Qualification of additive manufacturing for space and in-space materials and processes

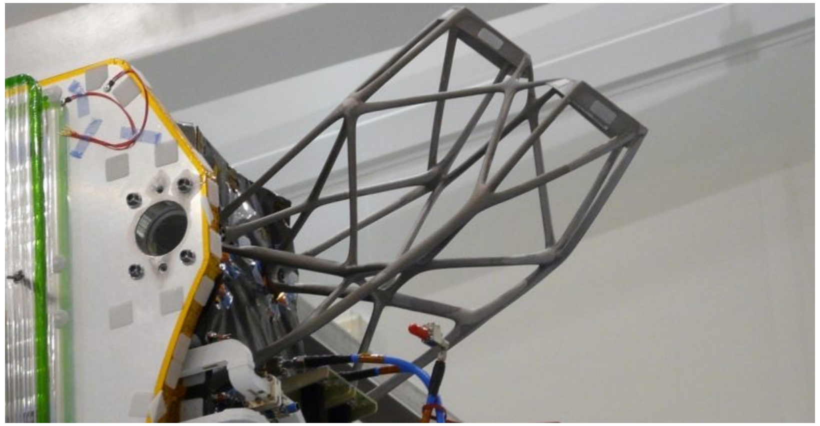
- NextSpace Testrig -

Gilles Bailet, M. Deans, and C. R. McInnes

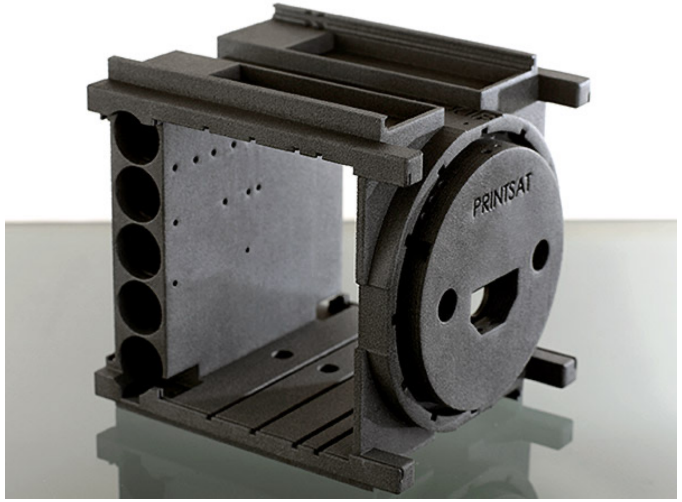
The NextSpace Testrig project was supported by the UK Space Agency under the Enabling Technology Program 3. GB and CM were also supported by the Royal Academy of Engineering under the Chair in Emerging Technologies program.

The authors wish to acknowledge the Manufacturing Technology Centre for being partners on the NextSpace Testrig project.

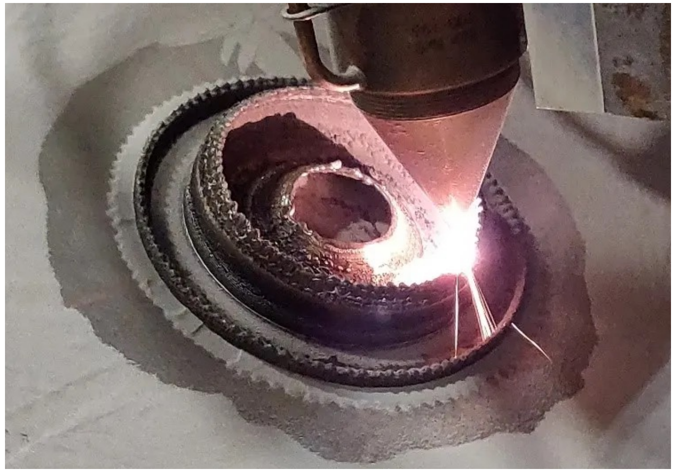
Additive manufacturing in the space sector



Optimised 3d printed bracket
(credit: Thales Alenia Space)



Nylon PA12+CF CubeSat structure
(credit: Windform, Windform® XT 2.0)



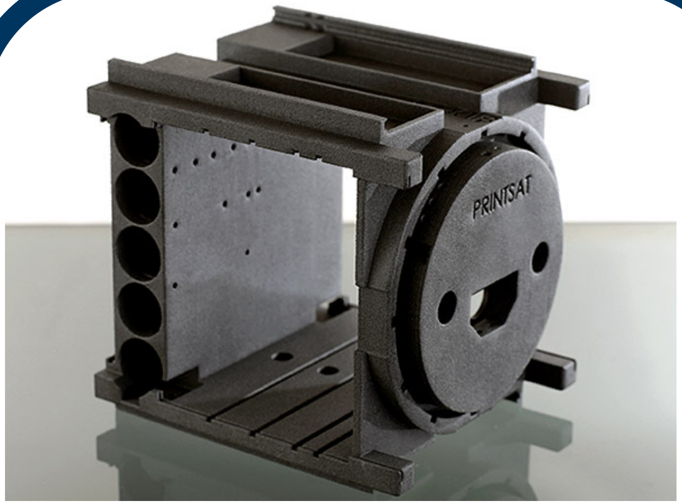
3d printing of a rocket engine
(credit: Skyrora)

PEEK CubeSat structure
(credit: ORION-AM)

Additive manufacturing in the space sector

Optimised 3d printed bracket
(credit: Thales Alenia Space)

3d printing of a rocket engine
(credit: Skyrora)

