Optimization Driven Design and Additive Manufacturing Applied for ESA Sentinel-1 Antenna Bracket

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Warwickshire, June 16th 2015

Why are companies looking to AM?

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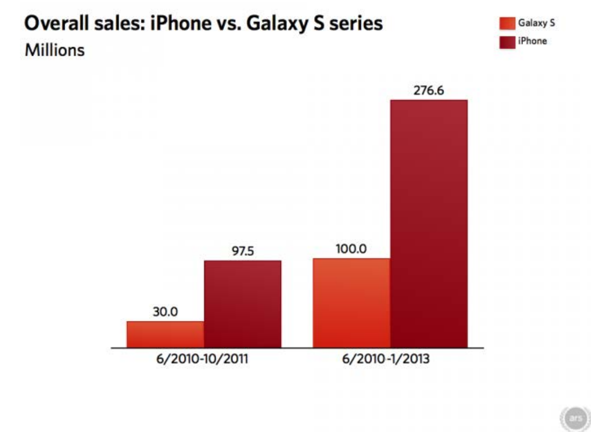
- **Today's market challenges:**
  - Lightweight eco/bionic-design
  - Cost reduction
    - Development
    - Manufacturing Process
    - Material
    - Supply chain
    - etc...
  - Design brings added value



GE quotes:

"By 2020 GE Aviation will manufacture more than 100,000 additive parts for the leap in GE9X engines."

"In the next 5 years we will invest more than 3.5 billion US$ in new equipment to produce advanced components."

"Complexity comes for free"

"Additive manufacturing is just a great game changer!"

Lockheed Martin Testing 3-D-Printed Subsystems On A2100 Space Bus

"My goal is to have over 50% of the structures 3-D-printed within two to three years,"

Richard Ambrose, executive vice president of Denver-based Lockheed Martin Space Systems
Jul 24, 2014
Lockheed Martin Testing 3-D-Printed Subsystems On A2100 Space Bus | AWIN ONLY content from Aviation Week

Where are we today?

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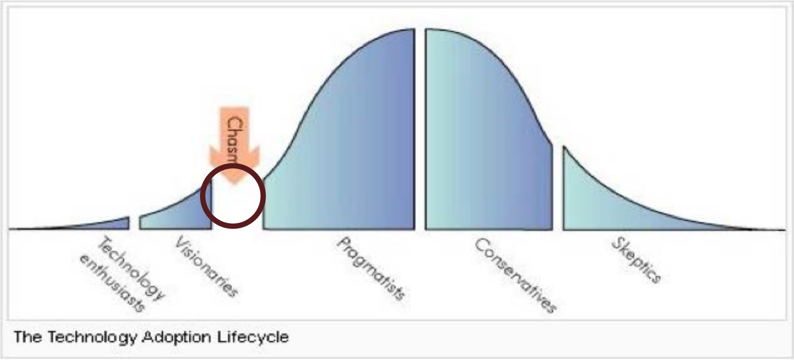
- **Industrial Revolution?**
  - Maker Movement
  - Rapid Prototyping
  - Manufacturing
- **Is it just for Freaks? Is it Over-hyped?**

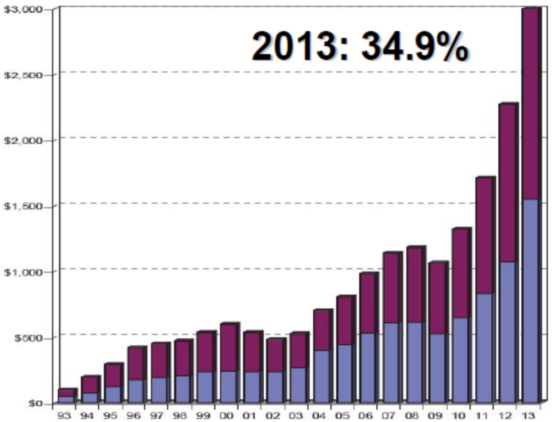
Desktop (home) printers: YES

Industrial Applications: NO



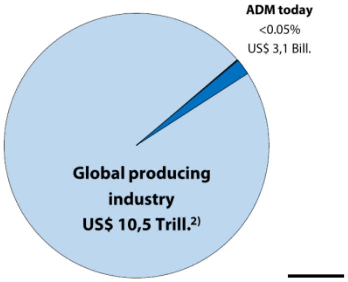
The Technology Adoption Lifecycle

- **$3.07B**
- **Nearly tripled in the past 4 years**
- **2014: $4B+**



Source: Wohlers Report 2014

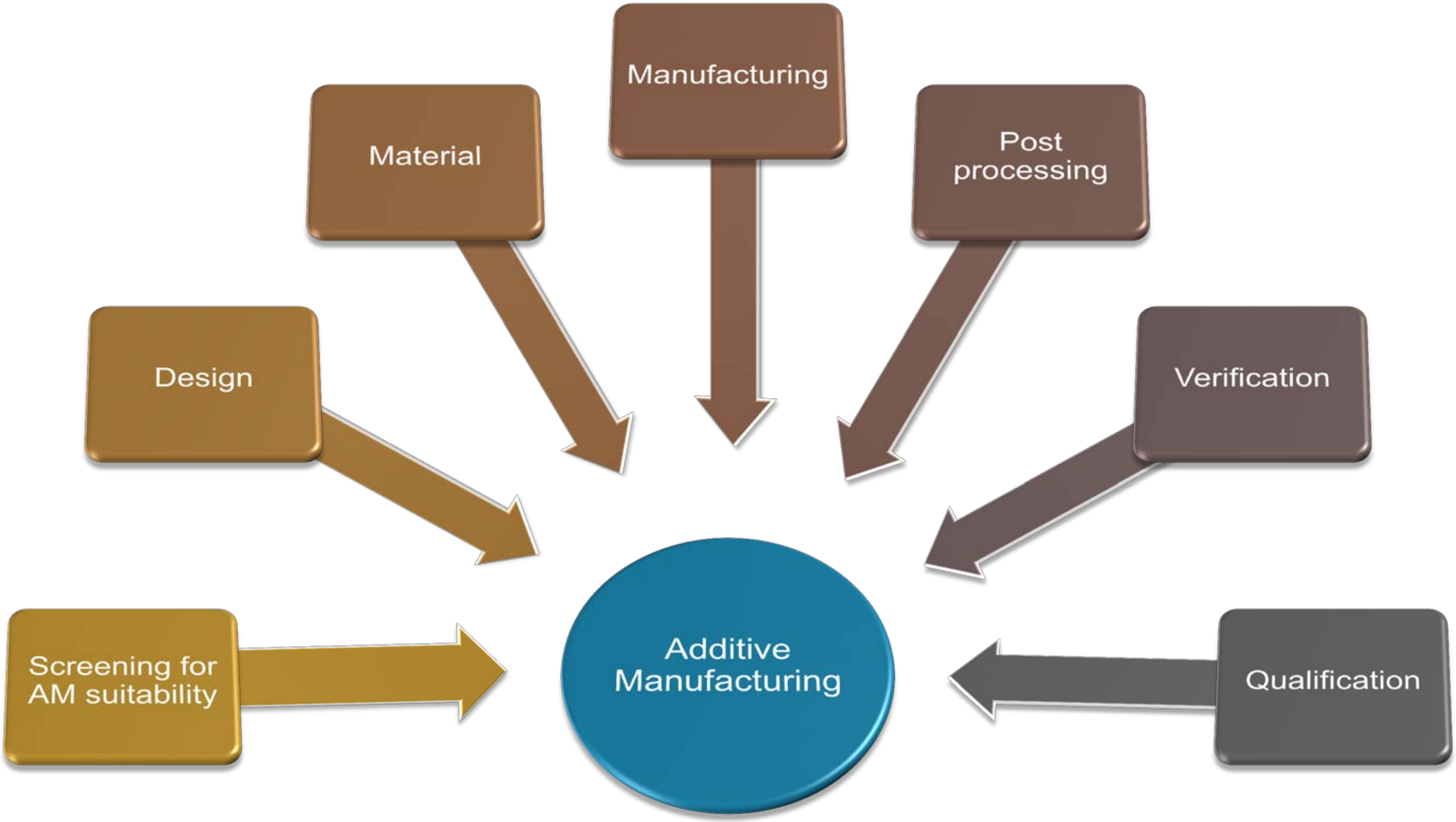
- **Growth Potential:**
- **Global manufacturing: $10.5 trillion**



How to get on this train?

