

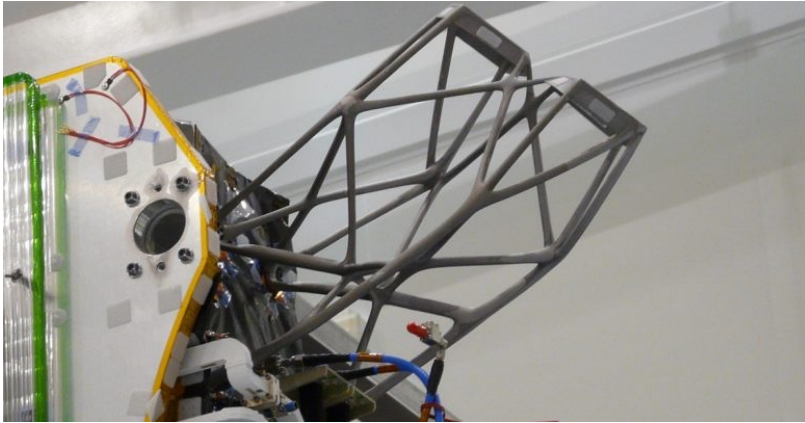
Qualification of additive manufacturing for space and in-space materials and processes - NextSpace Testrig -

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

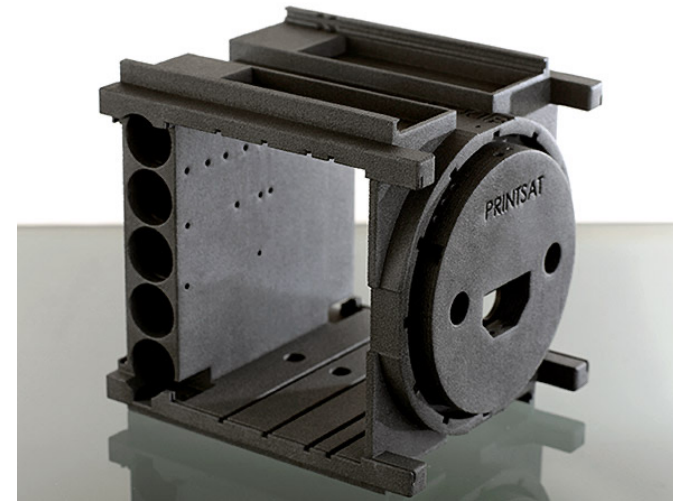
The NextSpace Testrig project was supported by the UK Space Agency under the Enabling Technology Program 3. GB and CM were also supported by the Royal Academy of Engineering under the Chair in Emerging Technologies program.

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

Additive manufacturing in the space sector



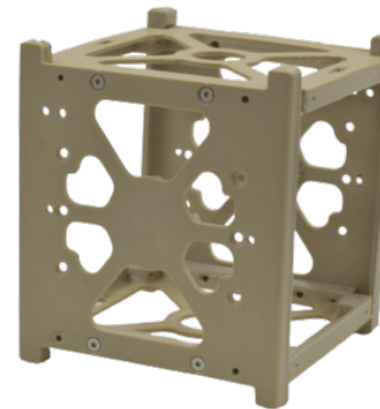
Optimised 3d printed bracket
(credit: Thales Alenia Space)



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

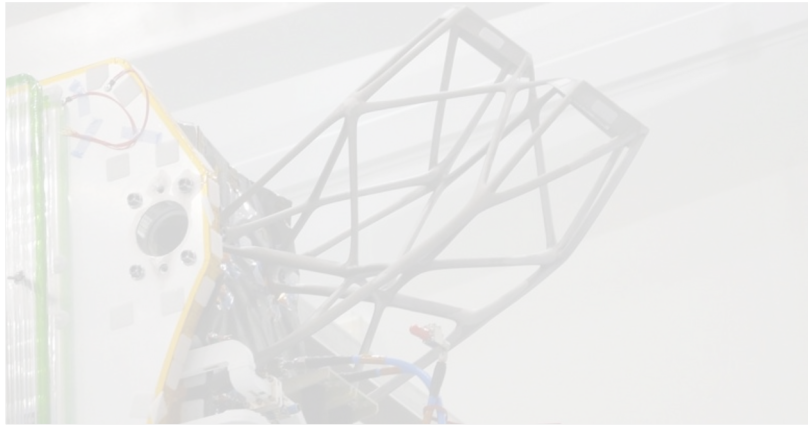


3d printing of a rocket engine
(credit: Skyrora)

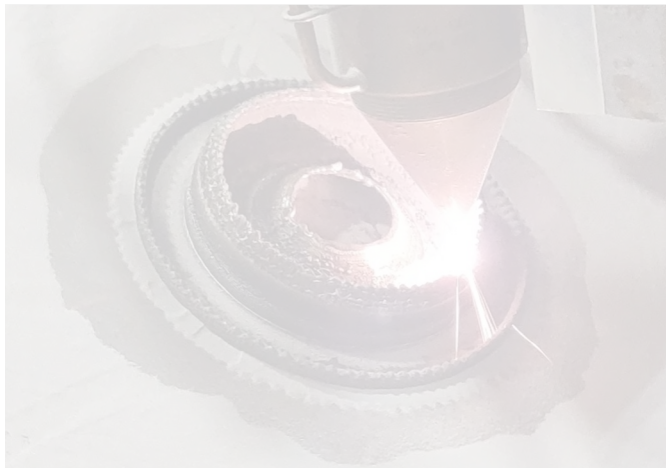


PEEK CubeSat structure
(credit: ORION-AM)

