e.Deorbit Symposium

NET DEBRIS CAPTURING AND GNC ACTIVITIES

AGENDA

- Overview of GMV activities in ADR
- e.Deorbit Phase-A studies
- PATENDER: Net debris Capturing
- GNC activities
- COBRA-PICARD
- Android
- ***platform-art©***
- Conclusions

OVERVIEW OF GMV ACTIVITIES IN ADR

- GMV can boast significant experience in the area of space debris in general and ADR in particular
- GMV has collaborated with key institutional entities and major European space industries
  - GMV has one of the few no French entities to be involved within the CNES OTV definition study (2010)
  - GMV is currently involved within two of the ESA's e.Deorbit Phase-A studies
  - GMV is designing and developing different technologies directly applicable to the e.Deorbit mission
  - GMV is owner of ground testing facilities suitable to increase the reliability of designed technologies and potentially reducing validation costs
- GMV longstanding background and experience within MA, GNC, image processing, GS areas and as subsystem provider is facilitating optimizing its involvement and development within different ADR-related projects

E.DEORBIT PHASE-A STUDIES

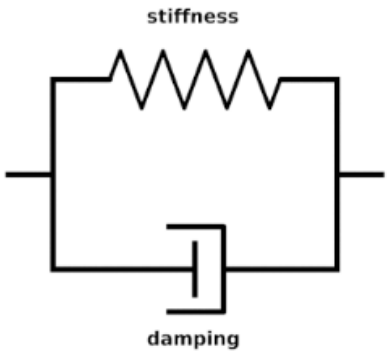
- GMV is currently involved within two over the three Phase-A study
  - Two independent GMV-ESP teams are closely working both with ADS and TAS (in alphabetical order ☺)
- Detailed presentation from the involved primes have been given this morning
  - For confidentiality GMV prefers do not enter into details about the technical contents of its activities
- Areas of participation (generally speaking):
  - ADS: Mission Analysis (i.e. Re-entry analysis, delta-V budget ground visibility, etc.)
  - TAS: Guidance and Navigation analysis for RVD scenario (approach optimization, support in sensor selection) for different capture approaches, Scenario Safety Assessment, etc.

PATENDER: NET DEBRIS CAPTURING (1)

- GMV is currently involved within one of the two parallel studies for Net Debris Capturing
- **GMV-E** is leading a consortium having PRODINTEC (ES), Politecnico of Milano (IT) and GMV-ROM as subcontractors.

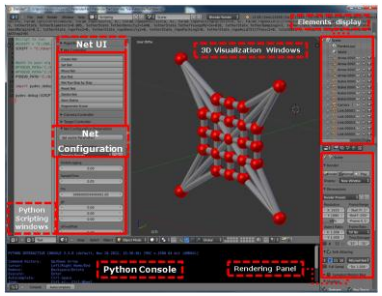
PATENDER: NET DEBRIS CAPTURING (2)

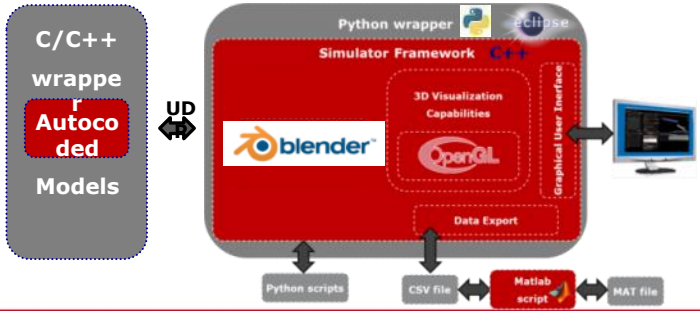
- Main goal is to develop a confident mean to further investigate, develop and validate the concept of **using nets for actively removing space debris** of different characteristics:
  - Design and development of a **high-fidelity and fast net simulator** under Blender environment
  - Validation of the net simulator in a **parabolic flight experiment**.
  - Design and set-up of a **net deployment experiment**
    - Selection and characterization of net materials.
    - Use of different net topologies (pyramidal/planar) and a satellite mock-up.
    - Manufacturing of a net launching system.
    - Use of high-speed motion cameras to record net motion and allow further 3D reconstruction of the deployment and wrapping around the target

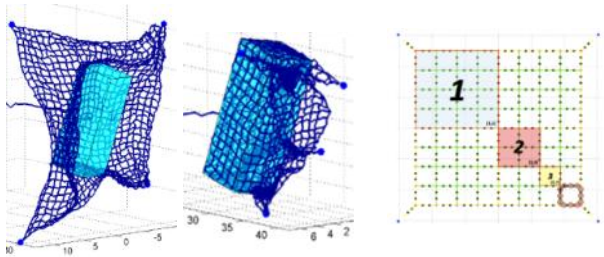


PATENDER: NET DEBRIS CAPTURING (3)

