University of Rome "Tor Vergata" — Department of Industrial Engineering

Space Sustainability Center

Manufacturing Technology Research Group

Active Debris Removal by Shape Memory Polymer Composite Devices

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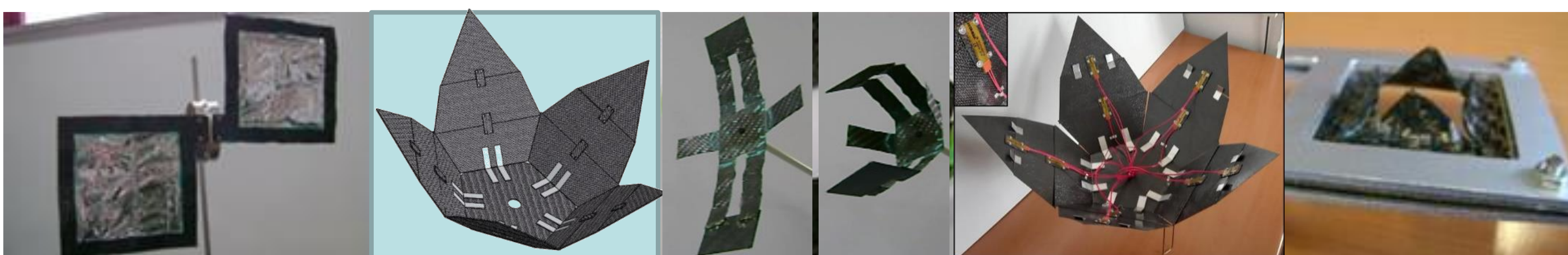


ESA's Clean Space Industry Days (2021 CSID)

Outline

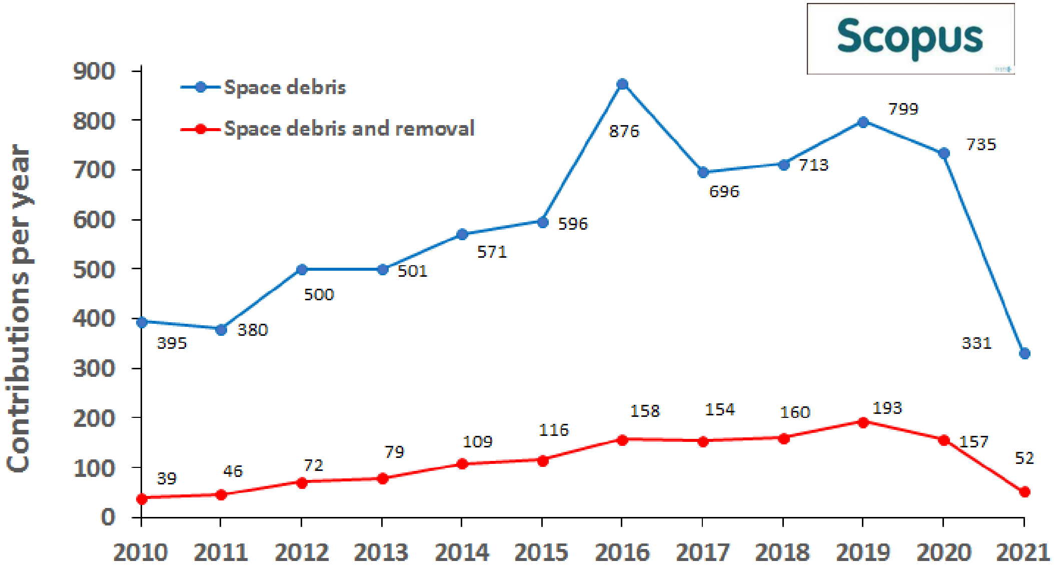
- ✓ Background and introduction on Shape Memory Polymer Composites (SMPC)
- ✓ Experiments in Space
- ✓ Design and modelling of smart composite structures
- ✓ The ESA project e-SpaDeS (Space Debris Suppression)
- ✓ Functional and performance requirements
- ✓ Analysis of debris distribution, properties and Space environment
- ✓ Conclusion

Background and potential of SMPC

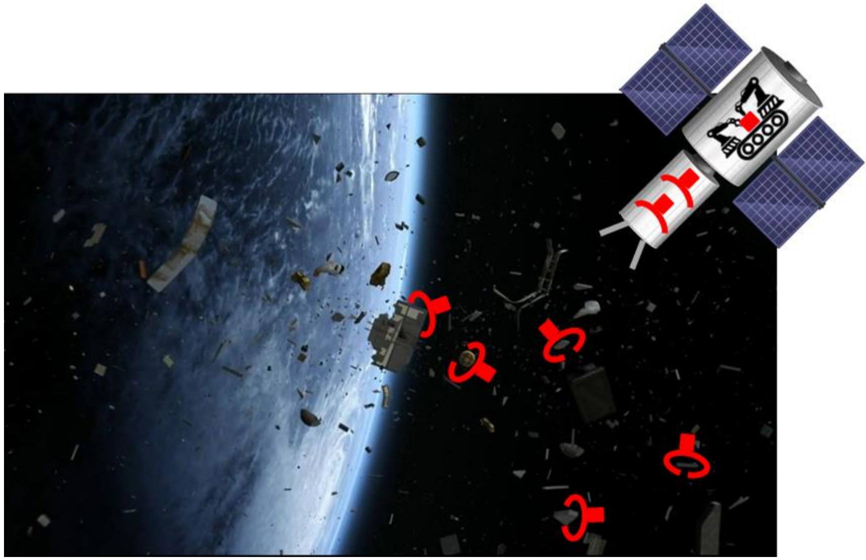
- Scientific Literature (Agencies)
- Internal Research
- Available Data from Market

- "Space debris" AND "Removal" AND "Shape memory polymer composites", only
  1. *Conceptual design of an experiment for the international space station about shape memory composite in space environment*, ASME 2017 12th MSEC).
  2. *Design and testing of self-deployable structures for advanced space applications*, 69th IAC 2018.

Proceedings of AVT-257 NATO Specialists Meeting on "*Best Practices for Risk Reduction for Overall Space Systems*", 26-29 September 2016, Avila, Spain)

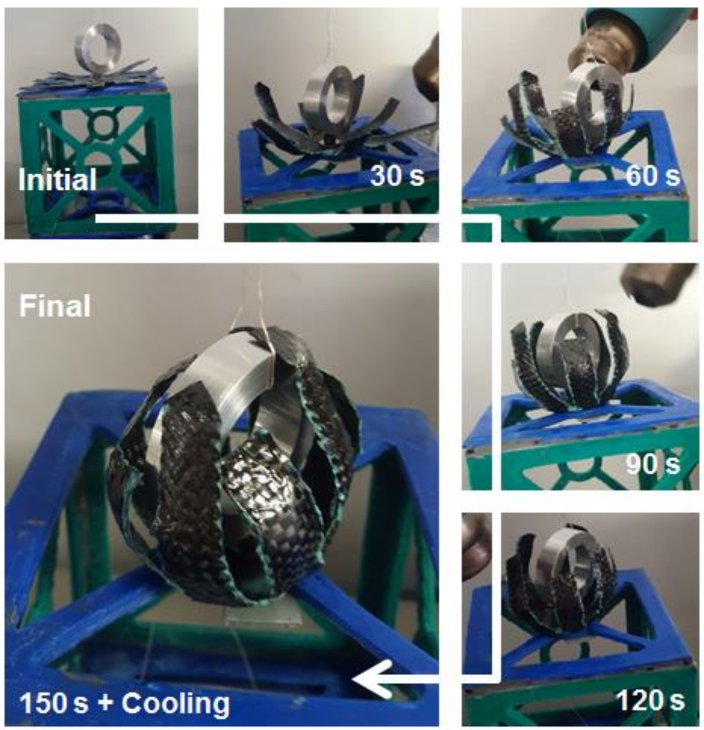


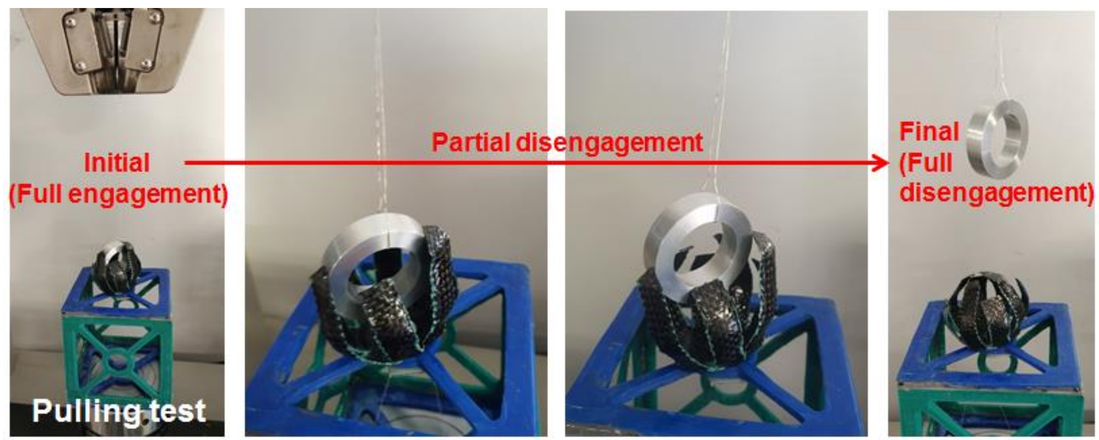
(SMPC) devices may play an important role for small debris removal with undefined shape, mainly in the optic of in-space manufacturing of cleaning satellites.