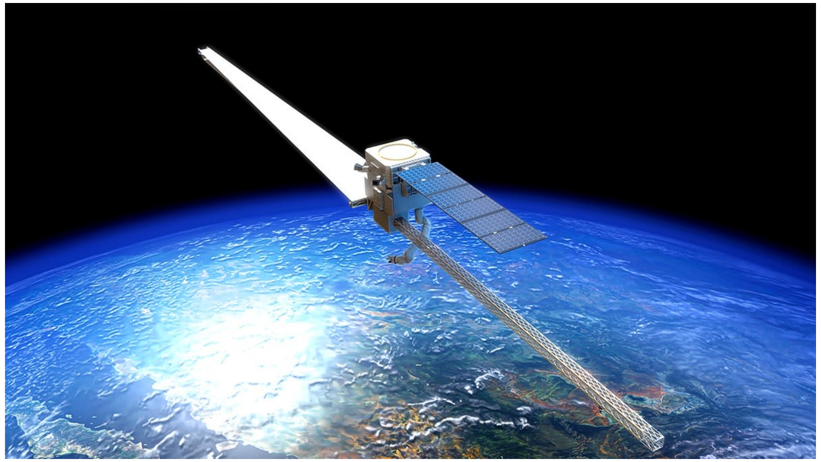


Nylon PA12+CF CubeSat structure
(credit: Windform, Windform® XT 2.0)

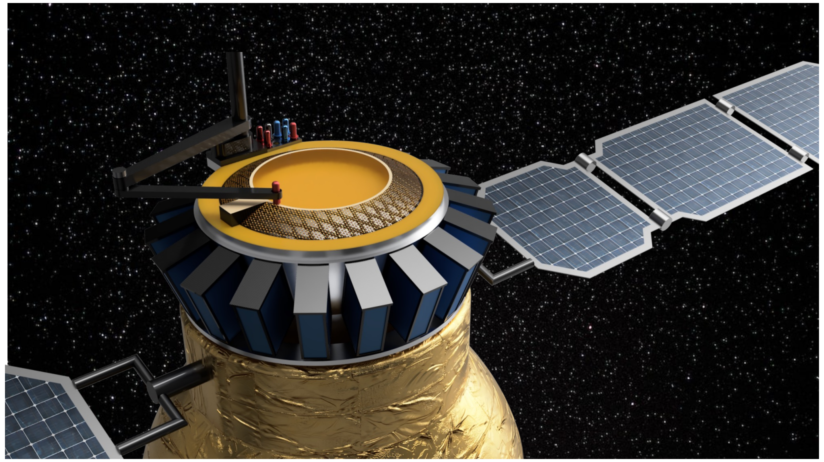
PEEK CubeSat structure
(credit: ORION-AM)

Let's look at additive manufacturing of polymers

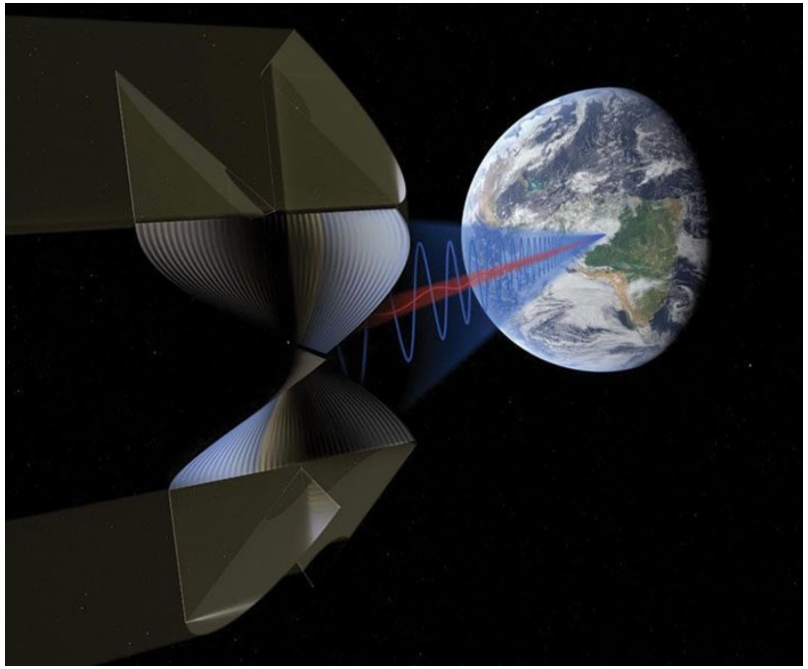
Additive manufacturing: stepping toward the future



Archinaut-1 mission demonstrator
3d printed 10m beam
(credit: RedWire)



