in Aerospace

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Numerical Simulation of Additively Manufactured Metal Component

12th International Symposium on
NDT in Aerospace
Williamsburg, VA, USA
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STUDENT CHALLENGE

ND - Taskforce


Mastan Raja Papanaboina

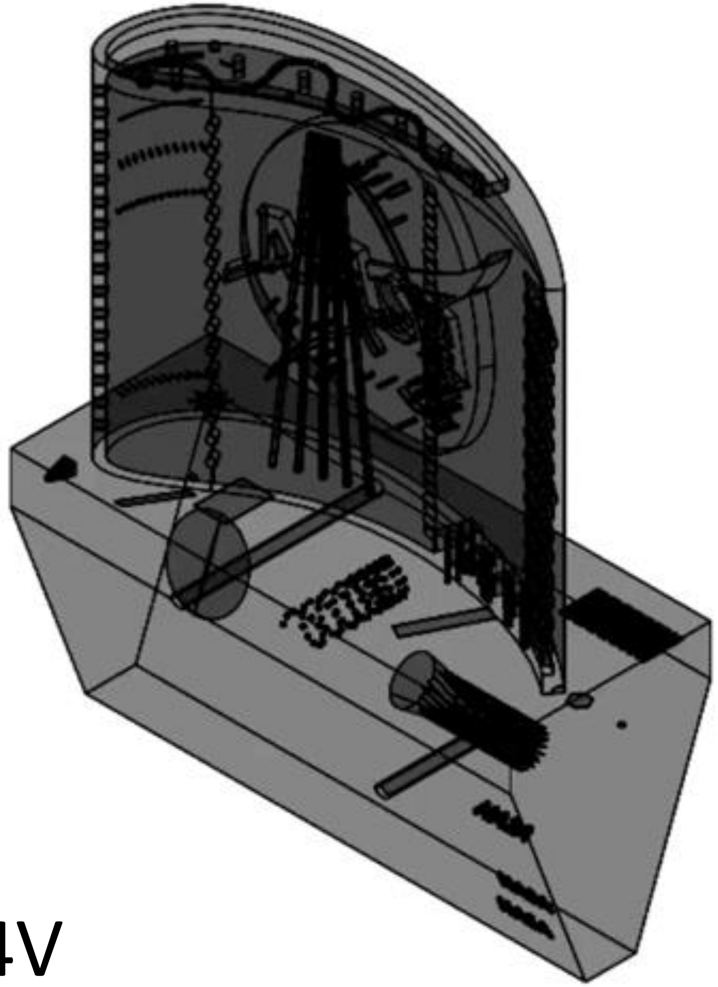

Donatas Cirtautas


Aadhik Asokkumar

Prof. Kazimieras Barsauskas Ultrasound Research Institute
Kaunas University of Technology
Lithuania

Flaws in the Jet Engine Turbine Blade

- Spherical volumes of trapped powder (50 µm-3 mm)
- 2D and 3D arrays of trapped powder
- Complex helical volumes of trapped powder
- Simulated cracks between airfoil & blade root
- Large enclosed volumes
- Trapped powder resolution grids
- Large prismatic trapped powder volumes (20mm)



Material:

Blade: Ti-6Al-4V

Defects: air/void

Aim

To identify defects and to propose most suitable technique for the inspections of additively manufactured components

Objectives

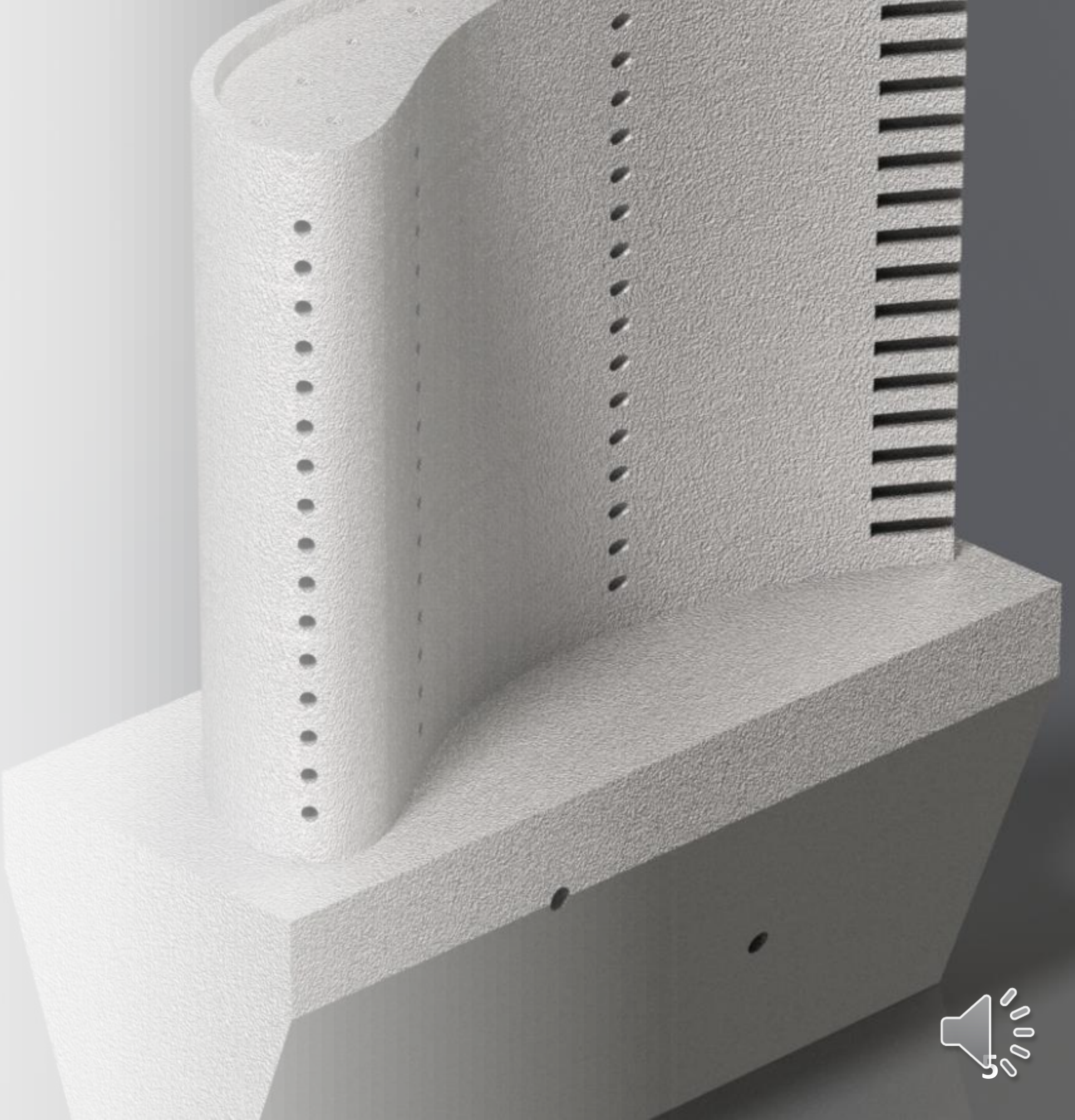
- Selection of suitable NDT techniques
- Tools and optimal parameters
- To set the benchmark NDT methods for inspection of various defects size (50 µm – 20 mm)

