Clean Space Industry Days
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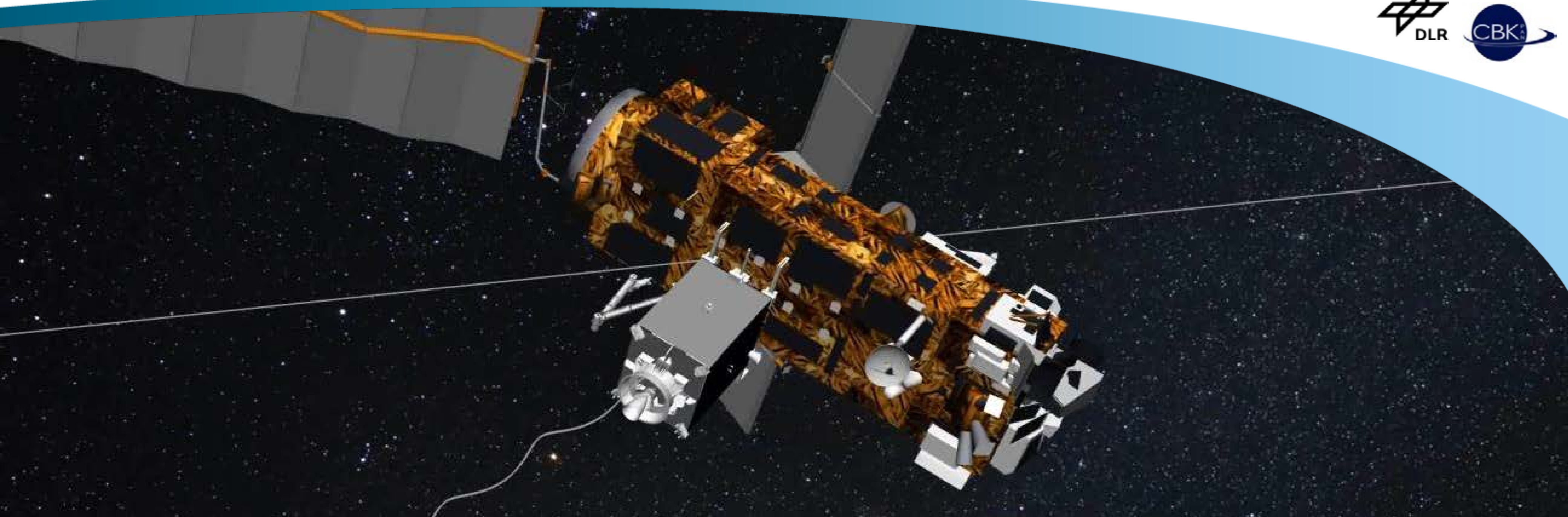

OHB Phase B1 Overview of GNC Baseline and Simulation Results

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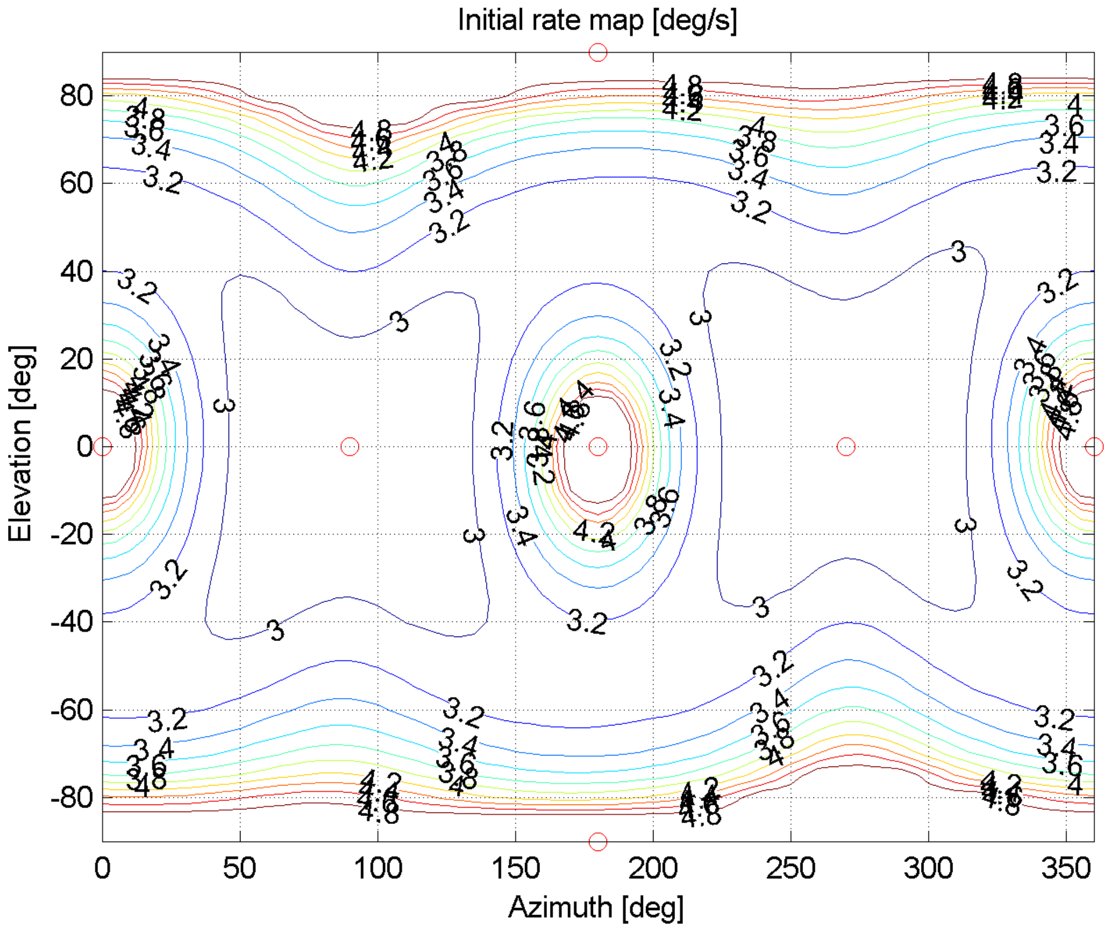
Outline

- Driving Requirements and Constraints
- GNC Baseline
  - AOCS Mode Architecture
  - Baseline AOCS Equipment
  - RendezVous Sensors
- Modes Design and Simulation Results
  - Far Range Approach & Inspection
  - Final Approach
- Conclusion

Target Rotation Rate

- R-SYSD-100: A target angular velocity of 5deg/s rotating around no single fixed axis shall be assumed.
- Driving the design and the sizing by many aspects
- Dimensioning case for the RCT configuration: synchronized motion before capture
- Current design compliant with the following rate map (with 50% margin)



Minimize the system mass

- R-SYSD-030: The mission shall be launched with Vega-C from the CSG as nominal launch.
- Effort to reduce the masses at all levels:
  - Reduce AOCS equipment mass
    - Low mass / low performance equipment
    - Remove RWs from the design
  - Minimize propellant consumption => driver for the AOCS controller design and tuning
    - Actuation at minimum impulse bit level
    - Trade-off between pointing performance and fuel consumption
    - Impact on the reference attitude to minimize external disturbance torques

