



Entwicklungsprozess für die Industrialisierung der
additiven Fertigung
Technologiesymbiose
Topologieoptimierung & 3D Druck

28.04.2016, Mirko Bromberger



Key questions of the Industry:

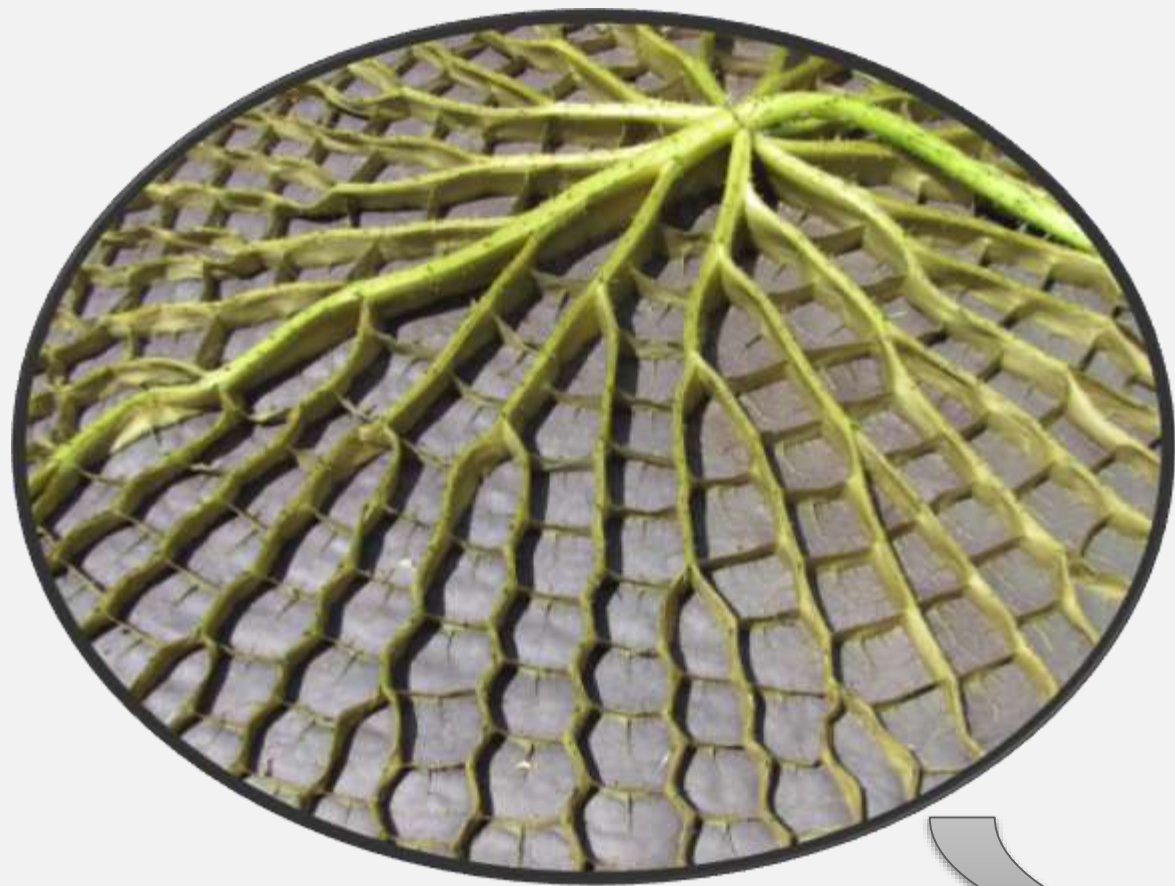
Where is Additive Manufacturing suitable?

Where is it feasible to apply?

How to create an Added Value?



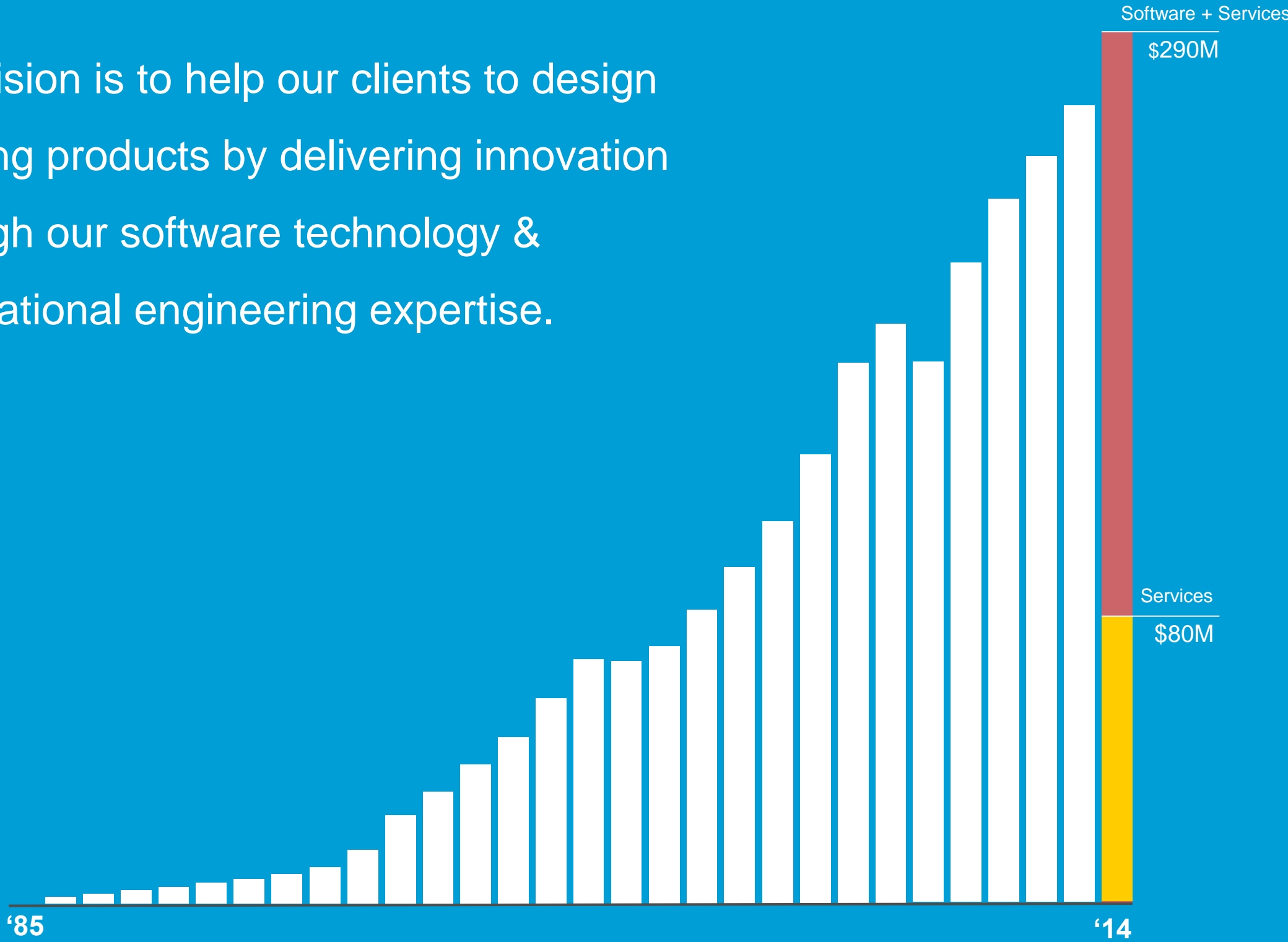
How to apply Bio principles in an Industrial application?



How to unlock the True Potential of Additive Manufacturing?

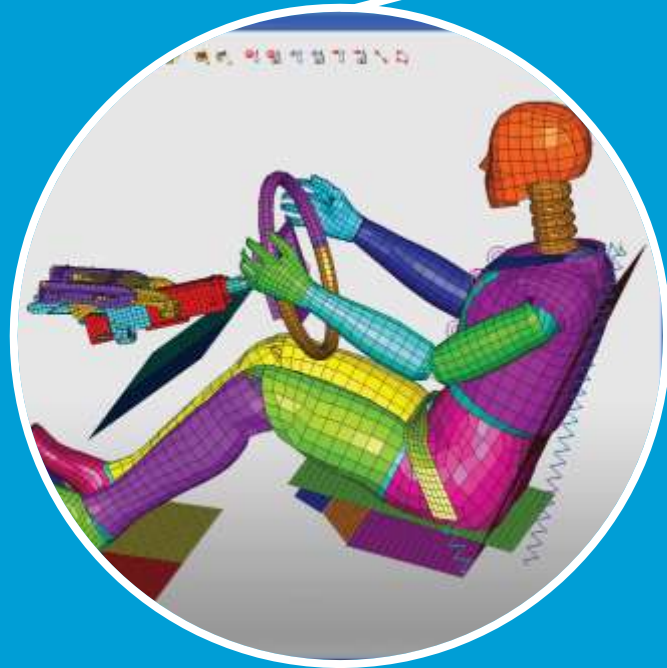


Our vision is to help our clients to design exciting products by delivering innovation through our software technology & international engineering expertise.



Altair

Business Units



HyperWorks

Industry's broadest integrated Simulation Software Suite (Model Builders, Solvers, Optimisers Visualization)



solidThinking

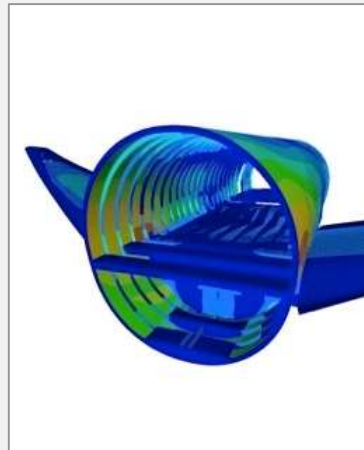
solidThinking **Inspire** enables Product Designers to quickly create and investigate structurally efficient concepts



