Structural Simulation with Voxels

Roger Wende
Acknowledgements: Lu McCarty, Johannes Fieres, Christof Reinhart

Volume Graphics Inc.
Charlotte, NC USA

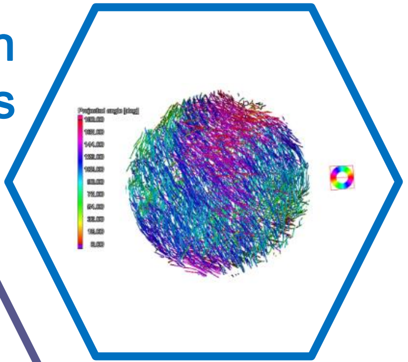
CINDE
CANADIAN INSTITUTE FOR NON-DESTRUCTIVE EVALUATION

NDT in Canada
NDTiC 2018
Canada's NDT Conference

June 19 - 21
Halifax Convention Centre
Halifax, Nova Scotia

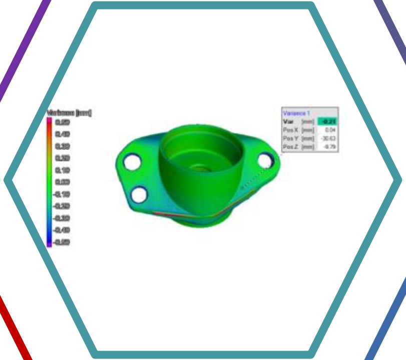
VGSTUDIO MAX Modules

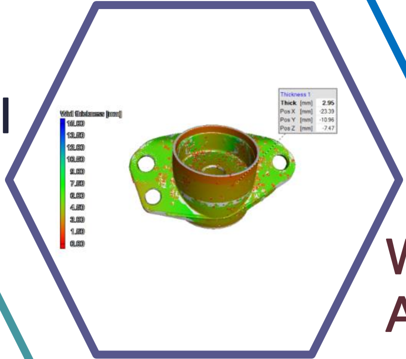
Fiber Orientation Analysis



Inline

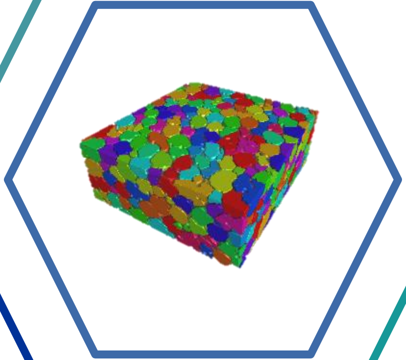
Nominal/Actual Comparsion

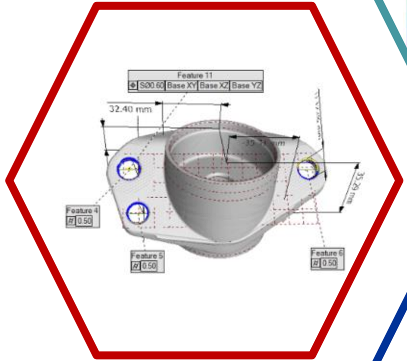




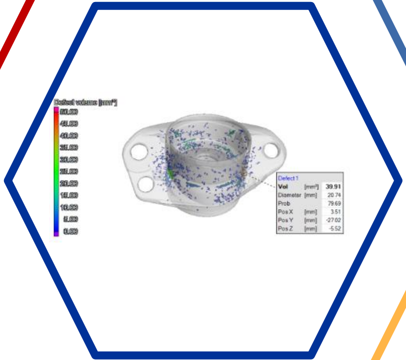
Wall Thickness Analysis

Foam Structure Analysis

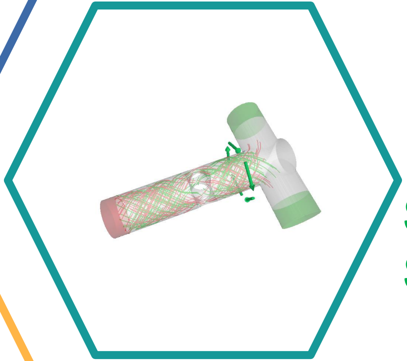




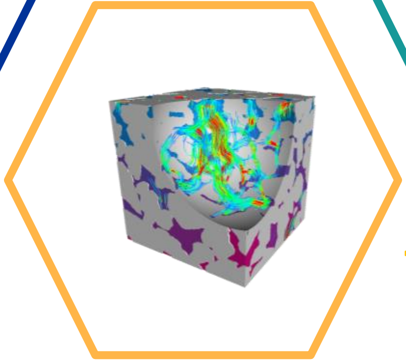
Metrology



Porosity/Inclusion Analysis

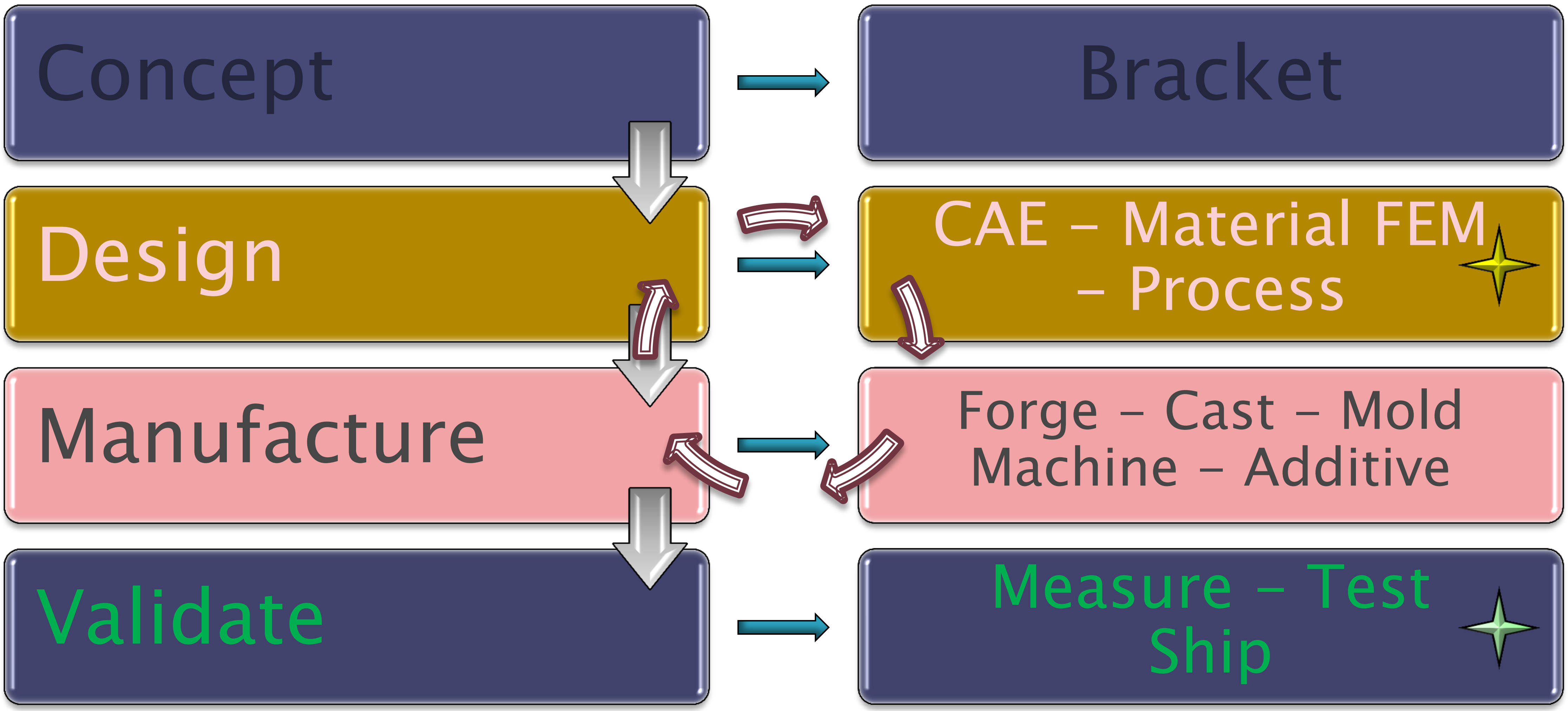


Structural Simulation



Transport Phenomena

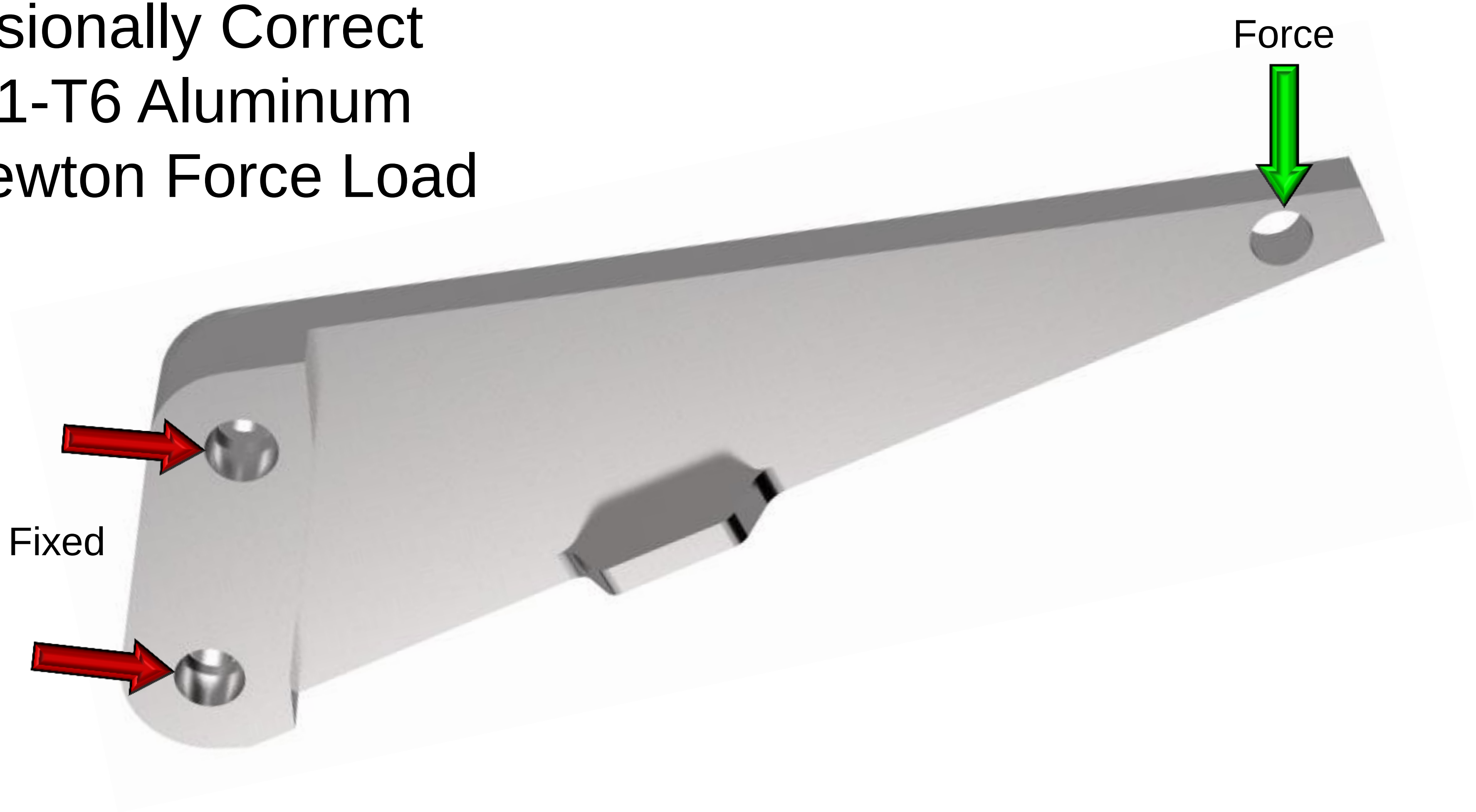
Simplified Part Workflow



Simple Bracket

Basic Design Criteria

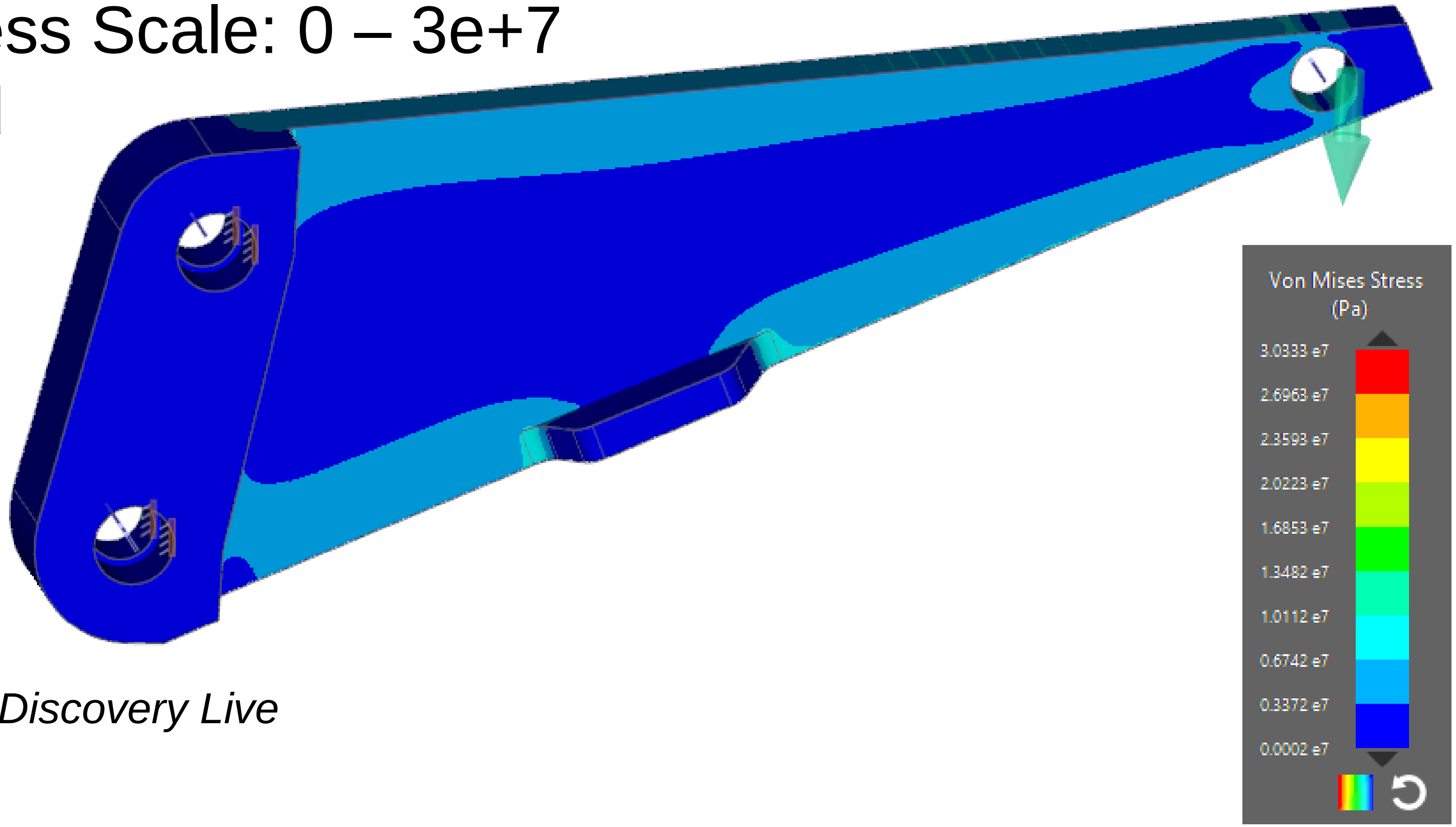
- 3 Point Design
- Dimensionally Correct
- AL6061-T6 Aluminum
- 220 Newton Force Load



