INVESTIGATION OF ACTIVE DETUMBLING SOLUTIONS FOR DEBRIS REMOVAL

# DETUMBLING

# Clean Space Industry days

23-27/05/2016

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- – Task 3: GNC system design and analysis
- – Task 4: (*Finalization, recommendations and future plans*)

■ Summary
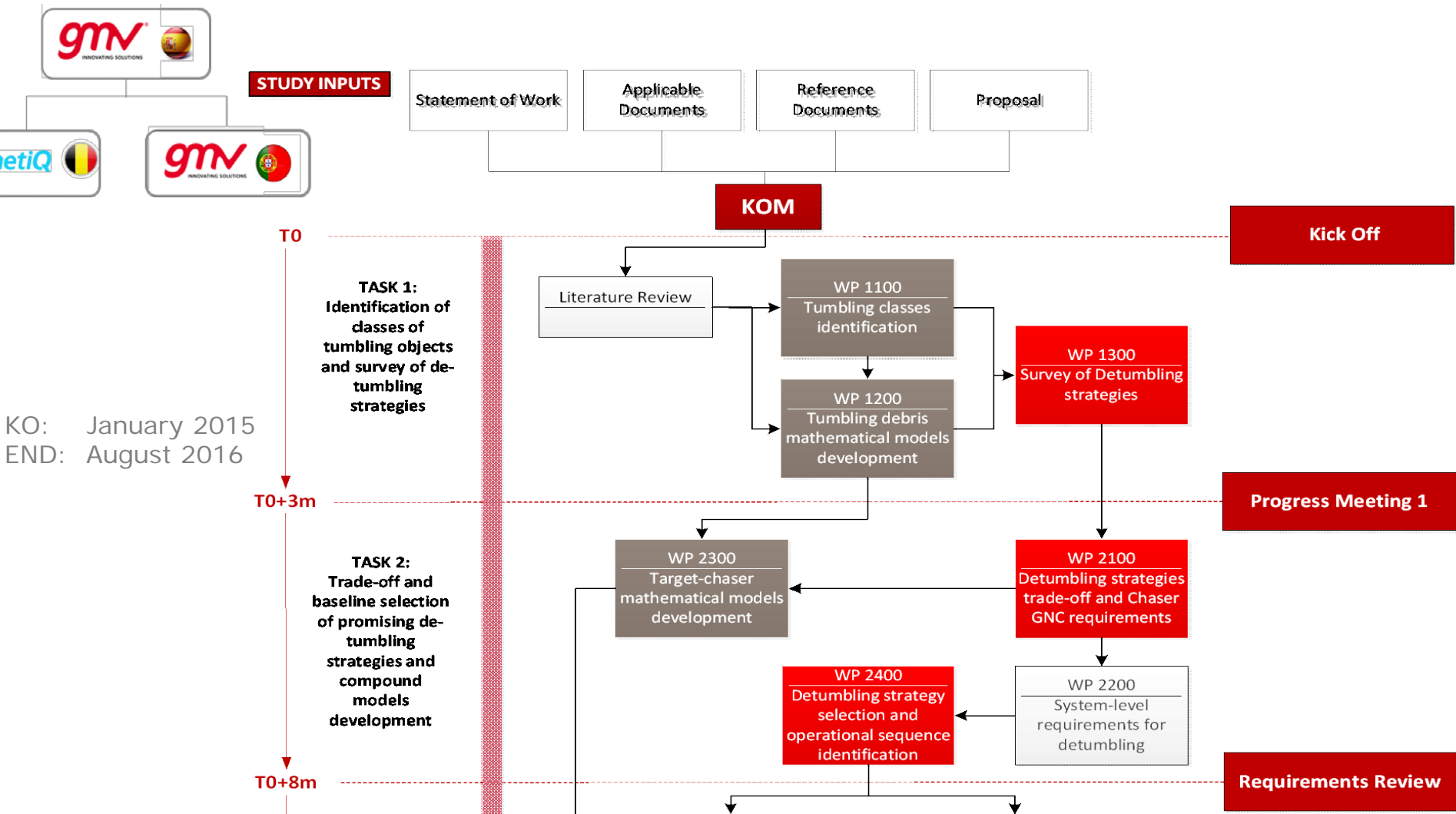
DETUMBLING
# Project objectives