Numerical Simulation

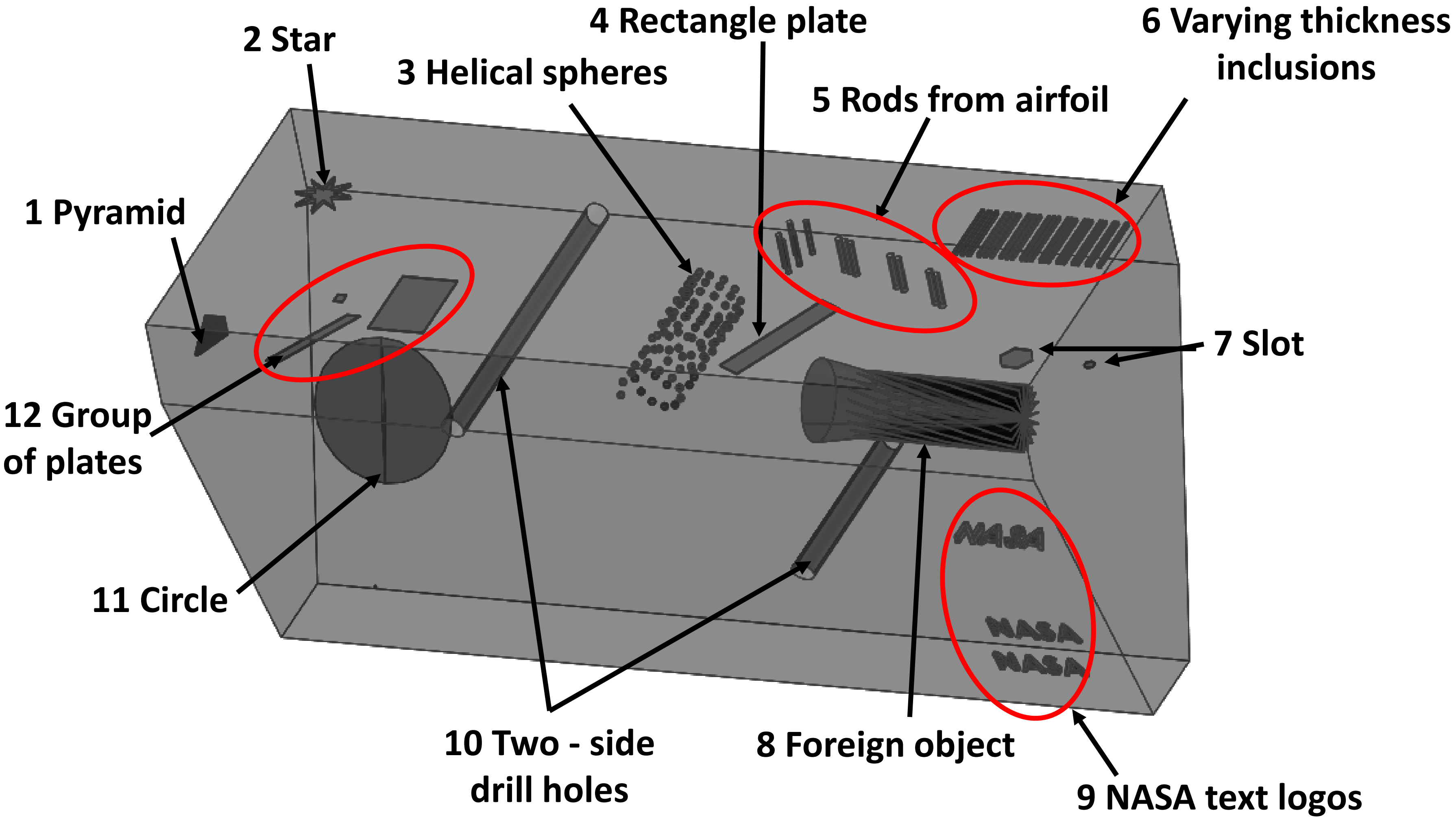
- Radiography testing
  - Inspection of Aerofoil
  - Inspection of Dovetail
- Ultrasound technique
  - Inspection of dovetail on jet engine turbine blade
    - Beam computations with single element contact and immersion
    - Inspection simulation using contact single element
    - Immersion technique
  - Inspection of Aerofoil on jet engine turbine blade
    - Beam Computation
    - Inspection of SDH with Contact and Immersion Technique
    - Contact and immersion test on top of the blade
    - Inspection of Spherical holes

