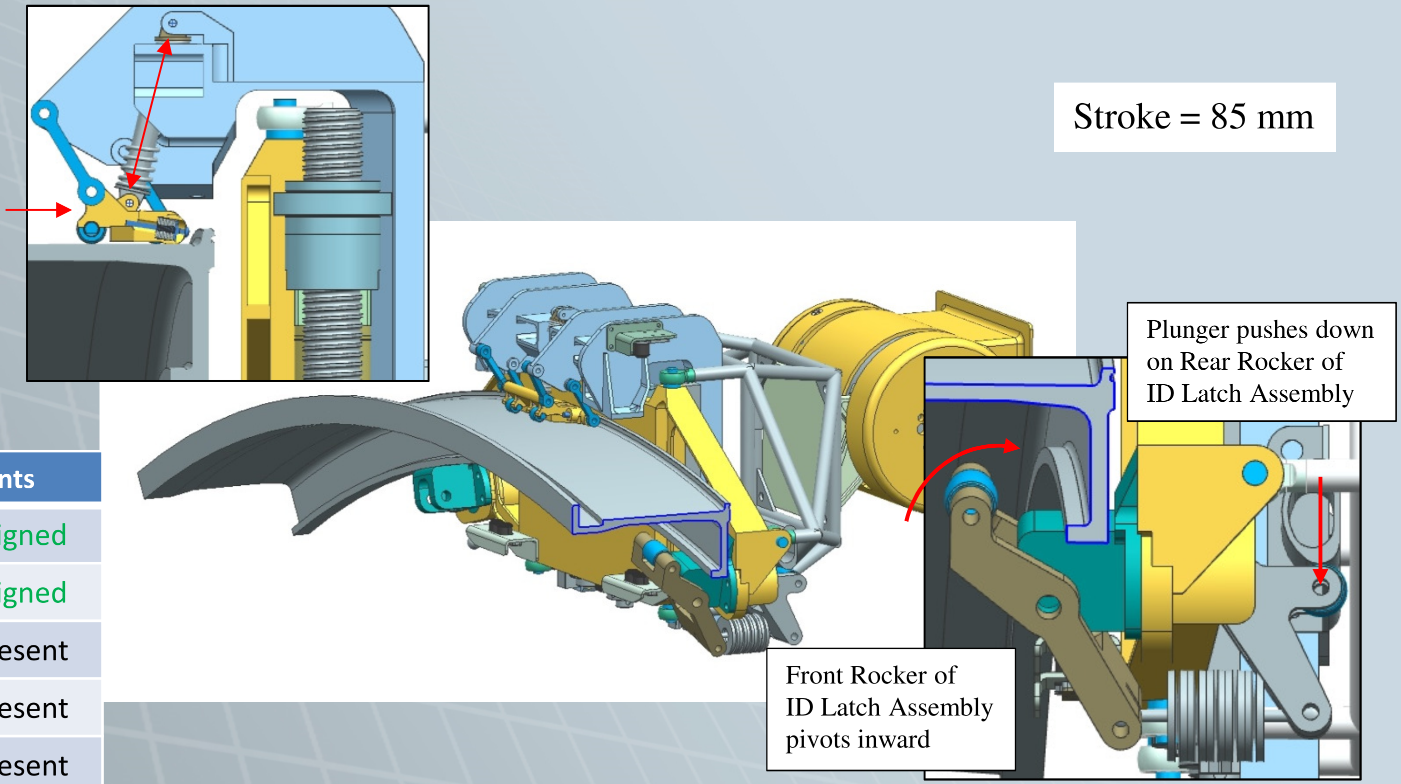
Clamping Sequence



Misalignments	
Vertical	Aligning
Roll	Aligning
Axial	Present
Yaw	Present
Pitch	Present

OD Rollers Contact LAR - Vertical misalignments start to be removed & once LAR ID contacts the ID latch assembly roll misalignments start to be removed

