Clean Space Industrial Days

PATENDER

NET PARAMETRIC CHARACTERISATION AND PARABOLIC TEST

AO / 1-7452 / 13 / NL / RA

POLITECNICO DI MILANO

FUNDACIÓN PRODINTEC FACTORY OF FUTURE

gmv INNOVATING SOLUTIONS

PATENDER PRESENTATION OUTLINE

- CONSORTIUM AND OBJECTIVES
- NET CHARACTERISTICS AND DESIGN
- NET MODELLING AND SIMULATOR
- PARABOLIC FLIGHT SET-UP
- 3D NET TRAJECTORY RECONSTRUCTION
- VALIDATION
- CONCLUSIONS

PATENDER PROJECT

- Industrial consortium lead by **GMV** with PRODINTEC (ES), University Polytechnic of Milano (IT) and GMV-ROM as subcontractors.

- 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.

NET CHARACTERISTICS (1/2)

- Dynamically scaled nets:
  - Representative of 24m and 36m nets
  - Material trade-off and selection:
    - Space qualified (**Technora** vs. Dyneema aramid fibres)
    - **Knotted** vs. weaved intersections
    - **Spliced** joints with bullets
    - Mechanical properties (foldable, strength, etc.)

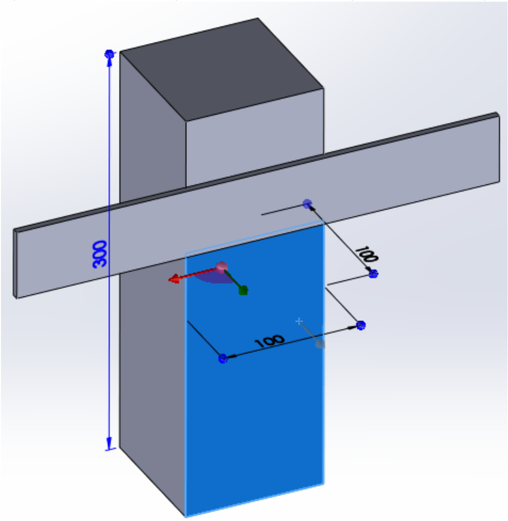
Scaled nets (parabolic flight)

Property	Value
Geometry	Planar/Square
Size	0,9x0,9 m 0,6X0,6 m
Mesh	0,05/0,025 m
Thread	0,001 m
Material & Manufacturing	Technora (black) Knotted
Bullet link	Splice (0,15 m)

Spliced connection

for bullets

Technora net
(5cm mesh)

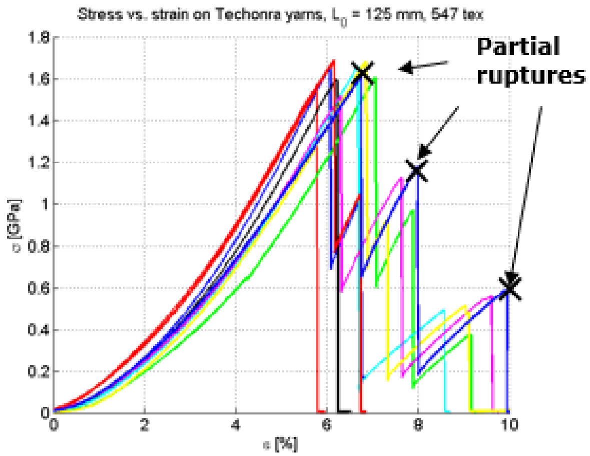


Simplified mockup of Envisat body (1:40 scale)

NET CHARACTERISTICS (2 / 2)

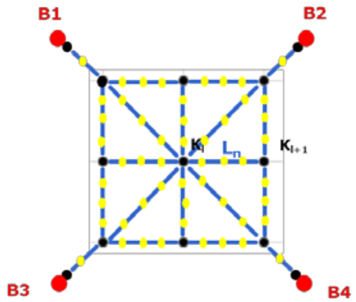
- Net material testing at PoliMi labs:
  - To characterize fiber ropes mechanical properties, reducing number of uncertain parameters during model validation
  - Tensile tests and dynamical mechanical testing to identify:
    - Young's modulus, breaking strength and knots strength retention
    - Axial, torsional and bending stiffnesses and dampings



Young's modulus [GPa]	25.367
Breaking stress [GPa]	1.626
Breaking strain [%]	6.43
Knot breaking stress [GPa]	0.536
Axial stiffness per unit length [N]	9.84·103
Torsional stiffness per unit length [Nm2]	2.94·10-6
Bending stiffness per unit length [Nm2]	1.34·10-6
Axial damping ratio [-]	0.106
Torsional damping ratio [-]	0.079
Bending damping ratio [-]	0.014

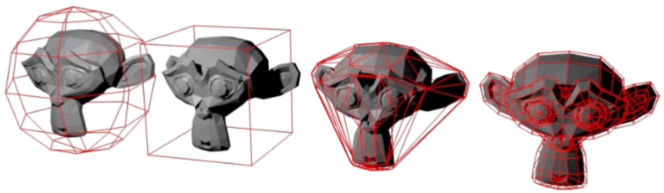
NET MODELLING



- **Net dynamics** :
  - Linear Kelving-Voight model
  - Orbital dynamics
  - Highly discretized approach
  - Net arbitrary shapes, thether, closing mechanism

$$T_{ij} = \begin{cases} [-k_{ij}(|\boldsymbol{R}_{ij}| - l_{nom}) - d_{ij}(\boldsymbol{V}_{ij} \cdot \widehat{\boldsymbol{R}}_{ij})]\widehat{\boldsymbol{R}}_{ij} & if\ |\boldsymbol{R}_{ij} > l_{nom}| \\ 0 & if\ |\boldsymbol{R}_{ij} \leq l_{nom}| \end{cases}$$