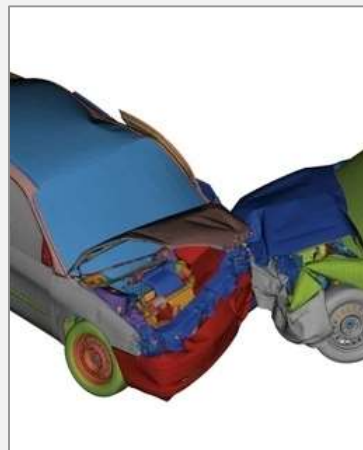
ProductDesign

A global engineering and design business delivering innovation to our clients

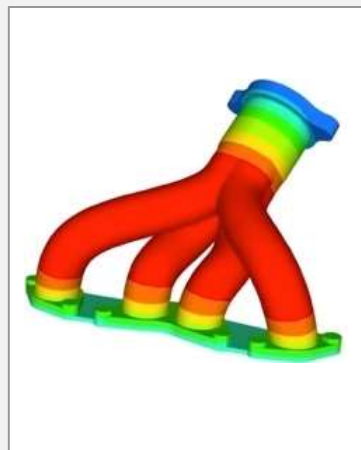
Who is Altair - solver technology



Structural
Analysis



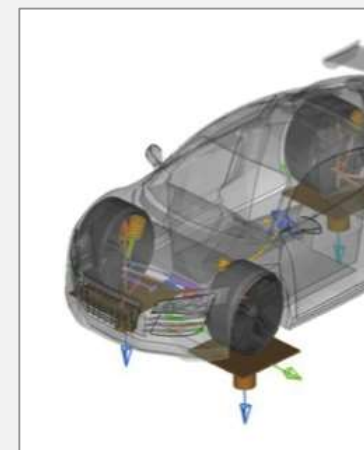
Crash, Safety,
Impact & Blast



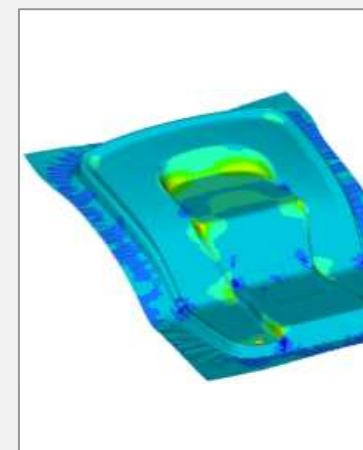
Thermal
Analysis



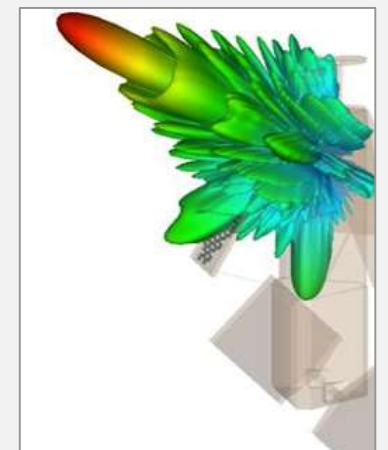
Fluid Dynamics



Systems
Simulation



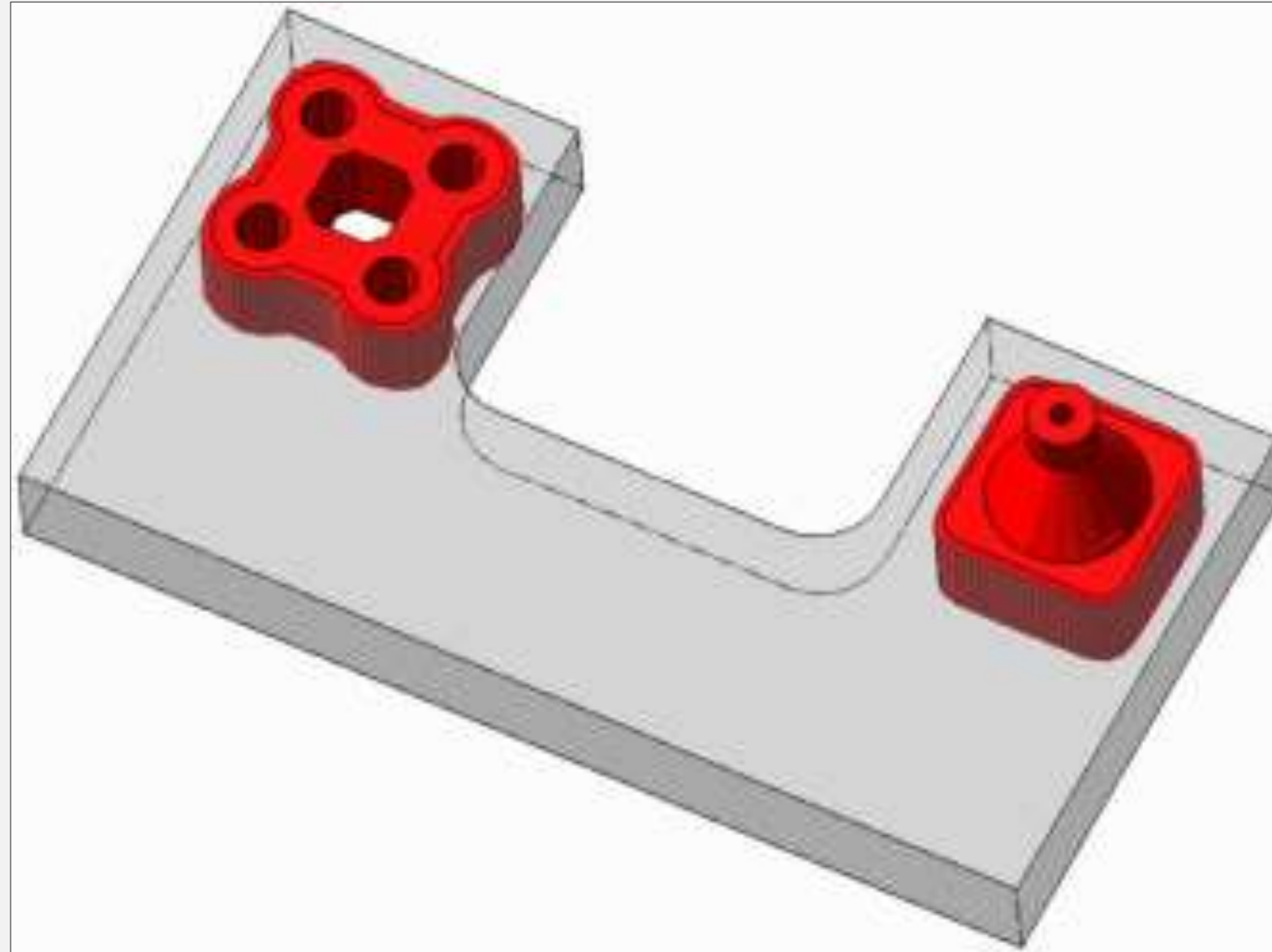
Manufacturing
Simulation



Electro-
Magnetics

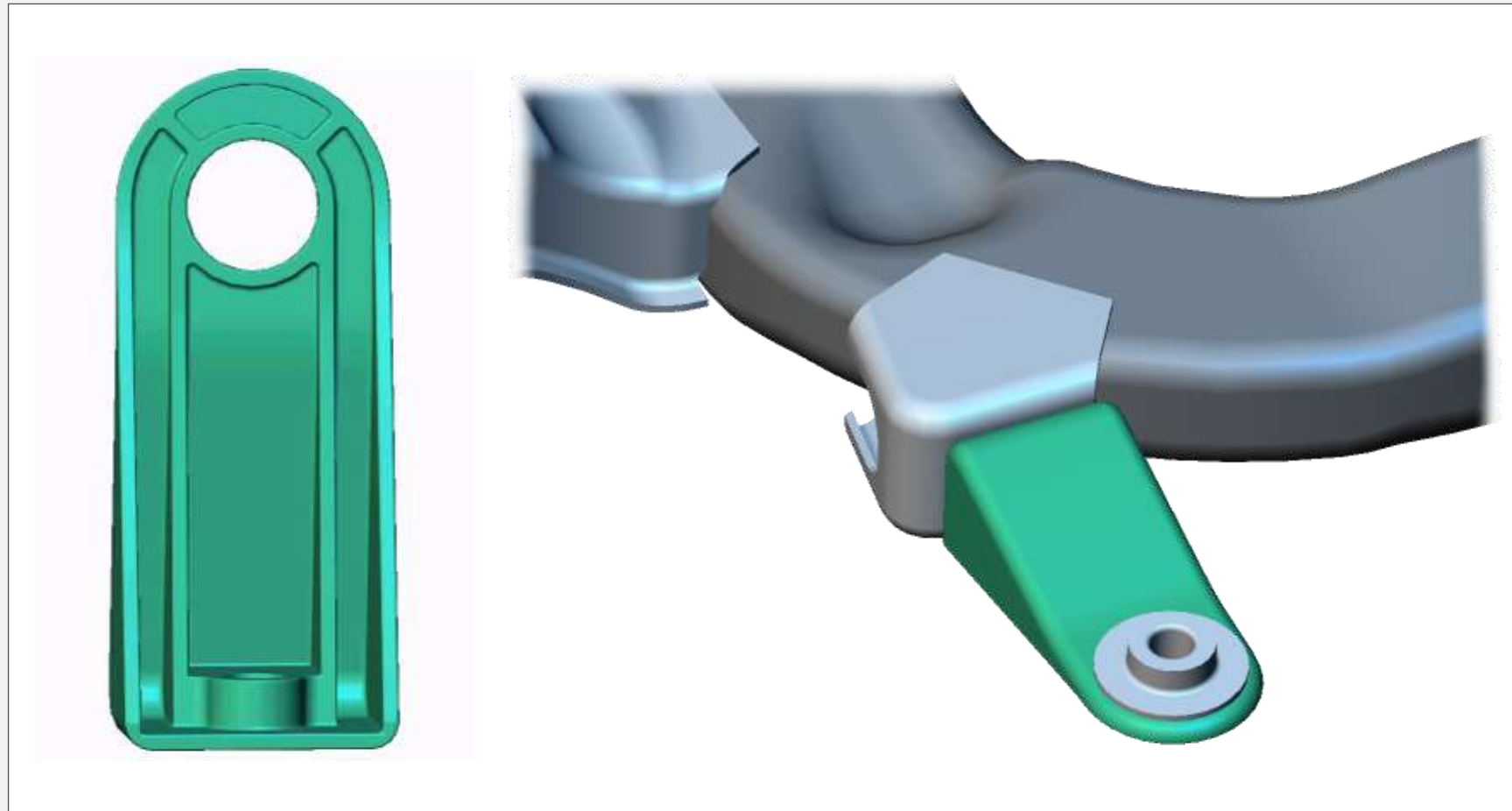
Multiphysics Analysis and Optimization

Intelligent Software Technology: “Free Form Optimization”



Free Form Optimization History

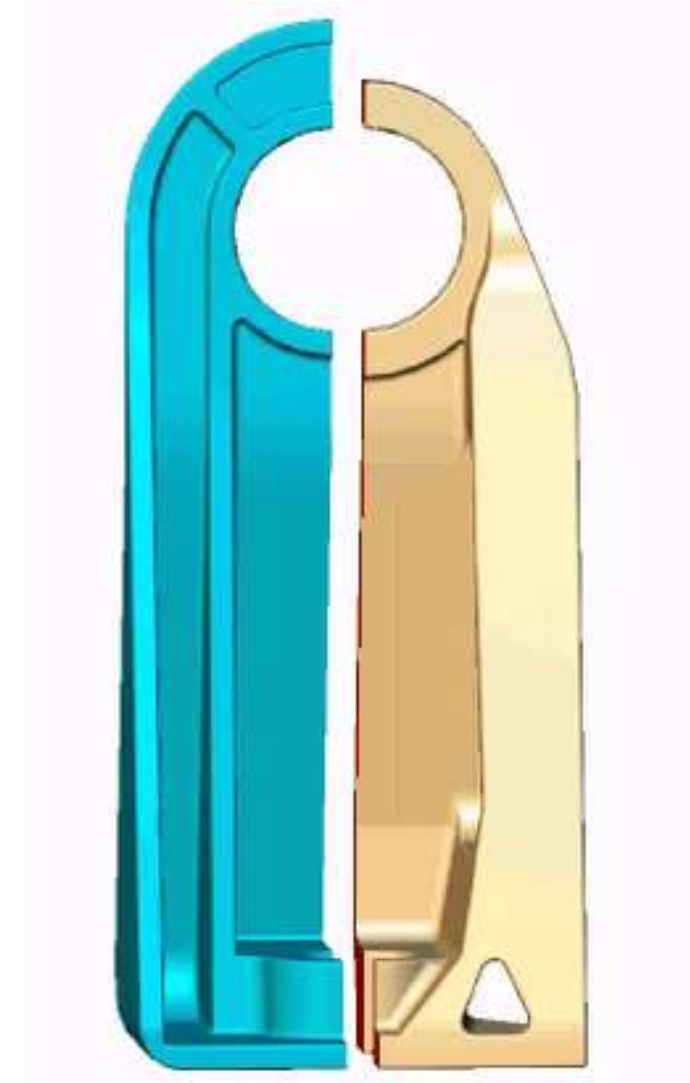
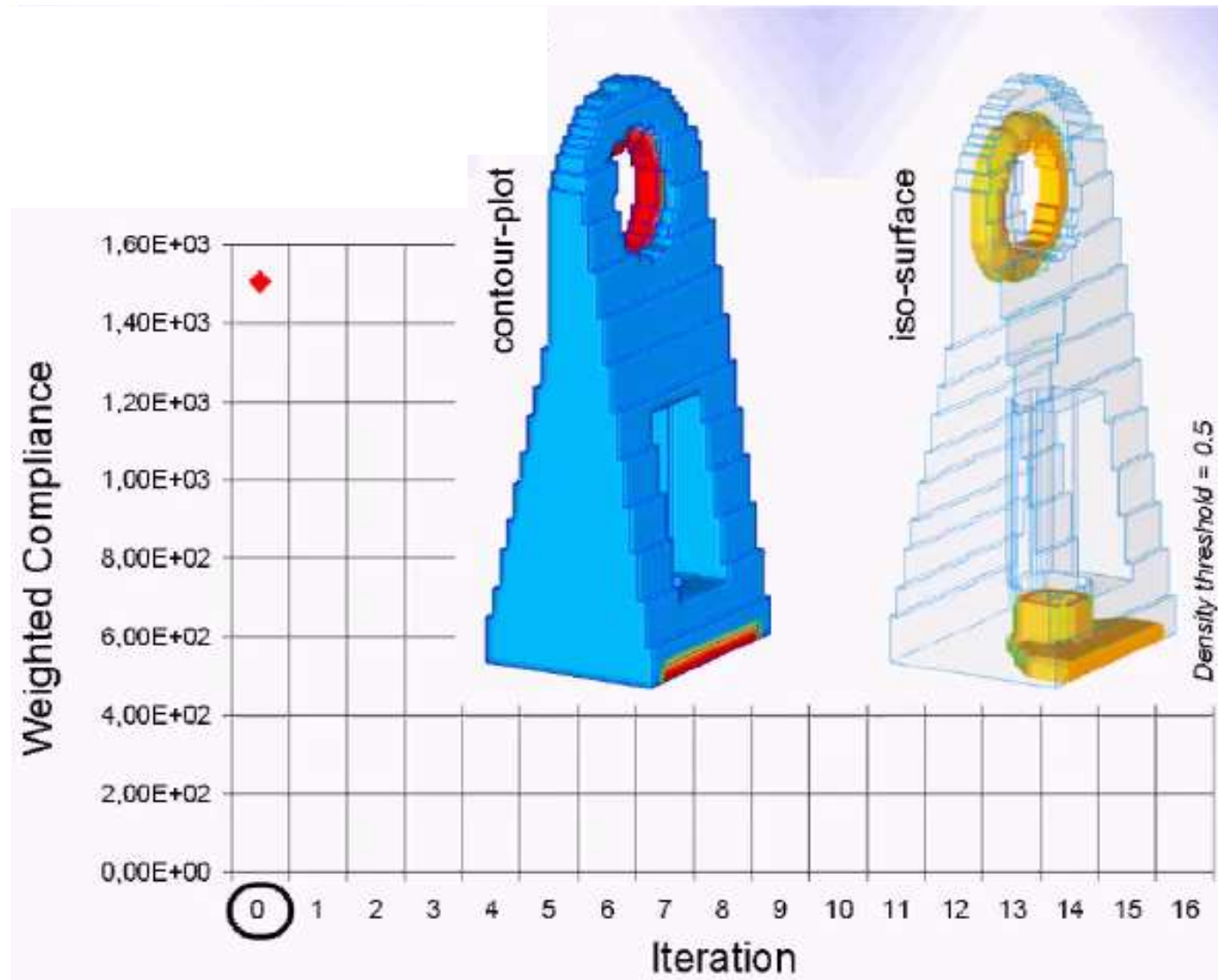
Radiator Bracket



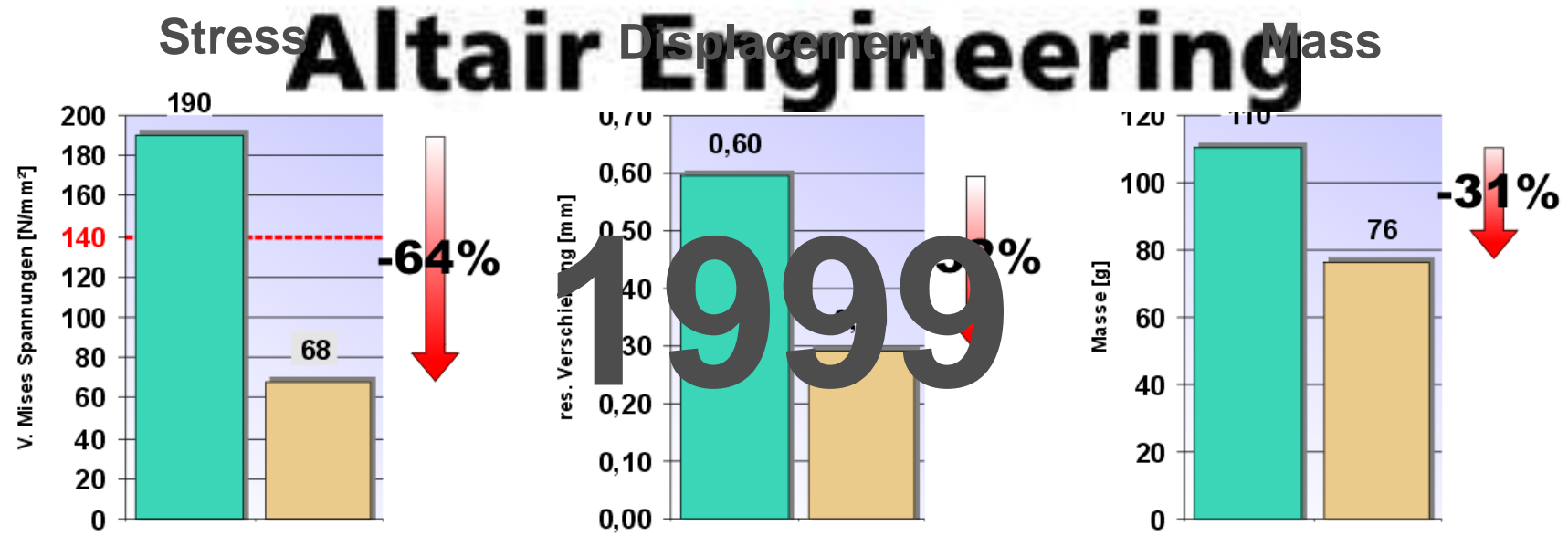
Original Bracket Failed

Redesign with Improved Performance / Weight

Radiator Bracket

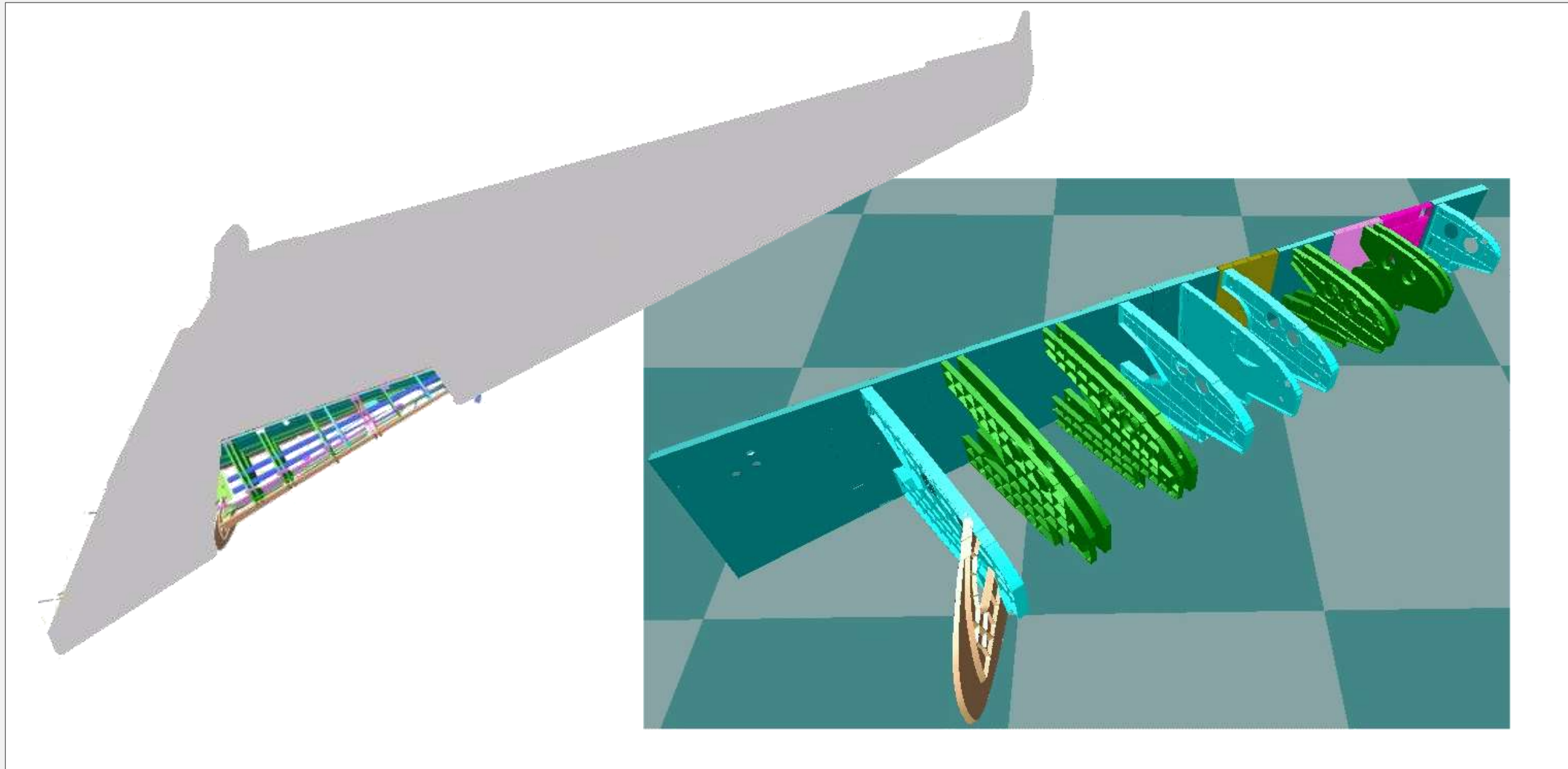


Radiator Bracket



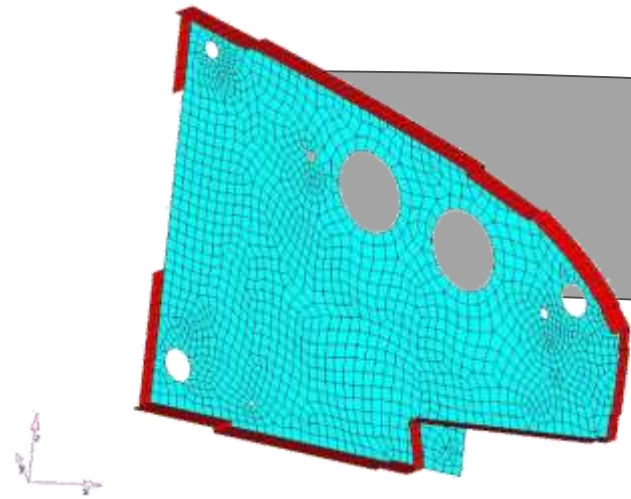
Significantly Increased Performance Characteristics

