ASTRA 2015

# CAPTURING NETS FOR ACTIVE DEBRIS REMOVAL: A FOLLOW-UP MICROGRAVITY EXPERIMENT DESIGN TO VALIDATE FLEXIBLE DYNAMIC MODELS

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# PATENDER PRESENTATION OUTLINE

- ADR AND CLEAN SPACE INITIATIVE BACKGROUND
- EXPERIMENT DESIGN
- NET DYNAMICS SIMULATOR
- PARABOLIC FLIGHT SET-UP
- CONCLUSIONS

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# ADR AND CLEAN SPACE INITIATIVE BACKGROUND

- Nowadays **ADR techniques** appears as solution to mitigate effects of the space debris (5000 satellites in orbit, 16.000 objects tracked by US Space Surveillance Network, 200 on-orbit fragmentations since 1961, 700.000 objects larger than 1cm; 4 recorded examples of collisions).
- NASA/ESA studies have demonstrated that 5/10 objects per year must be removed from LEO orbits.
- ESA **Clean Space** initiative focuses in four different branches:
  - Eco-design, Green technologies, space debris mitigation and
  - **Space debris remediation**
- Between other techniques, **throw-nets** is a promising technology for capturing non-cooperative debris (whit difficult grasping by robotic arms).
- ESA is funding current **PATENDER** (**Net Parametric Characterisation and Parabolic Test**) activity to develop a simulator for the capture of large space debris with a throw net, and to validate it through a parabolic flight experiment.

# PATENDER PRESENTATION OUTLINE



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# EXPERIMENT DESIGN (1/3)

- Dynamically scaled nets:
  - Representing on-orbit load conditions
  - Representative of 24m and 36m nets
  - Material trade-off and selection
    - Space qualified
    - Mechanical properties (foldable, strength, etc.)
    - Experiment requirements

→ TECHNORA

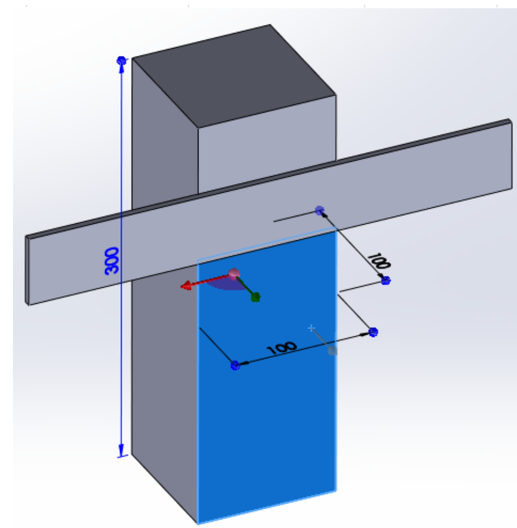
**Scaled nets (parabolic flight)**

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

Spliced connection

for bullets

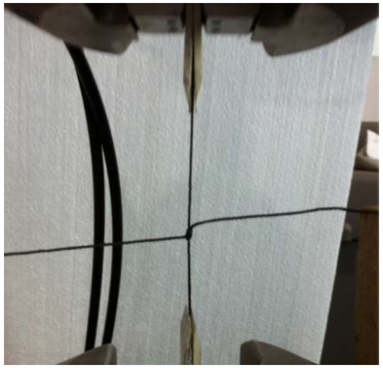
Technora net
(5cm mesh)

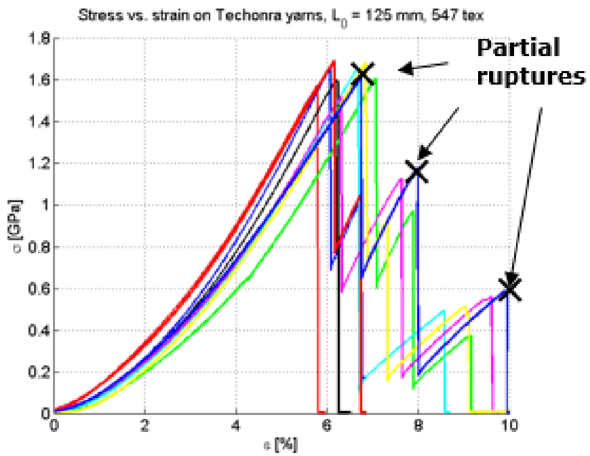



**Simplified mockup of Envisat body (1:40 scale)**

# EXPERIMENT DESIGN (2/3)

- 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



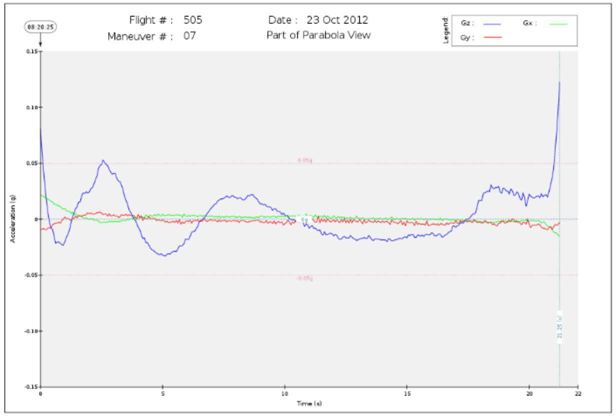



| | |
|---|---|
| Young’s modulus [GPa] | 25.367 |
| Breaking stress [GPa] | 1.626 |
| Breaking strain [%] | 6.43 |
| Knot breaking stress [ GPa ] | 0.536 |
| Axial stiffness per unit length [N] | 9.84·103 |
| Torsional stiffness per unit length [Nm2] | 2.94·10-6 |
| Bending stiffness per unit length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