# PROJECT OBJECTIVES

- Identification and characterisation of existing **classes of tumbling** objects
- Survey, trade-off and selection of **de-tumbling concepts** and strategies
- Development of mathematical **models** for tumbling debris
  - Prediction models for long term tumbling debris attitude prediction
  - Synthesis models for control design
  - Non-linear models for performance evaluation (both tumbling target and composite multi-body models)
- Baseline of a candidate concept and development of the GNC by means of ROBUST MIMO synthesis and analysis techniques
- Analysis of the applicability/scalability to a wider range of debris classes and contribution to technology Roadmaps
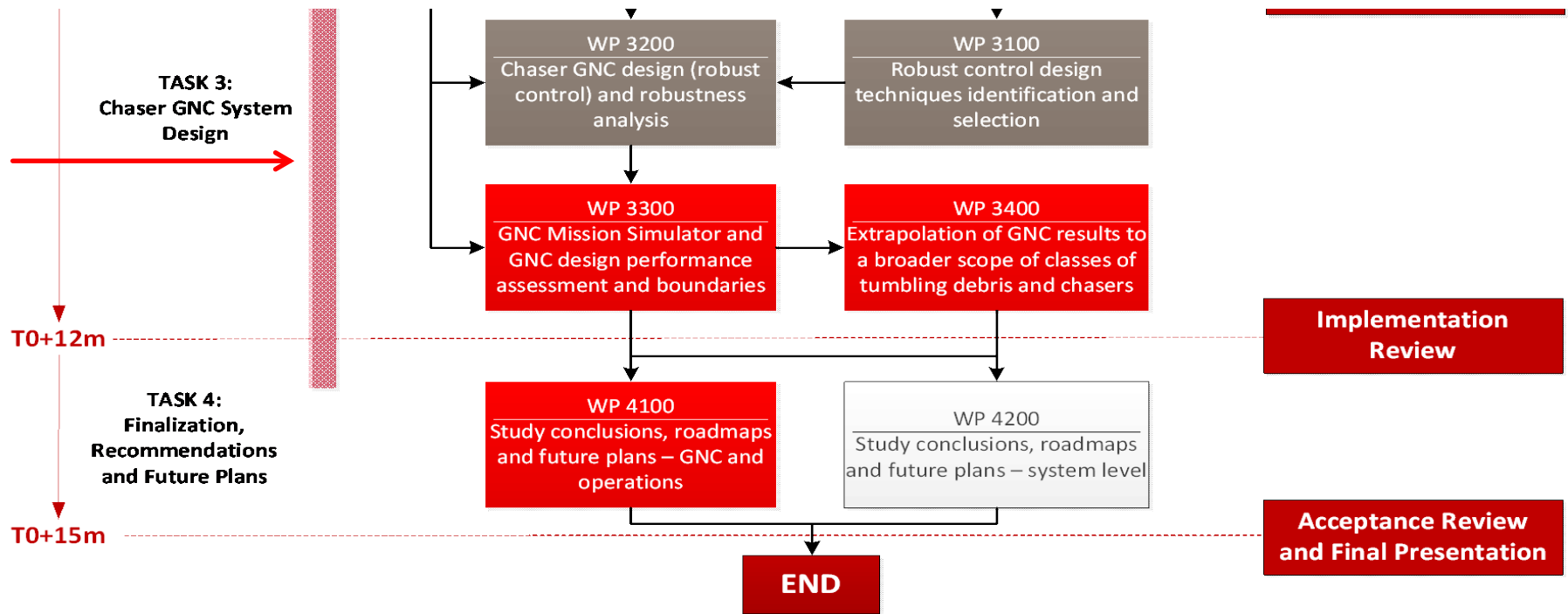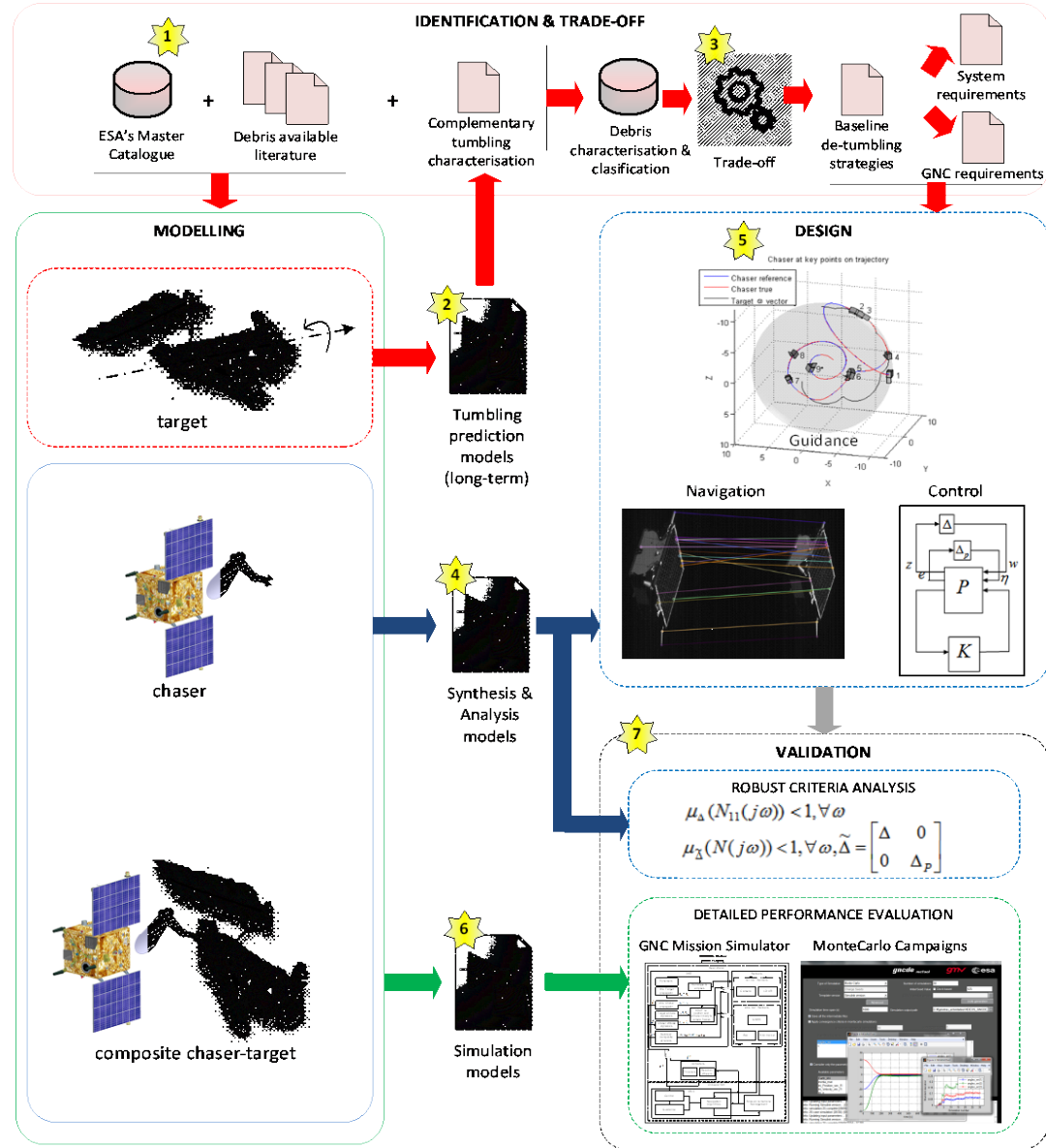
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# Study logic & current status