Airbus A380 Wing Rib

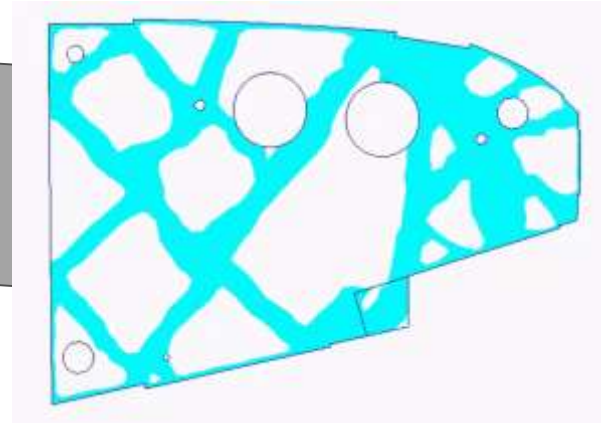


Traditional Design Delivered a Weight Challenge

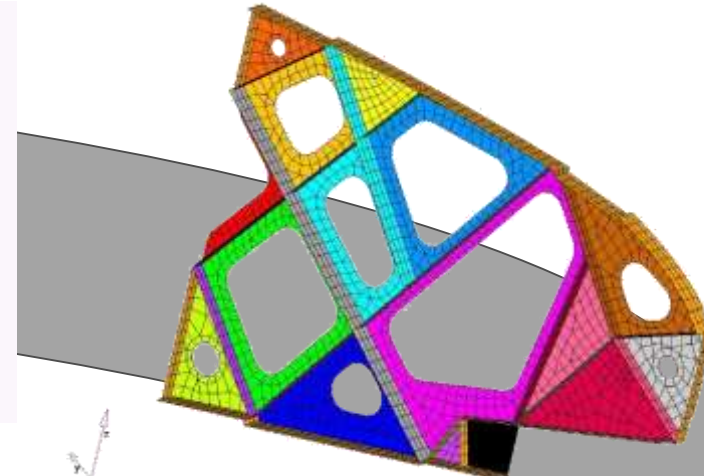
Airbus A380 Wing Rib



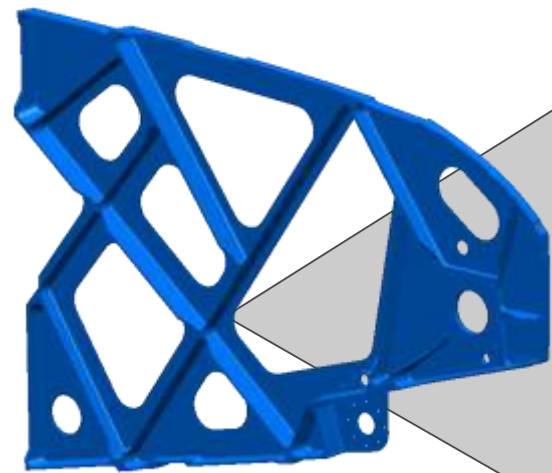
**Free Form Optimization
Package Space Definition**



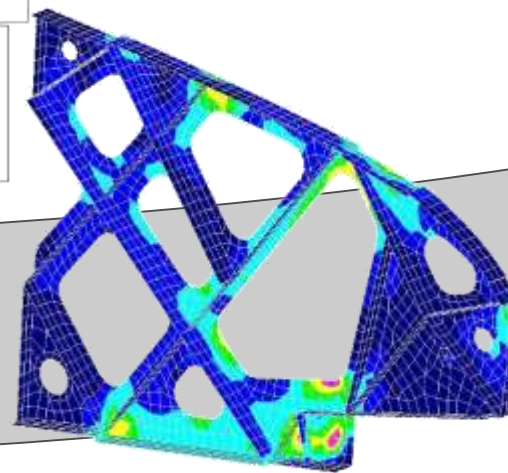
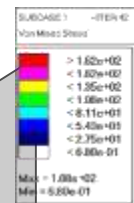
**Free Form Optimization
Material Layout**



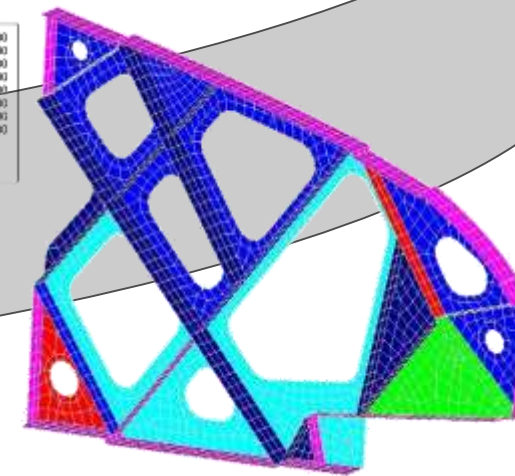
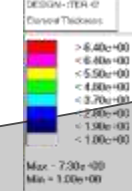
**Free Form Optimization
Geometry Extraction**



Solid Geometry Extraction



**Size & Shape Optimization
Buckling and Stress**



**Size & Shape Optimization
Geometry Extraction**

Airbus A380 Wing Rib



2001

"Through collaborative partnerships with Altair,
an innovative rib design resulted in
over 500kg saving per aircraft"

BAE SYSTEMS Press Release

AM Product Development

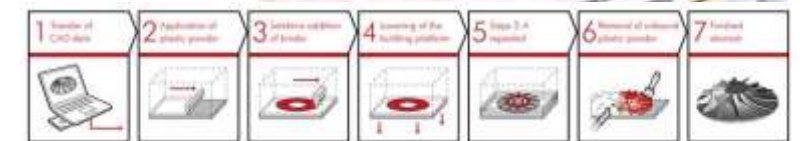
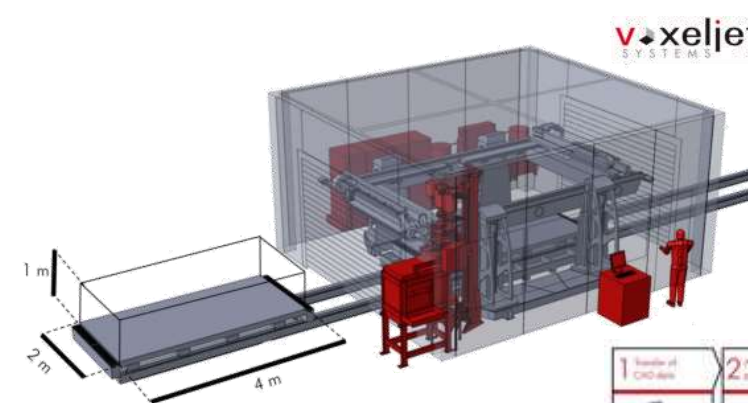
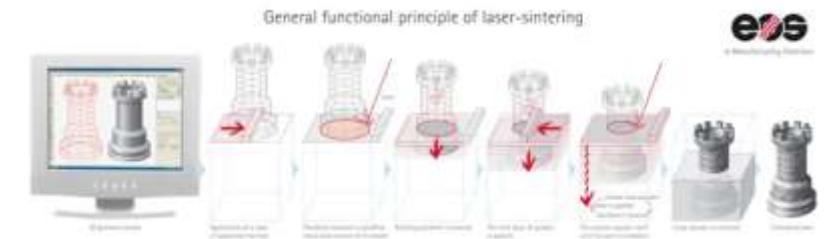
Complimentary Technologies

Product Industrialization

AM Design Challenges

Differentiated View – „What is Additive Manufacturing?“

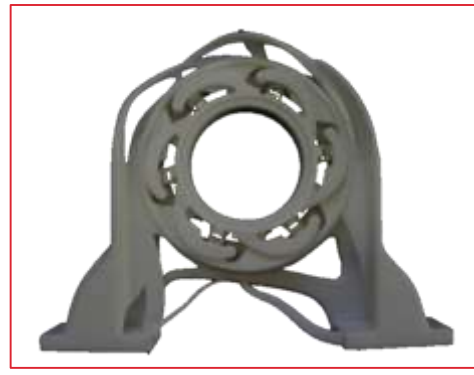
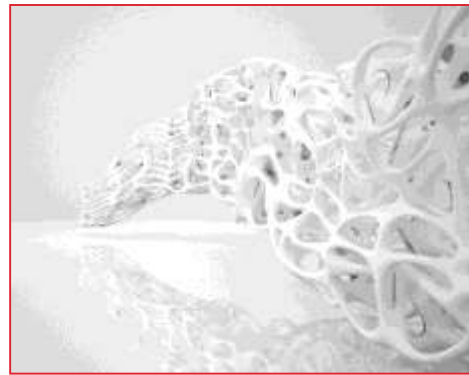
- Stereolithography
- Digital Light Processing
- **Fused Deposition Modeling - Thermoplastic extrusion (filament)**
- Inkjetted photopolymers
- wax deposition modeling
- Selective Laser Sintering plastics / metals
- **Selective Laser Melting of plastics / metals**
- Electronic Beam Melting
- Blown metal powder Welding
- **Sand binding**
- Binder jetted into metal powder (by ExOne)
- Smooth Curvature Printing (by Solidscape)
- Selective Deposition Lamination (by Mcor Technologies)
- Laminated Object Manufacturing
- **Hybrid CNC**
- ...



How to get an added value from 3D printing

Complexity for free!

How to convert the freedom into performance?



When does a part qualify for Additive Manufacturing?

Laser Additive Manufacturing is only interesting when minimum one of the following criteria is fulfilled:

Conventionally hard to manufacture

Improvement of the product performance by utilizing the design freedom

low quantity

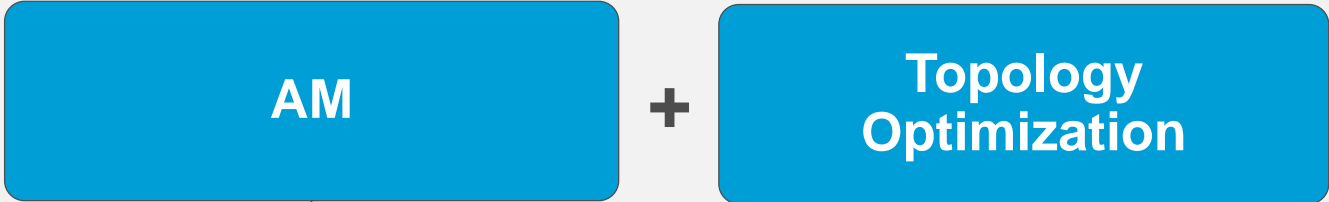
Possible integration of functionality

High part complexity

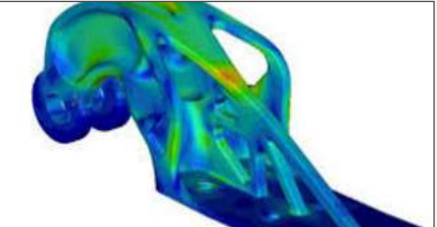


Quelle: autoneticind.com; forgingmanufacturer.com; masscustomization.blogspot.com; honeybuild.com; renishaw.com; os-gmbh.com; hrsflow.eu

Complementary Technologies



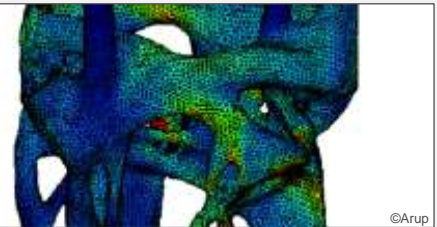
Geometric Freedom



Injects Innovation



Design Individuality



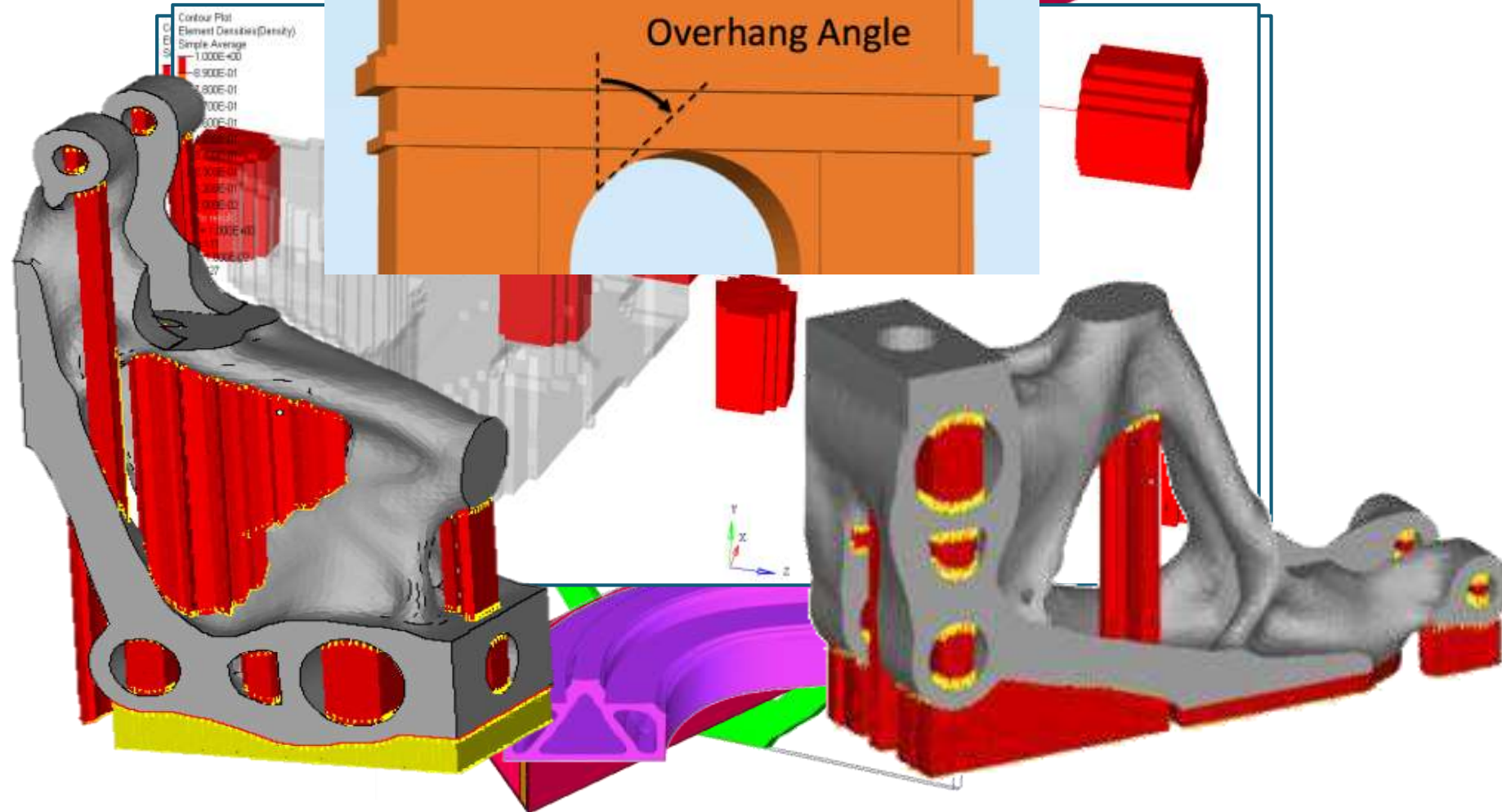
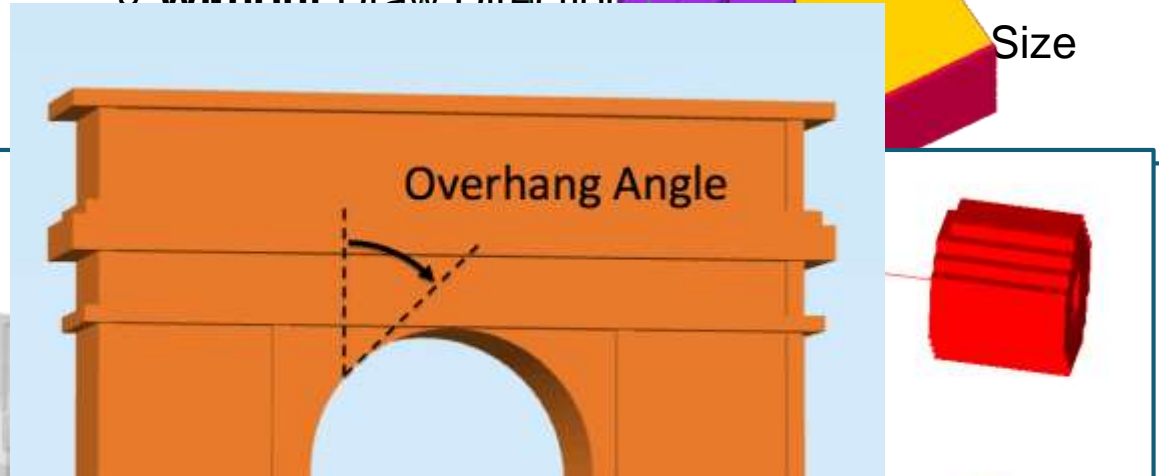
Accelerated Product Development



Product Industrialisation - Manufacturing

Minimise Support Structure by
Minimising Overhang Angle

Design Space



The Additive Manufacturing Design Challenge



3

challenges when designing for AM

The Additive Manufacturing Design Challenge



1

How can a designer come up with the best possible shape?