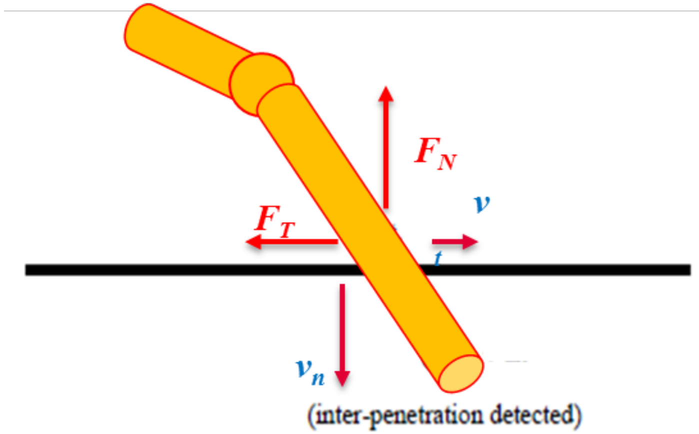
- **Collision detection**: Bullet hierarchical bounding boxes approach using multi-step refinement.



- **Contact Model**: Inelastic using penalty method with viscoelastic reaction forces (friction included)

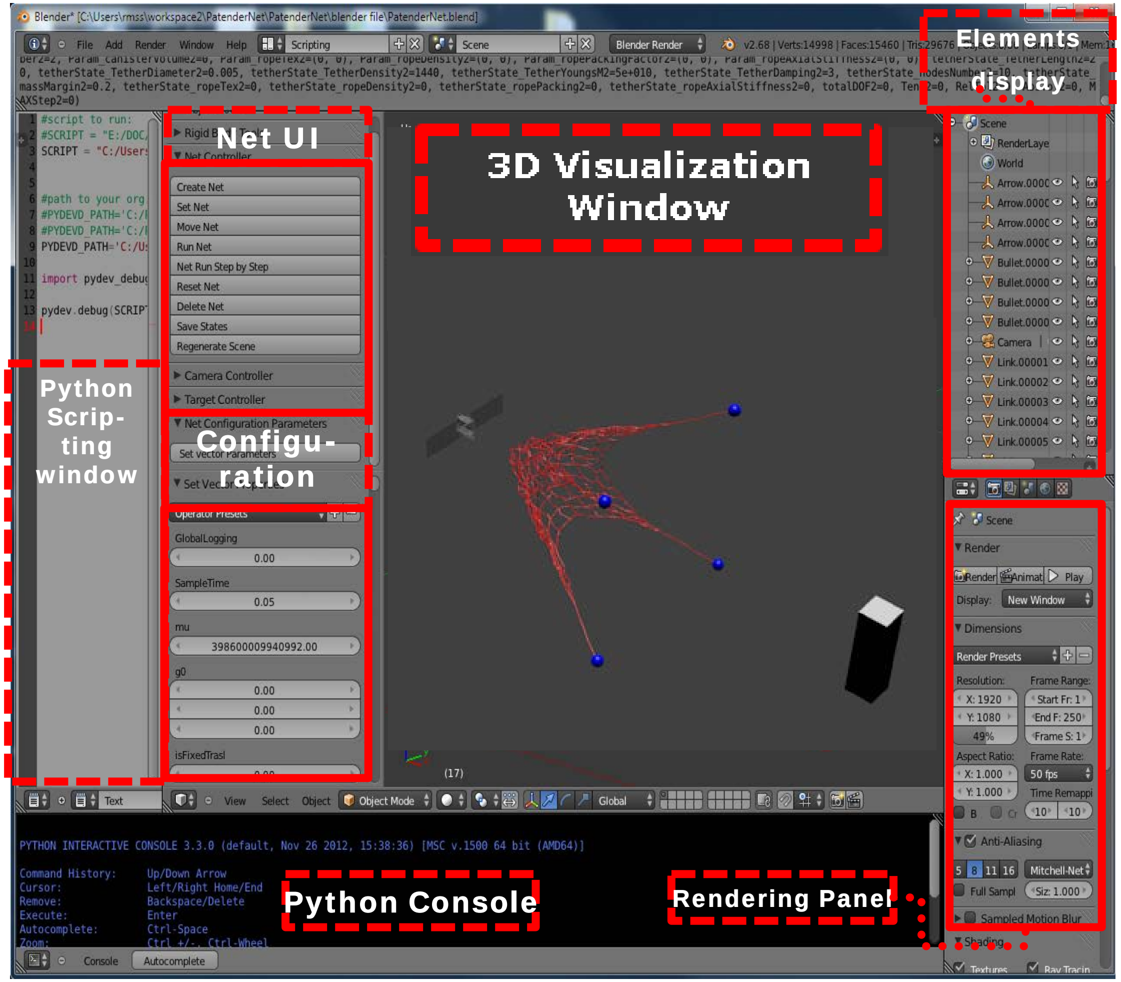
$$\boldsymbol{F_N} = -(k_n \cdot s_n + c_n \cdot |\boldsymbol{v_n}|) \cdot \boldsymbol{v_n}/|\boldsymbol{v_n}|$$

$$\boldsymbol{F_T} = -k_C \cdot |\boldsymbol{F_N}| \cdot \boldsymbol{v_t}/|\boldsymbol{v_t}|$$



NET SIMULATOR

- **Blender** environment provides a framework for the visualization of 3D objects composed by the following elements:

