Executive Summary Report

ESA Contract No. 4000132632/20/NL/GLC with Spherene AG OSIP

Open Channel Early Technology Development Activities Evaluation Session 2020-03

State of the Art

Additive Manufacturing (AM) is the fastest growing manufacturing technology in the current market. It allows faster development and a more economical approach for smaller lot sizes. This is predominantly important for space applications as its lot sizes can be as low as one. However, new methods have also new limiting factors. In the case of AM, there are no moulding or tooling limitations as for instance in CNC-milling, but printing restrictions need to be addressed and the component design needs to be adjusted.

Methods like generative design and topology optimization can deal with different boundary conditions but in highly complex situations they are reaching their limits. New methods to fill a volume with lattice or Triply Periodic Minimal Surface (TPMS) are now emerging.
They allow for reduced stress concentrations as those surfaces have a lot of beneficial properties such as high strength, self-support, low thermal stresses and a highly porous topology.

The mathematical definition of a minimal surface is the local minimization of the surface which is equivalent to a zero-mean curvature. Simply put, any curvature in one direction is cancelled out by the curvature from another direction. This makes such structures attractive for Additive Manufacturing where a high geometrical complexity does not influence the manufacturing difficulty, but other factors like overhangs and removing of excess build materials (depowdering) are major cost drivers and increase the developing time.

Figure 1 - Generative Design with CAD Software – Source: https://www.plm.automation.siemens.com/global/pl/our-story/glossary/generative-design/

Spherene’s promising technology

The Technology Developed by Spherene AG called Adaptive Density Minimal Surface (ADMS) allows the generation of a unique, patented minimal surface.
All other known minimal surfaces, like Gyroid, Schwarz or Lidinoid are triply periodic, this means they are repeating in three orthogonal directions. A property which firstly seems advantageous but doesn’t allow for any change in density or the connection to another structure or closed surfaces. Traditional CAD Software with its current approach to surface modelling struggles to capture the geometric complexity of components consisting out of minimal surfaces.
The ADMS Technology on the other hand allows for a seamless transition between surfaces and density changes for different loads through an intuitive algorithmic approach. The surfaces generated with this Software are thereby promising for the design of highly complex and functional integrated parts.

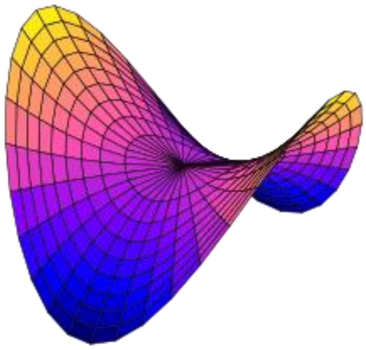

Figure 2 - A hyperbolic paraboloid represents the zero-mean property in an elemental way
Source: https://commons.wikimedia.org/wiki/File:HyperbolicParaboloid.svg

Furthermore, ADMS is based on a proprietary algorithm which allows to optimize parameters with machine learning and based on different physical boundary conditions such as mechanical loads, anisotropic stiffness requirements, heat source/dissipation, and fluid dynamical and acoustic effects.

The European Space Agency (ESA) conducted an evaluation session through its
Open Space Innovation Platform (OSIP). The appliance of this technology in space-related projects was investigated and maturity for the design and manufacturing of structural components needed to be verified.

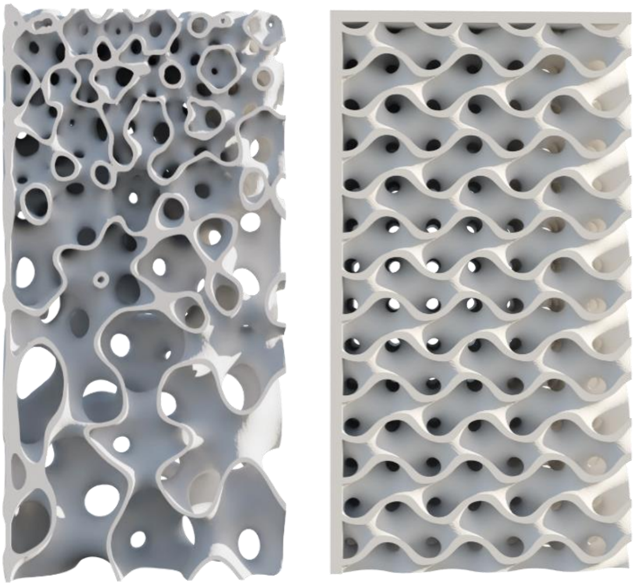

Figure 3 –(left) organic density gradient of the ADMS structure, (right) Gyroid without density change

Project Scope

Throughout the development of Spherene's software for space applications, the multi-physical boundary conditions were analysed, and possible use cases were considered.