picture by courtesy of Laser Zentrum Nord 



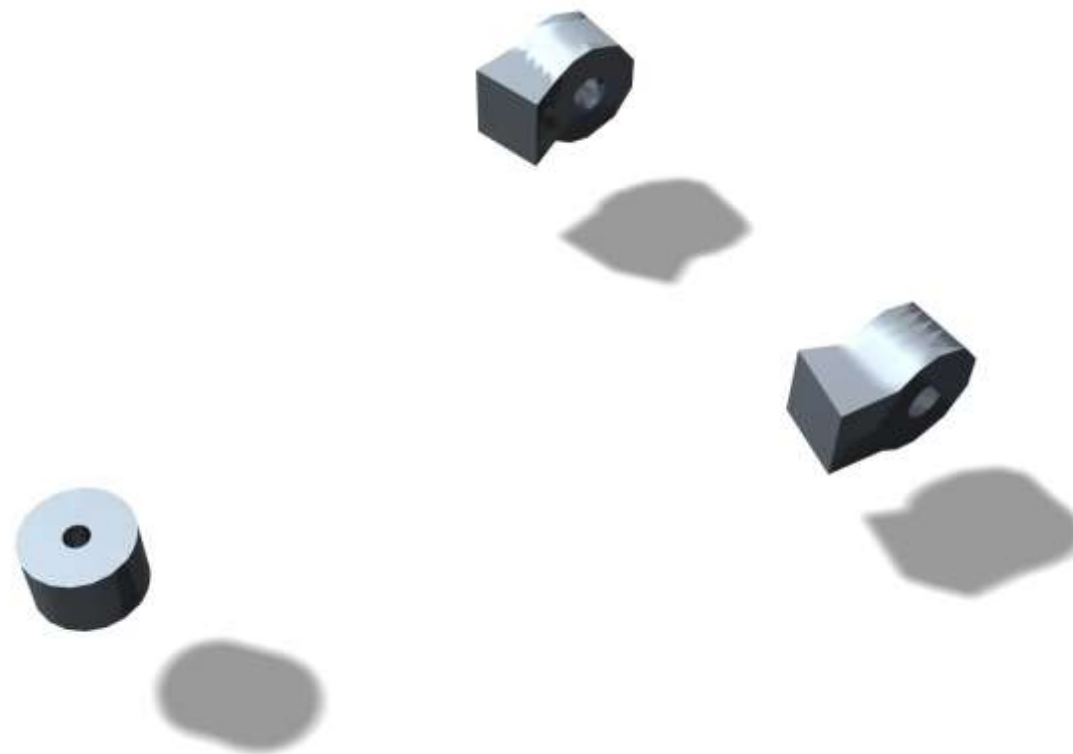
The Additive Manufacturing Design Challenge



Solution #1:

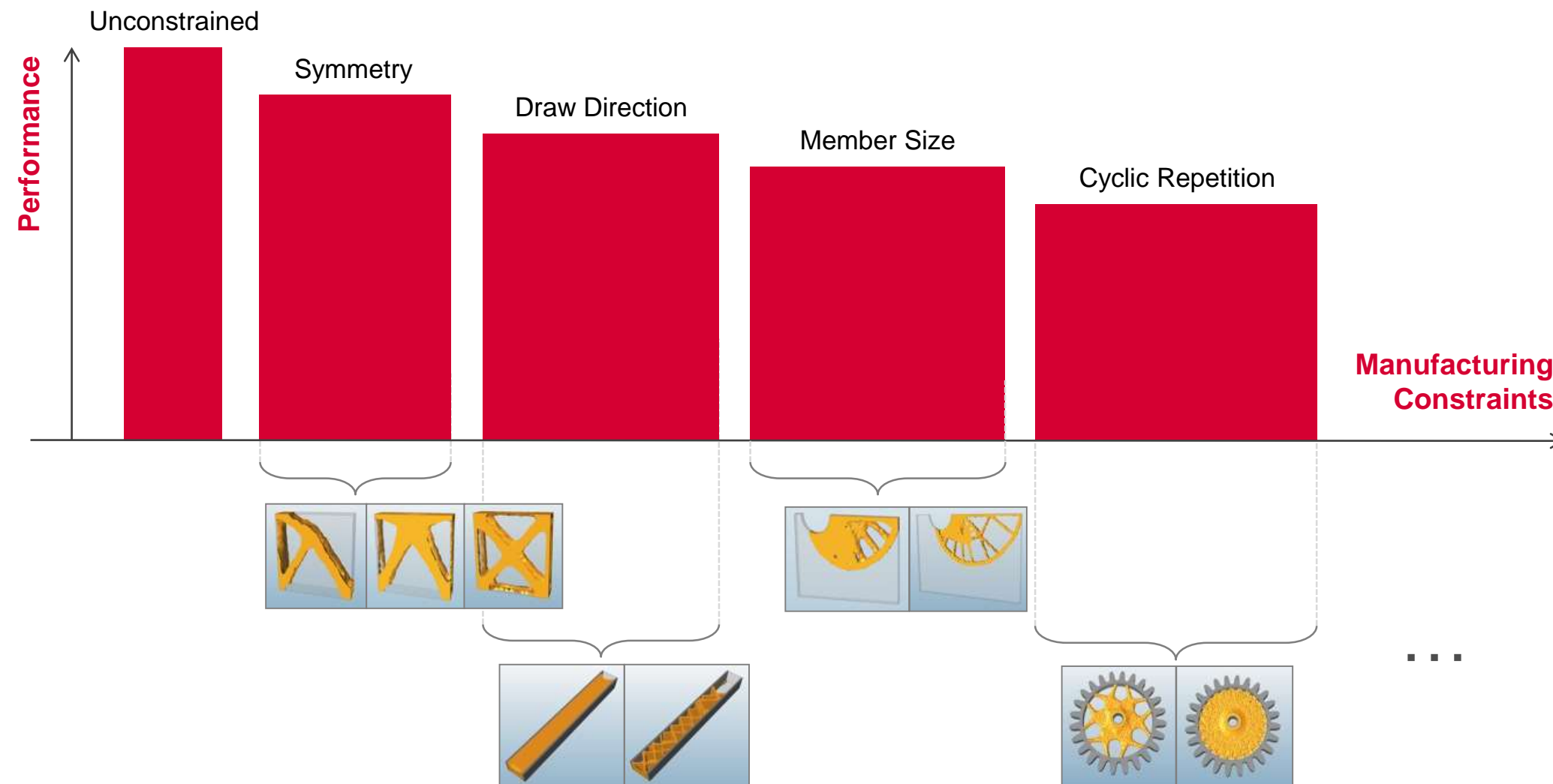
Topology Optimization

4827-108320100 - www.altair.com



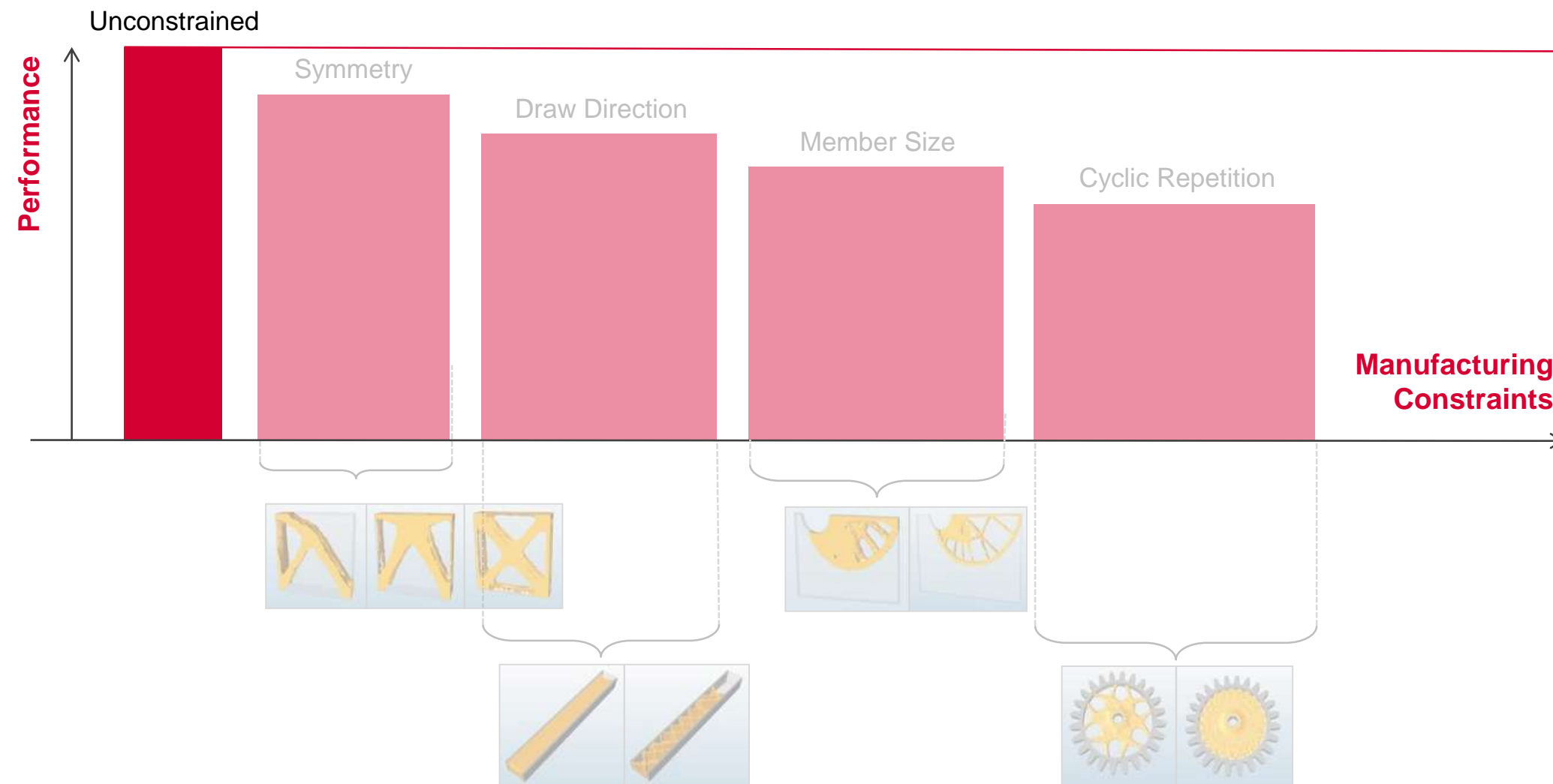
Technology symbiosis

Topology optimization provides the most efficient structure for a given load situation, but for traditional manufacturing designers always have to **trade performance for manufacturability!**



Technology symbiosis

Topology optimization provides the most efficient structure for a given load situation, with added manufacturing designers **no more** have to **trade performance for manufacturability**



“Industrialization” of Topology Optimization



The Additive Manufacturing Design Challenge



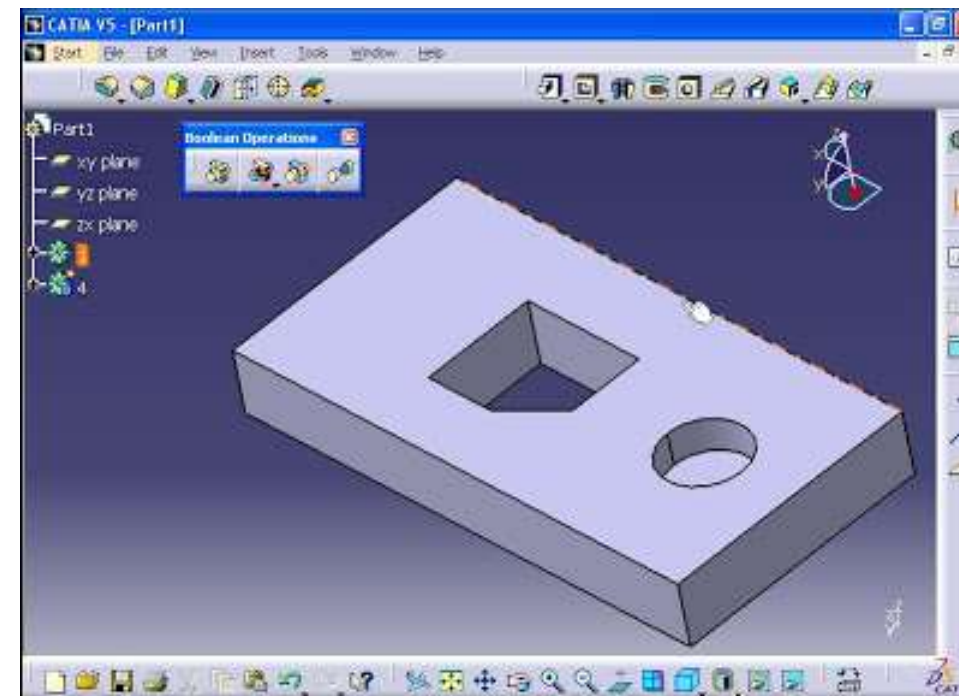
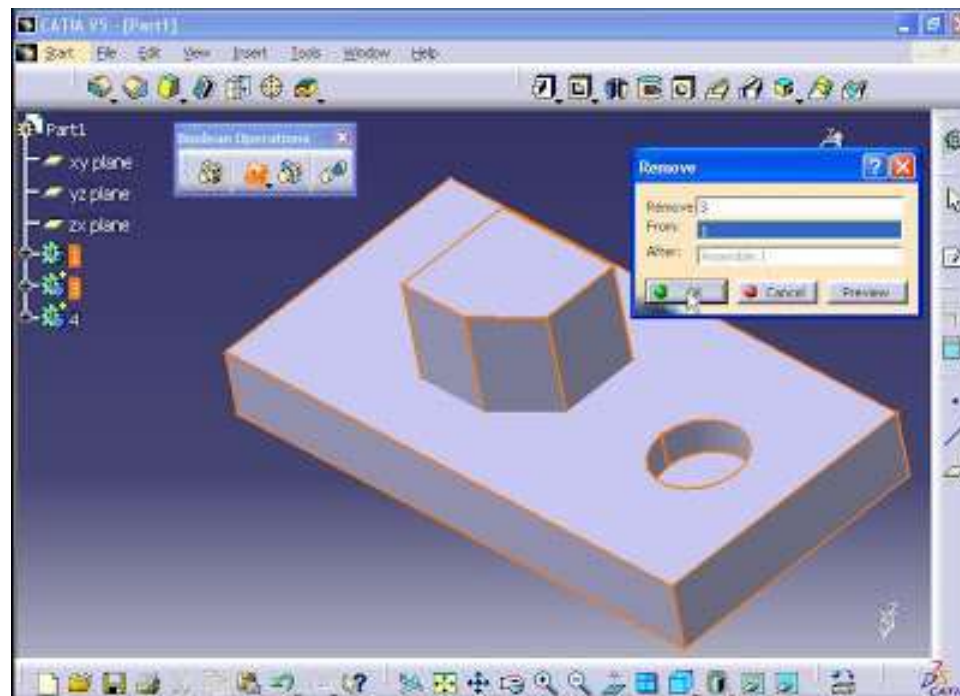
2

How can the engineer draw it in a CAD system?



The Additive Manufacturing Design Challenge

Problem:
Conventional CAD systems rely on boolean operations of simple geometric entities



The Additive Manufacturing Design Challenge

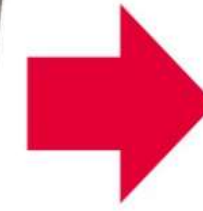
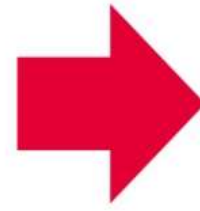
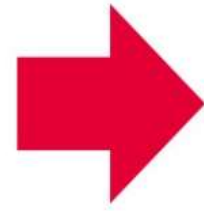
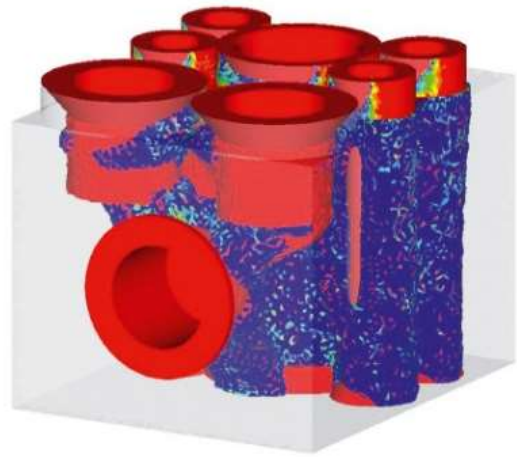
So “drafting” something like this
can take weeks with a conventional system:



pictures by courtesy of Laser Zentrum Nord 

Valve Block Redesign

Nurmi / VTT Technical Research Centre of Finland



Topology Optimization
with OptiStruct

Result Interpretation
using OSSmooth

Materialise
3-matic STL Model

Analysis of the
Redesign in OptiStruct



Design & Analysis by:

www.vttresearch.com



Optimal Fluid Flow

67 % Weight Reduction

„CAD Free“ _Realization

The Additive Manufacturing Design Challenge



Solution #2:

**Hybrid Modelling
Direct + Boolean**

**New
Polynurbs Design Technology**

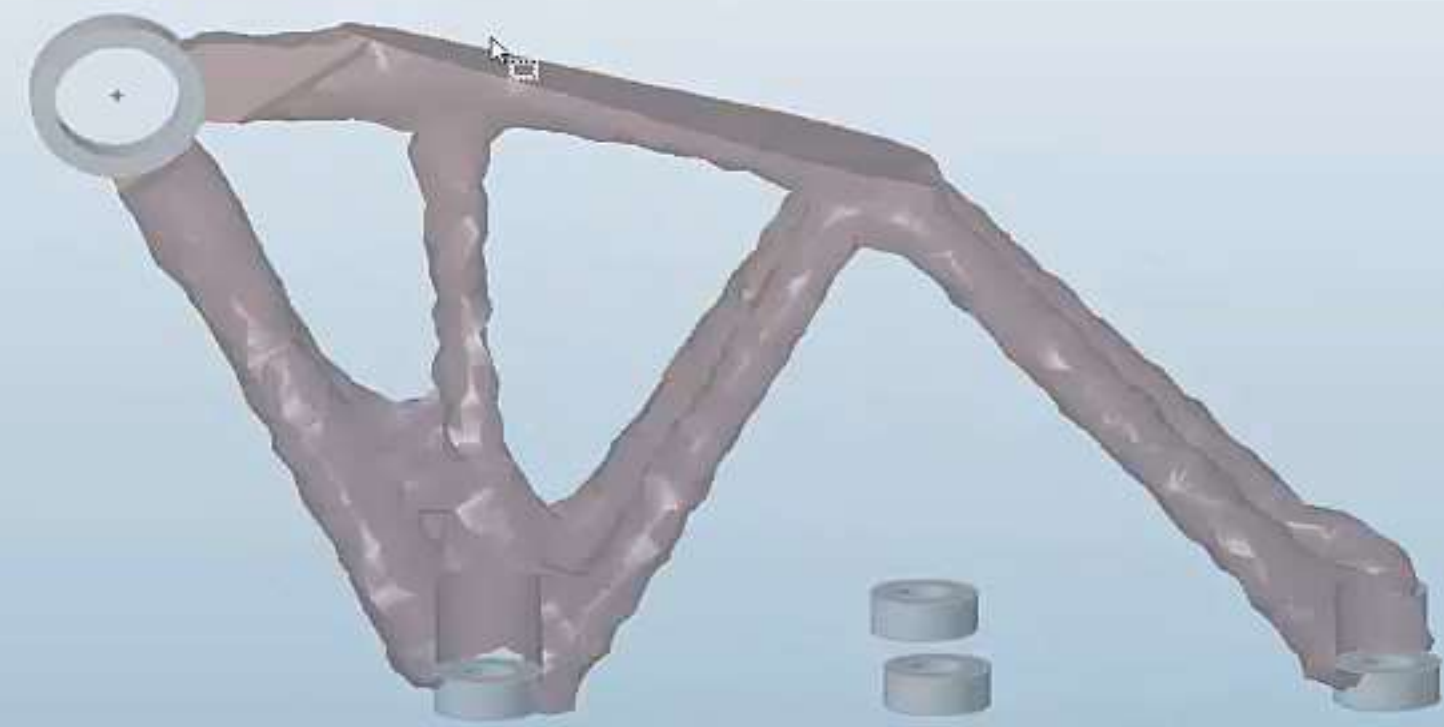


Model Browser

Object	Mass
optmodel_optimization_results	0.000211671
common	3.55861E-005
ngd	01
bolt	1.33596E-005
ngd Copy 1	01
ngd Copy 2	01
ngd Copy 3	01
ngd Copy 4	01
Part 1 Slice1	4.43341E-005
bolt Copy 1	1.33596E-005
Part 1 Slice1 Copy 1	4.43341E-006
opt	0.000176091
Part 1	0.000176091
Part 1	
Max Stiffness	
Min Mass SF	
Max Stiffness	
Min Mass SF	
Load Cases	
All Loads and Displacements	
Support 24	
Support 25	
Support 26	
Support 27	
Support 28	
Support 29	
Support 30	
Support 31	
Displacement Control	
Displacement Control	
Displacement Control	
Displacement Control	
Displacement Control	
Displacement Control	
Displacement Control	
Force 5	
Force 6	
Force 7	
Force 8	

Property Editor

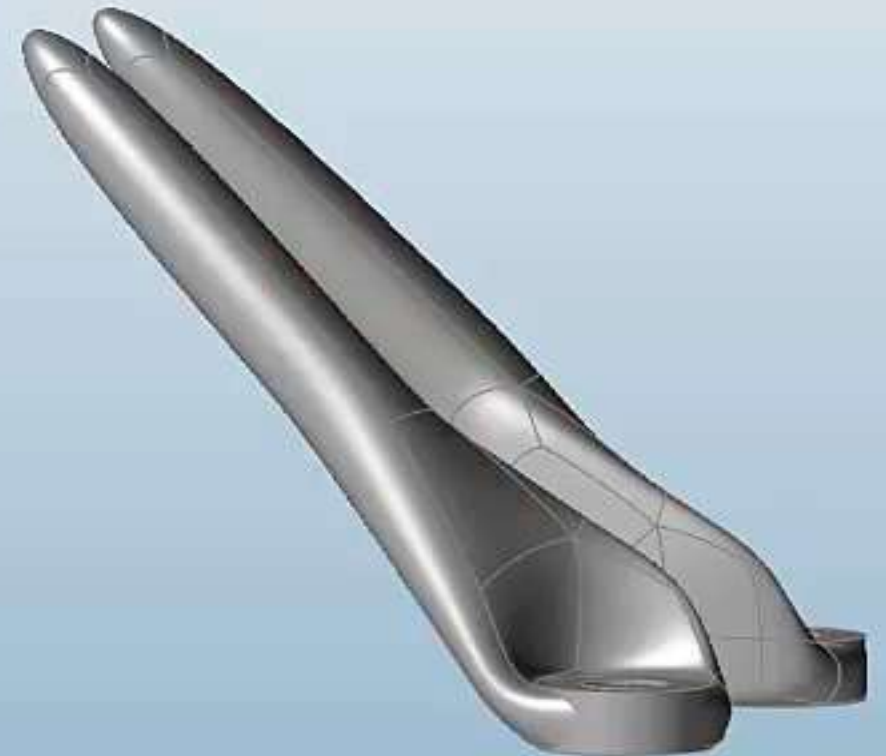
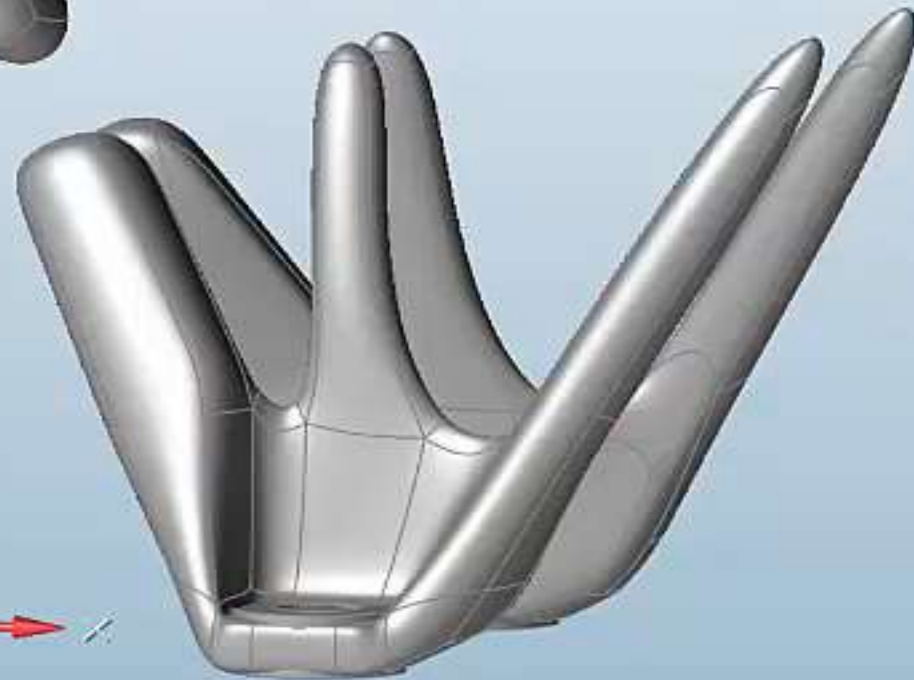
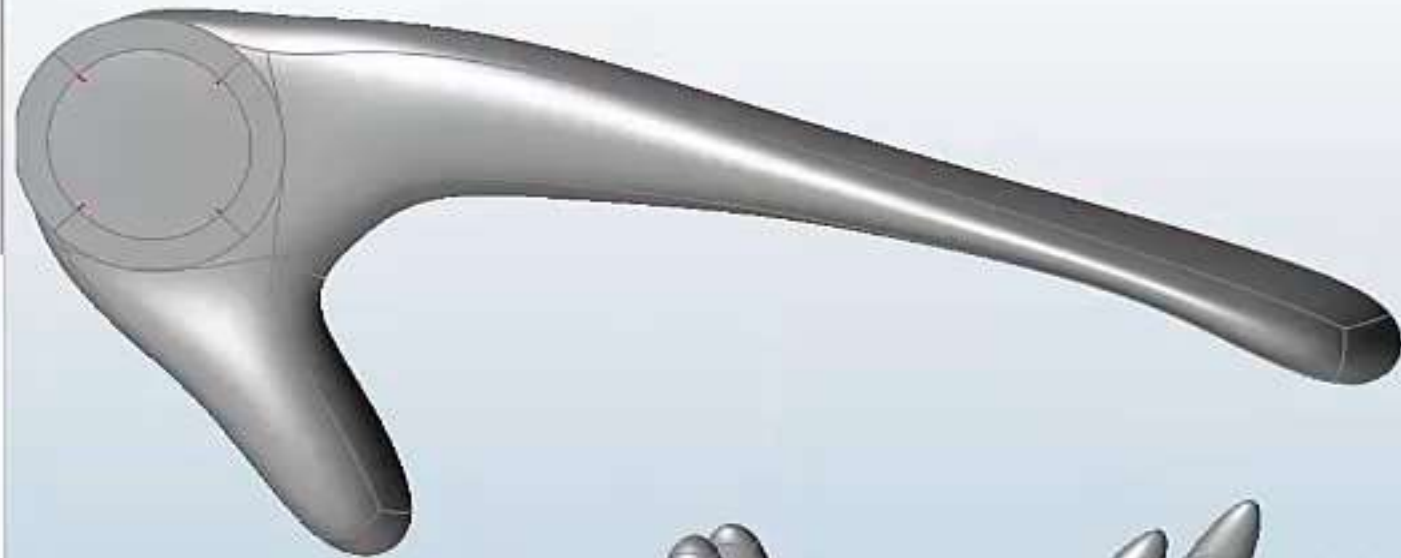
Name	Value





Model Browser

Object	Mass
optimodel_optimization_polynurbs...	0.000698251
common	5.62617E-005
rigid	01
bolts	1.3359E-005
rigid Copy 1	01
rigid Copy 2	01
rigid Copy 3	01
rigid Copy 4	01
Part 1 Slice1	4.43341E-006
bolts Copy 1	2.2268E-005
Part 1 Slice1 Copy 1	4.43341E-006
bolts Copy 1 Solid 1	6.36173E-006
bolts Copy 1 Solid 2	6.36173E-006
bolts Copy 1 Solid 3	6.36173E-006
bolts Copy 1 Solid 4	6.36173E-006
bolts Copy 1 Solid 5	6.36173E-006
cut1	0.000126091
Part 1	0.000126091
Max Stiffness	
Min Mass SF	
Max Stiffness	
Min Mass SF	
PolyNURBS Block Mirror...	0.00046521
Load Cases	
All Loads and Displaceme...	
Support 24	
Support 25	
Support 26	
Support 28	
Support 30	
Support 31	
Displacement Control...	
Displacement Control...	
Displacement Control...	
Displacement Control...	



Property Editor

Name	Value



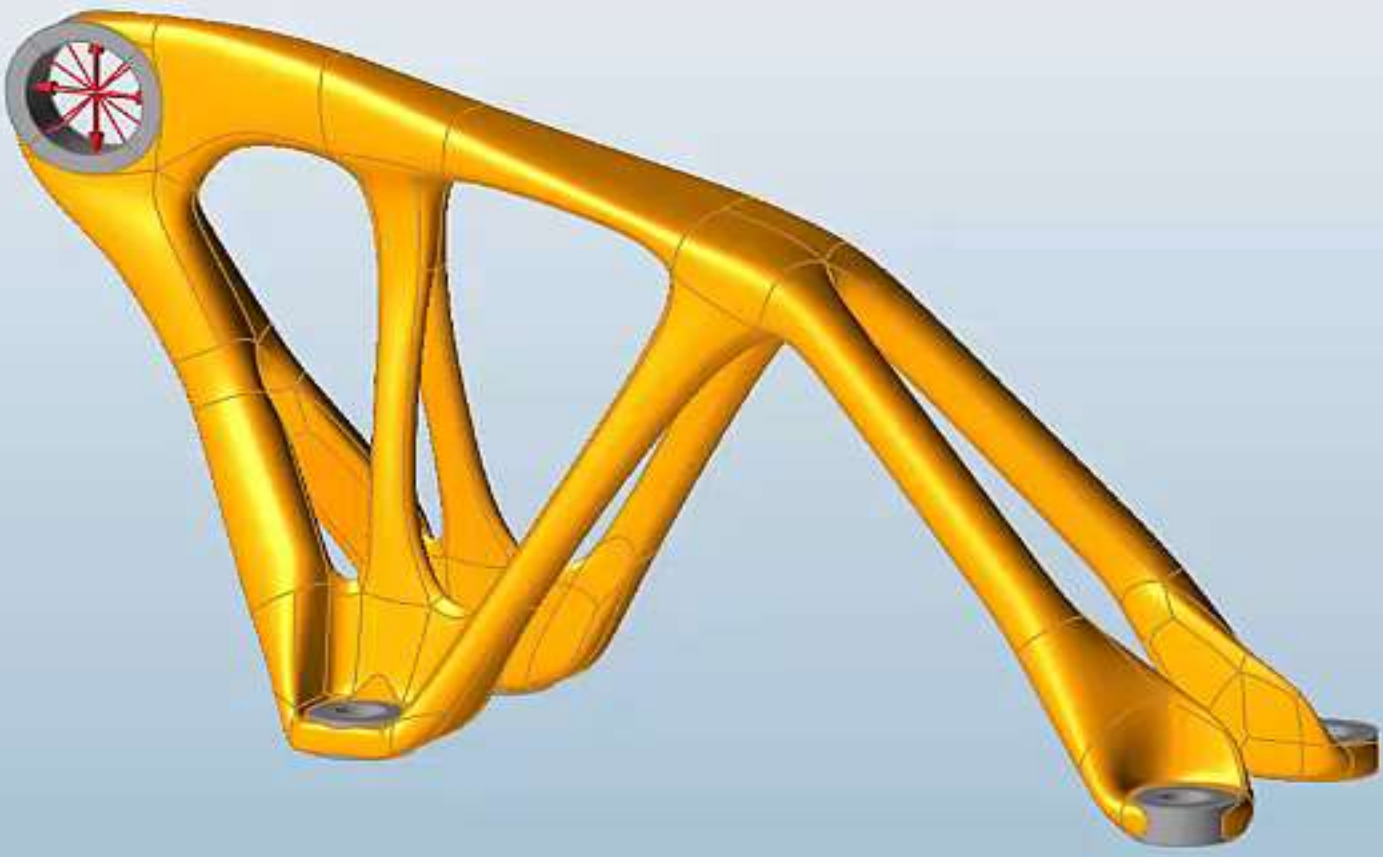


Model Browser

Object	Mass
Force 5	
Force 6	
Force 8	
Force 9	
Load Case 2	
Support 24	
Support 25	
Support 26	
Support 28	
Support 30	
Support 31	
Displacement Control...	
Displacement Control...	
Displacement Control...	
Displacement Control...	
Displacement Control...	
Displacement Control...	
Force 6	
Load Case 3	
Support 24	
Support 25	
Support 26	
Support 28	
Support 30	
Support 31	
Displacement Control...	
Displacement Control...	
Displacement Control...	
Displacement Control...	
Displacement Control...	
Displacement Control...	
Force 8	
Load Case 4	
Support 24	
Support 25	
Support 26	

Property Editor

Name	Value
General	
Name	PolyNURBS Block MirroredCopy
Material	Steel (AISI 304)
Design Space	<input type="checkbox"/>
Mass Properties	
Autocalc Mass	<input checked="" type="checkbox"/>
Mass	0.00055995t
Volume	69953 mm ³
Appearance	
Visible	<input checked="" type="checkbox"/>
Color	grey60
Transparency	0%
Permissions	
Detect Collisions	<input type="checkbox"/>
Movable	<input checked="" type="checkbox"/>
Mesh	
Autocalc Element S...	<input checked="" type="checkbox"/>



The Additive Manufacturing Design Challenge

3

How to consider the NEW Manufacturing Constraints?

Types of support

1. Simple fill-in
The most simple form of support is to fill in the area that needs support, and then cut this out when the build is complete by wire cutting or machining. If the support area is to be removed with wire cutting, a small hole needs to be placed in the support area to allow the wire to be located.

2. Other supports
Other supports require less machining. They are...

3. Overhanging features
Horizontal overhanging surfaces can be supported from the base, although this will require a considerable amount of material and energy. A better solution is to 'sketch' the surface from the main geometry at an angle (where not), design the supports into the geometry and remove the need for any additional work.

Support from main geometry

Downward facing surfaces

Any downward facing surface will require support. Support structures will need to be removed by wire cutting or machining, which will increase the energy and waste involved in the process.

The most simple support structure will fill the hole that creates the downward facing surface. This can be removed by wire cutting or machining.

An alternative to this approach will be to turn the part through 45 degrees to make all the surfaces angled and remove the need for supports. Orientation is a major issue in finding the most efficient build method - please see item 3 in Other issues (below) for more details on the limits and possible pitfalls of using angled edges like the ones shown above...

If the top surface of the hole can be made of a series of angles which are self-supporting the supports can be minimised to the base of each angled surface.

Angled surfaces and holes

The powder in the build chamber does not provide any support to the part as it builds, so any angled surfaces will ideally be self-supporting.

If the angle is too acute, the surface will need a supporting structure built in as part of the model. This supporting structure will then need to be removed by machining or wire cutting, increasing energy use.

The minimum angles that will be self-supporting are approximately:
- Stainless steel: 30 degrees
- Inconel: 45 degrees
- Titanium: 20-30 degrees
- Aluminum: 45 degrees
- Cobalt Chrome: 30 degrees

If the angle is near the point where it needs supports, the downward facing surface will become rough as it may require considerable post-finishing.

rough surface

rough surface

Small holes can be accommodated easily. Holes of less than 6mm diameter are ideal.

Larger circular holes will result in a roughened surface at the top which may need post machining.

Large holes will require support structures to be added in the centre to prevent the part collapsing or becoming distorted during the build process. These supports will need to be removed by wire cutting or machining.