Background

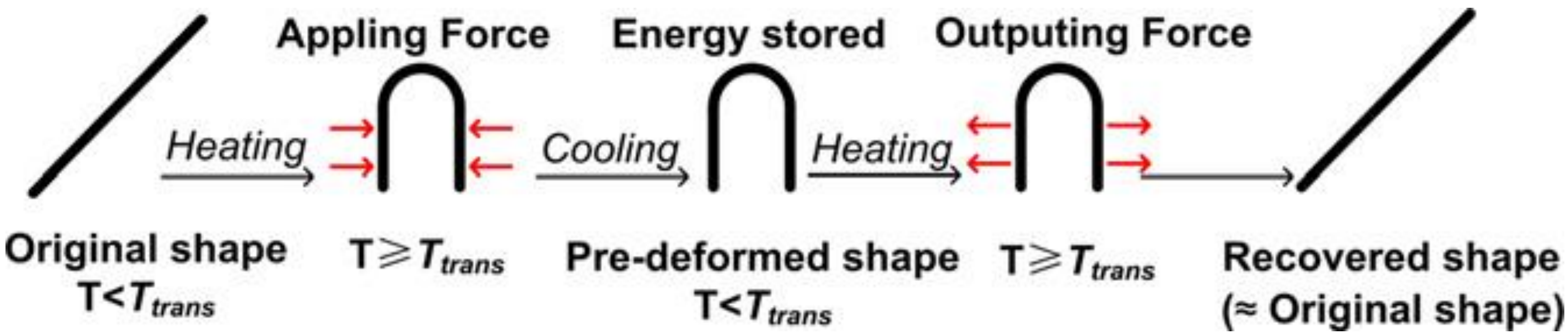
SMPC can freeze a non-equilibrium shape (open) and recover the equilibrium shape (closed) by heating. Heaters and sensors can be integrated in the SMPC structure during manufacturing.





Shape Memory Polymers and Composites

Ability to fix and recover a given deformation by cooling below and heating above Tg (thermo-mechanical cycle)

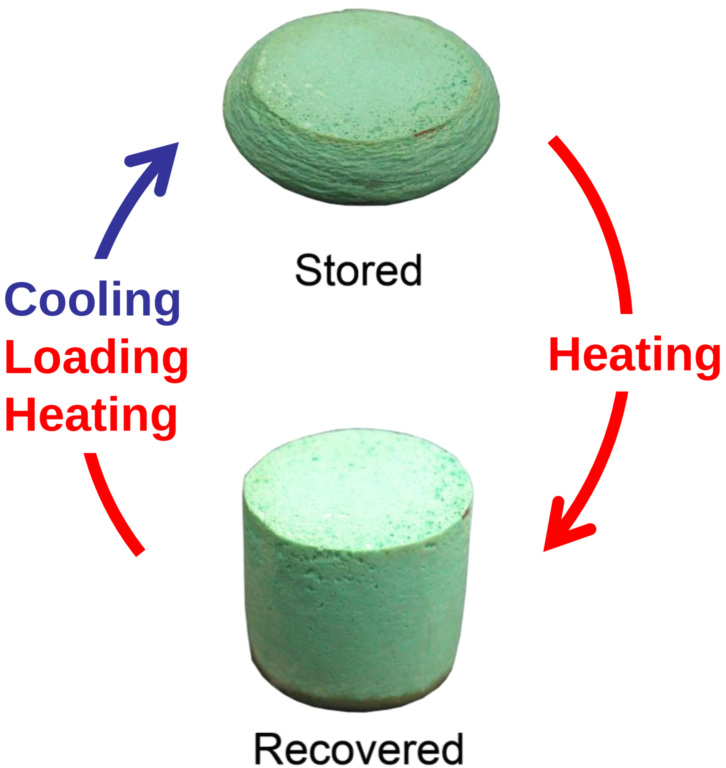


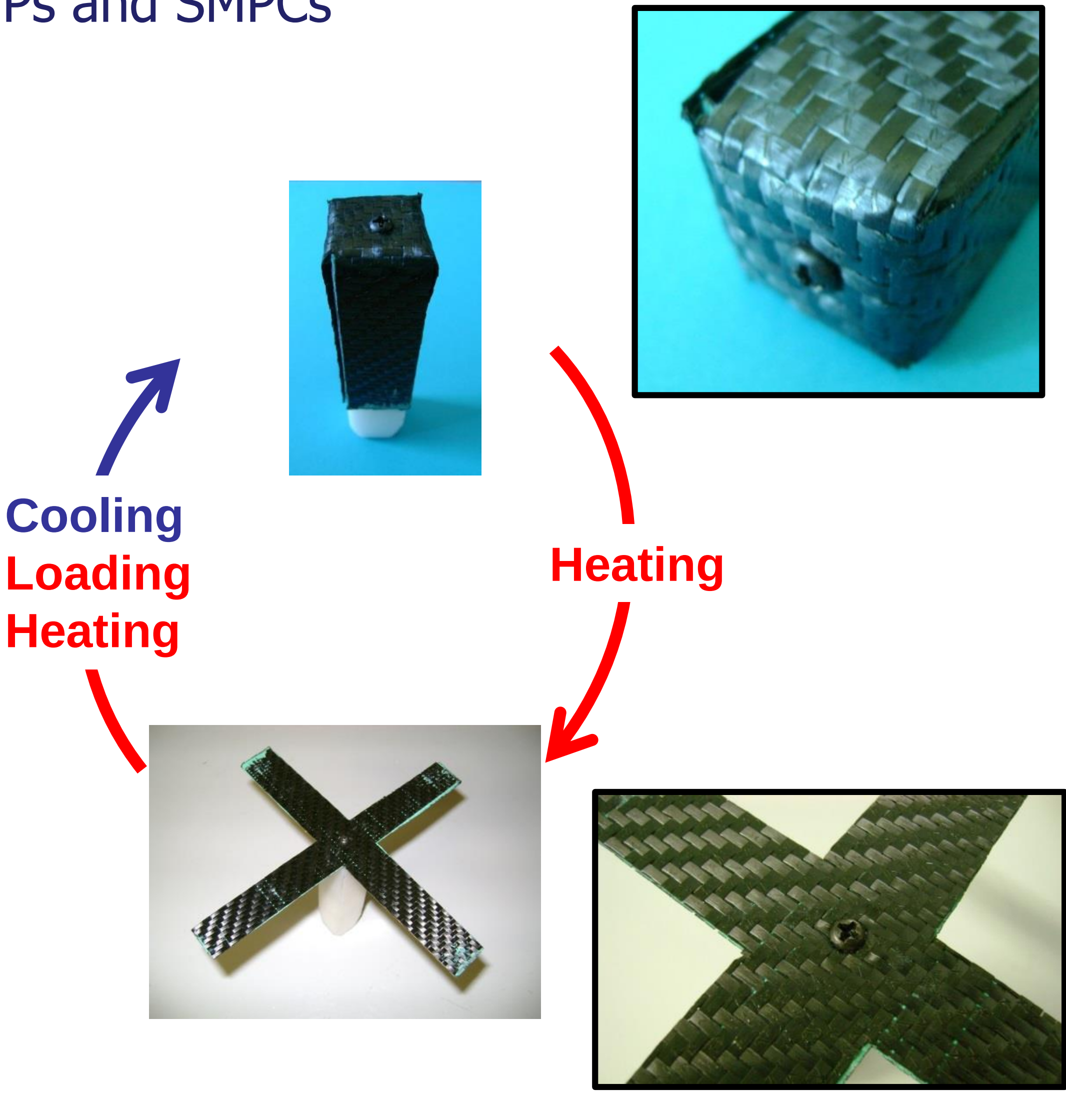
Self-deployable structures, actuators, biomedical devices