Simple Bracket

Basic Design Result

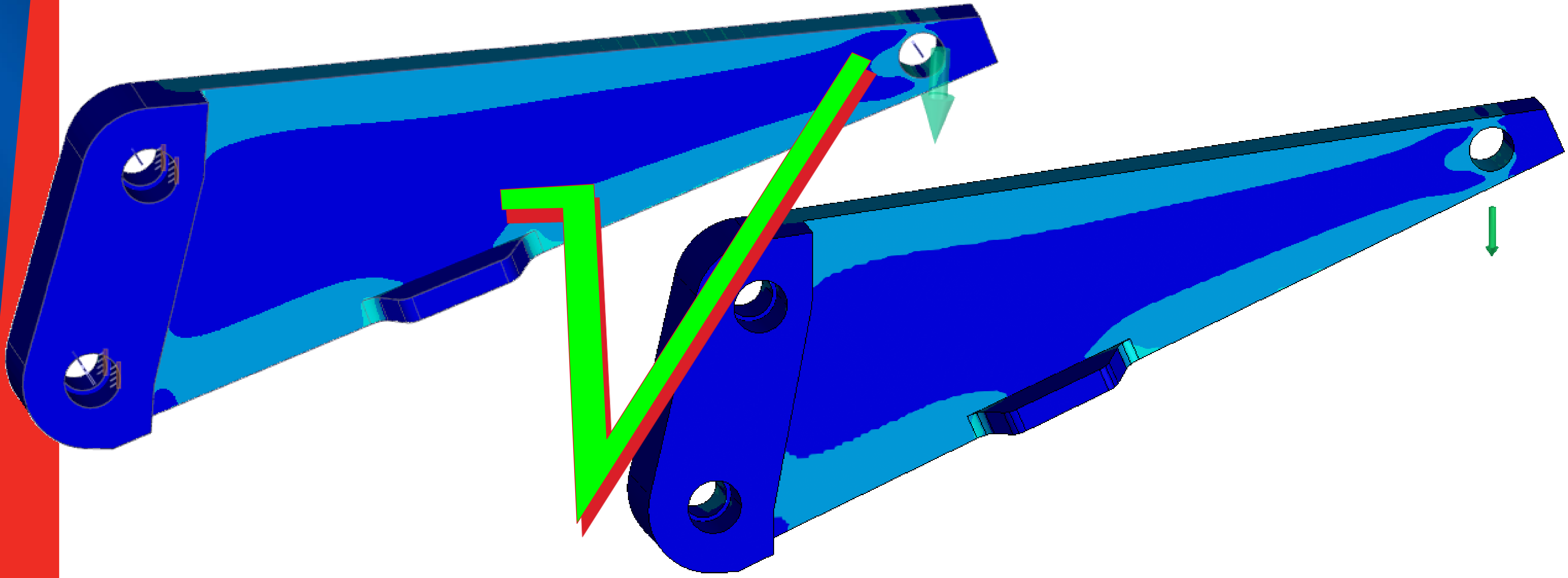
- Process: Machine Stock
- Weight: 290.7g
- Von Mises Stress Scale: 0 – 3e+7
- Analysis: Good



Results Courtesy of ANSYS Discovery Live

Simple Bracket

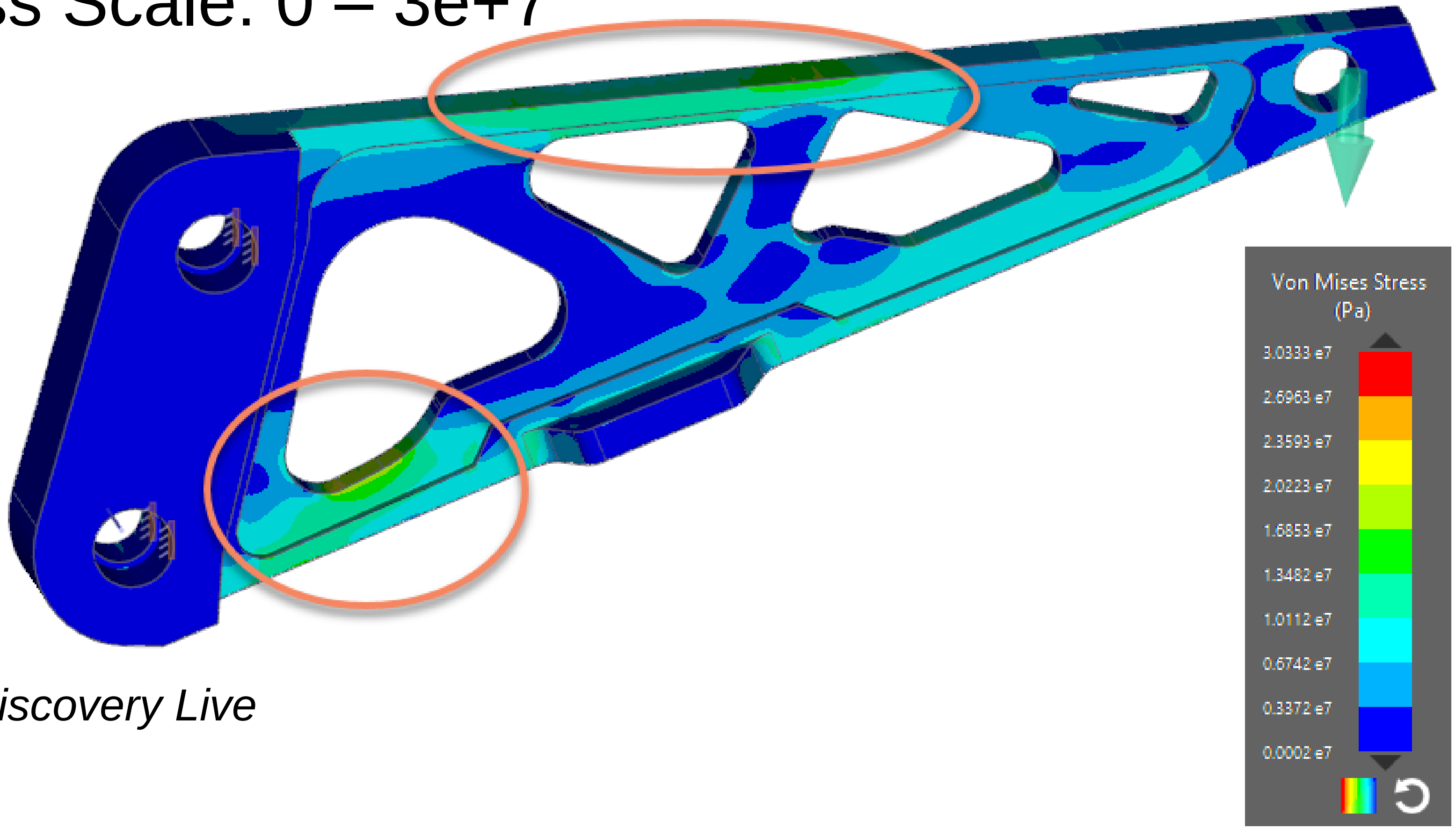
ANSYS result compared to VGSTUDIO MAX Structural Mechanical Simulation (SMS) Result



Simple Bracket

Modified **Design** Result

- Process: Machine (pocketed) from Casting
- Weight: 174.1g (40% reduction)
- Von Mises Stress Scale: 0 – 3e+7
- Analysis: Good



Results Courtesy of ANSYS Discovery Live

Simple Bracket

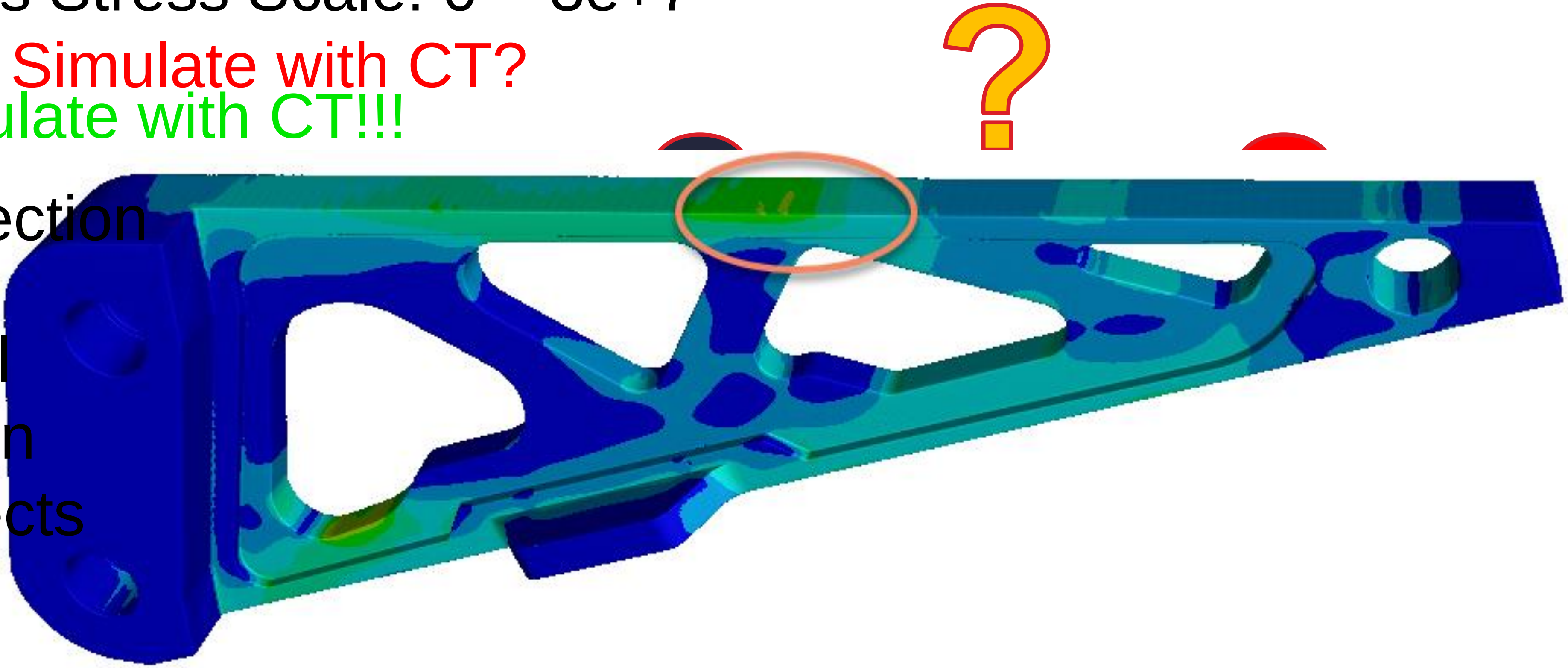
Modified **Actual** Result

- Process: Machine (pocketed) from Casting
- Weight: 174.1g (40% reduction)
- Von Mises Stress Scale: 0 – 3e+7
- Analysis: Simulate with CT?

- Analysis: Simulate with CT!!!

- Void Detection

- Structural Simulation with Defects

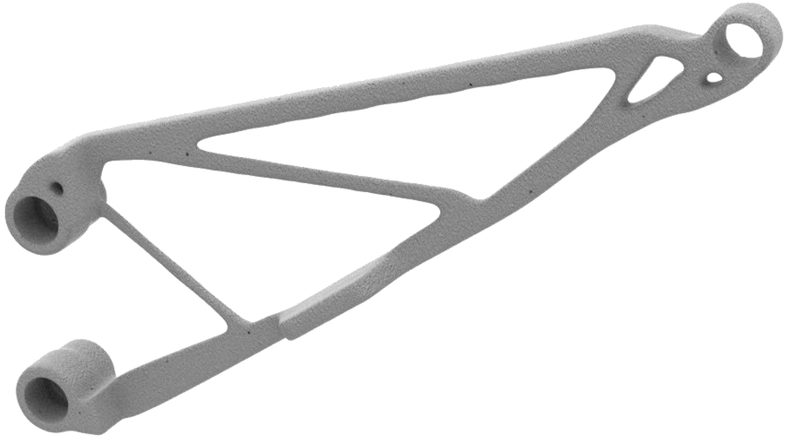


Bracket Summary

- Iterating between design and manufacturing phases produce results that help to define the final design and manufacturing process.
- Traditional CAE tools prove invaluable during the **design** phase.
- Traditional CAE tools require an STL with defects included, typically a low resolution mesh to compute FEA.
- VGSTUDIO MAX provides multiple analyses of a CT scanned part in one application.
- Defects of size and impurity are utilized when processing FEA on a CT scanned part with Structural Mechanical Simulation.
- Structural Mechanical Simulation uses **voxels**, not facets (**meshless**) to analyze complex structures accurately.