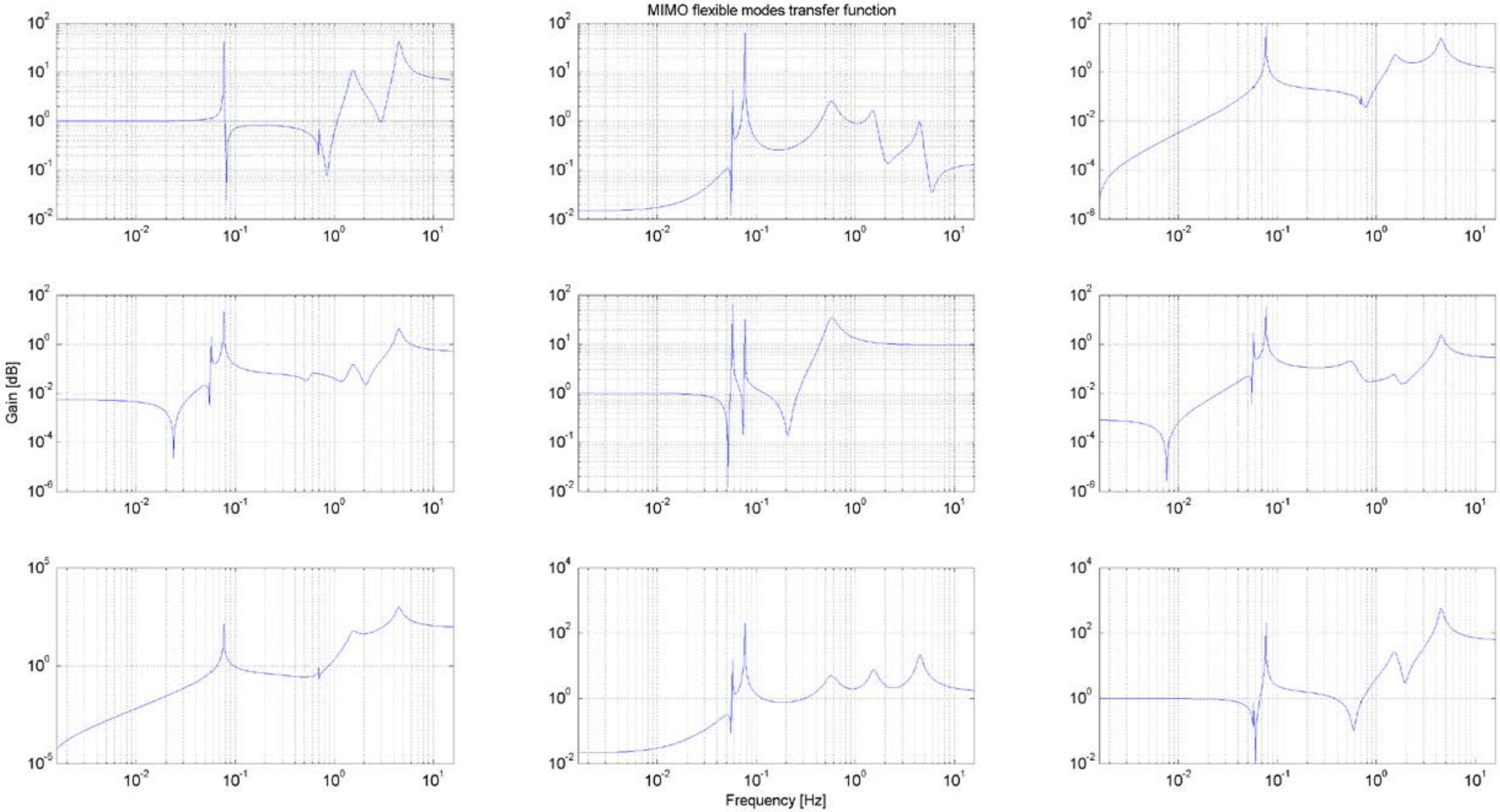
RendezVous requirements

- Autonomy: “autonomous” / “autonomously” mentioned 25 times in the GNC section of the MSRD

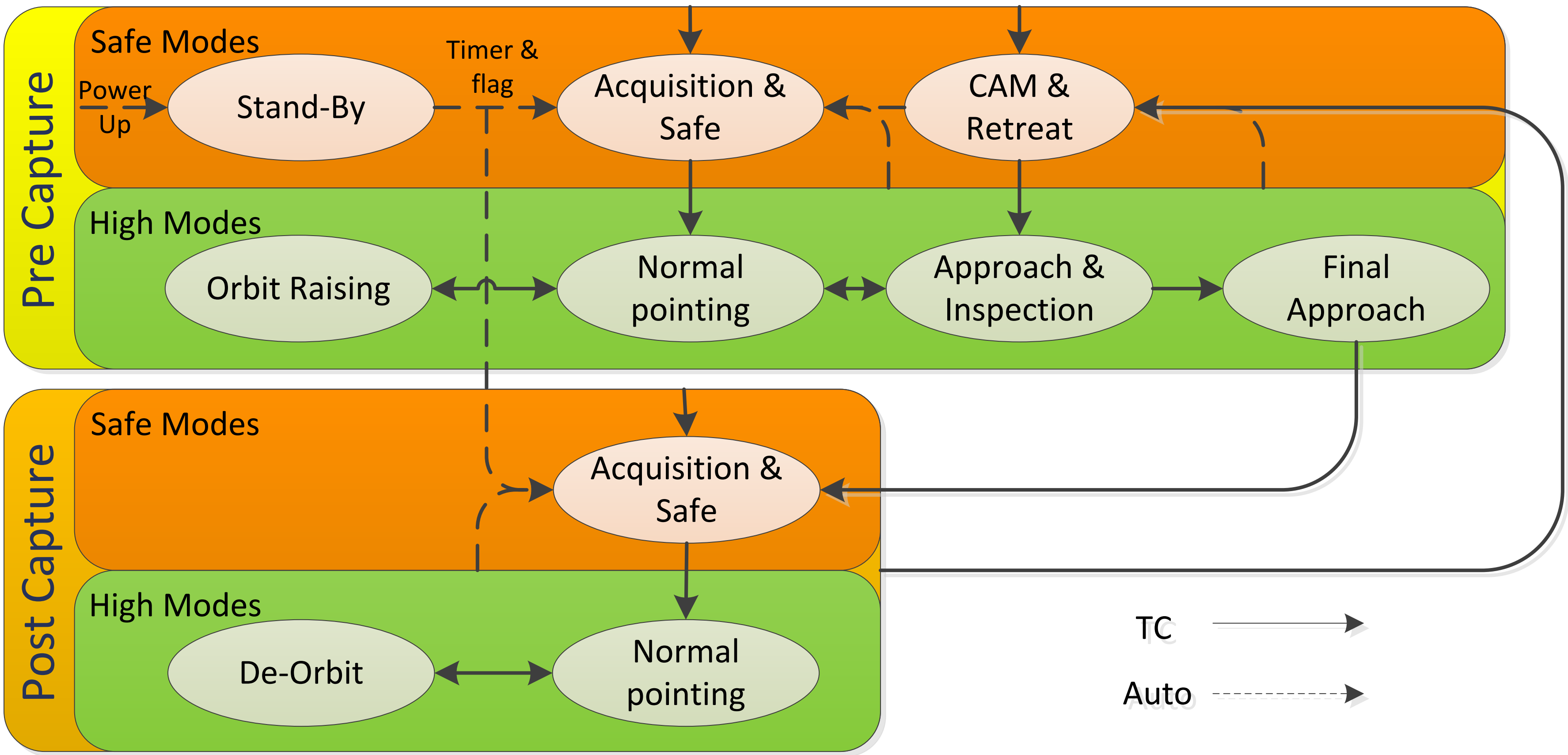
  => Requires all necessary functions on-board to perform attitude and relative orbit control without ground contact
- Capture with a robotic arm
  - Motion synchronization
  - Requirements on the motion stabilization accuracy:
    - Chaser pose control:
      - position: 0.1m, attitude: 0.5deg
      - position derivative: 0.01m/s, attitude derivative: 0.5deg/s
    - Target pose estimation:
      - position: 0.02m, attitude: 0.2deg
      - position derivative: 0.005m/s, attitude derivative: 0.005deg/s