If the hole has an angled or arched upper area it will probably not require any supports. This is one of the features of DMLS that can have a significant impact on the design process.

How to reduce support structures?

- We are working on it!

Design and sizing of Krüger flap

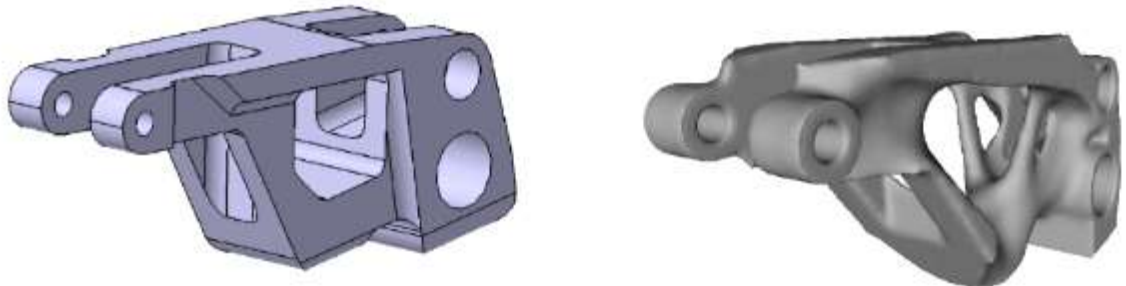
EADS INNOVATION WORKS

DRIVE STRUT LOAD INTRODUCTION Comparison milling & ALM design

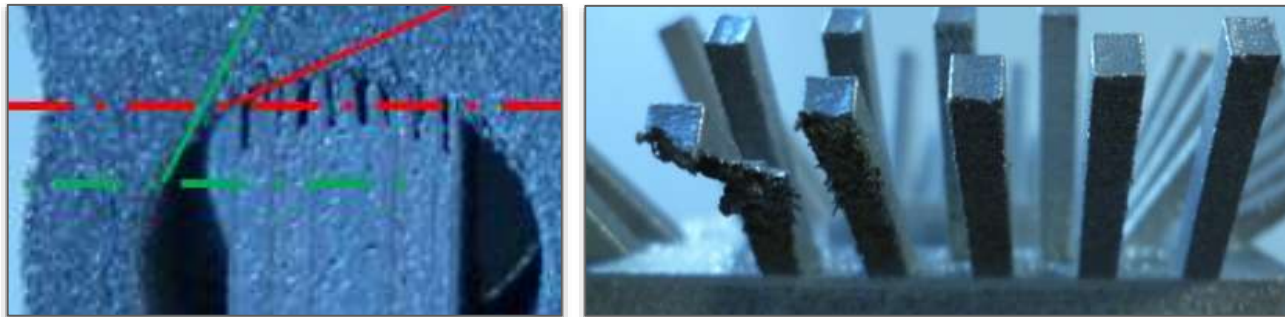
- Both designs feasible concerning stress and manufacturing
- Weight benefit of ALM drive strut bracket 14 %

Milling design

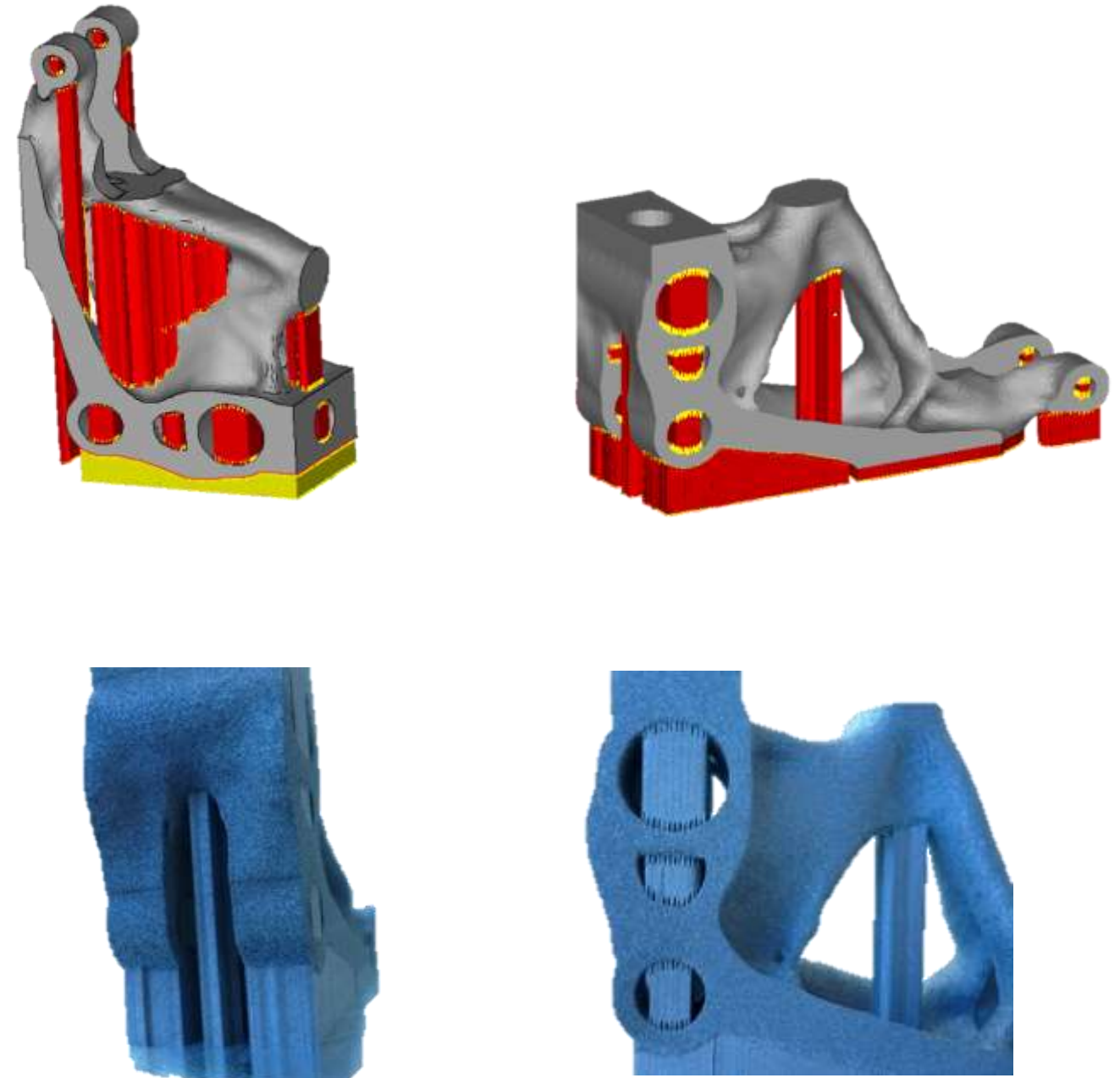
ALM design ISO 0.85



The image shows two 3D CAD models of a drive strut load introduction bracket. On the left is the 'Milling design', which is a solid, rectangular block with several circular holes and a complex internal structure. On the right is the 'ALM design ISO 0.85', which is a more compact and lighter version of the same part, featuring a lattice-like internal structure and a more rounded, organic shape.



Wolfgang Machunze, EADS
Topology Design of a Metallic Load Introduction Bracket Manufactured by ALM
Altair Technology conference 2014, Turin



The Additive Manufacturing Design Challenge



Solution #3.1. : design rule catalogues

Solution #3.2. : manuf. constraint implementation

AM Overhang Angle constraint



Design guidelines for laser additive manufacturing of lightweight structures in TiAl6V4
J. Kranz, D. Herzog, and C. Emmelmann

Citation: *Journal of Laser Applications* 27, S14001 (2015); doi: 10.2351/1.4885235
View online: <http://dx.doi.org/10.2351/1.4885235>
View Table of Contents: <http://scitation.aip.org/content/jla/journal/ja/27/S14001/1/vampdf>
Published by the Laser Institute of America

Articles you may be interested in

Surface structuring by remelting of titanium alloy Ti6Al4V
J. Laser Appl. 27, 529103 (2015); doi: 10.2351/1.4906387

Mechanical response of TiAl6V4 lattice structures manufactured by selective laser melting in quasistatic and dynamic compression tests
J. Laser Appl. 27, 517006 (2015); doi: 10.2351/1.4898835

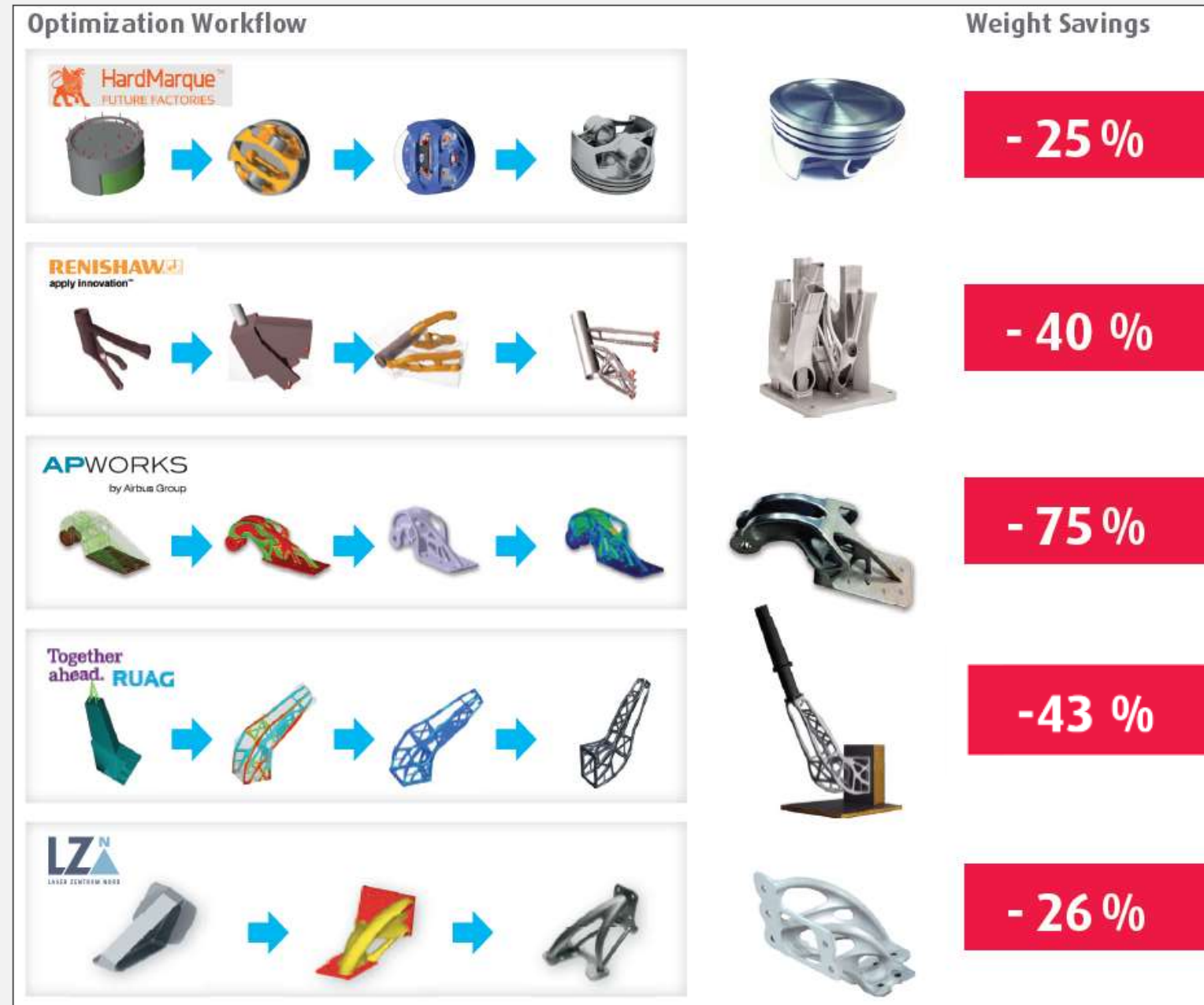
Mechanical stability of Ti6Al4V implant material after femtosecond laser irradiation
J. Appl. Phys. 112, 023103 (2012); doi: 10.1063/1.4797576

Tolerances of joint gaps in Nd:YAG laser welded Ti-6Al-4V alloy with the addition of filler wire
J. Laser Appl. 23, 012004 (2011); doi: 10.2351/1.3554266

Effect of phase transformations on laser forming of Ti-6Al-4V alloy
J. Appl. Phys. 98, 013518 (2005); doi: 10.1063/1.1944202

Innovation Examples

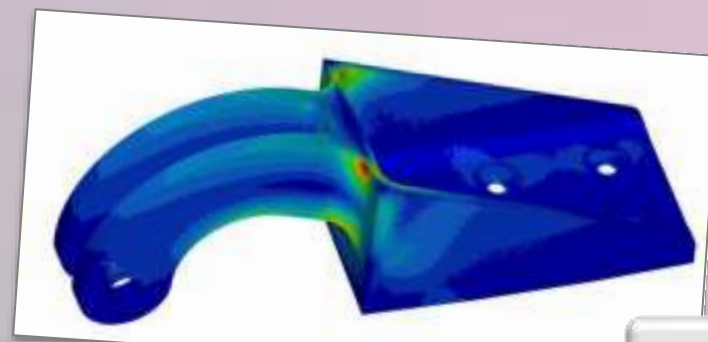
A Partnership Delivering Product Innovation



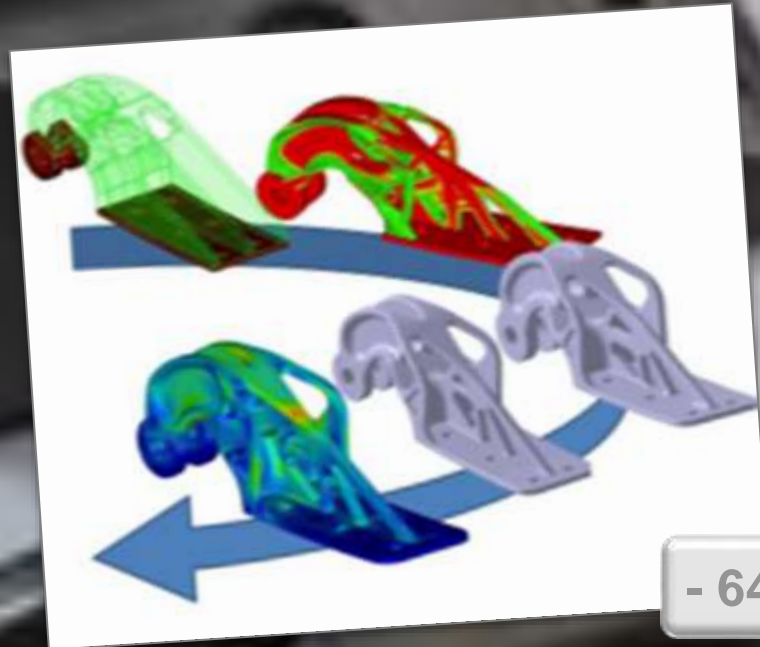
*Unlock the
lightweight
potential of **ALM** with
concept
optimization
for **EADS IW***

“OptiStruct allowed us to maximize the weight saving benefits of the ALM process.”