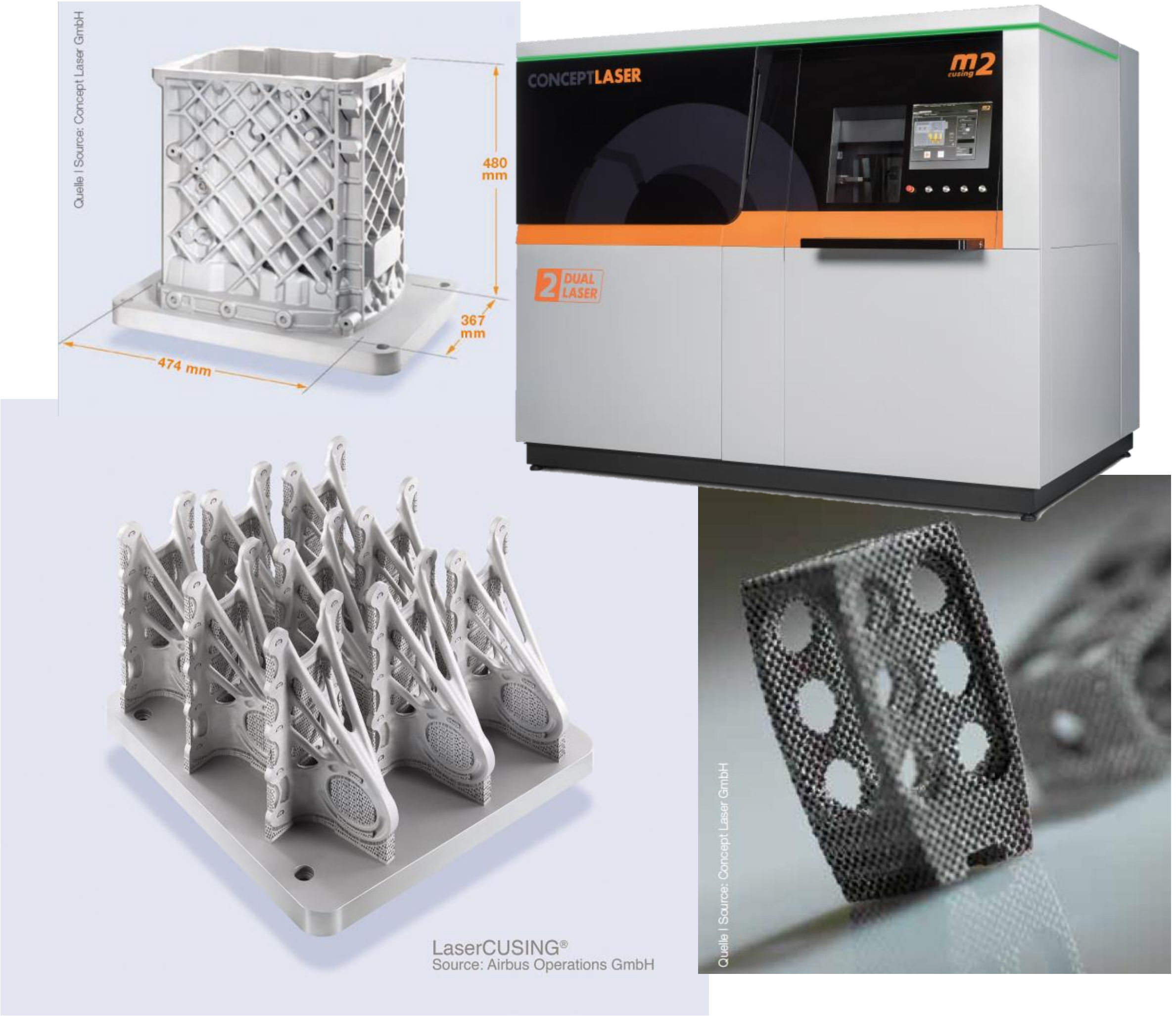
Additive Manufacturing contains Defects

Discoverable using CT & VGStudio MAX



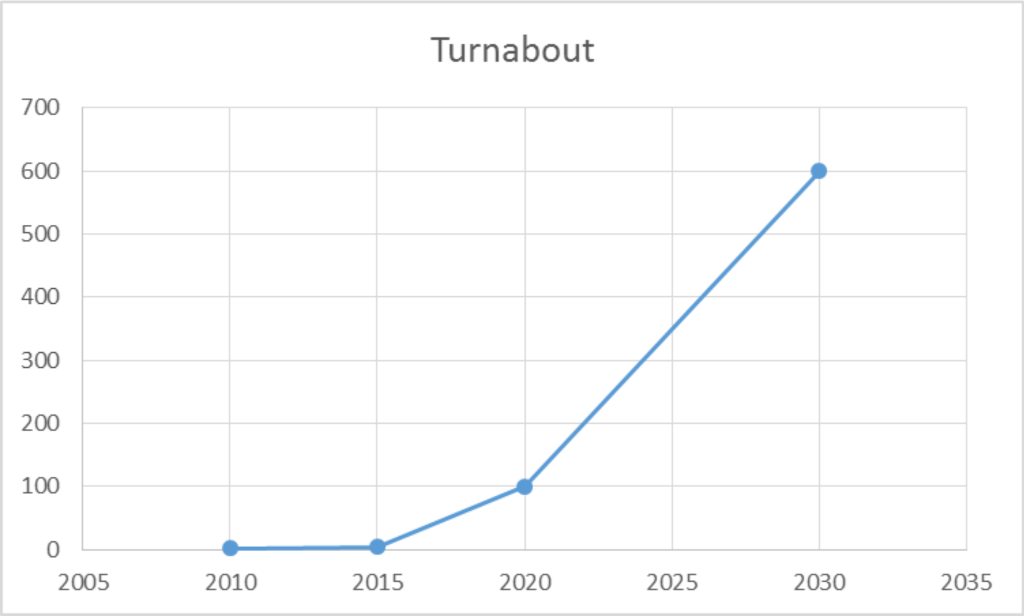
Additive Manufacturing (AM)

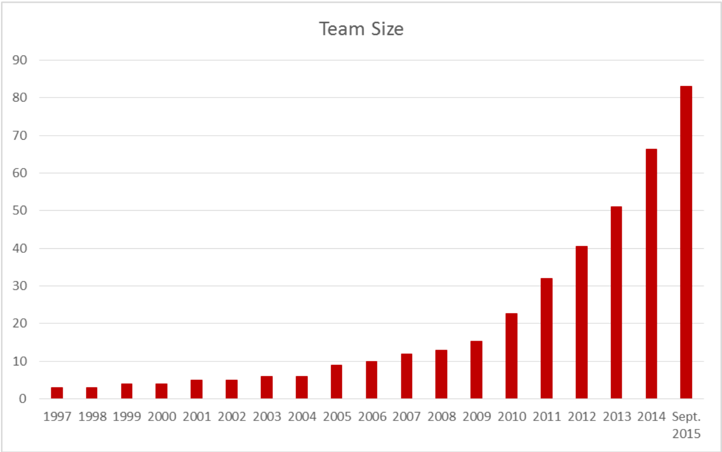
- AM is on its way to establish itself as additional production tool in various industries' toolboxes.
- CT is used as an inspection tool for AM for many obvious reasons. We at VG have seen AM driving industry segments in:
  - Aerospace
  - Automotive
  - Medical Devices
  - Industrial Machinery
  - …



Addictive Additive

- The only rapid growing Industry in Manufacturing
- 2016: 5 Billion
- 2020: 80 Billion
- 2030: 800 Billion





- Average growth between 30% and 50%
  - Their growth will support our growth

The Advantages of 3D Printing

1. Design Freedom
2. Complex Geometry
3. Minimal Tooling
4. Weight Optimization
5. Reduction of SKUs
6. Rapid Prototyping
7. High Value / Low Volume
   Time to Market

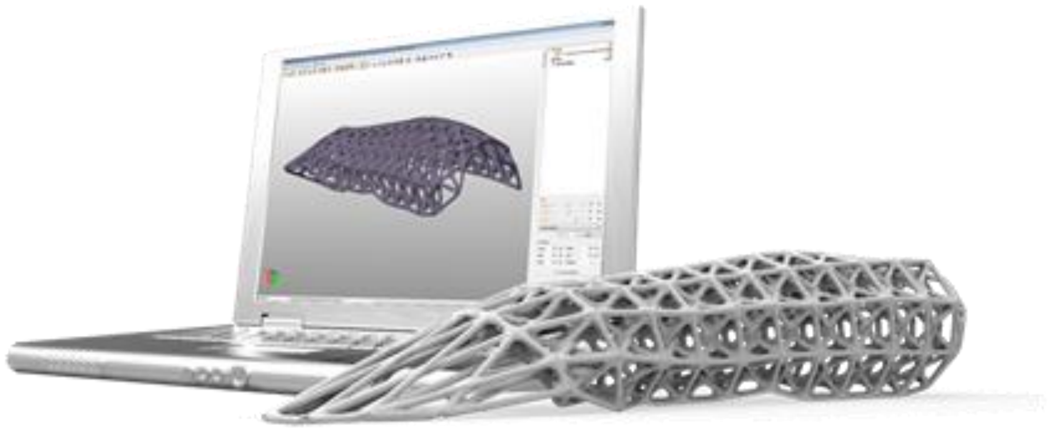


Image courtesy of Nettfabb

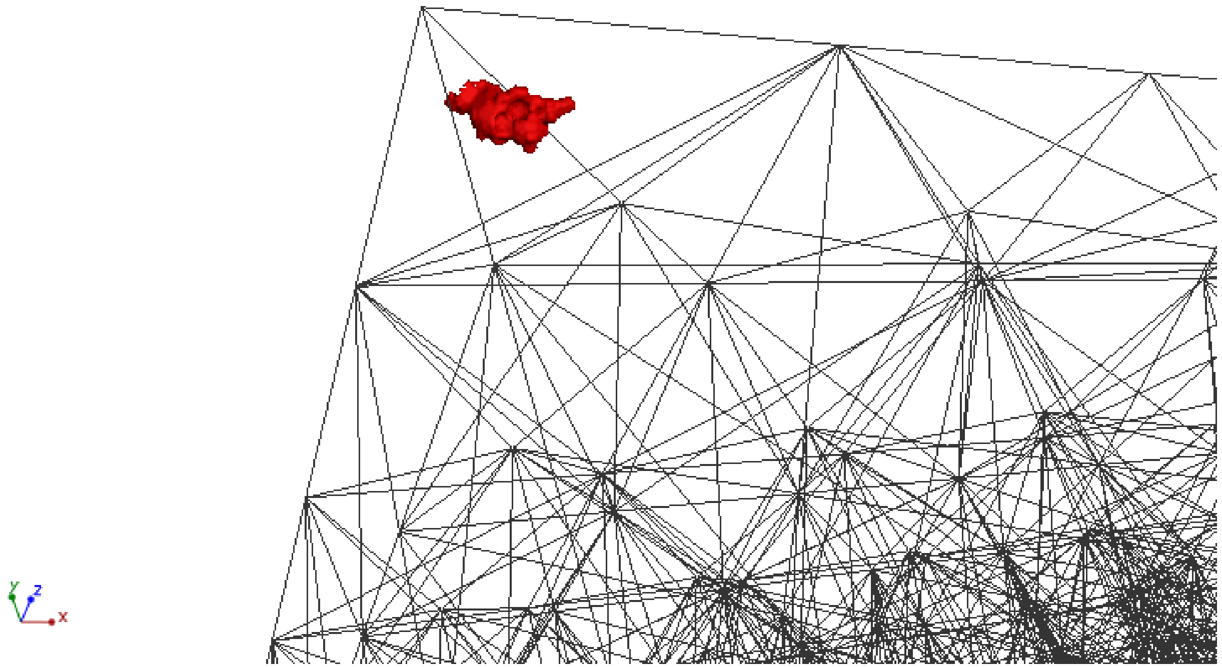
Mechanical Simulation of CT data

- In the past we learned calculating str analysis on "real", non CAD data in th traditional way can be quite complica
  - Customers have stated several times, t meshing the data into a suitable Finite Element (FE) model is often a challenge

    "Generating usable FE meshes from CT complex process itself, that can take lo than the actual FE calculation."

  - VG has been asked many times to exp geometries as STL meshes so that they be integrated into FE models and calculations.

  - But the defect data was often on a too small scale compared to the FE simulation grid cell size.



The challenges of AM

- Dimensions Outside
- Dimensions Hidden
- Dimensions Inside
- Porosity / Voids
- Inclusions
- Cracks
- Density
- Lacks of Fusion
- Wall thickness
- Lattice Analyses
- Surface Quality
- Residual Stresses

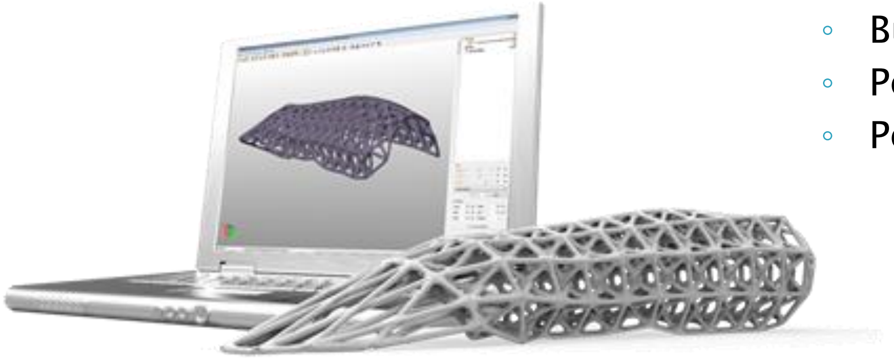


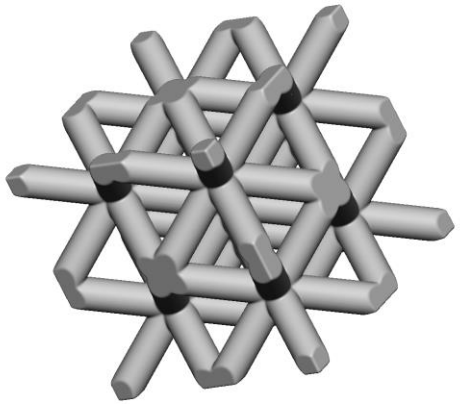
Image courtesy of Netfabb

- Dimensional and Defects caused by
  - Energy Density
  - Uneven cooling
  - Buckling of thin walls
  - Warping by thermal stress & rapid solidification
  - Distortion / lift off due to residual stresses
  - Burn / Melt through
  - Powder Contamination
  - Powder Inconsistencies

CT versus CMM & Optical Scanners

CT

- Dimensions Outside
- Dimensions Hidden
- Dimensions Inside
- Porosity / Voids
- Inclusions
- Cracks
- Density
- Lacks of Fusion
- Wall thickness
- Lattice Analyses
- Surface Quality