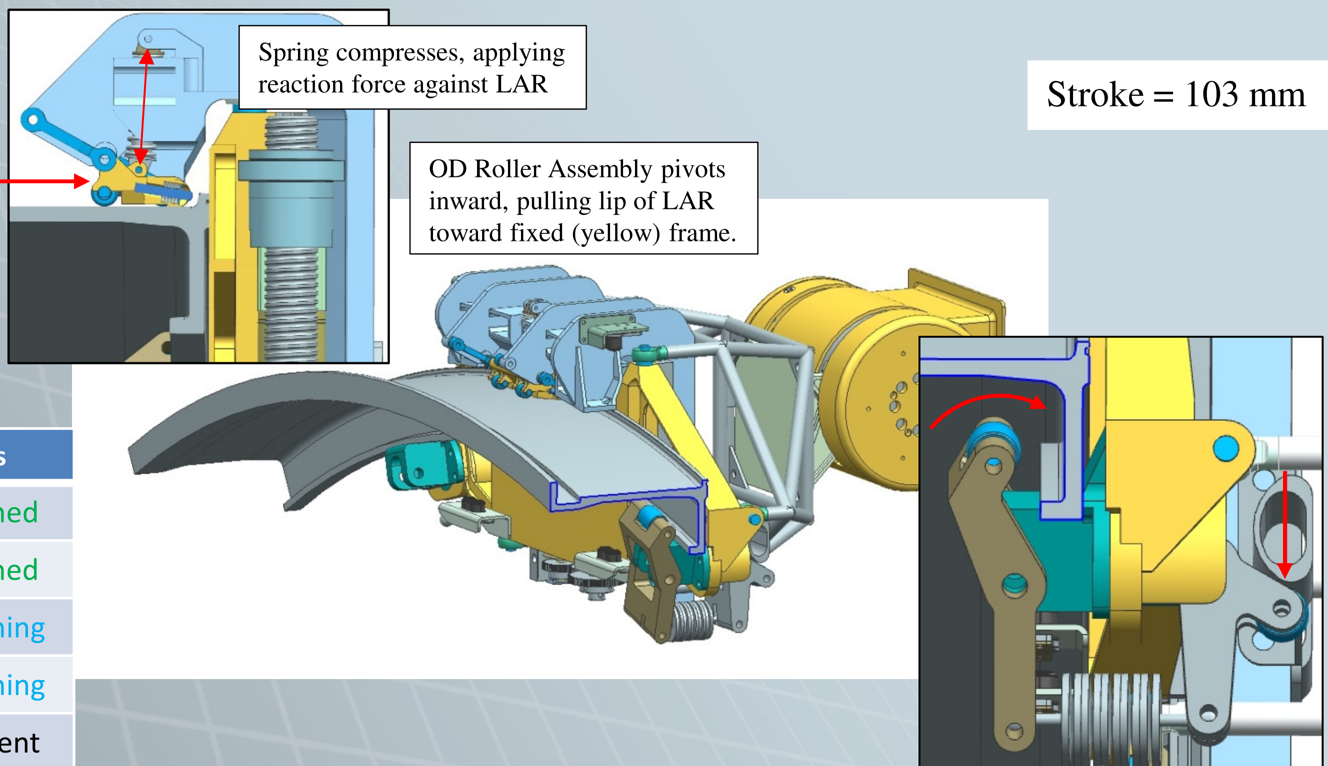
Clamping Sequence



Misalignments	
Vertical	Aligned
Roll	Aligned
Axial	Present
Yaw	Present
Pitch	Present

LAR is Seated, Plunger Contacts ID Latch Assembly – Vertical & roll misalignments are removed