On the first evaluation, the most feasible structural benefit could be found in mechanical applications like directional stiffness control, shock absorption and/or thermal isolation capabilities.

Spherene was able to develop, produce and test a Software Toolchain, to create adaptive minimal surfaces suitable for metal additive products, specified by the Space Industry. The capability to include AI optimization could be successfully shown. The Software developed and used by Spherene takes geometry inputs and mechanical constraints to generate an optimized surface structure that can be manufactured additively out of aluminium and many other materials, without the necessity for an additional support structure.

To verify the capability of the software, a use case was chosen to empirically test the structural properties of the geometry generated by Spherene.

Figure 4 Schematic Representation of the ADMS Toolchain on the example of the "GE Bracket"

Bracket Use-Case

To use an exemplary test case, a prototype satellite bracket was chosen. It has multiple boundary conditions. Including vibration, thermal, shock and different behaviour in in-plane and out-of-plane directions. Such a use case would pose a challenge for most traditional tools like topology optimization because each additional load case makes the geometry heavier and less flexible.

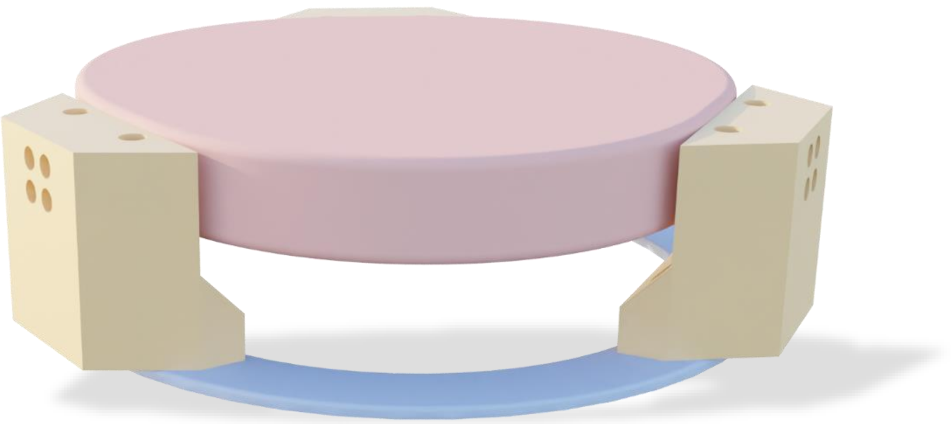

Figure 5 Boundary conditions for the three-legged satellite. Yellow: Boundaries, Red: Simplified load in the middle

Requirement	Out of plane	In-plane
Stiffness	Freq. > 140Hz	
Max Mount Radial Stiffness	-	450 N/mm
Min. mount thermal resistance	20 K/W	-
Quasi-Static loads	15g	11g
Sine levels	5 à 17 Hz: ±10mm	5 à 17 Hz: ±10mm
	17 à 125 Hz : 15g	17 à 125 Hz : 15g
Shock levels	100 Hz : 40g	
	1000 à 10000 Hz : 1000g	

Figure 5 - Various boundary conditions for the chosen use-case

Virtual set-up and validation

To ensure that all boundary conditions were satisfied, a digital twin was created in a simulation environment. In this way, the highly non-linear system with several component groups was modelled. The different vibrational, thermal and impact forces were also modelled as close as possible to the expected use cases.

As the identical bracket is used in multiple positions of the component group, all load conditions for each position were combined and interpolated.

The information gained from these simulations was used to generate the lightest possible structure with the proprietary ADMS algorithm, which additionally was optimized for production in an additive process.

A shell mesh-based workflow was developed to feedback and simulate the complex geometry of Spherene in high fidelity with a low trade-off in efficiency. Using the developed toolchain, the minimal surfaces generated by Spherene can be directly imported into industry-standard Simulation and Analysis Software and thus simulated efficiently.