Advantages over shape memory alloys, resulting potential substitutes (lightness, low cost, high shape recovery, easy to process)

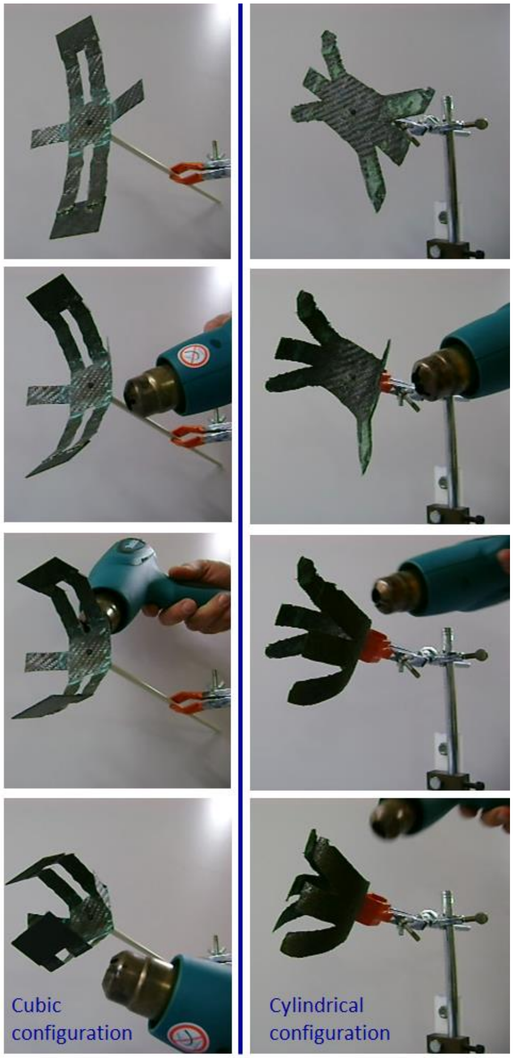
SMP foams and composites

- Thermo-mechanical cycle of SMPs and SMPCs

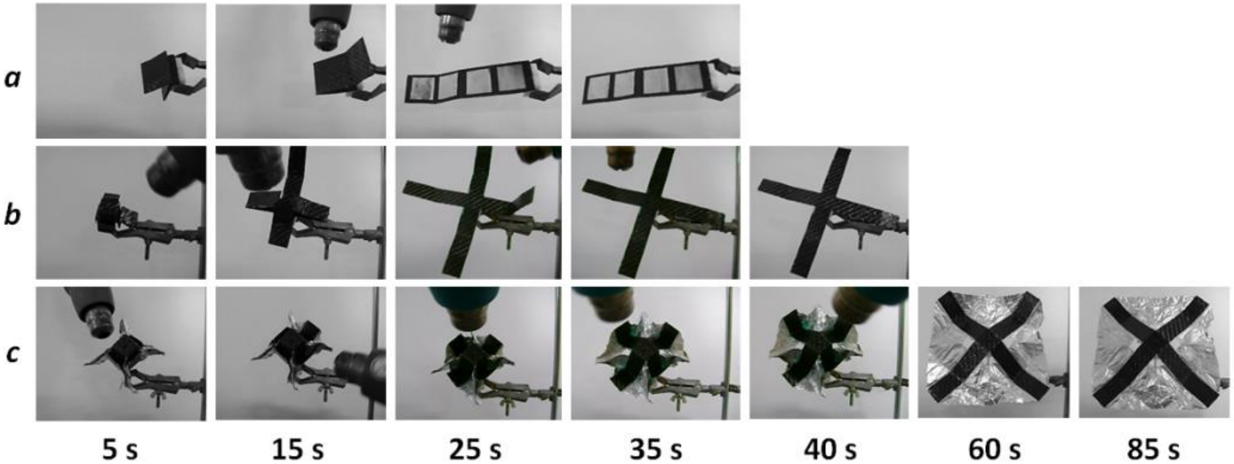




Grabbing systems

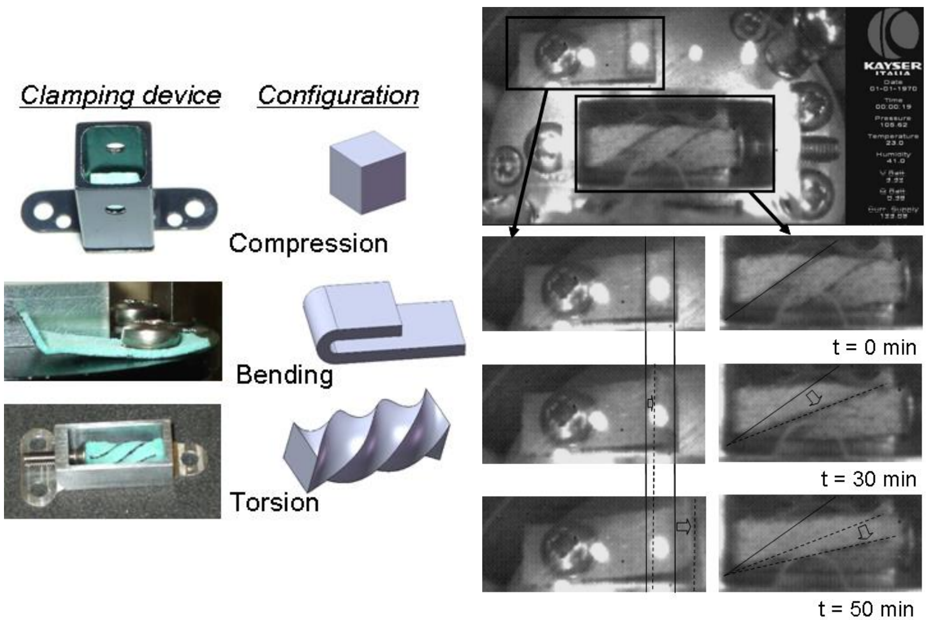


Deploying systems

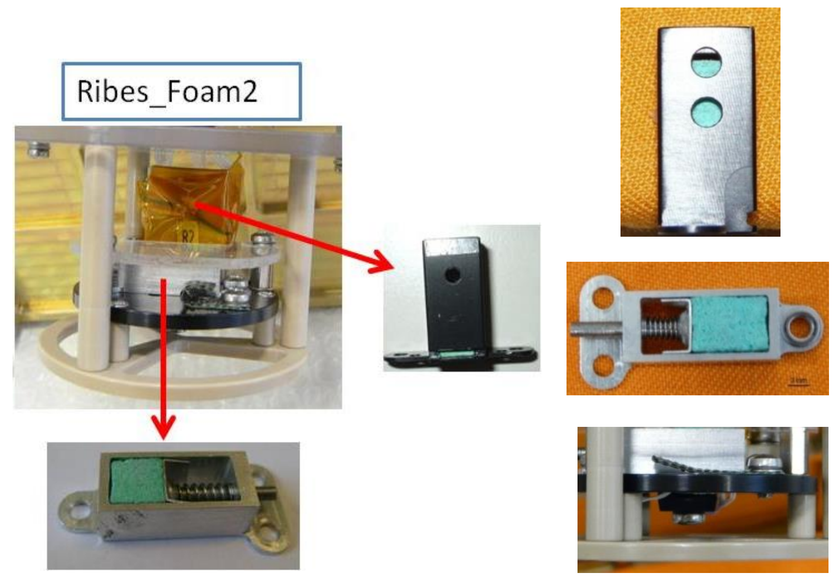


Experiments in microgravity conditions

I-FOAM
(Shuttle Mission STS 134, May 2011)



Ribes_Foam2
BION-M1 MissionSoyuz-2 launch vehicle
April 20, 2013



F. Quadrini, L. Santo, E.A. Squeo, "*Shape memory epoxy foams for space applications*", Materials Letters, 69 (2012) 20-23.

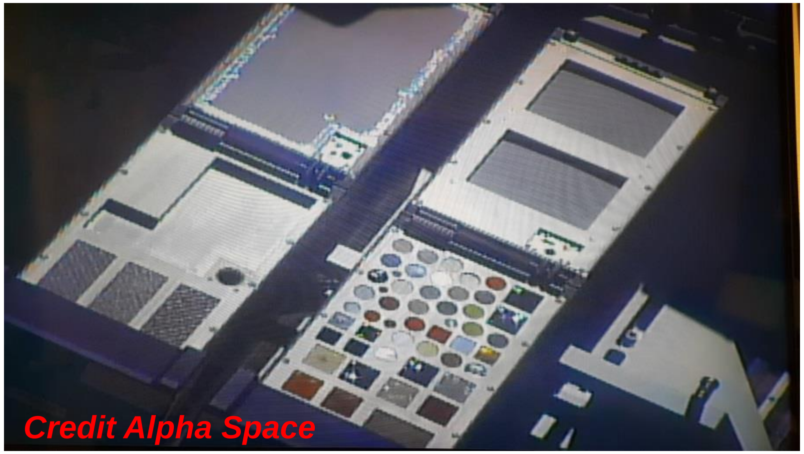
L. Santo, F. Quadrini, E.A. Squeo, F. Dolce, G. Mascetti, D. Bertolotto, W. Villadei, P-L. Ganga, V. Zolesi, "*Behavior of Shape Memory Epoxy Foams in Microgravity: Experimental Results of STS-134 Mission*", Microgravity Science and Technology, 24 (2012) 287-296.