- Extensive net materials **3election** and **characterization**:
  - Design and development of a **high-fidelity and fast net simulator** Final candidates: **Technora** vs. Dyneema aramid fibers.
  - **Weaved** vs. knotted; **Splices** joints with bullets.
  - Ground experiments to determine threads stiffness.
- **Net modelling**:
  - Net dynamics: Highly discretized approach using **Kelvin-Voigt** model and orbital dynamics
  - **Collision detection**: Hierarchical bounding boxes approach using multi-step refinement.
  - **Contact Model**: Inelastic using penalty method with viscoelastic reaction forces (friction included)
- **Net Software Simulator**:
  - Full user configurable simulator (net/target/chaser/tether)
  - Blender GUI + Auto-coded net models

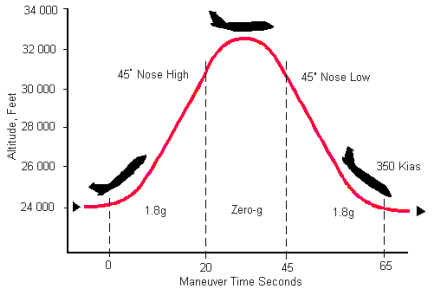


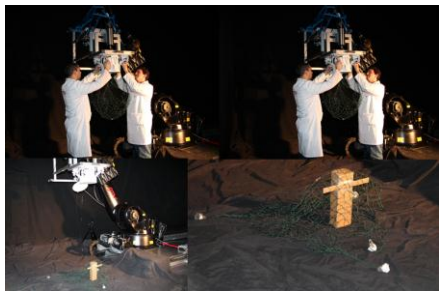


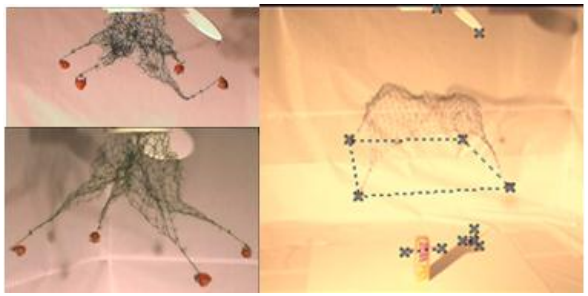


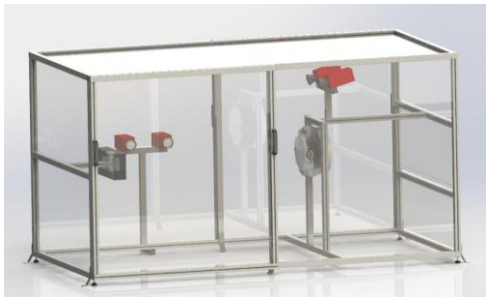
PATENDER: NET DEBRIS CAPTURING (4)

- **Net experiment design**:
  - Parabolic flight characteristics (20 parabolas of 20s under 0G conditions)
  - Experiment grided cabin of 3x1.5x1.5m.
  - Net launching system (pneumatic-based) able to launch 4 bullets at desired speed with angle adjustment and bullets reload tool.
  - Inclusion of a pulsed laser spot (camera sync), reference frame and an IMU (aircraft rates)
  - Recording of 3D motion using 4 cameras at 240fps
- **Preliminary results**:
  - Deployment of a net during horizontal/vertical launches (PDR, March 2014)
  - Manual reconstruction of 3D motion using high-speed cameras