gmv
INNOVATING SOLUTIONS

# STUDY LOGIC

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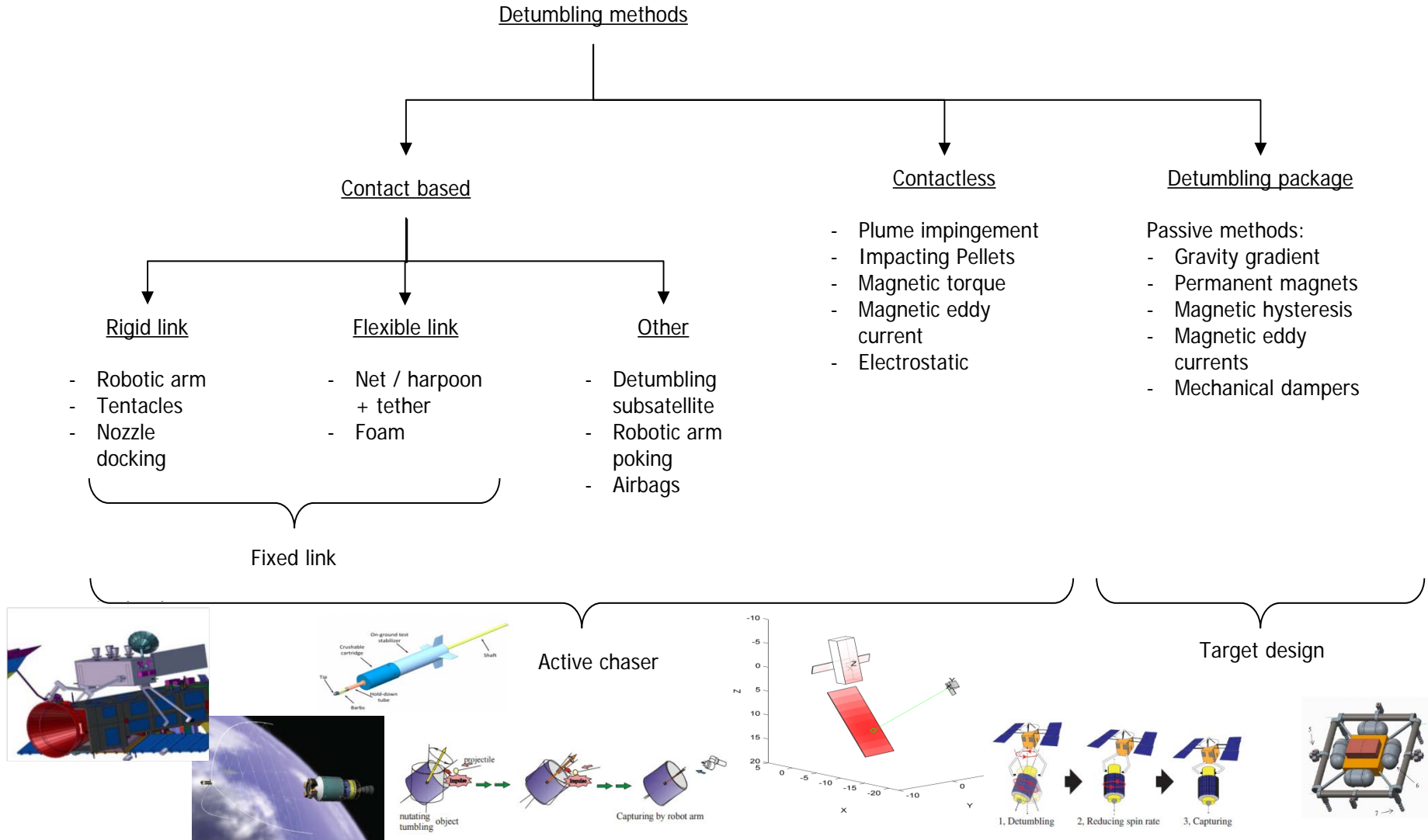- Main processes and resources of the activity

DETUMBLING

# Work performed and major outcomes

# WORK PERFORMED: TASK 1

■ Detumbling strategies review

Detumbling methods

### Contact based

#### Rigid link
- Robotic arm
- Tentacles
- Nozzle docking

#### Flexible link
- Net / harpoon + tether
- Foam

#### Other
- Detumbling subsatellite
- Robotic arm poking
- Airbags

Fixed link

### Contactless
- Plume impingement
- Impacting Pellets
- Magnetic torque
- Magnetic eddy current
- Electrostatic

### Detumbling package
Passive methods:
- Gravity gradient
- Permanent magnets
- Magnetic hysteresis
- Magnetic eddy currents
- Mechanical dampers