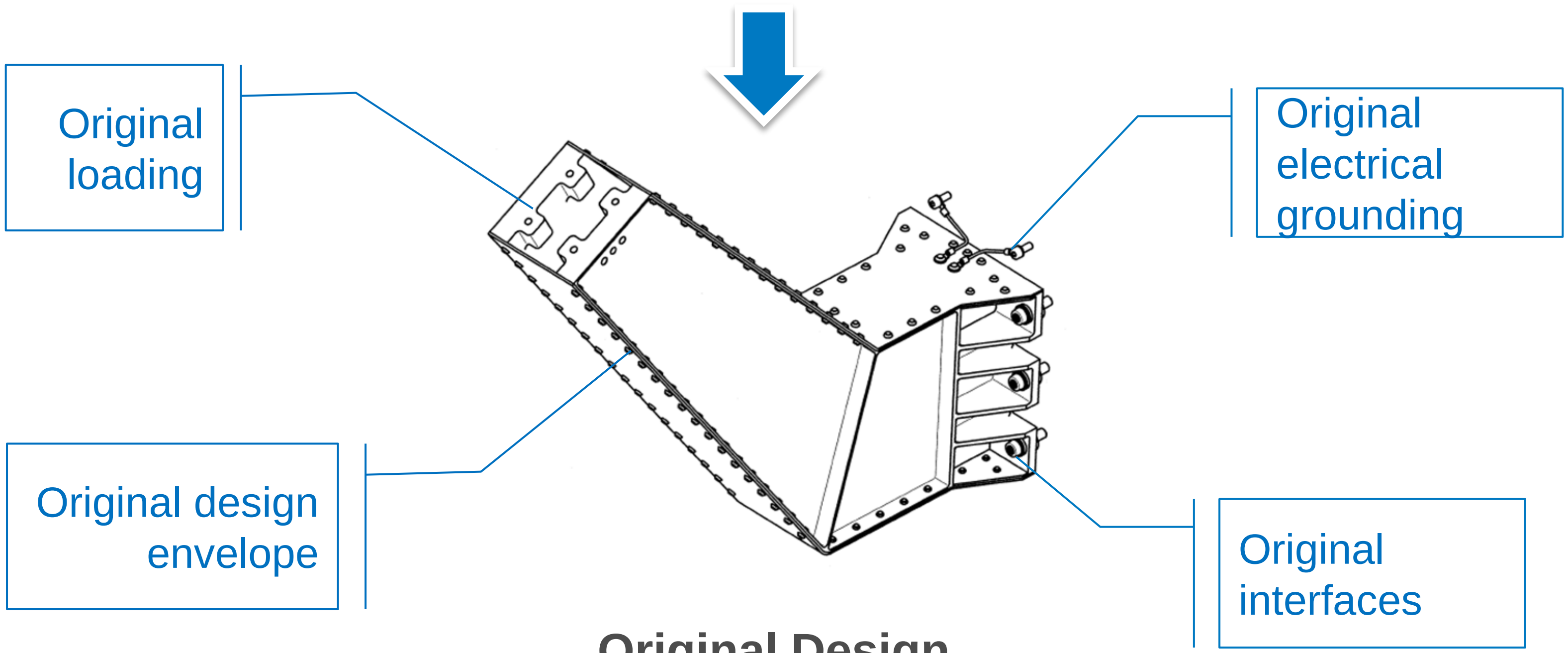
How to embrace this technology?

What does AM mean?



Sentinel-1 Antenna Support Bracket

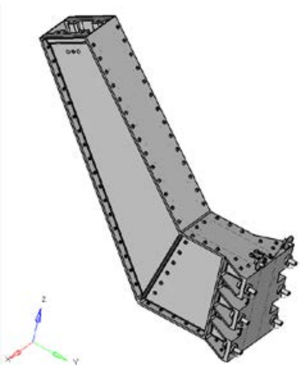
The challenge

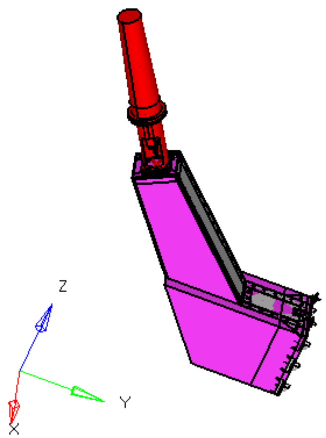


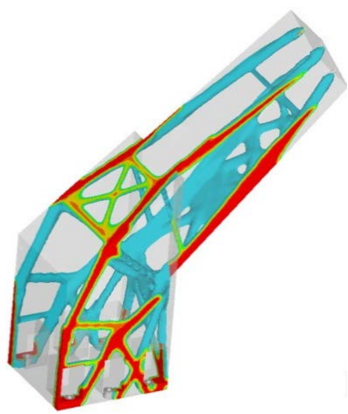
Original Design
Mass = 1.6kg
1st eigenmode = 88.7Hz
Peak stress = 163MPa

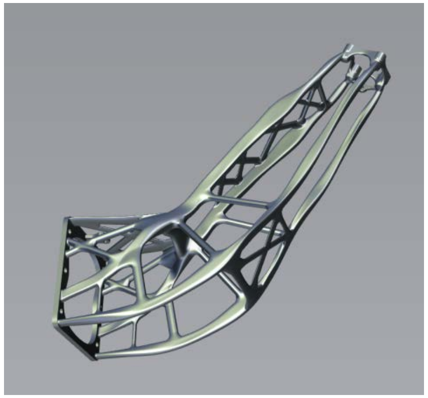
Designing for AM

- **Multi-step design process driven by optimisation, taking the advantages from Additive Manufacturing, but also knowing the limitations.**









Model Preparation → **Conceptual Optimisation** → **Concept Interpretation** → **Concept Design** → **Detailed Optimisation** → **Stress Verification** → **Additive Manufacture**

Model preparation

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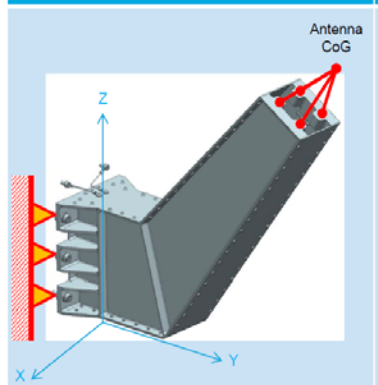
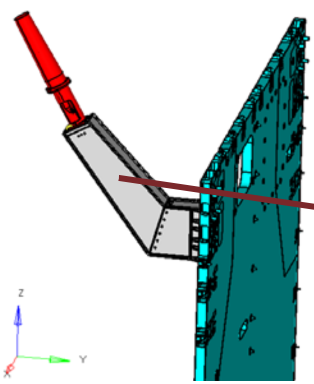
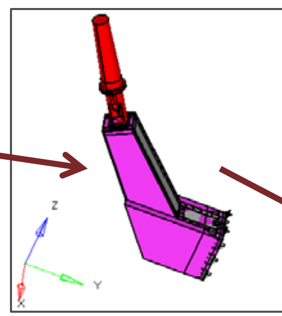
Model Preparation → Conceptual Optimisation → Concept Interpretation → Concept Design → Detailed Optimisation → Stress Verification → Additive Manufacture