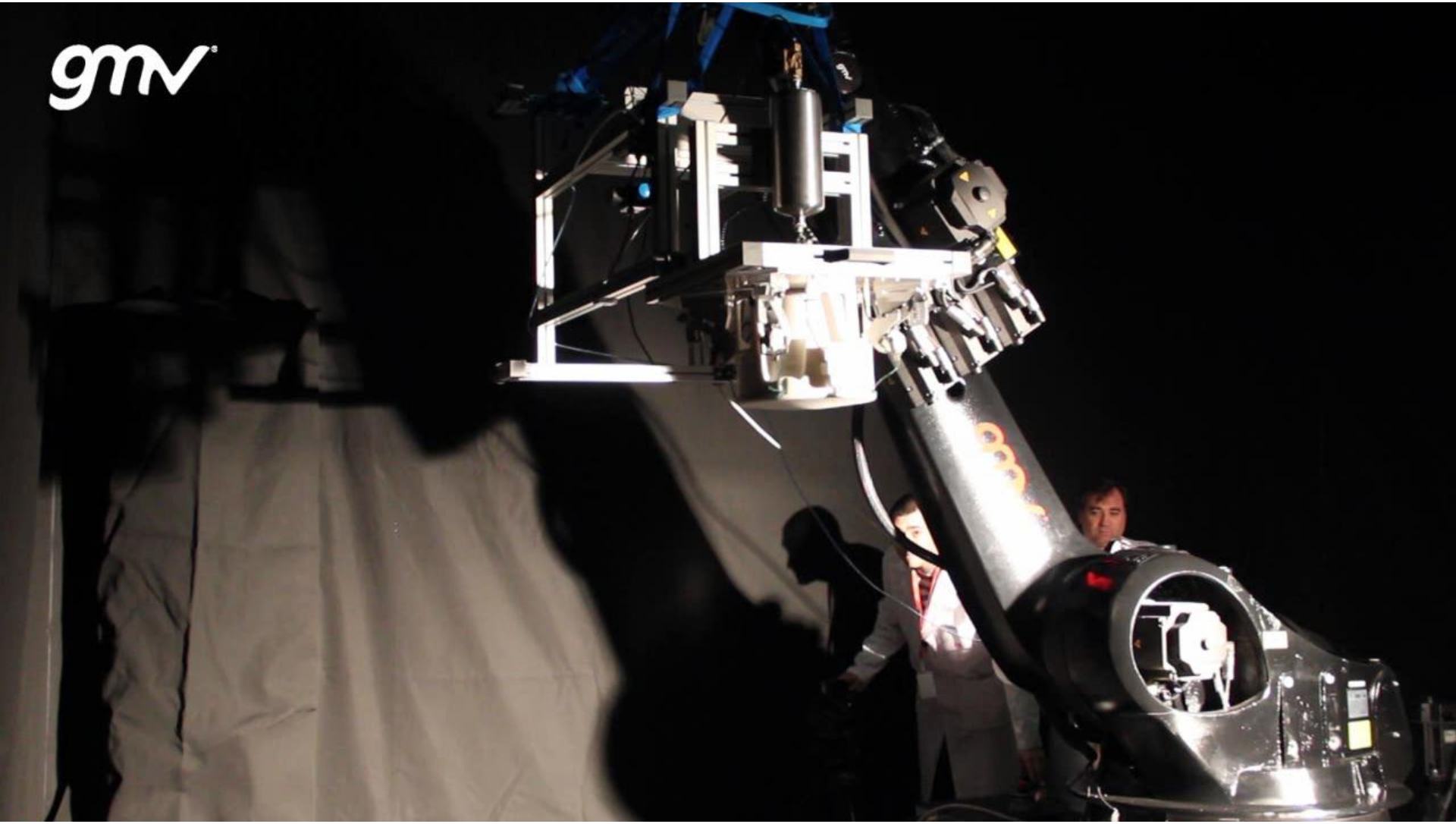




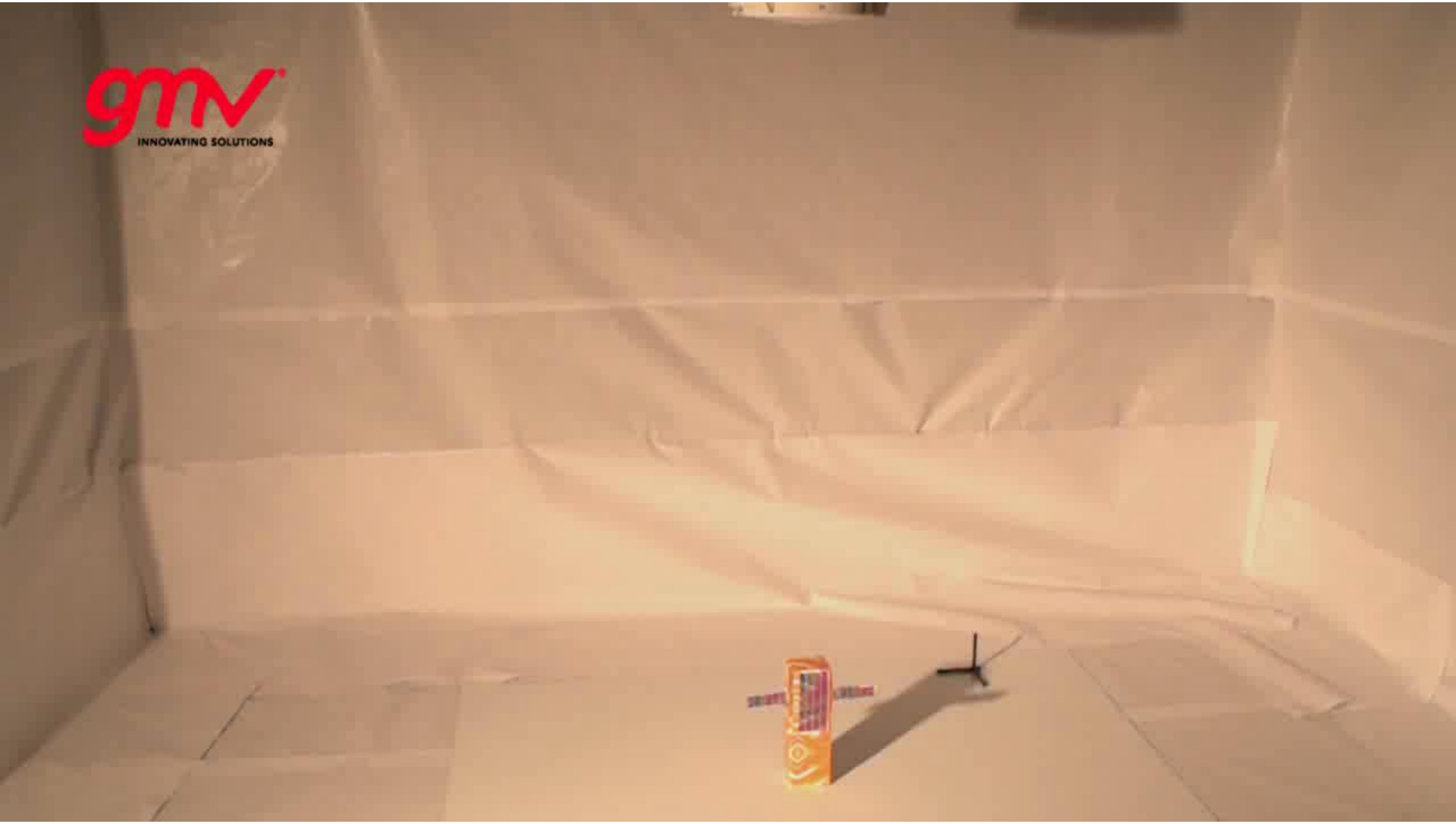




PATENDER: NET DEBRIS CAPTURING (5)



PATENDER: NET DEBRIS CAPTURING (6)

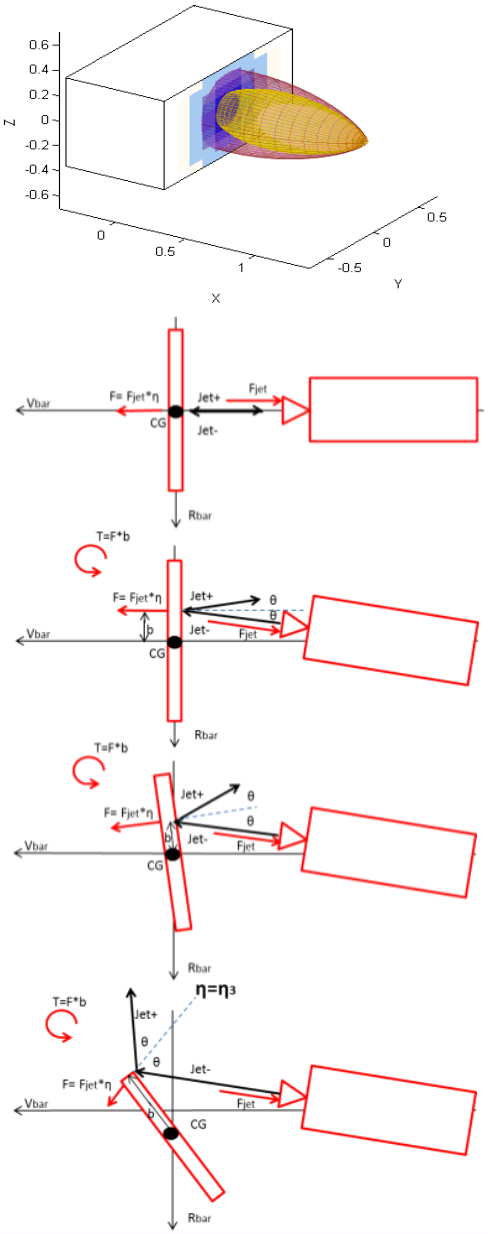


GNC ACTVITIES

- GMV is currently running different projects which are allowing developing GNC-related technologies potentially-highly suitable for a future e.Deorbit mission concept
  - Image Processing
  - GNC
  - On-ground validation of GNC functionalities
- In the frame of this presentation GMV will focus exclusively on ESA's projects