# EXPERIMENT DESIGN (3/3)

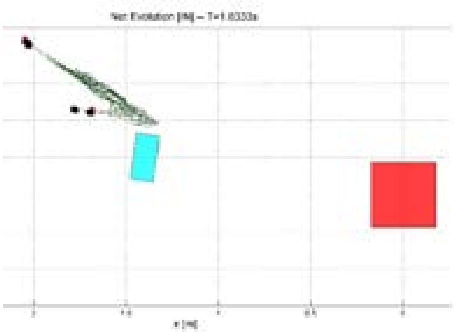
| ACCELERATION | MAXIMUM VALUES | AXIS |
|---|---|---|
| **Disturbance [m/s²]** | ≈ ±0.5 | Z axis |
| **Coriolis [m/s²]** | ≈ +0.06 | Z axis |
| **Centrifugal [m/s²]** | ≈ ±0.005 | X axis |
| **Air drag [m/s²]** | ≈ 10^-6 ÷10^-7 | - V axis |

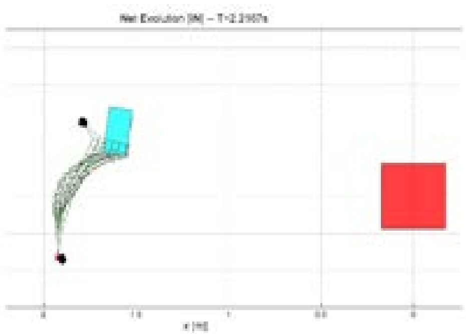
- Parabolic flight conditions implies:
  - Residual accelerations (non-perfect microgravity)
  - Apparent accelerations (Coriolis, centrifugal)
  - Air drag



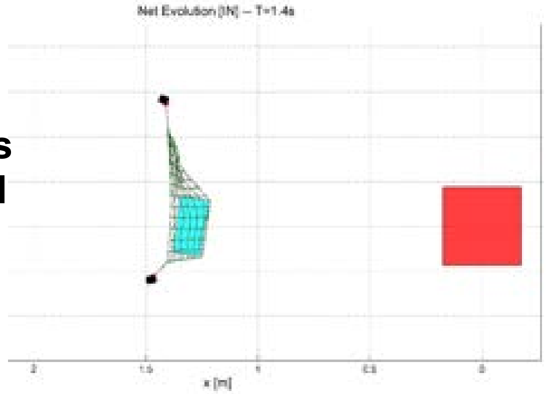

- Design drivers:
  - Maximize chances of target hitting occurence
  - Completely deploy the net
  - Compliance with acquisition set-up

| Net shooting velocity [m/s] | Net shooting angle [deg] | Target Distance [m] |
|---|---|---|
| **≈ 1** | **≈ 21** | **≈ 1,3** |





**Successful vs unsuccessful wrapping simulations**



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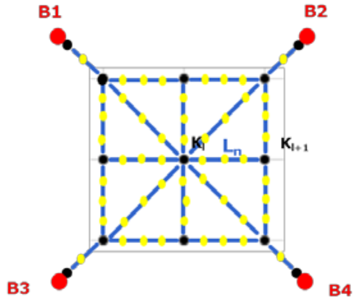
# NET DYNAMICS SIMULATOR