Stack Flexibility

- Flexibility due to clamping between the Chaser and the Target (0.2 to 0.5 Hz)
- Target solar array flexible modes (0.05 – 0.06Hz)



AOCS Mode Architecture



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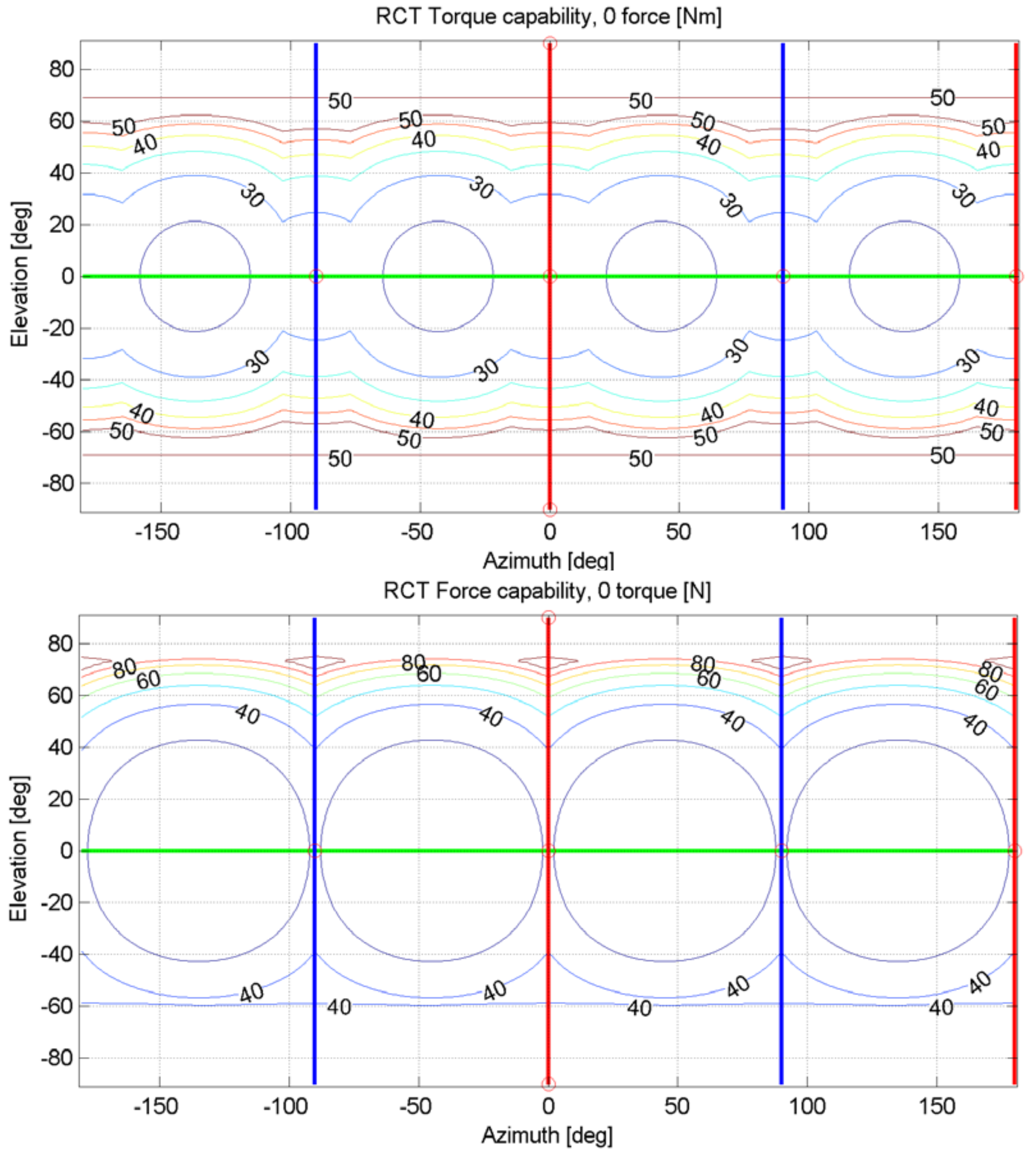
Baseline AOCS Equipment

Function	Equipment	Configuration	Typical Model	Comment
Safe Modes attitude measurement	Cosine Sun Sensor	12 fully redundant sensors	Moog Bradford CoSS	Additional pyramid sensors may be needed, depending on the pointing requirement in Safe Mode
High Modes attitude measurement	Star Tracker	2 cold redundant assemblies (2 CHUs + 1 DPU)	DTU MicroASC	Selection driven by mass requirement + reference attitude during entire mission
Angular Rate measurement	Low class Gyro	2 cold redundant 3-axis	Selex ES SiREUS	Selection driven by mass requirement Alt. 1 single 4-axis or 5-axis
Orbit Determination	GNSS receiver	2 cold redundant	SSTL SGR-07	
Acceleration measurement	Accelerometer	1 single 5-axis (or 4-axis) Alt. 2 cold redundant 3-axis	Honeywell QA3000	
~~Attitude control~~	~~Reaction Wheels~~	~~4 hot redundant in pyramid configuration~~		~~Removed from the design for mass savings~~

Reaction Control Thrusters

- 22N bi-prop thrusters
- Pulse modulation, 20ms <   < 480ms
- Configuration:
  - 2x10 RCTs (2 cold redundant branches)
  - RCTs divided into 3 sets in an assymmetric configuration to best fit the actuation needs

Configuration protected by a Swedish / European / International Patent Application