Active chaser

Target design

# WORK PERFORMED: TASK 1

ENVISAT study case



- **Long Term Prediction** (LTP) simulator (for debris rotational state)
  - To include only the strictly relevant effects (computational efficiency)
    - Preliminary study of the order of magnitude of each perturbation contribution for the long term behavior
    - Use analytical models and reasonable assumptions to obtain the estimation of the individual contributions of each perturbation
  - Implemented perturbations: gravity gradient, Earth magnetic torque, eddy currents, sloshing
    - Energy dissipation due to eddy current can be important for long term prediction (typically for upper stages)
      - Analytical model available for basic shapes and used to validate numerical model (surface is replaced by thin rods connected at nodes)
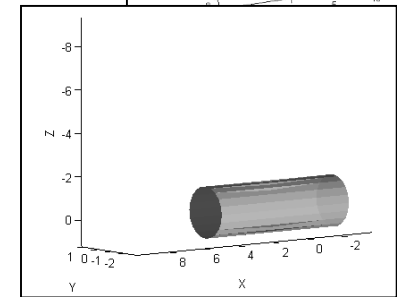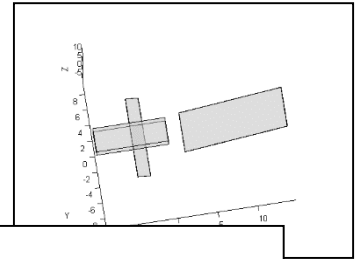
KOSMOS 3M study case
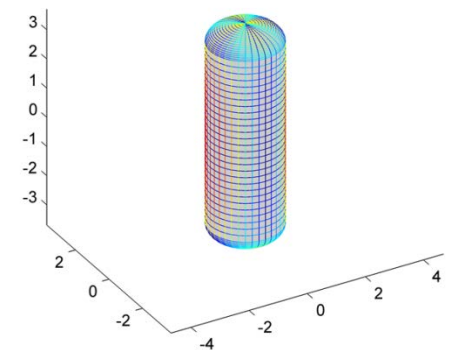


Current flow model on cylindrical tank

# WORK PERFORMED: TASK 2

- Detumbling concepts trade-off
  - Analytical hierarchy process (Thomas Saaty, 1970s) was used for the trade-off:
    - Breakdown of the problem into smaller sub-problems that are arranged in a **hierarchy**, and **pair-wise comparison** of elements
  - Robotic arm capture is selected as baseline for TASK 3 (GNC development)
    - Performs well across all three criteria (risk, technical, reliability)
    - High TRL (highest TRL of all capture and de-tumbling techniques)
    - Can partially be tested
    - Least amount of development would be required
  - It is observed that contactless methods tend to perform well on risk criterion because
    - No physical contact and no attitude synchronization
    - Plume impingement de-tumbling and electrostatic tractor also perform well on technical criteria
    - Contactless methods tend to score lower in reliability criterion

# WORK PERFORMED: TASK 3 — GNC SYNTHESIS

■ Synthesis plants with solutions for multi-body systems

  – (e.g. using 2-port models Alazard, et al "Two-input two-output port model for mechanical systems" 2015). It allows exchange of generalized accelerations and forces between the parent and child connections of an intermediate flexible element.

  – We have developed extended 2-port models to consider also rotational flexibility in arm joints

■ Focus on configurations for close range operations and composite (ENVISAT + chaser linked by means of a robotic arm)

■ A single state-space model containing the linear dynamics for the multi-body system including:

  – Slosh/Flexible modes from the solar array on the Chaser

  – The capture mechanism (e.g. a multi-segment arm)

  – Rigid dynamics from the Target spacecraft

  – Flexible modes from appendages attached to the target.