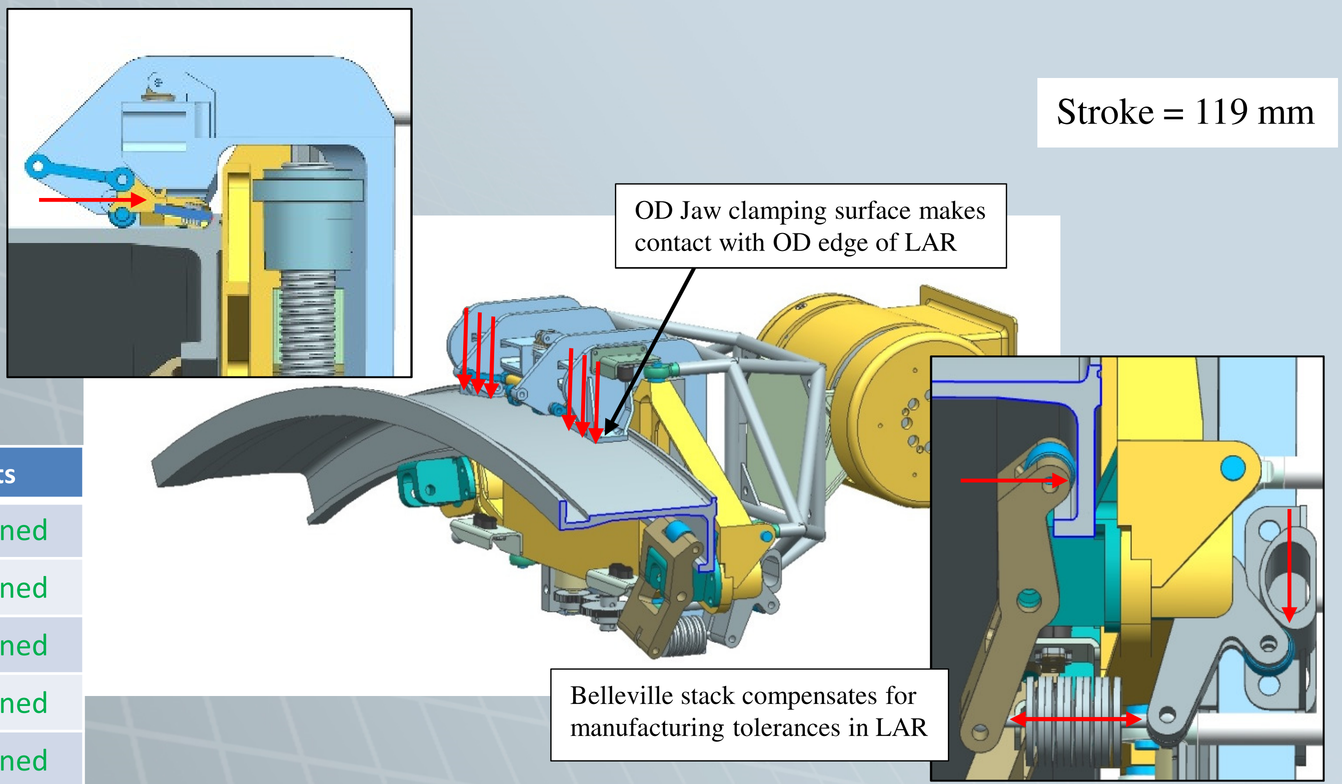
Clamping Sequence



Misalignments	
Vertical	Aligned
Roll	Aligned
Axial	Aligning
Yaw	Aligning
Pitch	Present

OD Rollers Compress & Pull LAR In; ID Latch Assembly Closing – axial and yaw misalignments start to be removed as the LAR ID and OD edges are pulled forward into their seated position

Clamping Sequence



Misalignments	
Vertical	Aligned
Roll	Aligned
Axial	Aligned
Yaw	Aligned
Pitch	Aligned

Fully Clamped – pitch misalignments are the last to be removed

Next Steps – Clamping System

- The Clamping System is structurally capable of reacting worst-case loads with a minimum of 100% margin.

Moments at LAR Caused By Main Engine Thrust	
M_x	394 Nm
M_y	1425 Nm
M_z	394 Nm

- The Clamping Subsystem is fully compliant with all requirements and supports the mission operations concept.

Primary Ry Stiffness (Nm/rad)	Cross-Axis Rx Stiffness (Nm/rad)	Cross-Axis Rz Stiffness (Nm/rad)	Steady-State Ry Deflection	Peak Ry Deflection
1.2E+05	1.7E+05	9.8E+05	0.35 deg	0.67 deg

- The Clamping Subsystem design has been advanced to the point where a breadboard can be built and tested.
- Going forward, there are possible areas for optimization with respect to mass and cost. This will be reviewed as the program proceeds and the requirements and technical budgets / margins are evolved.

Thank You!

Questions?