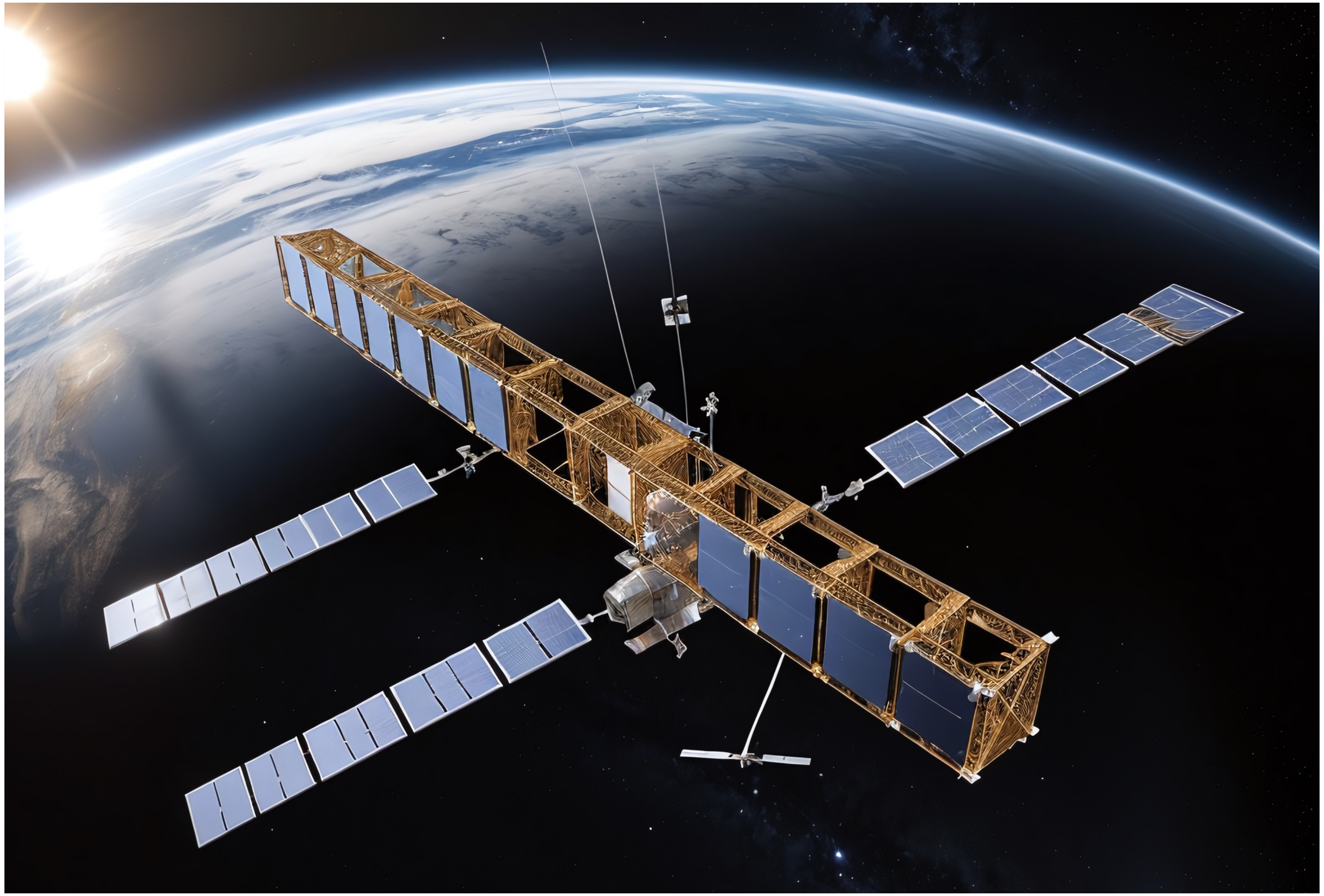
3d printing of full systems in space
Active antenna manufacturing
(credit: UofG spin-out)



CASSIOPeIA
Km-scale space based solar power
(credit: Space Solar)

Additive manufacturing: a miracle solution?

Without proper quality insurance, oversight, regulation and new standards, this miracle solution breaking the constraints of rocket launchers could open up Pandora's box and accelerate the forthcoming Kessler syndrome



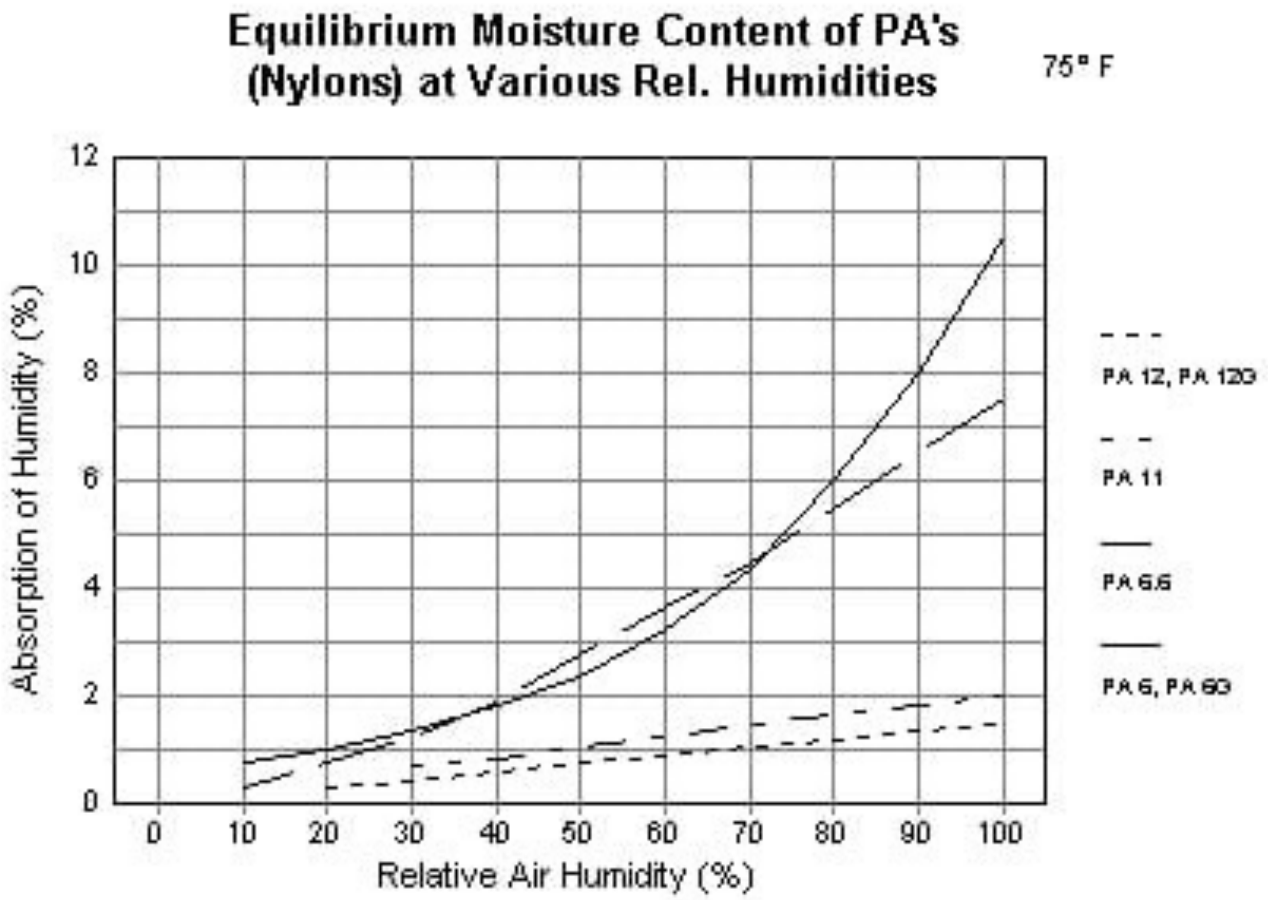
Openart.ia
Prompt: a satellite split in thirds in the middle because of the structure is flying away, flying over the stars, with a very long truss with a big space in the middle attached to the side of the earth, separated in the middle, Felix-Kelly, space art, ue 5, a computer rendering.