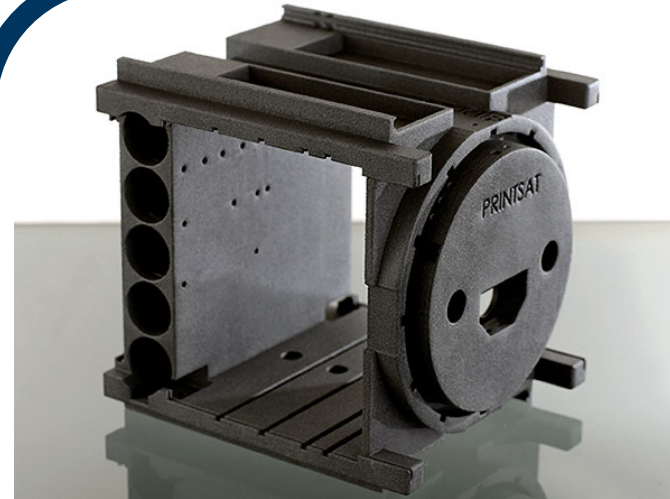
Additive manufacturing in the space sector



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



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



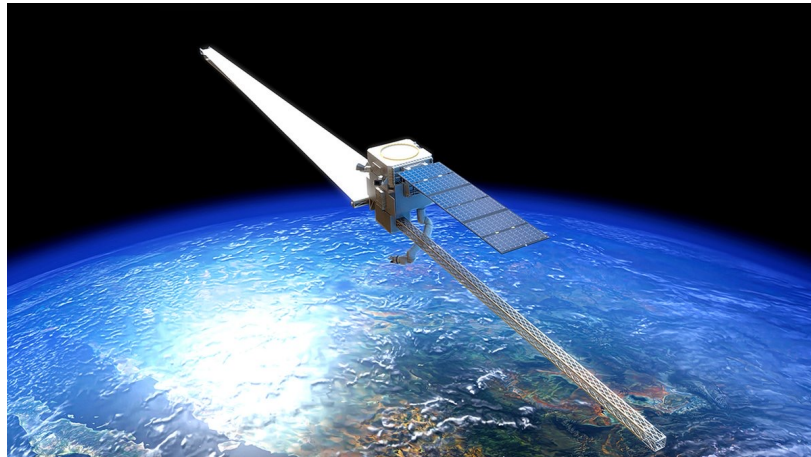
Nylon PA12+CF CubeSat structure
(credit: Windform, Windform® XT 2.0)



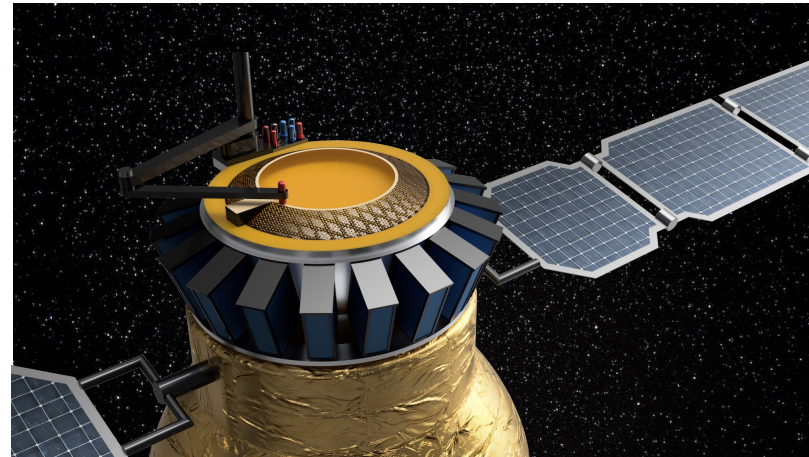
PEEK CubeSat structure
(credit: ORION-AM)

**Let's look at
additive
manufacturing
of polymers**

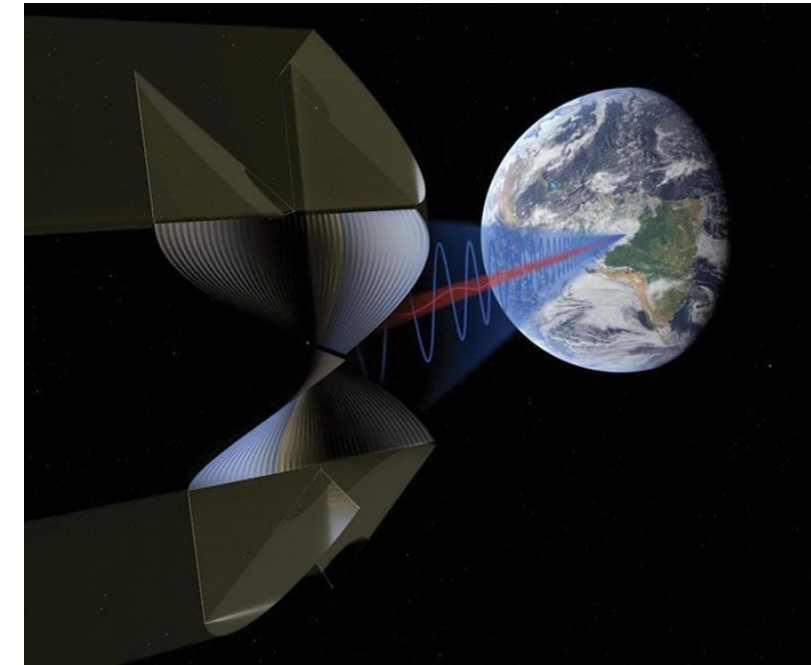
Additive manufacturing: stepping toward the future



