3D Defect Analysis for Additive Manufacturing

A cost-effective alternative to Computed Tomography

LynX Inspection

PRATT & WHITNEY
DEPENDABLE ENGINES

NDT in Canada
NDTiC 2022
Canada's NDT Conference

Luc Perron
CEO, LynX Inspection

About 3D Printing

- Additive Manufacturing (AM) is a very promising technology
  - Rapid Prototyping
  - Complex Shapes that would not be possible through conventional means
  - Same function for less than half the weight
- But:
  - Presence of imperfections due to build conditions, residual stress, etc.

Need for reliable quality control methods

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Computed Tomography (CT)

- Considered an effective approach for inspecting metallic AM parts
  - Complete 3D volumetric reconstruction
  - Established method
  - Accurate dimensional measurements
    - Assuming high quality image acquisition system and sufficient data coverage
- But:
  - Very costly and time consuming
    - Scanning a 30x30 cm part at 50 micron resolution can easily take 2 hrs for scanning and another hour for 3D reconstruction

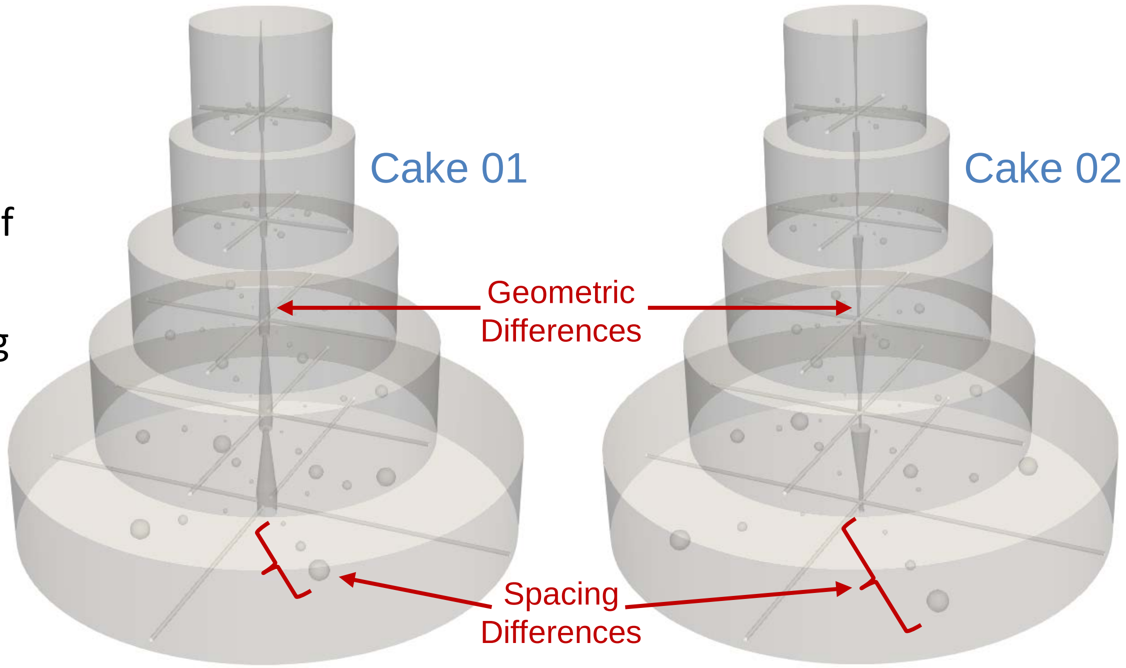
There's got to be a better way to support production

Project Main Objectives

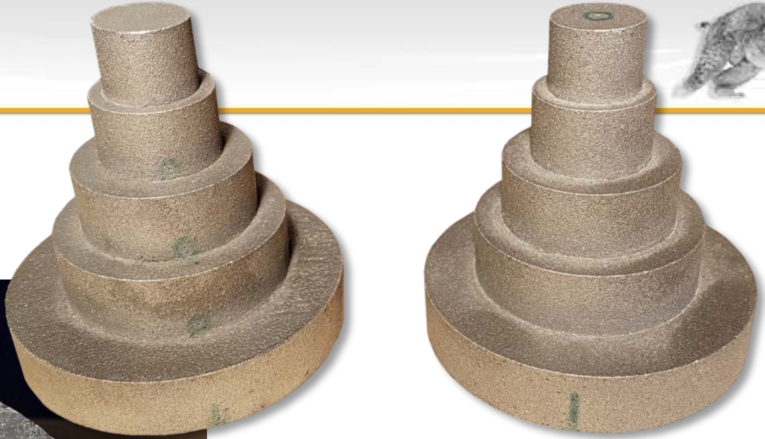
- Evaluate « Predictive 3D Radiography » as an alternative method to qualify AM parts
  - Works from a limited set of 2D images taken from different viewing angles
  - Complements acquired X-ray imagery with simulated data generated from reference 3D model
  - Uses parallax and triangulation to extract 3D information
  - Concentrates on positioning defect in 3D space rather than performing a full 3D reconstruction
- Compare new method against conventional micro-CT results previously obtained