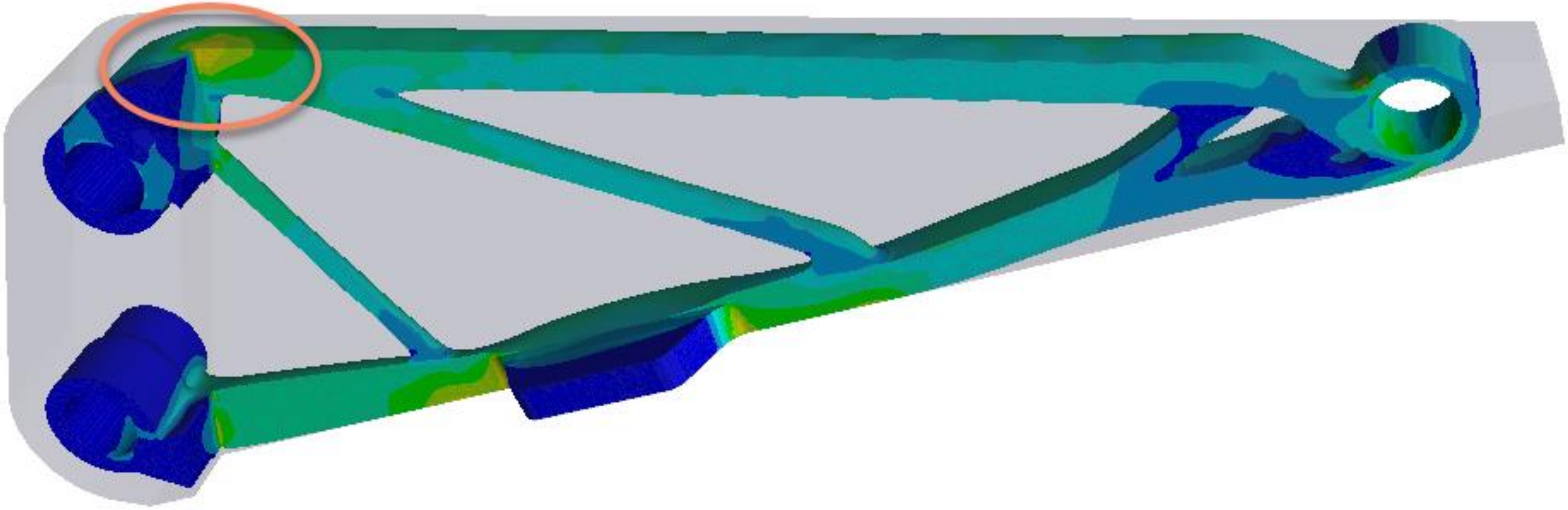
CMM / Optical Scanner

- Dimensions Outside
- Dimensions Hidden
- Dimensions Inside
- Porosity / Voids
- Inclusions
- Cracks
- Density
- Lacks of Fusion
- Wall thickness
- Lattice Analyses
- Surface Quality

Simple Bracket

Optimized Design Result

- Process: **Additive Manufacturing**
- Weight: 71.7g (75% reduction)
- Von Mises Stress Scale: 0 – 3e+7
- Analysis: Good



Optimized model via FEA courtesy of Frustum Generate

Simple Bracket

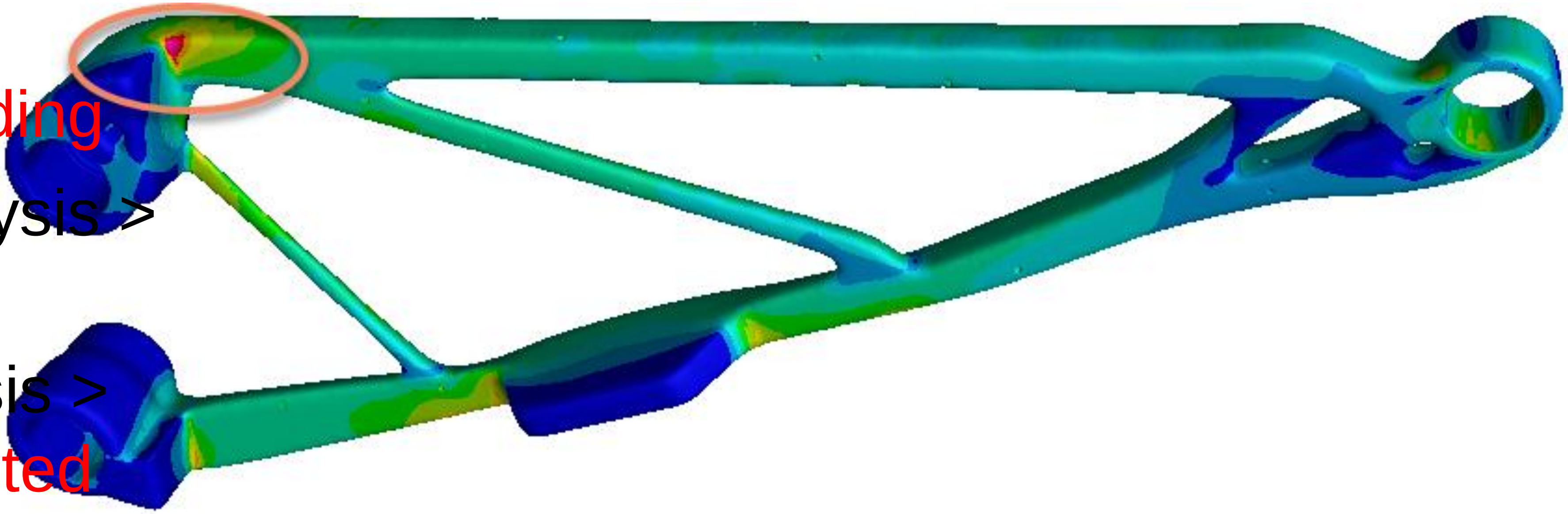
Optimized **Actual** Result

- Process: Additive Manufacturing
- Weight: 71.7g (75% reduction)
- Von Mises Stress Scale: 0 – 3e+7
- Analysis: Marginal

- Deviation Analysis >
- Shrinkage
- Edge Rounding

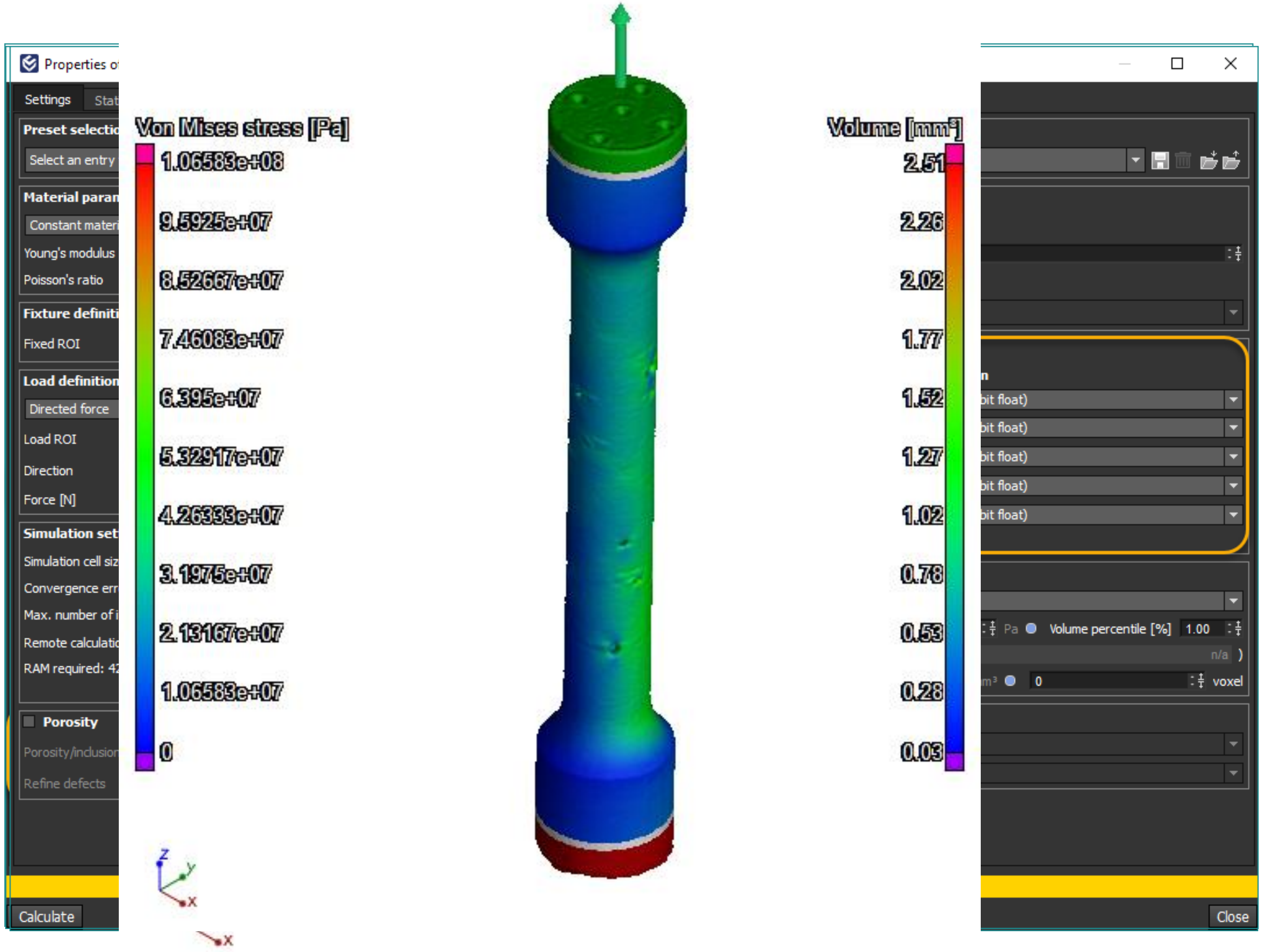
- Defect Analysis >
- Voids found

- SMS Analysis >
- Strain detected



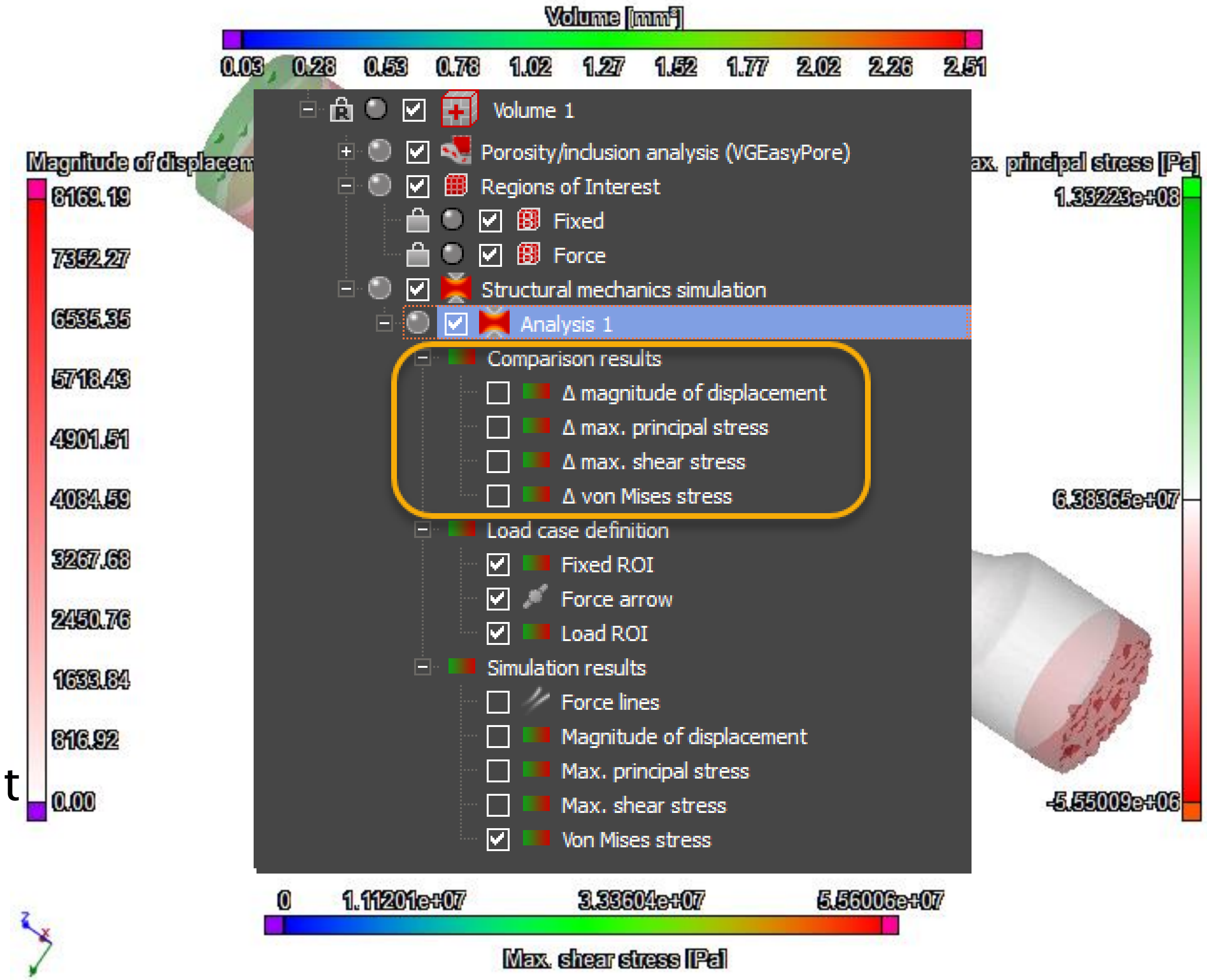
VGSM Stress Analysis

- Simple steps how to:
  - Open your VGL data set or import your data and apply a surface determination.
  - Perform a Porosity/Inclusion Analysis.
  - Create an ROI where the part is fixed and an ROI where force is applied.
  - Select the SMS command.
  - Apply the material properties.
  - Select the Force type, and the "Fixed"/"Load" ROIs.
  - Define Force Direction and Magnitude.
  - Add Porosity Analysis.
  - Select Visualizations.
  - Calculate.