Nylon PA12 as a first example

Nylon as other polymers is hygroscopic:

- NASA low Total Mass Loss is 0.29-3.40% for 24h
- Total absorption is up to 10+%
- Water Vapor Regain is 4% for 24h at 50% RH

- PA12 is now widely used in the space industry up to the point that it is core to many CubeSat structures



Effects of Moisture Absorption on Nylon parts (credit: Intech Corporation 2014)

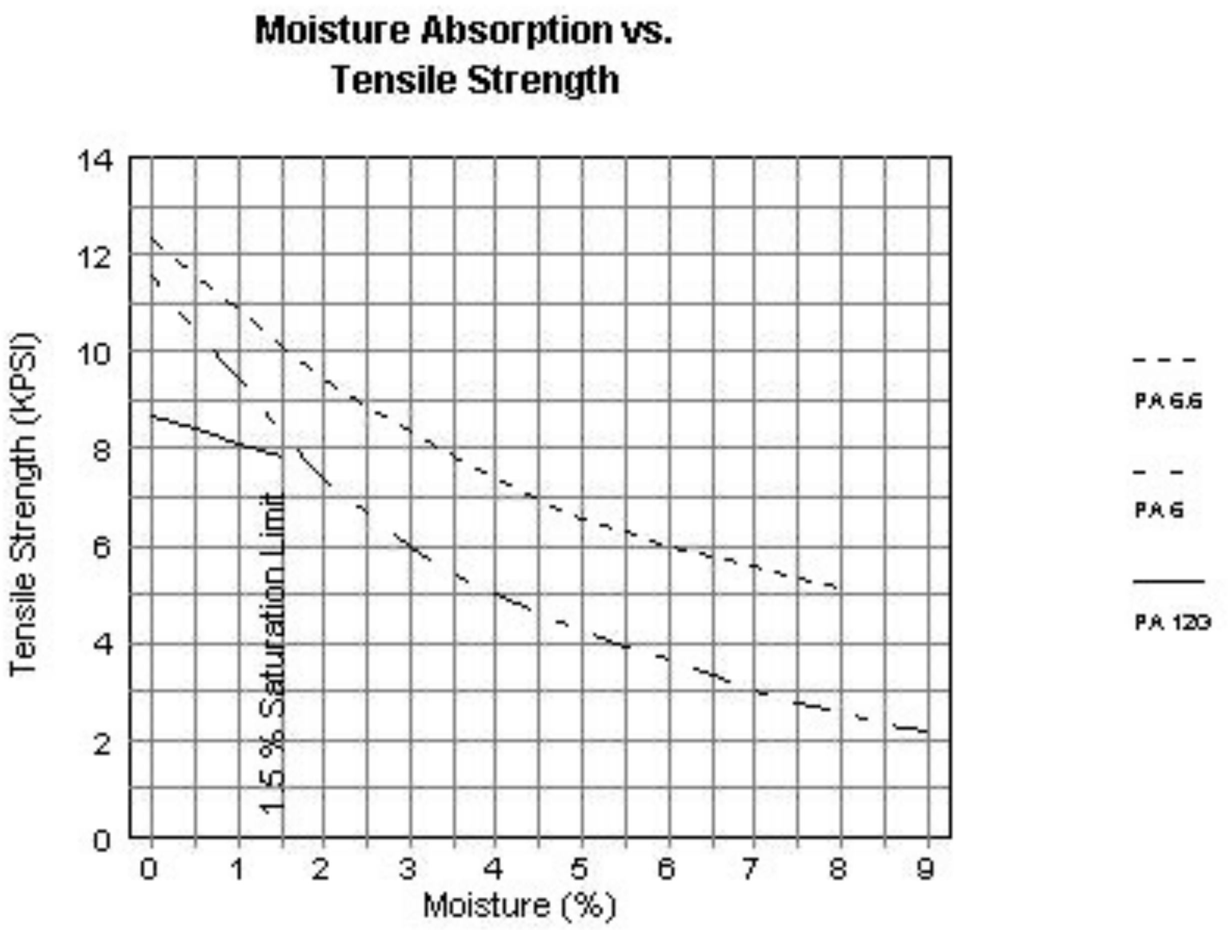
Nylon PA12 as a first example

Discrepancy between material properties and testing protocols

- Even for NASA/ESA ECSS approved materials, water vapor regain (WVR) can decrease performances by >10%.