- **Understand where to start**
- **Generation of Design Space**
- **Multiple load case creation and handling**

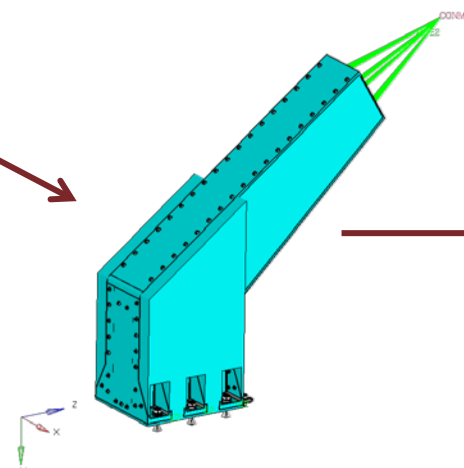
Original Design	Specification	
	▪ Eigenfrequency	> 70Hz
	▪ Boundary condition	Hard Mounted
	▪ Dimensions	385 x 345 x 115 mm3
	▪ Static Load (QL)	20g (X,Y) / 25g (Z)
	▪ S-Band Antenna	0.783kg
	▪ CoG Position	X = 436.2mm Y = -1091.8mm Z = 3330.6mm



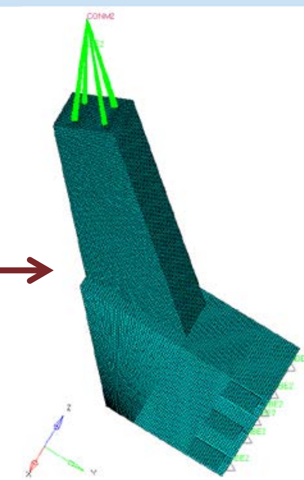
Baseline



Design Space Envelope



Design Space

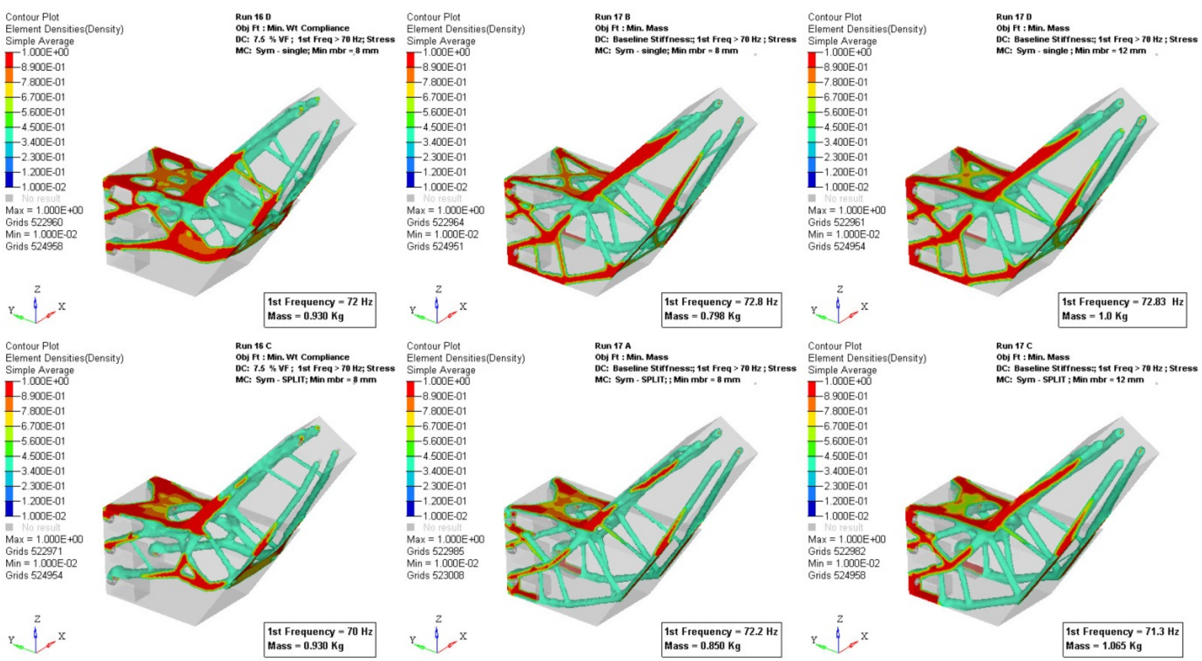


Hexahedral Elements
Total Elements = 236004

Conceptual Optimisation

Model Preparation → **Conceptual Optimisation** → Concept Interpretation → Concept Design → Detailed Optimisation → Stress Verification → Additive Manufacture

- **Optimisation problem formulation:**
  - Objective: Minimize Mass OR Compliance
  - Constraints: Volfrac 20%, 10% 7.5% / Stress (110MPa) / 1^{st} mode > 70 Hz
  - Variables: Element densities



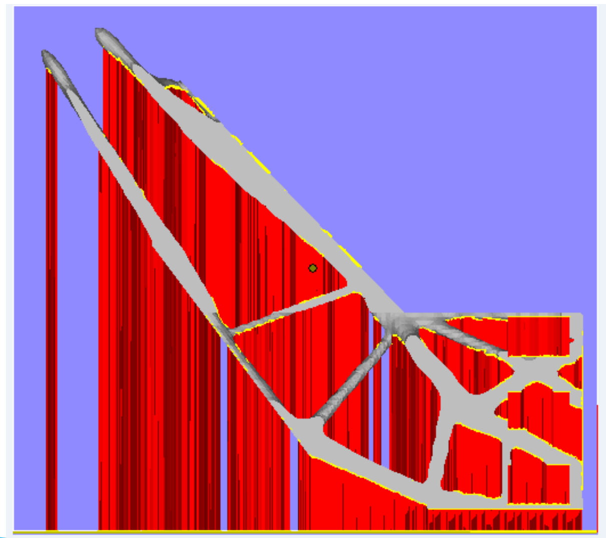
Goals of multiple runs:

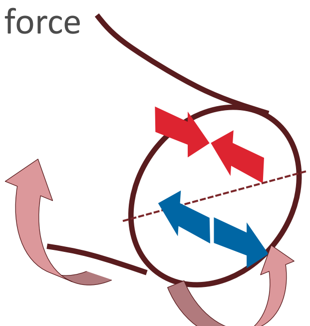
1. Understand tendency of the optimisation
2. Which are the primary and secondary load paths
3. Numerical noise?
4. Explore different designs
5. Observe similarities

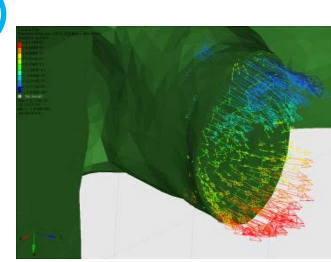
Conceptual Design

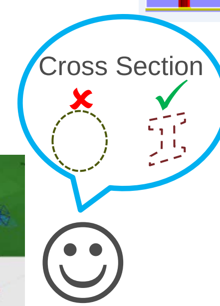
Model Preparation → Conceptual Optimisation → **Concept Interpretation** → Concept Design → Detailed Optimisation → Stress Verification → Additive Manufacture

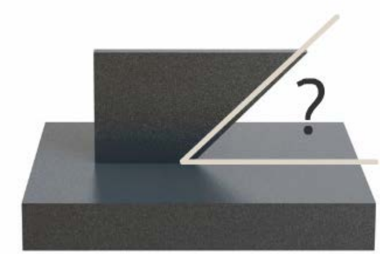
- **Obtained topology must be realized into a proper CAD design**
- **Apply design principles and interpret results**
  - Understand results from optimization
  - Cross sections geometries depending on structural behavior
  - Apply design principles to generate an organic design
- **Understand and apply design principles and limitations from AM**
  - Overall architecture of support structure (slicing with Magics, Cura, Repetier, etc)
  - Overhang angle consideration
  - Heat dissipation and stress concentration
  - Post processing consideration
  - Recoater force







