Additive Manufacturing for Aerospace

X-ray CT as an Approved Production Inspection

James Willcocks

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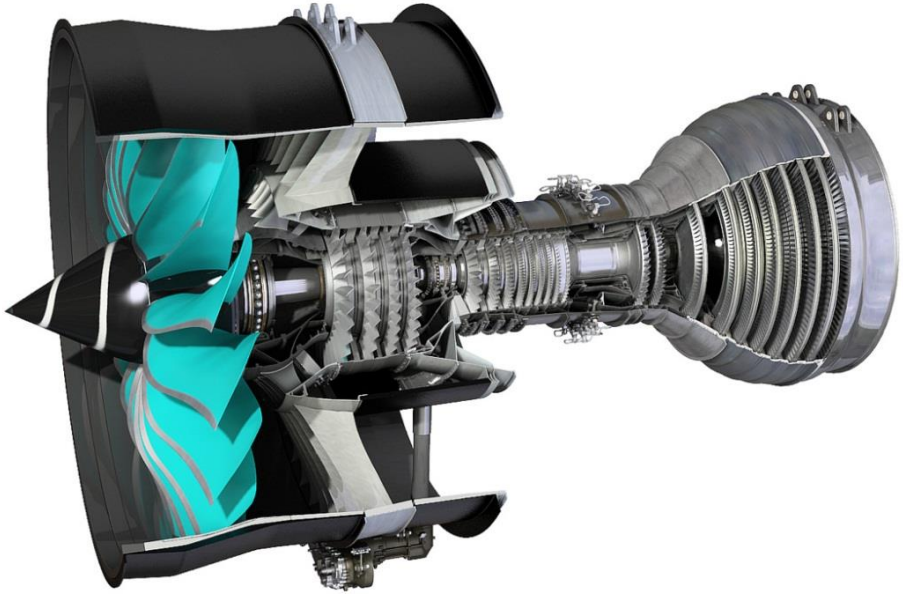

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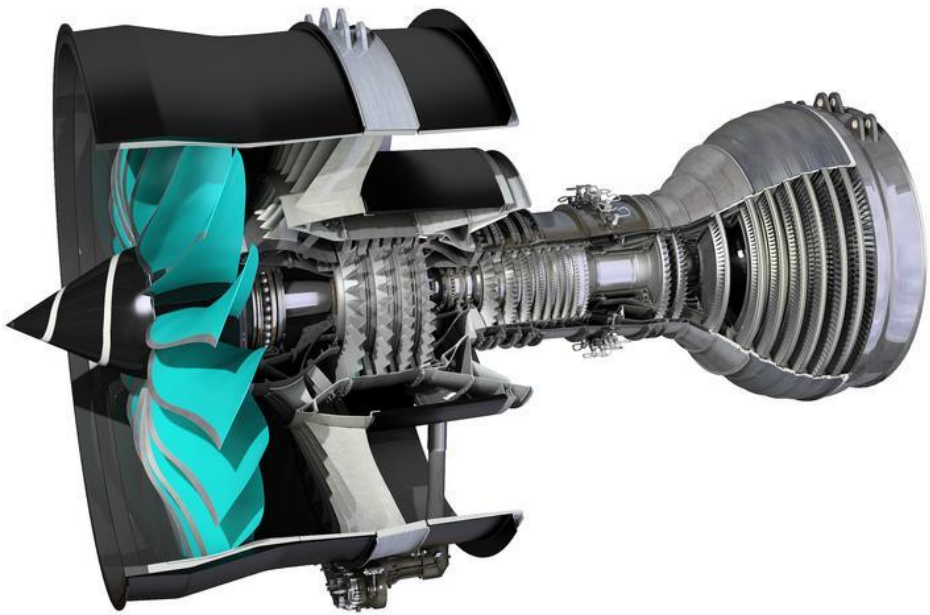
Aero Engine ALM Inspection