L. Santo , F. Quadrini , W. Villadei , G. Mascetti , V. Zolesi, *Shape memory epoxy foams and composites: ribes_foam2 experiment on spacecraft "bion-m1" and future perspective*, Procedia Engineering 104 (2015) 50 – 56

Santo L., Quadrini F., Ganga P., Zolesi V. , "*Mission BION M1: Results of Ribes/Foam2 experiment on shape memory polymer foams and composites"*, Aerospace Science and Technology, 40 (2015) 109-114.

Experiments outside the ISS

The effect of the Space environment on the Shape Memory Polymer Composite (SMPC) behavior has been investigated thanks to experiments on the MISSE platform. The Materials International Space Station Experiment (MISSE) is a NASA exposing platform mounted externally on the International Space Station (ISS) which investigates the effects of long-term exposure of materials to the harsh space environment. Small SMPC samples have been mounted in the MISSE-9, MISSE-10, MISSE-12, and MISSE-13 experiment in collaboration with Kim de Groh of NASA Glenn Research Center.



Credit Alpha Space

Credit NASA

MISSE
Materials International Space Station Experiment

Misse-9

Misse-10

Misse-12

Misse-13

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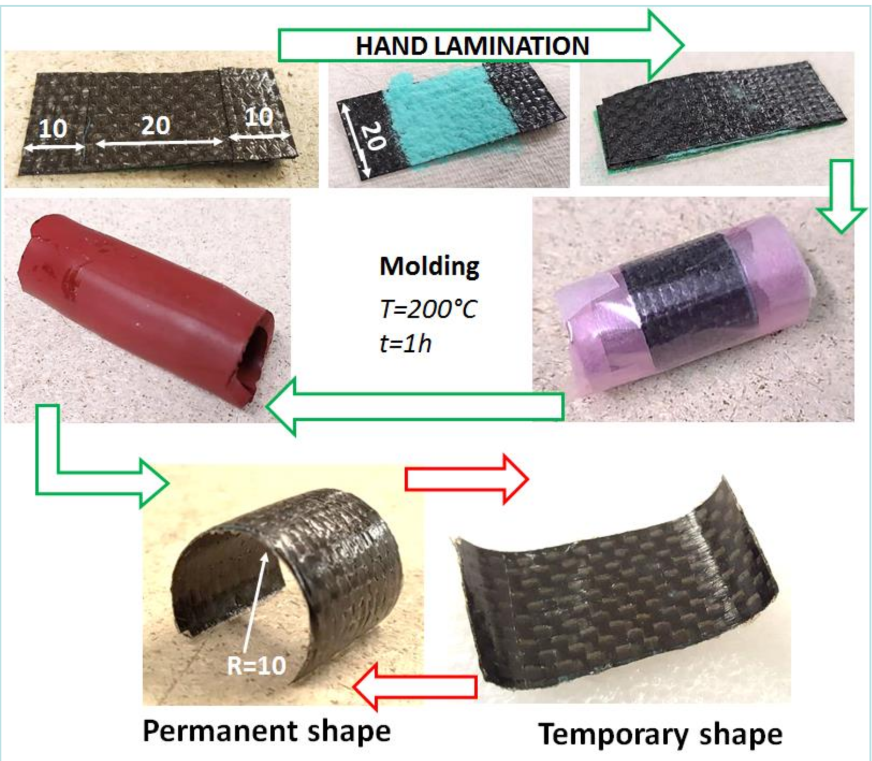
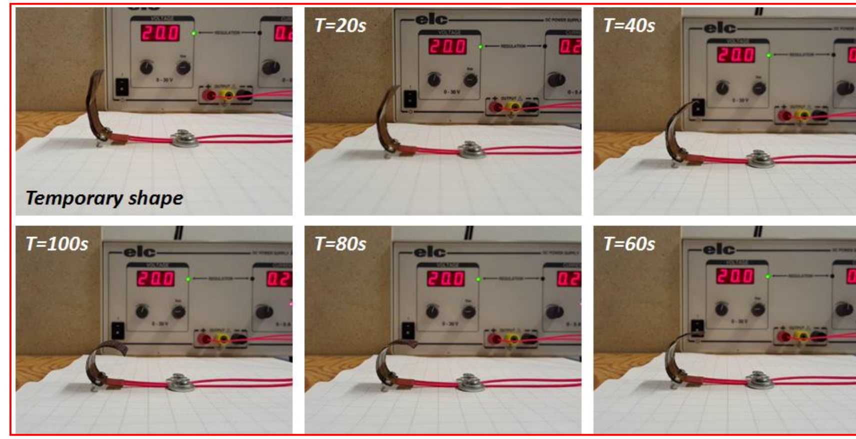
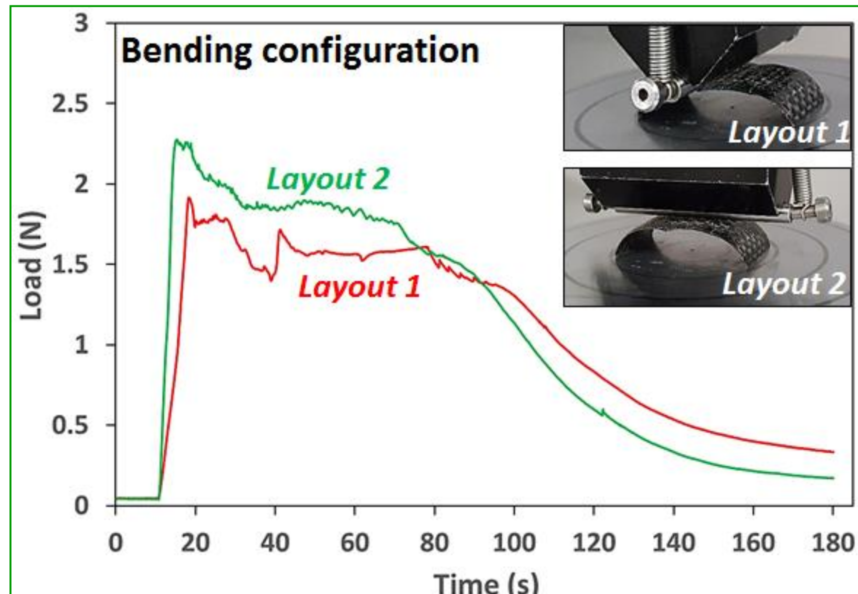
Department of Industrial Engineering