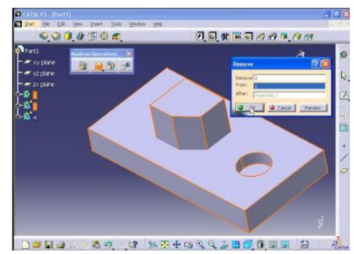


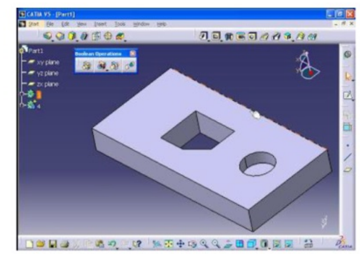


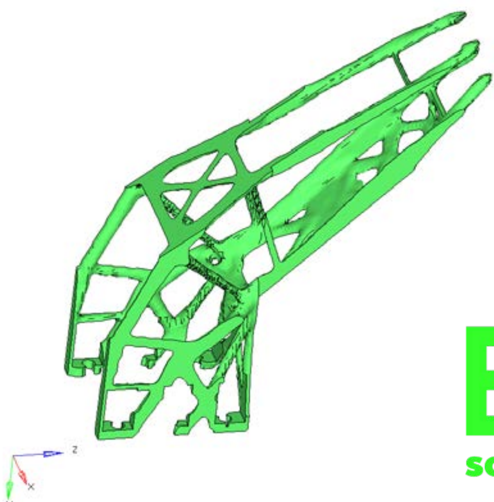
Conceptual Design

Model Preparation → Conceptual Optimisation → Concept Interpretation → **Concept Design** → Detailed Optimisation → Stress Verification → Additive Manufacture

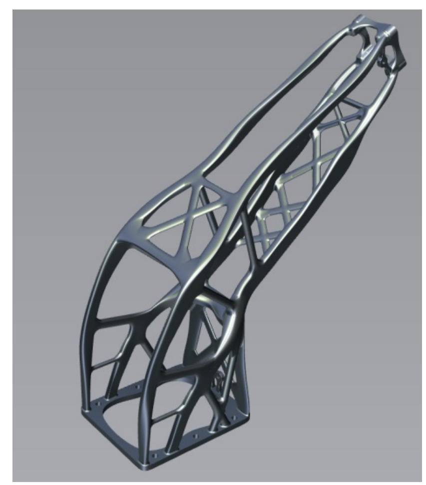
- **Traditional CAD tools modelling approach is limited and time consuming.**
- **High level of freedom is required.**
- **Hybrid modelling tools**
  - Boolean approach
  - NURBS surface modelling
  - PolyNURBS







EVOLVE
solidThinking®

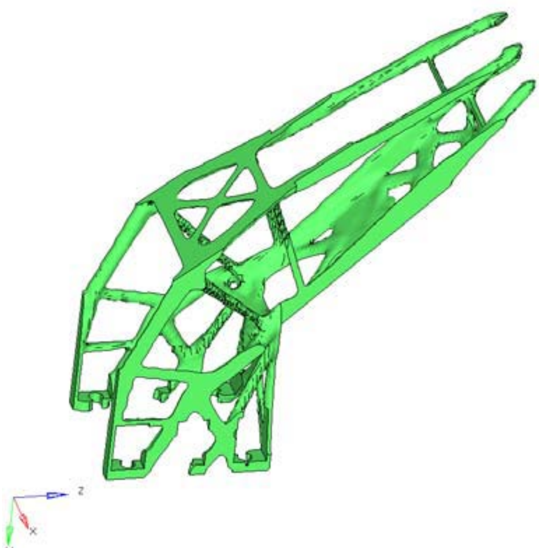


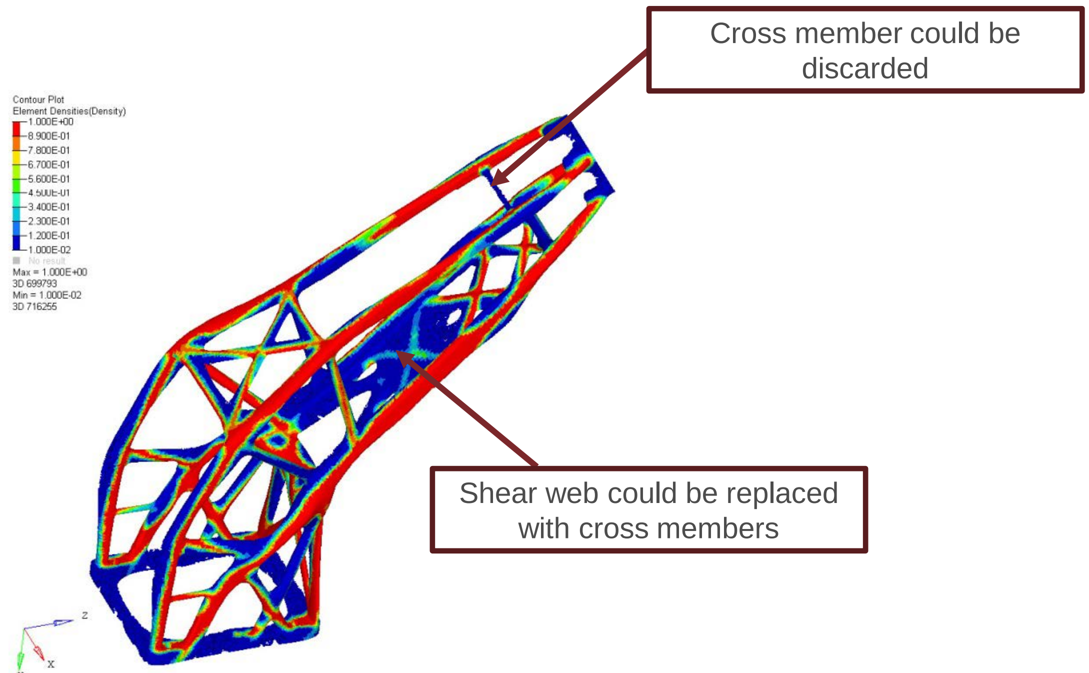
Standard formats:
- ⇨ Parasolid
- ⇨ STEP
- ⇨ IGES

Detailed Optimisation

Model Preparation → Conceptual Optimisation → Concept Interpretation → Concept Design → **Detailed Optimisation** → Stress Verification → Additive Manufacture

- **Secondary Topology iterations are carried out to evaluate and tweak the interpreted model from Loop 1.**
- **Findings from Loop 2 topology iterations to be implemented in the new CAD**