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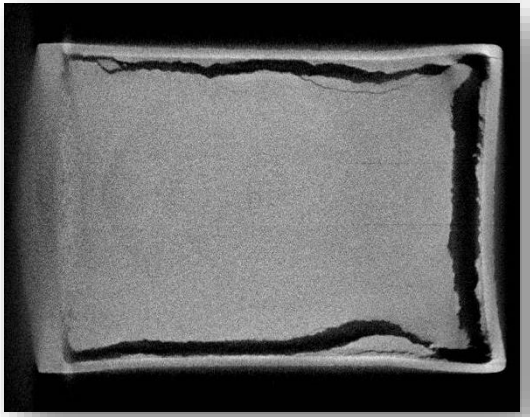
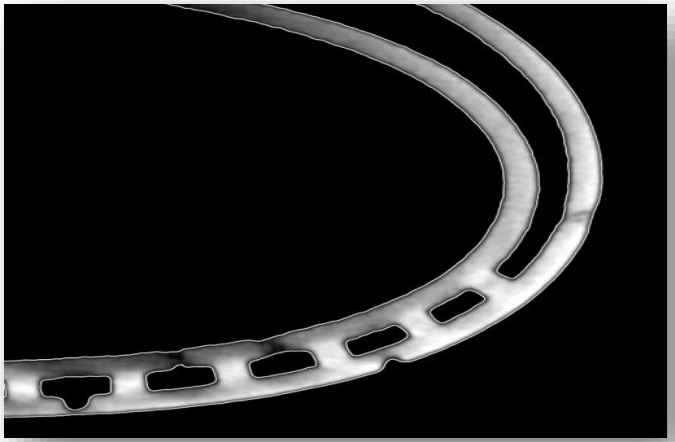
- ALM Benefits:
  - Increased cooling efficiency
  - Part reduction
  - Reduce manufacturing steps
  - Optimised design

- ALM Challenges:
  - Part Complexity
  - Geometry
  - Access (Physical / Line of Sight)
  - Surface finish.

Aero Engine ALM Inspection

- CT can provide dimensional interrogation of internal features:
  - Cooling holes
  - Wall Section Thickness





- Verification of additive build processes.
- Evaluation of material integrity:
  - Voids / Porosity
  - Cracks
  - Layer Defects
  - Trapped Powder