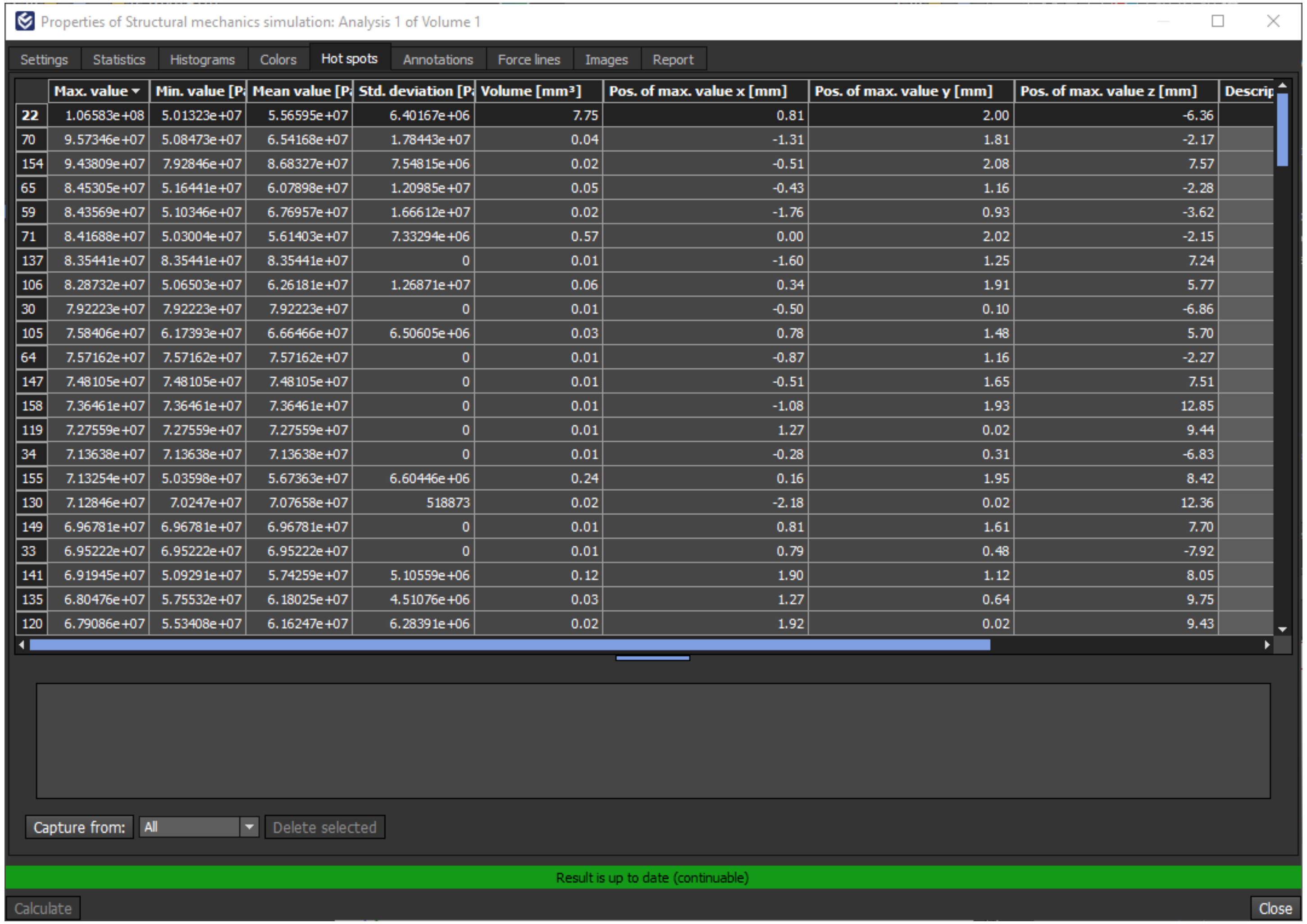
Stress Analysis Results

- There are numerous result visualizations, all visualizations have their own color bar and scene tree entry.
- For Volumes
  - Force Lines
  - Magnitude of Displacement
  - Max. Principal Stress
  - Max. Shear Stress
  - Von Mises Stress
- Also if a CAD SMS is available
  - Comparison of CAD Displacement
  - Comparison of CAD Principal Stress
  - Comparison of CAD Shear Stress
  - Comparison of CAD Von Mises Stress



Stress Analysis Results

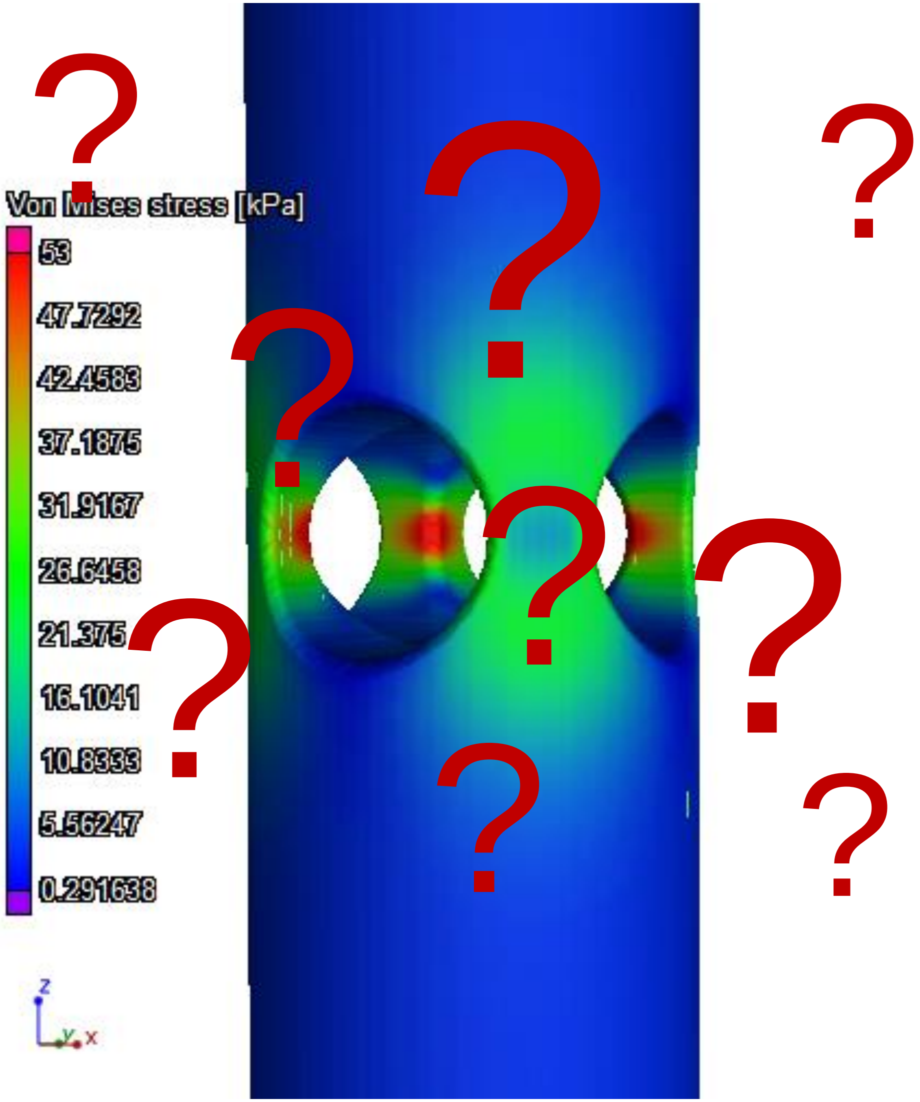
- Statistical results
- Histograms for each visualization
- Hot spots



	Max. value	Min. value [Pa	Mean value [Pa	Std. deviation [Pa	Volume [mm³]	Pos. of max. value x [mm]	Pos. of max. value y [mm]	Pos. of max. value z [mm]	Descrip
22	1.06583e+08	5.01323e+07	5.56595e+07	6.40167e+06	7.75	0.81	2.00	-6.36	
70	9.57346e+07	5.08473e+07	6.54168e+07	1.78443e+07	0.04	-1.31	1.81	-2.17	
154	9.43809e+07	7.92846e+07	8.68327e+07	7.54815e+06	0.02	-0.51	2.08	7.57	
65	8.45305e+07	5.16441e+07	6.07898e+07	1.20985e+07	0.05	-0.43	1.16	-2.28	
59	8.43569e+07	5.10346e+07	6.76957e+07	1.66612e+07	0.02	-1.76	0.93	-3.62	
71	8.41688e+07	5.03004e+07	5.61403e+07	7.33294e+06	0.57	0.00	2.02	-2.15	
137	8.35441e+07	8.35441e+07	8.35441e+07	0	0.01	-1.60	1.25	7.24	
106	8.28732e+07	5.06503e+07	6.26181e+07	1.26871e+07	0.06	0.34	1.91	5.77	
30	7.92223e+07	7.92223e+07	7.92223e+07	0	0.01	-0.50	0.10	-6.86	
105	7.58406e+07	6.17393e+07	6.66466e+07	6.50605e+06	0.03	0.78	1.48	5.70	
64	7.57162e+07	7.57162e+07	7.57162e+07	0	0.01	-0.87	1.16	-2.27	
147	7.48105e+07	7.48105e+07	7.48105e+07	0	0.01	-0.51	1.65	7.51	
158	7.36461e+07	7.36461e+07	7.36461e+07	0	0.01	-1.08	1.93	12.85	
119	7.27559e+07	7.27559e+07	7.27559e+07	0	0.01	1.27	0.02	9.44	
34	7.13638e+07	7.13638e+07	7.13638e+07	0	0.01	-0.28	0.31	-6.83	
155	7.13254e+07	5.03598e+07	5.67363e+07	6.60446e+06	0.24	0.16	1.95	8.42	
130	7.12846e+07	7.0247e+07	7.07658e+07	518873	0.02	-2.18	0.02	12.36	
149	6.96781e+07	6.96781e+07	6.96781e+07	0	0.01	0.81	1.61	7.70	
33	6.95222e+07	6.95222e+07	6.95222e+07	0	0.01	0.79	0.48	-7.92	
141	6.91945e+07	5.09291e+07	5.74259e+07	5.10559e+06	0.12	1.90	1.12	8.05	
135	6.80476e+07	5.75532e+07	6.18025e+07	4.51076e+06	0.03	1.27	0.64	9.75	
120	6.79086e+07	5.53408e+07	6.16247e+07	6.28391e+06	0.02	1.92	0.02	9.43	

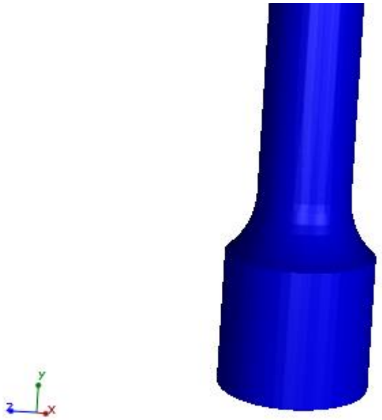
Stress Analysis Tool Validation

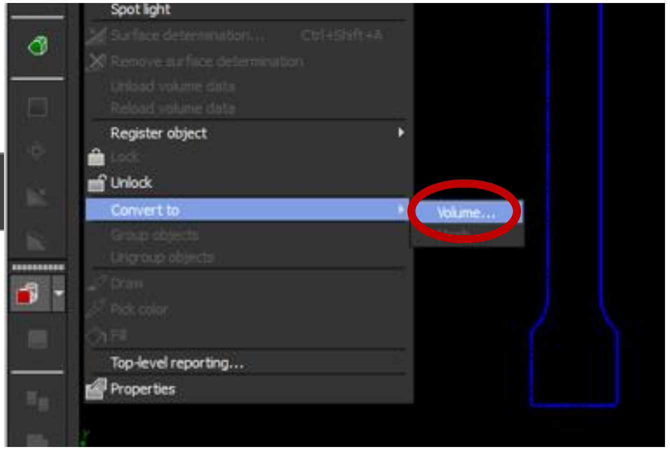
- Can we trust in the calculated results?



Stress Analysis Tool Validation

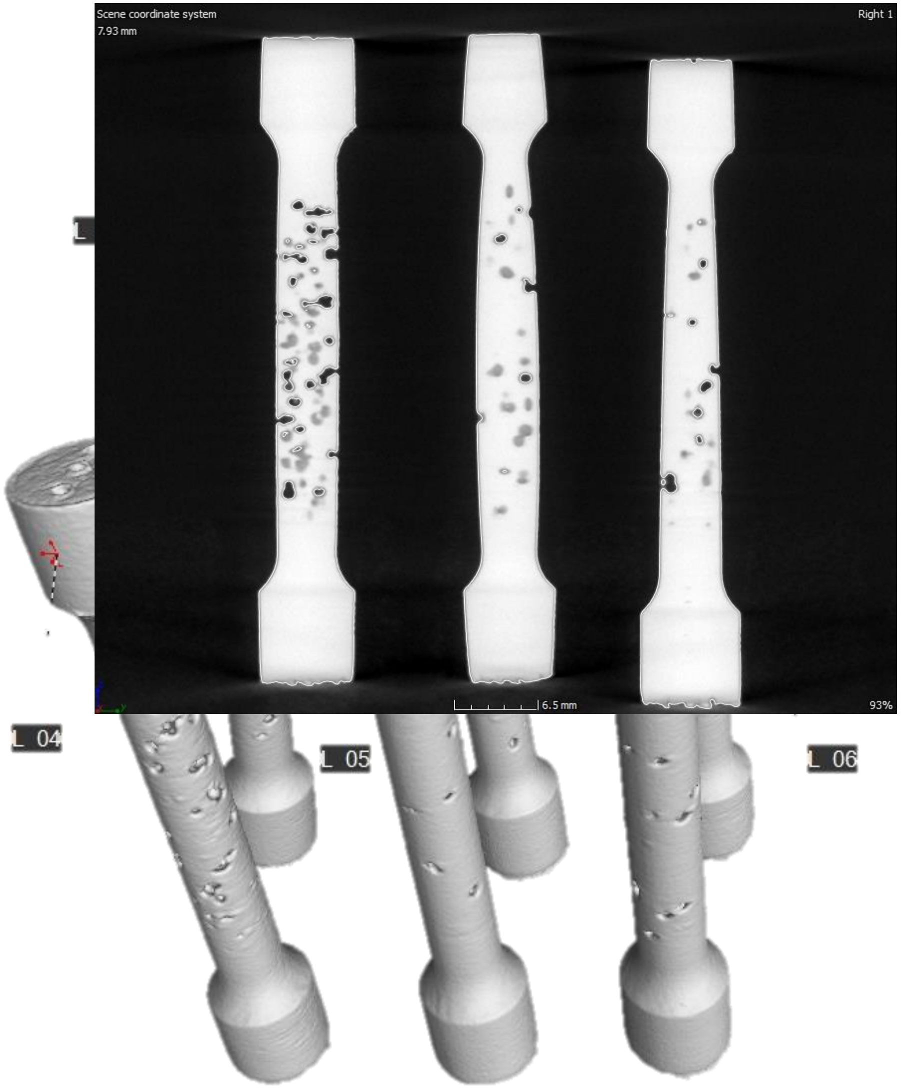
- To validate our new tool we performed classical tension rod experiments.
- The rods were built by Additive Manufacturing in Aluminum by Concept Laser in Lichtenfels.
- Using VGSTUDIO MAX we designed 6 different kind of tension rods with 75, 125 or 250 pores in two different random pore distributions each.
  - We imported the tension rod template in STL file format,
  - converted it into a voxel data set,
  - inserted voids,
  - and converted it back to STL for AM.
- Concept Laser printed 3 samples of each kind in CL 31 Aluminium. The parts have not been heat-treated.