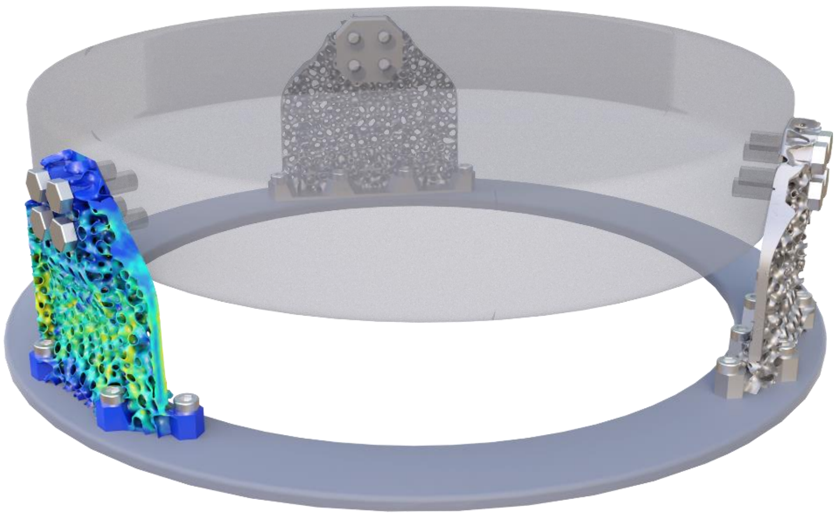

Figure 6 three-legged satellite bracket with the simplified load in the centre

The final structure was additionally Simulated in a high fidelity "Print Simulation" and analysed for warping and blade crashes during production. The result showed very low thermal stresses during Additive Manufacturing and no blade crashes.

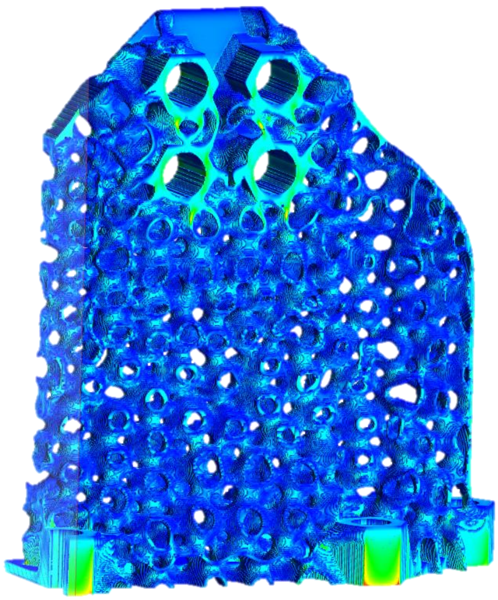

Figure 7 - High fidelity print simulation results, showing the distribution of the thermal stresses in the component

For production, Ecoparts AG (Hinwil, CH) was chosen. They are one of the best-qualified manufacturers in Switzerland and currently undergoing the steps to become a space-grade manufacturer. In close cooperation with Spherene two versions of the bracket were produced out of high-quality AlSi10Mg on an EOS SLM Machine.

After initial inspection at Spherene, the part was tested at the FHNW in Windisch, where random vibration and harmonic loads were put onto the bracket. The same test protocol which is used for stress-testing of satellite parts was applied and the response of the bracket was analysed.

The test data was evaluated and Spherene could prove that the bracket was able to withstand the specified forces without any structural damage. The measured data was fed back into the simulation. This allowed for a comparison of the simulated forces with the measured test data. A very close match between the simulated and real parts could be achieved in the vibrational modes and flexibility. This allowed confirming, that Spherene reached not only the capability to design complex minimal structures but also to simulate and manufacture those in a space-grade process that in the end has a low deviation from the required specifications.