X-ray CT Challenges for ALM

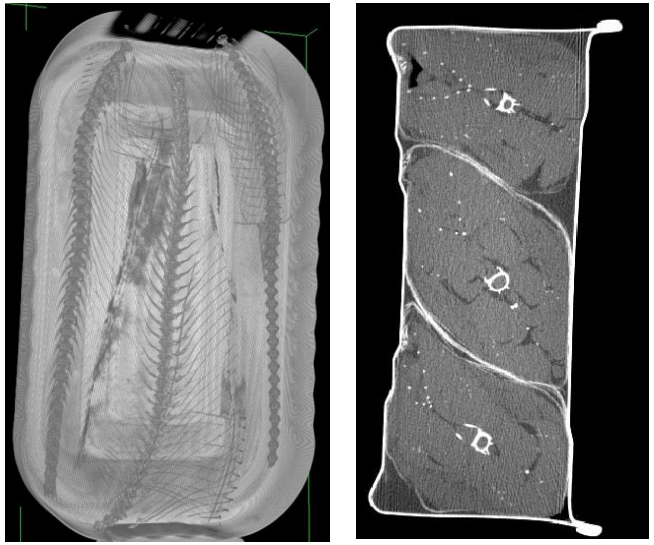
Image : © Rolls-Royce plc

Film x-ray

Image : © Rolls-Royce plc

Digital x-ray

Image : © Rolls-Royce plc



X-ray CT

X-ray CT Challenges for ALM

Image : © Rolls-Royce plc

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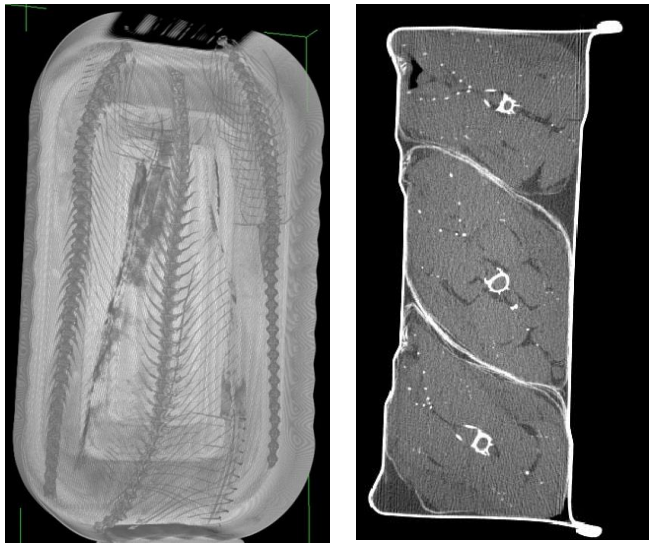


X-ray CT

How to make this Transition?

Technology Readiness Levels (TRL)

Implementation	TRL9. Actual system proven through successful mission operations.
Pre-production	TRL8 Actual system completed and qualified through test and demonstration
	TRL7 System prototype demonstration in an operational environment
Process understanding (application specific)	TRL6 System/subsystem model or prototype demonstration in a relevant environment
	TRL5 Component and/or partial system validation in a relevant environment
Technology assessment	TRL4 Component and/or partial system validation in a laboratory environment
	TRL3 Analytical and experimental critical function and/or characteristic proof of concept
	TRL2 Technology concept and/or application formulated
	TRL1 Basic principles observed and reported

Technology Readiness Levels (TRL)

Production Implementation	TRL9. Actual system proven through successful mission operations.
Personnel approval Equipment and Process optimisation for cost and rate	TRL8 Actual system completed and qualified through test and demonstration
	TRL7 System prototype demonstration in an operational environment
Control checks Technical risks Draft procedure Training requirements Equipment	TRL6 System/subsystem model or prototype demonstration in a relevant environment
	TRL5 Component and/or partial system validation in a relevant environment
Fundamental understanding Proof of concept	TRL4 Component and/or partial system validation in a laboratory environment
	TRL3 Analytical and experimental critical function and/or characteristic proof of concept
	TRL2 Technology concept and/or application formulated
	TRL1 Basic principles observed and reported

Fundamental understanding for X-ray CT (TRL 4)

- Many years of research and development:
  - Universities
  - Research Centres
  - Suppliers

- All factors which influence the inspection are understood for example:
  - Defect orientation
  - X-ray Penetrating Power
  - X-ray Source
  - Detector Resolution
  - Number of Projections
  - Magnification / field of view
  - Component Orientation
  - Part geometry
  - Manipulator

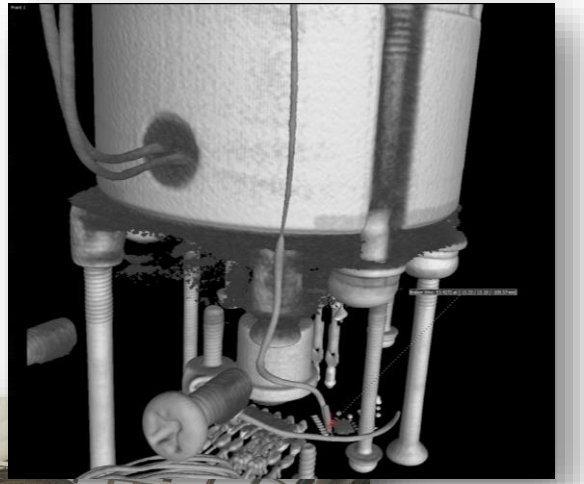
Image : © University of Southampton

How to achieve a repeatable X-ray CT process (TRL 6)

- Detailed Process understanding established
  - Risk review
  - PFMEA Completed

- Control plan / NDE procedure in Place
  - Equipment requirements
  - Training requirements
  - System Control / Performance Checks

