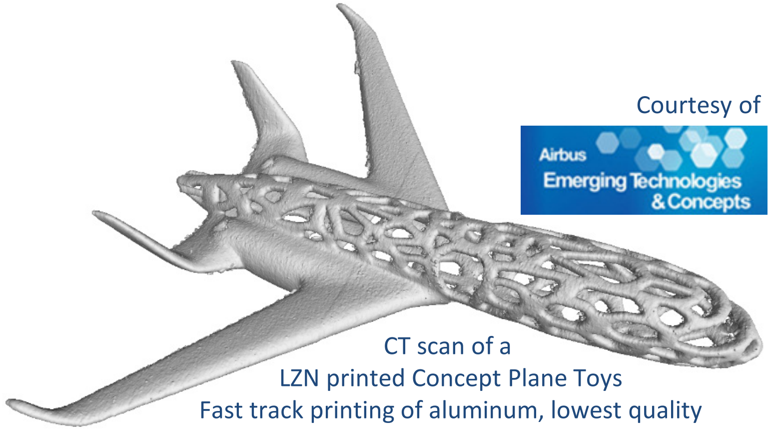

CT scan of a
LZN printed Concept Plane Toys
Fast track printing of aluminum, lowest quality

Utilising Computed Tomography in Additive Manufacturing (AM)

Jens Lübbehüsen – GE Digital Solutions – Sensing & Inspection Technologies

93. Fachkonferenz zerstörungsfreie Werkstoffprüfung, München – 14.9.2017

Outline

CT Principle

Added Values of CT in Additive Manufacturing

Example CT Results on AM workpieces

Conclusion

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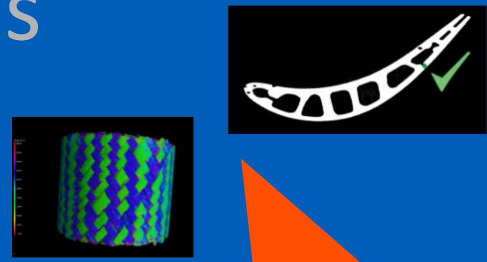
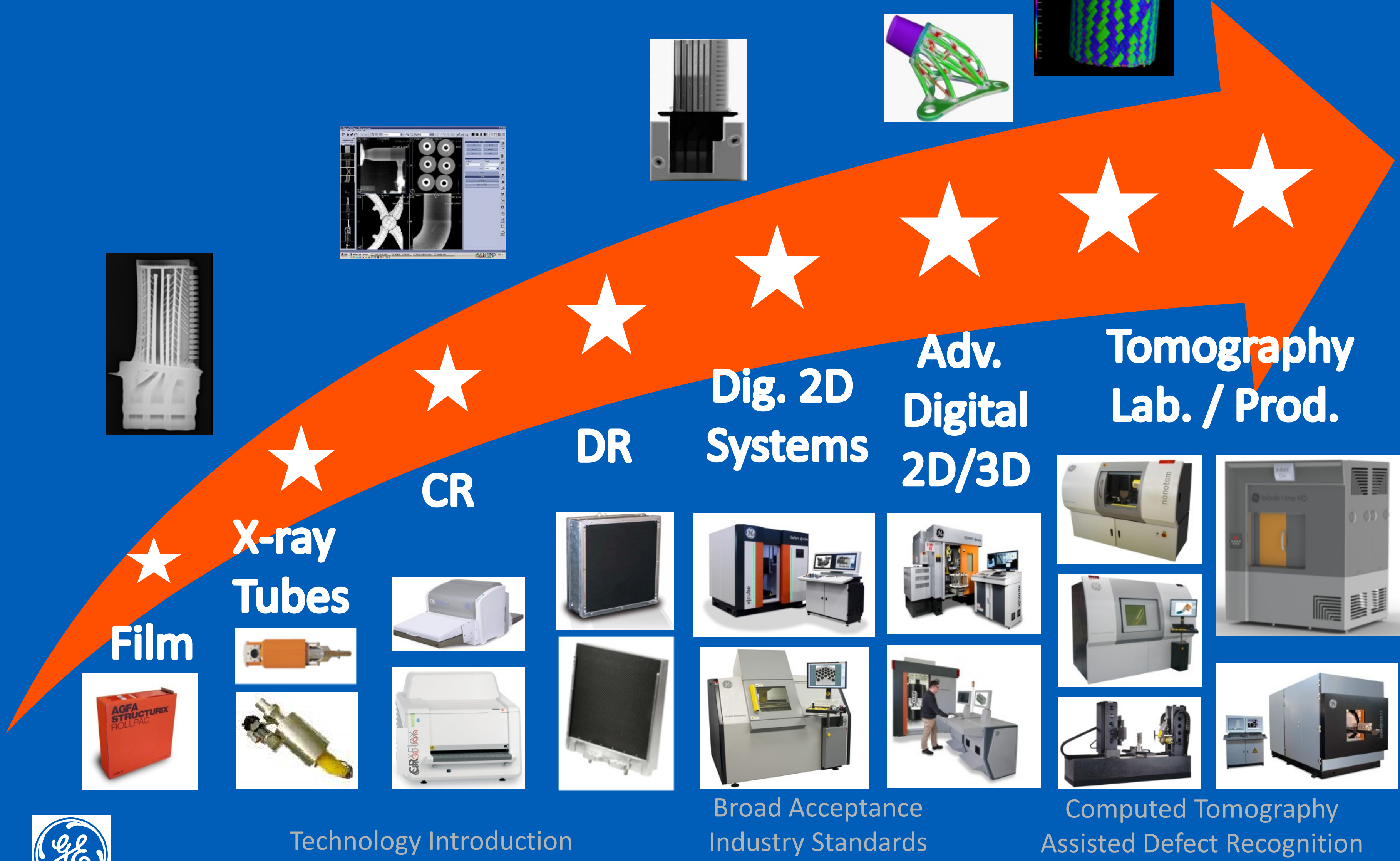
Aero X-ray applications & solutions

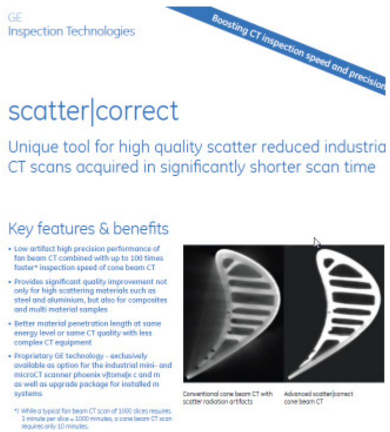
Increasing X-ray inspection requirements driving change

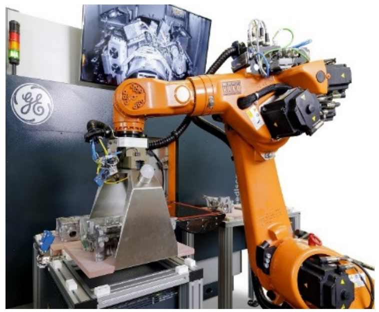




New X-ray/CT Technologies: Highlights

X-ray detectors	X-ray sources	X-ray Imaging	Robotics & Automation

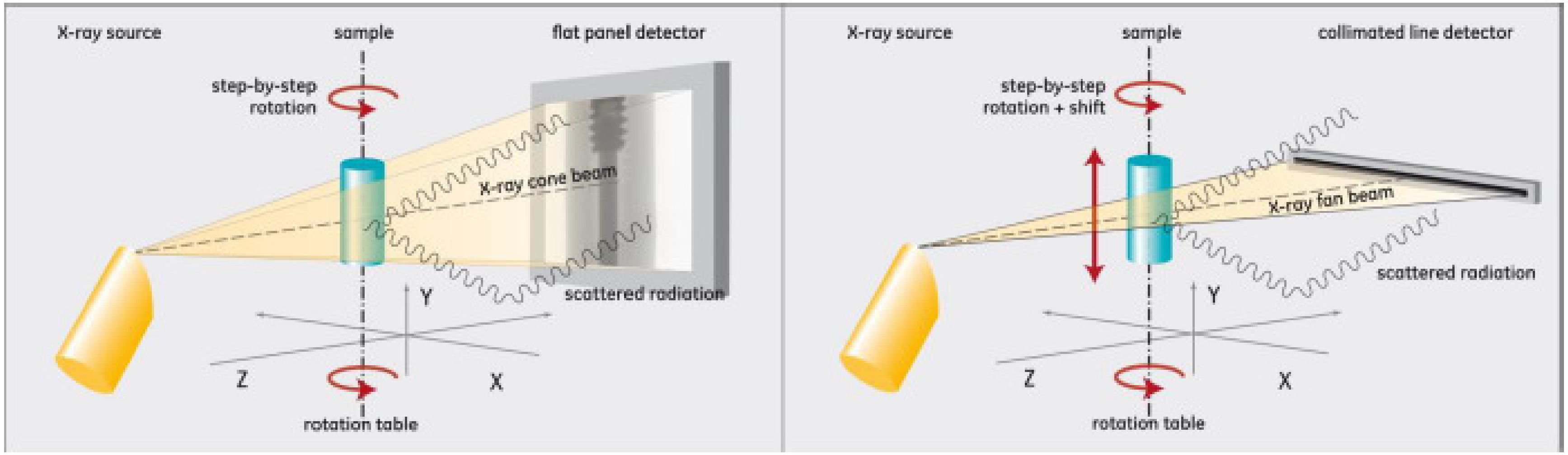




CT Principle – video sequence

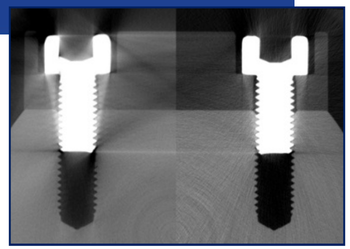
Please watch here: https://www.youtube.com/watch?v=ozH_zAgDuFE