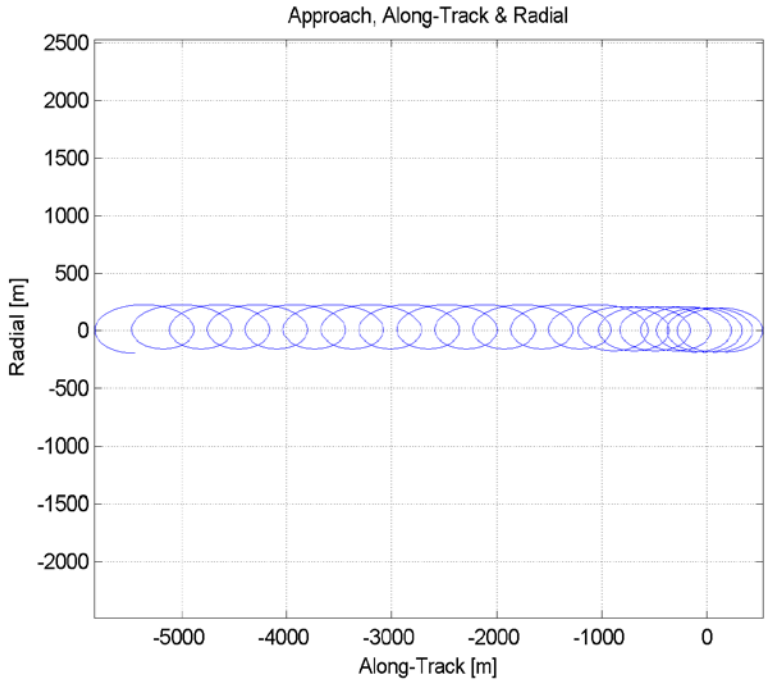
RendezVous Sensors

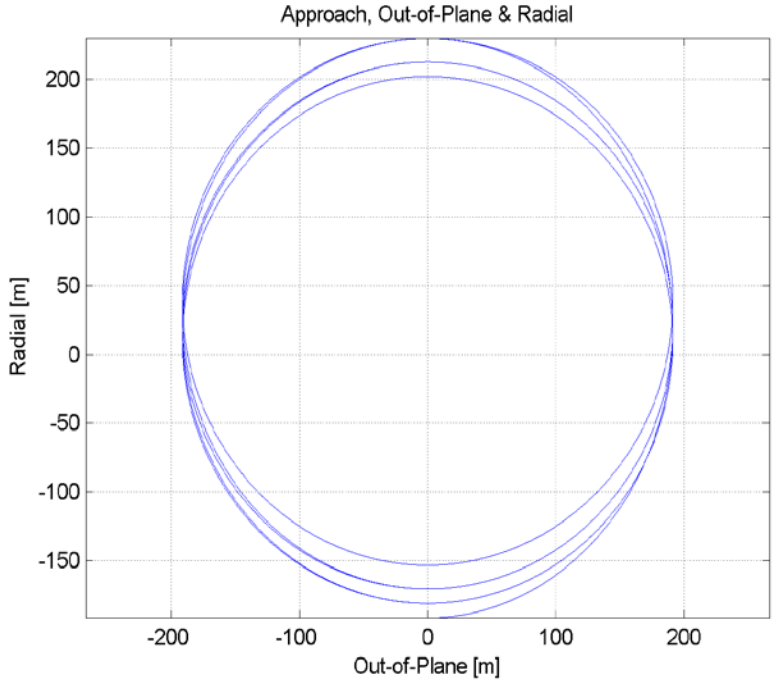
Sensor	Measurements	Range	Performance
Far Range Camera	• Absolute Direction to Target ('Angles Only' navigation) • FoV Direction and Distance to Target	1000m – 10000m 50m – 1000m	< 0.016deg (1pixel) < 0.016deg (1 pixel), <10% distance
LIDAR	Full Pose, nominal solution	1m – 400m	< 1% distance, < 0.2deg
Close Range Camera	Full Pose, back-up solution	1m – 70m	< 1% distance, < 0.2deg

- Illumination system for Proximity Operations
- Sensor outputs can be cross-checked for navigation solution monitoring

Approach and Inspection

- Approach and Inspection based on Safe T-periodic orbits
  - Starts at Safe Hold Orbit (typically 5km), start for the Relative Navigation
  - Radial / out-of-plane separation typically 200m, reduced for inspection
  - Adjustable drift 20 – 350 m/orbit
- Autonomous Relative Navigation and Relative Orbit Control On-board (PRISMA experience)