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



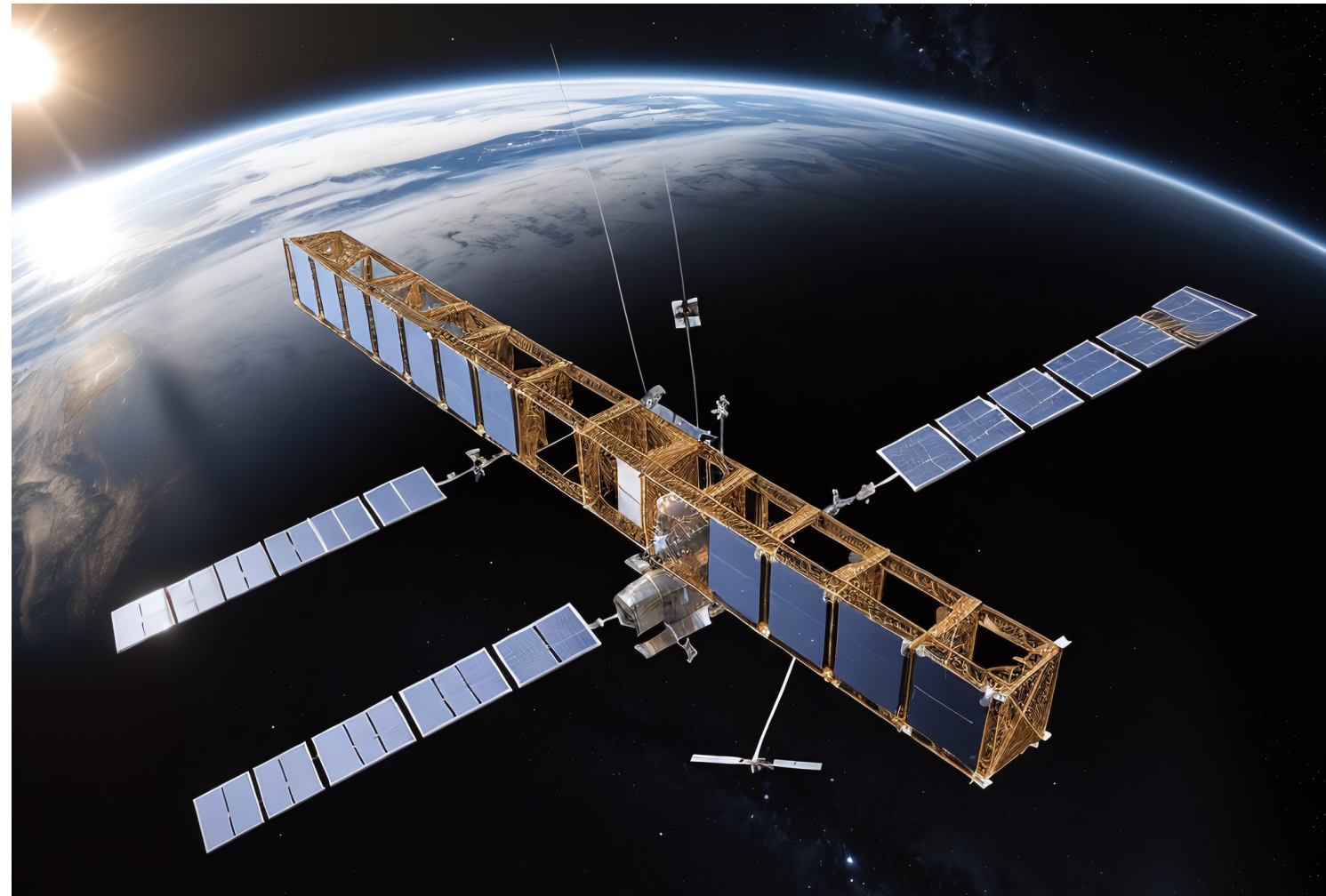
3d printing of full systems in space
Active antenna manufacturing
(credit: UofG spin-out)