Detailed Optimisation

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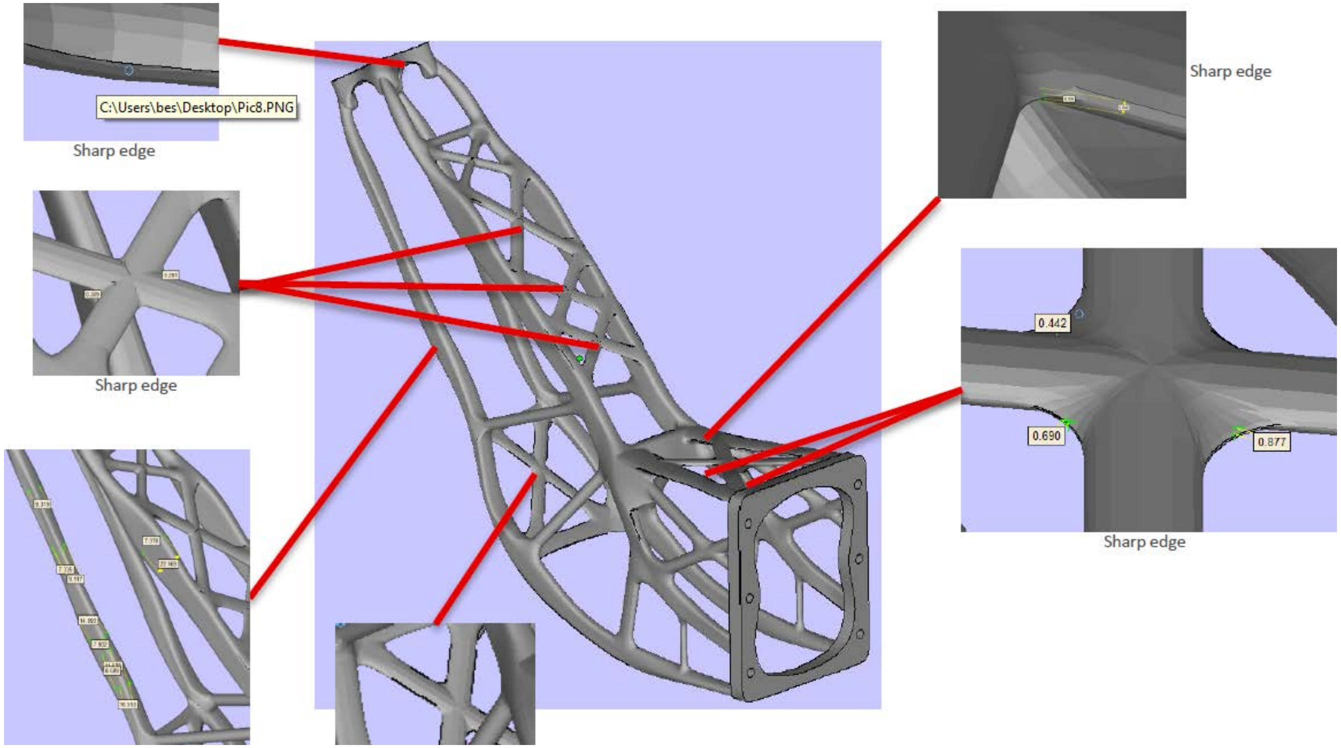
Model Preparation | Conceptual Optimisation | Concept Interpretation | Concept Design | **Detailed Optimisation** | Stress Verification | Additive Manufacture

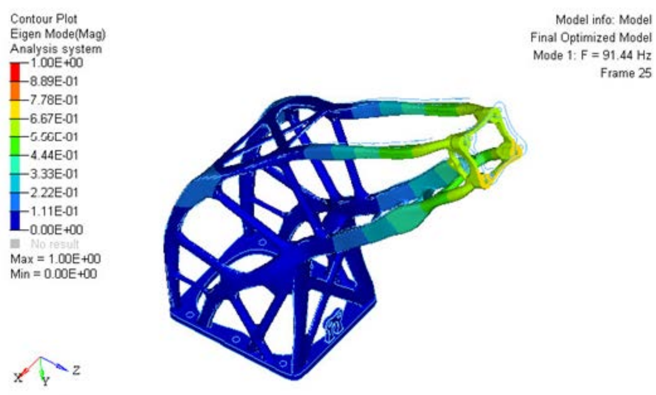
- **Detailed tuning for manufacturing.**
- **Overhang angle minimisation.**
- **Cross section optimisation for AM.**



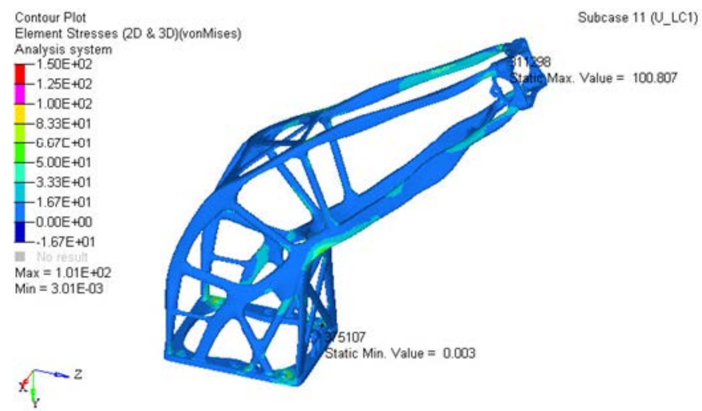
Final Optimised CAD Model:

Model Preparation | Conceptual Optimisation | Concept Interpretation | Concept Design | Detailed Optimisation | **Stress Verification** | Additive Manufacture

Second order mesh for precise results:



First Frequency in 91.44 Hz



Stress distribution is below 110 MPa

Loadcase Title	First Buckling LoadFactor
U_LC1	18.2
U_LC2	18.3
U_LC3	46.1
U_LC4	45.9
U_LC5	46.1
U_LC6	45.9
U_LC7	18.2
U_LC8	18.3

The buckling loadfactors are all above 1.2

Result

4 weeks

Mass = 1.626 Kg
1st Eigen mode = 88.7 Hz
Peak Stress = 163 MPa

Mass = 0.936 Kg
1st Eigen mode = 91.44 Hz
Peak Stress = 103 MPa

Additive Manufacturing and Testing

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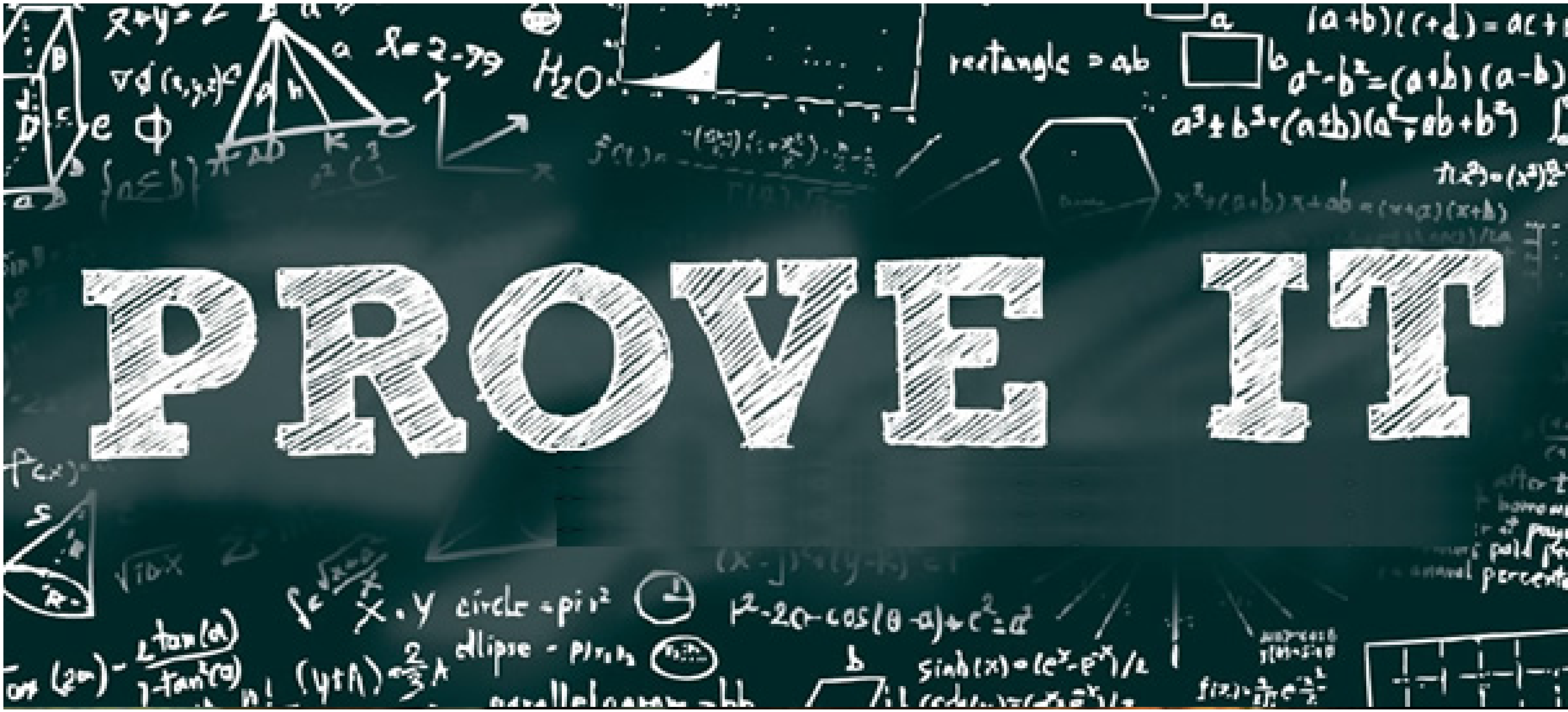
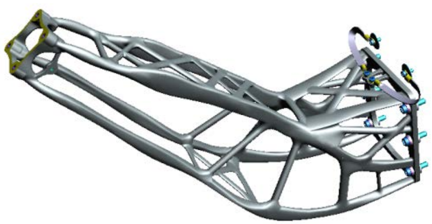
Model Preparation → Conceptual Optimisation → Concept Interpretation → Concept Design → Detailed Optimisation → Stress Verification → **Additive Manufacture**