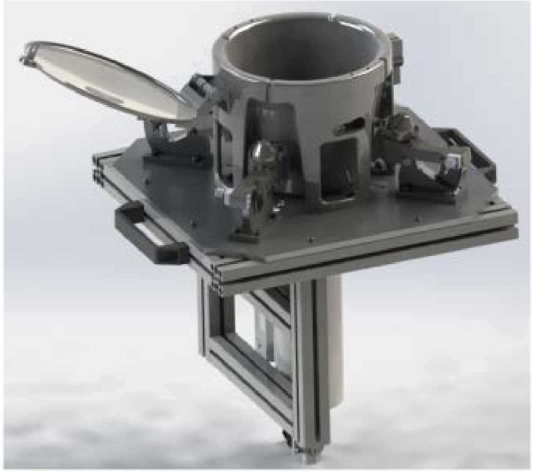


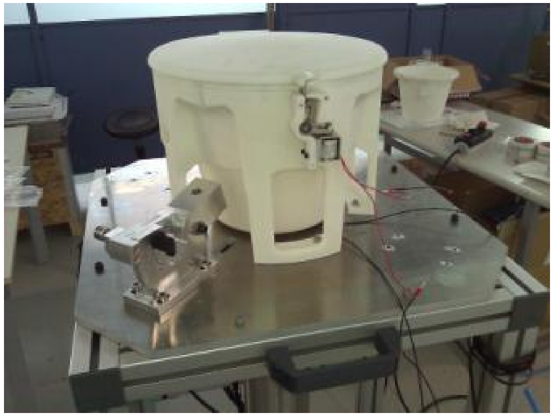
- **3D Visualization window**:
  - Knots, nodes, bullets (type: “spheres”)
  - Links/Threads (type:”cylinder”)
- **User Interface**
  - Net commands and configuration panels
- **Python scripting window**
  - Connection to the scripting files
- **Elements display**
  - Vizualisation of all the elements in the scene
- **Rendering panel**
  - Image and video recording
- **Python Console**
  - Interactive console