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

**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



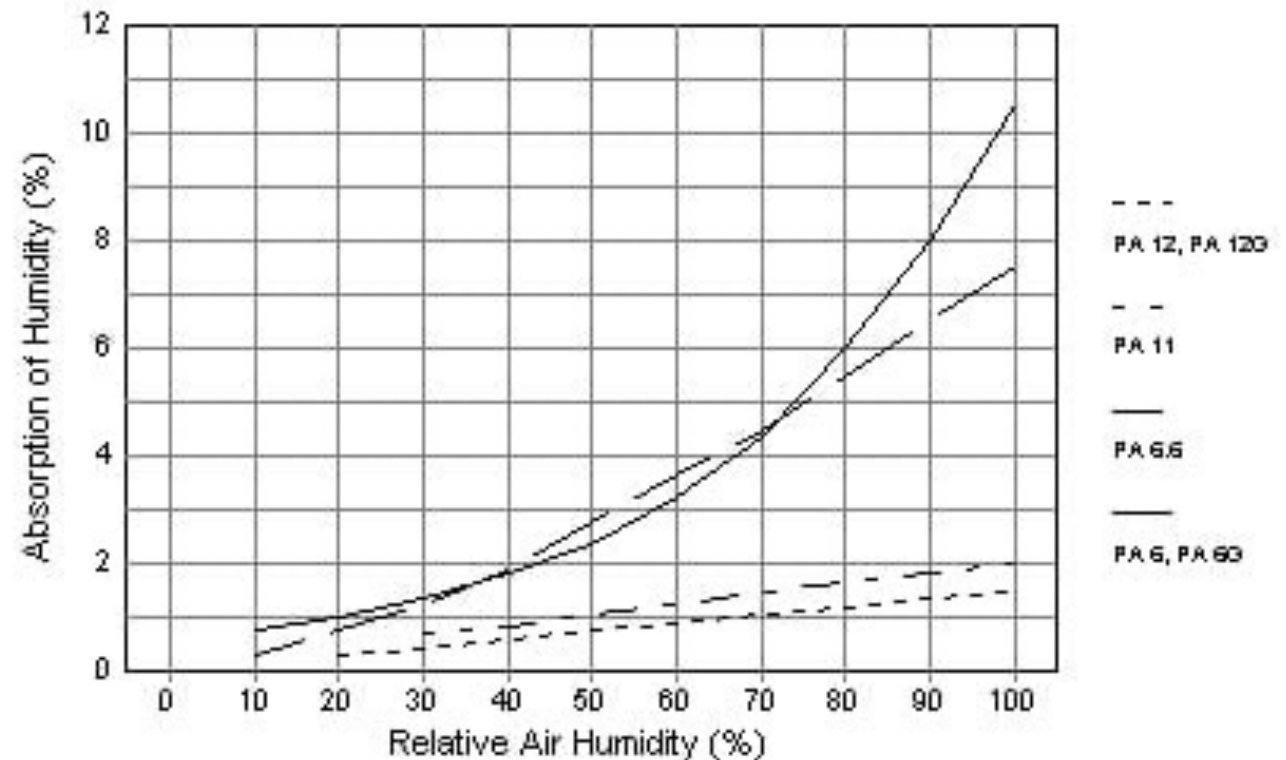
Openart.ia

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 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

Equilibrium Moisture Content of PA's (Nylons) at Various Rel. Humidities 75° F

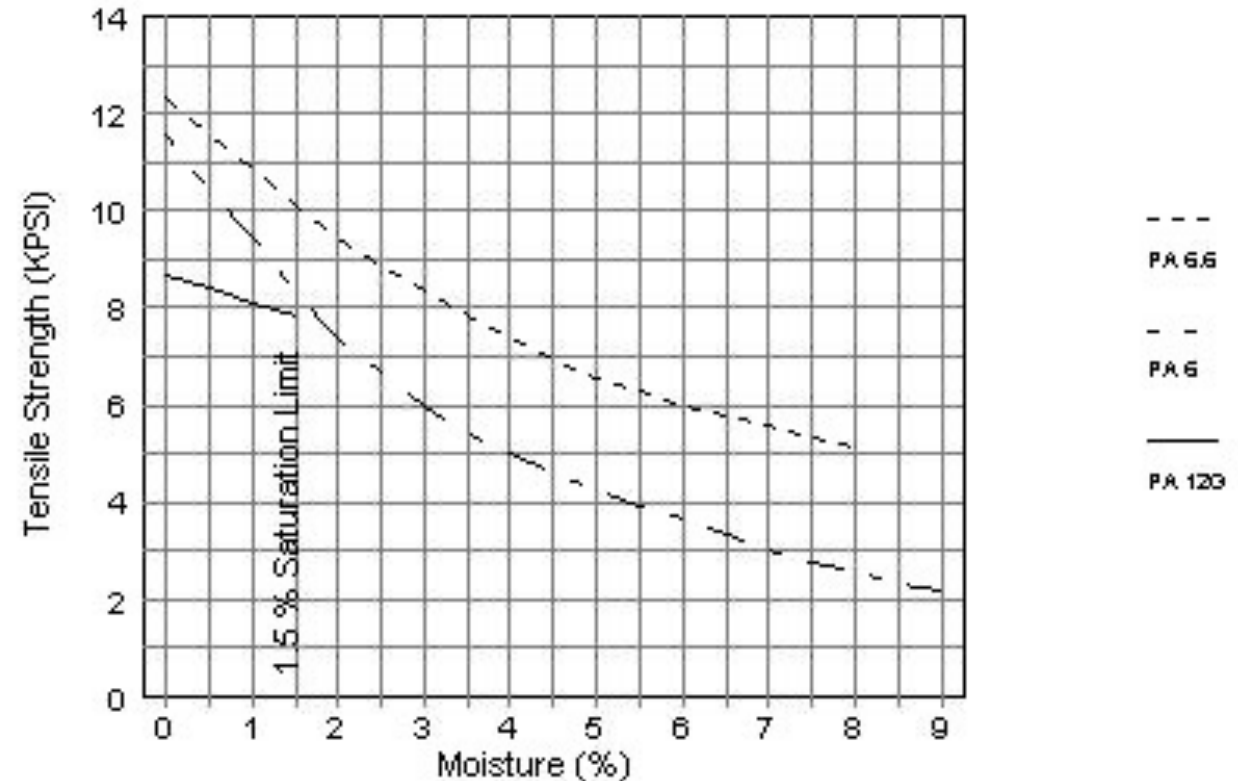


Effects of Moisture Absorption on Nylon parts
(credit: Intech Corporation 2014)