Designing smart composite hand

- Prototyping of smart hinges
- Testing smart hinges
- Measuring recovery loads



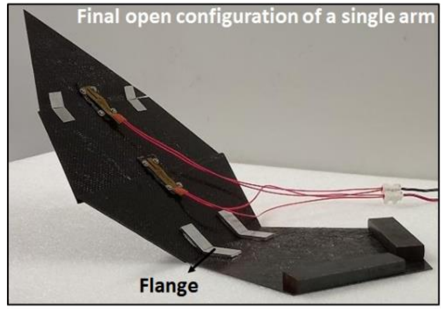


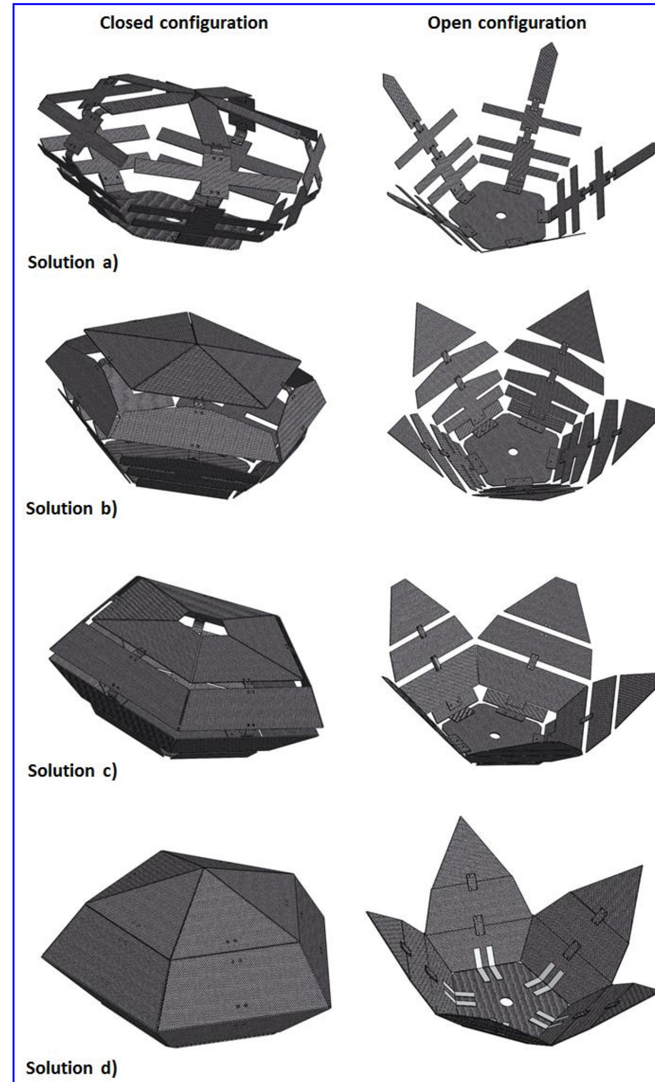


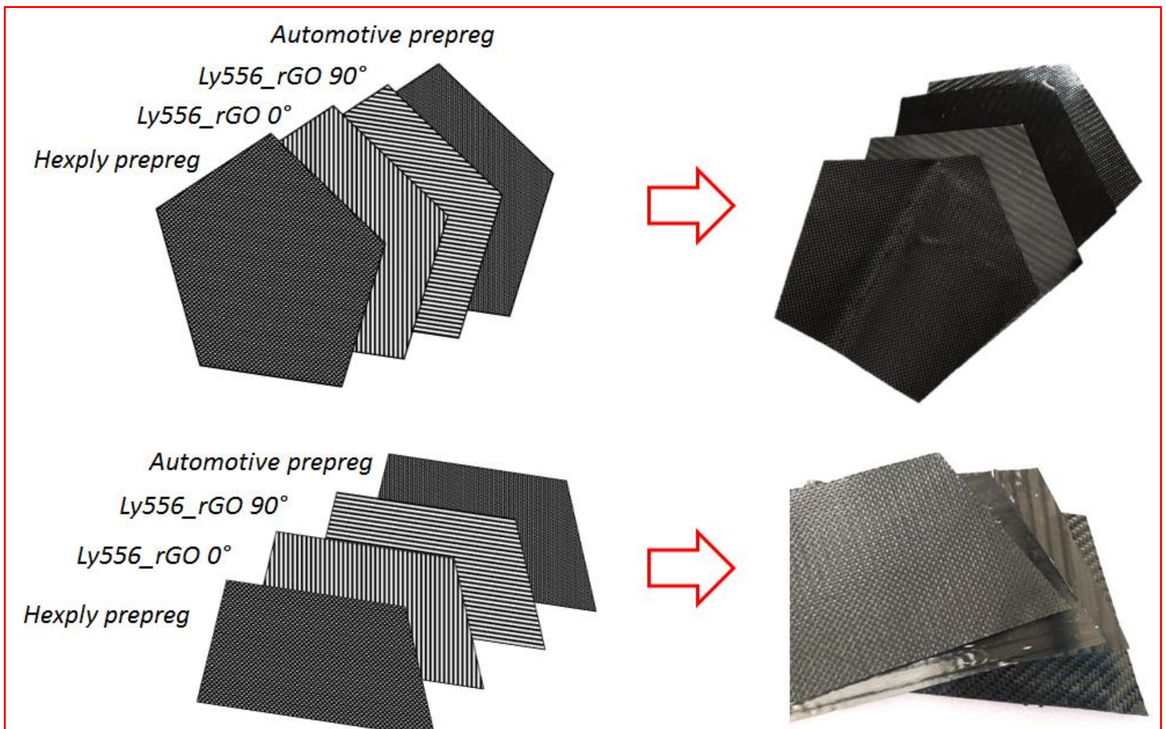
“This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No760779”.

Designing smart composite hand

- Structure modelling
- Prepreg cutting
- Laminate molding
- Structure assembly







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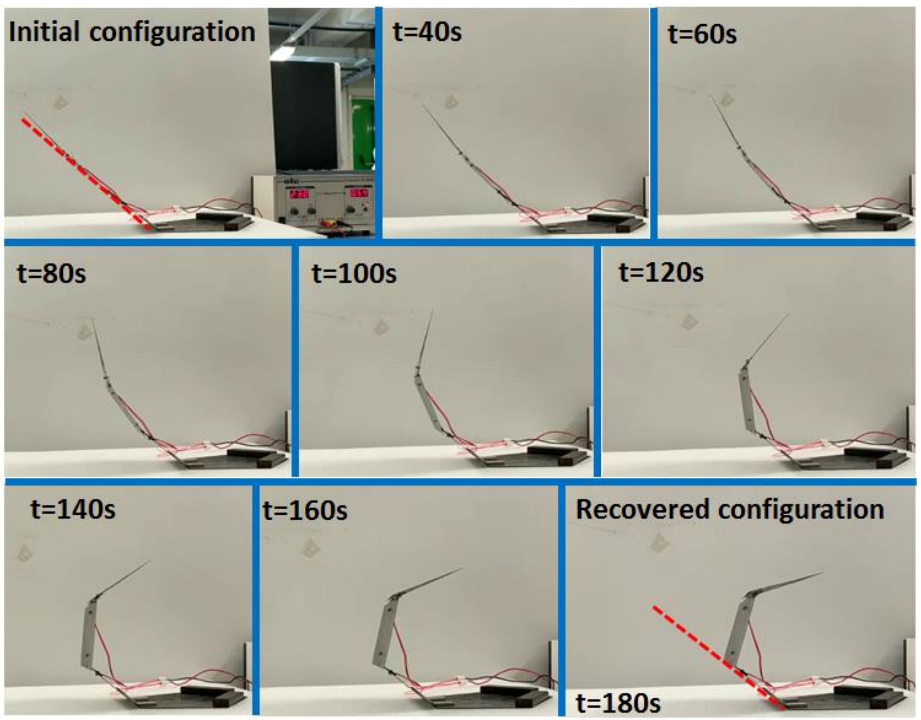
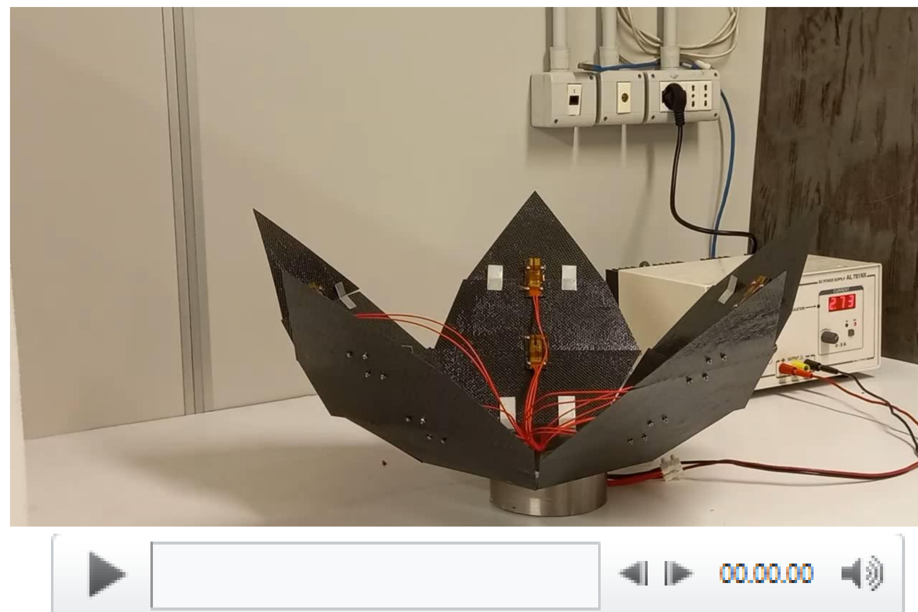
Designing smart composite hand