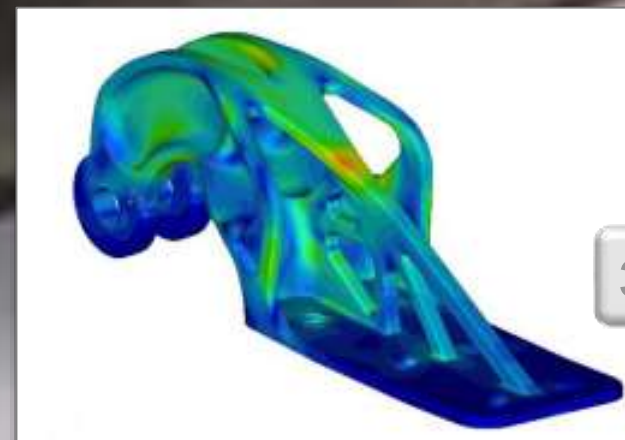
Jon Meyer EADS Innovation Works



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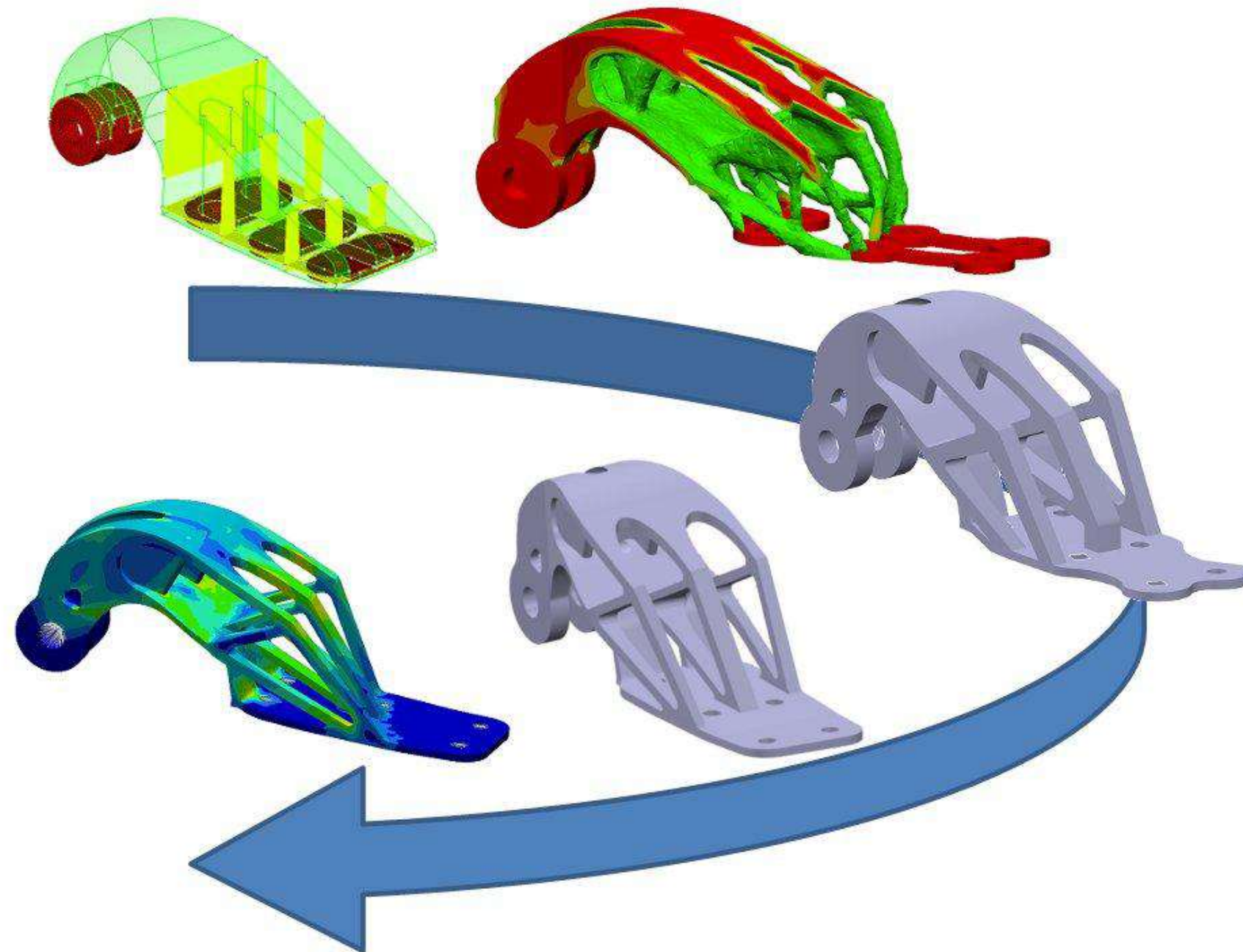


- 64%

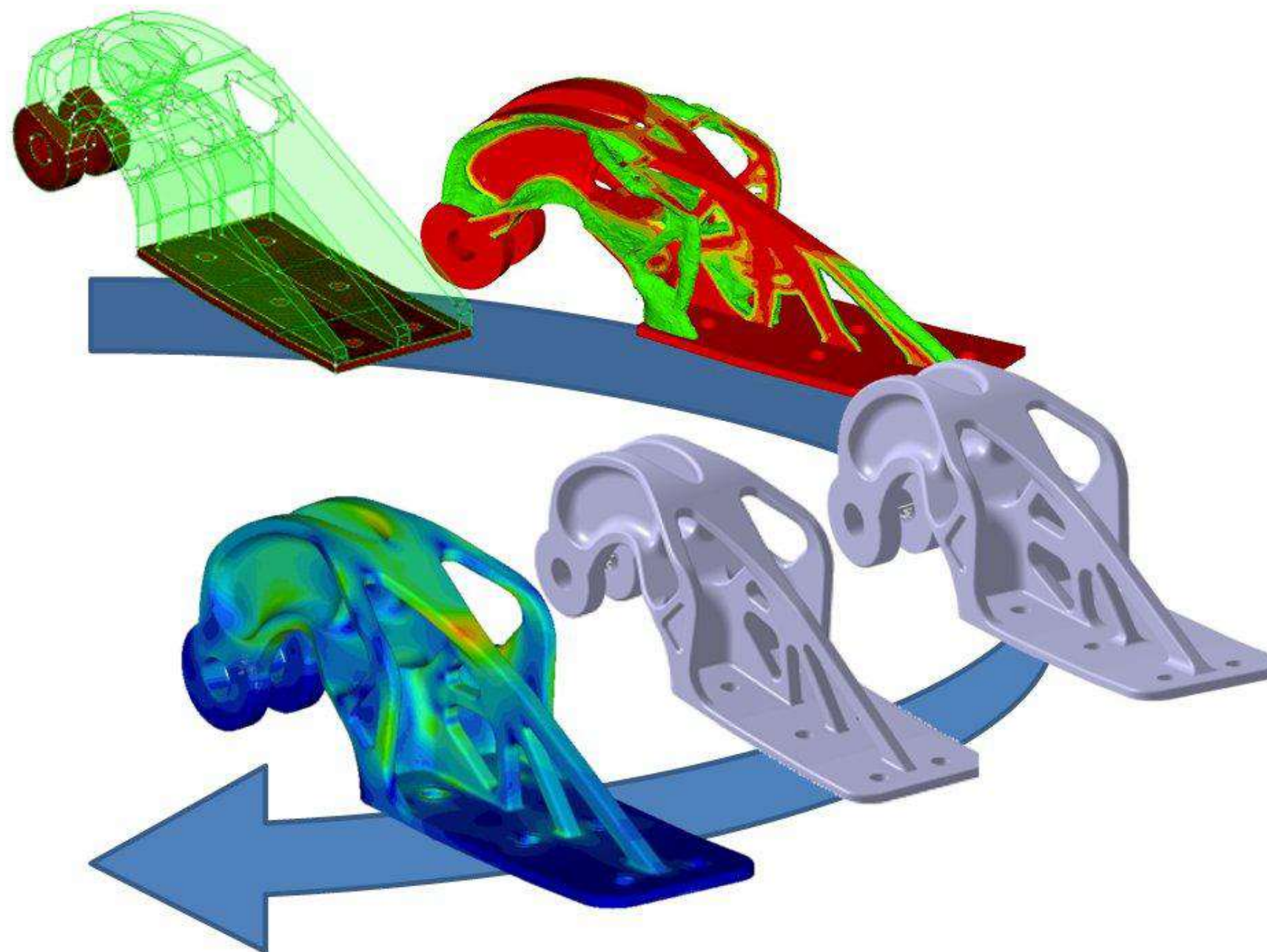


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Engineering ability



Engineering ability



Engineering ability



- Front loading
- Only the right assumptions lead to the desired result

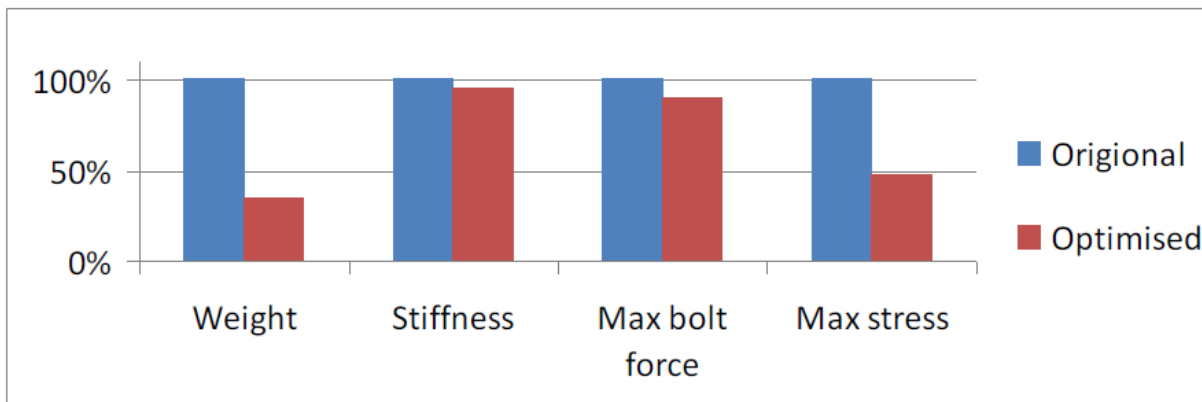
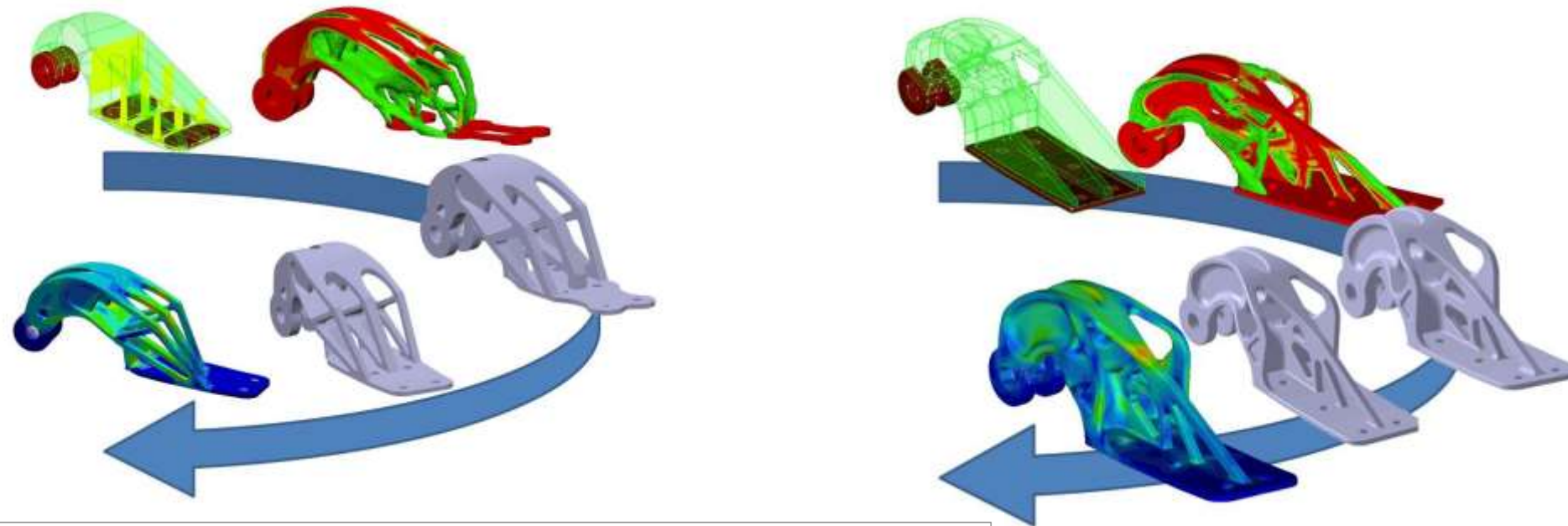


Figure 10: Performance comparison of original and new design

Topology Optimization of an Additive Layer Manufactured (ALM) Aerospace Part

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Abstract

As part of research into the benefits of Additive Layer Manufacturing (ALM) manufacturing process, an Airbus A320 nacelle ring bracket was optimized, incorporating a topology optimization method. The design freedom of the ALM process meant that a significant proportion of weight could be saved in the part, while also reducing maximum stress and maintaining stiffness. Optimization of small-scale parts presents a large opportunity for weight saving, and may become economically viable if tools are developed to reduce the man-hours used in the design process.

Keywords: Optimization, Optibuck, topology

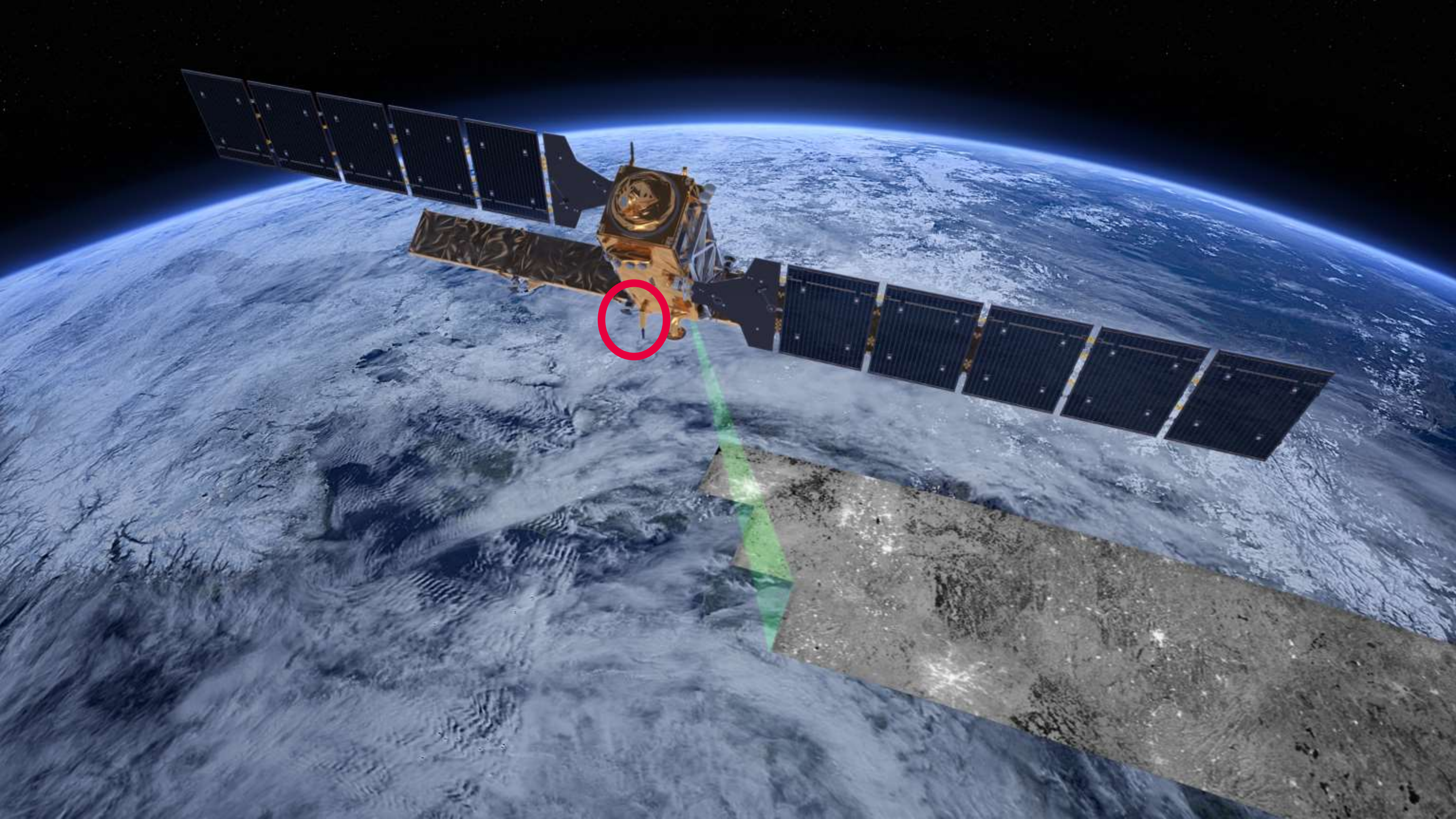
1.0 Introduction

Metallic Additive Layer Manufacture (ALM) technology is a relatively young technology in the early stages of being implemented into the manufacture of aircraft. The main benefits of the ALM process come in design flexibility, low material waste, low CAD-to-part time and cost of producing parts from hard materials that are otherwise difficult to machine. ALM is currently a comparatively expensive process, but this expense is acceptable in high-value applications where specialised materials are used or where a customer requires a complex part.

Because of the design freedom available with ALM, it is a perfect application for topology optimization. Where usually a topology optimization has to be 'interpreted' and sacrifices in the design have to be made for manufacturability. With ALM, the principle is that the topology optimized shape can be maintained and the final weight and structural properties can be closer to that of the optimized shape.

Reducing weight also means that the part manufacture costs less. As ALM is an additive process the part cost is proportional to the volume of the part. The more material used, the more expensive the part will be. This is opposed to how many parts are currently made. Subtractive processes (e.g. milling) are often used to reduce weight, these incur a trade-off between cost and weight, this does not happen with ALM.