Problems in inspecting additively manufactured components

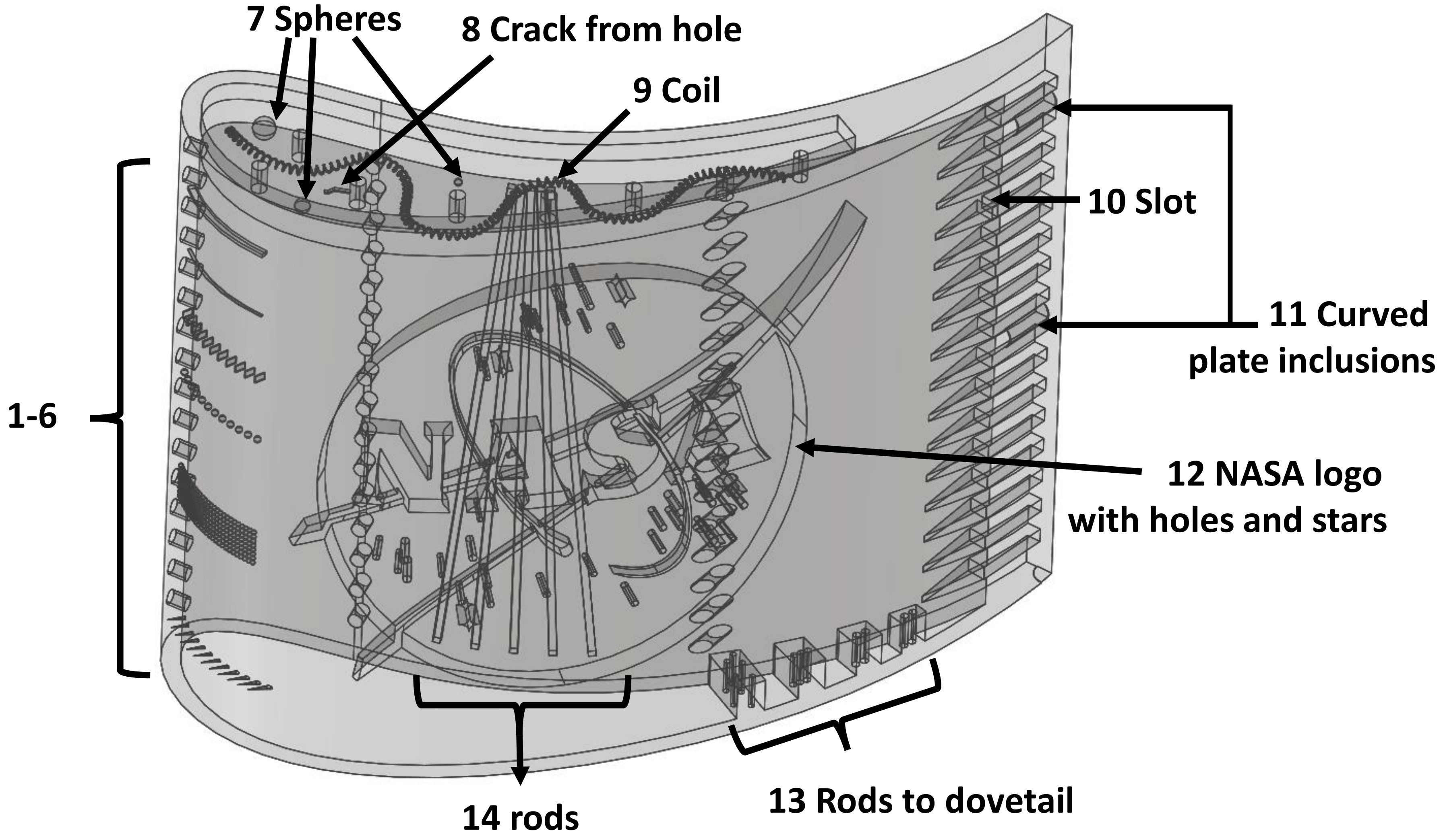
- High attenuation due to grainy structure.
- Ultrasonic wave scattering leads to mask the small flaws.
- Planar cracks with length that lie parallel to the direction of ultrasonic wave travel are not detectable.



Defects in the Dovetail of the blade



Defects in the Airfoil of the blade



Radiography Inspection

Source Specification

X-Ray

- Intensity current – 1mA
- Acceleration voltage – 450V
- Radius – 1.5mm
- Opening angle – 22 deg

Gamma

- Source intensity – 2000 GBq (Becquerel of radioactivity)
- Radius – 1.5mm
- Opening angle – 22 deg
- Height – 3 mm