- Structure testing
- Memory-recovery cycles



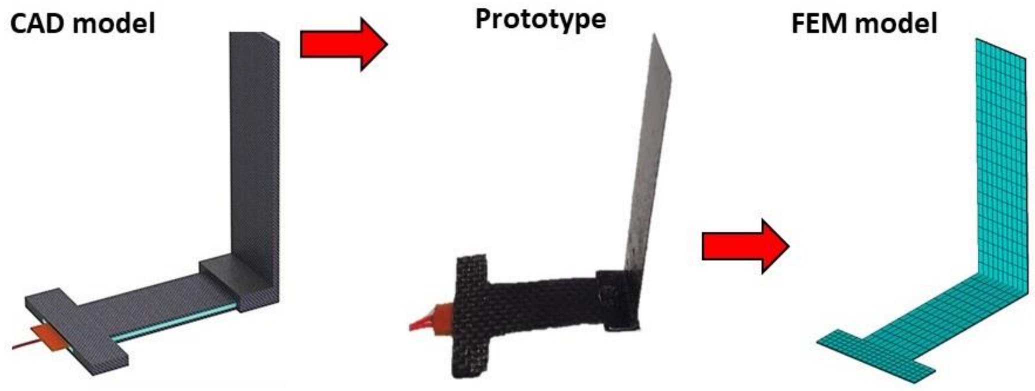


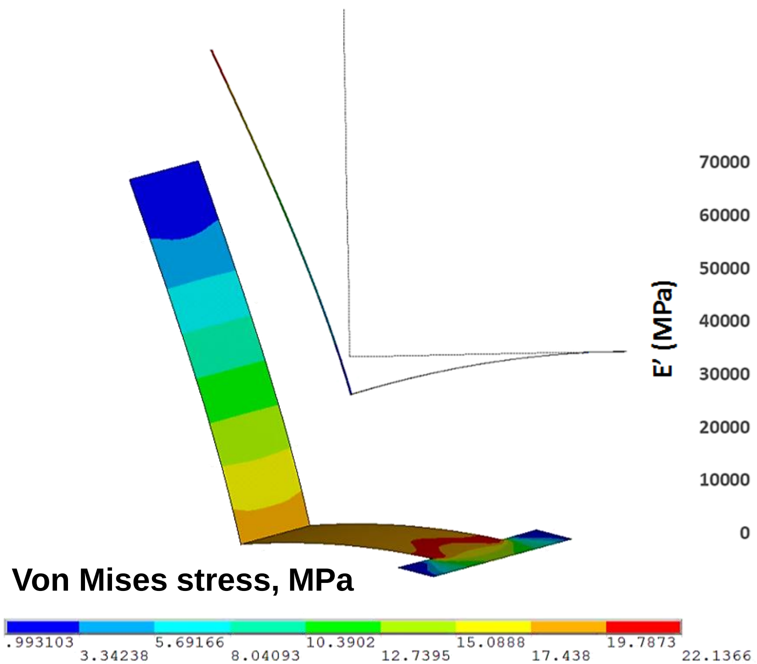
SHA.RE. (SHApe REcovery)

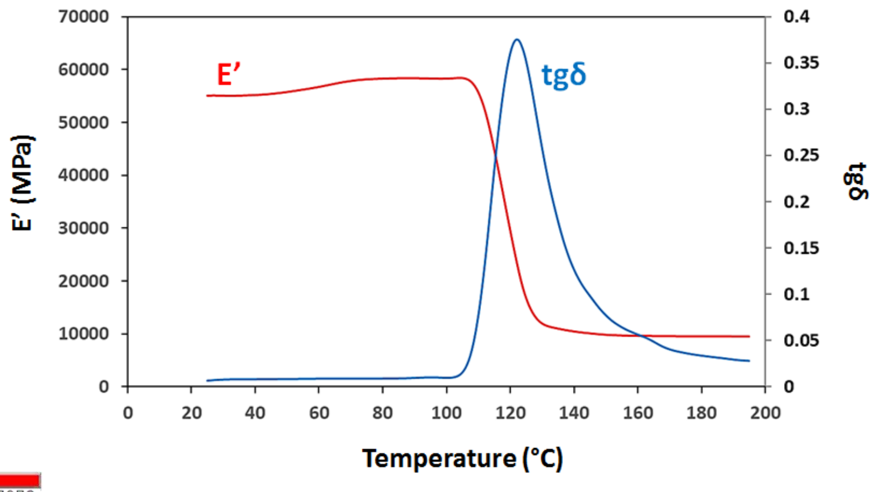
"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No760779".

Modelling

- Modelling shape memory behavior
- Applying to the SMPC finger
- Simulating SMPC actuation
- Development of FE models

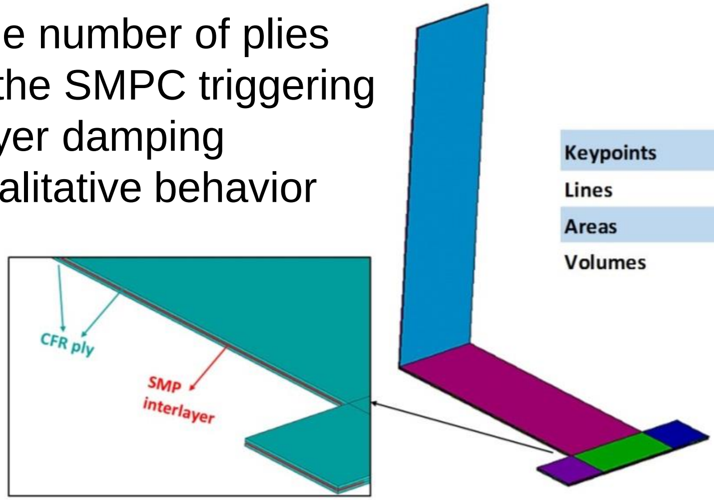




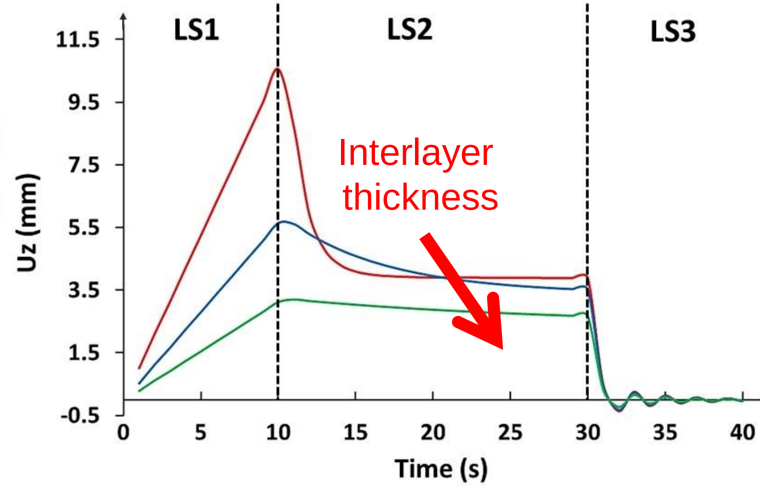


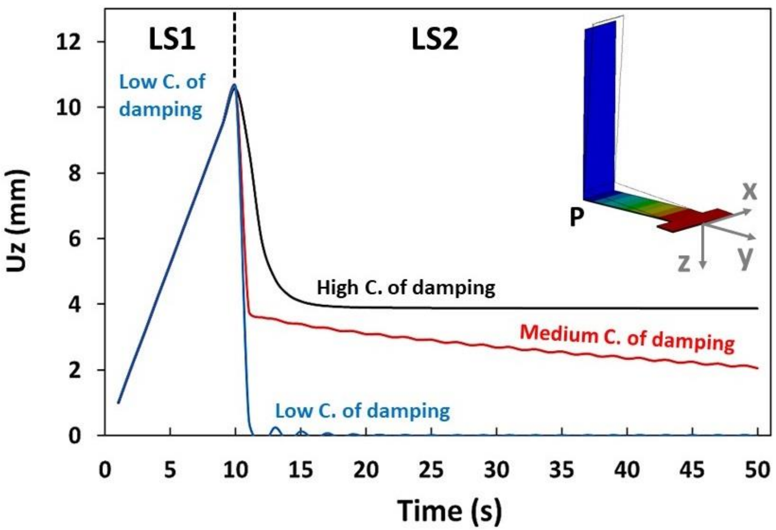
Modelling

- Effect of the number of plies
- Modelling the SMPC triggering
- SM interlayer damping
- Correct qualitative behavior

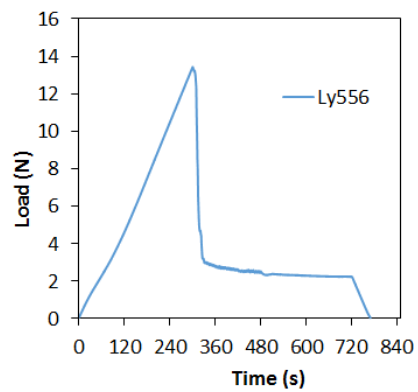


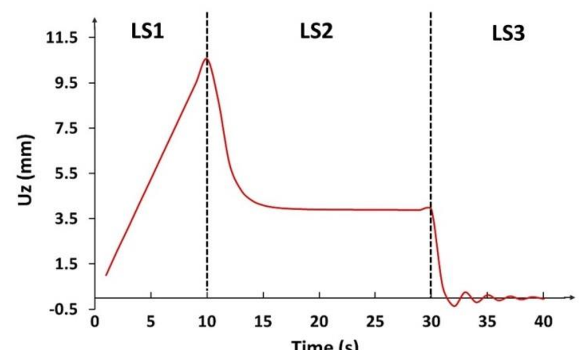
Keypoints	52
Lines	108
Areas	73
Volumes	16





(a)





(b)

The ESA project e-SpaDeS (Space Debris Suppression) has the goal to design SMPC devices for space debris grabbing.