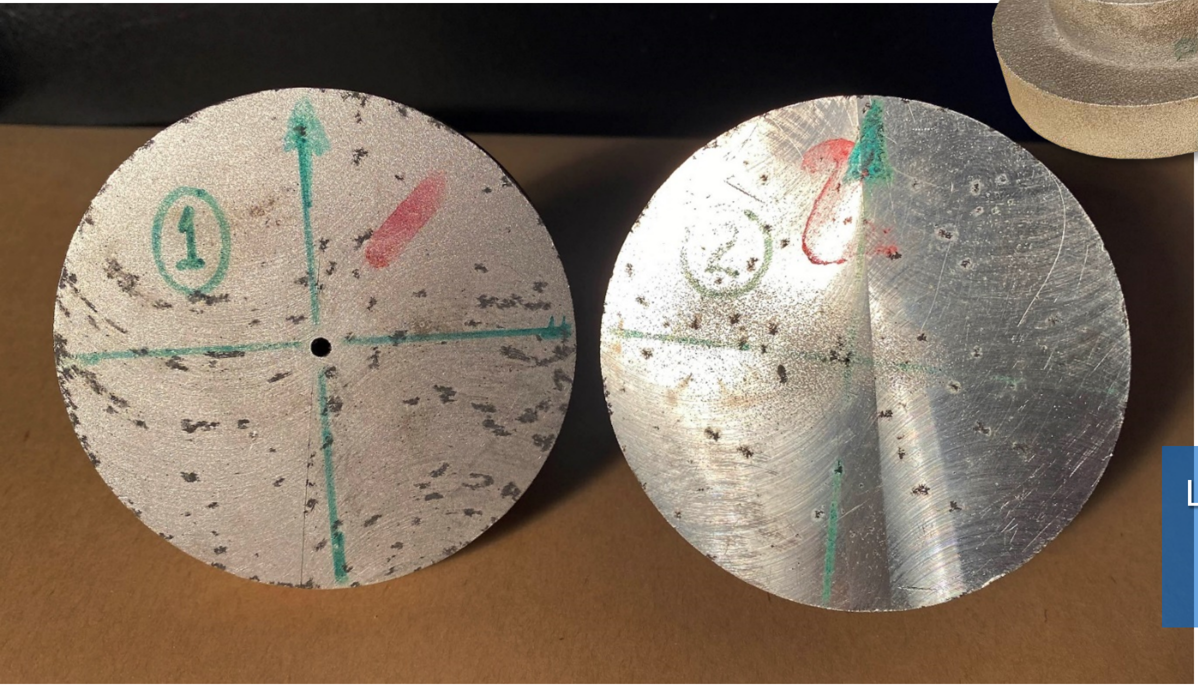
Layer Cake Phantoms

- Phantom Design
  - Inspired by IQI used in standard 2D radiography
  - Stacked cylindrical sections with central conical void
  - Seeded defects (empty spheres) of proportional diameters
  - Printed by Additive Manufacturing Innovation Centre (AMIC) at Mohawk College
    - Laser Power Bed Fusion (LPBF) process using 6061 Aluminum
    - 2 different Print Orientations



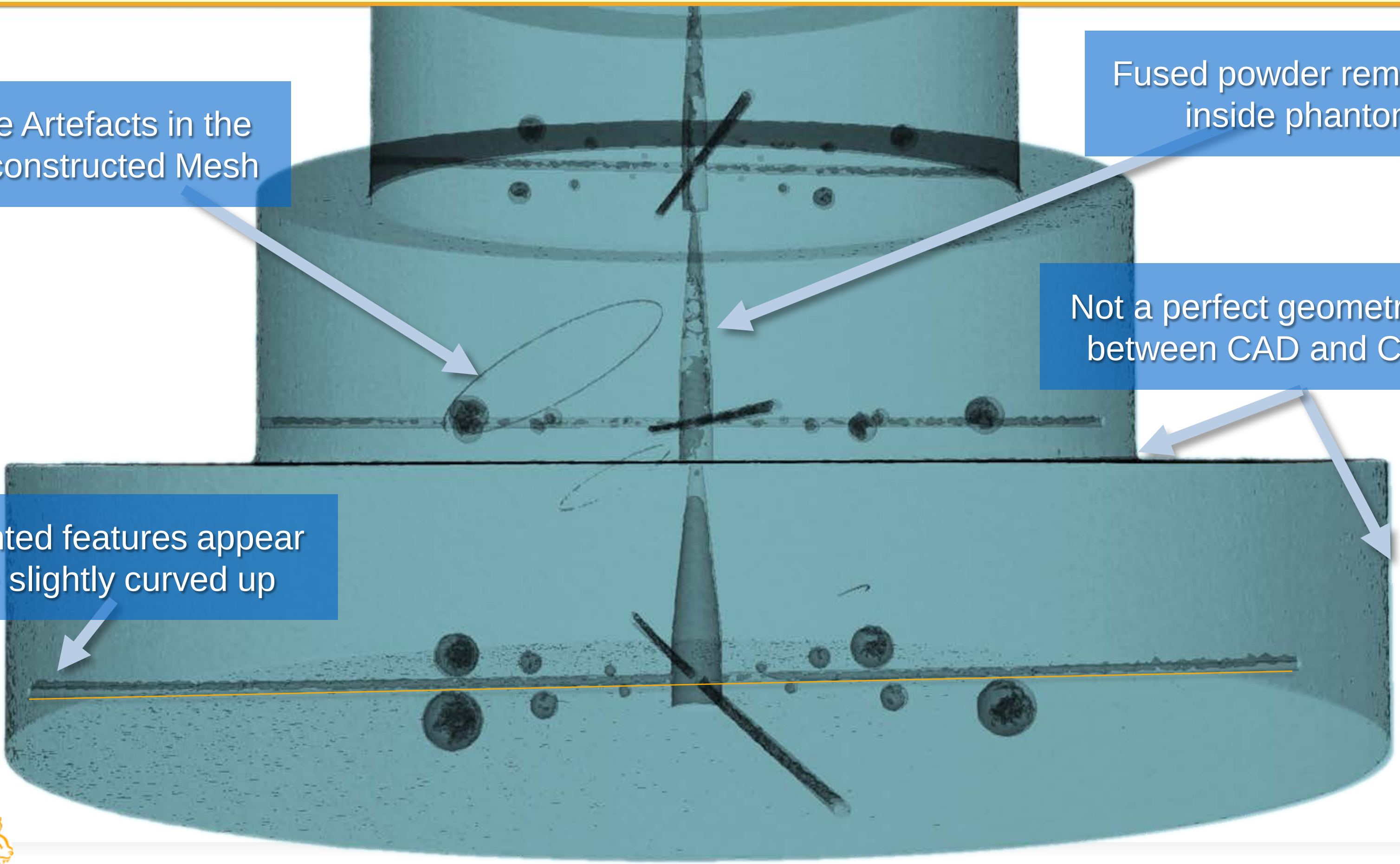
Resulting Layer Cake Phantoms





Lack of powder fusion apparent in the base of each phantom
Small Random Porosities