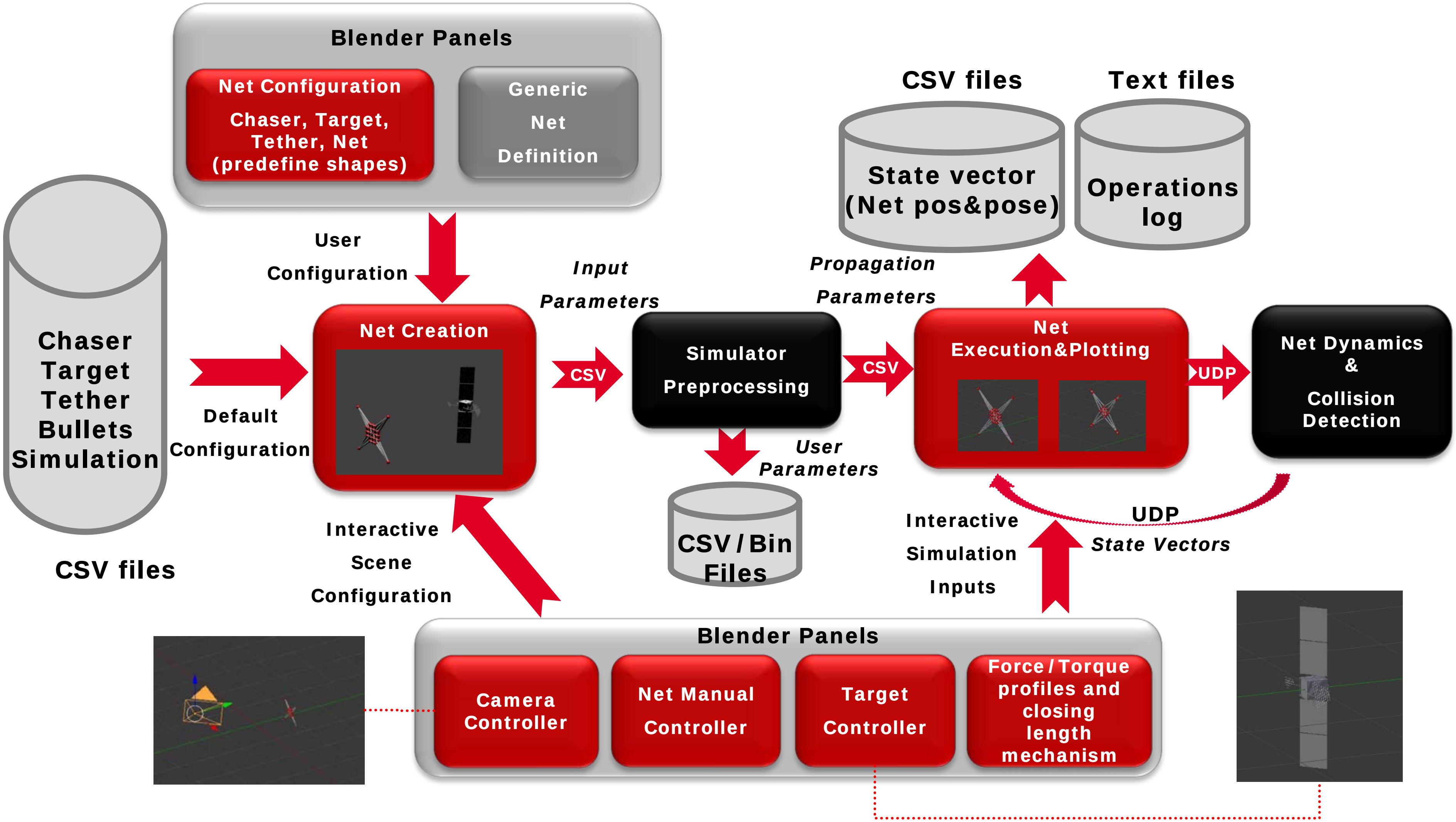



- Three-layer architecture:
  - Net dynamic models:
    - Linear Kelving-Voight modelling
    - Orbital dynamics
    - Net arbitrary shapes, thether, closing mechanism

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

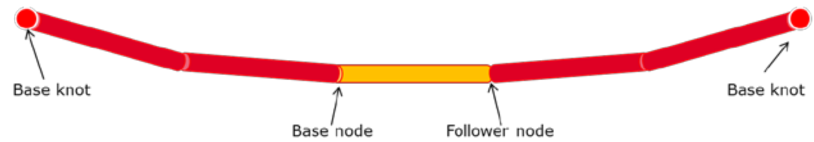
  - Net dynamic applications:
    - Autocoding of Matlab/Simulink Net dynamics
    - Collision detection through Bullet Physics engine
    - Collision dynamics through dedicated algorithms
  - Graphical User Interface (GUI):
    - Based in Blender (3D capabilities)
    - User-interaction trhough Python scripts

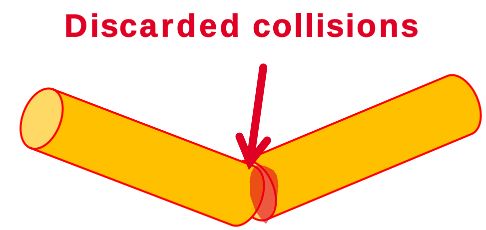
# SOFTWARE ARCHITECTURE OVERVIEW

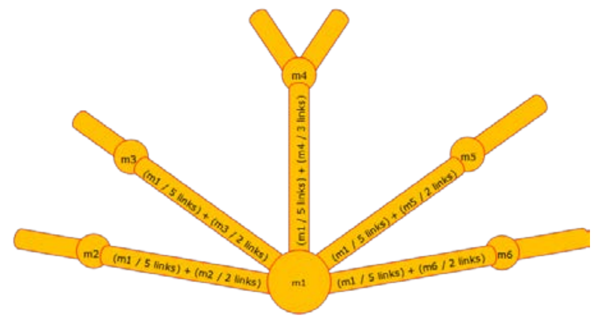


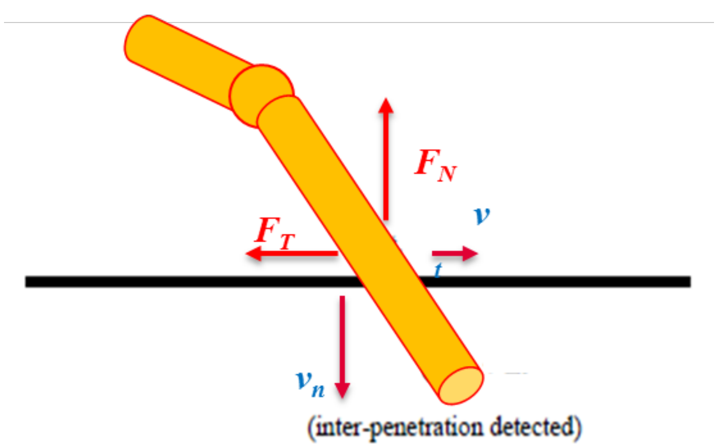
# CONTACT DYNAMICS

- Collision detection computed by Bullet engine based in cylinders
- Discarding collisions between adjacent links
- Determination of cylinder masses from the net particles
- Computation of contact dynamics following Hippmann algorithms based on stiffness, damping and friction forces.