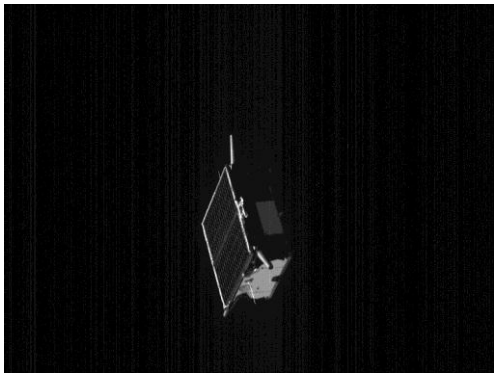
COBRA CONCEPT

- COBRA (COntactless deBRis Action) concept proposed by GMV led consortium as part of ESA´s SysNova technology assessment scheme (winner concept - 2012)
- Contactless method for deorbit or attitude control of the target via chemical engine plume impingement
- Small niche of application for deorbit purposes
- Suitable for ARD missions to de-tumble/reduce the spin rate of target before capture operations
- Different control strategies analysed from continuous actuation to pulsed actuation
- Control aspects determined by the collision mechanism (diffuse or specular) and the target characteristics (geometry and mass properties)



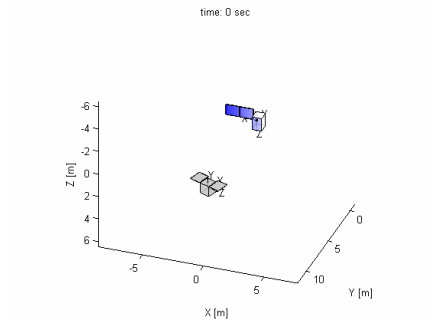
COBRA-PICARD EXPERIMENT (1)

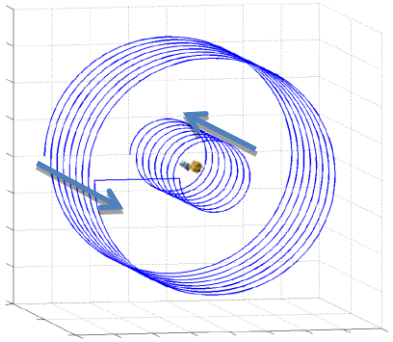
- GMV is currently running a project analysing the feasibility of applying the COBRA concept to MANGO-PICARD S/Cs
- The study is led by GMV-ESP with the TAS-I and PoliMi (as in COBRA) and the kind support of CNES and OBH-Sweden
- Goal is to predict the change in attitude motion exerted to CNES PICARD S/C, execute it and measure it with enough accuracy
  - Picard will not be operational by the time of the possible experiment, therefore no telemetry will be available (**no-cooperative target**)
  - Only available source of information will be the one provided by the on board sensors of Mango (i.e. VBS camera and DVS camera/ No relative GPS)

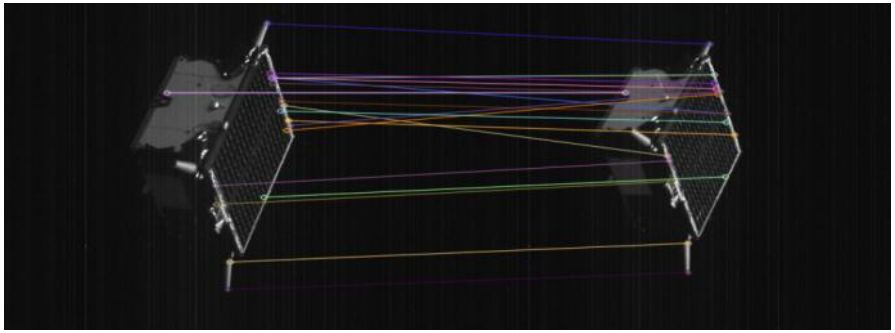


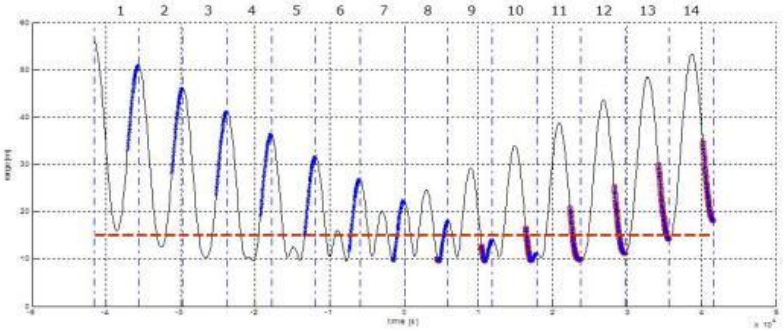
COBRA-PICARD EXPERIMENT (2)