- What about performances at extreme of temperatures?

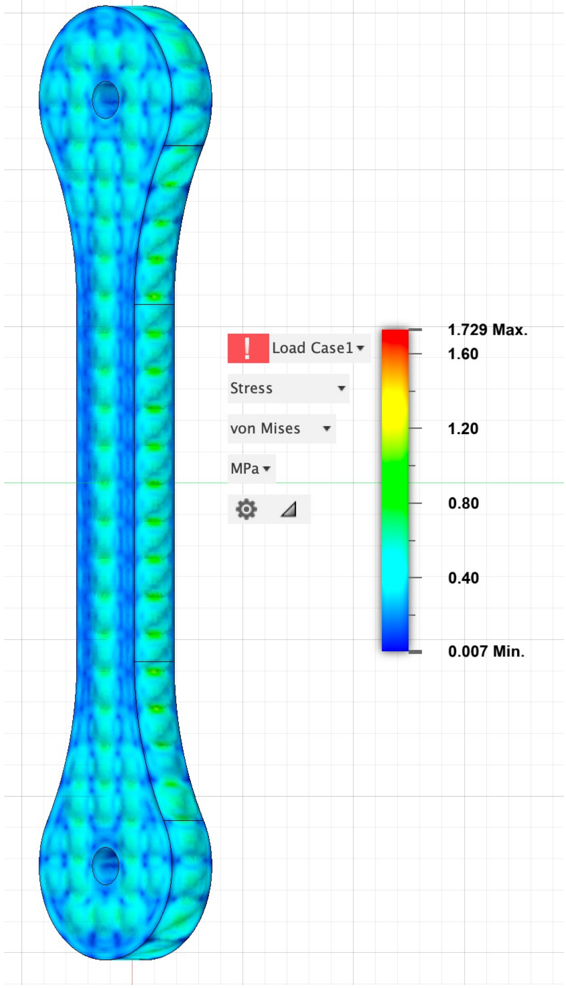
current standards characterise properties at 25^{o}C



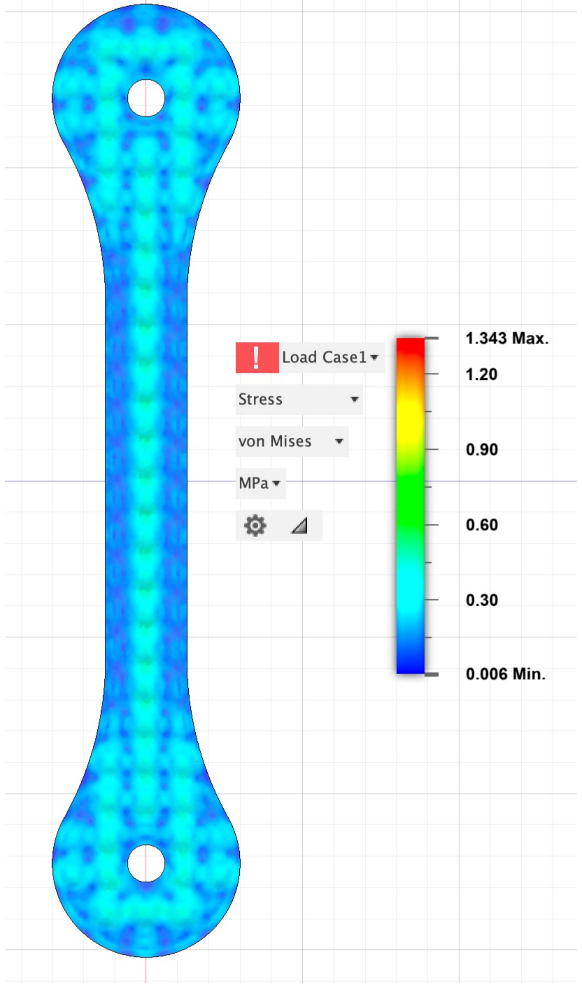
Effects of Moisture Absorption on Nylon parts (credit: Intech Corporation 2014)

What about other polymers?

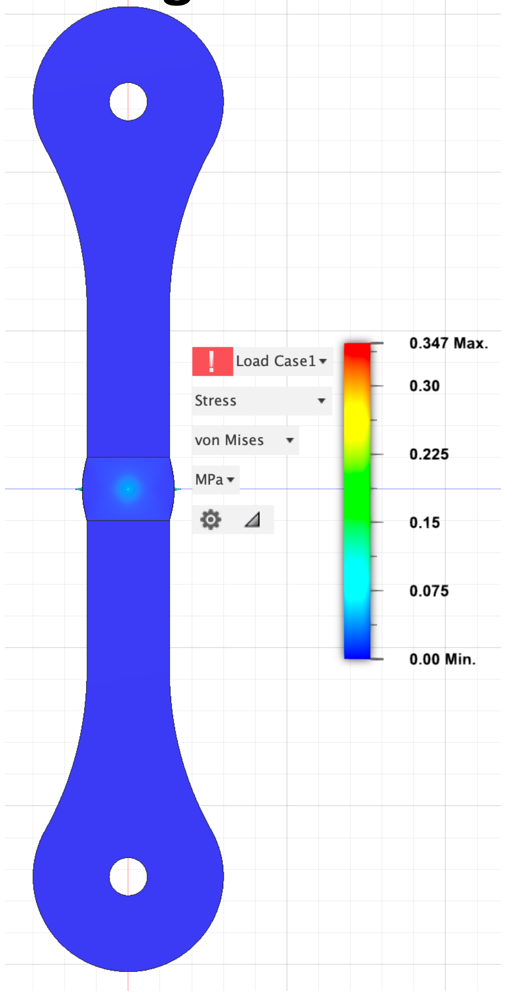
Effect of internal cavities, the limits of infill and NDT; ex. FDM PEEK tensile strength = 87.6 MPa



PEEK sample @10% infill
(von $Mises_{max}$=1.729 MPa)



PEEK sample @30% infill
(von $Mises_{max}$=1.343 MPa)



PEEK sample w/ $1mm^3$ internal defect
(von $Mises_{max}$=0.347 MPa)

What does the space segment needs?
- our thoughts -

Pain point:

- Current standards do not allow to account for the complexity of AM for use in space.
- What about AM parts created ex nihilo in space?