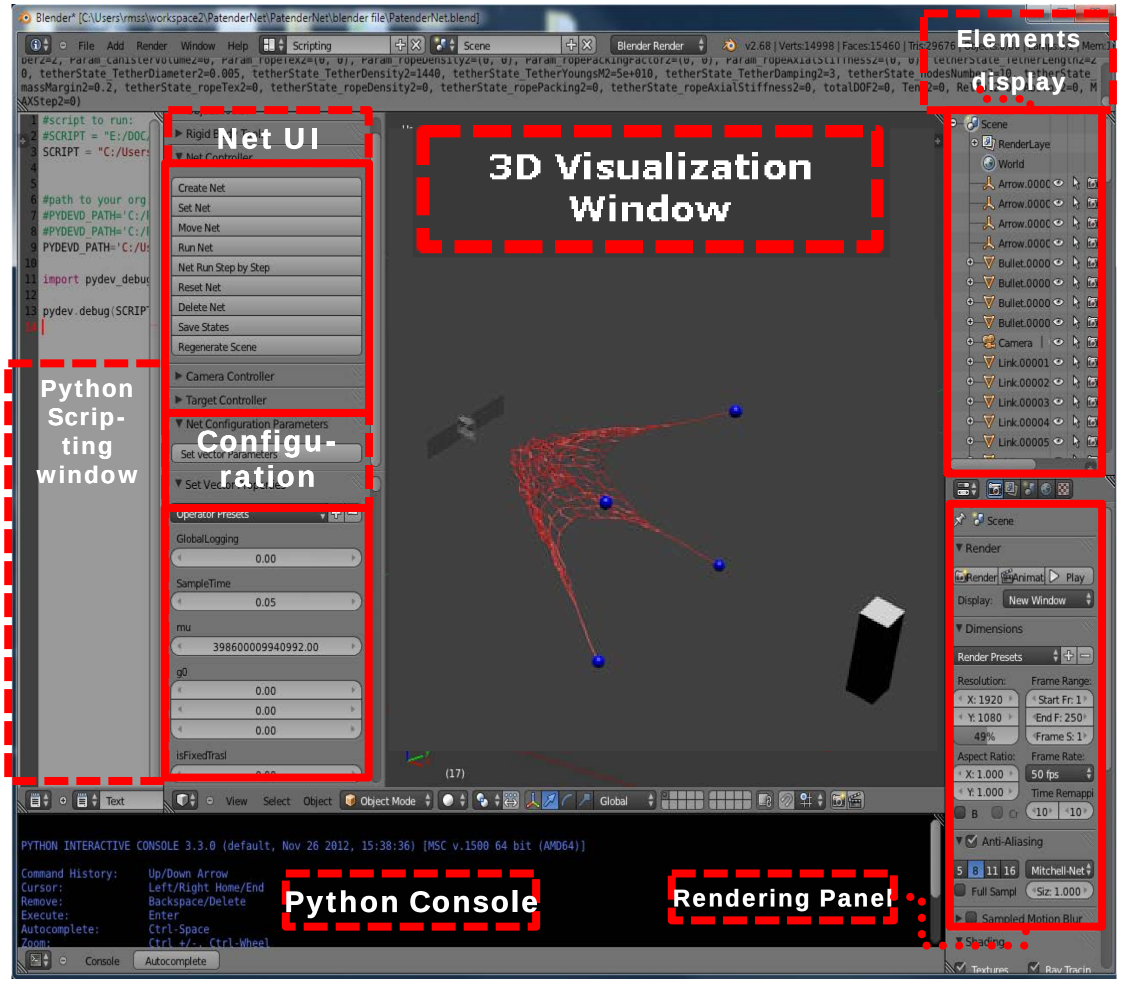



$$\boldsymbol{F_N} = -(k_n \cdot s_n + c_n \cdot |\boldsymbol{v_n}|) \cdot \boldsymbol{v_n}/|\boldsymbol{v_n}|$$

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

# PATENDER 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

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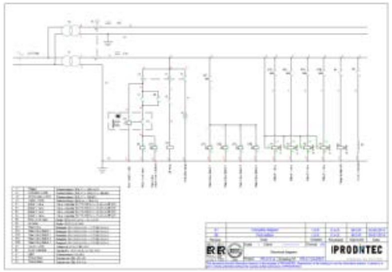
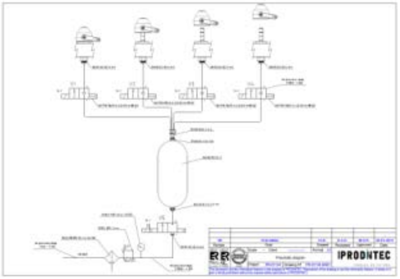
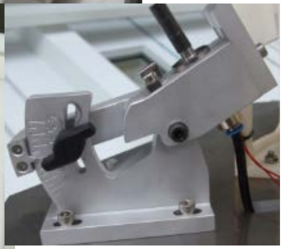
# NET LAUNCHING SYSTEM (1/2)