Resulting CT Scan Data



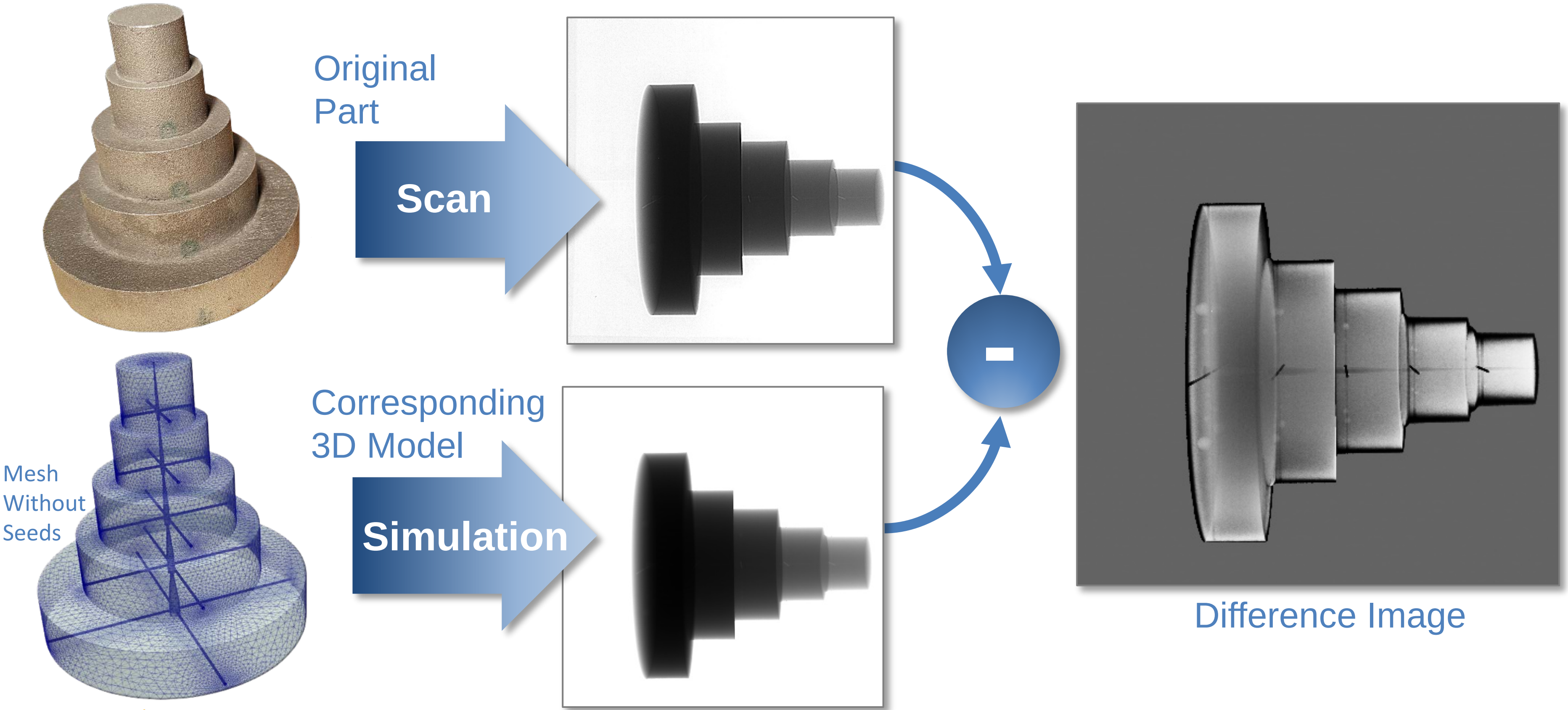
Multiple Artefacts in the CT Reconstructed Mesh

Fused powder remaining inside phantom

Not a perfect geometric match between CAD and CT Mesh

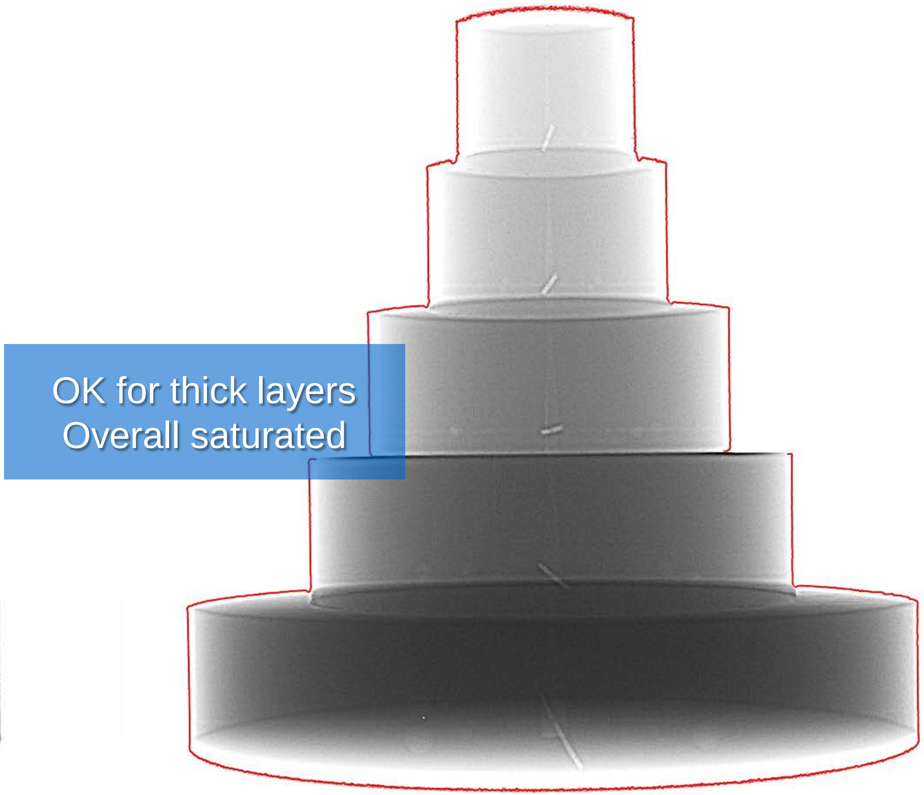
3D printed features appear to be slightly curved up