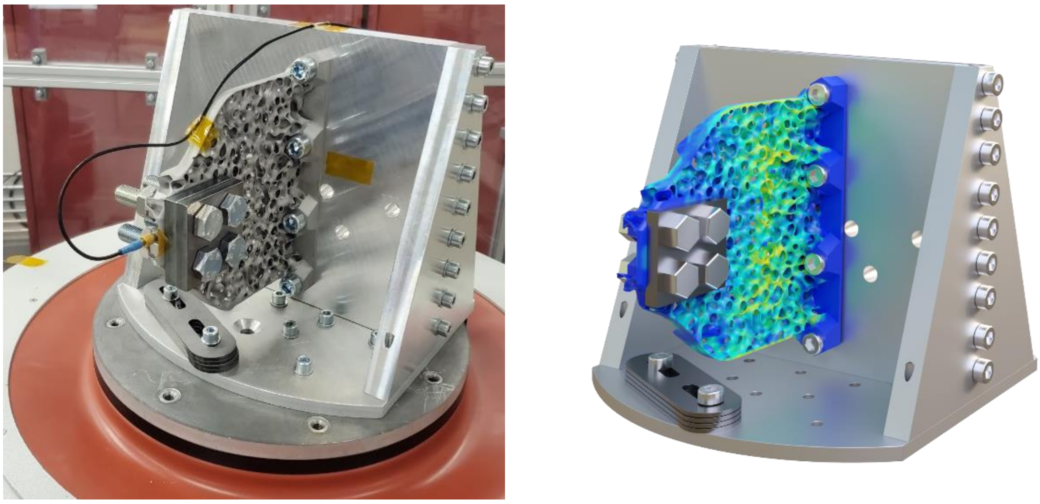

Figure 9 (left) Bracket During Vibration Testing (right) simulated vibration response

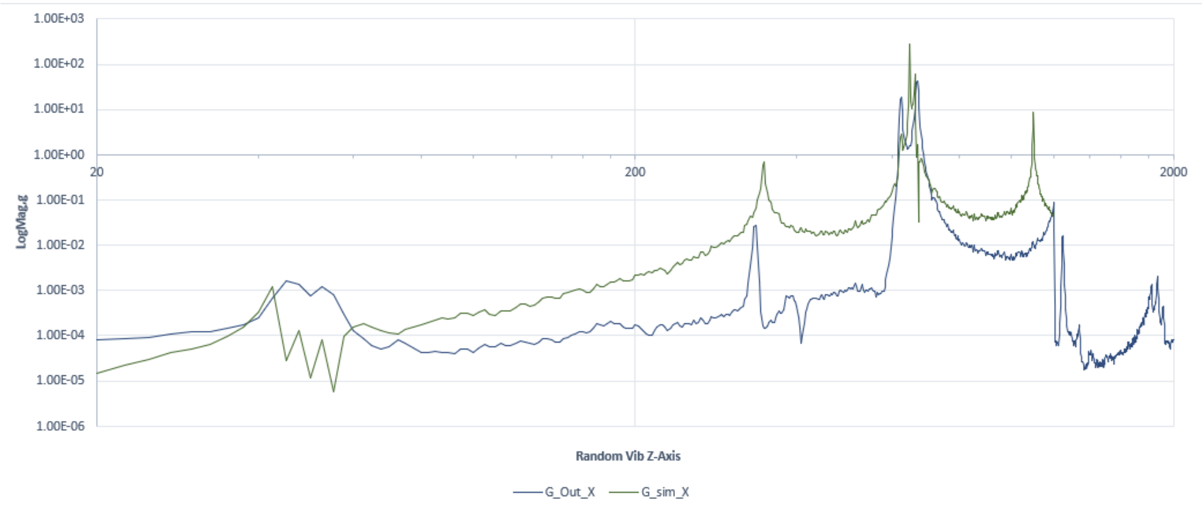

Figure 8: Frequency Response to the Excitation in Z Axis of the Simulation (Green Line) and the Measured Data during Testing (Blue Line)

Conclusion and Outlook

Spherene could show that the development of its software for the intuitive and powerful toolset matured to a point, at which the created geometries can be used with confidence.

Furthermore, Spherene proved the capabilities to validate those geometries in Software as well as on empirical data through manufacturing and testing of the components.

For future projects, the load cases could be even more complex with a higher amount of integrated components. This would allow unleashing even more capabilities of the ADMS toolchain and increase the potential benefits in light-weighting and use of more of the inherent properties of Minimal Surfaces. Topics that might be included could be Heat Exchanger, vibroaccoustics and Damping, toroidal Tanks, and anisotropic behavior while always maintaining high structural rigidity.

Such complex load cases combined with always guaranteed good manufacturing properties could make ADMS Technology an interesting candidate for many future cooperations with the Space Industry.

Figure 10 Spherene demonstration object with dynamic growth to boundaries and support free printability in various Materials