Design → Manufacturing → Assembly → Test







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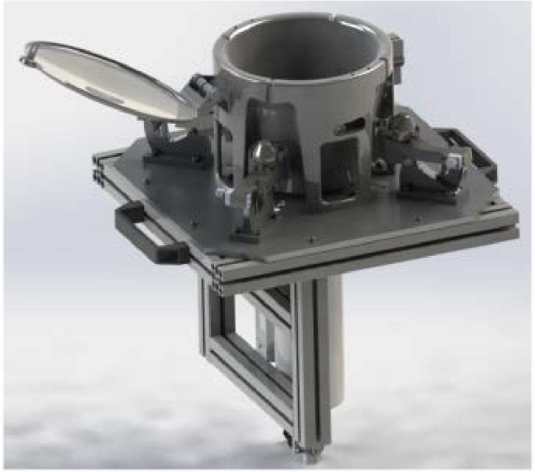
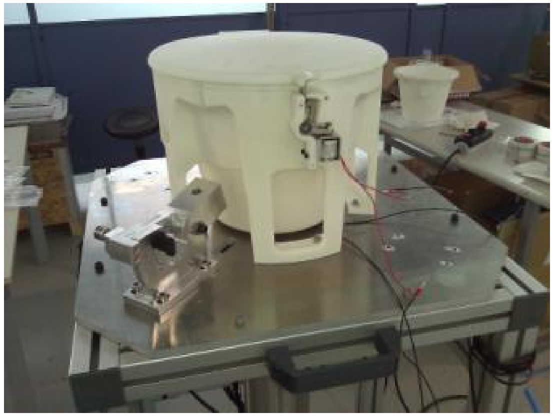
# NET LAUNCHING SYSTEM (2/2)