Difference Image: helps to find seeds



Dynamic Range is challenging

Voltage = 150 kV FS = 50 microns

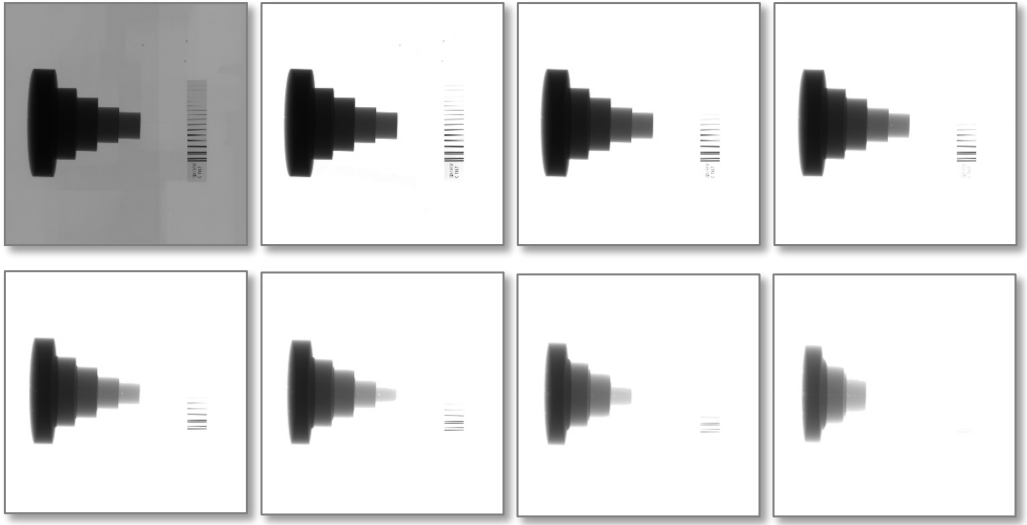


Voltage = 225 kV FS = 50 microns

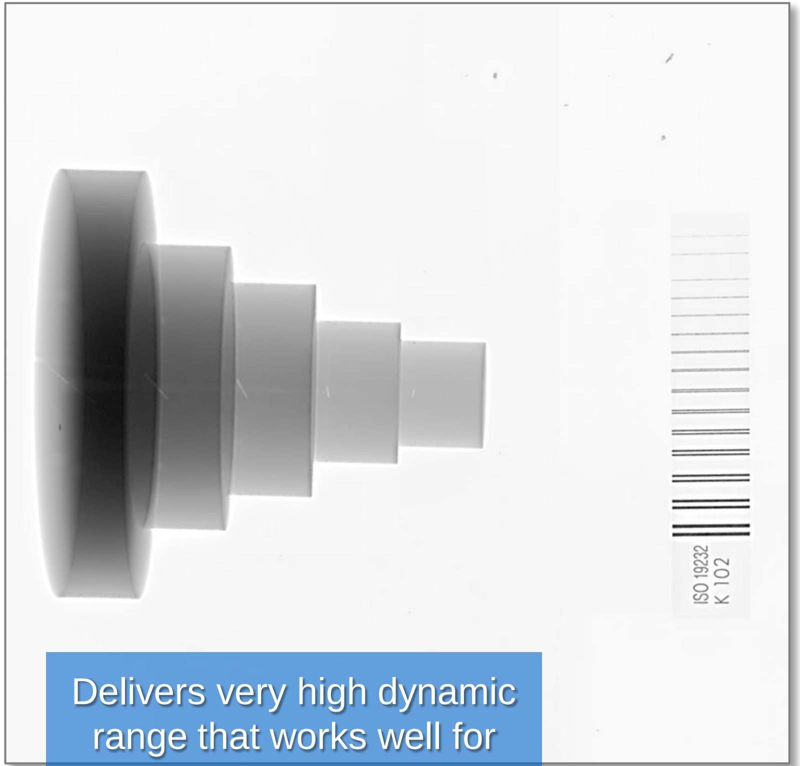
High Dynamic Range (HDR) Image Acquisition