Solution:

- Rethink the way we approach AM material and processes testing and qualification.
- Listen to the use cases of the space community. **(that's why we are here)**

NextSpace Testrig

- **Project funded by the UK Space Agency.**
- **University of Glasgow (PI), the Manufacturing Technology Center (Co-I).**
- **End-user partners: Thales Alenia Space UK, Skyrora, In-Space Missions, AVS.**
- **...join us to identify the needs of the community.**

Project Partners

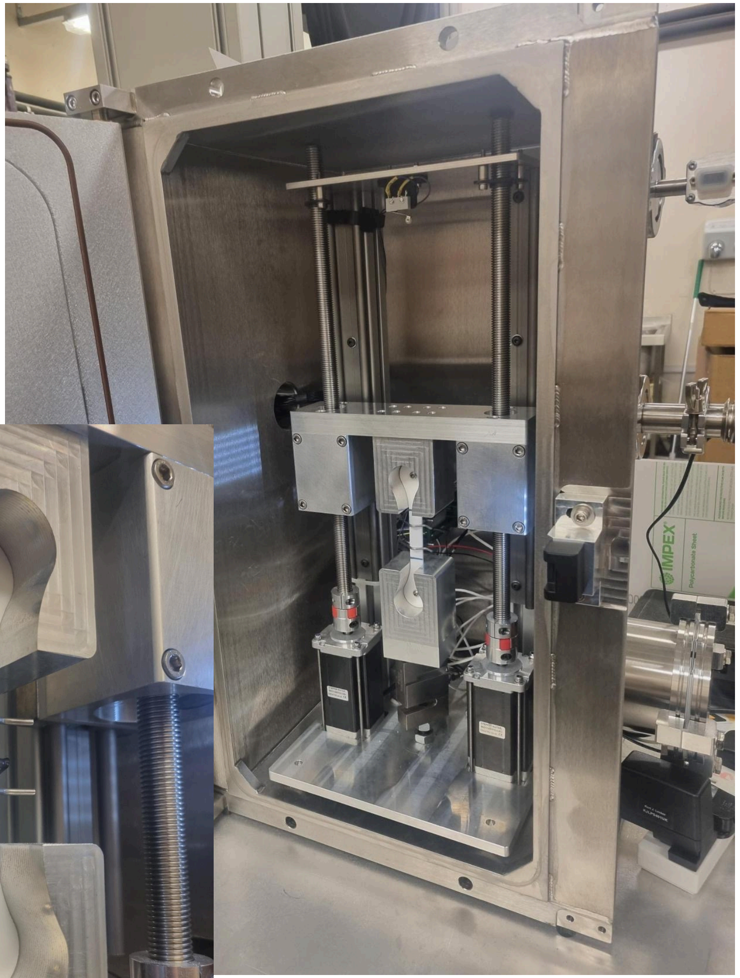
End-users

NextSpace Testrig

UK SPACE AGENCY
University of Glasgow
Royal Academy of Engineering
James Watt School of Engineering

Objectives

- Deliver a novel universal test machine and associated novel technologies able to characterize and qualify 3d printed materials and processes in a simulated space environment.
- Engage end-users to maximize space sector impact.
- Provide datasets to assess policy changes needed.



Requirements

Universal Test Machine (UTM) requirements

- Able to swap jaws to different test types (see table)
- Test plastics and metals [1]
- Simulated Space Environment
  - High-Vacuum, 10^{-3} Pa [2]
  - Thermal cycling, 200°C to -100°C (392 °F to -148 °F)
- Automation (in consideration)
  - Increase throughput of system
  - Multiple tests without cycling vacuum chamber

Test Types	Materials
Tensile	Metals
Compressive	Thermoplastics
3-point bending	Elastomers
Shear	Ceramics
Impact	
Friction	
Tear	
Peel	

[1] ISO 527, 'Plastics — Determination of tensile properties', 2019
[2] ASTM E595, Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment, 2021

Test sample geometry

- Modified dog bone tensile specimen [3]
- Force translated through shoulders
  - Compact
  - Enables future automation

Thickness = 3mm to 9mm (1/8’’ to 23/64”)