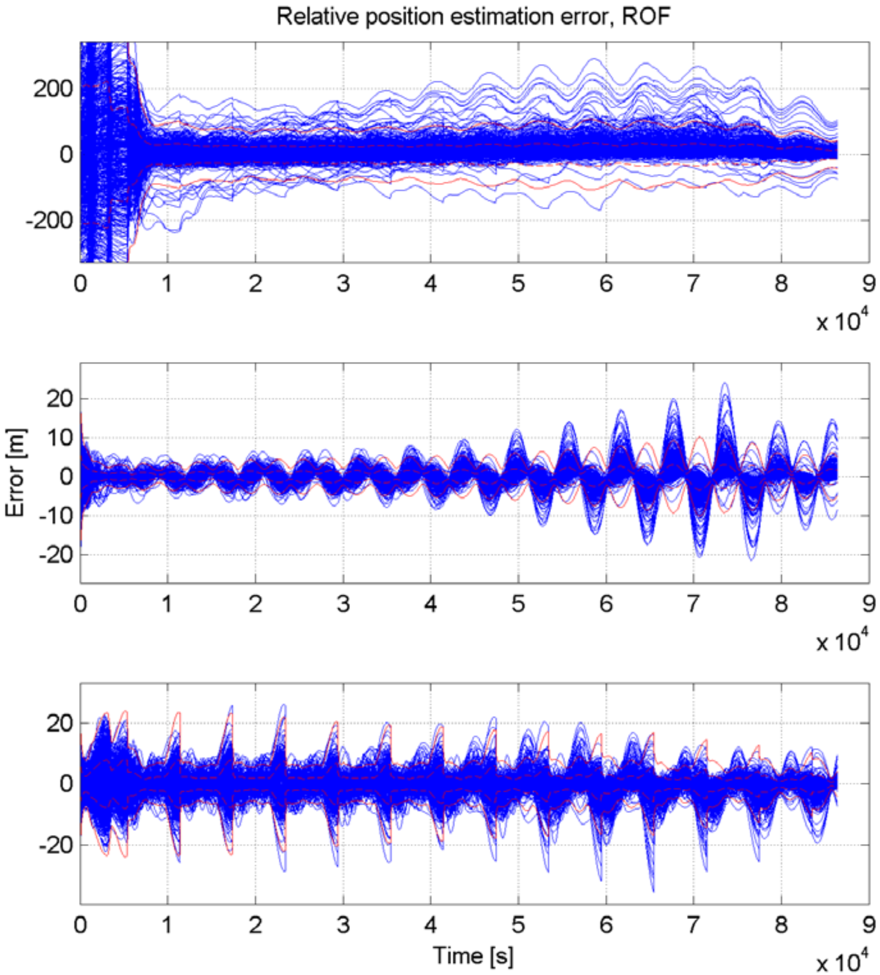


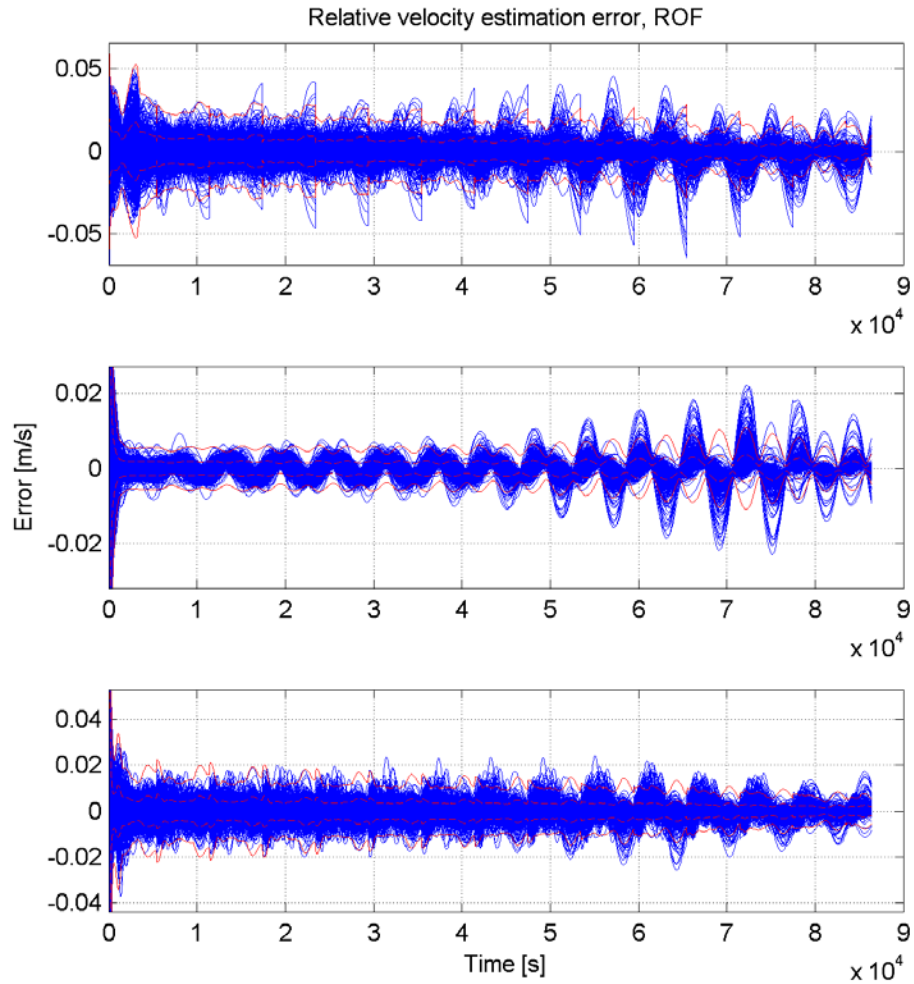


Relative Orbit Navigation, concept

- Extended Kalman filter:
  - Estimates the Chaser relative position and relative velocity in spherical ROF
  - State update based on relative orbit propagation (Yamanaka Ankersen equation)
  - Measurement update based on Rendez-vous Sensor inputs
- Two modes:
  - Far Range / ”Angles Only” navigation
  - 3-D relative position measurement (Lidar, FRC at intermediate distances, CRC)
- PRISMA heritage to a large extent. Adaptation to the specific e.Deorbit parameters and conditions
- Exemple of results: Far Range Approach
  - FRC errors:
    - White Noise (58’’ / 1 pixel 3sigma)
    - Random bias (29’’ / 0.5pixel, uniform)
    - Difference CoM / CoL, 6m in the Target X direction, max 10pixel
  - Relative J2, relative air drag, relative SRP included
  - 30min eclipse on all orbits
  - Pessimistic assumption on applied DV (only limited to a few manoeuvres)

Relative Orbit Navigation analysis results, FRC



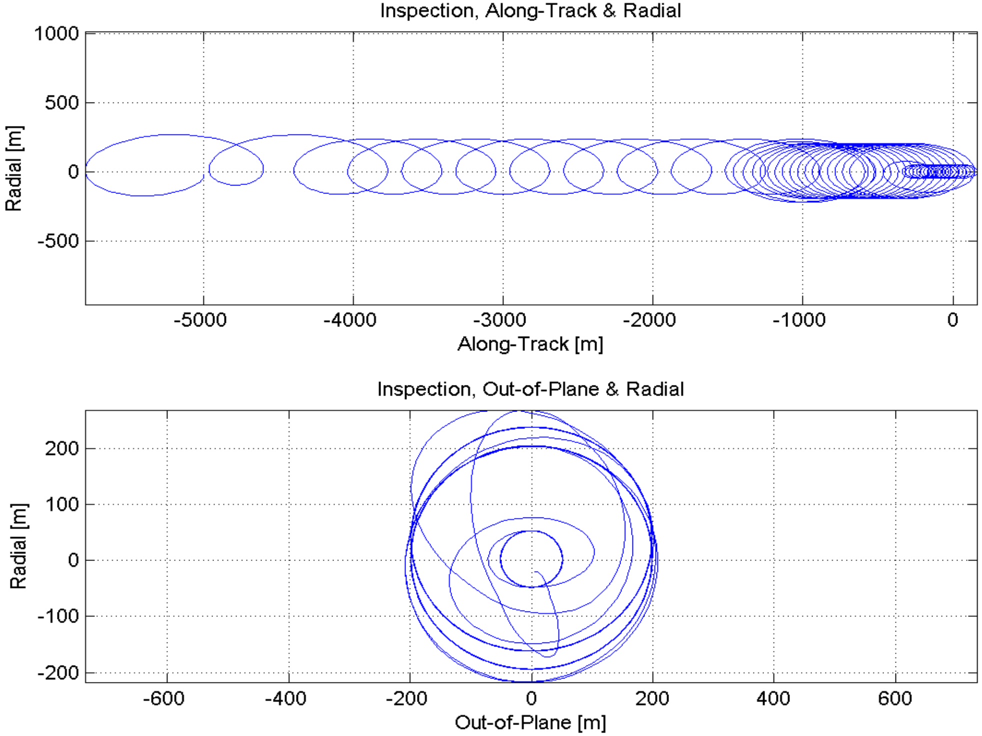


T-periodic Orbit Guidance

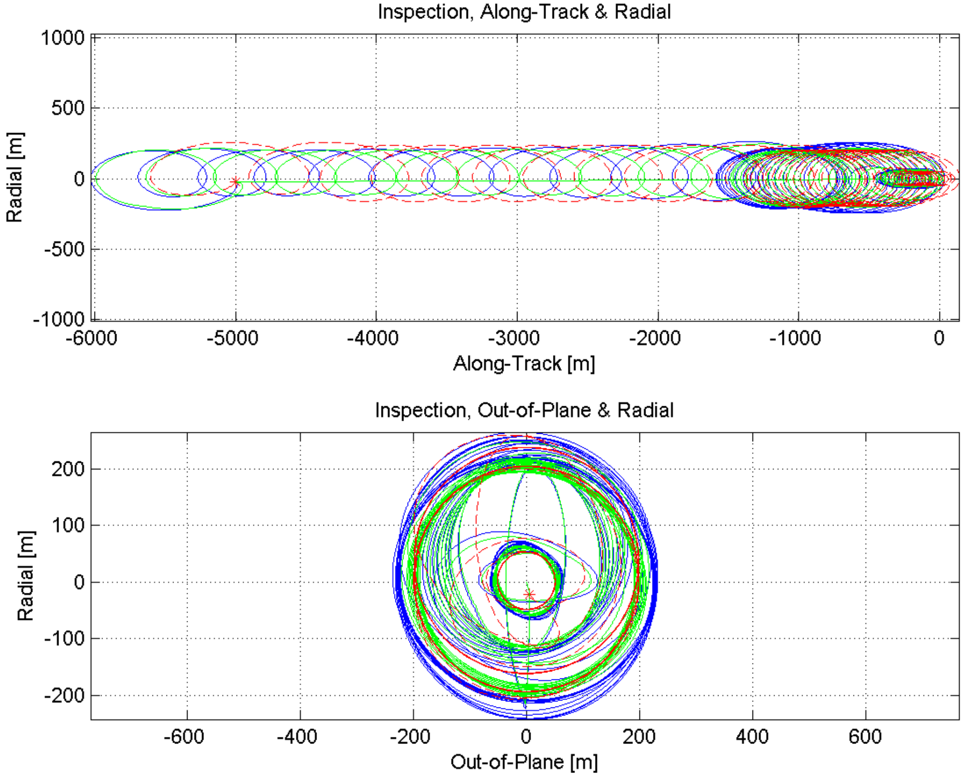
- Provides controller with reference position and error box in Rotating Orbital Frame (ROF)
- For the Approach and Inspection phases the reference is generated by the on ground T-Periodic Orbit Guidance and Control tool
- Error box for the Approach and Inspection phases set to allow for larger error in along track position to take into account navigation uncertainties. Radial/out of plane position error box is set to guarantee a collision free orbit
- As the chaser gets closer to the target the error box shrinks