■ Take into account the uncertainty for design and analysis (LFT representation)
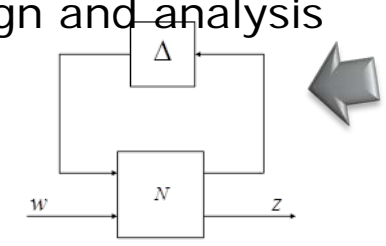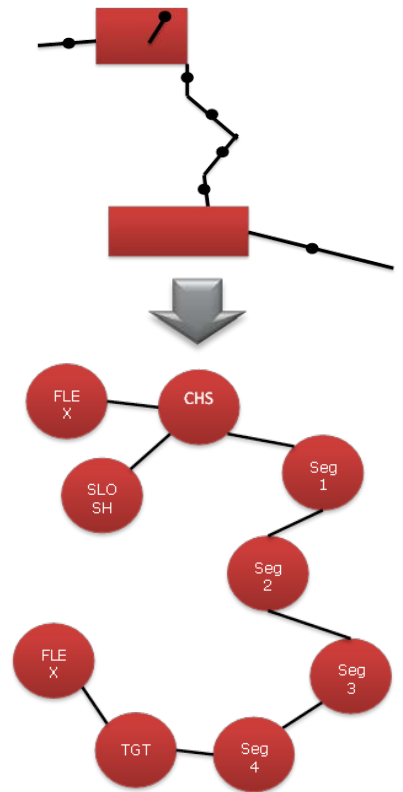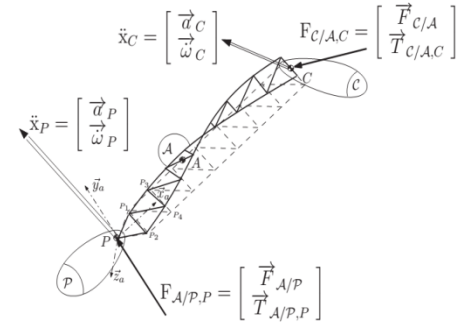
# WORK PERFORMED: TASK 3 – GNC SYNTHESIS

- **Guidance**
  - Computation of reference trajectory and attitude profiles for close rendezvous
  - Safe trajectory for target approach, for synchronisation with target body, and of the feed-forward actions (also including de-tumbling torques)

- **Control synthesis**
  - Focus on close RDV, synchronisation/capture and de-tumbling
  - Synchronisation and approach with deployed robotic arm
  - Forced motion during de-tumbling, robust to:
    - The M.C.I. properties of the composite
    - The set of thrusters, and a lower controllability during the manoeuvre application
    - Flexibility of composite body (and links)
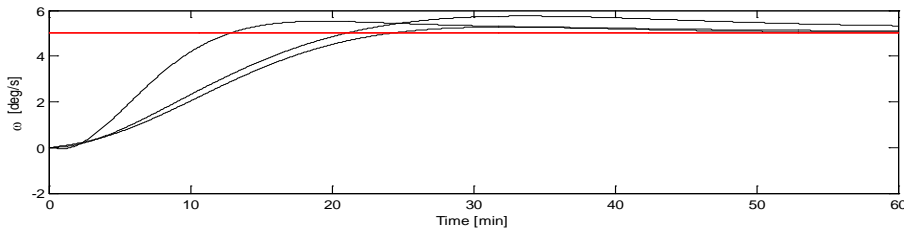  - Robust synthesis and analysis framework (Hinf. and uncertainty with LFT plants
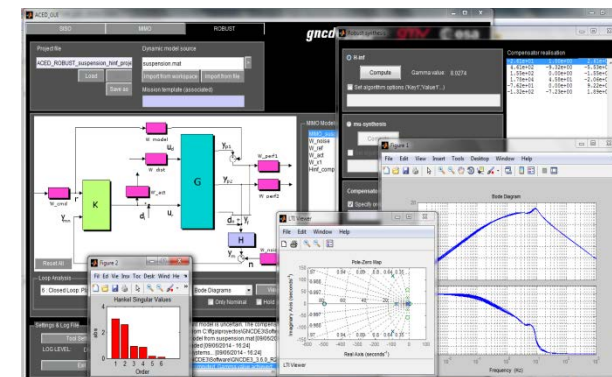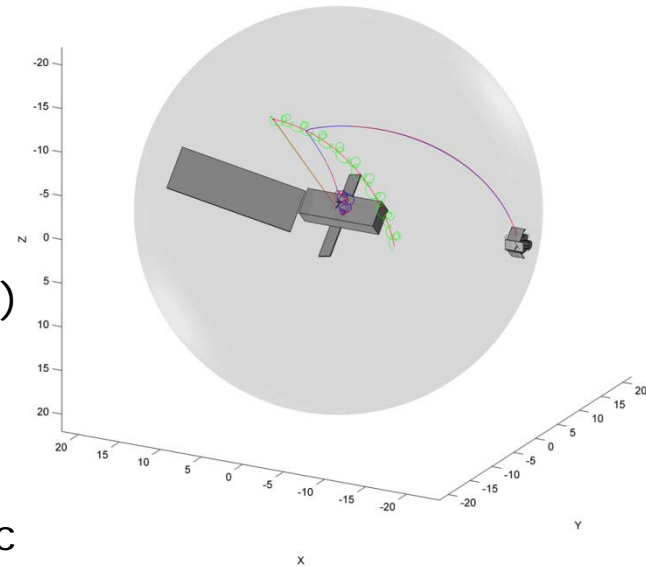
ACED Tool in GNCDE suite
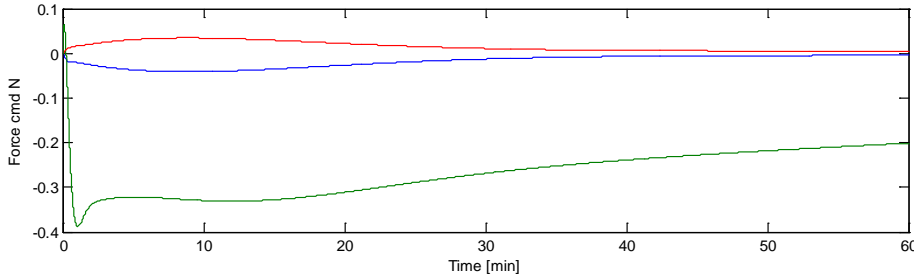
# WORK PERFORMED: TASK 3 – GNC SYNTHESIS