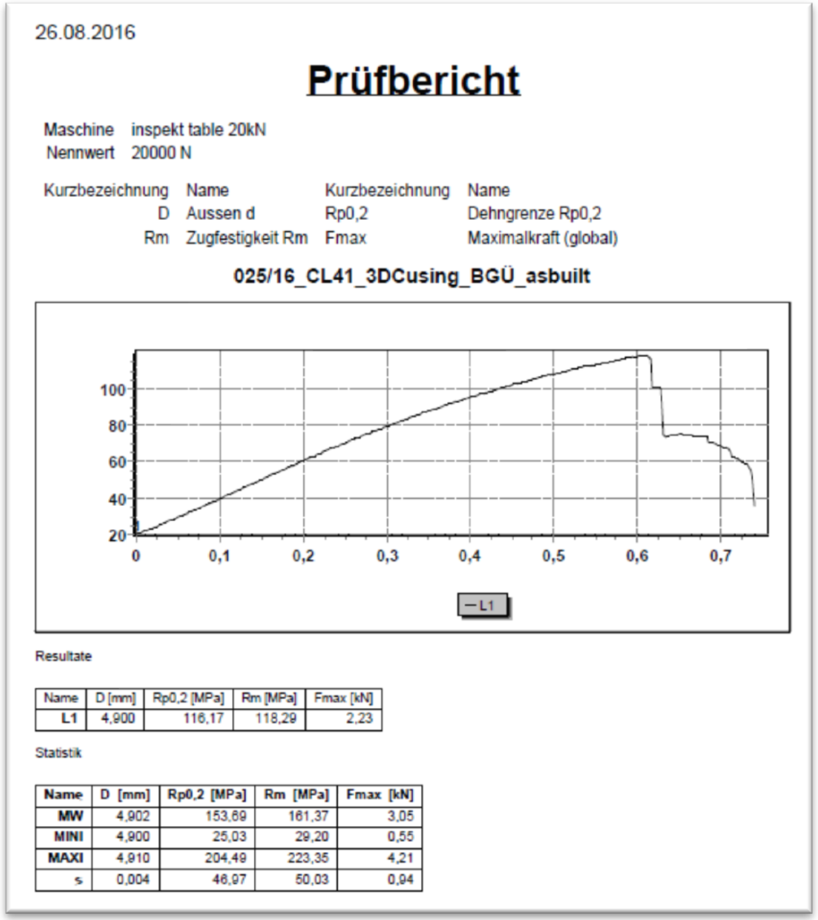
Stress Analysis Tool Validation

- Before testing all 18 samples have been CT scanned.



Tension Rods – Pull Test

- Concept Laser performed pull tests on all 18 samples.



26.08.2016

Prüfbericht

Maschine inspekt table 20kN
Nennwert 20000 N

Kurzbezeichnung	Name	Kurzbezeichnung	Name
D	Aussen d	Rp0,2	Dehngrenze Rp0,2
Rm	Zugfestigkeit Rm	Fmax	Maximalkraft (global)

025/16_CL41_3DCusing_BGÜ_asbuilt

Resultate

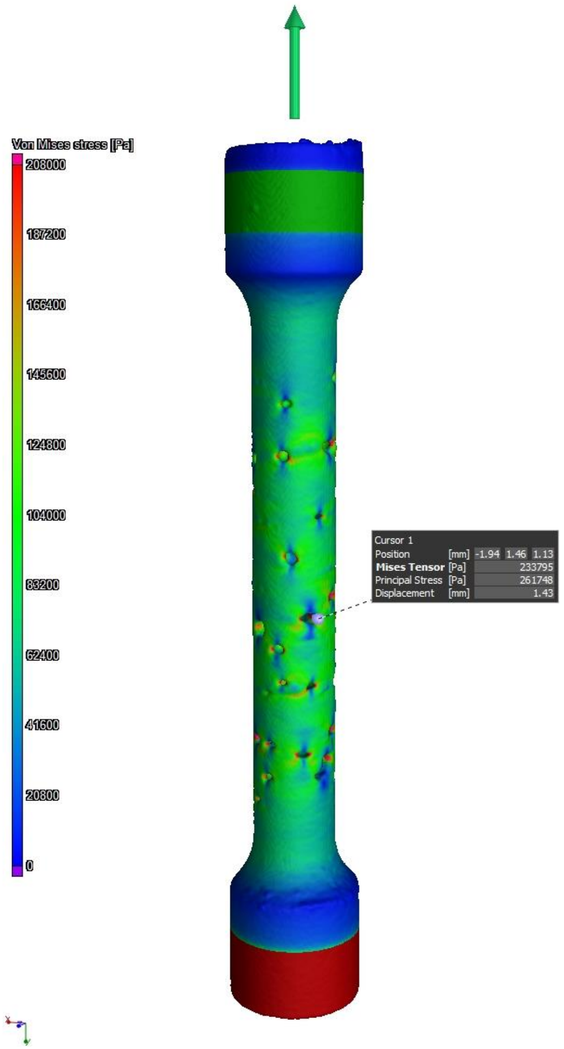
Name	D [mm]	Rp0,2 [MPa]	Rm [MPa]	Fmax [kN]
L1	4,900	116,17	118,29	2,23

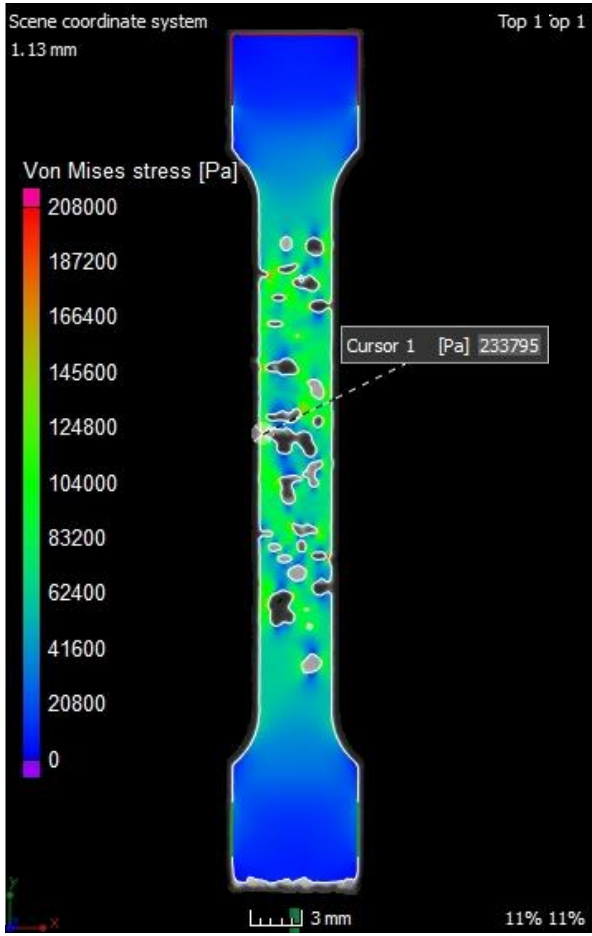
Statistik

Name	D [mm]	Rp0,2 [MPa]	Rm [MPa]	Fmax [kN]
MW	4,902	153,69	161,37	3,05
MINI	4,900	25,03	29,20	0,55
MAXI	4,910	204,49	223,35	4,21
s	0,004	46,97	50,03	0,94

Stress Analysis Tool Validation

- In parallel we performed our Stress Analysis on all 18 CT data sets and …
- calculated the predicted tensile strength.

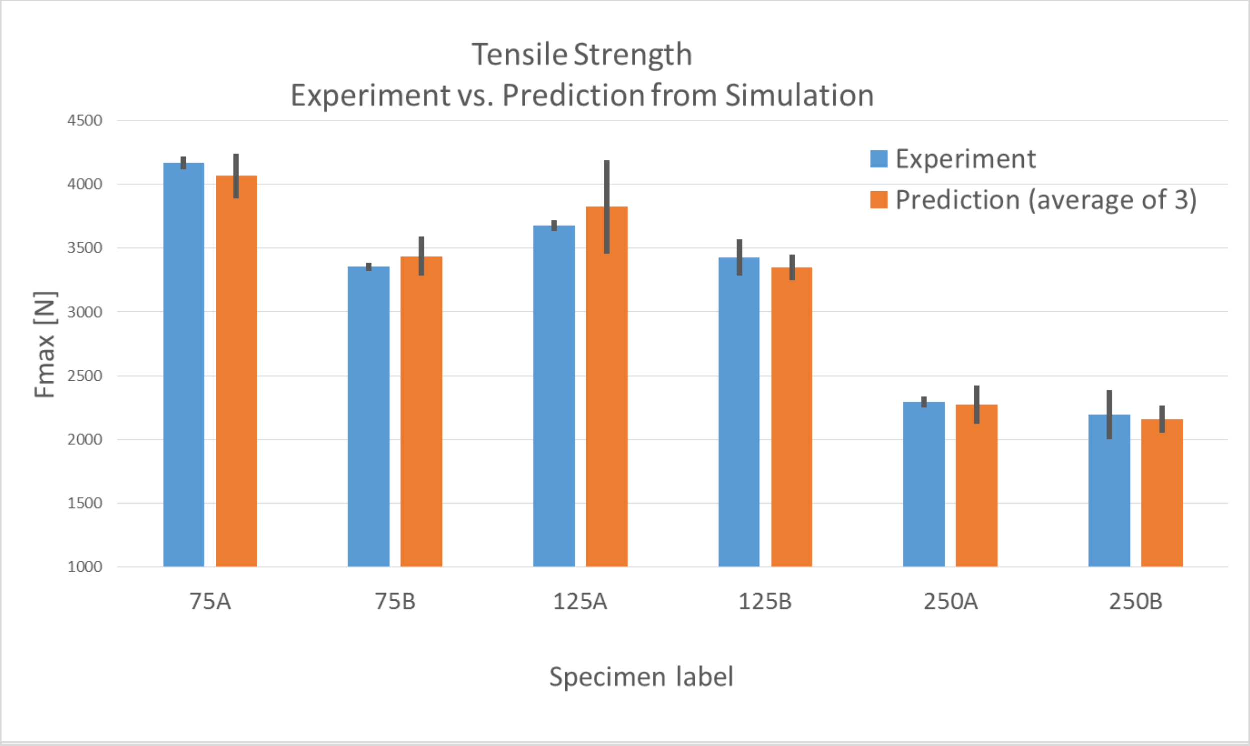




Validation Results

- Here are the results:

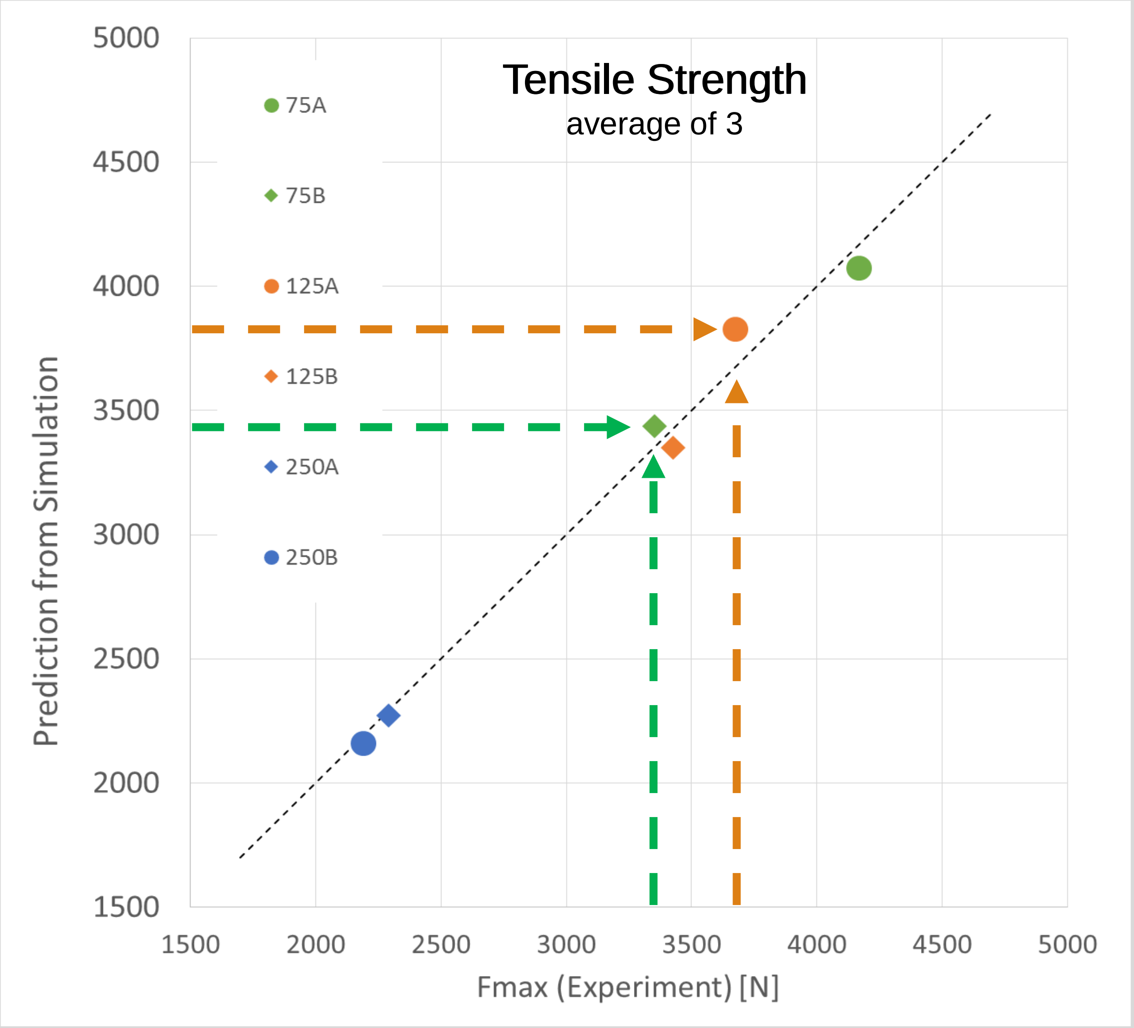
- The excellent correlation results between experiment and simulation



Prediction data has been scaled by a uniform scaling factor.
Error bars indicate the Std. Dev. within a set of 3 samples.

Validation Results

- Here are the results displayed as scatter plot.
- We can see that the strength of the rods do not depend on the total number of pores only but on their distribution within the sample as well.
- The sample with 125 pores shows a higher tensile strength in the experiment than …
- the sample with 75 pores and …
- we can predict that with our simulations!



Prediction data has been scaled by a uniform scaling factor.

Validation on “Real” Parts

- With friendly support from Airbus Emerging Technologies & Concepts we have been allowed to use their **bionic cabin bracket** that is used in the Airbus A350 XWB for our tests.
- The original part is build by Concept Laser in Titanium CL 41TI ELI (TiAl6V4 ELI) with their additive LaserCUSING® process.
- For our tests the parts were build in Aluminum at approx. half size.