- "Some" Mission Analysis
  - Mango orbiting around Picard in a spiral orbit (passively safe)
  - Single short burn on Picard
  - Several consecutive opportunities in a single day
- Experiment proposed as continuation of IRIDES experiment involving PRISMA (Mango) and Picard spacecraft
  - No show stoppers identified at this stage from technical point of view, but system definition not yet complete (to be completed June 2014)
  - Envisaged for August-November 2014 <u>if finally confirmed</u>



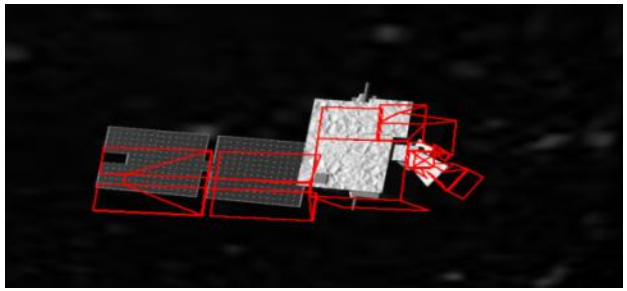


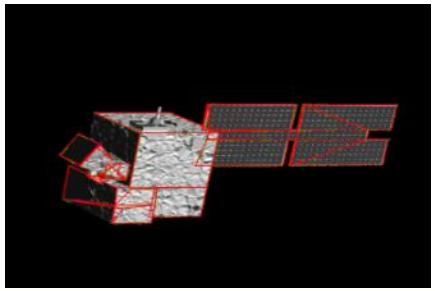




COBRA-PICARD EXPERIMENT: GNC ACTIVITIES

- A key element of the COBRA-PICARD experiment is the GNC associated developments in the area of **Image Processing**
  - Images acquired by the cameras will have to be processed to extract the pose (relative state and attitude) of Picard with respect to Mango
    - The target is known and CAD model is available (thanks to CNES)
  - With measurements before the push and after the push it will be possible to evaluate the effect of applied plume impingement (chemical propulsion)
  - 2 cameras available on-board MANGO, VBS and DVS
  - Given the low image rate and possible rotational status of the target, it will not be possibly to rely on automatic tracking to process subsequent images
  - A **relative position and attitude filter** is thus required to support the image processing
- A batch filter to refine the IP solution and estimate the S/C parameters and experiment effect



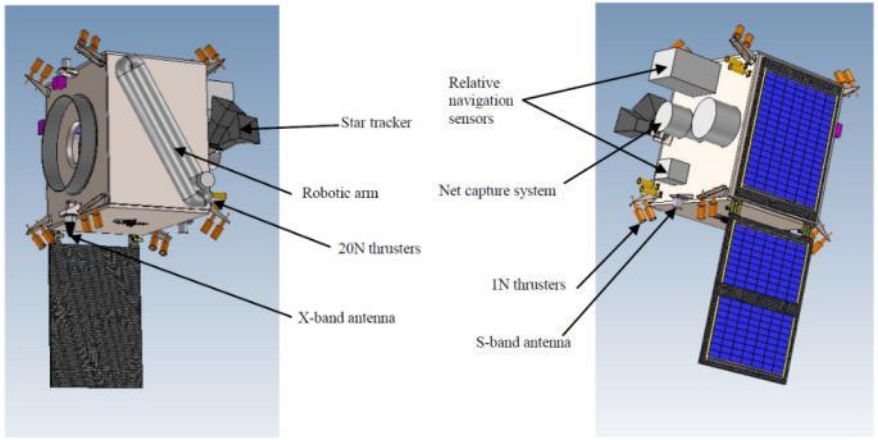


ANDROID SYSTEM STUDY (1)

- ANDROID is an ESA feasibility system study for a small mission targeting small debris removal
- Main focus is on GNC design and simulation, technologies development and programmatic aspects of the full mission
- Consortium led by GMV-ESP with QinetiQ (BE), SRC/CBK (POL) and GMV-ROM

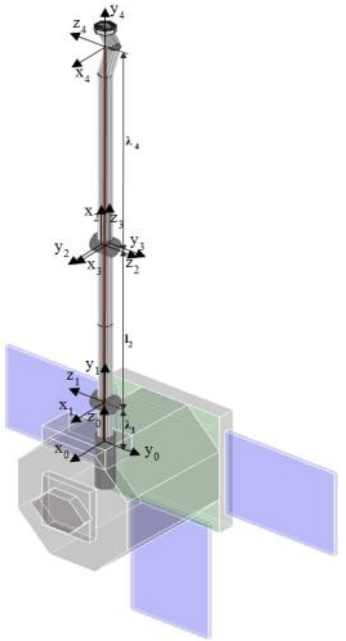
ANDROID SYSTEM STUDY (2)