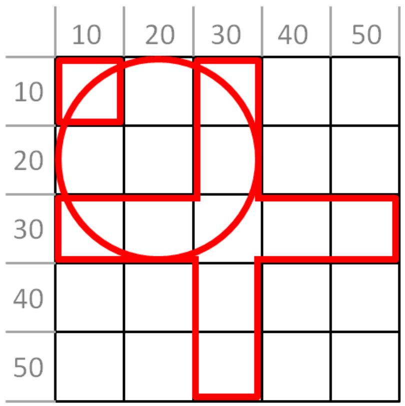
SMPC devices apply low grabbing forces and high damping during debris capture approach, thus minimizing possible fragmentation and issues due to debris spin.

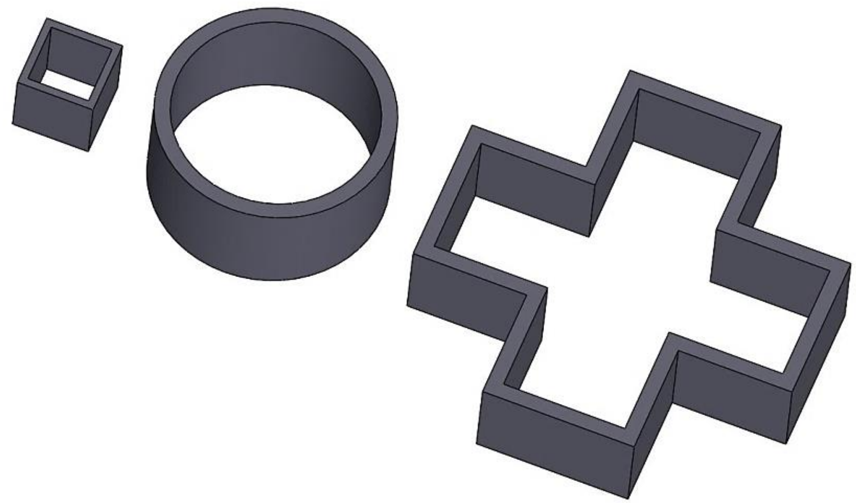
Moreover, SMPC devices are light structures with manufacturing procedures compatible with the additive logic, therefore in the line of the concepts for in-space manufacturing.

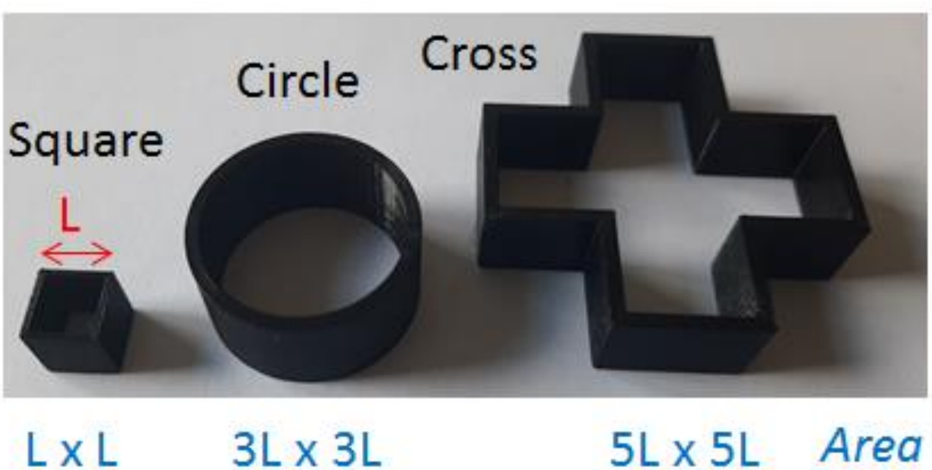
The project aims to define, for the first time, the optimal SMPC geometry for debris capture.

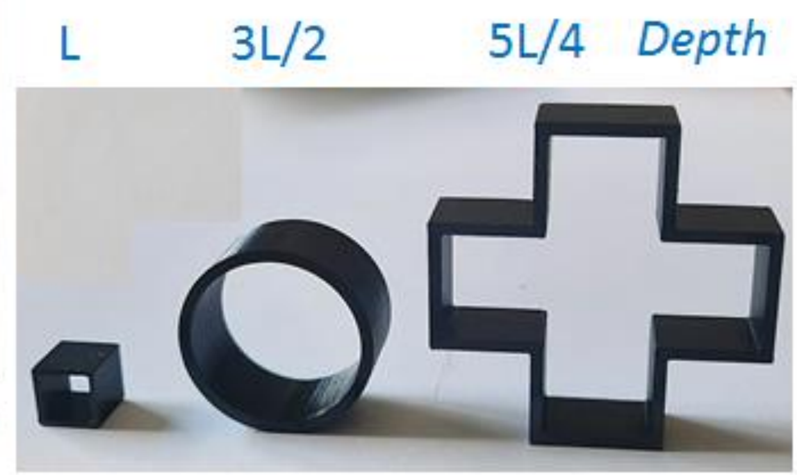
Functional and performance requirements

- 1-10 cm: 1, 3, 5 cm (with the same architecture)
- 10x10, 30x30, and 50x50 with l, l/2, and l/4 shape ratio
- Altitude of 800 km
- Possibility of different weights
- Rotational speed
- From large debris fragmentation