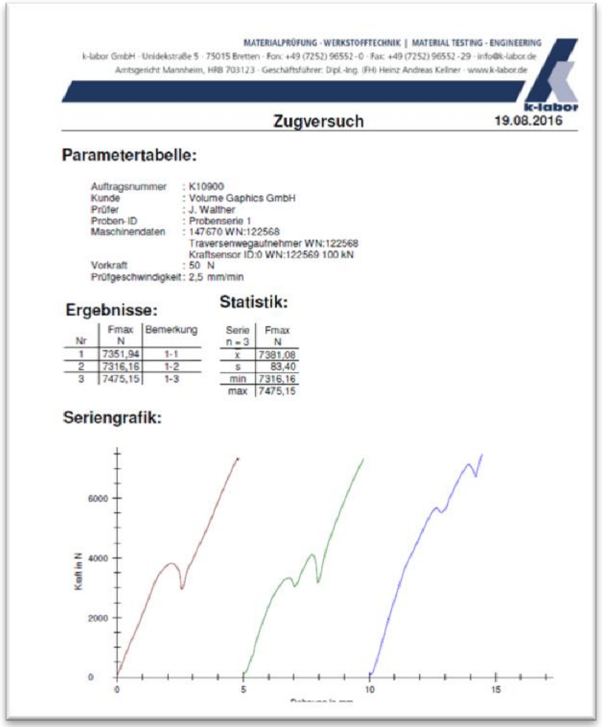
Bionic cabin bracket in Airbus A350 XWB built on **M2 cusing /** Material CL 41TI ELI (TiAl6V4 ELI) / Lightweight natural construction solutions can be generated almost 1:1 with the additive LaserCUSING® process. The laser-generated component with an optimized structure delivers a weight saving of more than 30% compared with the component produced by conventional means!

Bionic Cabin Bracket

- Again we designed 6 different kind of brackets with statistically varying pore distributions or defects and provided the STL files to Concept Laser.
- Concept Laser printed 3 samples of each kind in CL 31 Aluminium. The parts have not been heat-treated.
- All 18 samples have been CT scanned.

Bionic Cabin Bracket – Pull Test

- On all 18 samples a pull test was performed at k-Labor GmbH.



MATERIALPRÜFUNG · WERKSTOFFTECHNIK | MATERIAL TESTING · ENGINEERING
k-labor GmbH · Unidekstraße 5 · 75015 Bretten · Fon: +49 (7252) 96552-0 · Fax: +49 (7252) 96552-29 · info@k-labor.de
Amtsgericht Mannheim, HRB 703123 · Geschäftsführer: Dipl.-Ing. (FH) Heinz Andreas Kellner · www.k-labor.de

k-labor

Zugversuch 19.08.2016

Parametertabelle:

Auftragsnummer : K10900
Kunde : Volume Gaphics GmbH
Prüfer : J. Walther
Proben-ID : Probenserie 1
Maschinendaten : 147670 WN:122568
Traversenwegaufnehmer WN:122568
Kraftsensor ID:0 WN:122569 100 kN
Vorkraft : 50 N
Prüfgeschwindigkeit : 2,5 mm/min

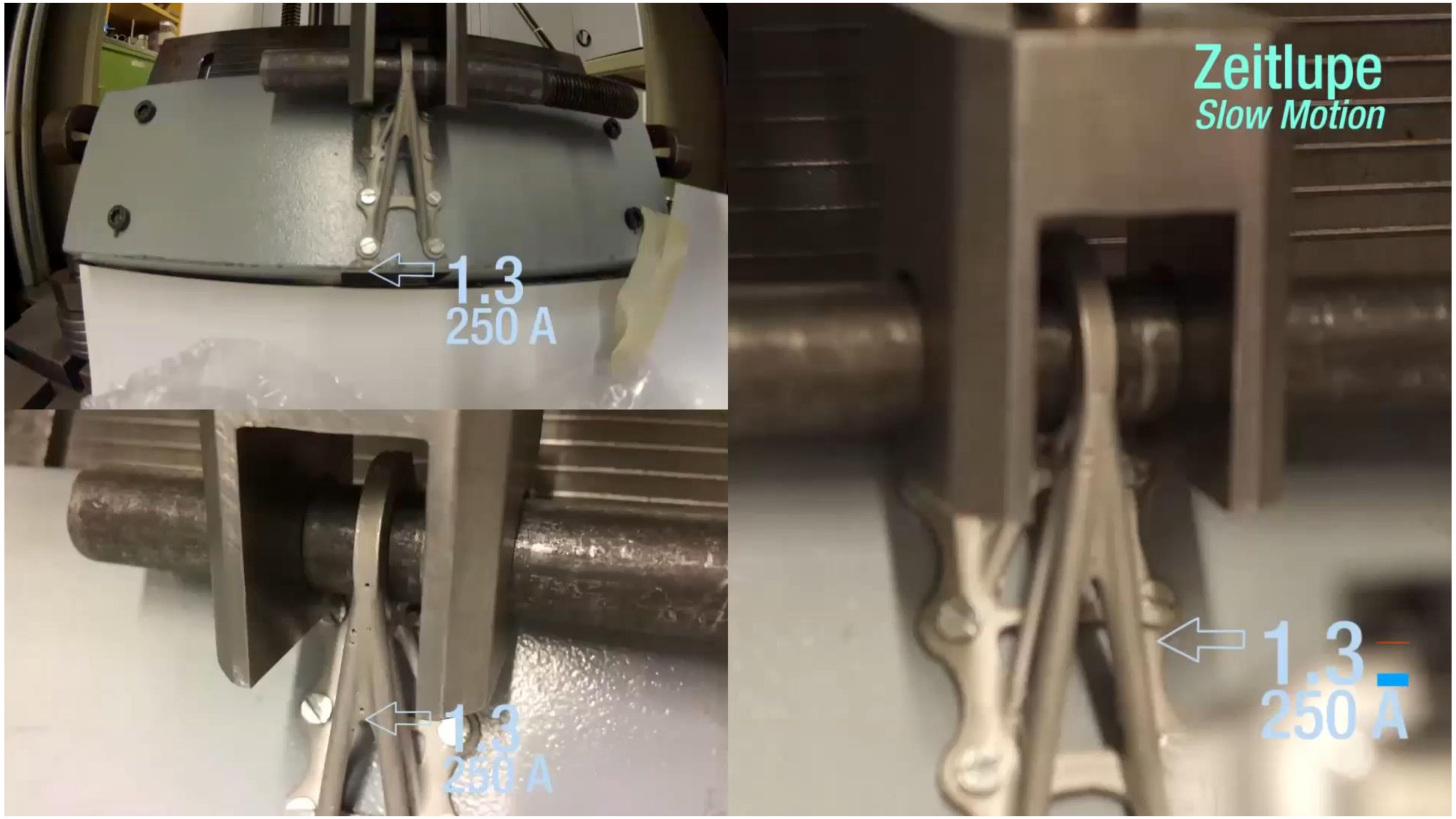
Ergebnisse:

Nr	Fmax N	Bemerkung
1	7351,94	1-1
2	7316,16	1-2
3	7475,15	1-3

Statistik:

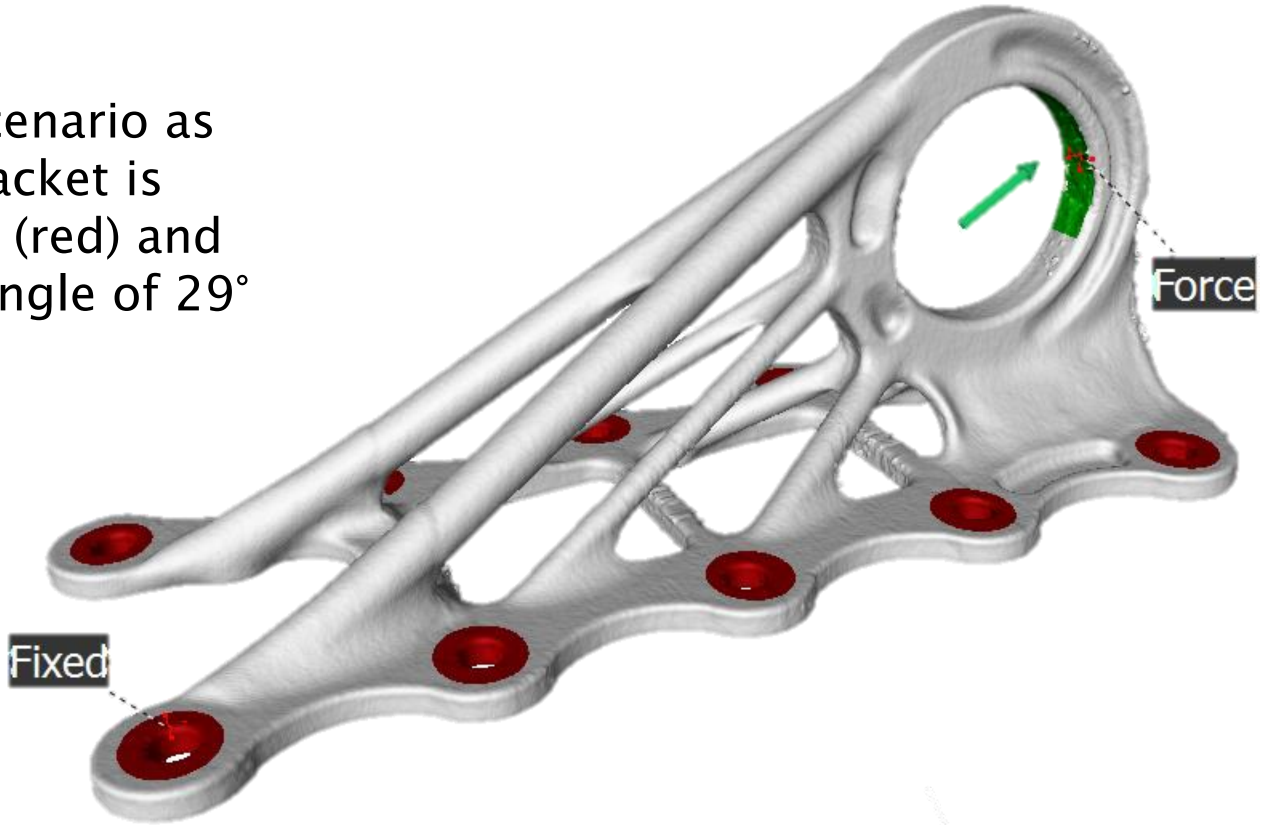
Serie n = 3	Fmax N
x	7381,08
s	83,40
min	7316,16
max	7475,15

Seriengrafik:



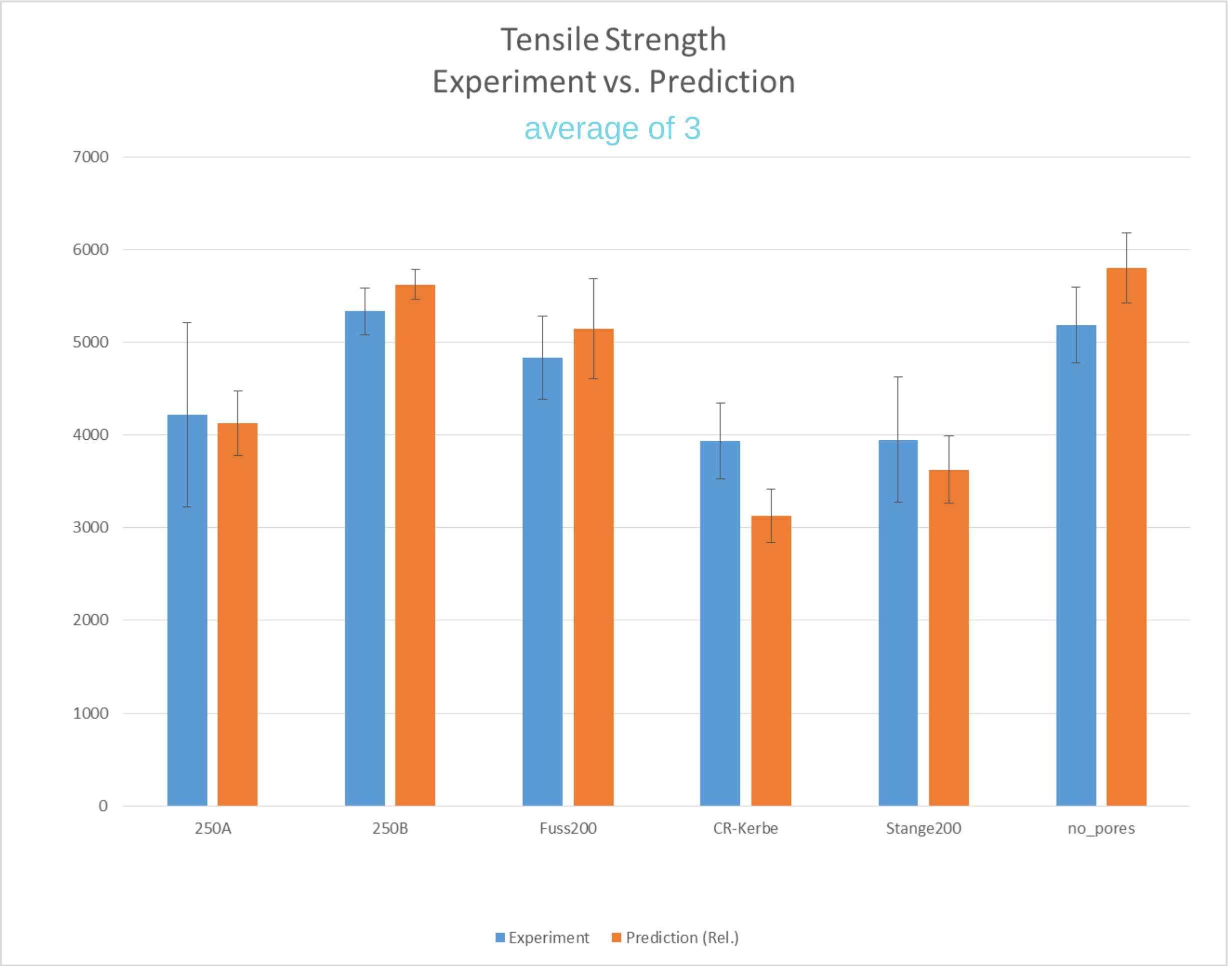
Bionic Cabin Bracket – Load Scenario

- We calculated simulations on all 18 samples' CT-data sets.
- We used the same predefined load scenario as used in the experiment where the bracket is fixed to the ground plate by 10 bolts (red) and the application of force is under an angle of 29° into the ring (green).