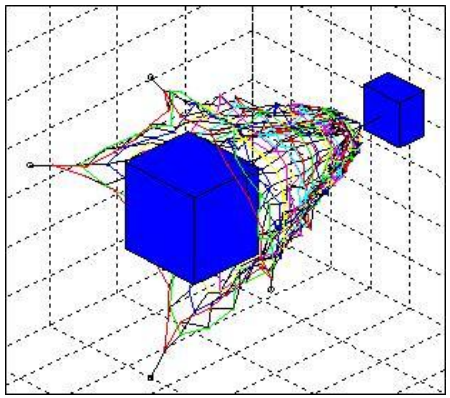
- PROBA2 as un-cooperative target debris
- Removal platform based on PROBA Next
  - System wet mass 350kg, propellant 68kg
- GNC based on existing visual camera and LIDAR, making extensive use of safe orbits, capture in free floating mode
- Both contact and contactless strategies and devices are considered:
  - Net system design (GMV-ROM) based planar design, sizing and materials according to mission
  - Manipulator based on SRC developments / DexArm with 6 joints, end effector to grasp adaptor ring
- End of project: June 2014



ANDROID SYSTEM STUDY: GNC ACTIVITIES (1)

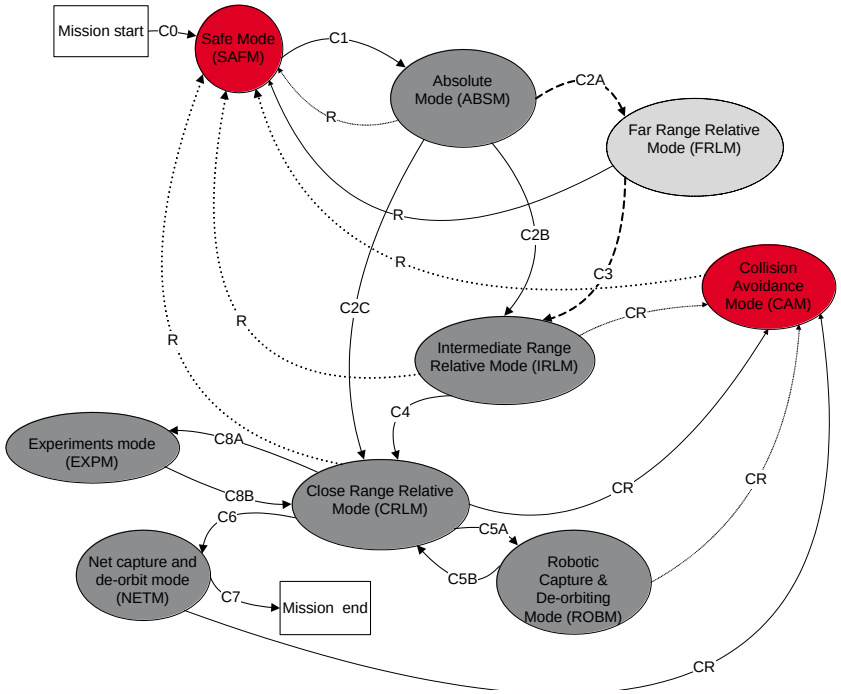
- Demonstration of two capture GNCs and devices technologies:
  - Rigid combo: Robotic Arm
  - Non-rigid combo: Net
- Perform a simulation campaign of the required GNC system functionalities
- High level of autonomy of the system for almost all phases except for orbit synchronisation
- Analysis of potential contingency cases
  - CAM
  - Retreat after robotic arm failure
  - Net catching failure
  - Non-execution of de-orbit burn
- Asses scalability of the proposed ADR scenario to larger scale debris removal scenario





ANDROID SYSTEM STUDY: GNC ACTIVITIES (2)

- GNC system is one of the key technologies in an ADR mission
- AnDROiD GNC is highly representative of the GNC required for future ADR missions, also for different range of targets
- Proposed GNC system is fully scalable, though certain modifications will be required depending on the final scenario
- System architecture, modes and transitions defined
- Almost all the required guidance and control strategies are evaluated, navigation based on visual camera and LIDAR
- The mission is divided in nominal mission (actual capture scenarios) and additional experiments to test GNC/HW required for other missions/targets
- Some modifications might be required depending on the sensor suite and capture strategy selection (target)
- Simulation of key functionalities currently on going