CT Principle cone & fan beam, scatter|correct



- Cone beam CT (3D) is fast but scattered radiation can affect the image quality
- Fan beam CT is not affected by scattered radiation but is slow

GE's scatter|correct utilizes the advantages of both methods



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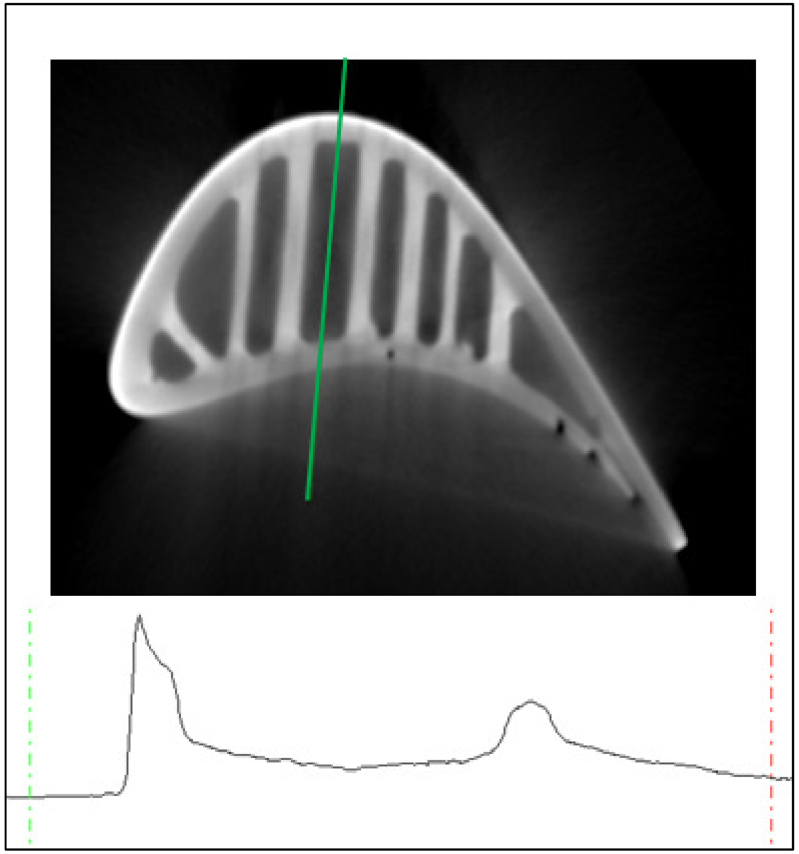
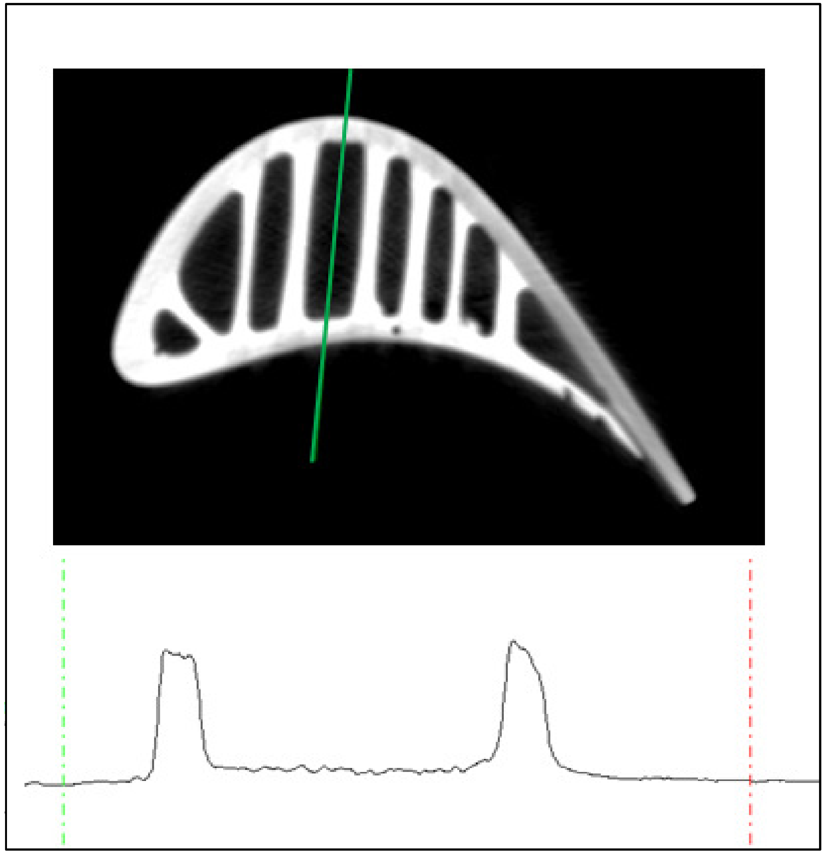
CT Principle cone & fan beam, scatter|correct

scatter|correct application examples, turbine blade

CT slice without scatter|correct
thickness measurement NO



CT slice with scatter|correct
thickness measurement YES



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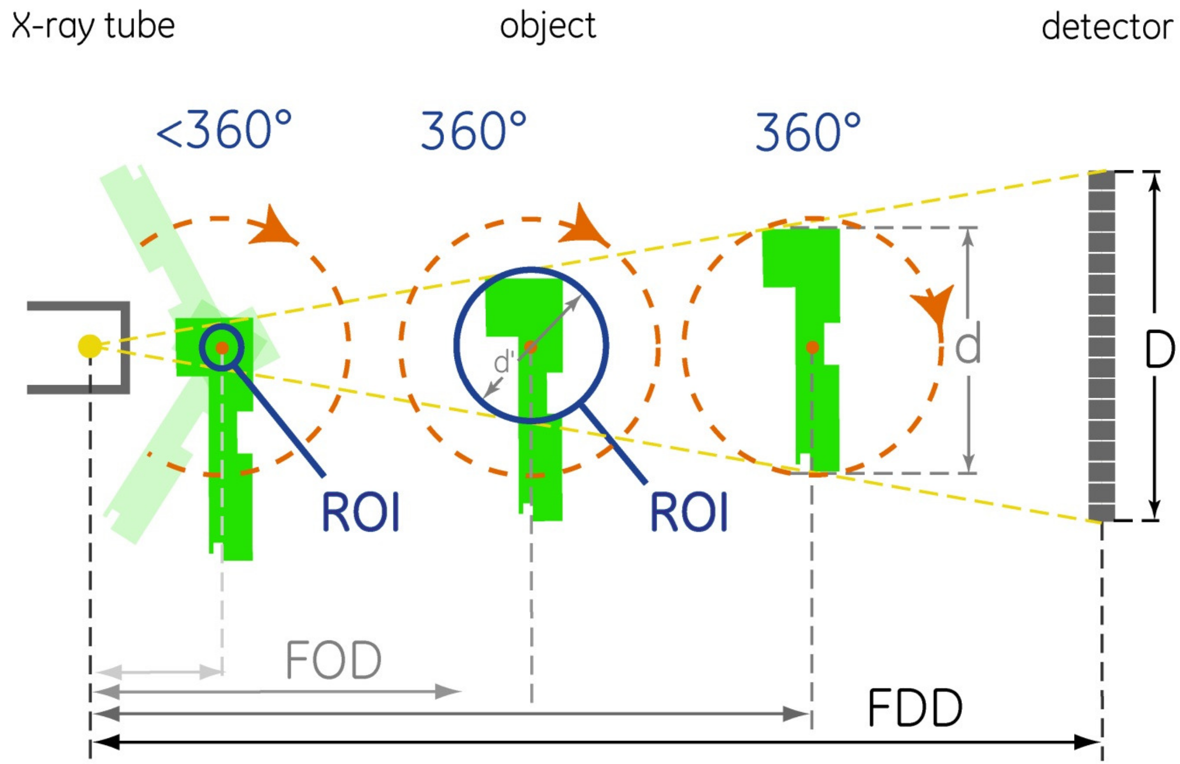
CT Principle complete and ROI scan

If the entire sample diametre d is scanned with a detector D of N pixels the voxels size is limited to $V = \frac{d}{N}$

In an ROI (region of interest) scan only a cylinder of diametre d' is scanned, leading to a smaller voxel size and higher resolution (if the geometric unsharpness U_g allows this):

$$V' = \frac{d'}{N}$$

In case the sample is very broad the rotation angle might be restricted to less than 360°. Down to about 270°, a good image quality may still be expected.