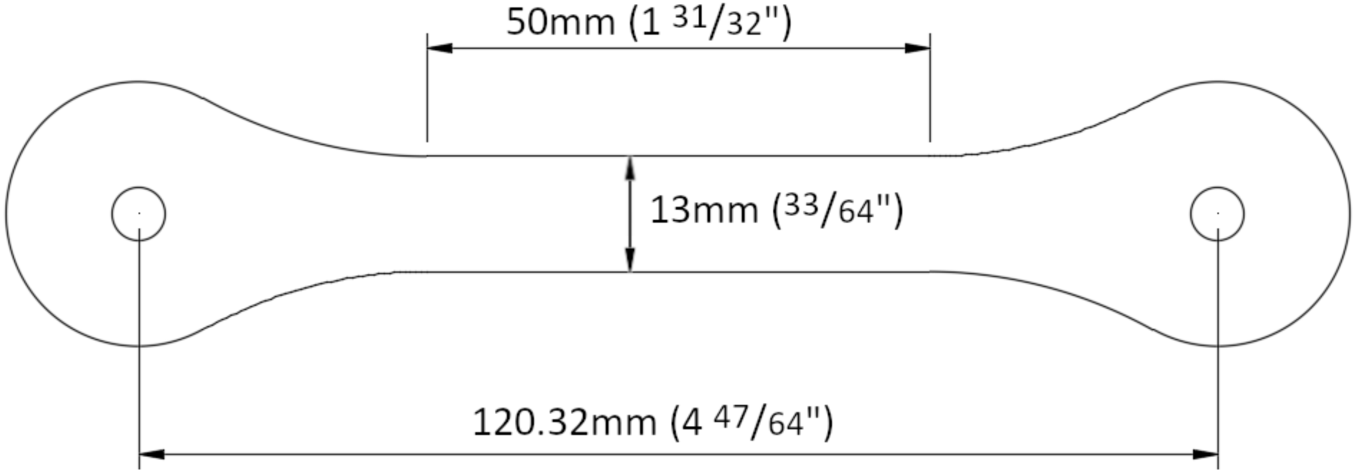
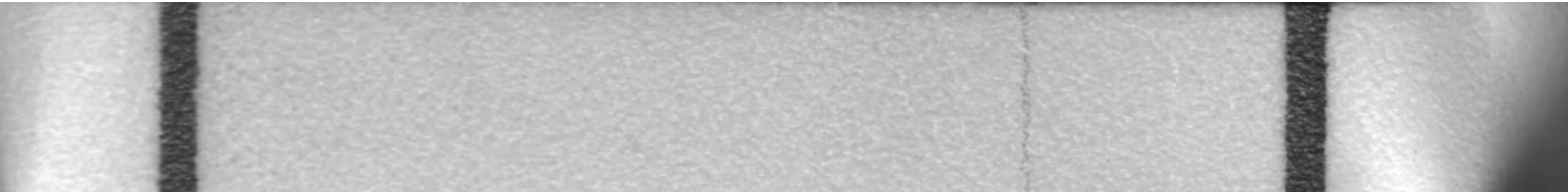


Figure 1: Tensile specimen design

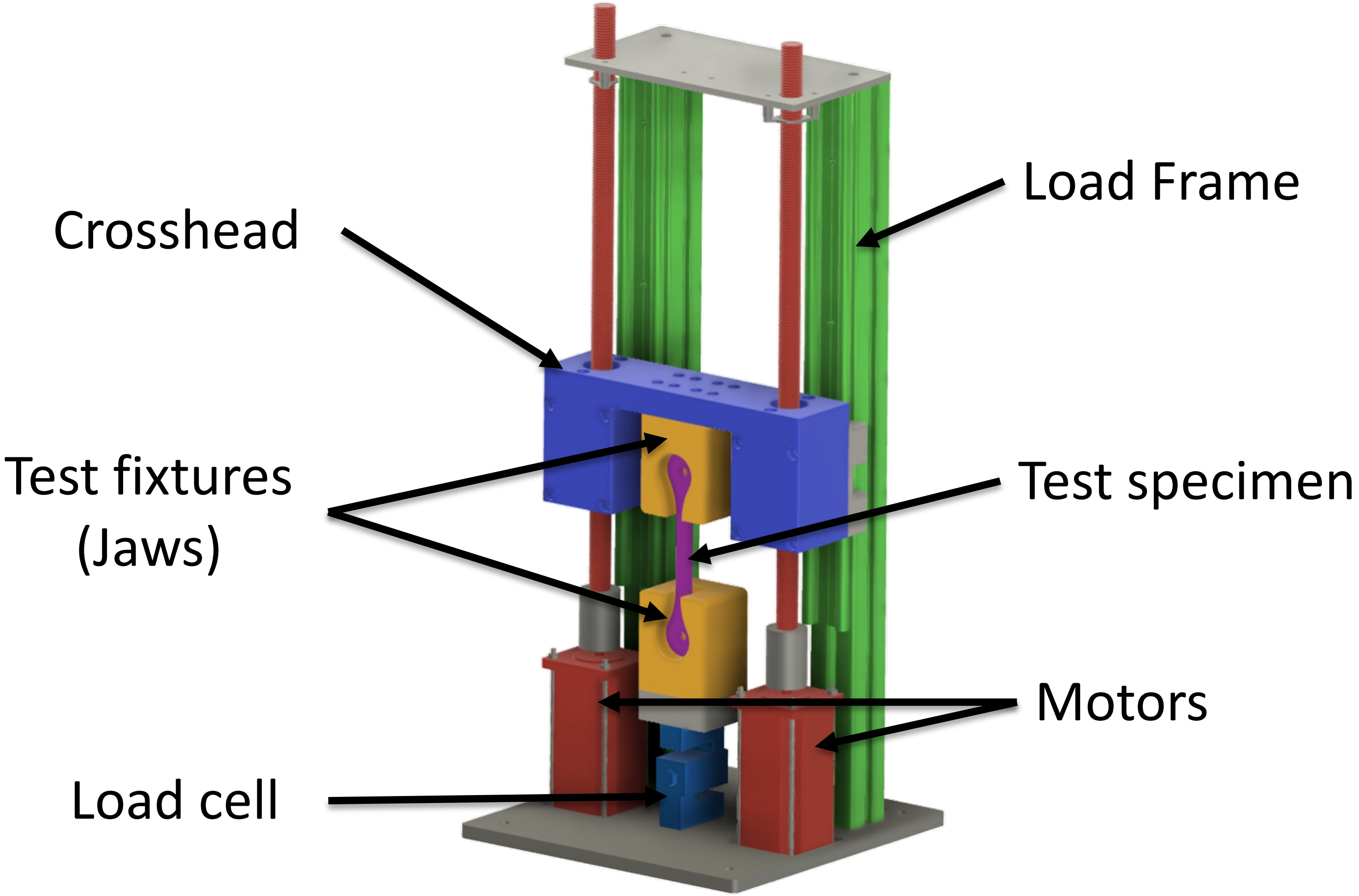


[3] Bergonzi, L., Vettori, M. and Pirondi, A. (2019) ‘Development of a miniaturized specimen to perform uniaxial tensile tests on high performance materials’, *Procedia Structural Integrity*, 24, pp. 213–224. doi:10.1016/j.prostr.2020.02.018.