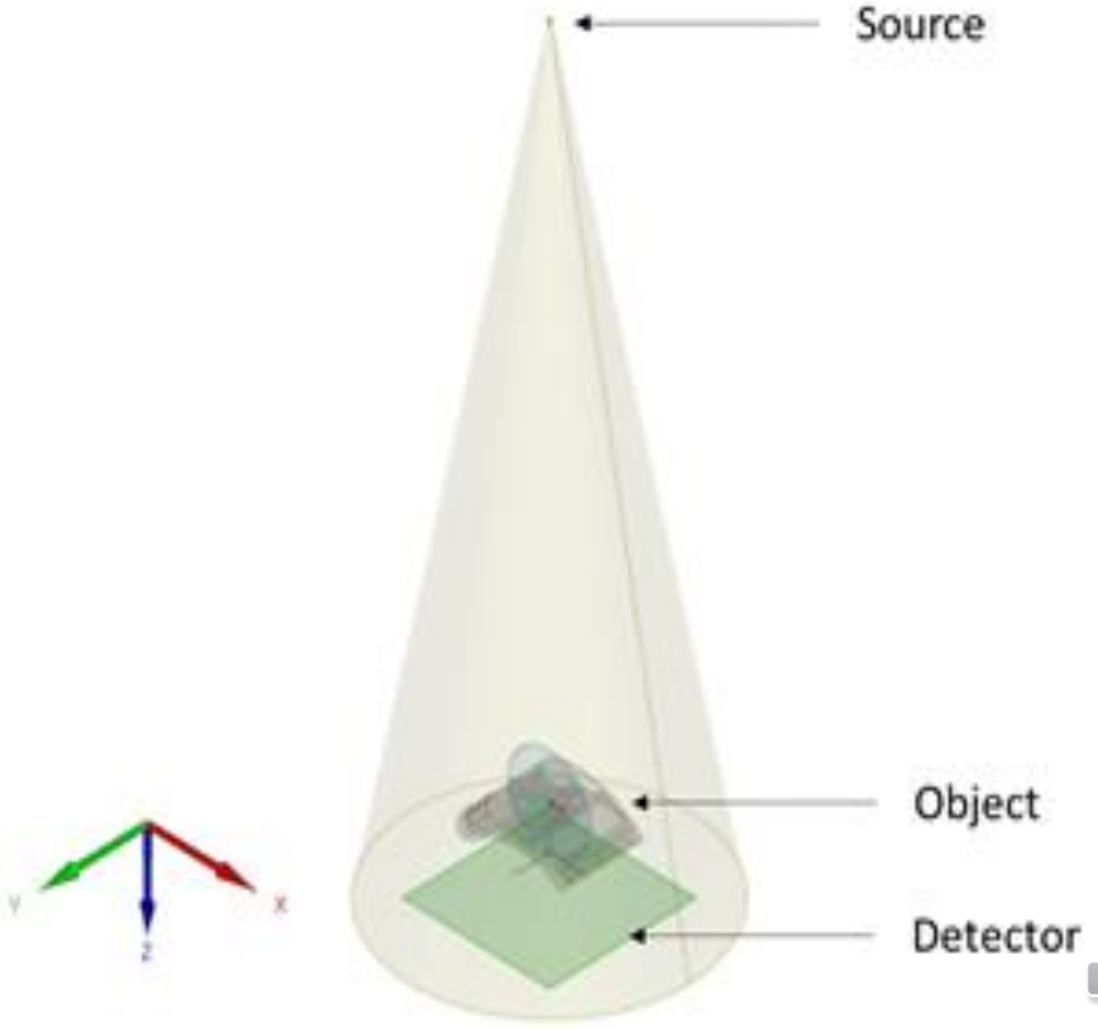
HE

- Dose rate – 1GY/min (Gray Unit/min)
- Radius – 1.5mm
- Opening angle – 22 deg

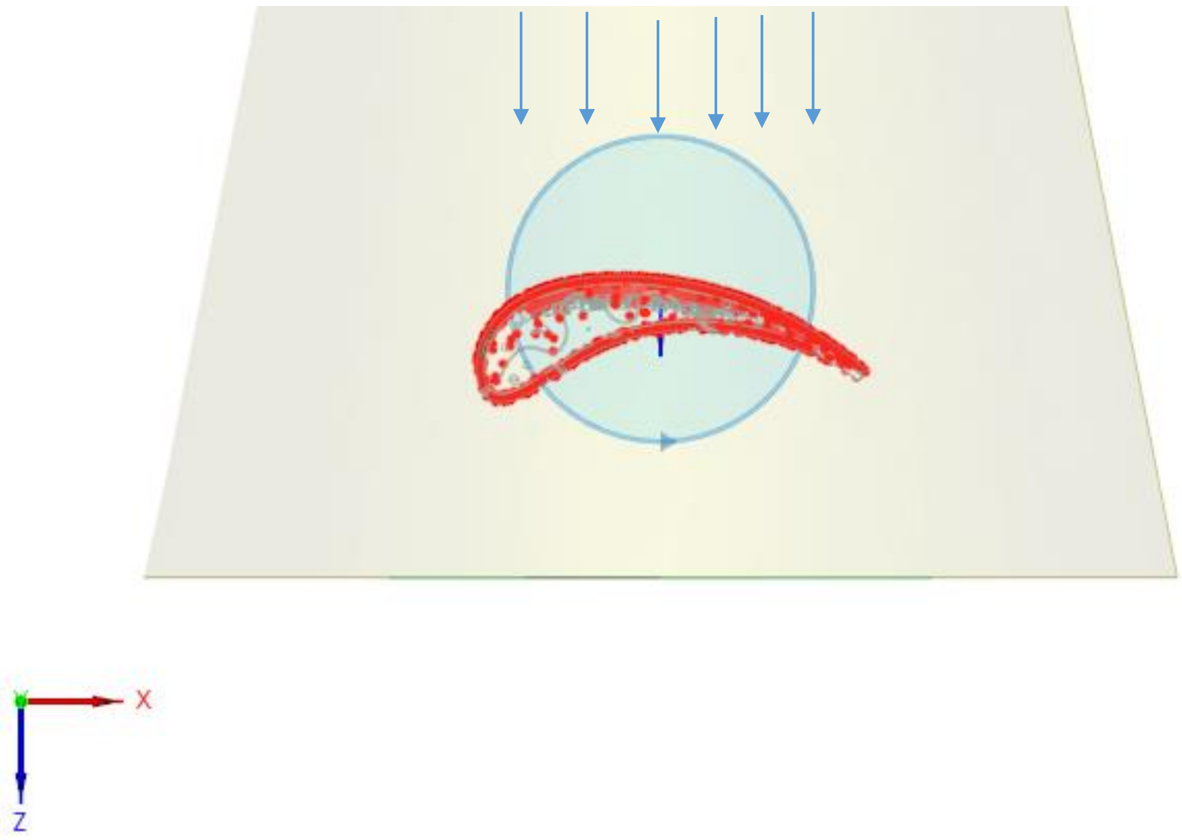
Detector and scanning specification

- Pixel size – 0.1mm
- Resolution – 1600x1200 pixels
- Source to Object (SOD) – 690 mm
- Object to Image (OID) – 85 mm