NET LAUNCHING SYSTEM

Whole system

Launching system





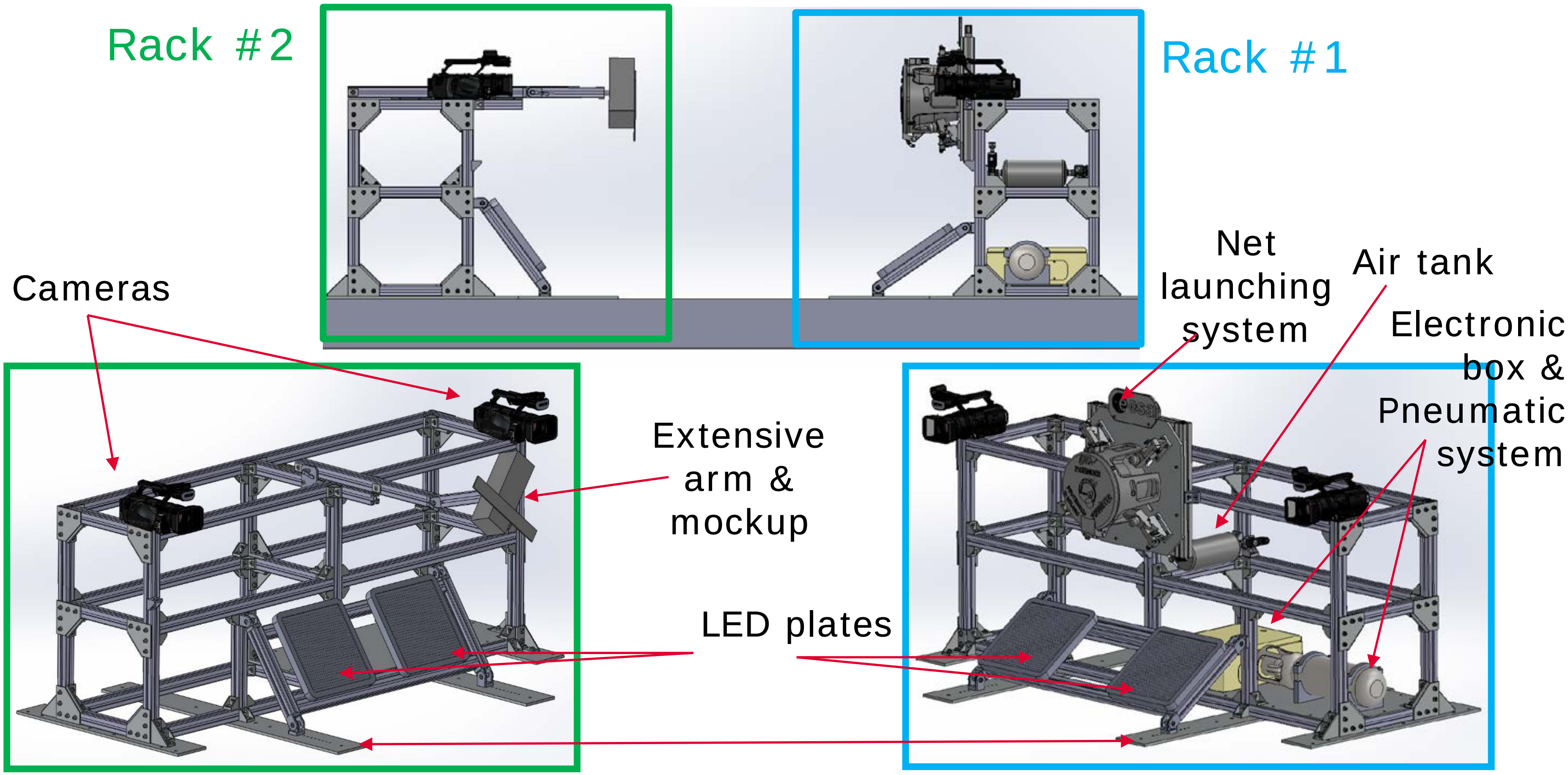
Angle adjustment

Canister

Canister and cover support

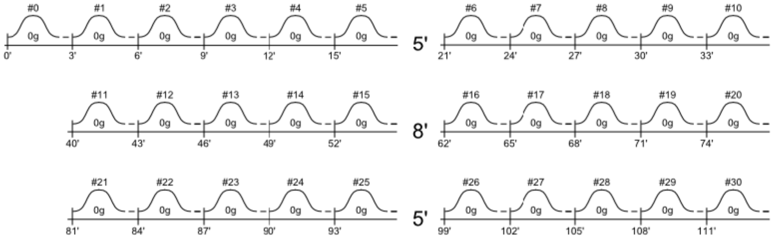
PATENDER PARABOLIC FLIGHT SET–UP

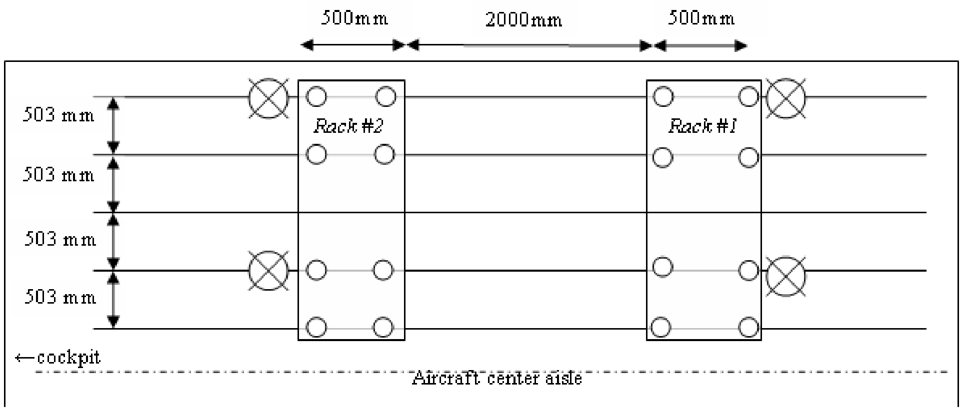
- Set of two racks with dimensions (LxWxH) 500 x 2000 x 810 mm.
- Overall flight set – up: 3000 x 2000 x 1500 mm
- Adjustable Mock-up position (vertical and horizontal).

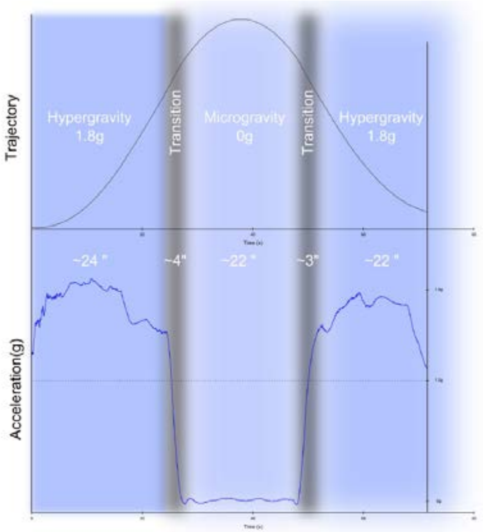


NOVESPACE PARABOLIC FLIGHT

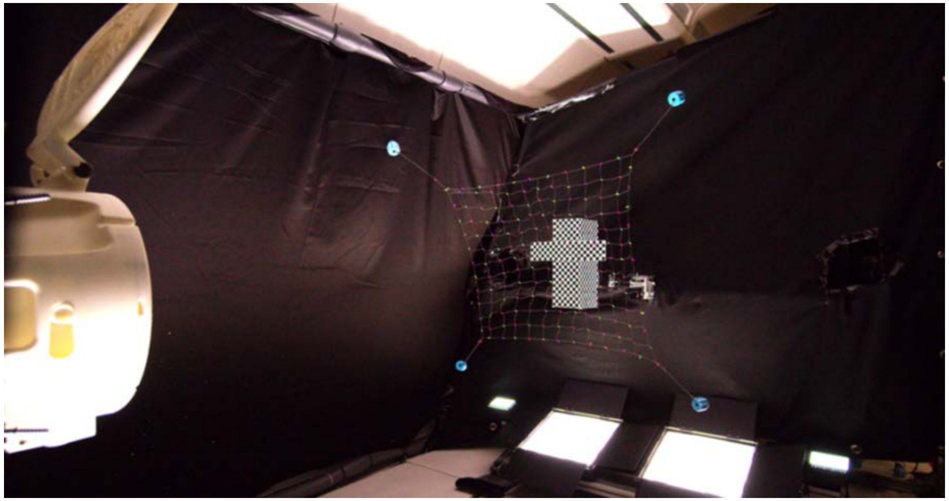
- Participation in the 62nd ESA parabolic flight campaign VP 116 (June 9th 2015)
- Six set of 5 parabolas (total of 30 parabolas)
- Microgravity periods of 22s
- Intensive assessment of hazard risks
- Patender experiment:
  - Use of 5 nets+mockups
  - Deployment time of 2-3s
  - Net reload operations between breaks