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°C

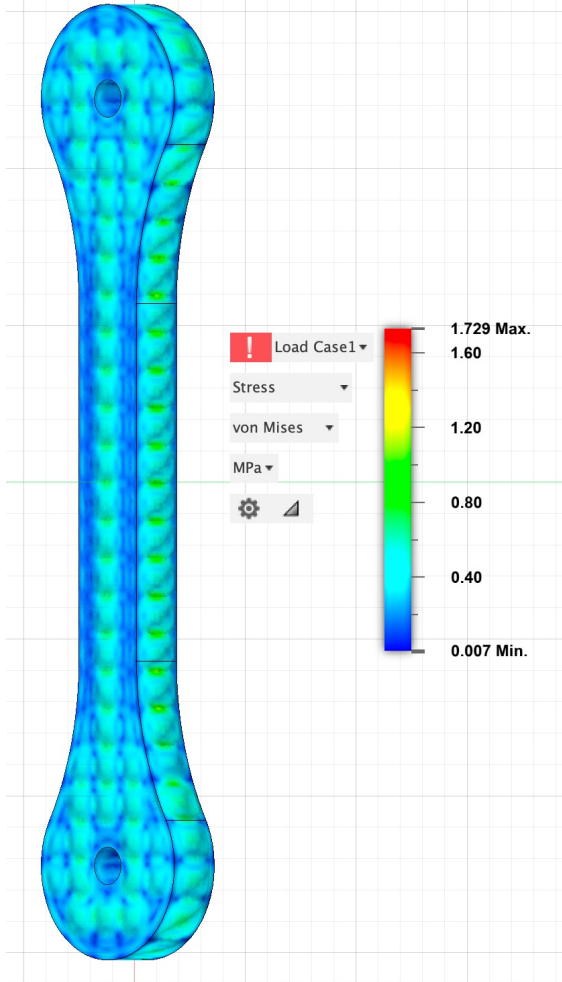
Moisture Absorption vs. Tensile Strength



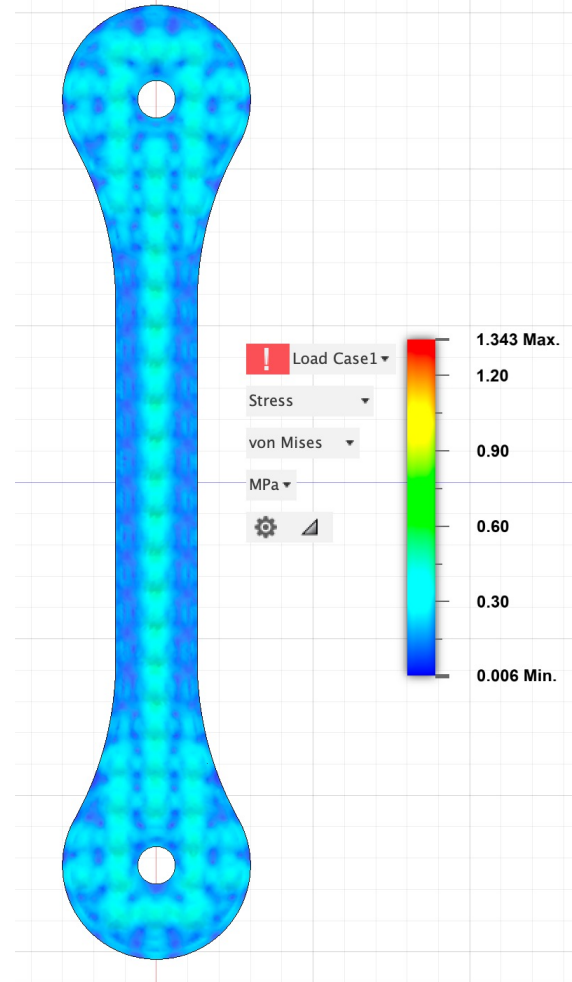
Effects of Moisture Absorption on Nylon parts
(credit: Intech Corporation 2014)

What about other polymers?

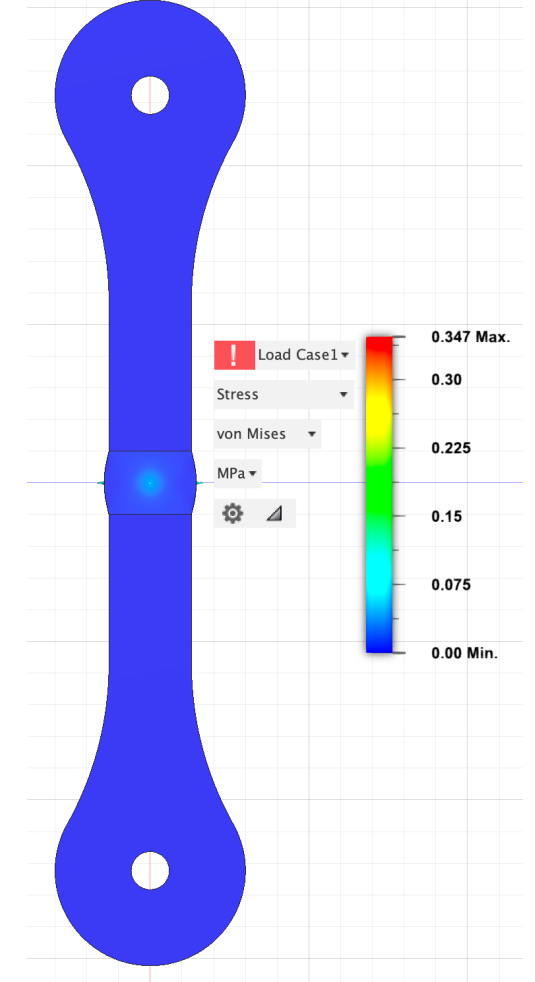
Effect of internal cavities, the limits of infill and NDT; ex. FDM PEEK tensile strength = 87.6 MPa



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



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



PEEK sample w/ 1mm³ 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)**

Project Partners



- Project funded by the UK Space Agency.
- University of Glasgow (PI), the Manufacturing Technology Center (Co-I).