Approach and Inspection Closed Loop Test results

Reference relative position (output from ground tool)



Reference (dashed red), true (blue) and estimated (green) relative position

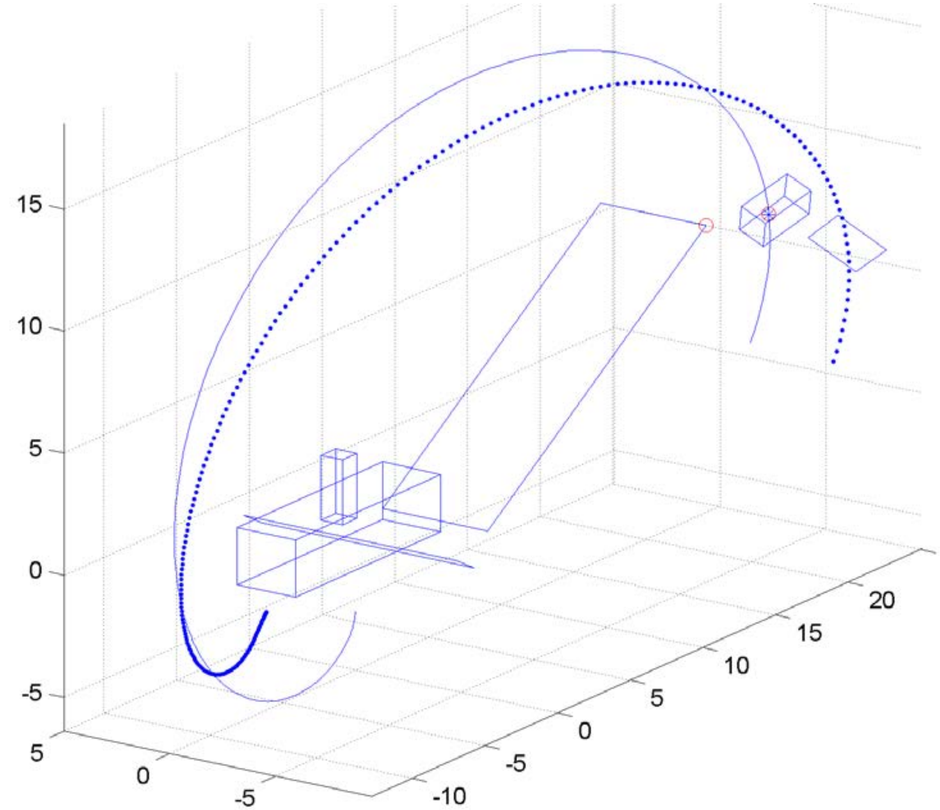


Close Range / Final Approach

Step	Description	Distance	Duration
Transfer to Pick-Up Point	Transfer on a (passive) T-periodic orbit	35 m - 250 m	6000 s (one orbit)
Fuel-optimized approach and Transfer to Arm Delivery Point	Approach, synchronization of the Chaser motion (translational and rotational) with the Target	50 m - 1.5 m	10 min (TBC)
Arm Delivery Point Acquisition	Reduction of the Control Error box at Arm delivery point in order to fulfil the Arm capture requirements.	1.5 m	1 min (TBC)

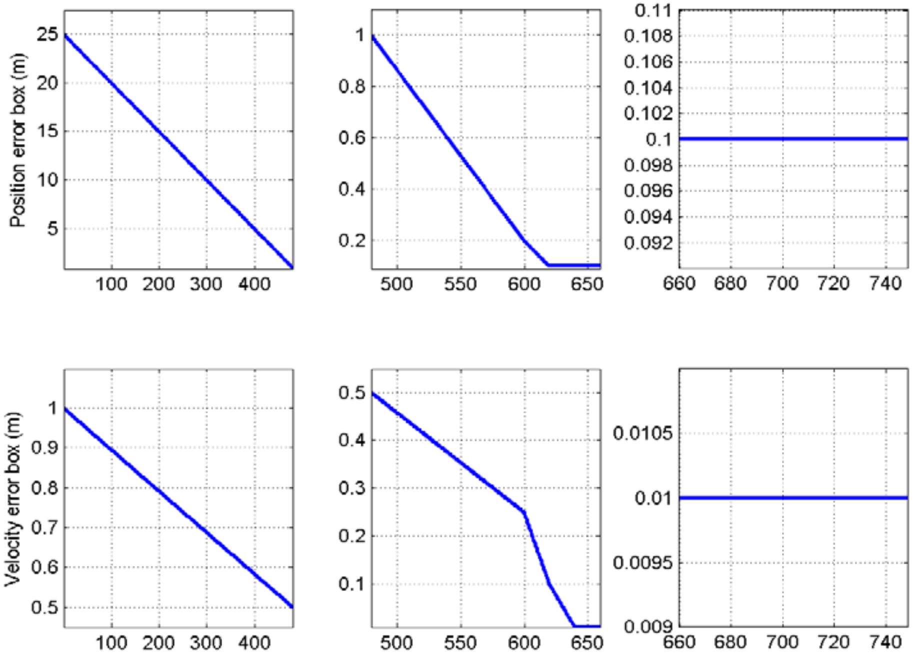
Force-Motion Guidance Planner

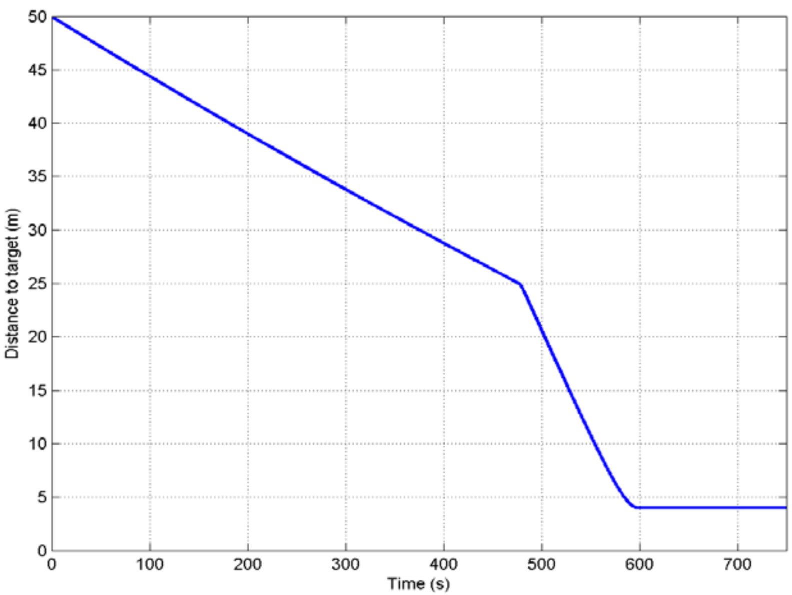
- Ground function that generates the Final Approach guidance parameters:
  - Chaser position and velocity relative to Target, expressed in the TGFF
  - Chaser attitude and angular rate relative to Target, expressed in CGFF
- Profiles based on a prediction of the Target attitude and angular rate evolution.
- The function computes the most natural orbit in order to reach the synchronized position and attitude at the desired time. This minimizes the propellant consumption
- It guarantees a minimum distance between the Chaser CoM and any point on the Target (including appendages)
- It computes the Chaser attitude so that the Chaser Solar Panel is away from the Target direction (i.e away from the closest point to the Target)