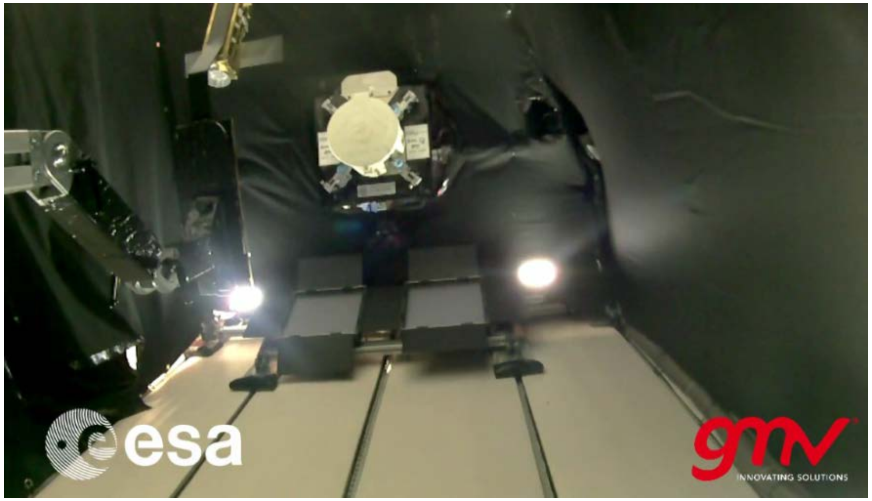


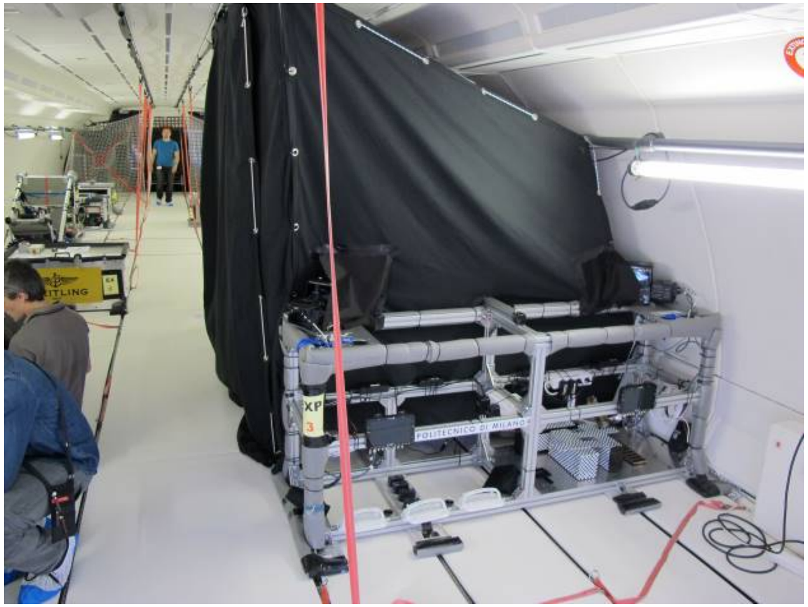




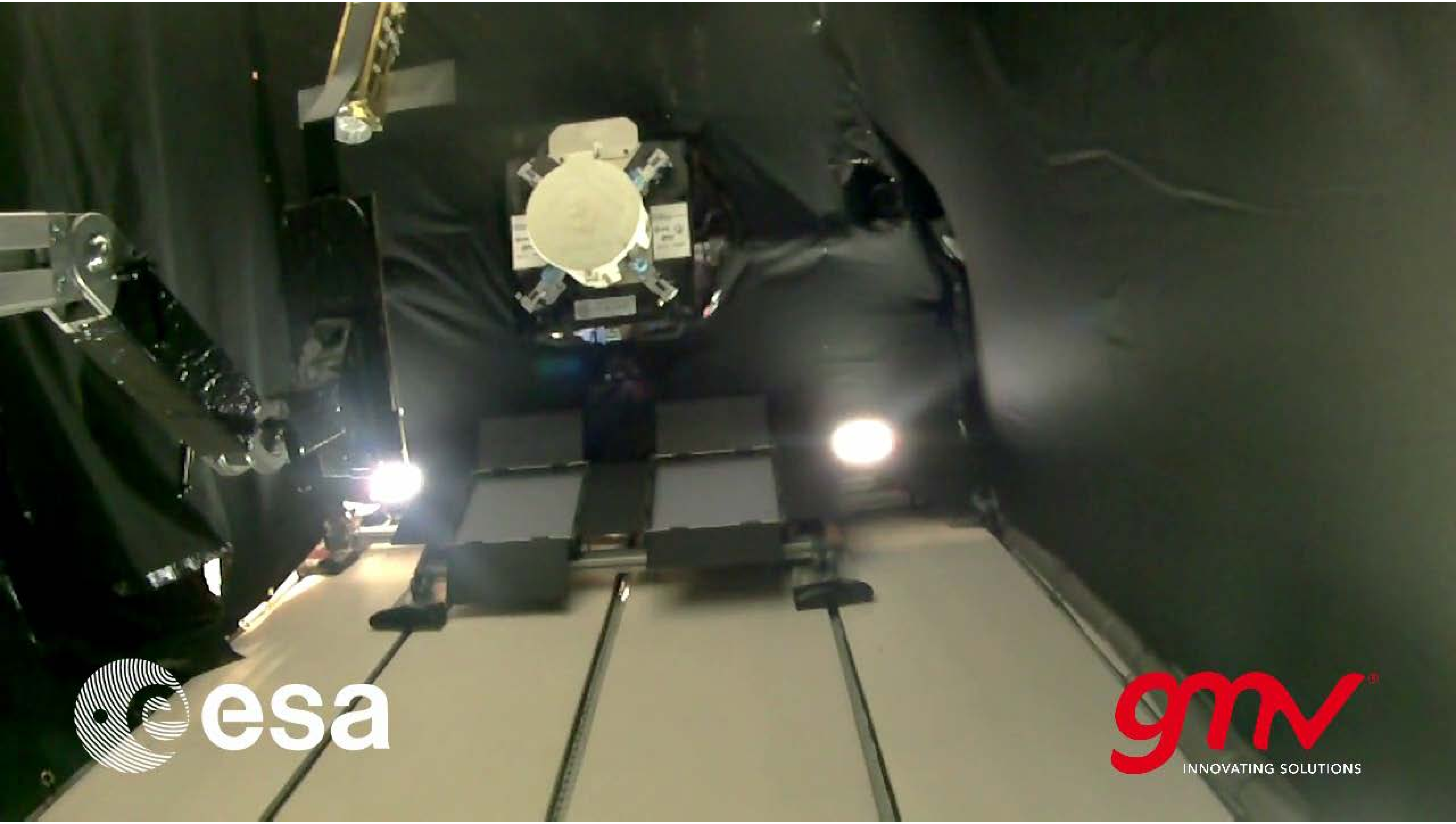
PATENDER ONBOARD EXPERIMENT





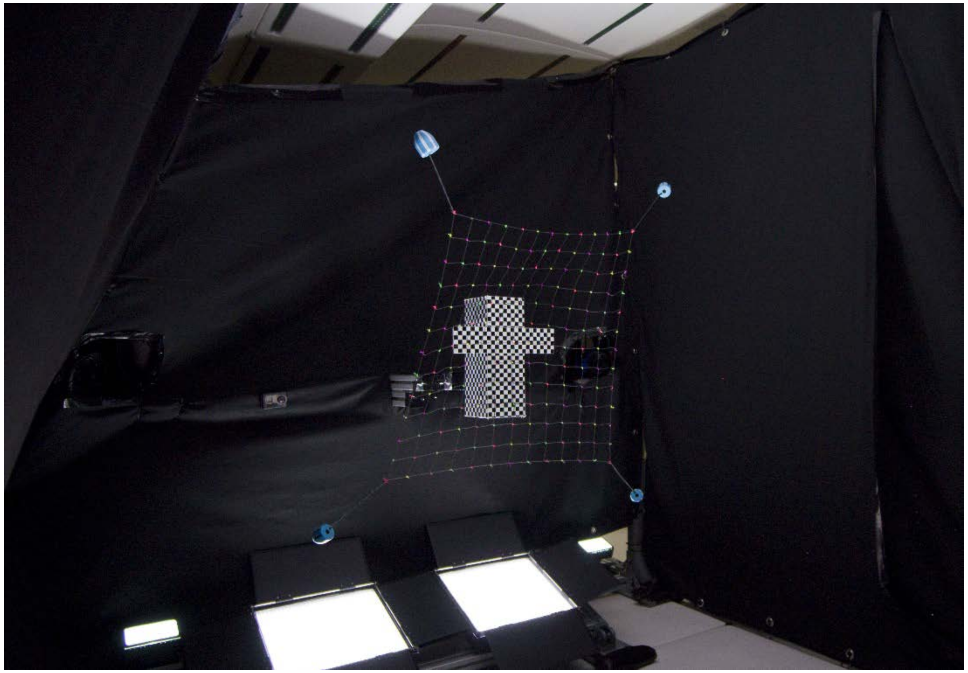


PARABOLIC FLIGHT EXPERIMENT



PARABOLIC FLIGHT RESULTS