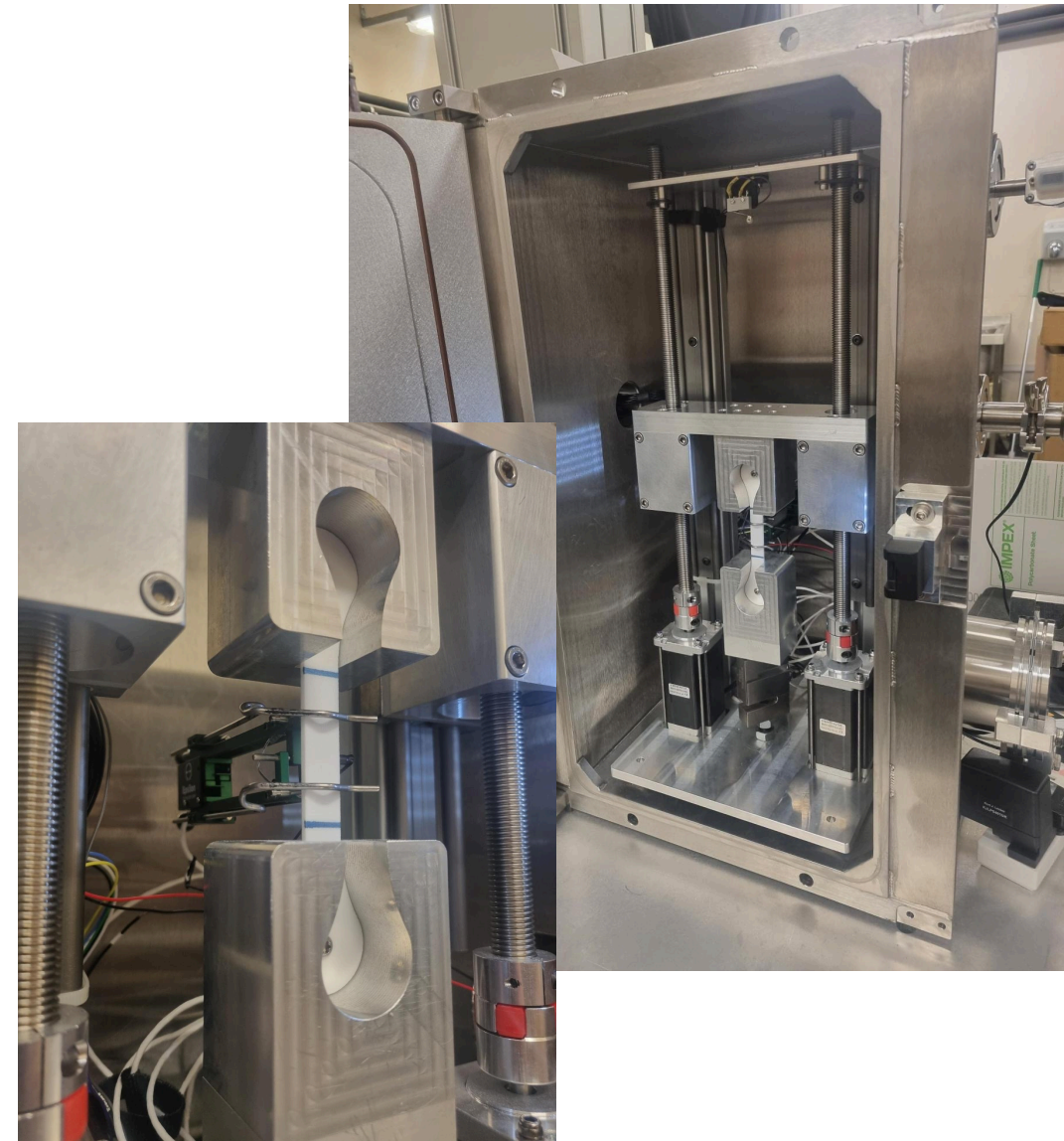
End-users

- End-user partners: Thales Alenia Space UK, Skyrora, In-Space Missions, AVS.
- ...join us to identify the needs of the community.



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.