Image : © Rolls-Royce plc



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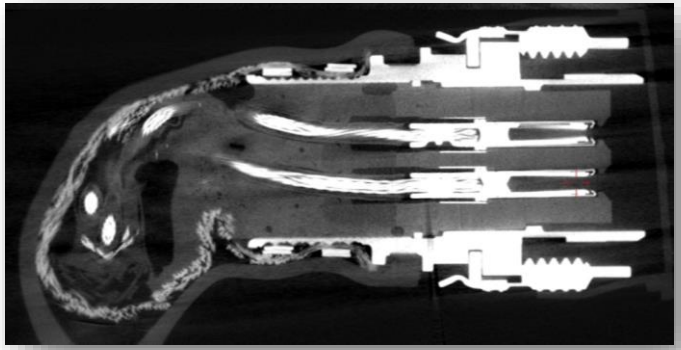
Implementation of X-ray CT Technology (TRL8)

- Fundamental Process Understanding

- Approved personnel
- Equipment specification
- Formal Technique Instruction
- Training and experience requirements
- Control checks
- Calibration standards



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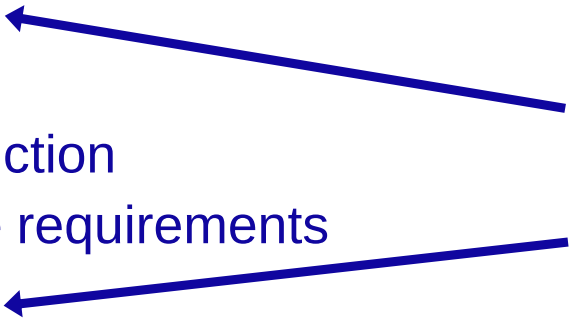
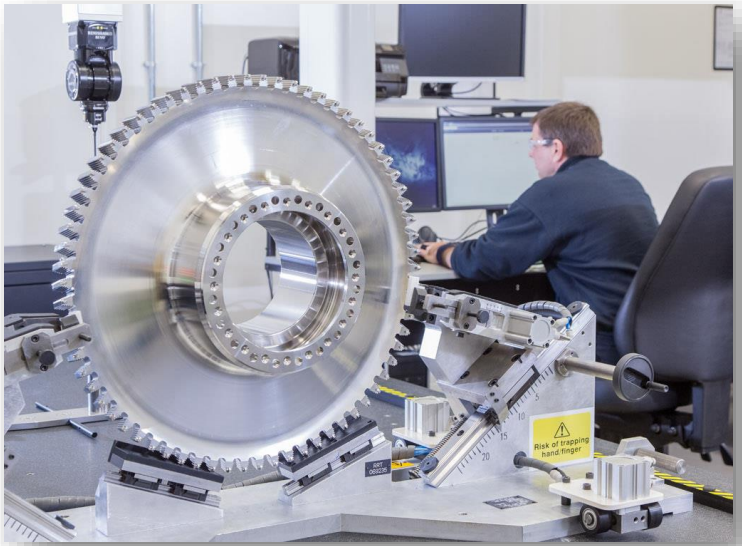


These factors are the blockers for X-ray CT for NDE.

X-ray CT Process Control checks

- Does the data have sufficient signal to Noise.
- Does the data have sufficient Contrast.
- Is the Detector is Working Correctly.
- Is the X-ray focal spot size correct.
- Have the manipulator axis been calibrated.
- Has capability been demonstrated on a representative RQI.