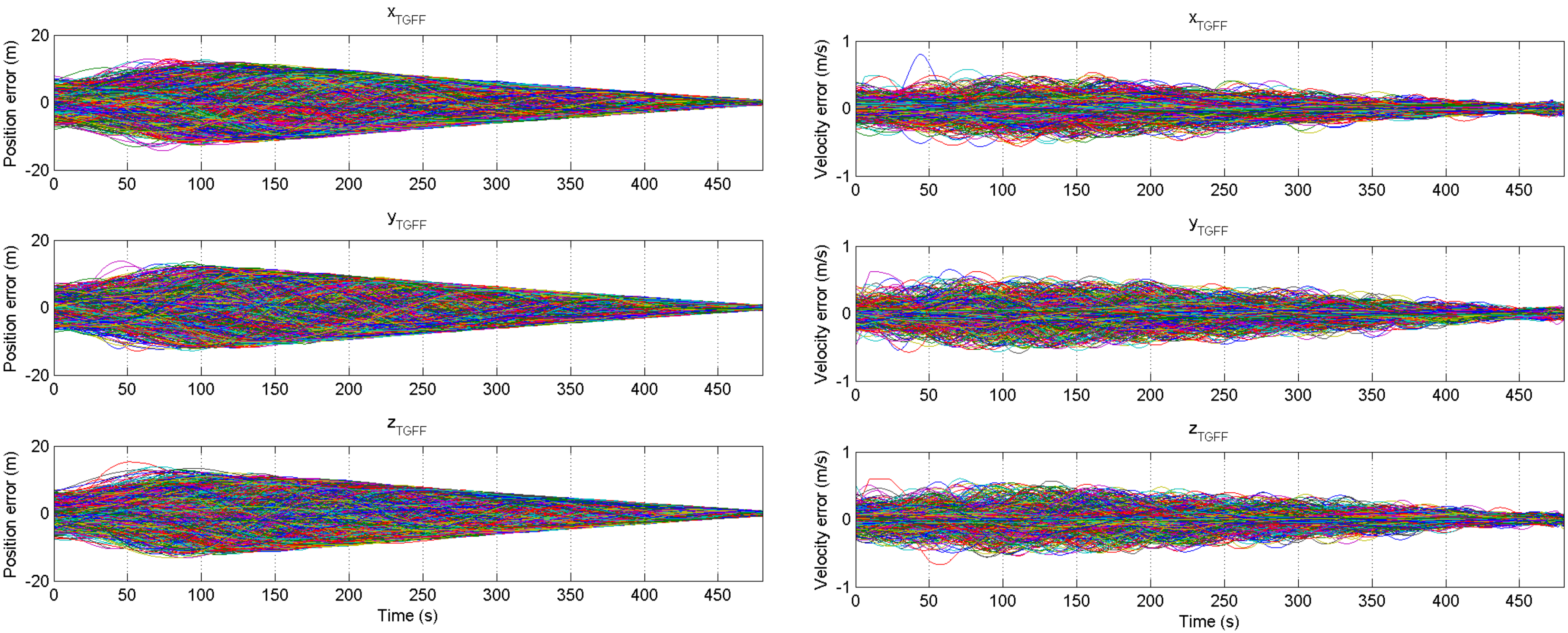
Orbit Control for Final Approach

- Model predictive controller to minimize propellant consumption while keeping position and velocity within error box of reference
- Prisma heritage with following modifications:
  - Control error box set in Envisat body frame
  - Input constraints updated to e.Deorbit thruster configuration.