platform-art® FEATURES SHORT DESCRIPTION

- Functional features:
  - Dynamic test bench with real air-to-air metrology stimulation
  - Raises the GNC S/S (SW+sensors) validation till level 5/6 (ESA scale)
  - Two numerically controlled robotic arms + 15 m length rail, allowing:
    - Short-range RdV and FF scenarios (up to 525 meters using scalability factor 1:35, reasonable for 1 m S/C size level; can be higher for bigger S/C), including GNC mode transition, scenario stop/resume, change of sensors, …
    - Robotics/rovers scenarios by *platform-art*© configuration update
- Performance features:
  - **Facility certified with real (flight) data**
  - Dynamic range: 18 m
  - Accuracy: O(0.1 mm) (FARO laser tracker calibration)
  - Resolution: < 0.01 mm
  - Mock-ups (Inc. metrology): < 1 m size, 150 kg, sensors remote control
  - Darkness: full darkness room (optical spectrum)
  - Illumination: space representative at optical spectrum
  - Location/Access: GMV head-quarters
  - Others: WIFI, canteen, offices, meeting rooms, …

platform-art© ELEMENTS AND FEATURES

- ***platform-art©*** system elements:

AVIONICS

1

- Real time simulator (dSPACE board): I/F with motion control system,RW and relative kinematics computation
- Target processor (LEON): GNC on-board SW execution
- Development, monitoring & debugging systems

MECHATRONICS

2

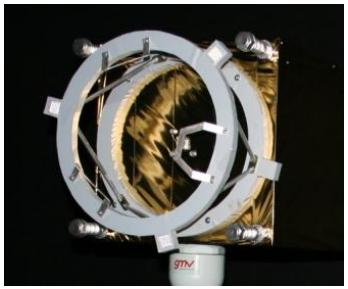
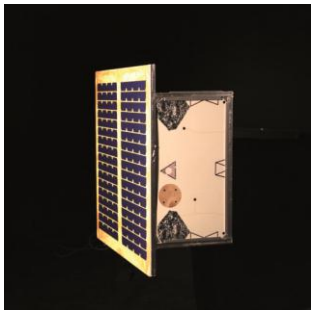
- Mitsubishi PA10-6CE
  - 6 DOF robotic arm
  - Target satellite trajectory reproduction
  - Communication delay < 1ms
- Motion control system
  - sends control commands to the robotic arms
  - security checks on arms kinematics
- KUKA KR150-2
  - 7 DOF robotic arm
  - Chaser satellite trajectory reproduction
  - 7th DOF provided by a 15m rail track
  - Communication delay < 12ms
- S/C mock-ups
  - Representative in shape and materials of the target spacecraft

SENSORS

3

- Sensors I/F:
  - Ethernet UDP/IP
  - Serial port (RS-232, RS-422)
  - MIL-bus 1553, SpaceWire (to be developed)
- Default sensor:
  - Optical navigation camera by GMV
- Customer sensors (examples of use):
  - ILT LIDAR by Jena Optronik
  - VBS by DTU



platform-art© SCALABILITY ANALYSIS

- The facility scalability analysis based on key parameters of **RF Equipment**, **Optical Camera**, and **LIDAR**
- Conclusions (for 1 meter typical spacecraft size)
  - **High-fidelity** space representativity (for all analysed sensors), including mode transitions, is achievable with **$f_{scale} \leq 10$**
  - **Medium-fidelity** space representativity (for all analysed sensors) is achievable with $10 \leq$ **fscale** ≤ 30

Dynamic test bench fidelity (1-meter target size)	PLATFORM – 15 meters Effective Testing distance
Full 1:1 scale	0 – 15 m
High- fidelity space representativity (fs ≤ 10)	15 – 150 m
Medium- fidelity space representativity (10 ≤ fs ≤ 30)	15- 450 m

platform-art©

FEST PROJECT

- FEST is an ESA project (TRP) devoted to the design and development of innovative filters for autonomous mission scenario including, among others, **autonomous ADR navigation with uncooperative targets**
- Robust estimation (square root polynomial filter, hybrid EKF/UKF, Gaussian Mixture Model)
- Line-Of-Sight only (no distance measurements) for relative position
  - From far range to very close range
- Estimation of relative attitude using vision-based observations
- Extensive validation
  - Monte Carlo simulation in MIL and SIL
  - Validation with real data from PRISMA experiment
  - Test in real time at different frequencies with representative Processor-In-the-Loop (LEON2)

CONCLUSIONS

- GMV is highly involved within e-Deorbit/ADR system concepts and technological developments
  - GNC technologies
  - Image processing
  - Tools development for system and subsystem design
- GMV on-ground facilities have been demonstrating to be very suitable to increase reliability and robustness of GNC technologies and reducing validation costs
- GMV is very interested in being part of the e-Deorbit missions


Thank you
INNOVATING SOLUTIONS