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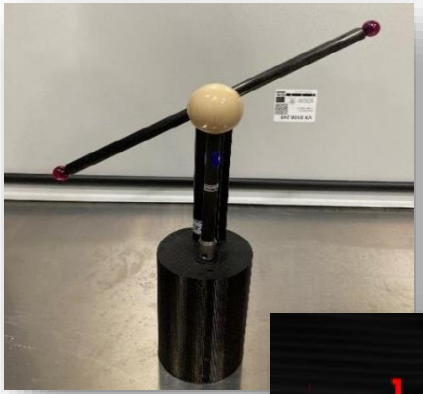
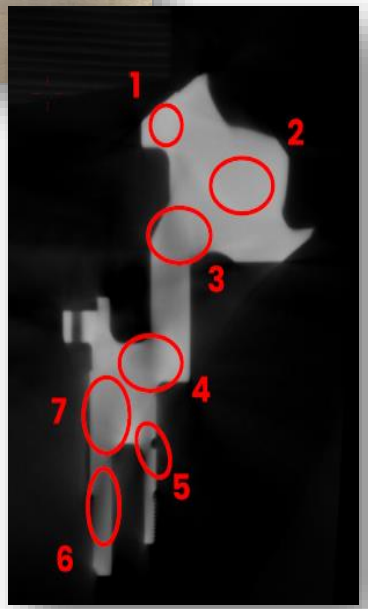
5 - Inspection Process Control

- X-ray CT inspection can be controlled using the following system process checks:

System Process Control Check	Frequency
MTF and CNR	**Daily**
Geometric Magnification (Ruby Spheres)	**Daily**
Representative Quality Indicator (RQI)	**Daily**
Detector Gain and Offset	**Daily**
Detector Bad Pixel Mapping	**Weekly**
Focal Spot	**Monthly**
Detector Resolution	**Monthly**

Ruby Spheres© Waygate technologies



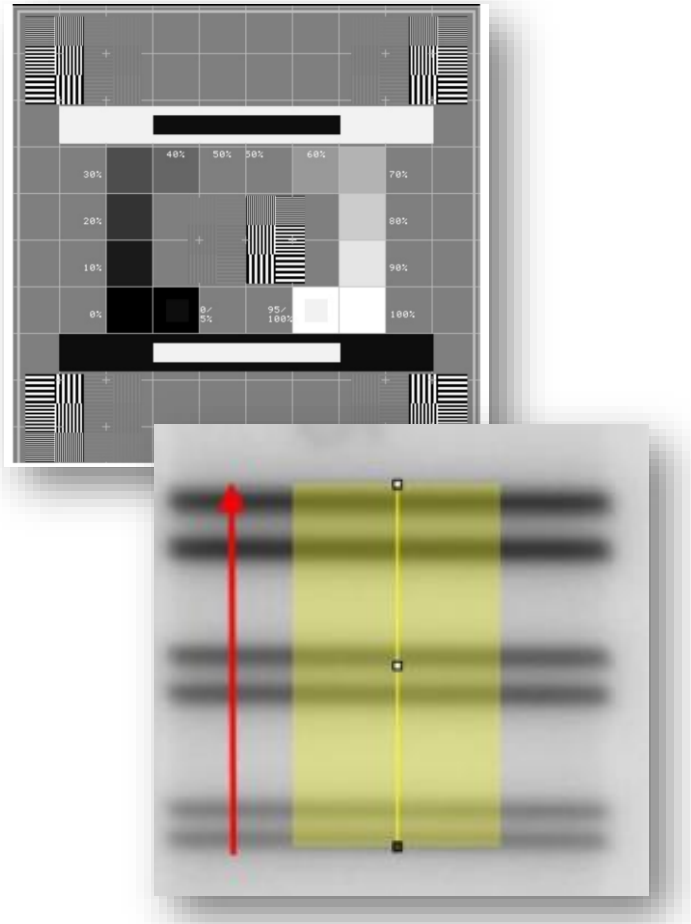


RQI Layout © Rolls-Royce

5 - Inspection Process Control

- X-ray CT data interpretation may be controlled usingg the following process checks:

Viewing Process Control Checks	Frequency
Eye Adaption Time	**per inspection**
Ambient Light Levels	**Daily**
Monitor Performance (SMTPE Pattern)	**Daily**
Monitor Brightness / Contrast	**Monthly**



Process Controls © Waygate technologies

Questions?