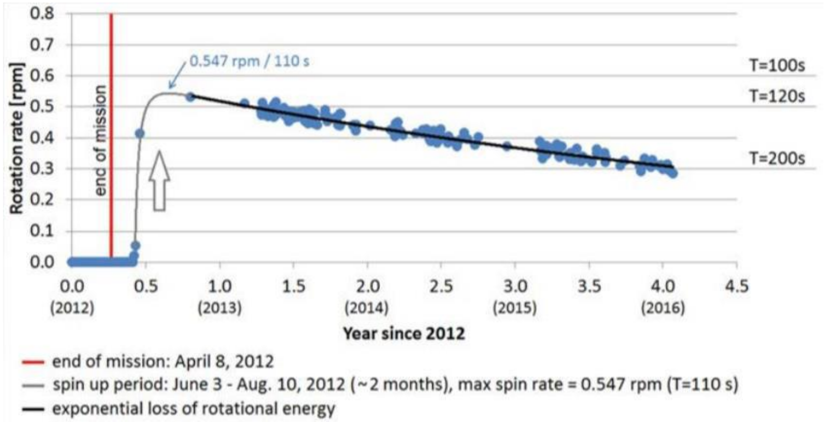


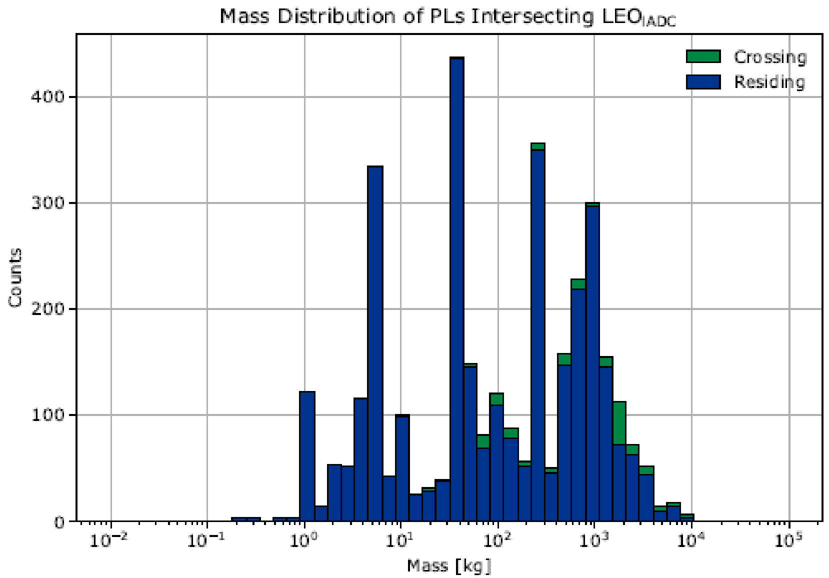


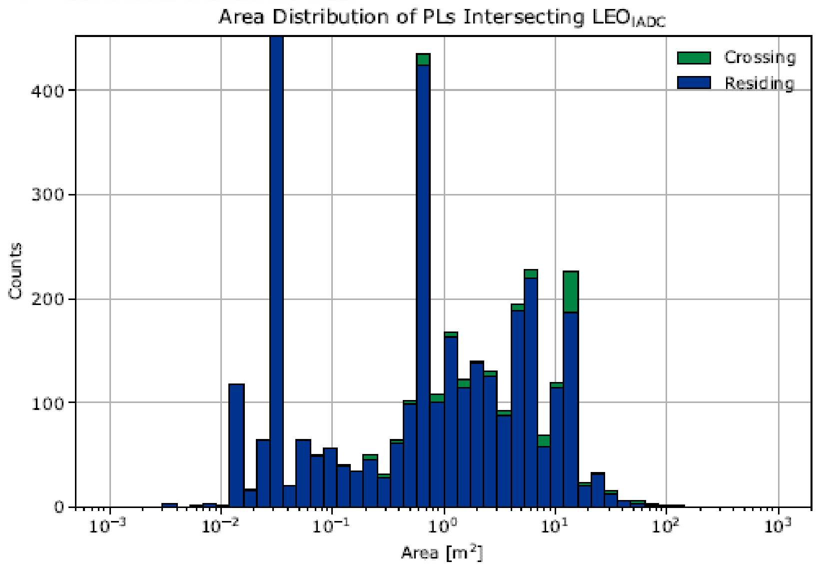


Analysis of debris distribution and properties

- Data from ESA
- *Existing Space object catalogues are typically limited to objects larger than 5 - 10 cm at low altitudes (LEO)*
- Focus of large debris
- ENVISAT spin < 1 rpm

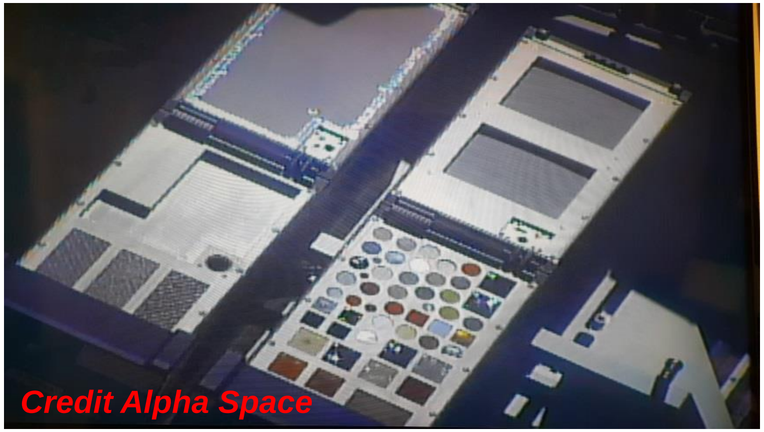


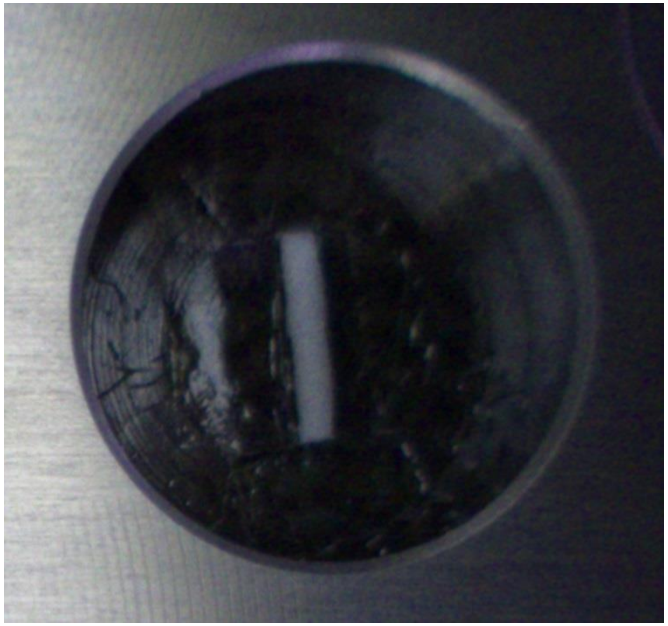




Analysis of Space environment

- Data from ISS
- MISSE 9, 10, 12, 13 with NASA Glenn
- Complex environment
  - Vacuum: outgassing
  - Atomic oxygen
  - Ultraviolet radiation
  - Particulate or ionizing radiation
  - Plasma
  - Temperature extremes and thermal cycling: -120°C to 120°C
  - Micrometeoroid and orbital debris impact: from 10 to 60 km/s

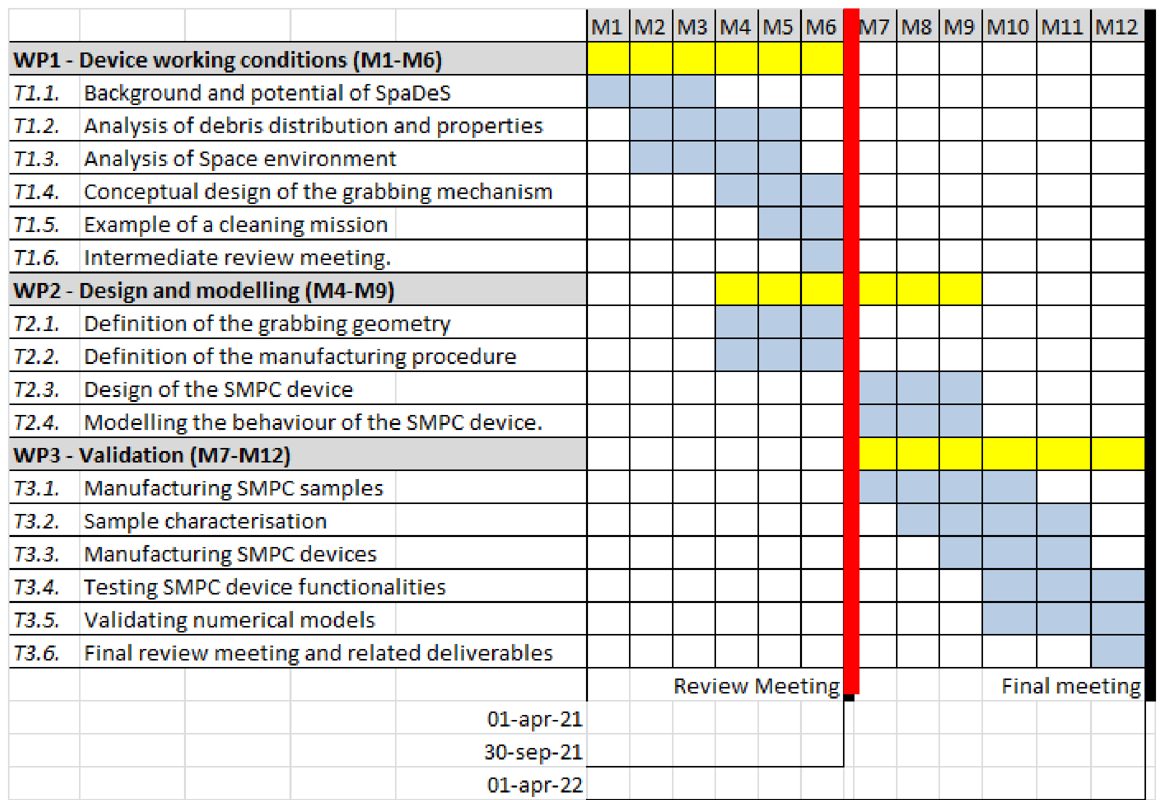




M.inO.S.
Materials in Open Space

Conclusion

- Possible target: 1, 3, 5 cm in size, different shape and shape ratio, spin of 10 rpm, variable mass;
- This debris size is compatible with a low-cost low-size expendable cleaning satellite, above all in the optic of Space manufacturing;
- As a first requirement, the size of the SMPC grabbing device will be confined
- in 1U;
- Moreover, the same device will be able to capture 3 objects with different size in the selected range.
- Next steps



Space Sustainability Center

e-SPADES

Manufacturing Technology Research Group MaTeRG

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