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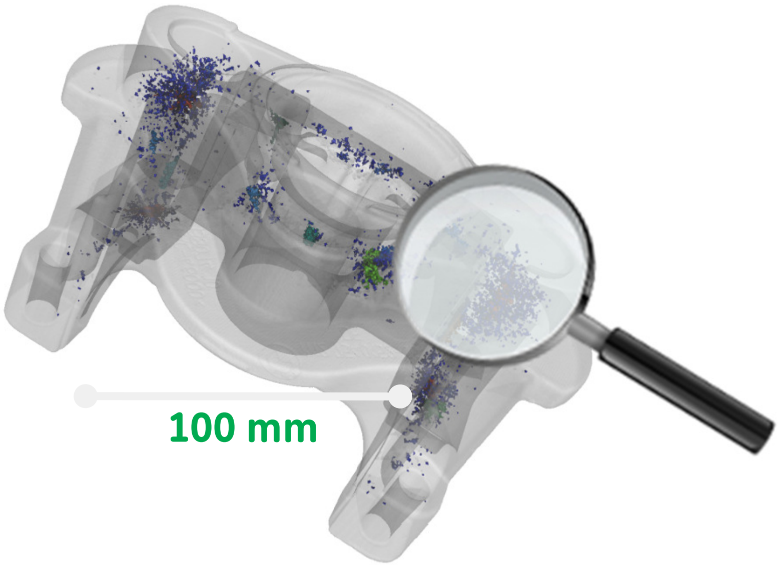
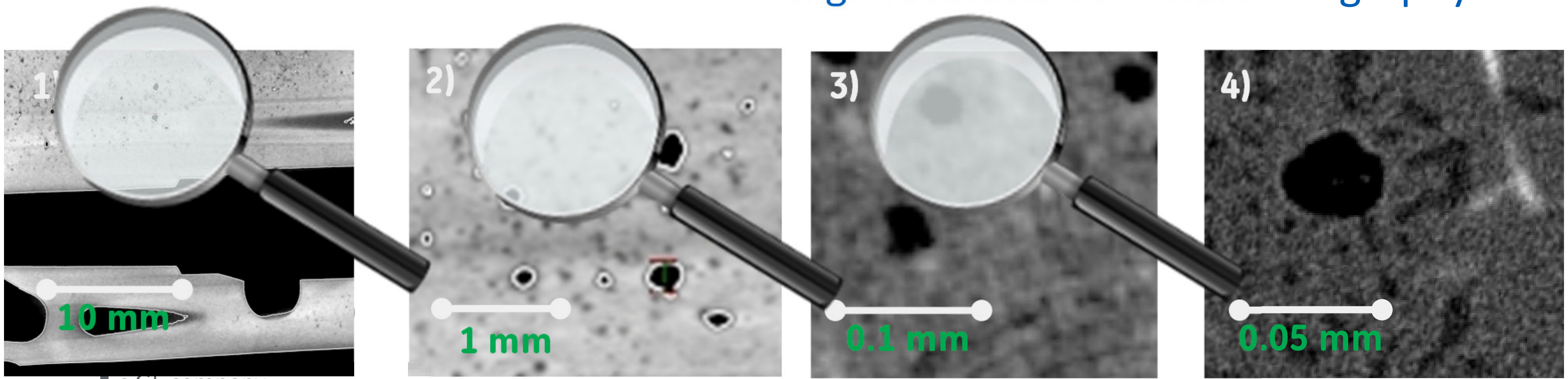
CT Principle critical parameter voxel resolution - inspection on four different length scales, e.g. casting



Complete casting:
1) 150 µm Voxelsize, microfocus:
macroporosities, metrology
2) 30 µm Voxelsize, microfocus:
microporosities

Subsection of casting:
3) 3 µm Voxelsize, microfocus tube:
detailed analysis of micropores
4) 0.5µm Voxelsize, Nanofocus tube,,
high resolution 3D materialography



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Aerospace AM applications

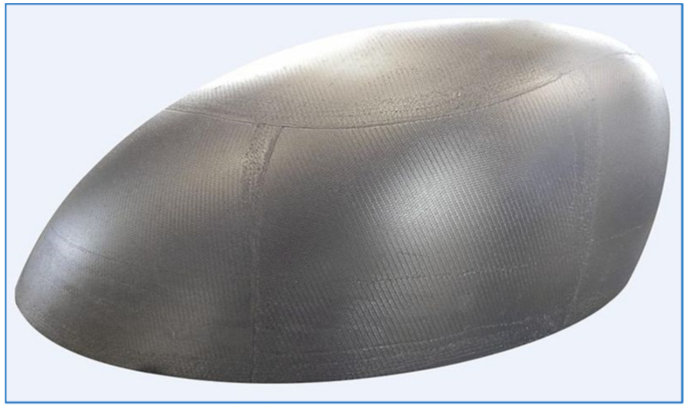
Reaction Wheel Bracket for Telecommunication Satellites
Additive Manufactured in Project NewStructure
© Tommaso Ghidini @ TEDxESA

Structurals, turbochargers, nozzles, brackets…

Source: https://www.ge.com/stories/brilliantfactory

Source: https://gereports.ca/slideshow/look-ahead-master-class-advanced-aviation/

Credit: GE Aviation



Source: http://www.jeccomposites.com/knowledge/international-composites-news/ceramic-matrix-composites-shield-atmospheric-reentry-system

Courtesy of Premium Aerotec

…blades, CMC workpieces

Courtesy of Avio Aero

Additive Manufacturing – where and how computed tomography (CT) can add value

- 3D printing machine manufacturers:
  -> verify system performance, merge with in-situ monitoring
- printing powder manufacturers:
  -> check powder grain sphericity & size, distribution, porosity inside the grains, foreign particle contamination
- 3D print service companies/users:
  -> conduct rapid prototyping and QA (failure analysis, dimensional measuring and pre-machining test) of printed workpieces
- standardisation organisations:
  -> perform CT measurements to help defining guidelines in volumetric inspection, complementing to standard NDT techniques for surface and below surface inspection (eg. UT, EC)

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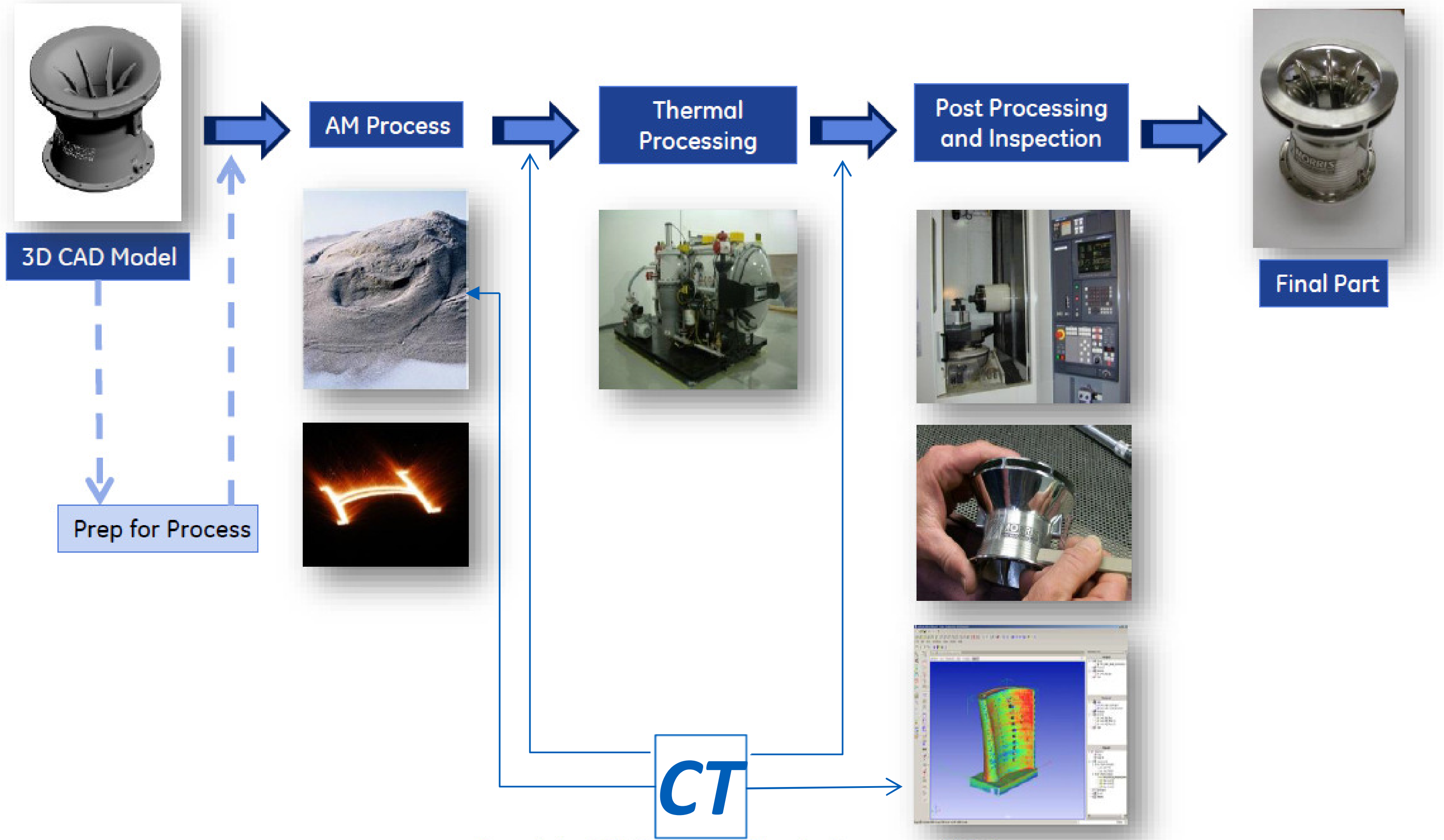
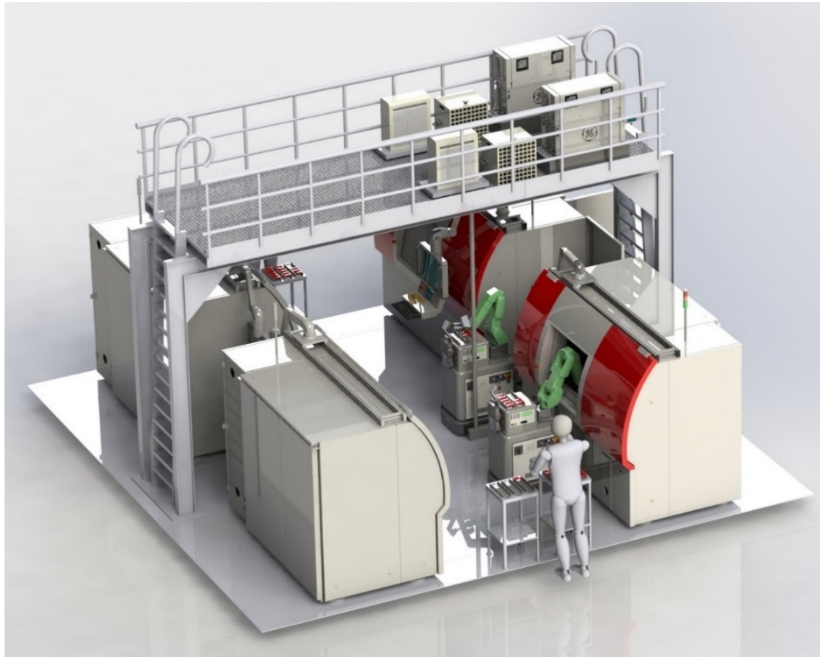
Additive Manufacturing – Principle - Workflow

Much more than just printing!