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

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

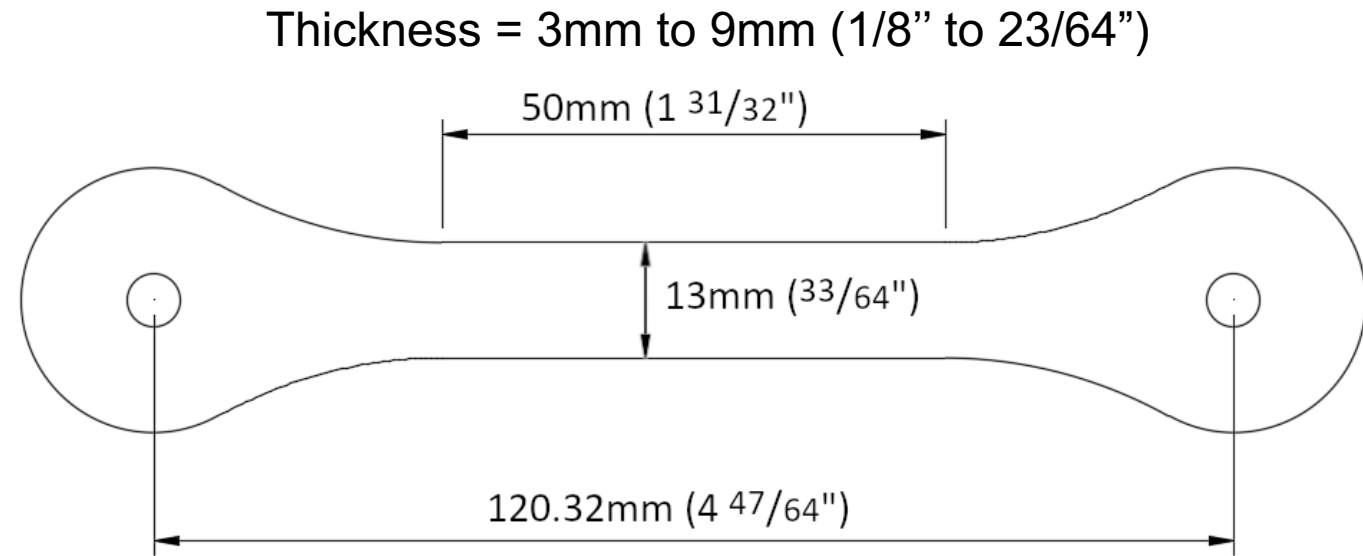


Figure 1: Tensile specimen design

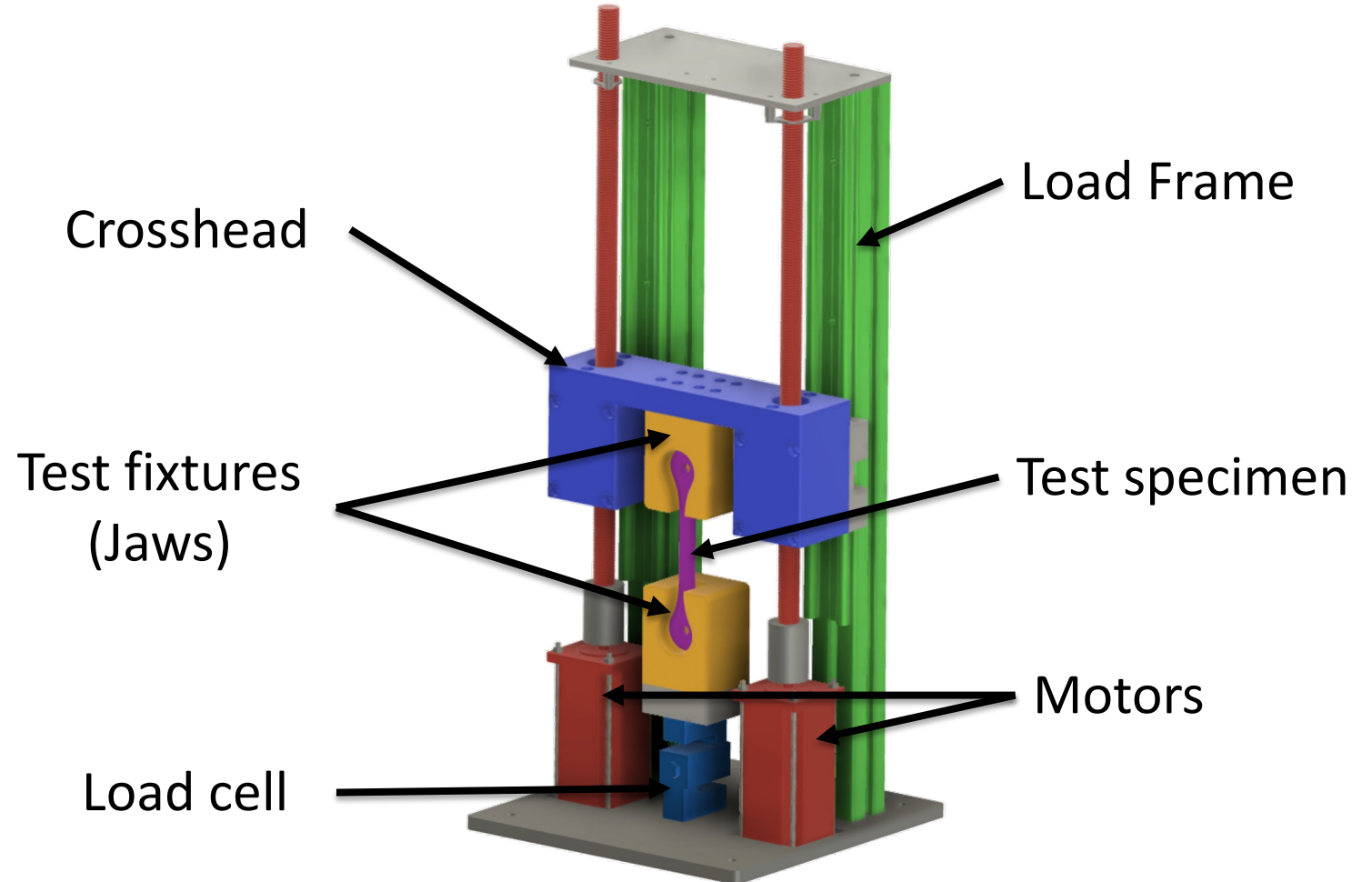


[3] Bergonzi, L., Vettori, M. and Pironi, A. (2019) 'Development of a miniaturized specimen to perform uniaxial tensile tests on high performance materials', *Procedia Structural Integrity*, 24, pp. 213–224. doi:10.1016/j.prostr.2020.02.018.