8 Different Energy Settings
for each scan position

Low Exposure



High Exposure



Delivers very high dynamic range that works well for each cake layer

Multi-View Scanning Configuration

Translation Only

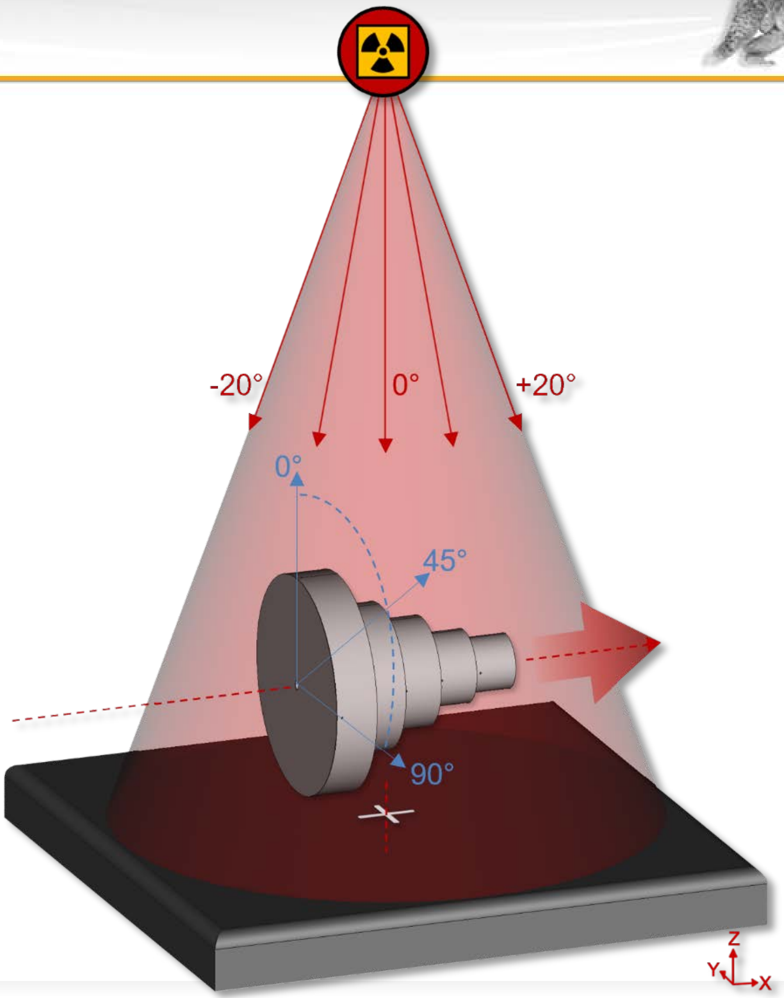
Did not provide sufficient angular coverage for 3D positioning

Translation + Rotation

Easy to implement in a traditional multi-axis Xray Cabinet

Minimal number of views selected to provide sufficient angular coverage while being possible to acquire in just a few seconds