- EOS M400 with AlSi10Mg alloy
- Surface finishing
- Support structure removal
- Interface machining for geometric tolerances


PROVE IT

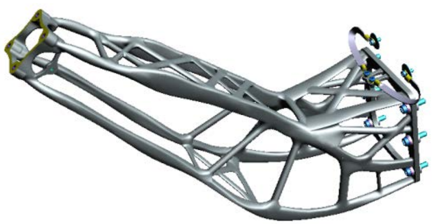
Model Philosophy

Qualification



- Geometrical verification
- Modal verification
- Quasi-static load test
- Sine vibration tests (3-dir.)
- Random vibration tests (3-dir.)
- Vibration Test

Flight

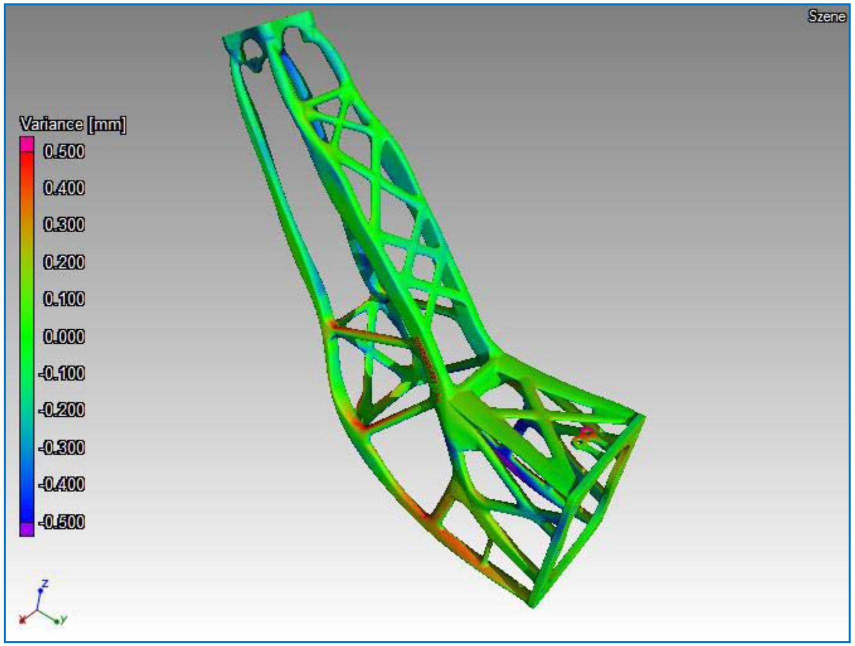


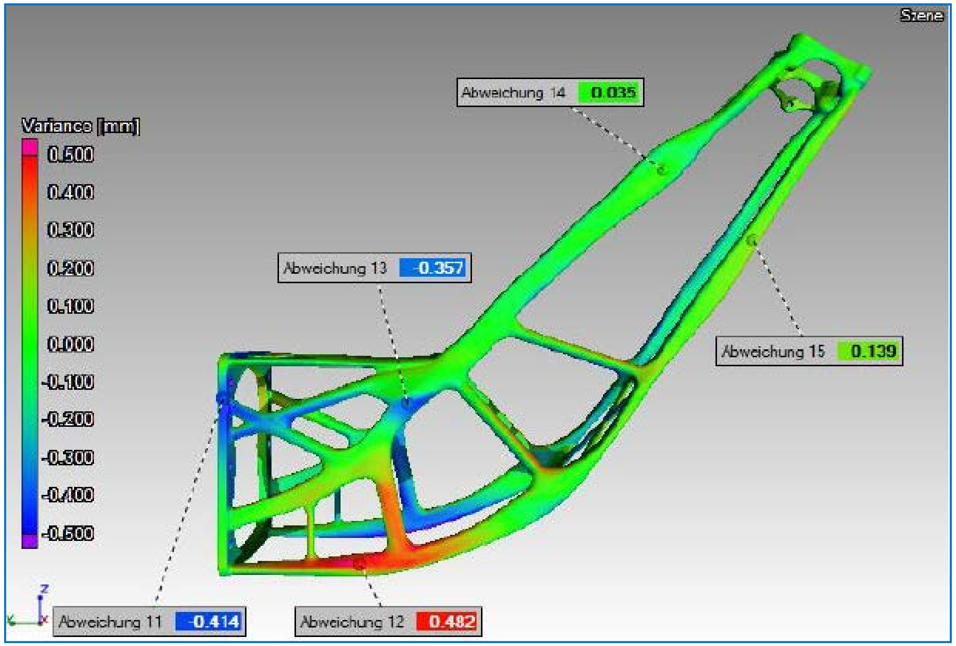
- Geometrical verification
- Modal verification
- Quasi-static load test

Together ahead. RUAG

Verification

- **Comparison of CAD model with physical model through Computer Tomography.**
- **Scan resolution of 320 μm**





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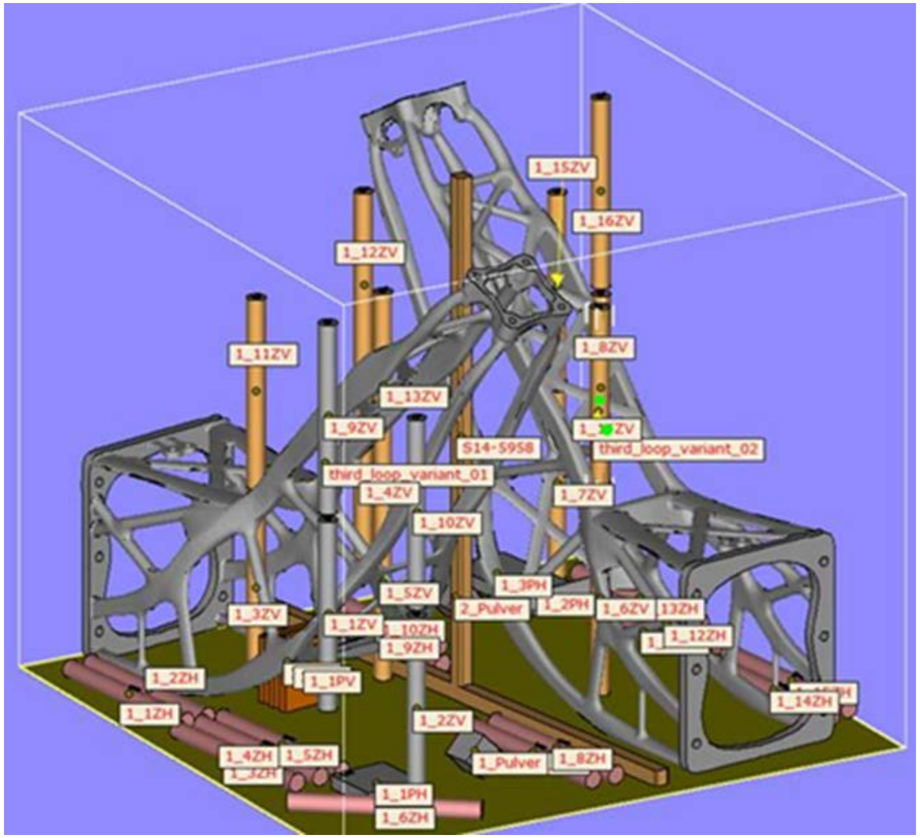
Verification