Whole system

Launching system





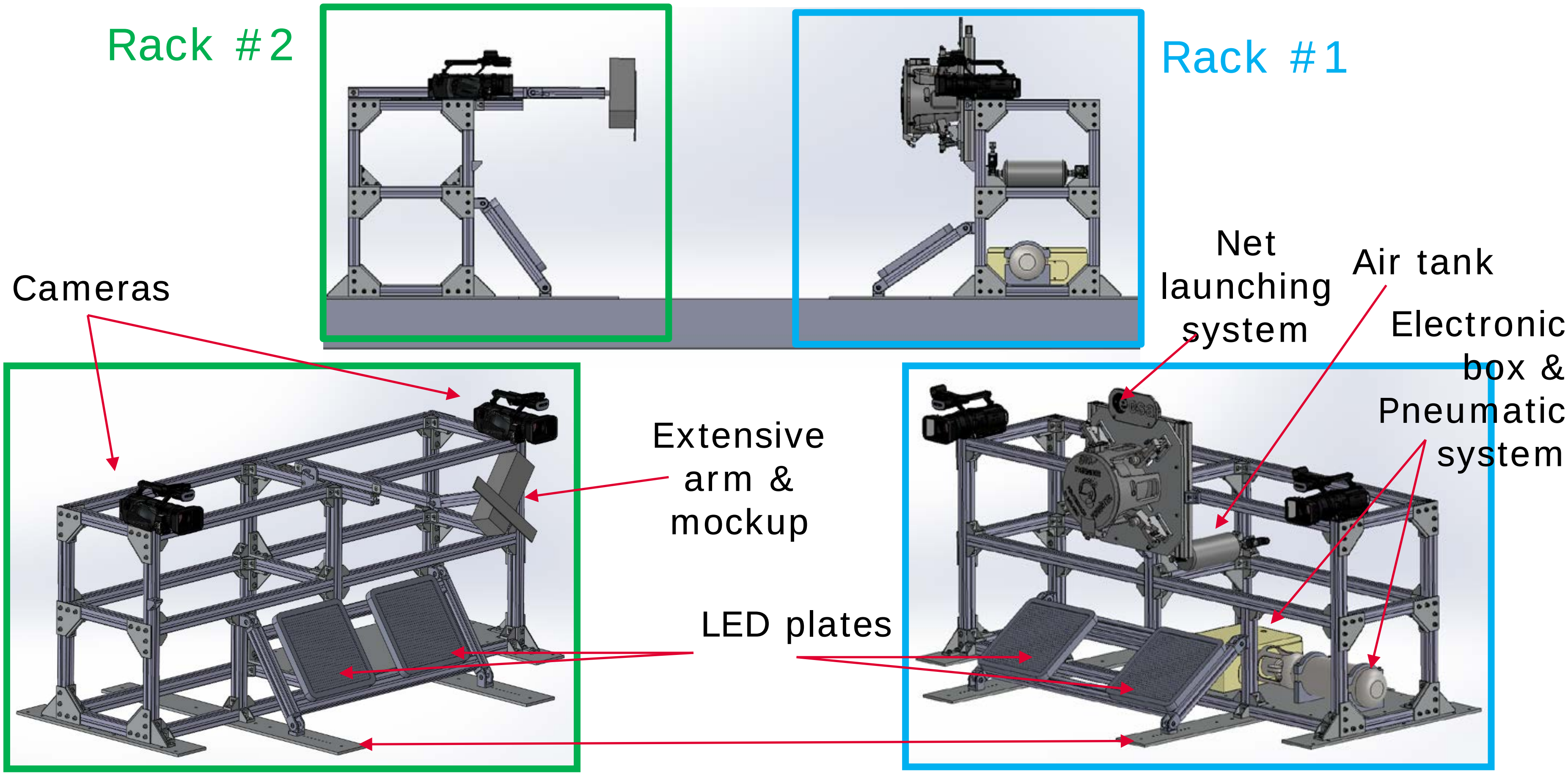
Angle adjustment

Canister

Canister and cover support

# PARABOLIC FLIGHT SET – UP (1/2)

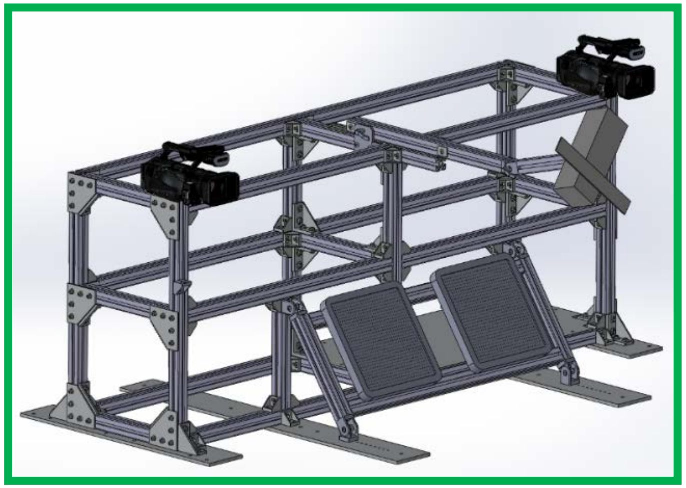
- Set of two racks with dimensions (LxWxH) 500 x 2000 x 810 mm.
- Overall flight set – up: 3000 x 2000 x 1500 mm
- Adjustable Mock-up position (vertical and horizontal).



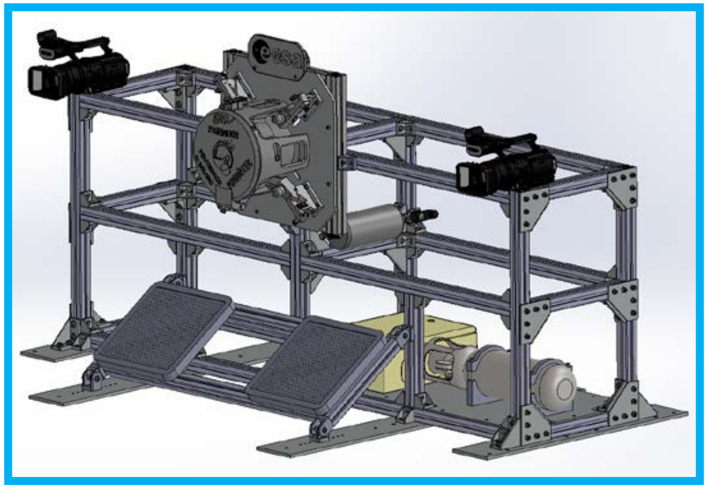

 

# PARABOLIC FLIGHT SET – UP (2/2)

Rack #2



Rack #1



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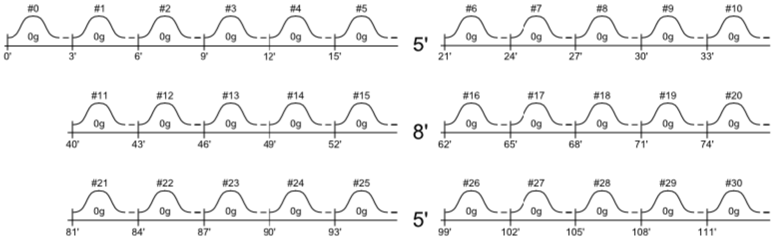
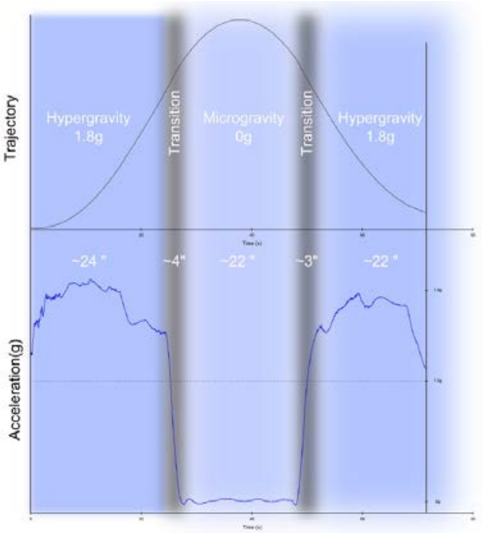
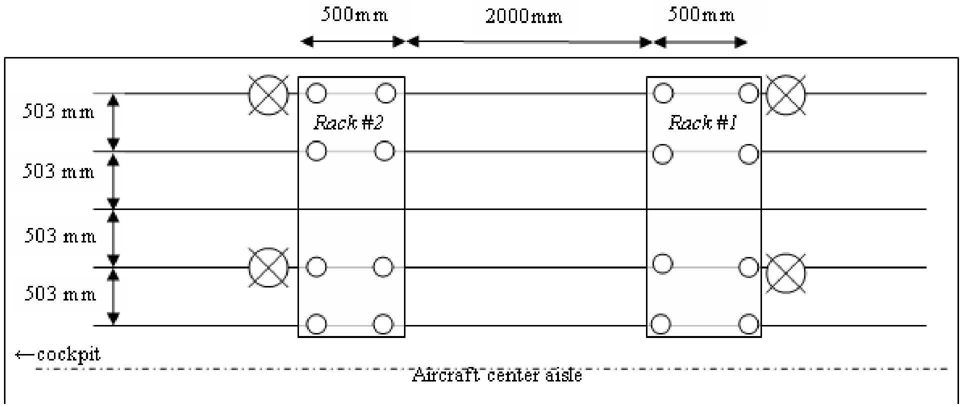
# NOVESPACE PARABOLIC FLIGHT


- Participating in the 62nd ESA parabolic flight campaign VP 116 (June 9th 2015)
- Six set of 5parábolas (31 in total)
- 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