Testrig design

NextSpace Testrig mounted in vacuum chamber

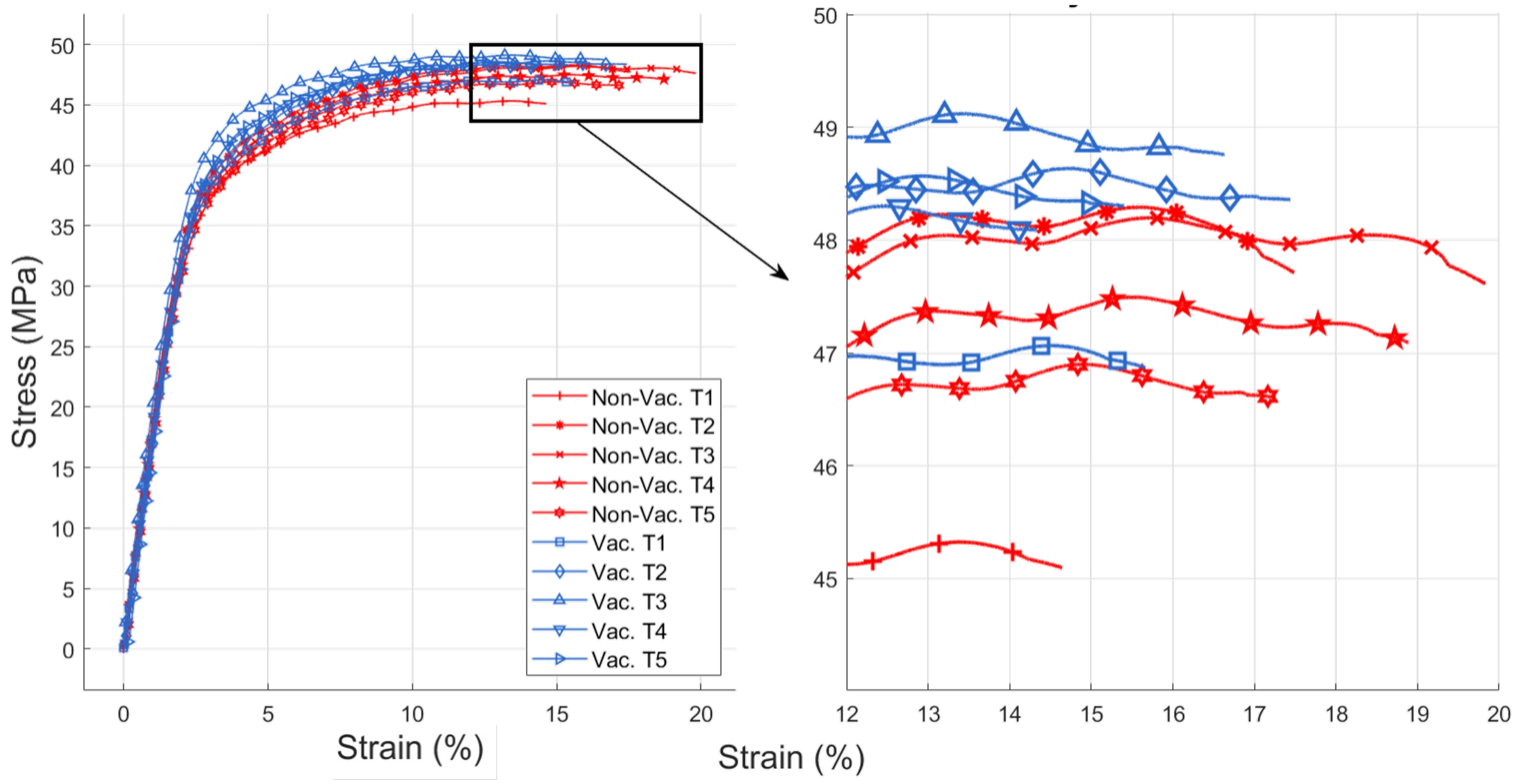
NextSpace Testrig schematic of key components



gilles.bailet@glasgow.ac.uk

Preliminary results

Tensile strain at fracture of Nylon PA12 sample in vacuum and non-vacuum



Test No.	Fracture Strain (%) Non-Vacuum	Vacuum
1	14.64	15.67
2	17.49	17.44
3	19.83	16.63
4	18.88	14.34
5	17.26	15.39
Avg.	17.62 ± 1.76	15.89 ± 1.06

- **Mechanical performances reduced by 9.8%**

Looking forward

Program development

- **Include Ultra High Vacuum capability**
- **Include liquid nitrogen cooling in the jaws**
- **Include infrared/induction heating**
- **Investigate high resolution Direct Image Correlation**

Thank you for your attention
@SpaceGlasgow
gilles.bailet@glasgow.ac.uk

Some more details
at Matthew Deans poster
tonight

Come build a safer and more
reliable in-space manufacturing
future