- **Test specimens printed in the same job to corroborate material properties.**



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Verification

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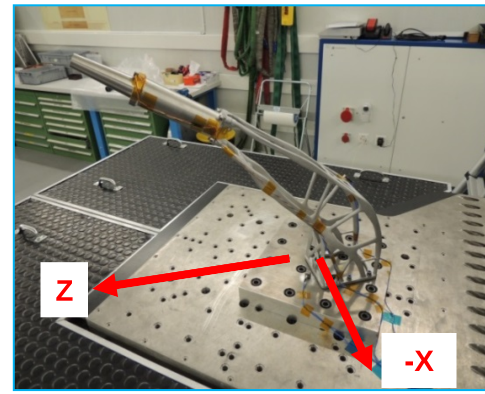
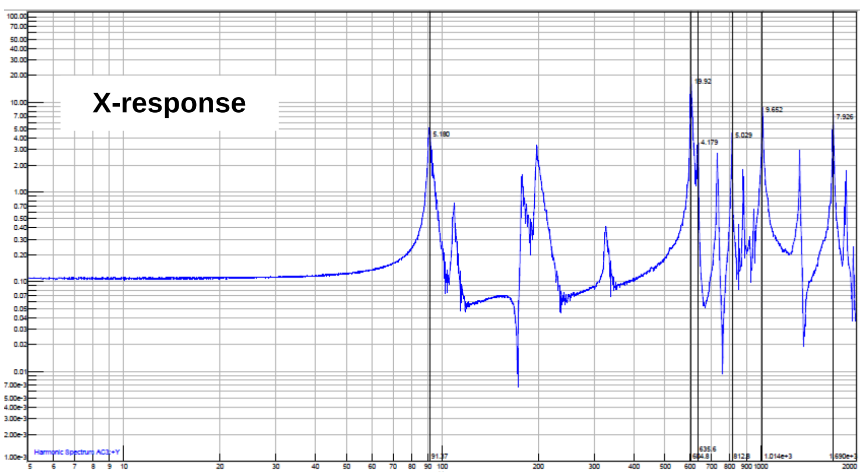
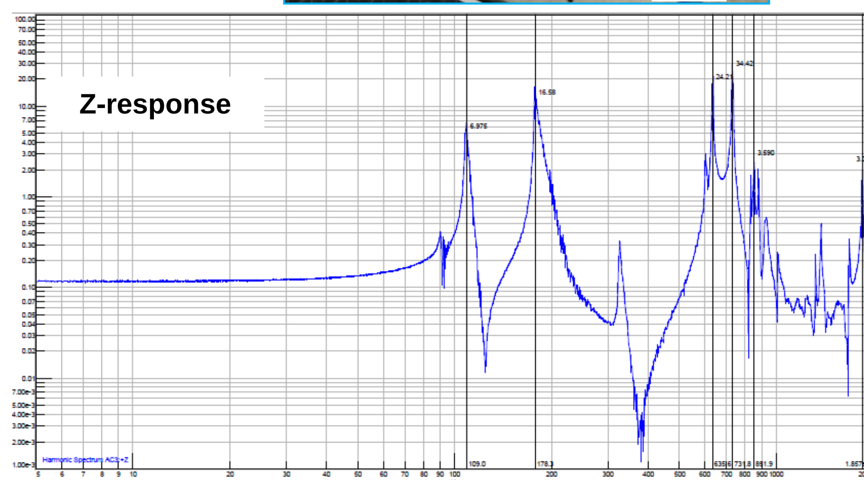
- **In-plane (XZ) low level sine sweep to verify the frequency requirement**

Frequency search spectrum			
Frequency [Hz]	Amplitude [g]	Speed [oct/min]	direction
5 to 2000	0.2	2	One sweep up

TEST RESULTS	Predicted (Optistruct)	Measured (Test)
1st Eigen frequency (X)	90.0 Hz	91.4 Hz
2nd Eigen frequency (Z)	106.9 Hz	109.0 Hz







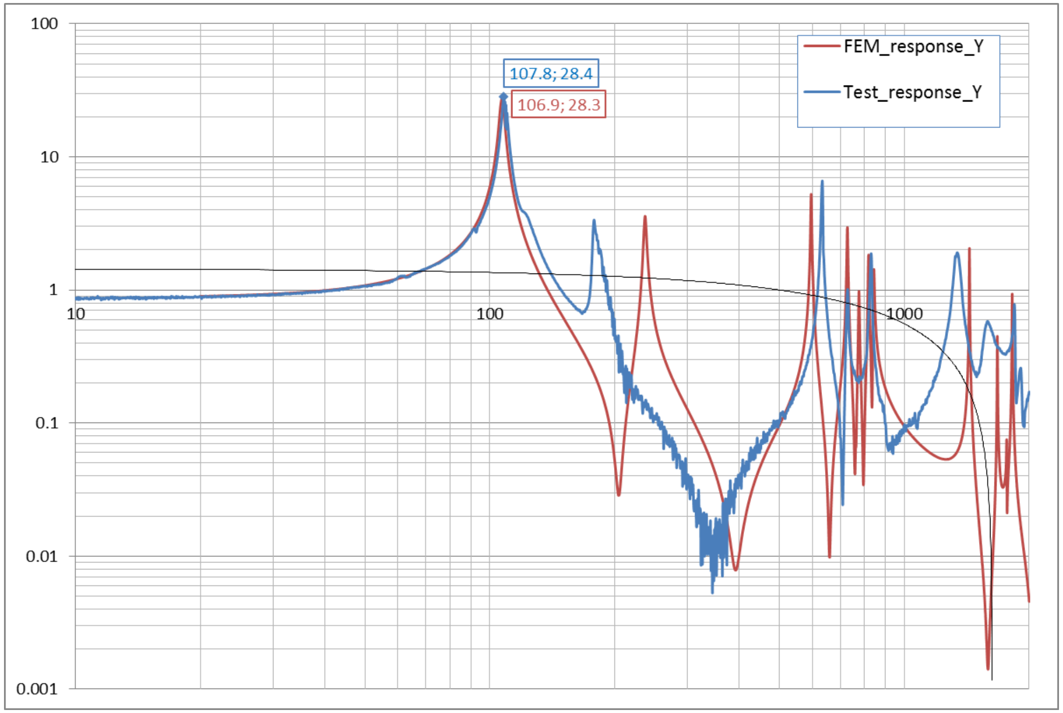
Together ahead. RUAG

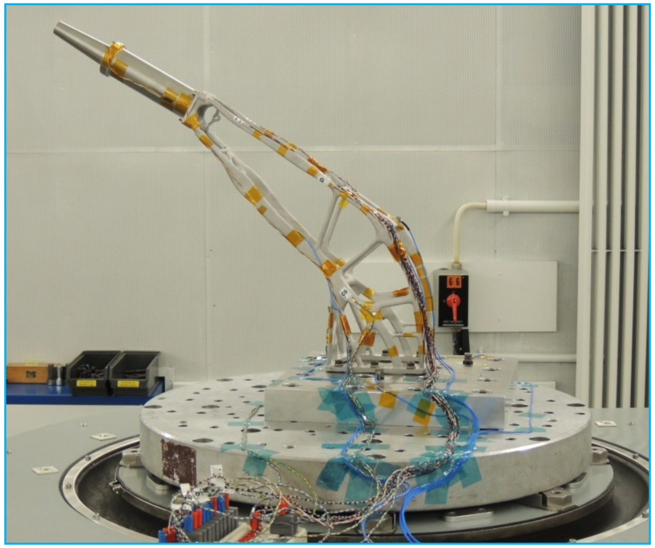
Verification

Altair

- **Out-of-plane (Y) low level sine sweep to verify frequency requirement**

TEST RESULTS	Predicted (Optistruct)	Measured (Test)
1st Eigen frequency	106.9 Hz	107.8 Hz