Additive Manufacturing – Principle - Automation

Showcase: collaborative robot with CT scanners



- Flexible and extendable for up to 4 automatic CT Systems
- Robot based part handling with Automated Guided Vehicles
- Compact for optimized floor space
- Flexible interface to Brilliant Manufacturing IT system

Additive Manufacturing – applicable standards (ASTM)

American Society for Testing and Materials (ASTM) Standards

ASTM International Technical Committee F42 on AM Technologies is a non-profit organization working on AM. The scope of the committee is to promote knowledge, stimulate research and implement technology through the development of standards for additive manufacturing technologies. Standards developed by F42 are:

- F2792 Standard Terminology for Additive Manufacturing Technologies
- F2915 Standard Specification for Additive Manufacturing File Format (AMF)
- F2921 Standard Terminology for Additive Manufacturing--Coordinate Systems and Nomenclature
- F2924 Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion.

A proposed new ASTM International standard will serve as a guide to determine specific mechanical properties of materials made with an AM process. WK43112, Guide for Evaluating Mechanical Properties of Materials Made via Additive Manufacturing Processes, is being developed by Subcommittee F42.01 on Test Methods, part of ASTM International Committee F42 on AM Technologies.

In addition to WK43112, F42.01 is currently developing two other proposed standards:

- WK30107, Practice for Reporting Results of Testing of Specimens Prepared by Additive Manufacturing
- WK40419, Test Methods for Performance Evaluation of Additive Manufacturing Systems Through Measurement of a Manufactured Test Piece.

-> WK47031: CT Workgroup

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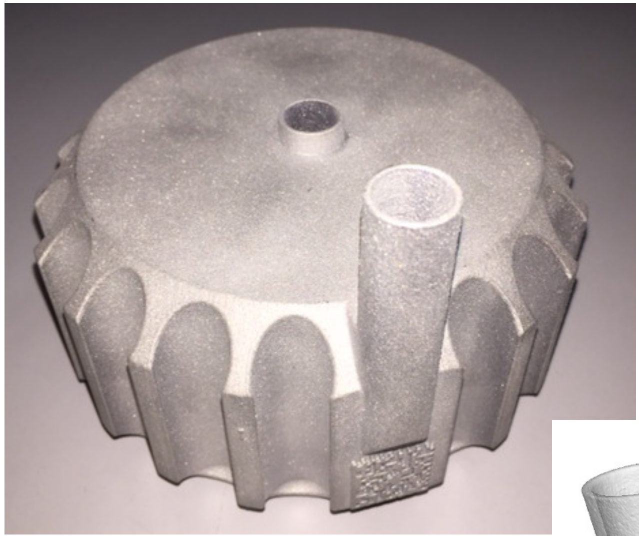
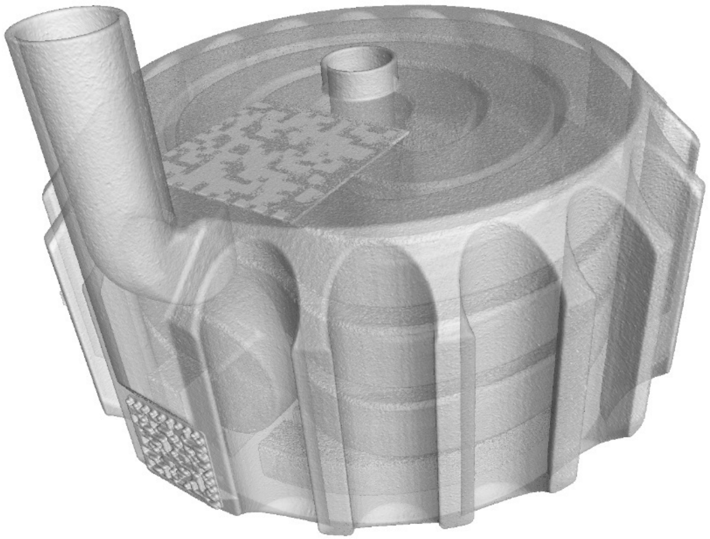
Additive Manufacturing – example for CT analysis SLM method





Workpiece #1:

Medical rotary carousel for test tubes

Material: AlSi10Mg

Dimensions (LxWxH):

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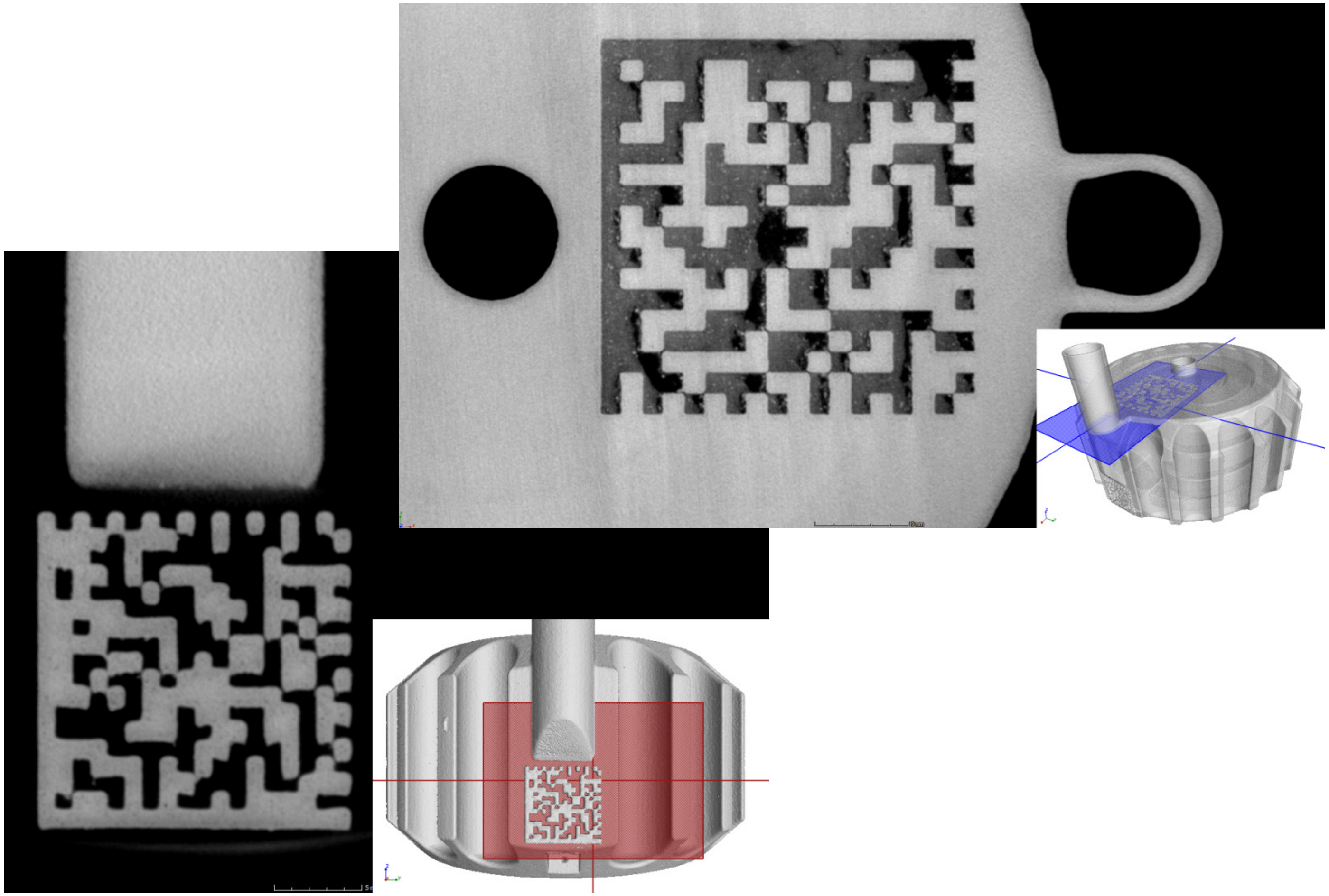
By courtesy of DMRC DIRECT MANUFACTURING RESEARCH CENTER

Additive Manufacturing – example for CT analysis SLM method

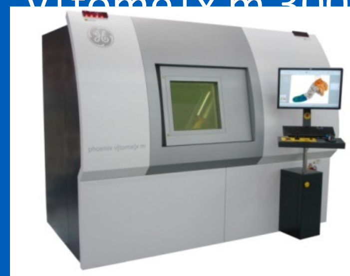


2D slices and 3D rendered image:

Visualisation of QR code and powder entrapments

Used µCT system:

v|tome|x m 300



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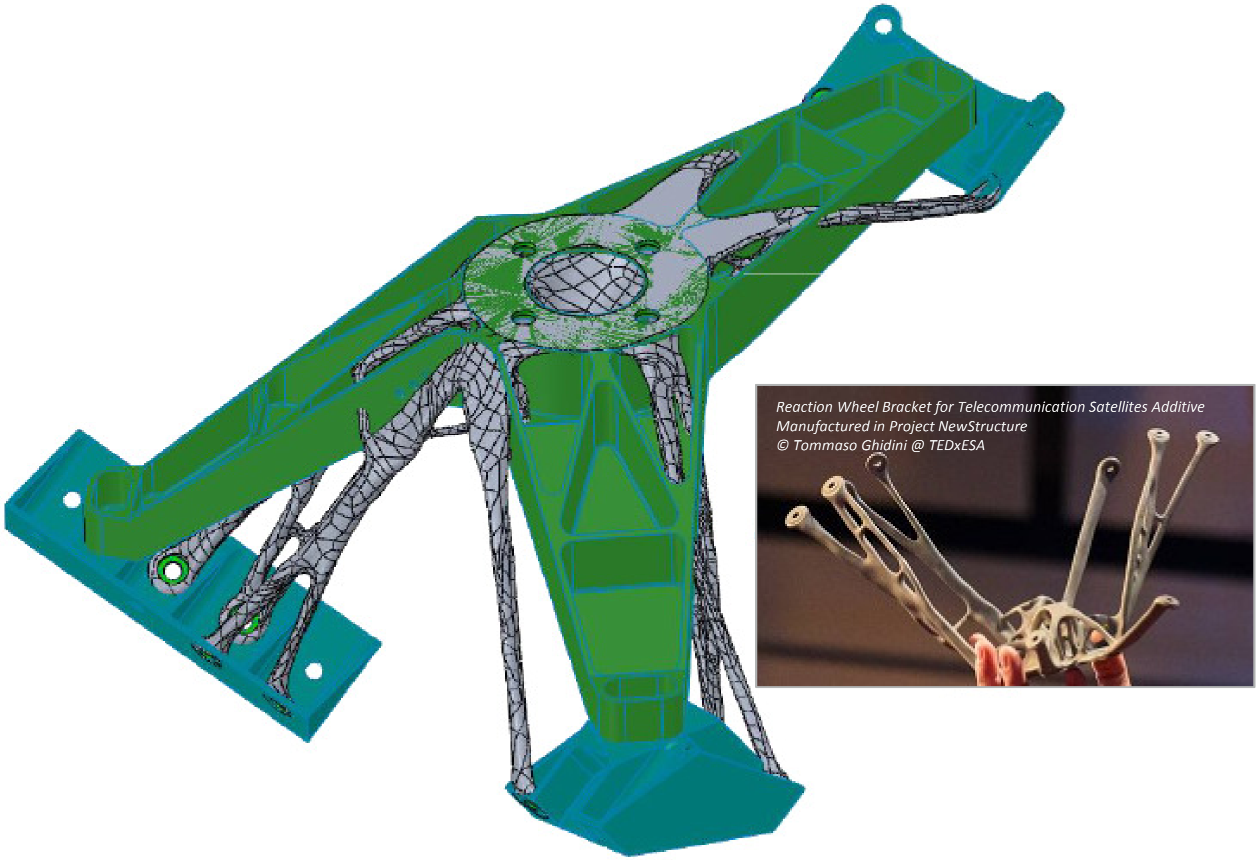
Additive Manufacturing – example for CT analysis SLM method



Workpiece #2:

Reaction wheel bracket (ESA)

Material: AlSi10Mg

Motivation to implement AM:

weight reduction (-60%), optimised topology

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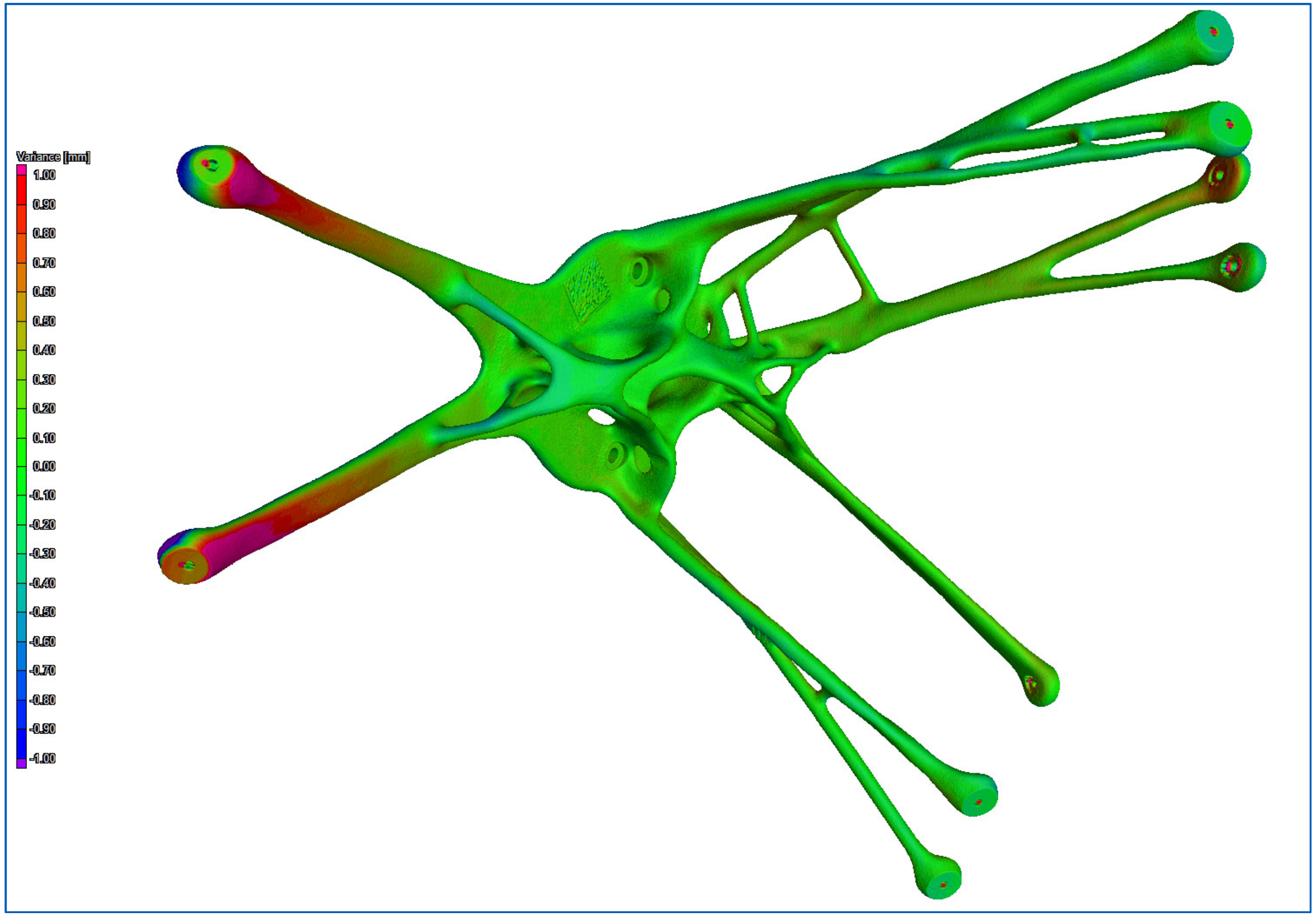
Additive Manufacturing – example for CT analysis SLM method



3D image:

nominal-actual comparison (part vs. CAD)

Used µCT system:

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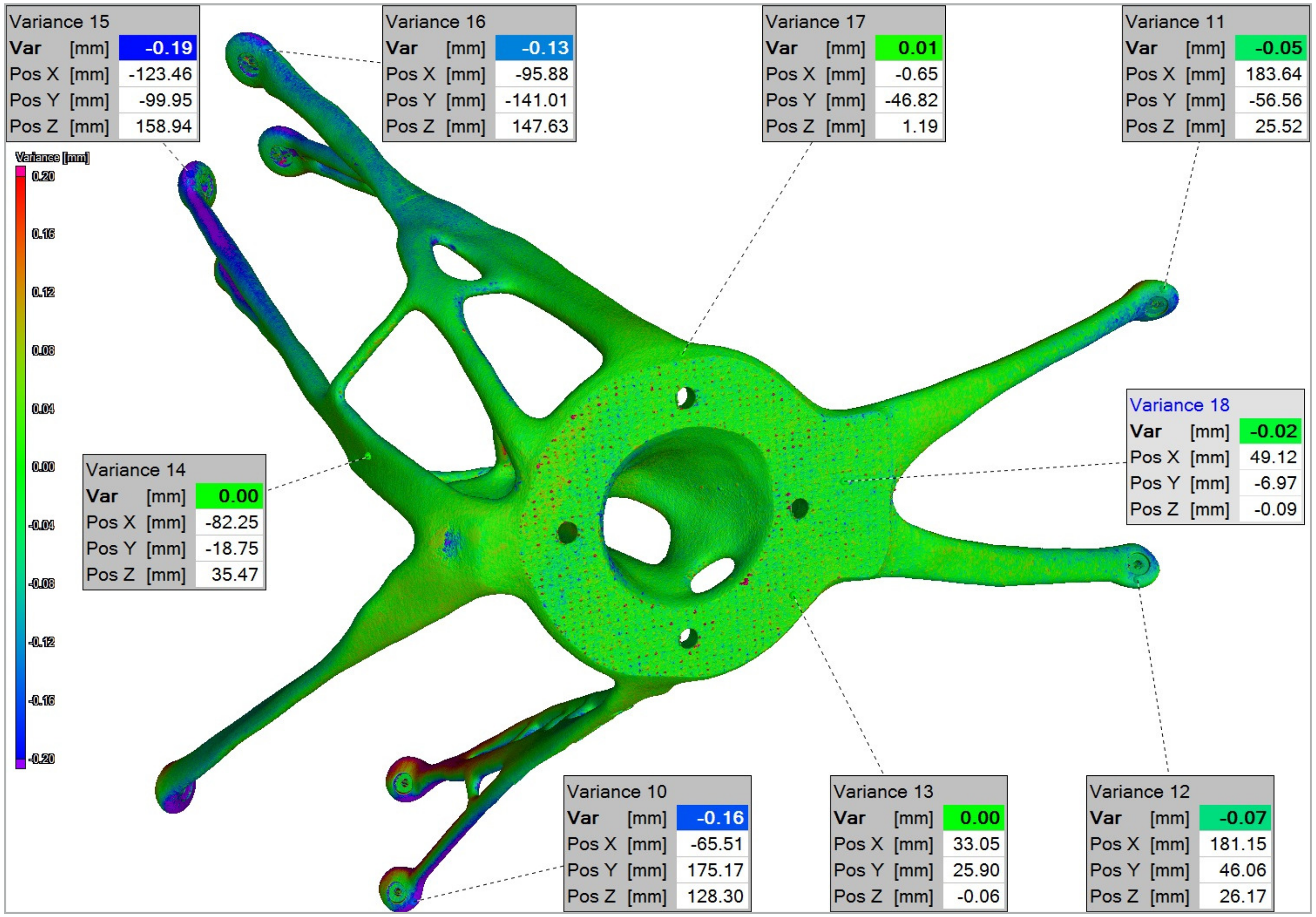
Additive Manufacturing – example for CT analysis SLM method