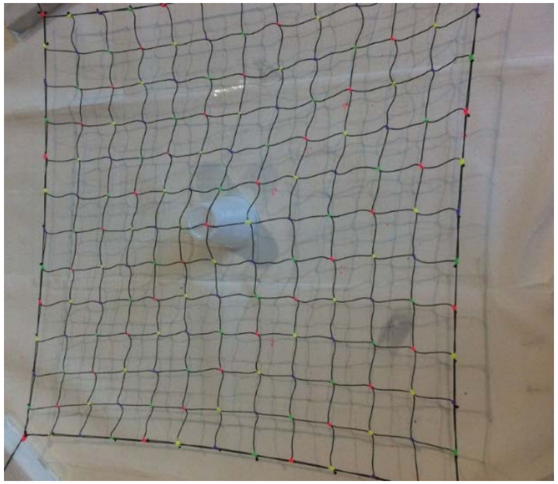
Type of deployment	#
GOOD Quality	9 (7+2)
Reduced quality	6
Non reconstructable	5+3(Envisat)
Failed	7



Major difficulties:

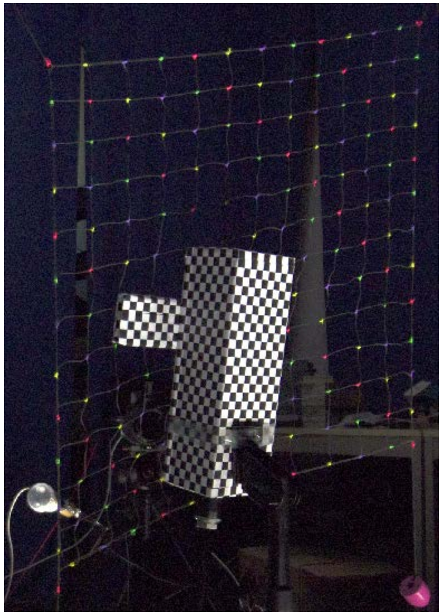
- Complexity of operations
- Non-simultaneous bullets
- Use of high deployment speed