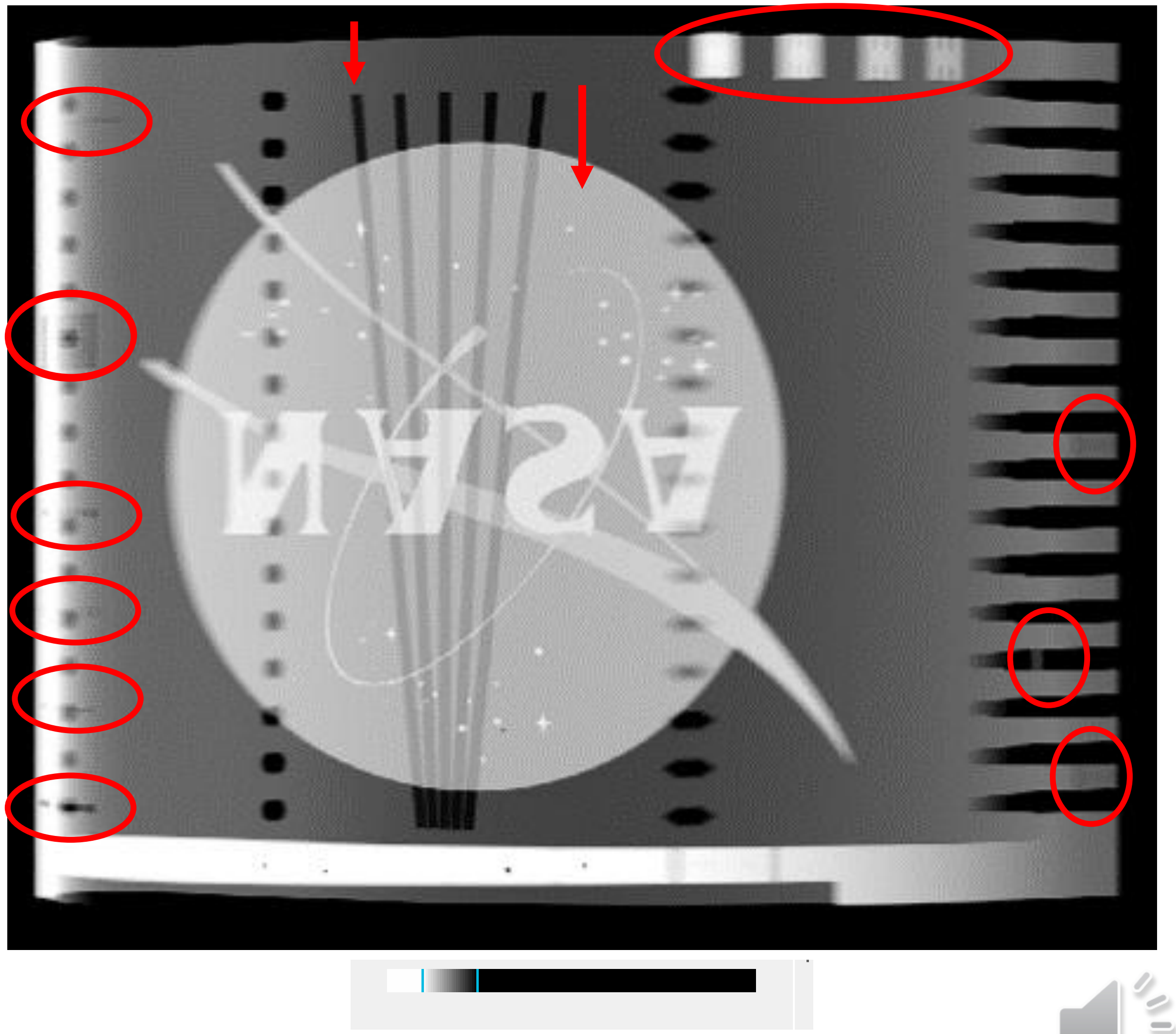
- Exposure time – 4s



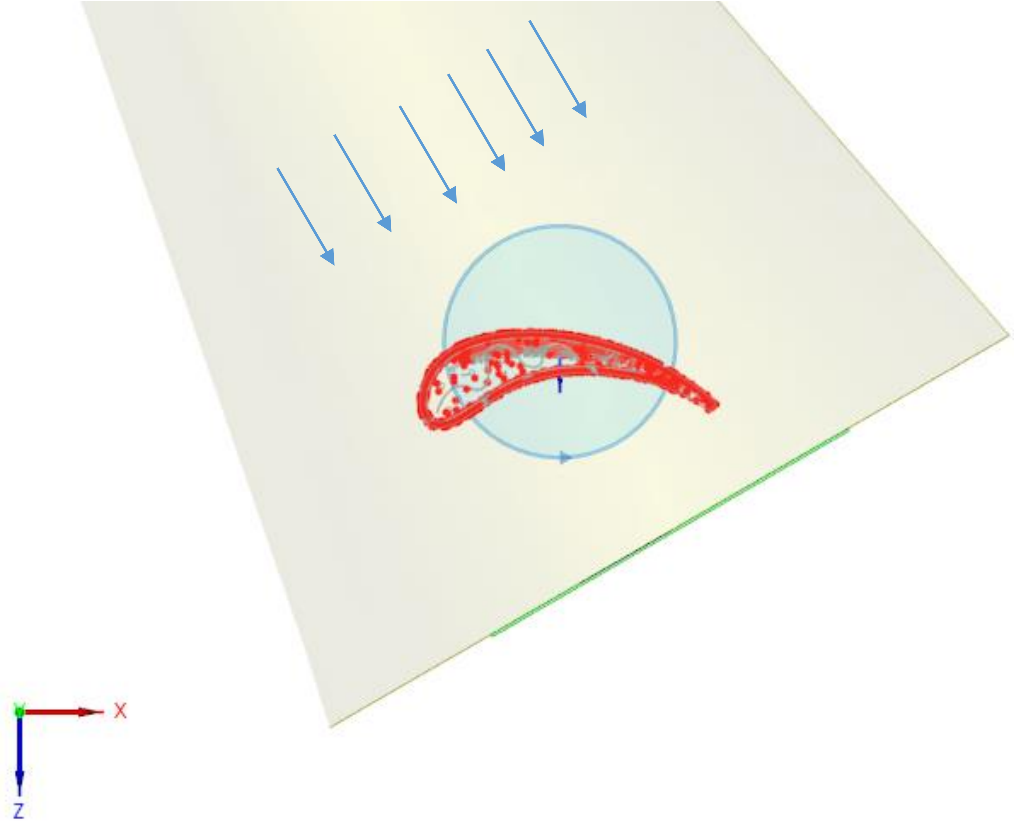
X-Ray Result – Angle 0°