3D image:

nominal-actual comparison (partA vs. PartB)

Used µCT system:

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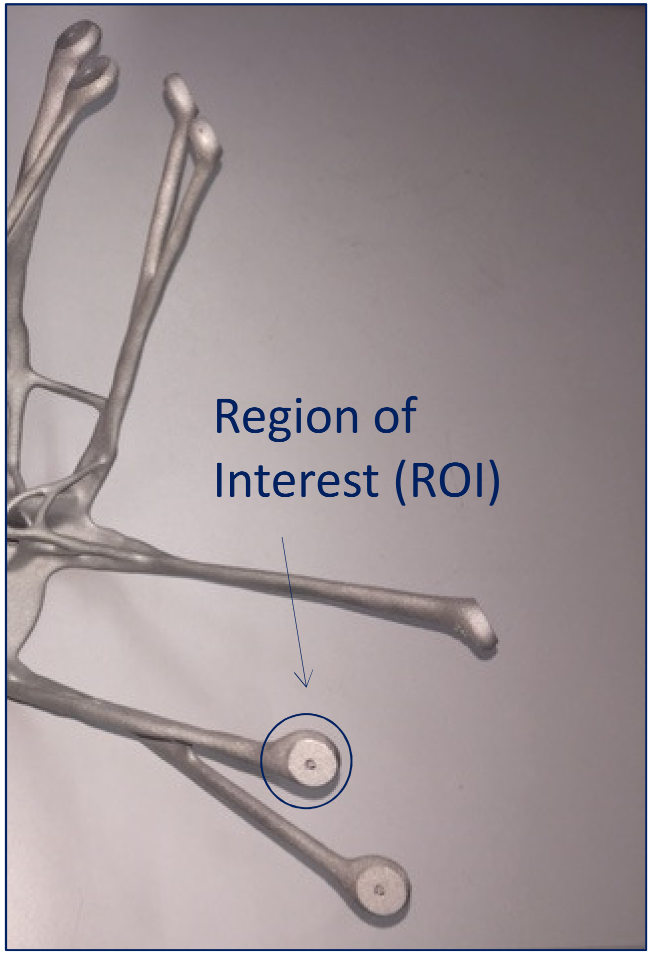
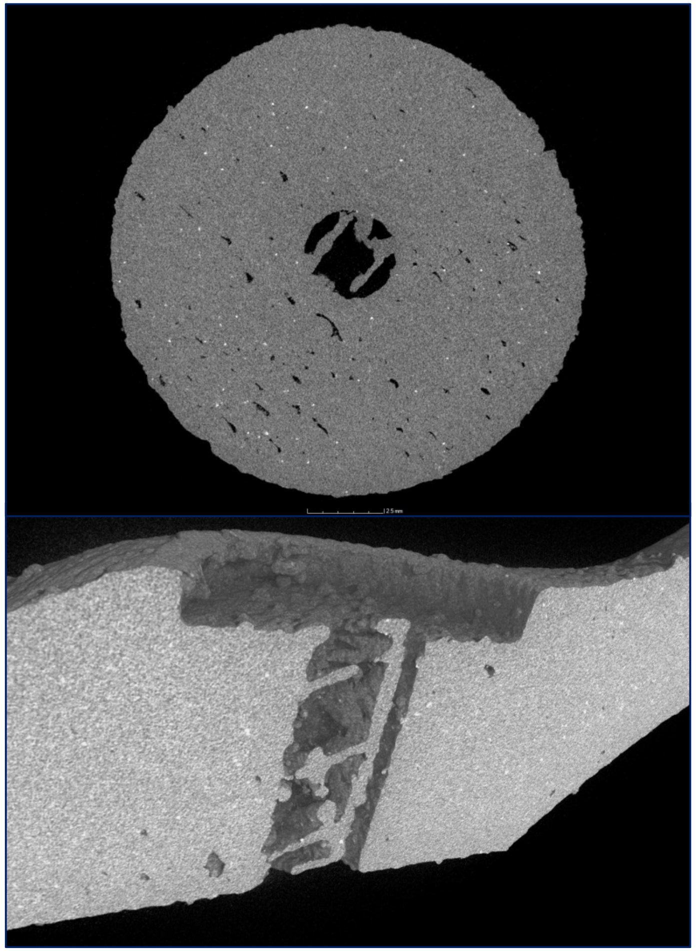
Additive Manufacturing – example for CT analysis SLM method – ROI scan





2D slice and 3D rendered image:

borehole shape, inclusions, pore orientation

Used µCT system:

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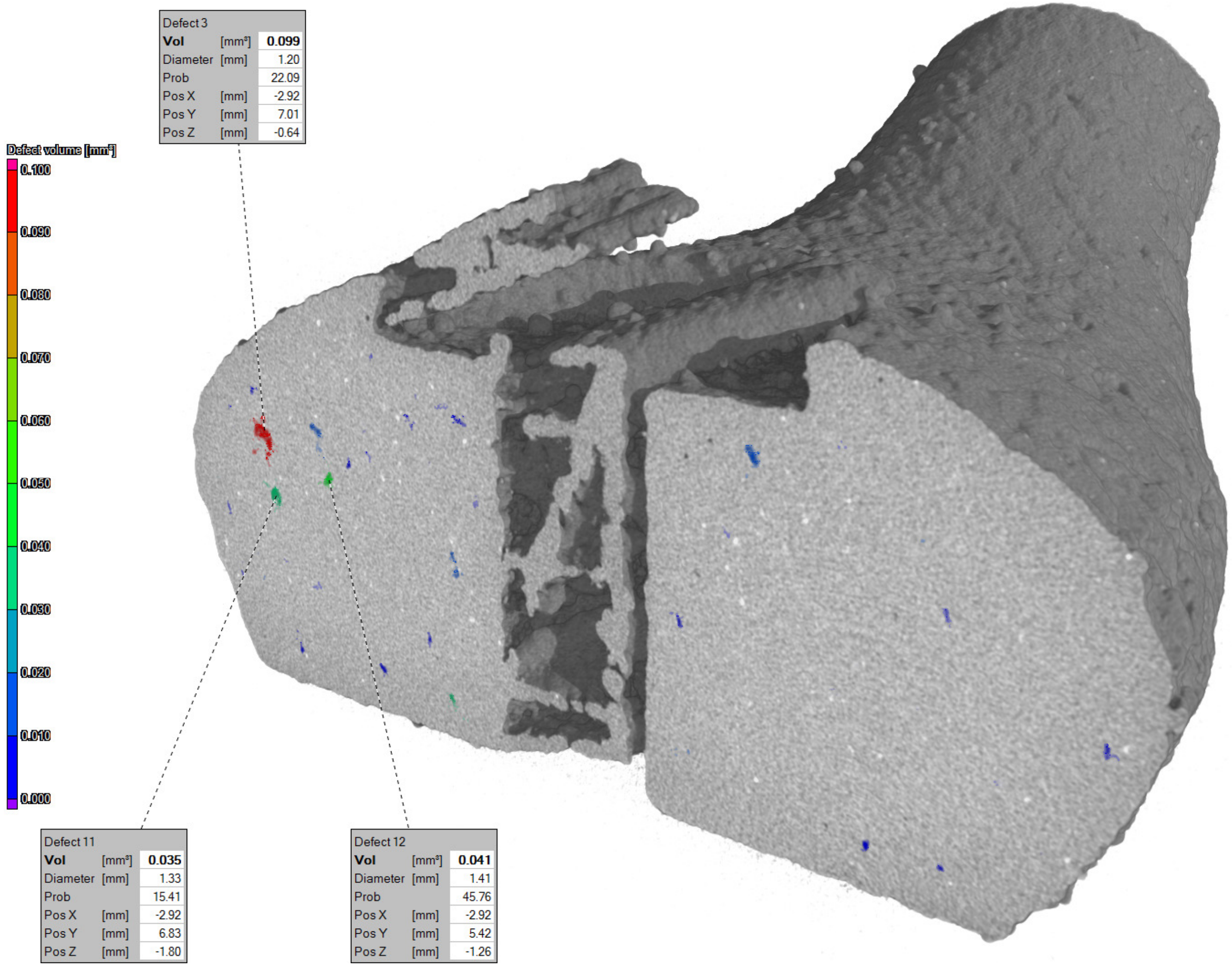
Additive Manufacturing – example for CT analysis
SLM method – ROI scan – porosity analysis