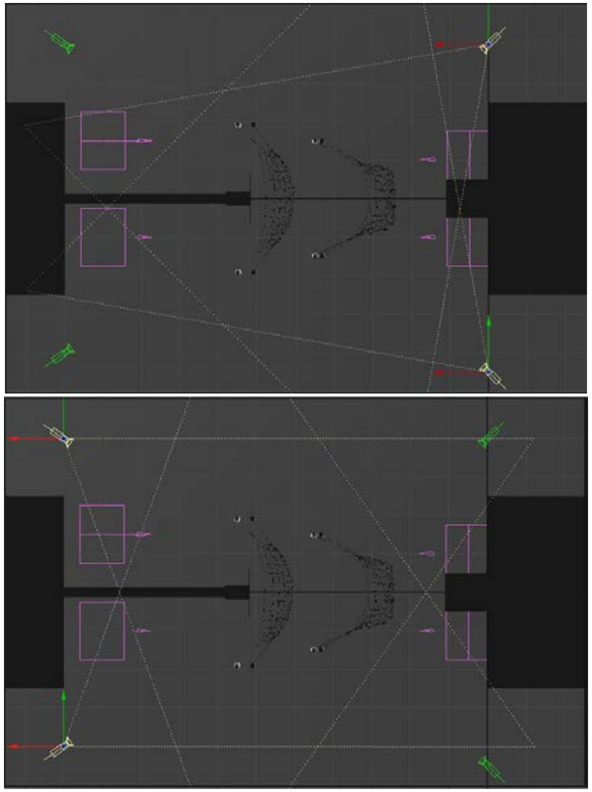



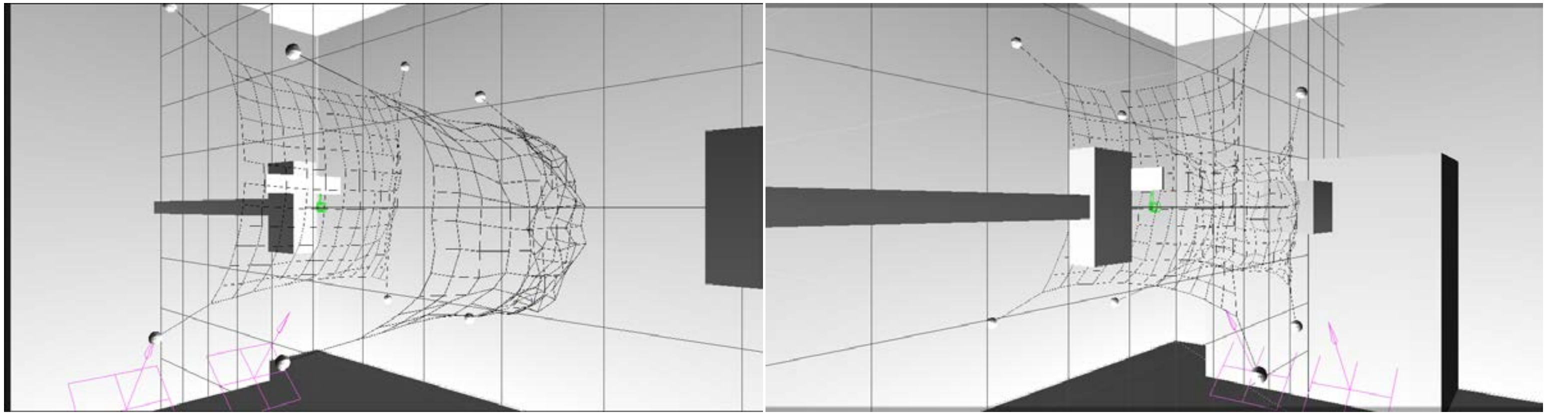



# 3D RECONSTRUCTION (1/3)

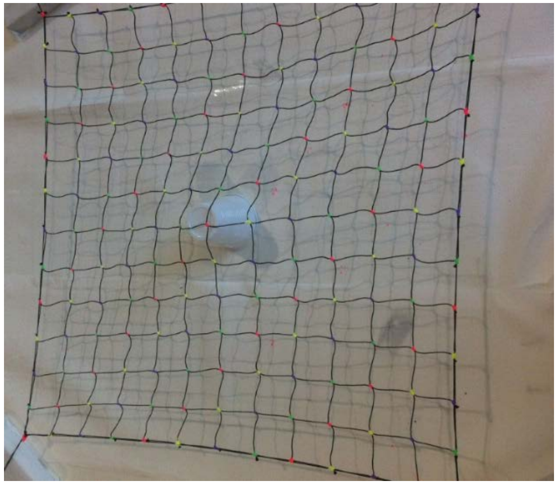
- Acquisition set-up design drivers:
  - Stereo coverage (FoV, focal length, position/orientation)
  - Resolution: knot size / pixel size > 6
  - Limit blurring (shutter)
  - Focus depth of field

| Setting | Value |
|---|---|
| **Cameras** | 4x Sony NEX FS700 |
| **Resolution** | 4K (4096x2160) |
| **Frame rate** | 60 fps |
| **Shutter speed** | 1/1000s – 1/1500s |
| **Focal length** | 14 |
| **Iris** | F4 |