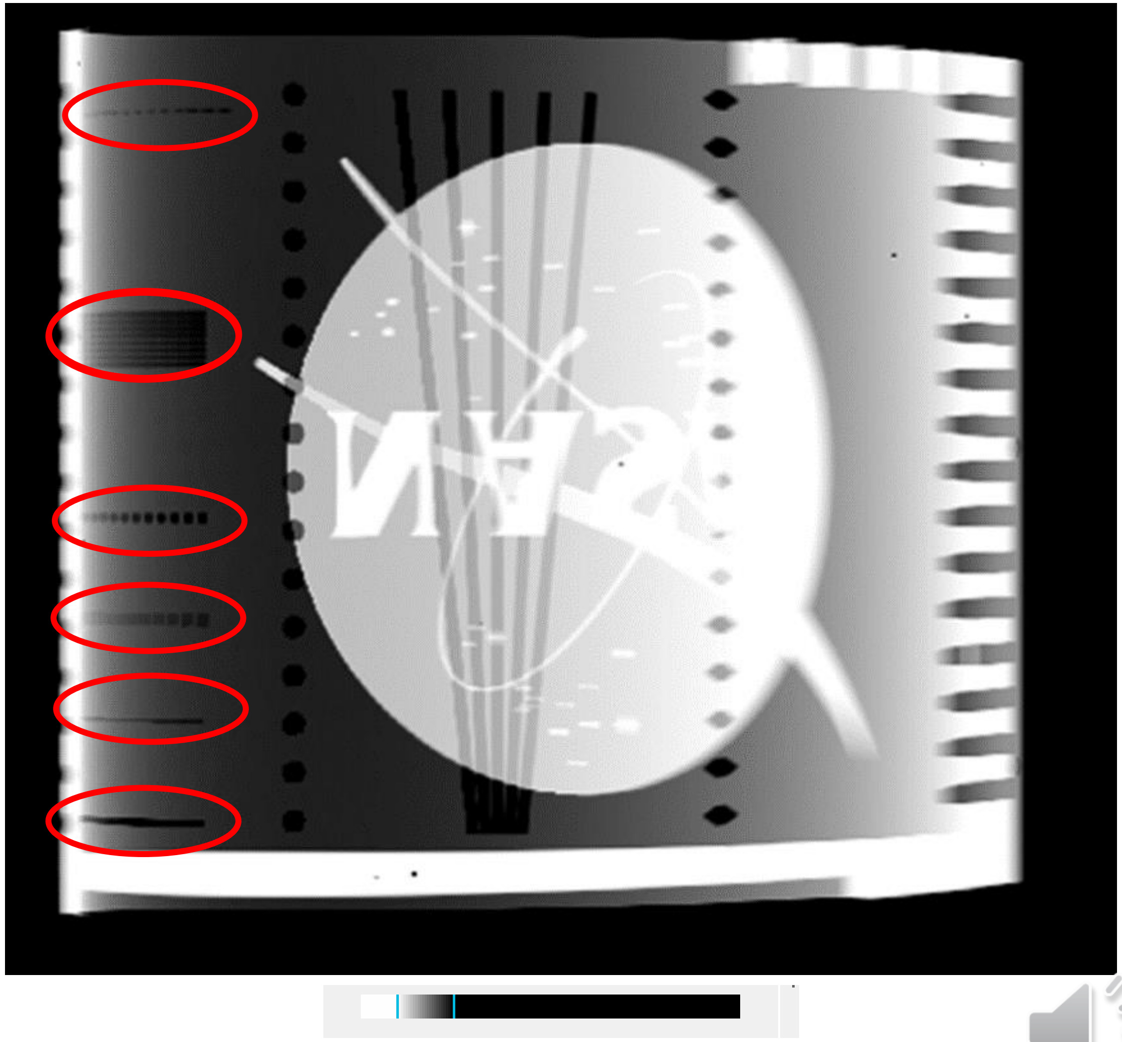
Photon beam penetration



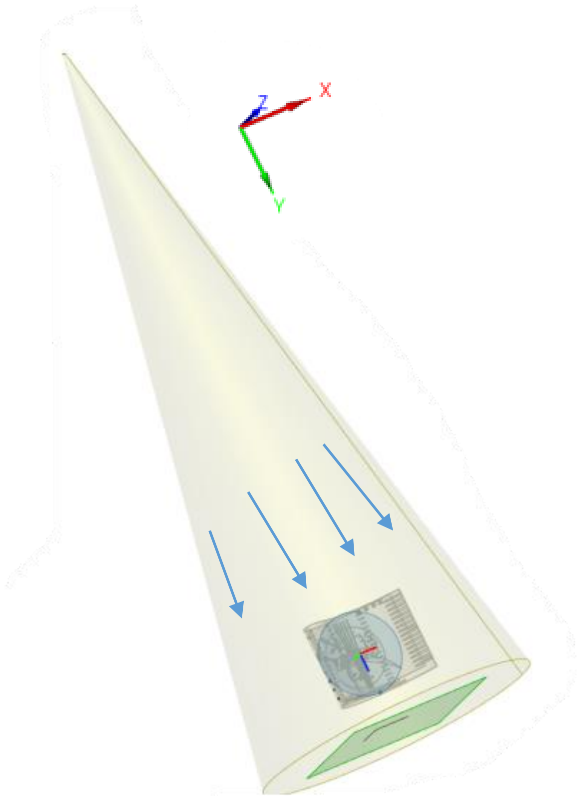
X-Ray Result – Angle 30°