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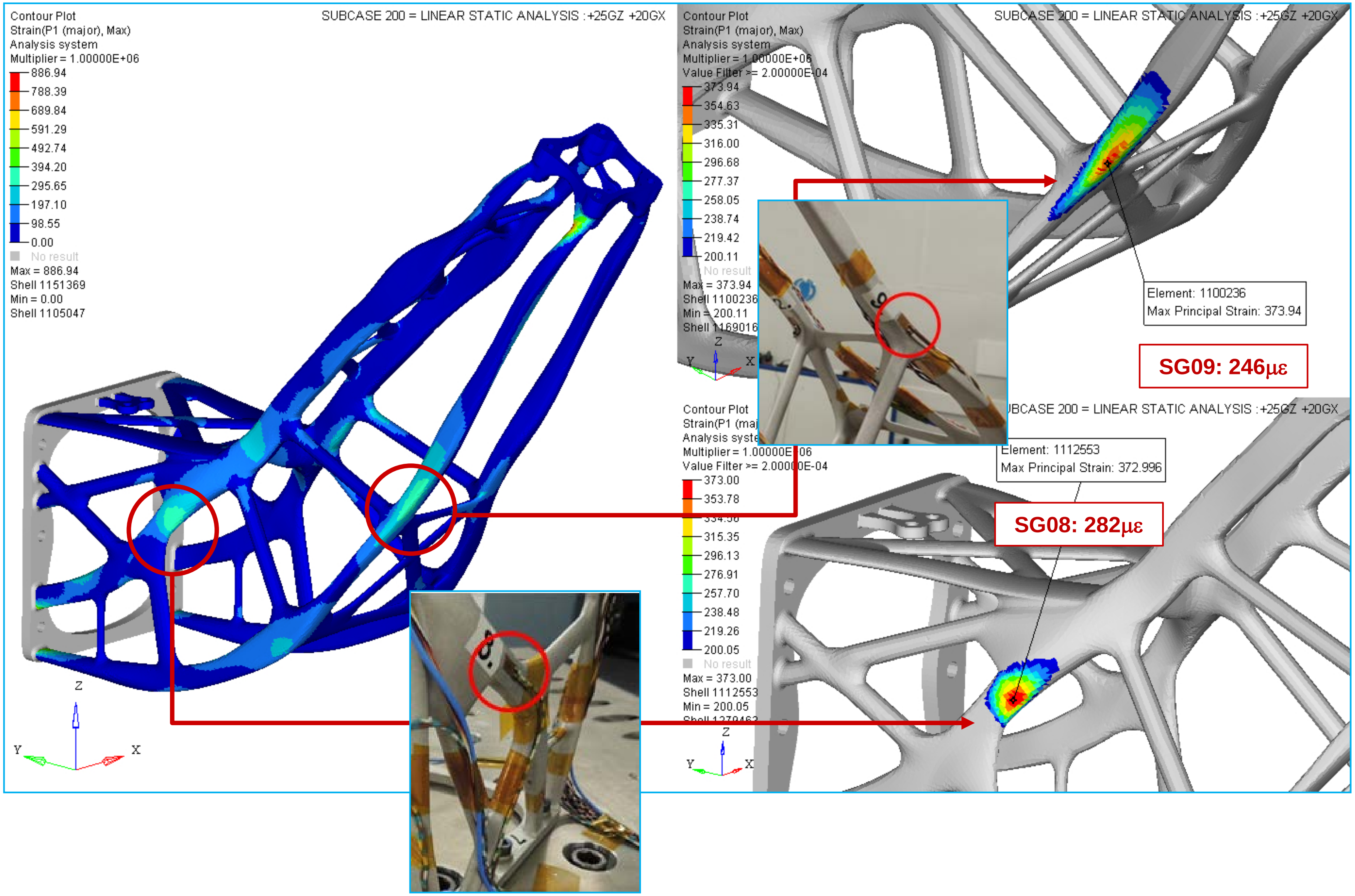
Qualification

- **Strength verification under static, sine and random loading**



Qualification

Additive Manufacturing Development Process

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Design

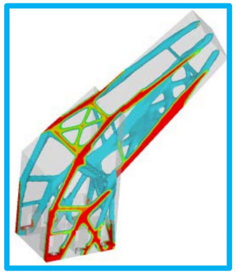
- Functional analysis
- Topology optimisation
- CAD Interpretation
- Size/Shape optimisation
- Detail stress analysis

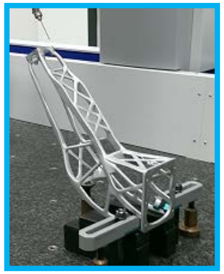
Manufacturing

- Optimisation
- Post-Processing
- Samples definition
- Process control

Verification / Testing

- Quality control
- Test definition
- Qualification testing
- Model correlation





Conclusion

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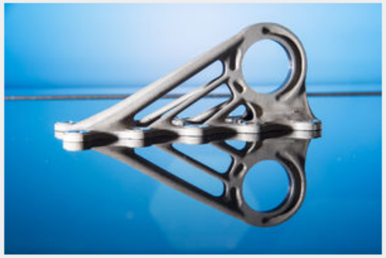
- **Altair technology is industry proven to provide the right solution.**
- **+20 year of development of OptiStruct**
- **+20 years of development of Evolve**
- **Best in class technology and software used as a seamless AM design tool.**
- **Experience and collaboration in the field of lightweight design and AM**

Courtesy of RUAG Space

Printing the future: Airbus expands its applications of the revolutionary additive layer manufacturing process



3 MARCH 2014 FEATURE STORY

Innovative 3D-printing (additive layer manufacturing) technology used by Airbus is beginning to shape the future of aircraft component manufacture for its jetliners.

Parts produced with this method are beginning to appear on a range of the company's aircraft – from the next-generation A350 XWB to in-service jetliners form the cornerstone A300/A310 Family. The 3D-printing results in lighter parts, with shorter lead times, fewer materials used during production and a significant reduction in the manufacturing process' environmental footprint.

"We are on the cusp of a step-change in weight reduction and efficiency – producing aircraft parts which weight 30 to 55 per cent less, while reducing raw material used by 90 per cent," said Peter Sander of the Airbus. "This game-changing technology also decreases total energy used in production by up to 90 percent compared to traditional methods."

Press Release Airbus March 2014

Questions

Appendix: Test campaign RUAG

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SENTINEL-1 Antenna Support Bracket

- **NDT** (Non Destructive Testing)
  - **CT -Testing** (Computer Tomography)
  - **Eddy Current Testing**
  - **CMM** (Coordinate Measure Machine)
- **Mechanical Testing** (Component Level)
  - **Thermal Cycling**
  - **Quasi-Static Testing**
  - **Low Level Sine**
  - **High Level Sine**
  - **Random Spectrum**
  - **Rupture Testing**
- **Mechanical Testing** (Coupon Level)
  - **Tensile Testing**
  - **Fatigue Testing**
  - **Fracture Toughness** (K1C)
  - **Hardness**
  - **Creeping**
- **Physical Testing** (Coupon Level)
  - **SCC** (Stress Corrosion Cracking)
  - **Surface Corrosion** (Neutral Salt Spray Test)
  - **SEM** (scanning electron microscope)
  - **Micro Sectioning** (incl. Metallography)