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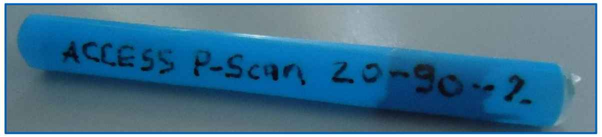
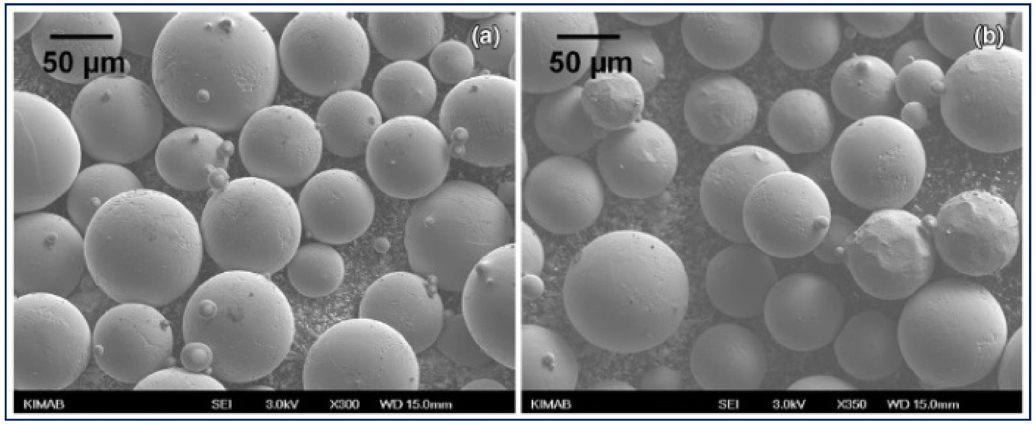
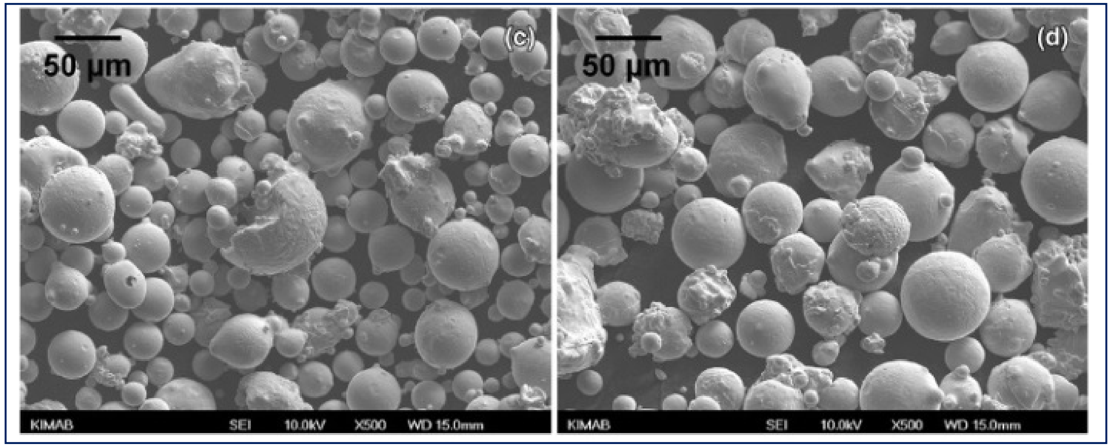
DMRC
DIRECT MANUFACTURING RESEARCH CENTER

Additive Manufacturing – example for CT analysis
AM metal powder





<- Ti6Al4V EBM powder (new/recycled)



Inconel 718 -> SLM powder (new/recycled)

Workpiece #4: Powder

SEM images

Left: new powder

Right: new & recycled powder

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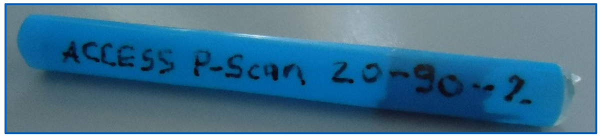
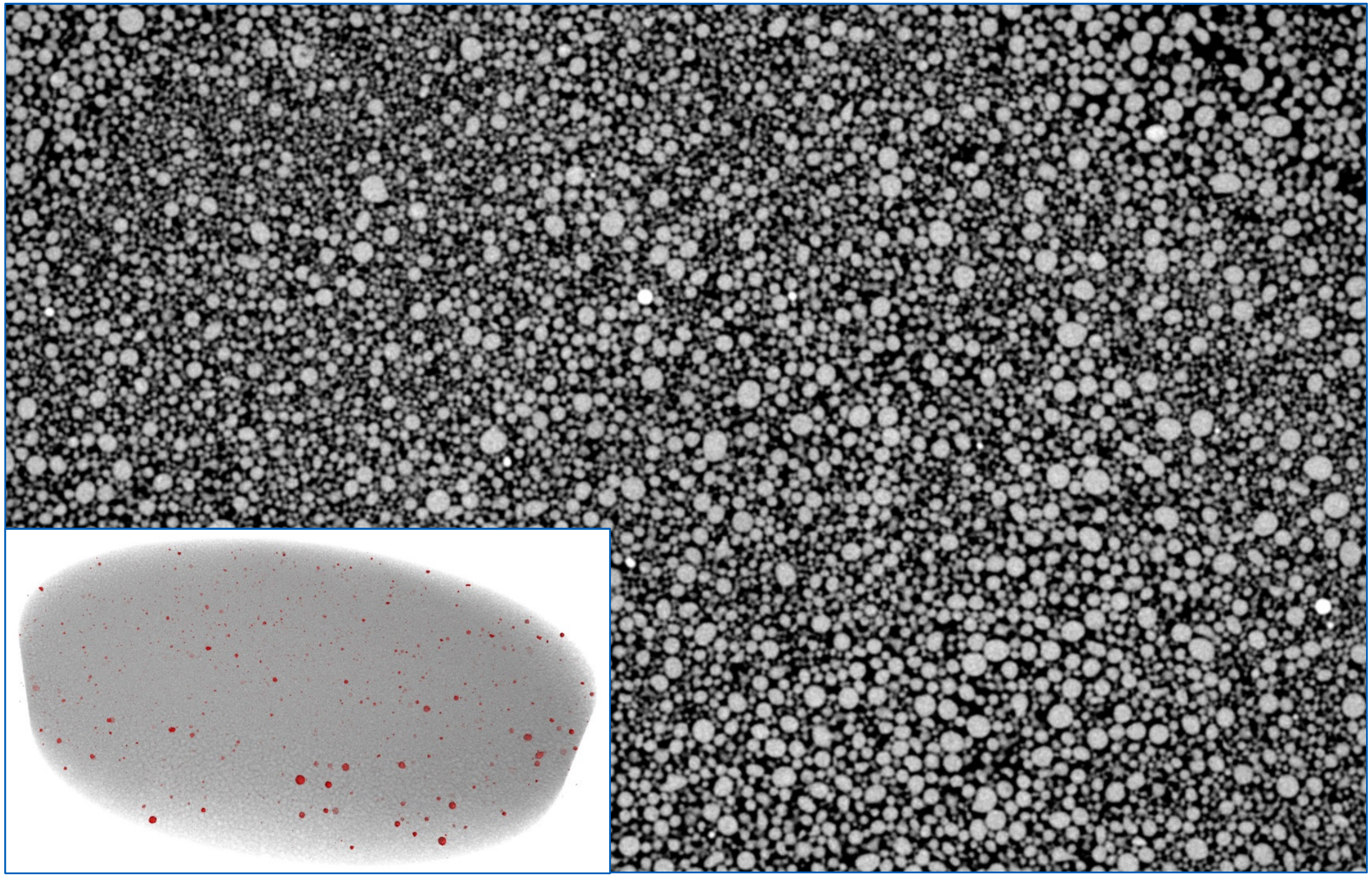
By courtesy of access

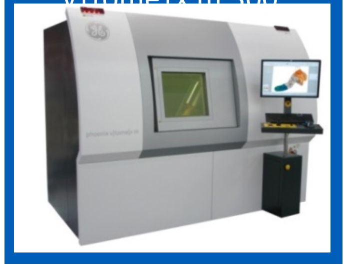
Additive Manufacturing – example for CT analysis
AM metal powder





2D slice & 3D view: pores, particle absorption and distribution, morphology, sphericity

Used µCT system: v|tome|x m 300



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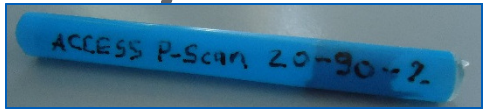
Additive Manufacturing – example for CT analysis
AM metal powder