■ Forced Motion Control of Composite mode (preliminary control synthesis/analysis)
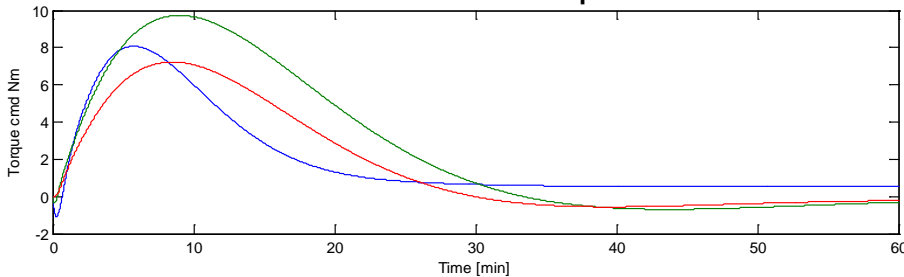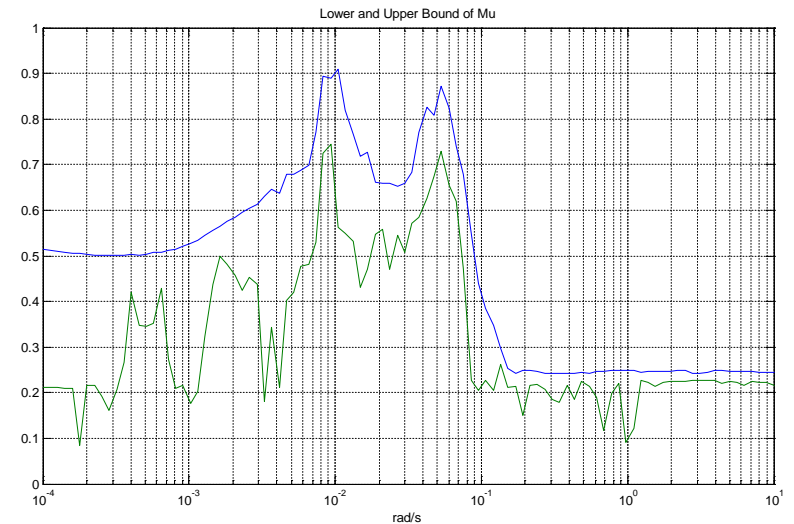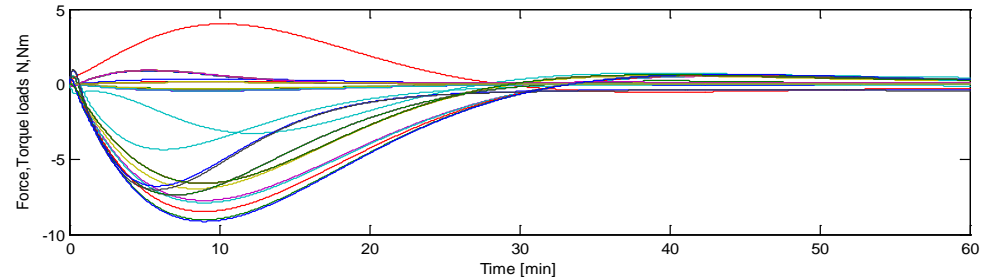
# WORK PERFORMED: TASK 3 – GNC SYNTHESIS