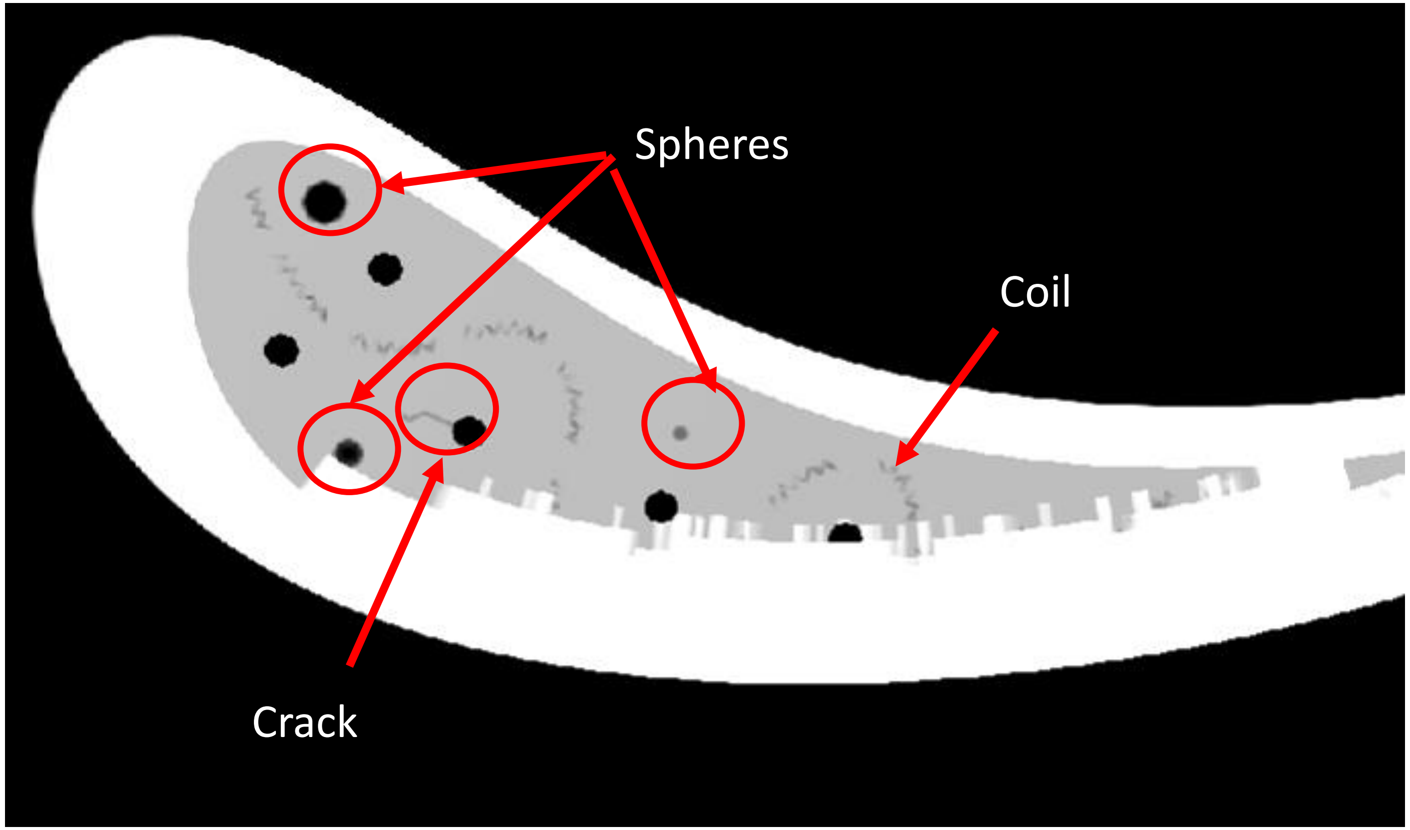


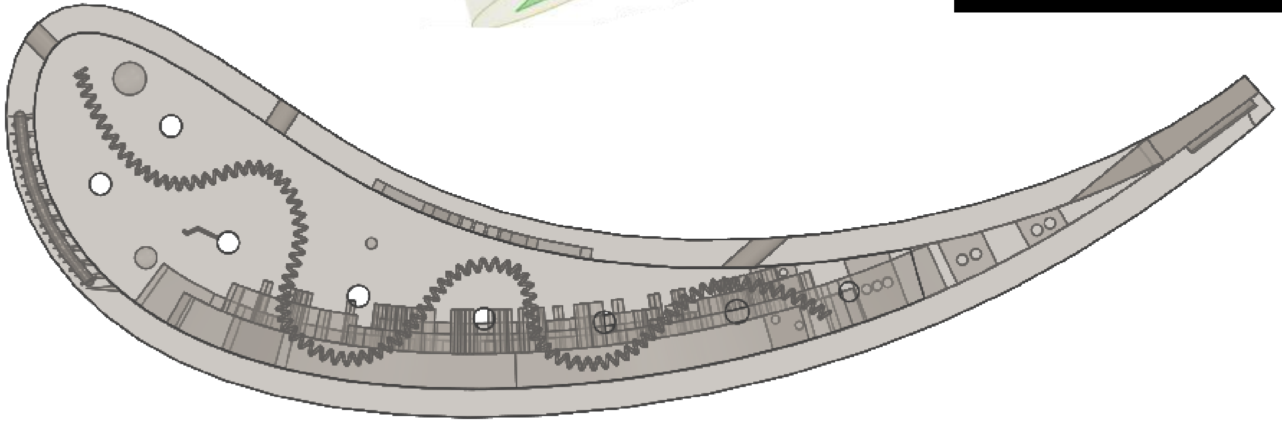
Photon beam penetration



X-Ray Result – x rotation 90°