Bionic Cabin Bracket – Results

- Here are the results:
- The excellent correlation results between experiment and simulation



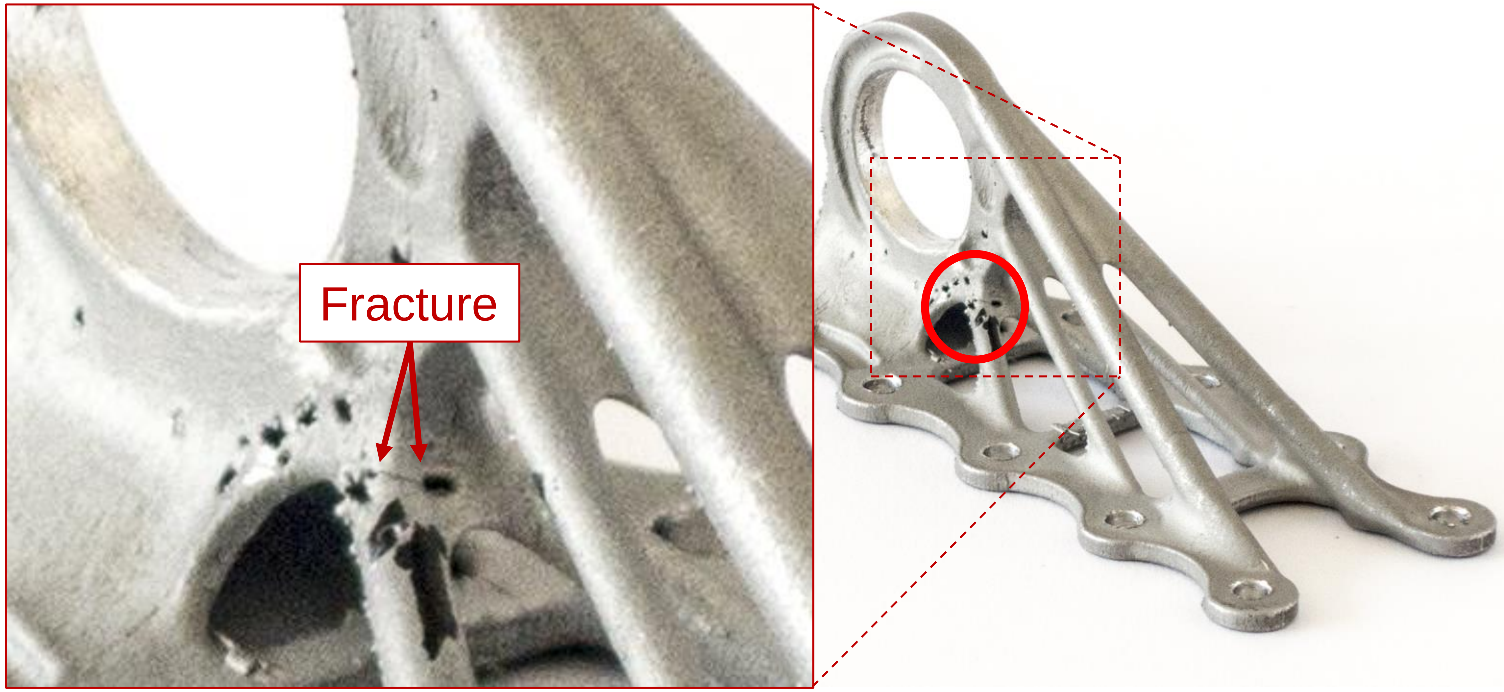
Prediction data has been scaled by a uniform scaling factor.

Predicted Hotspots vs Actual Failure Position

- Sample 1.1
- Prediction hotspot #1
- Fractured in the ring

Predicted Hotspots vs Actual Failure Position

- Sample 3.2
- Prediction hotspot #2
- Fractured in the lower strut



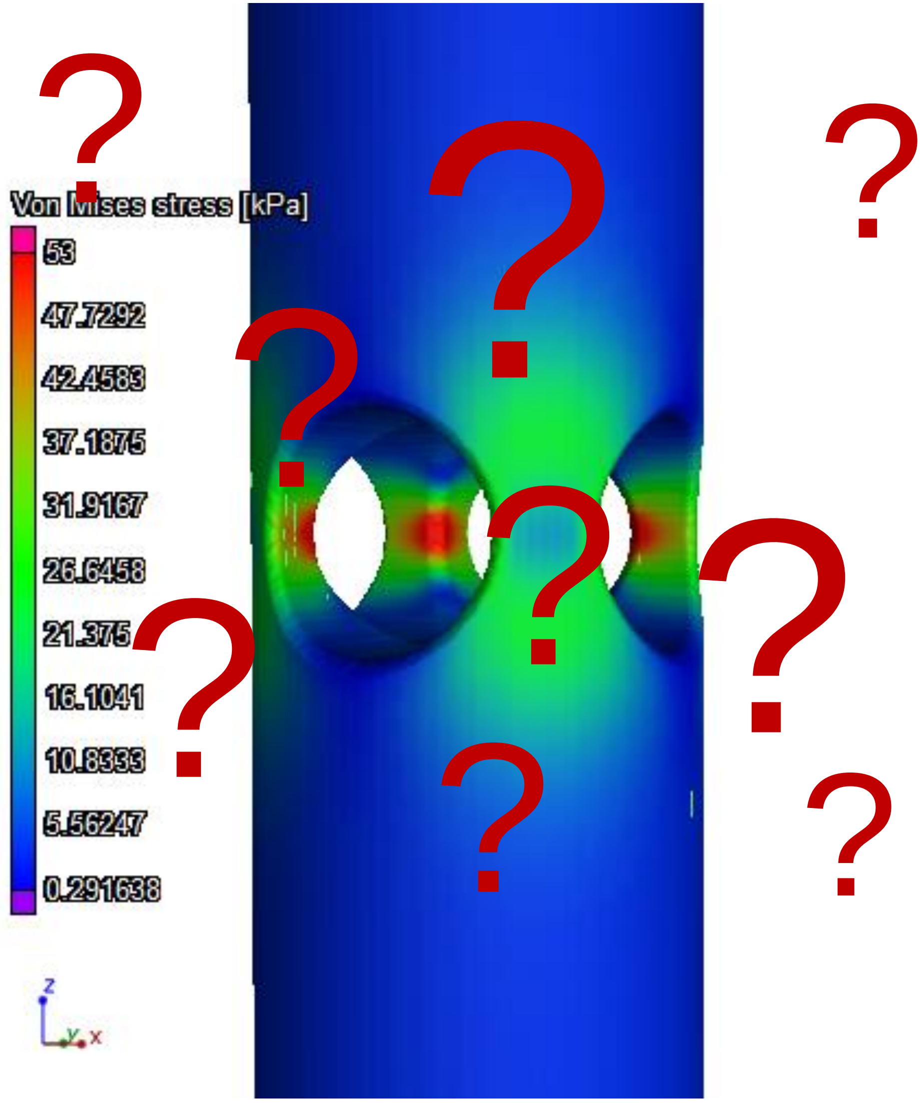
Predicted Hotspots vs Actual Failure Position

- Sample 5.2
- Prediction hotspot #1
- Fractured in the struts

Stress Analysis Tool Validation

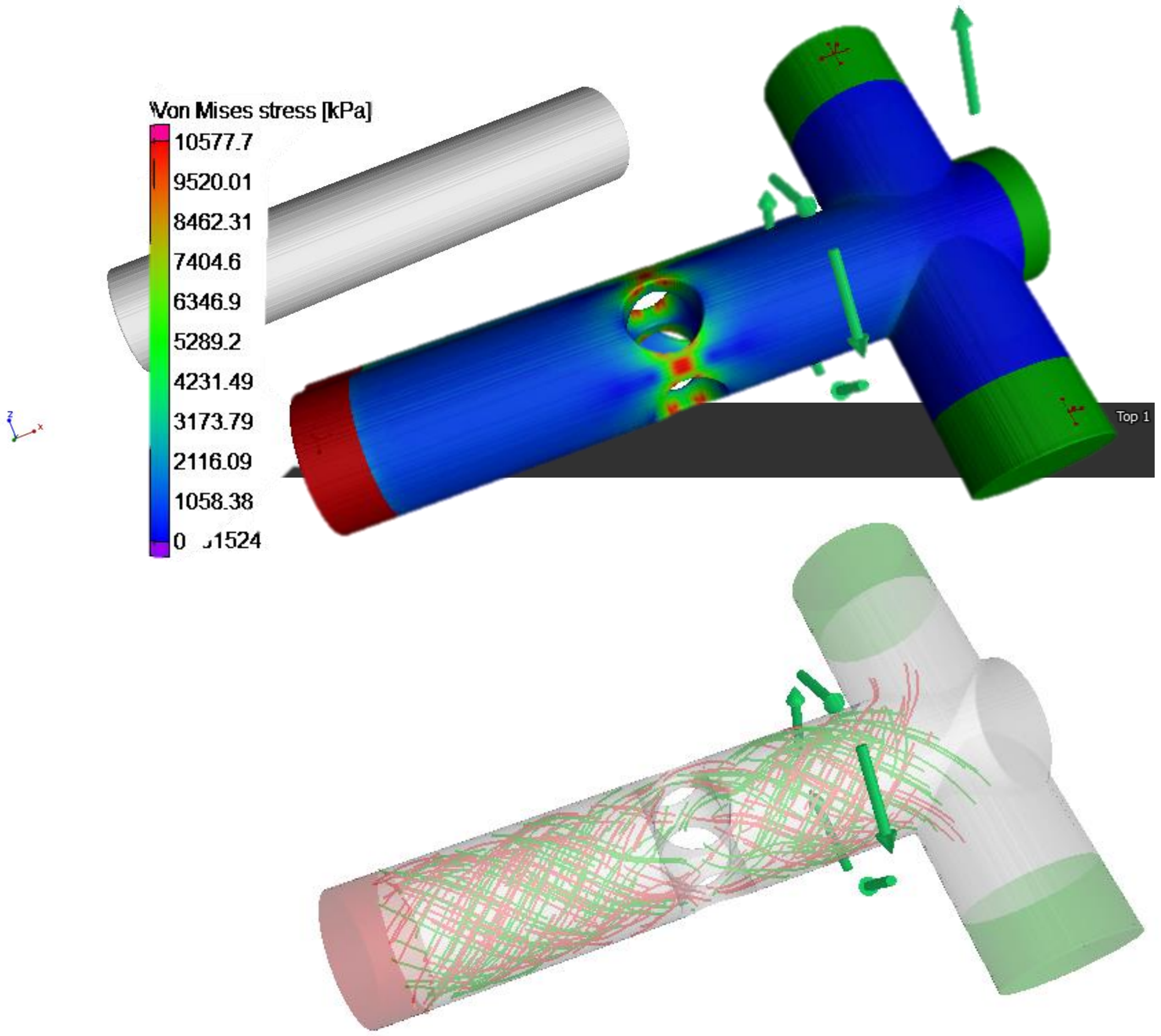
- Can we trust in the calculated results?

- **Yes we can!**



Structural Mechanical Simulation

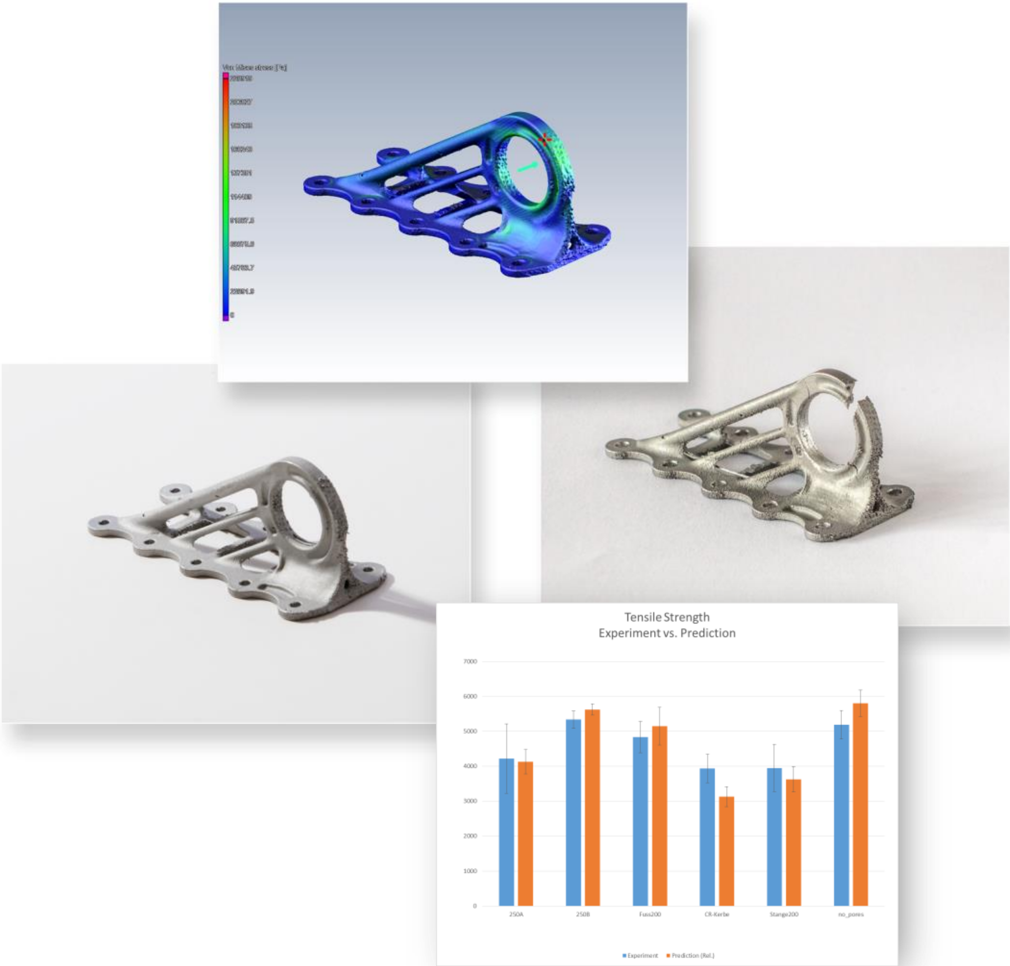
- Our Stress Analysis module allows simulation of linear stress on single and multi-material objects.
- It supports three force types:
  - Directed force
  - Torque
  - Pressure
- It calculates multiple stress plots directly on CT data, no meshing.



Volume Graphics VGSTUDIO MAX Structural Mechanical Simulation

- With the SMS module VG combines ease of use with other analysis types for the next level in digital inspection.

- The SMS module is available in VGSTUDIO MAX now.



Thank you