3D RECONSTRUCTION

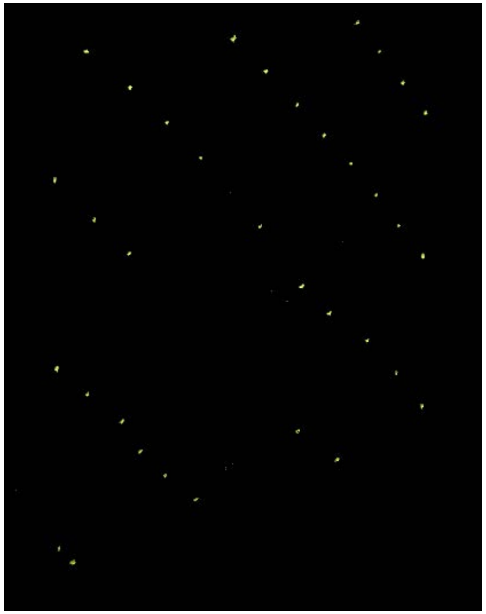


- Reconstruction process: Semi-automatic based on net colour-coding:
  - Requires uniform background
  - Requires strong illumination (led lights to cope with aircraft safety rules)
- Reconstruction steps:
  - Raw processing fro white/gain correction
  - Colour segmentation and filtering
  - Points cloud reconstruction and stereo matching
  - Open net topology reconstruction
  - Tracking back/forward (ICP + constraints)

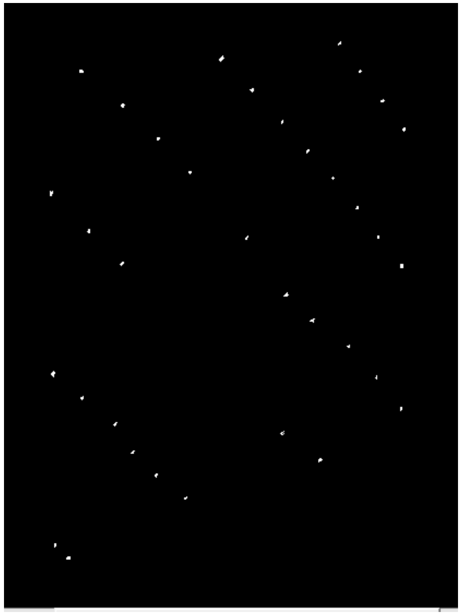
RAW Image



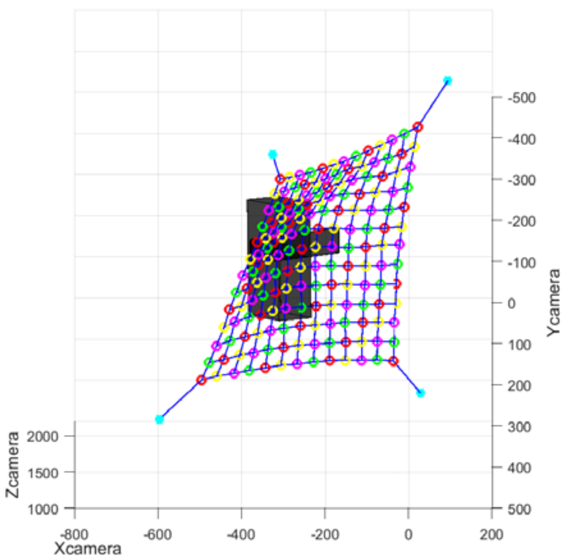
Colour filter

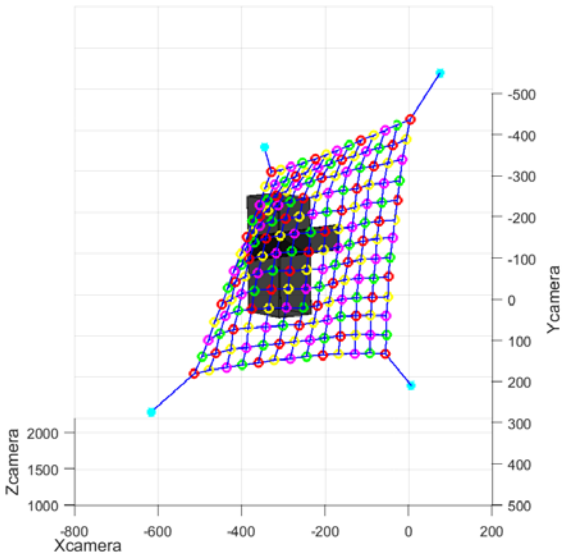


Binary image



3D RECONSTRUCTION RESULTS





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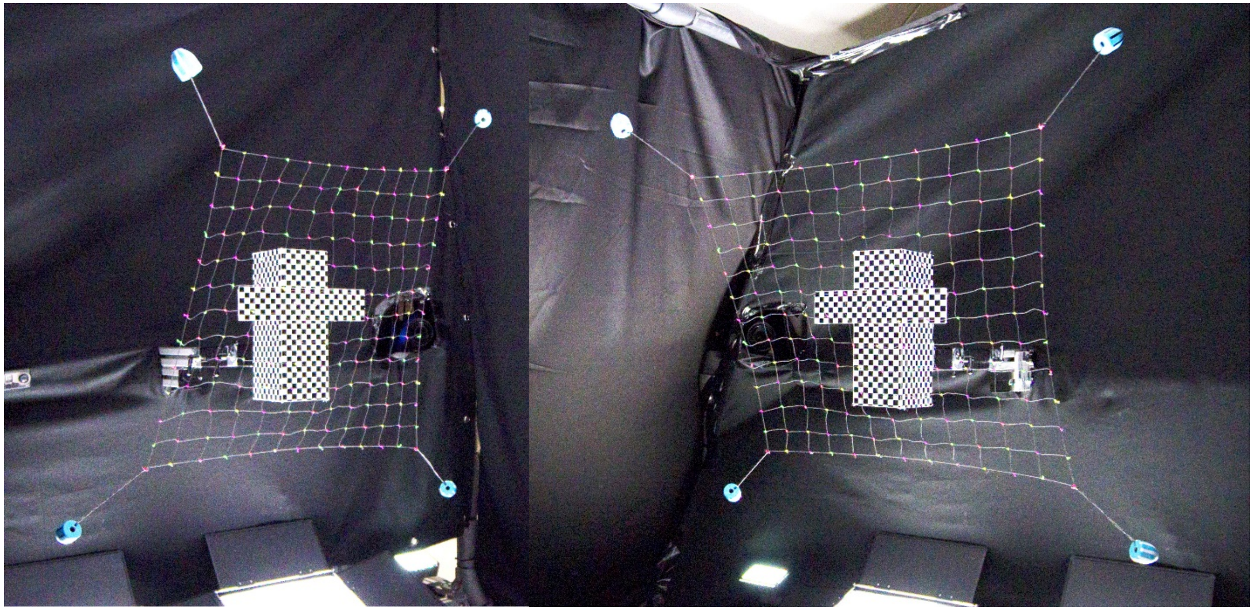