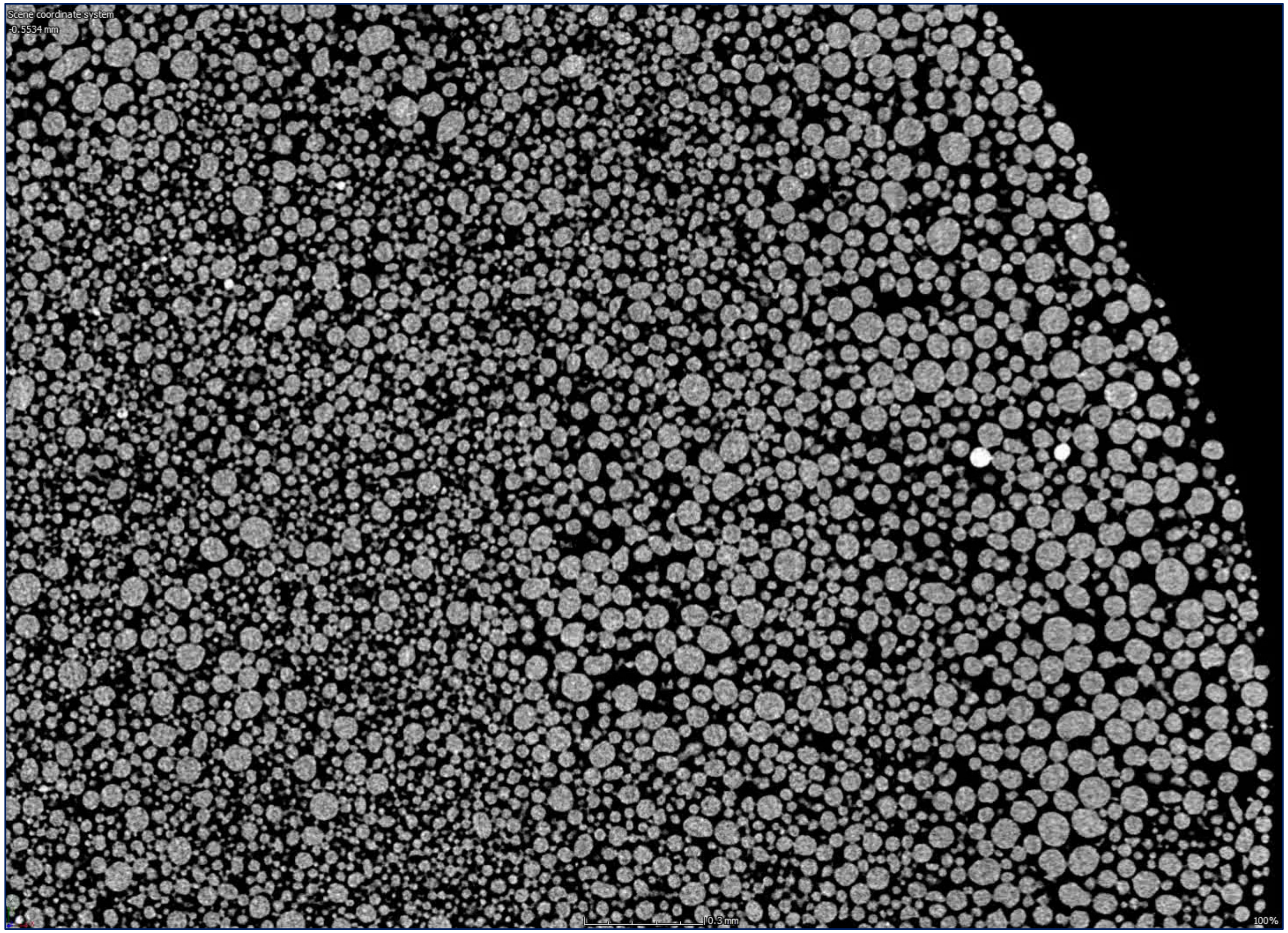


Image stack:

Particle size

analysis

Used µCT system:

v|tome|x m 300

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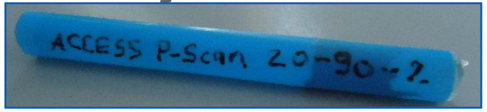
https://geog.my.salesforce.com/sfc/p/A0000000QC05/a/12000000DvHN/_1PeZd3V8F.rbGE0F3cLBh1Frrwo0j.4qZnsh.OZ3ck

Additive Manufacturing – example for CT analysis
AM metal powder



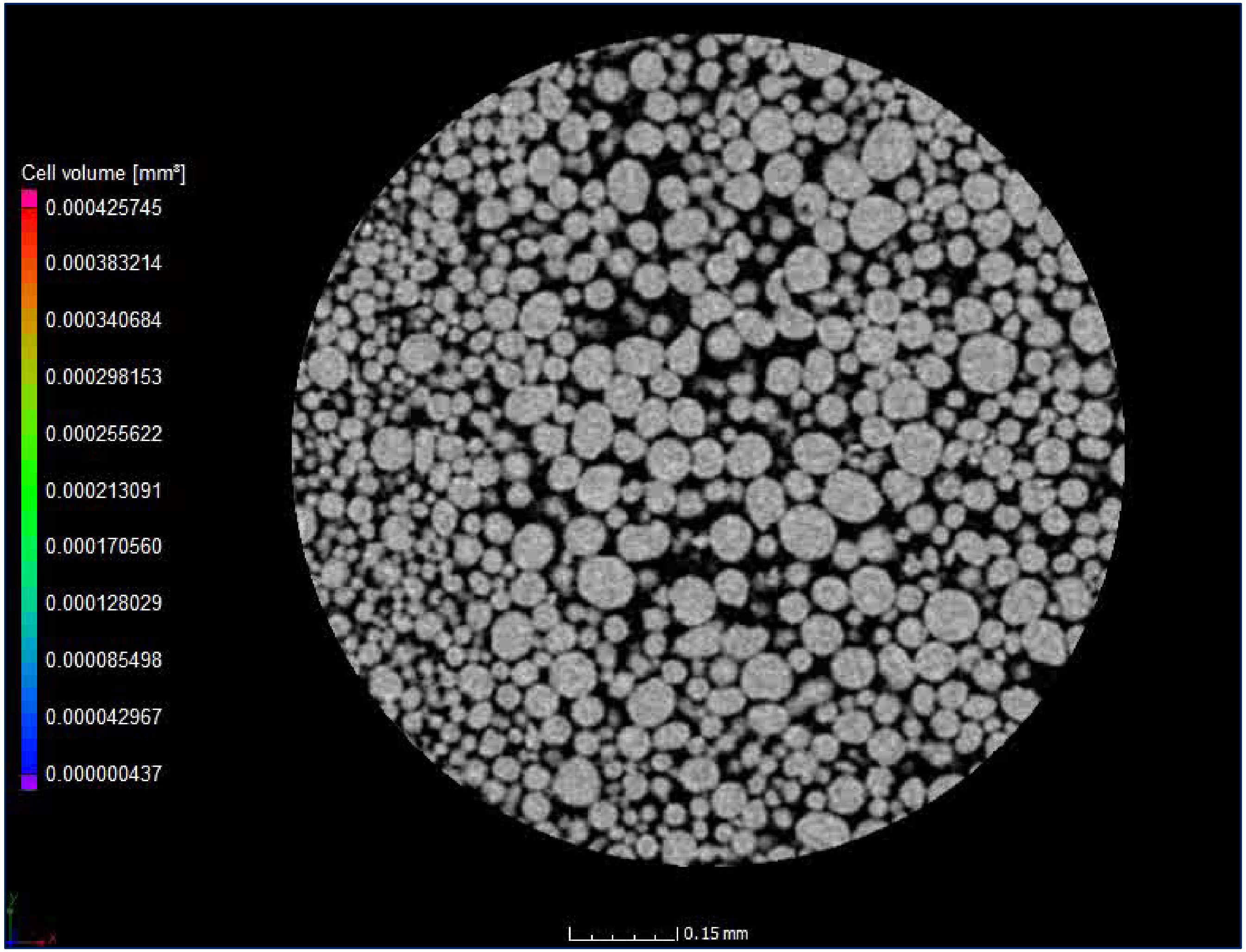
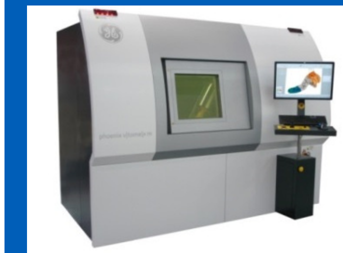


Image stack:

Particle size analysis (coloured segmentation)

Used µCT system: v|tome|x m 300



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https://geog.my.salesforce.com/sfc/p/A0000000QC05/a/12000000DvHS/eySaLWLktWUxq_sgV5yhUosSklPNzov7stYO_cRnvGg

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Conclusion

- Computed Tomography is a leading NDT technique for non-destructive testing of additively manufactured workpieces and complementary to other techniques in use (e.g. in-situ visual inspection, CMM).

- The classical casting/moulding defect types will be substituted by much smaller and new types of failures in AM to be detected by NDT.

- Computed tomography fits the AM industry‘s needs for quality assurance, if it delivers enough X-ray energy, contrast, resolution & speed.

- Automatic workflows as enabler to production based NDT and in communication with other NDT techniques for AM parts are critical.

- Apart from the standardisation work already done, ISO and ASTM will need to establish guidelines for CT utilisation/interpretation. GE Digital Solutions will be continuously supporting the ASTM WK 47031 Workgroup.

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Announcement

powered by:

Visit GE Inspection Technologies at formnext tct

International exhibition and conference
on the next generation of
manufacturing technologies
Frankfurt am Main, 14.–17.11.2017

Come and see our innovative automated CT inspection solution „v|tome|x m 300“ in hall 3.1, booth # D28.

Register here for a free entry ticket:
https://www.mesago.de/en/formnext/For_visitors/Tickets/index.htm

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Acknowledgements

We'd like to sincerely thank the following companies for having agreed to show CT results on their AM workpieces:

Premium AEROTEC GmbH
Riesweg 151-155
D-26316 Varel/Germany
www.premium-aerotec.com

University of Paderborn - DMRC
Mersinweg 3
D-33098 Paderborn/Germany
www.dmrc.de

GE Avio S.r.l.
Strada Giuseppe Gabrielli
I-28062 Cameri (NO)/Italy
www.avioaero.com

ACCESS e.V.
Intzestrasse 5
D - 52072 Aachen/Germany
www.access-technology.de

Thank you very much for your attention!

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More information at www.gemeasurement.com/CT

...any questions? Please contact me -

Jens Lübbehüsen

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1999-2013:	phoenix|x-ray GmbH / GE M&C phoenix – Area Sales Manager
2014-6/2017:	GE DS Radiography Sales Manager Aerospace Europe
7/2017- :	Baker Hughes GE DS Key Account Manager Aerospace Europe

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