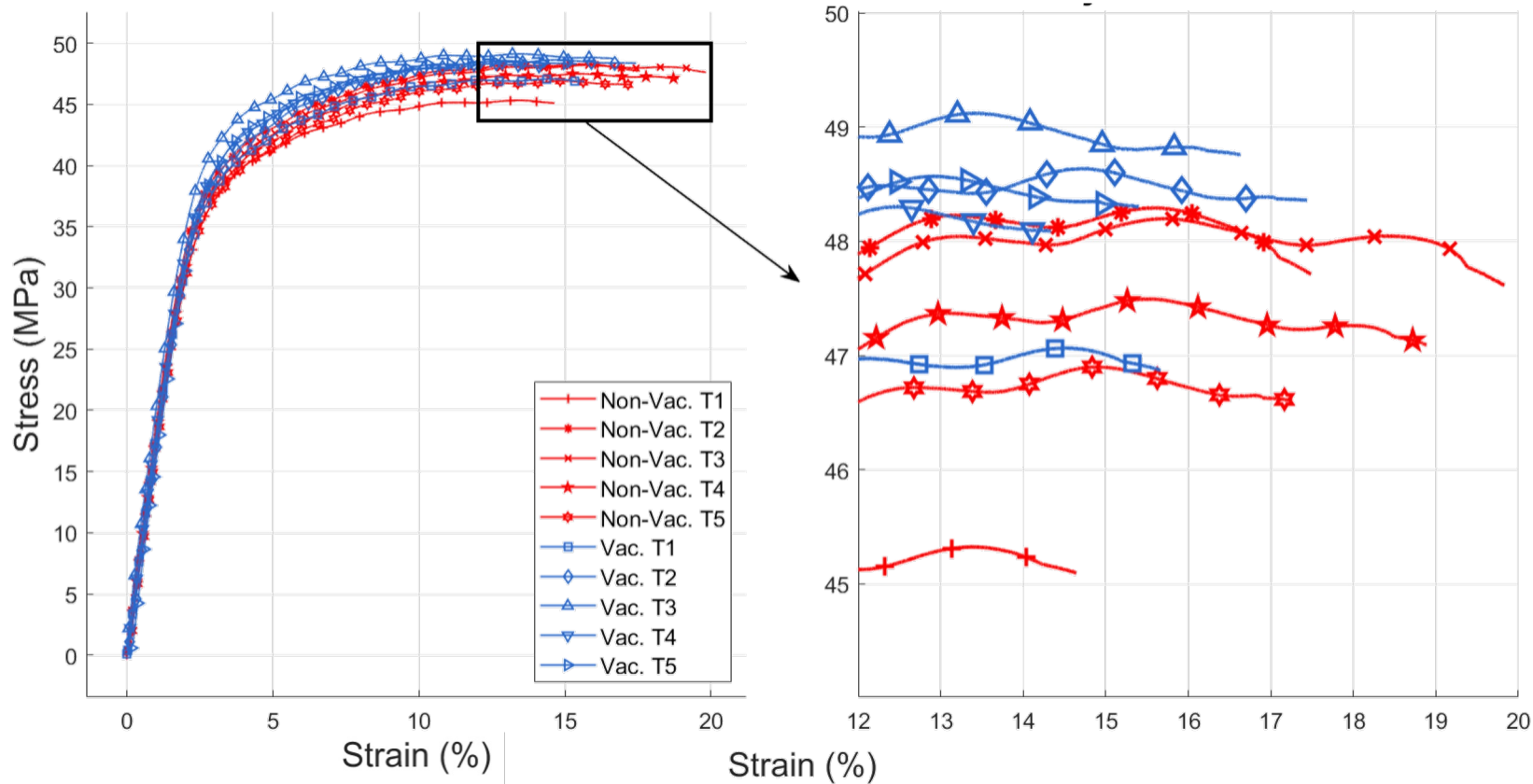
NextSpace Testrig mounted in vacuum chamber



NextSpace Testrig schematic of key components



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%**

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
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Some more details
at Matthew Deans poster
tonight

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

University of Glasgow
NextSpace Testrig Nylon PA12 Tensile Testing Campaign
M. Deans, C. Patterson, C. R. McInnes and G. Bailet
James Watt School of Engineering, University of Glasgow, Scotland, UK, G12 8QQ.

Introduction
The NextSpace Testrig, seen in Fig. 1, is a novel manufacturing technology that aims to play a key role in the future growth of the space industry offering spacecraft weight reduction, reduced manufacturing, material, and processing. The working hardware is four current generation space parts and material produced in a standard manufacturing facility. The test rig is used to measure the tensile strength of the parts and material produced in the space industry. The test rig is used to measure the tensile strength of the parts and material produced in the space industry. The test rig is used to measure the tensile strength of the parts and material produced in the space industry.

Context
Space agencies and private companies continue to push the boundaries of space exploration and utilization. As a result, the space industry is growing rapidly. This growth is leading to a need for more reliable and safe manufacturing processes. The space industry is growing rapidly. This growth is leading to a need for more reliable and safe manufacturing processes. The space industry is growing rapidly. This growth is leading to a need for more reliable and safe manufacturing processes.

The NextSpace Testrig
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Preliminary Testcase: Nylon PA12
Nylon PA12 was selected for the preliminary test case. The test case was designed to measure the tensile strength of the parts and material produced in the space industry. The test case was designed to measure the tensile strength of the parts and material produced in the space industry. The test case was designed to measure the tensile strength of the parts and material produced in the space industry.

Test No.	Non-Vacuum	Vacuum
1	14.84	15.67
2	17.49	17.44
3	18.83	18.83
4	18.88	18.94
5	17.25	18.39
Avg.	18.37 ± 1.70	18.89 ± 1.66

References
1. Watanabe, K., et al. "3D technologies for space manufacturing." 4th International Conference on Space Station, vol. 1, Amsterdam, The Netherlands: IOS Press, 2011.
2. ASTM D5556. "Standard Test Method for Tensile Properties of Extruded and Cast Polyamide (Nylon) Resin and Molded Parts." ASTM International, 2015.
3. NASA. "Technology Data for Space Manufacturing Materials." NASA/TM-2015-215, 2015. <https://ntrs.nasa.gov/doc/20150101131212main>

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