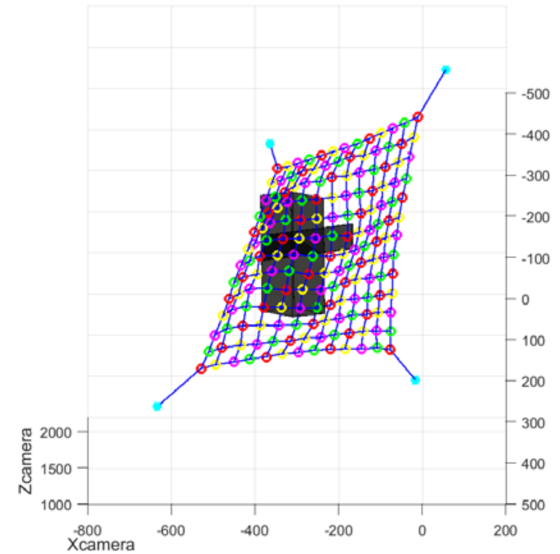

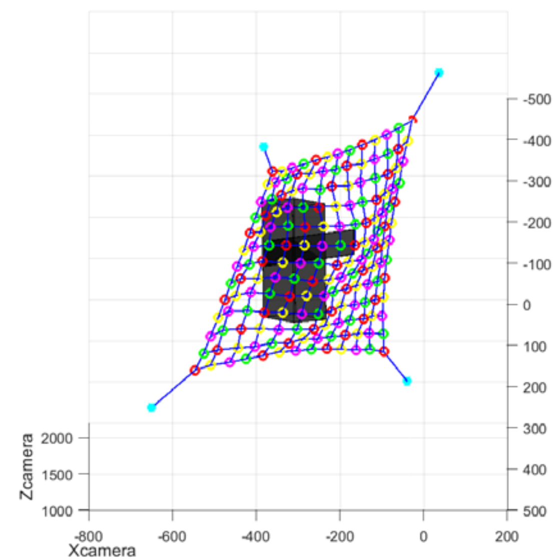

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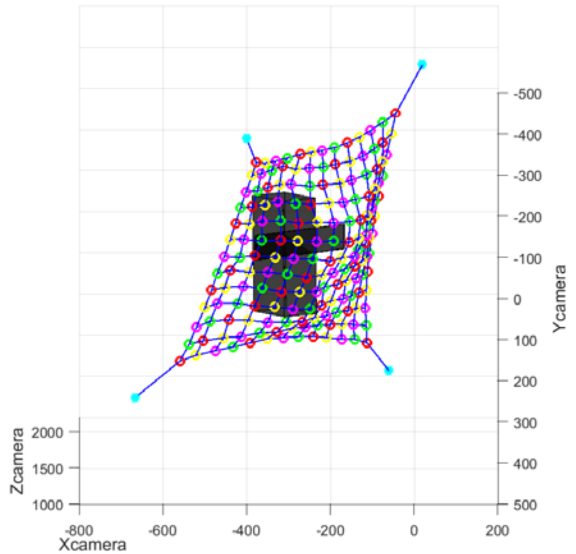

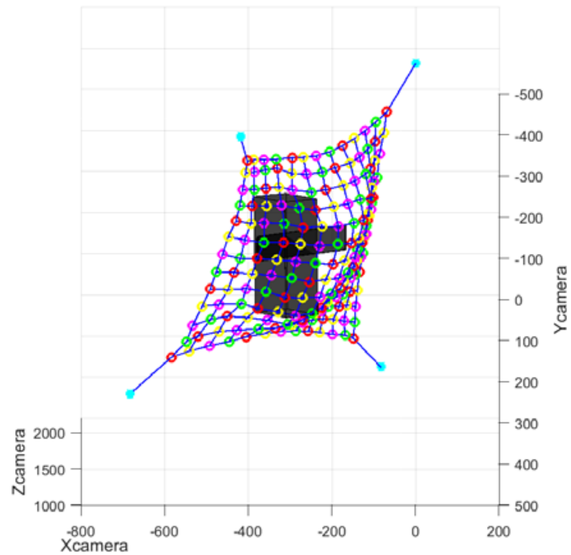

3D RECONSTRUCTION OF PARABOLA #17

CONCLUSIONS

- ADR using thrown-nets is a very promising technology:
  - Need of a validated simulator to demonstrate its effectiveness.
  - The ESA-funded PATENDER activity is implementing such simulator:
    - Accurate and fast simulation capabilities.
    - Validated through a parabolic flight campaign (TRL 5).
    - Using a space representative scaled net and satellite mockup.
    - Performed on-ground tests to prove the capability of the net launching system and the 3D reconstruction.
    - Validated within a Novespace parabolic flight:
      - Net motion trajectory was recorded in slow motion mode by four synchronized high-speed video cameras.
      - The 3D trajectory of relevant points is being reconstructed using stereo matching and triangulation.
      - On-going work is related to the cross-validation of results.

Thank you

The PATENDER Team

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