Optimal number of views depends on specific part geometry

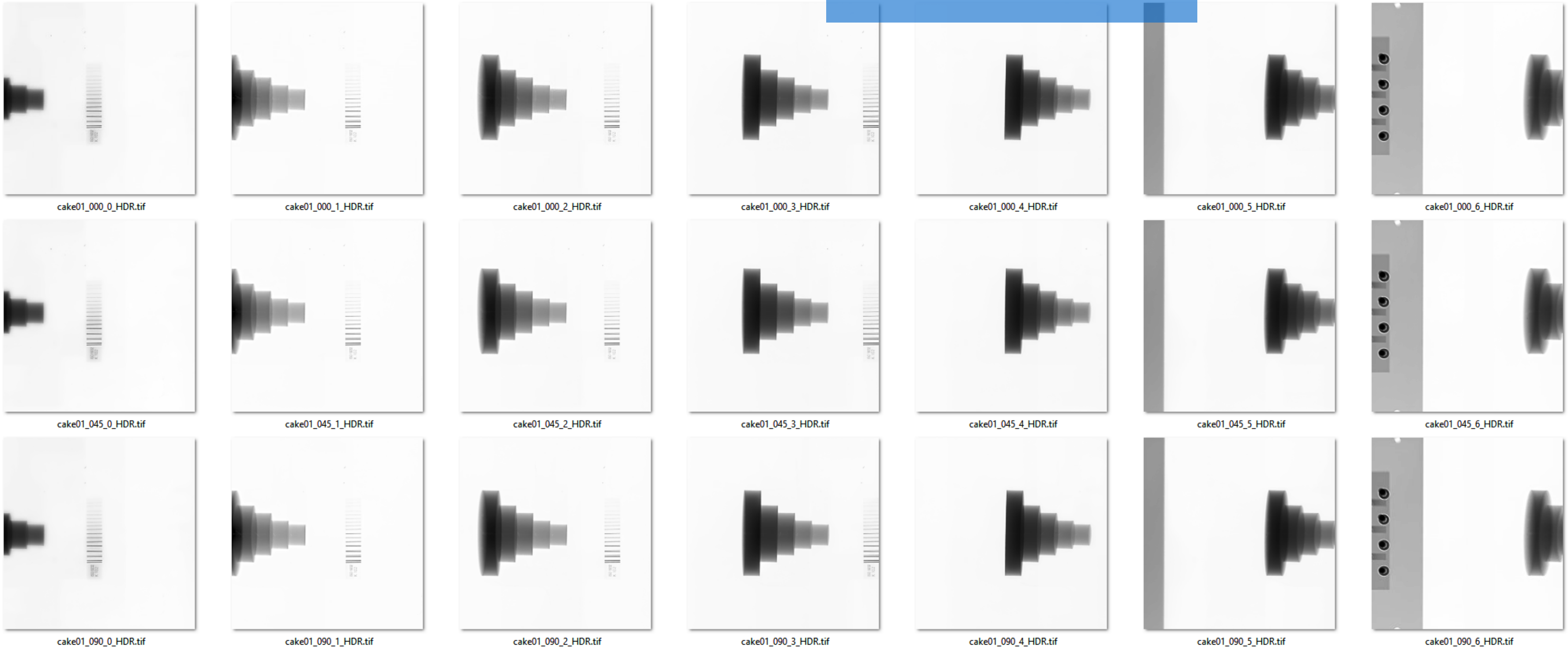


Data Acquisition Geometry

Total of 21 scan positions

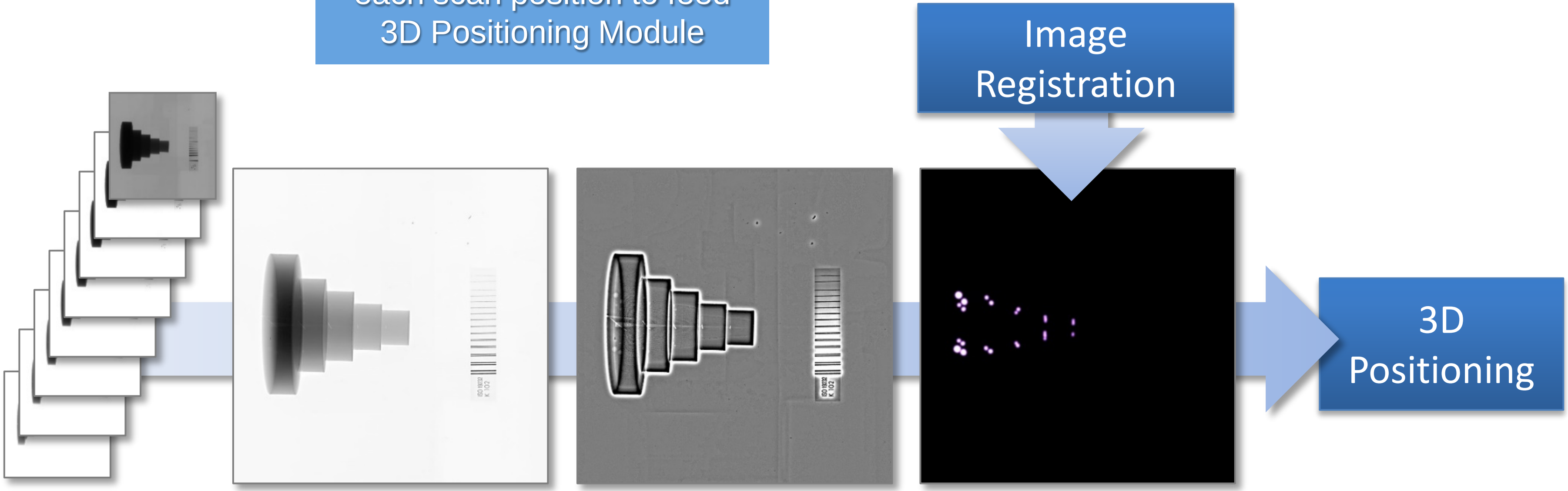
3 Rotations

7 Translations



Data Processing Workflow

Data Processing workflow for each scan position to feed 3D Positioning Module



Multi-Energy Acquisition

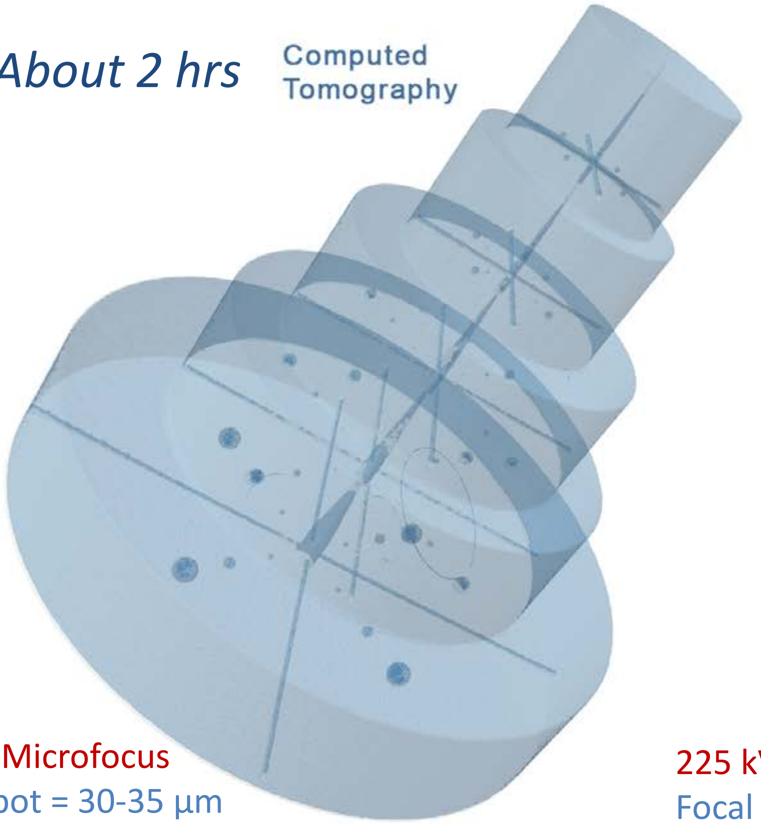
High-Dynamic Range (HDR)