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From the Printer into Space



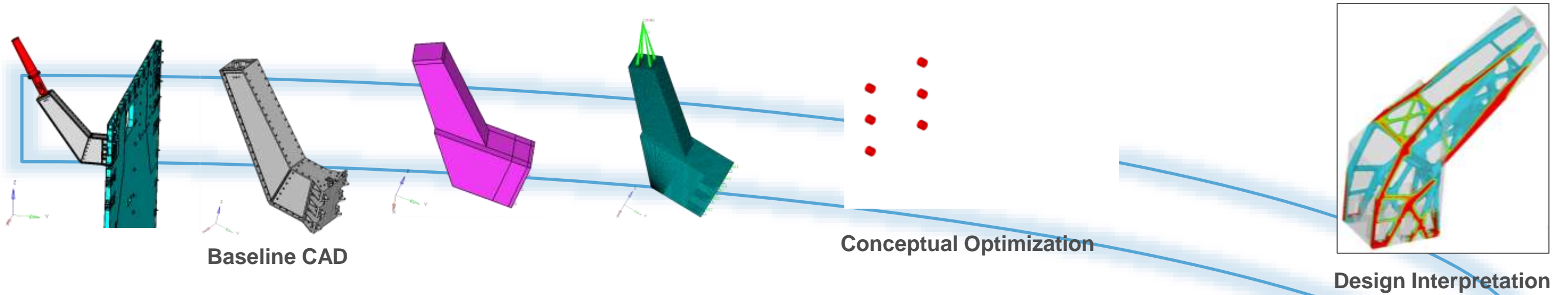
3D Printed Antenna Bracket for Sentinel-1 Satellite:

- **43% weight reduction**
(from 1.626 kg to 0.936 kg)
- Increased Eigen frequency
(70Hz → 90 Hz)
- Improved static behaviour, strength, stiffness, stability

Together
ahead. **RUAG**



From the Printer into Space



Design Process for AM

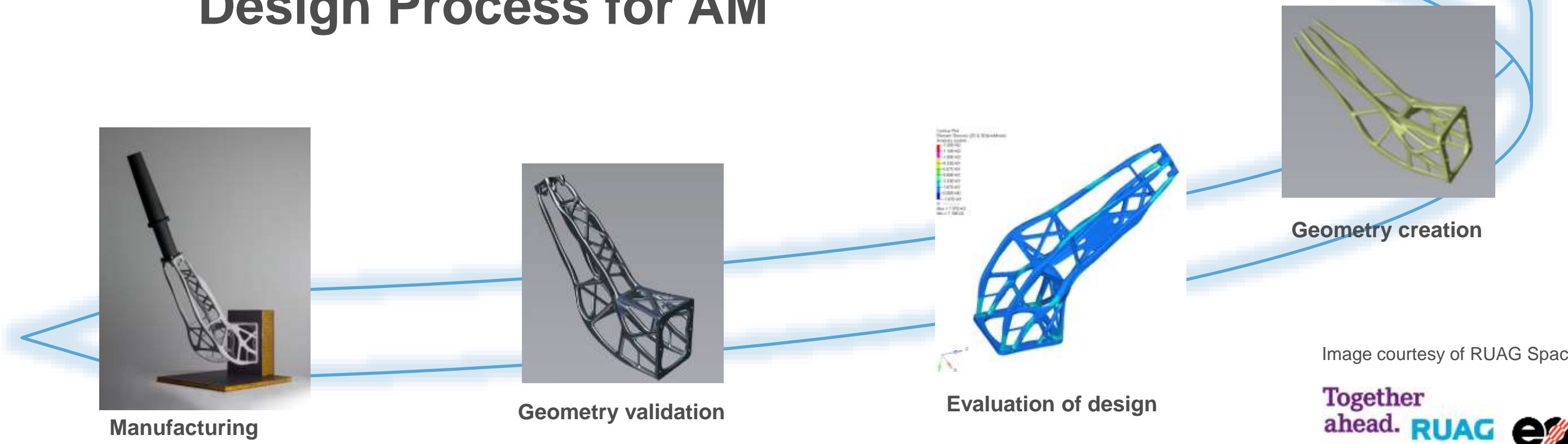


Image courtesy of RUAG Space



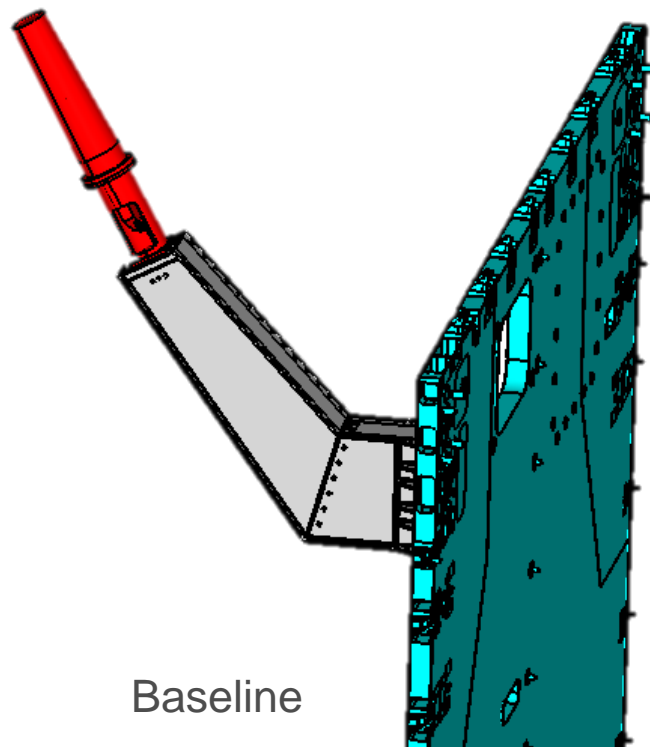
Model preparation



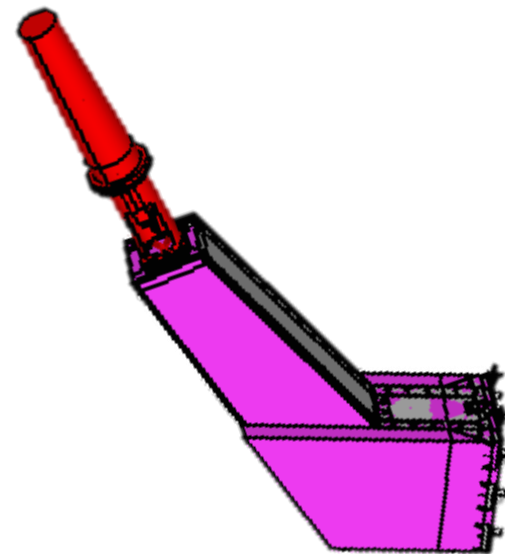
Understand design requirements

- Generation of Design Space
- Generate Optimization setup
 - Proper mesh
 - Proper BCs
 - Proper Optimization definition

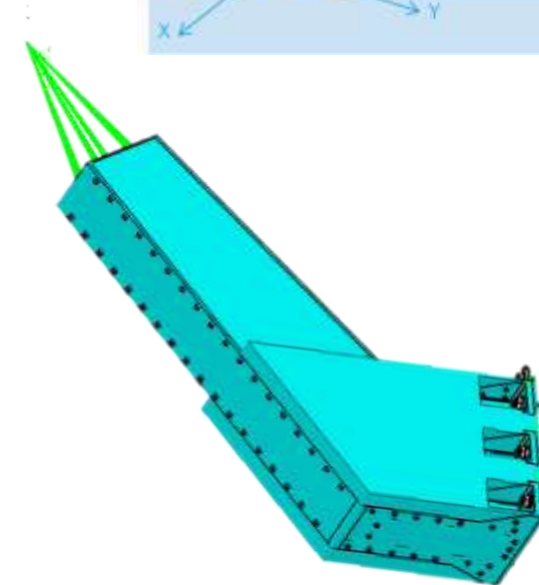
Original Design	Specification		
	▪ Eigenfrequency > 70Hz		
	▪ Boundary condition Hard Mounted		
	▪ Dimensions 385 x 345 x 115 mm ³		
	▪ Static Load (QL) 20g (X,Y) / 25g (Z)		
	▪ S-Band Antenna 0.783kg		
	▪ CoG Position <table border="1" style="margin-left: 20px;"> <tr> <td>X = 436.2mm</td> </tr> <tr> <td>Y = -1091.8mm</td> </tr> <tr> <td>Z = 3330.6mm</td> </tr> </table>	X = 436.2mm	Y = -1091.8mm
X = 436.2mm			
Y = -1091.8mm			
Z = 3330.6mm			



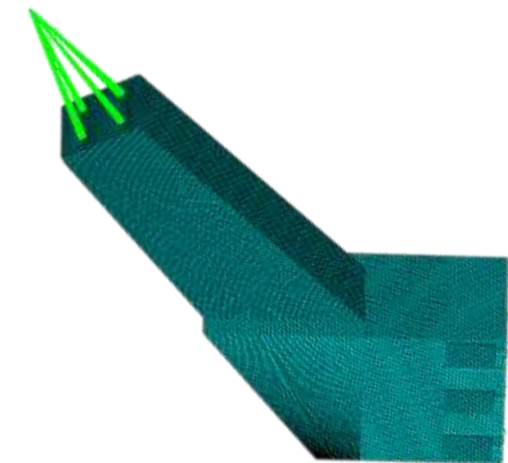
Baseline



Design Space Envelope



Design Space



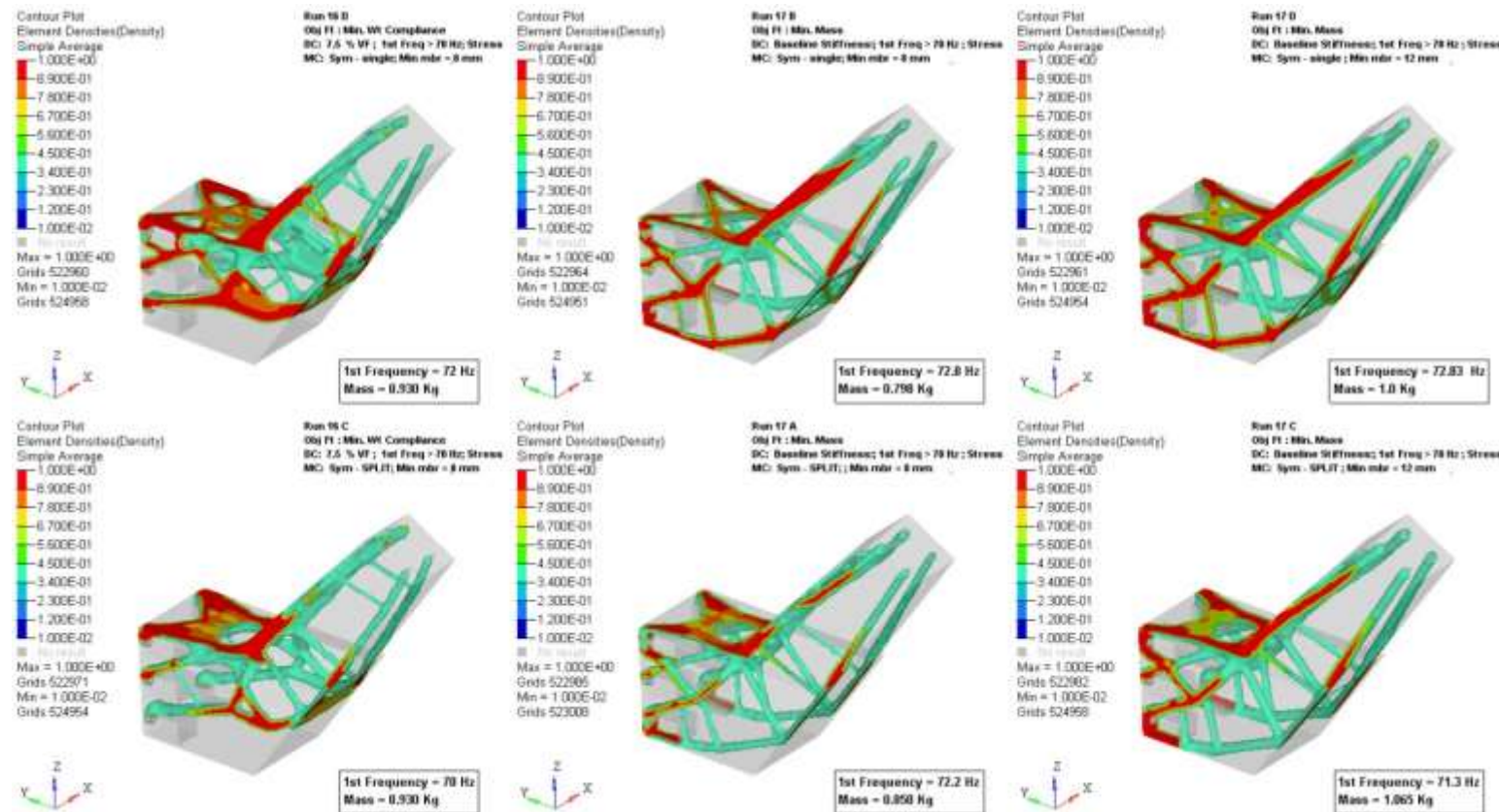
Hexahedral Elements
Total Elements = 236004

Conceptual Optimization



Optimization problem formulation:

- **Objective:** Minimize Mass or Compliance
- **Constraints:** Volfrac 20%, 10%, 7.5% / Stress (110MPa) / 1st mode > 70 Hz
- **Variables:** Element densities



Goals of multiple runs:

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

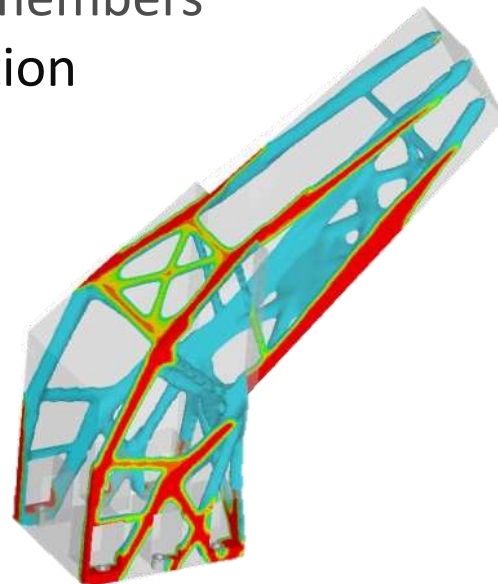
Conceptual Design



Goal = Obtain easily the right information from the optimization result to make the right decisions for realizing a design

Structural behavior:

- Understanding results of optimization
 - Primary and secondary load paths
 - Local vs Global optima
 - Discrete results
- Cross section behavior
 - Tension-Compression-Shear members
- Stress distribution after optimization
 - Uniform stress

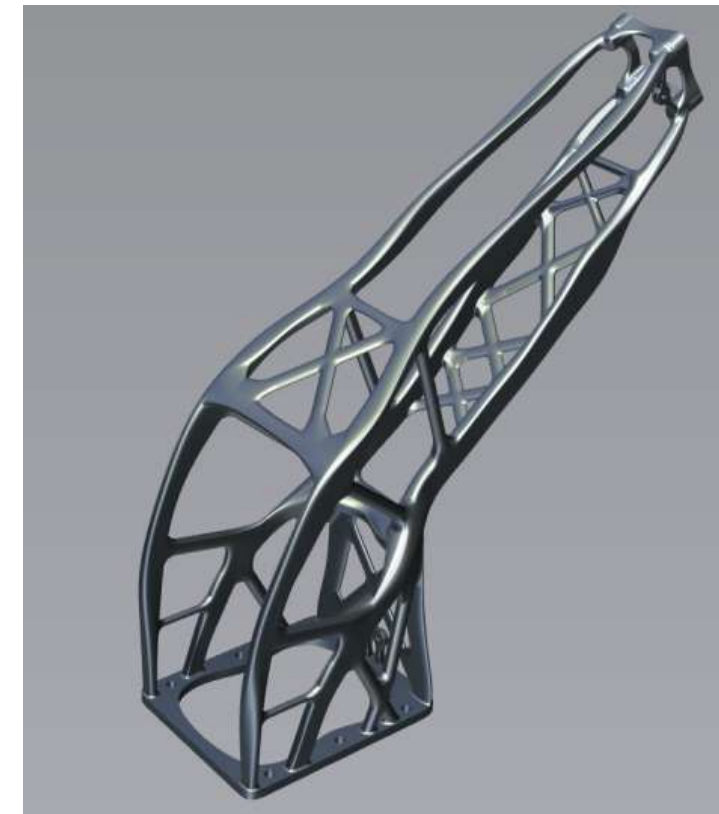
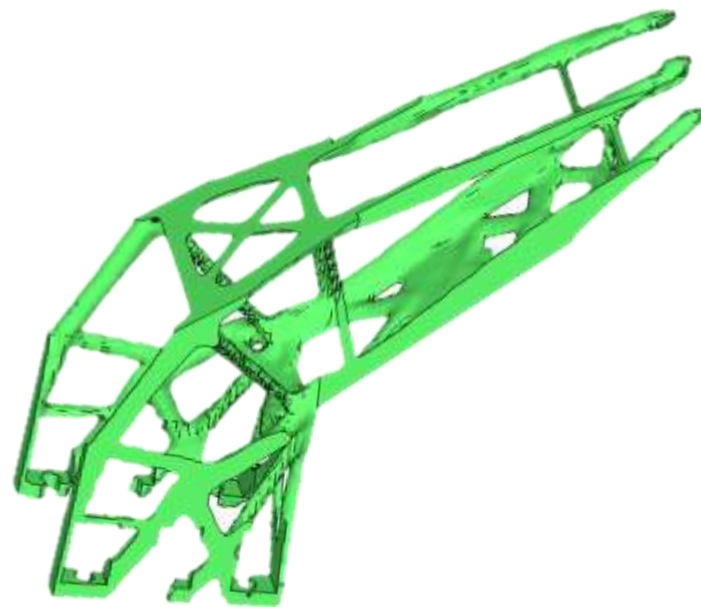


Conceptual Design



Concept freeze 

- Evolve helps to realize the process of creating the CAD model **3x-4x faster** than traditional CAD tools
- Parametric modeling & Traditional surface modelling techniques (loft, sweep, etc...).



Standard formats:
⇒ Parasolid
⇒ STEP
⇒ IGES

RUAG Space – Sentinel 1 Satellite Antenna Support

One more word on the topic support structures



From the Printer into Space



- Sentinel-1 AM Bracket **successfully completed its qualification test campaign!**

- Results exceed requirements:

- 1st Eigenfrequency:

Requirement:	> 70 Hz
Simulation (OptiStruct)	91.44 Hz
Test:	90.9 Hz

- 2nd Eigenfrequency:

Simulation (OptiStruct)	106.9 Hz
Test:	107.6 Hz



Key Aspects in Design for Additive Manufacturing

- Additive Manufacturing requires **new Designs** to benefit from the design freedom!
- **Topology Optimization** is the best way to **inject innovation** in structural designs!
new concept generation, part consolidation projects, biomimicry adaption
- The **geometry complexity** of ideal Designs for AM overexerts conventional CAD environments!
- **Confidence in the Design** is vital in all stages of the design process!
- Simulation Driven Design is the best way to **convert the Design Freedom into Product Performance**

Meet us in Hall 7 Booth B32



pictures by courtesy
of Laser Zentrum Nord 