# 3D RECONSTRUCTION (2/3)

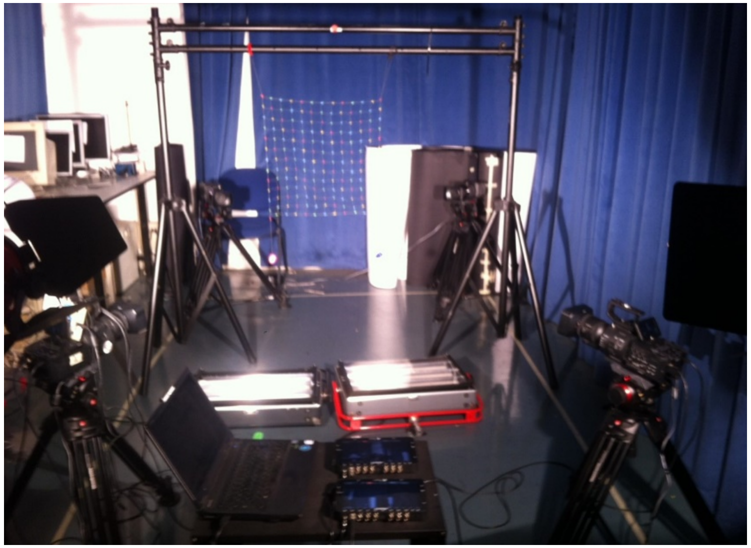


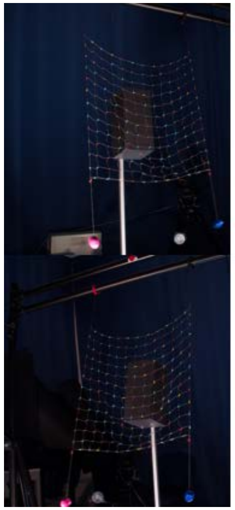
- Reconstruction process: based on net colour-coding
  - Requires uniform background
  - Requires strong illumination (led lights to cope with PF safety rules)
- Reconstruction steps:
  - Raw processing for white/gain correction
  - Colour segmentation and filtering
  - Points cloud reconstruction and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

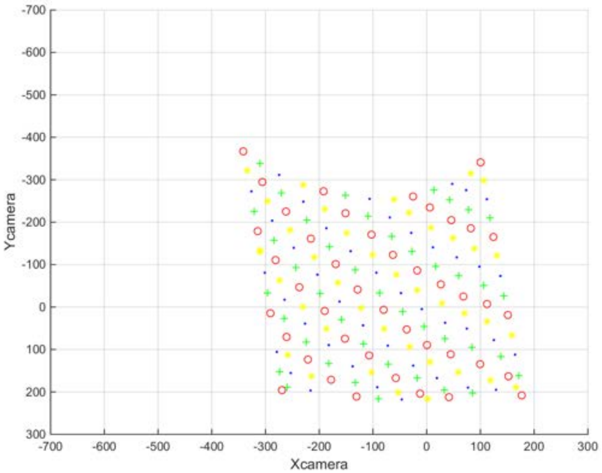
RAW Image | Colour filter | Binary image

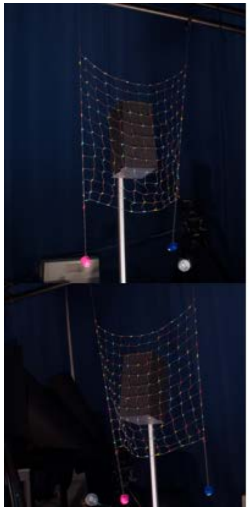
# 3D RECONSTRUCTION (3/3)

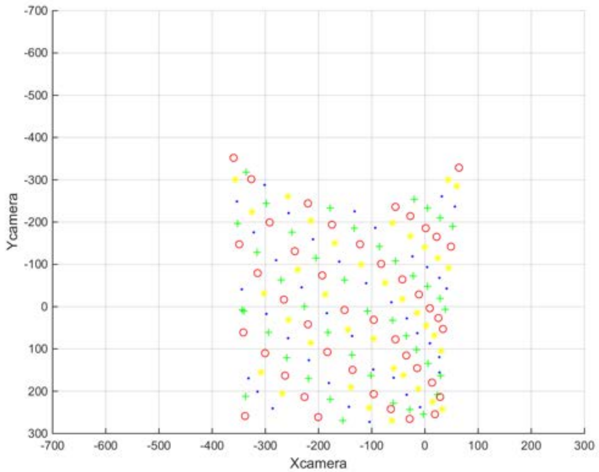
- Preliminary ground tests to validate
  - Reconstruction process
  - Cameras set-up and settings
- Calibration performed a priori through double-faced chessboard
- Camera synchronization through audio signal
- Partial wrapping reconstruction: accuracy decreases when points are occluded from both stereo-pairs (only estimates are possible)









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# CONCLUSIONS

- ADR using thrown-nets is a promising technology:
  - Need of a validated simulator to demonstrate its effectiveness.
  - The PATENDER activity will implement such simulator:
    - Accurate and fast simulation capabilities.
    - Validated through a parabolic flight campaign (TRL 5).
    - Using a space representative scaled net and satellite mockup.
    - Net motion trajectory will be recorded in super-slow motion mode by four synchronized high-speed video cameras.
    - The 3D trajectory of relevant points will be then reconstructed using stereo matching and triangulation.
    - Preliminary on-ground tests have already proved the capability of the net launching system and the 3D reconstruction.

- Further work is devoted to the performance of the parabolic flight and the cross-validation of results.

# Thank you

The PATENDER Team

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# SIMULATION RESULTS