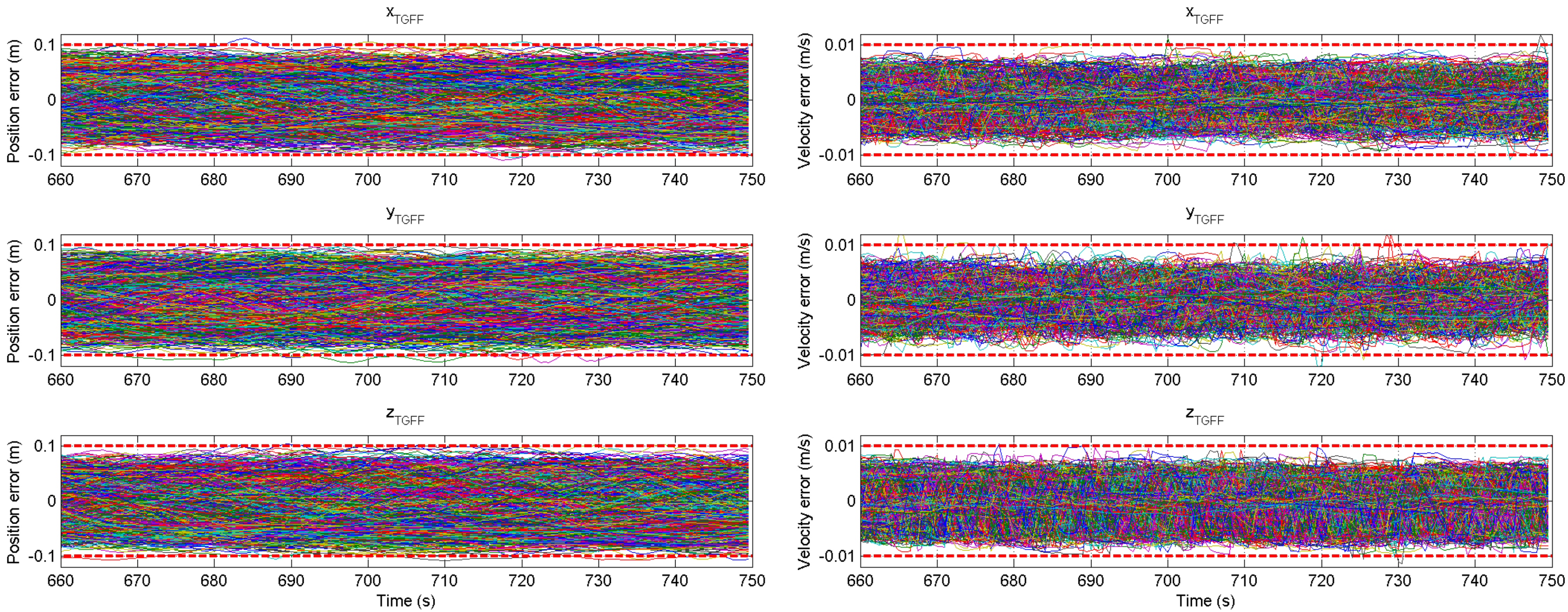




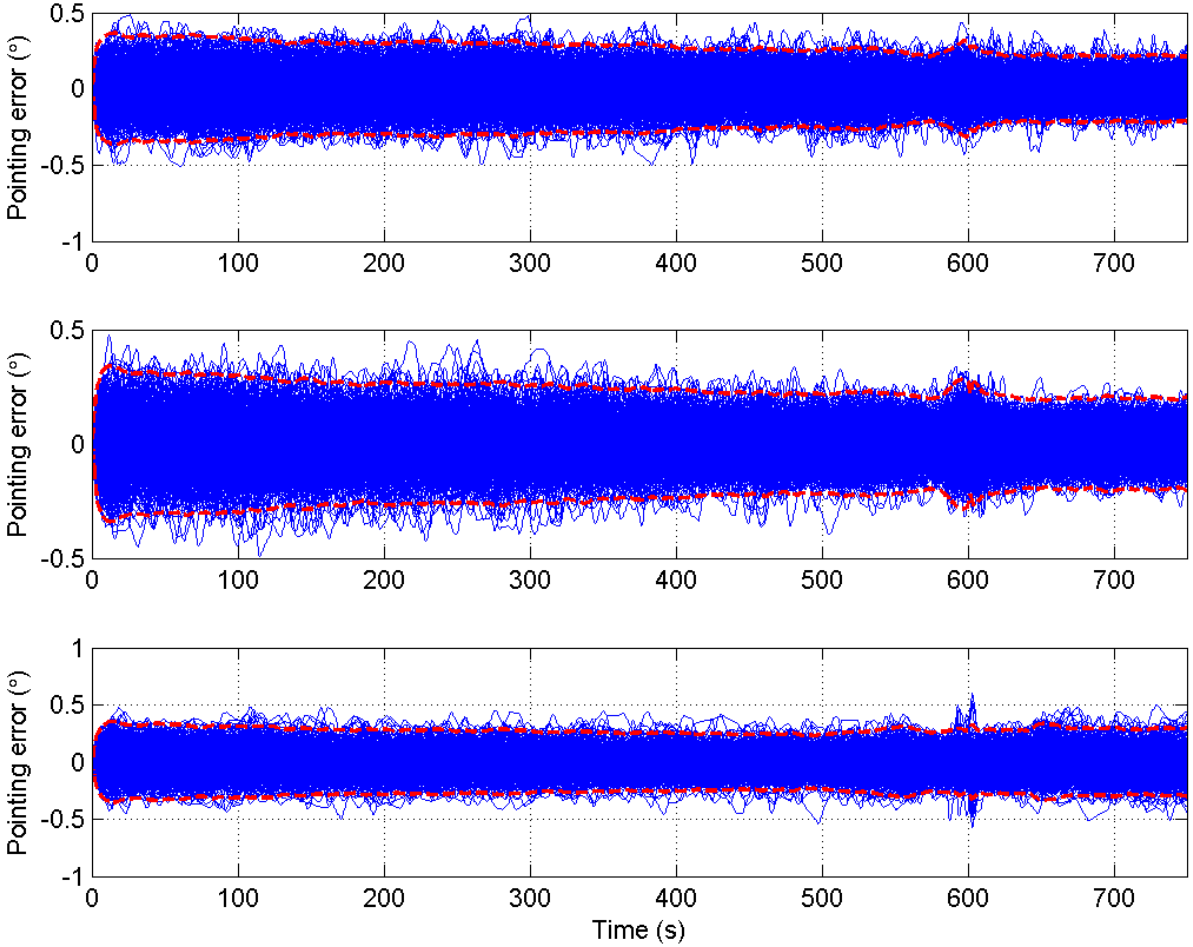
Final Approach: Position & Velocity Error



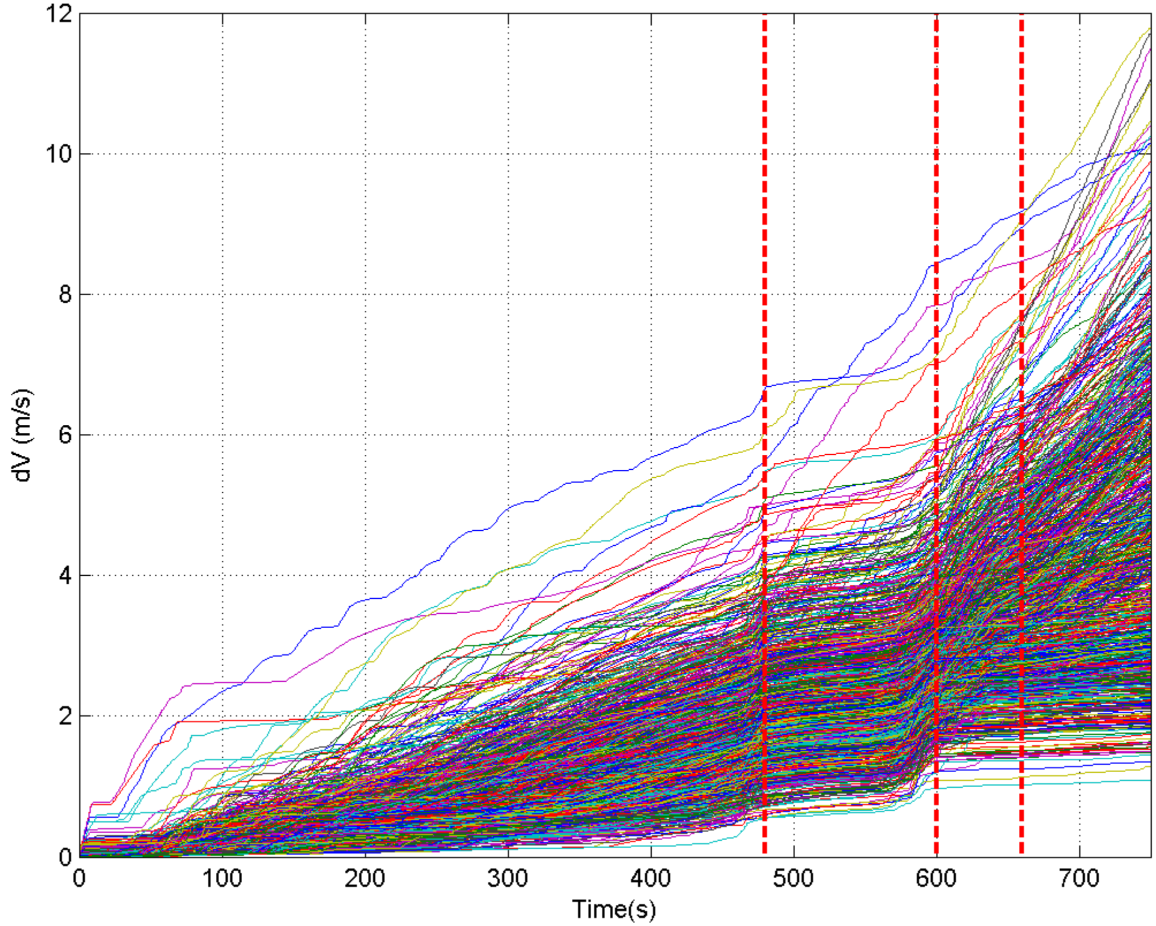
Synchronized motion: Position & Velocity Error



Pointing error



DeltaV consumption



Close Range / Final Approach example

Conclusion

- Status of the e.deorbit GNC design at end of phase B1 has been presented.
- Iteration in order to consolidate and update the design in view of the new phase B1 requirements and constraints (especially challenging requirement on Target rotation rate)
- AOCS design has been implemented, a good Sofware prototype now exists for the mission most critical phases (rendez-vous phases, Stack Stabilization, Stack Normal Mode and de-orbit boosts)
- Validation by Monte Carlo simulaitons done for Final Approach, to be fully finalized for Approach / Inspection and Stack Modes

Any question?