■ V&V in GNCDE

– A representative non-linear performance simulator has been developed (with SpaceLab libraries)

– Several DKE configurations depending on the simulated phase:

• **Close RDV** with stowed robotic arm: Independent chaser and target rigid bodies + solar array flexible modes and sloshing

• **Robotic arm** un-stowing & **deployment/reconfiguration up to capture**: Chaser multibody model (including a 3 segments robotic arm) + sloshing and independent target rigid body + solar array flexible modes

• **Composite control** (Chaser-Target multibody model with arm flexibility in locked configuration + solar array flexible modes and sloshing)
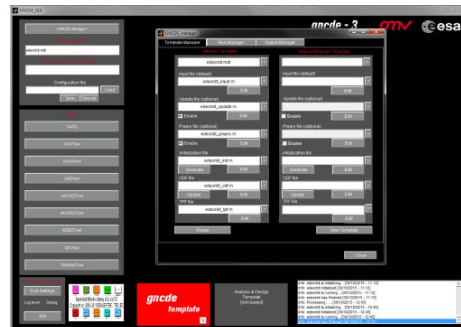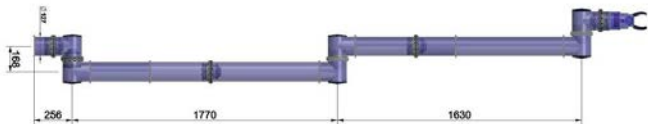
Induced base angular rate in body frame by arm deployment
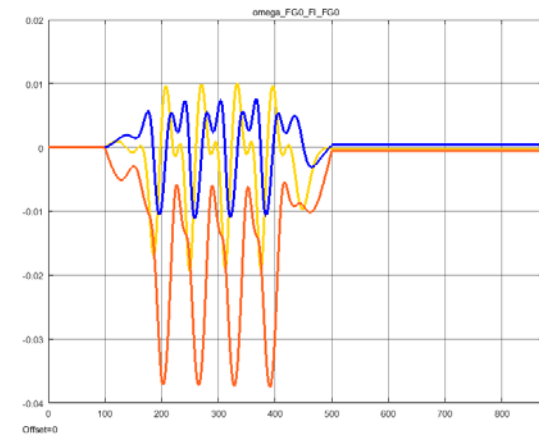


Effect from arm joints flexibility on base angular rate after torque perturbation
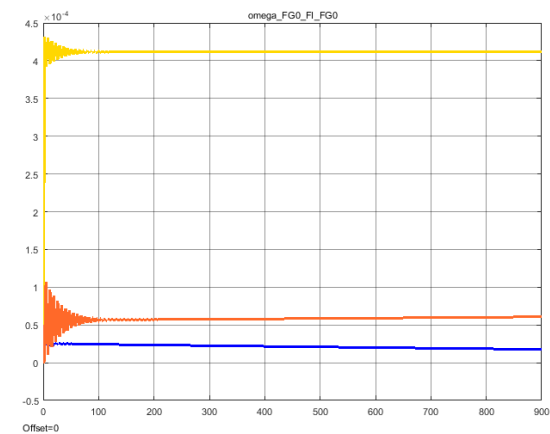
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# Summary

# SUMMARY

- Extensive **survey** performed on tumbling objects classes and de-tumbling techniques (both contact and contact-less)

- Selection of a baseline concept based on an Analytical Hierarchy Process **trade-off** (three sets of criteria used: risk, technical, reliability)

- Specification of System and **GNC requirements** applicable to the baselined concept (robotic capture).

- Development of mathematical models for tumbling debris **long term prediction** of the rotational state.

- Development of **rigid/flexible and multibody** synthesis models for robust control synthesis/analysis (including LFT)

- Development of a non-linear performance assessment simulator, including different Multibody configurations for chaser and composite (chaser + arm + target)

- Currently progressing in the robust synthesis/analysis of MIMO controllers for close rendezvous, synchronisation/capture and detumbling phases.

# Thank you

Thomas Vincent Peters

Nuno Miguel Gomes Paulino

Fernando Gandía