Image Enhancement

Defect Detection Masks

Comparison between micro-CT and Predictive 3D

About 2 hrs

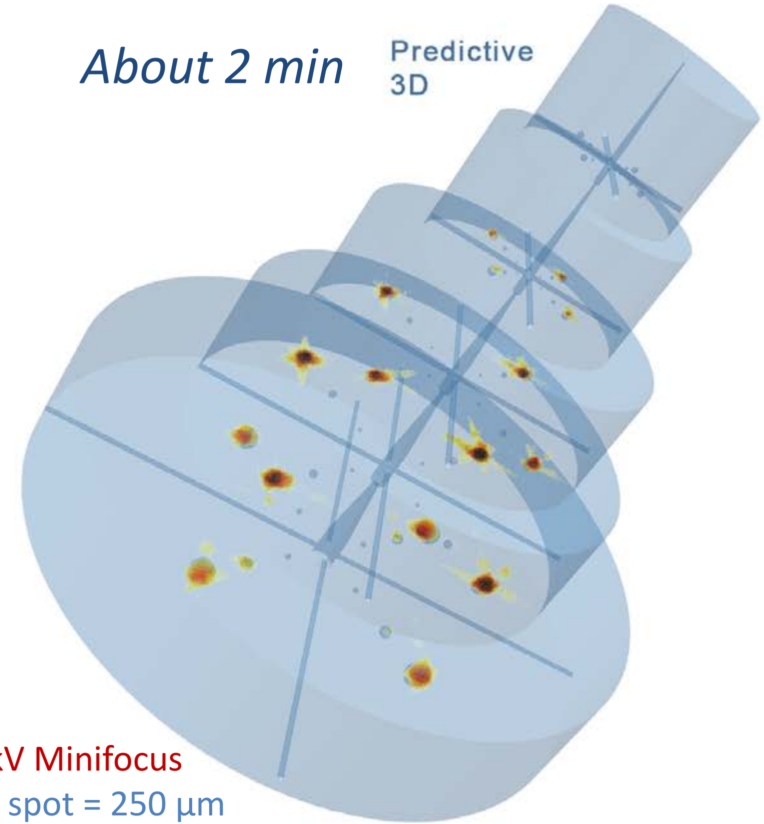


225 kV Microfocus

Focal spot = 30-35 µm

1536x1920 pixels @ 127 µm/pixel

About 2 min

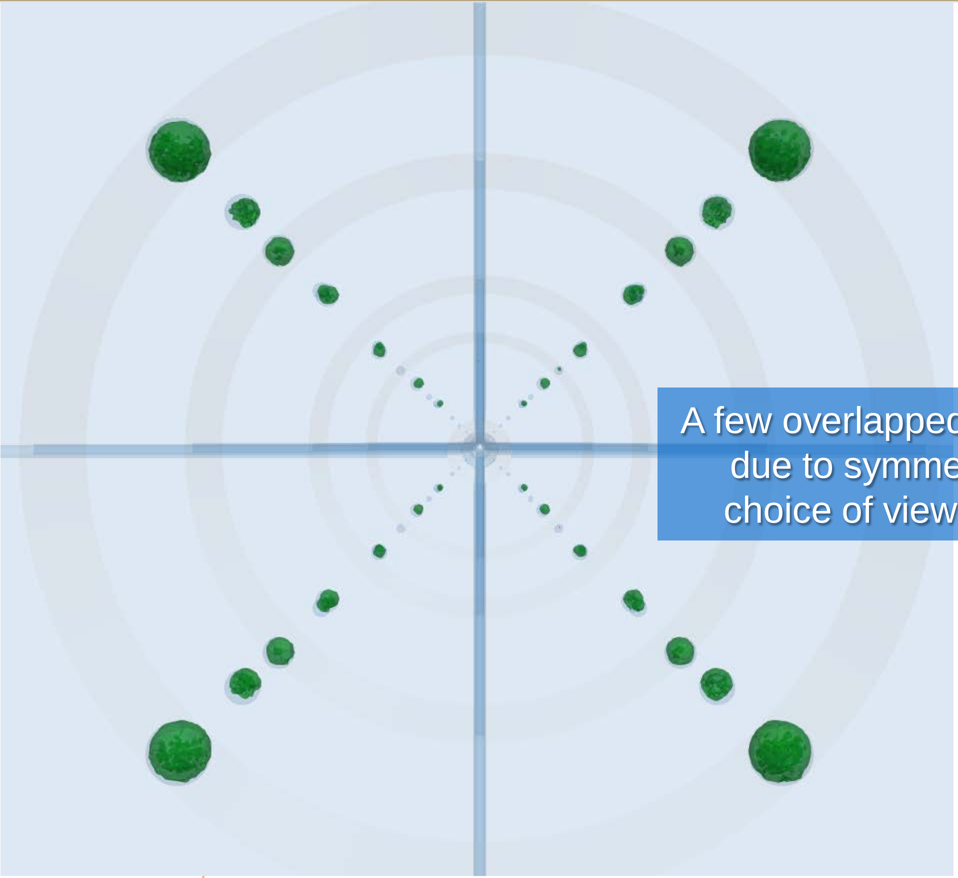


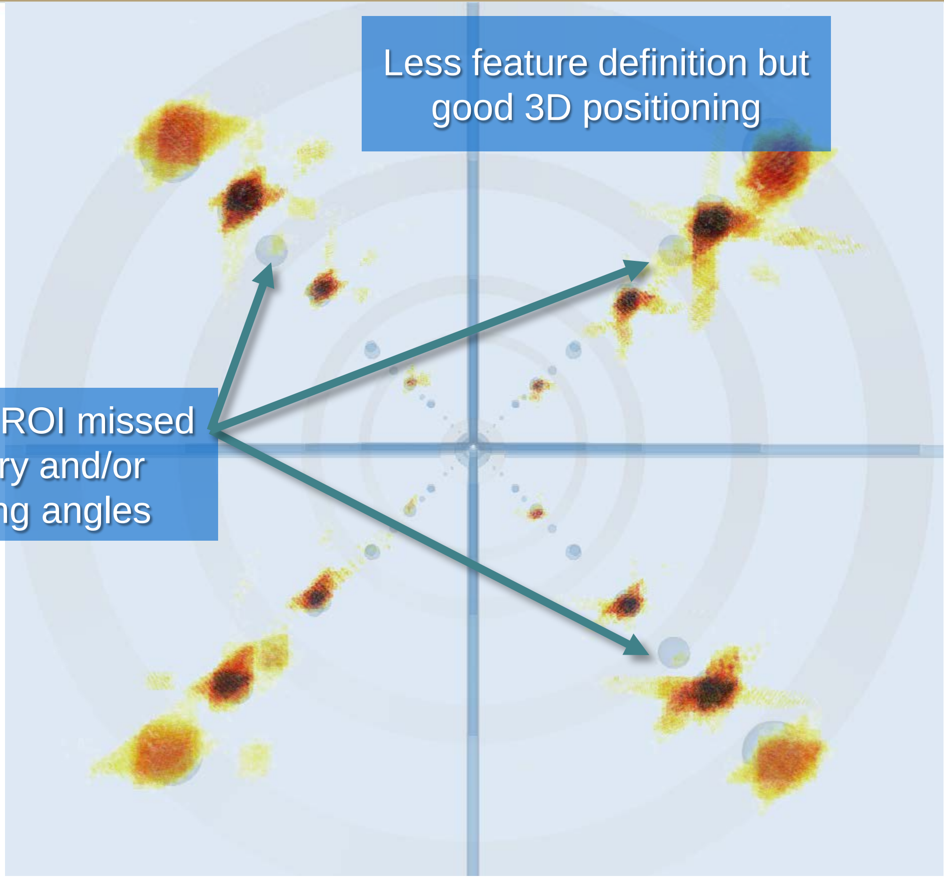
225 kV Minifocus

Focal spot = 250 µm

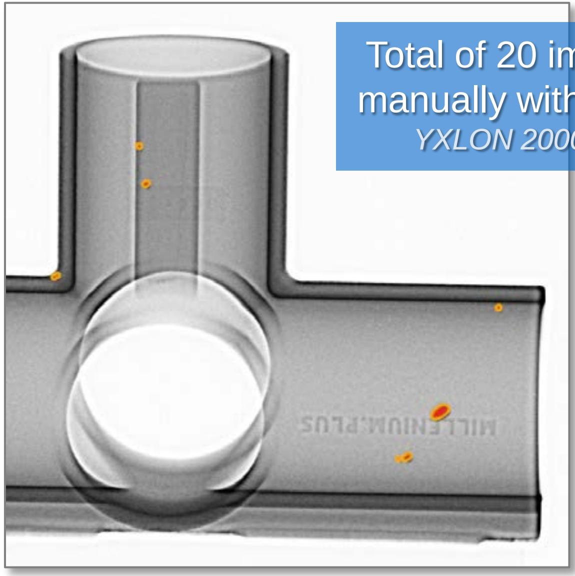
3096x3096 pixels @ 99 µm/pixel

Comparison between micro-CT and Predictive 3D

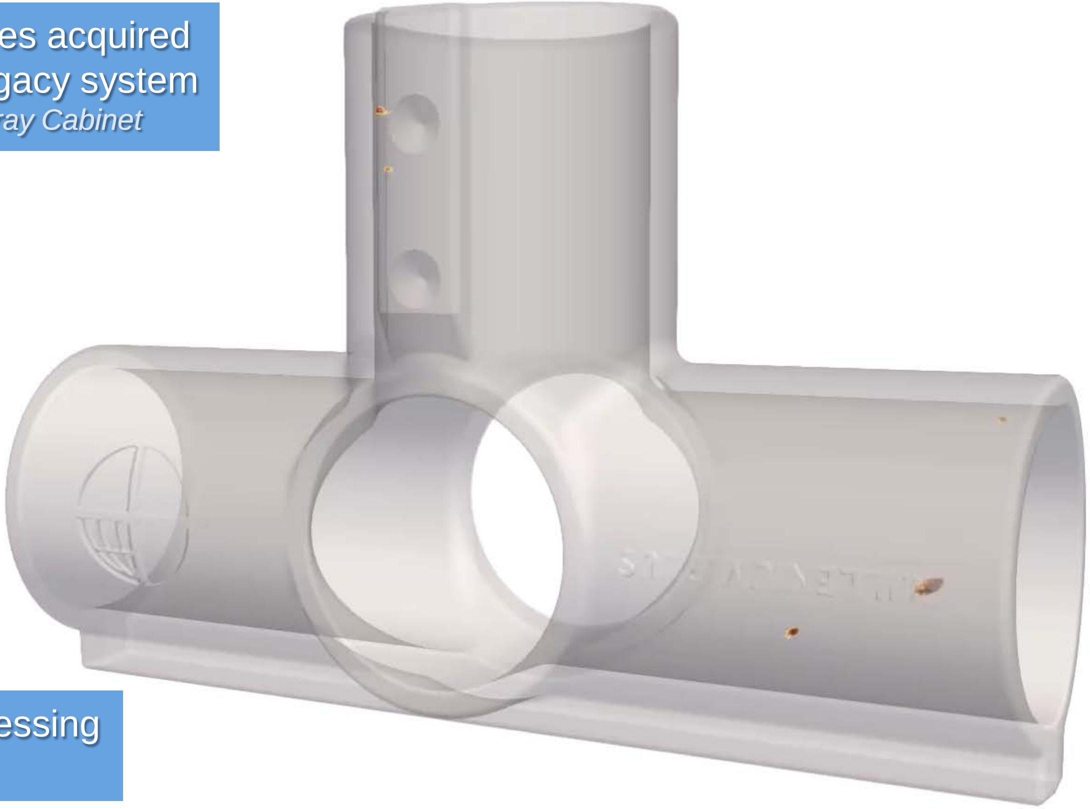




3D Positioning example with Aluminum Casting



Total of 20 images acquired manually with legacy system
YXLON 2000 X-ray Cabinet



3D Positioning helps assessing defect severity

Conclusion

- Proposed 3D Positioning Method Works!
  - Can easily be automated
  - Can work with practically any conventional X-ray cabinet
  - Estimated processing time between **2 – 5 minutes** per part depending on number of images acquired
- HDR Processing significantly helps with parts that have dynamic range challenges
- Defect Detection Capability
  - **3D Positioning Accuracy** relatively easy to achieve with limited number of viewing angles
  - **Detection Performance** highly dependent on part geometry and choice of viewing angles
  - **Defect Shape** less precise than CT due to limited viewing angles for reconstruction
    - Need to refine tools to convert weighted point cloud into 3D mesh
  - More viewing angles lead to better 3D Positioning Accuracy, higher detection performance and better Defect Shape Definition, but greater acquisition time

Thank You! / Merci

Collaborators

LynX Inspection: Luc Perron lperron@lynxinspection.com
Yohan Bélanger
Steeves Roy

Pratt & Whitney Canada: Justin Byers

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