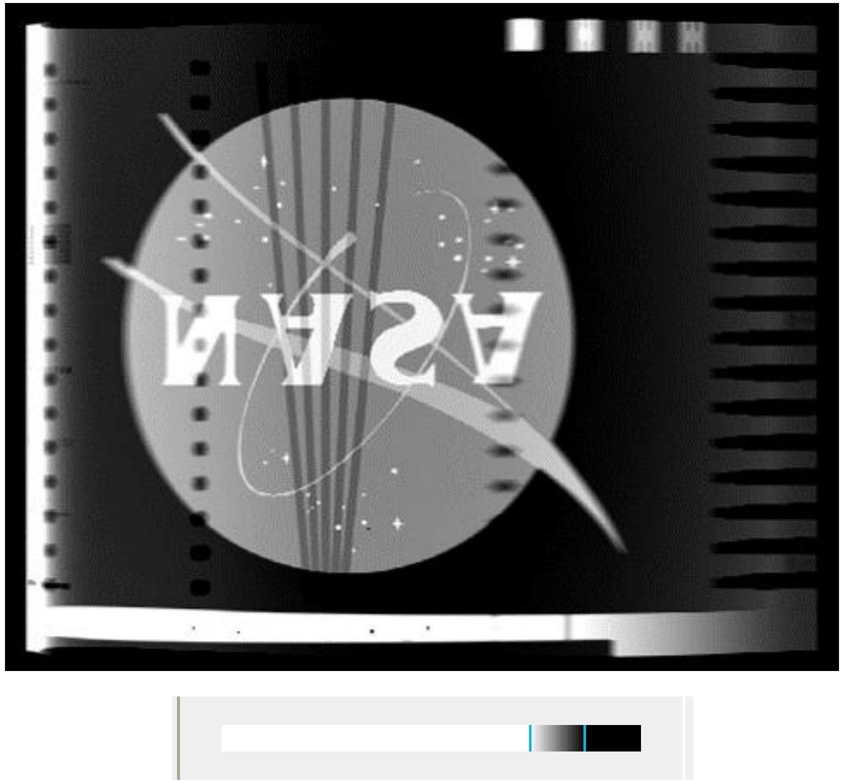




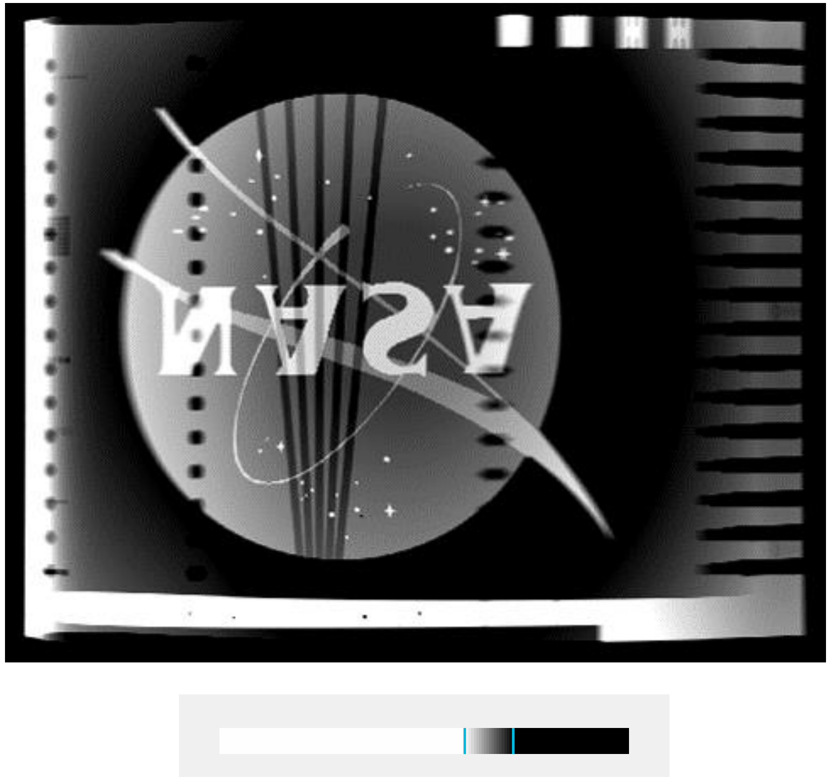


X-Ray

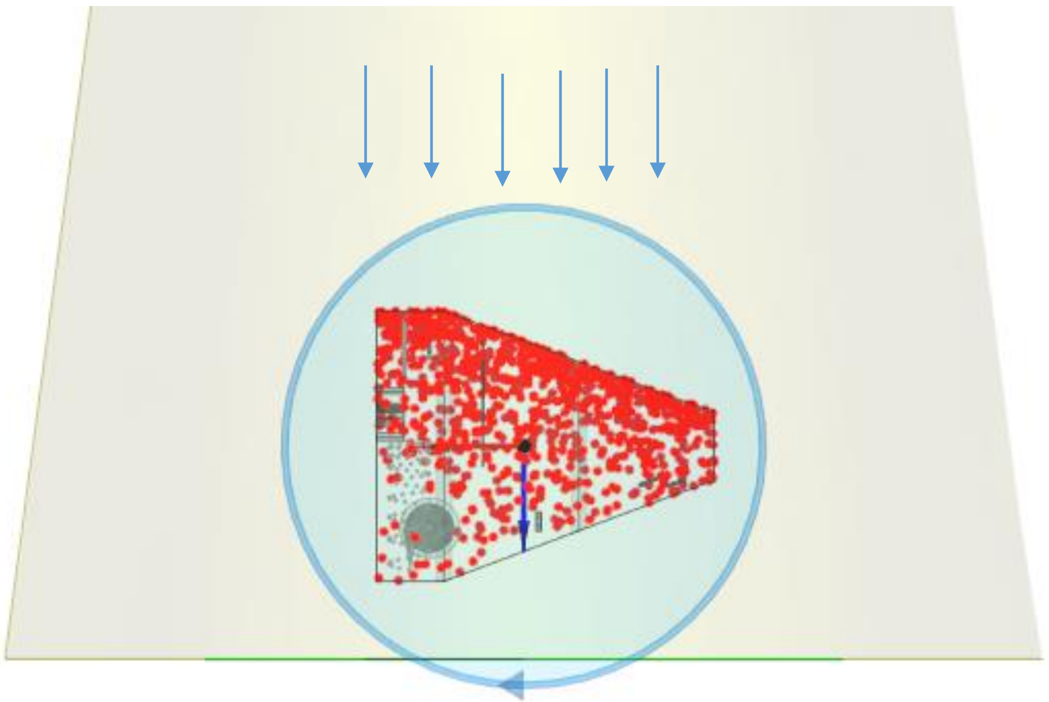
Gamma



High Energy

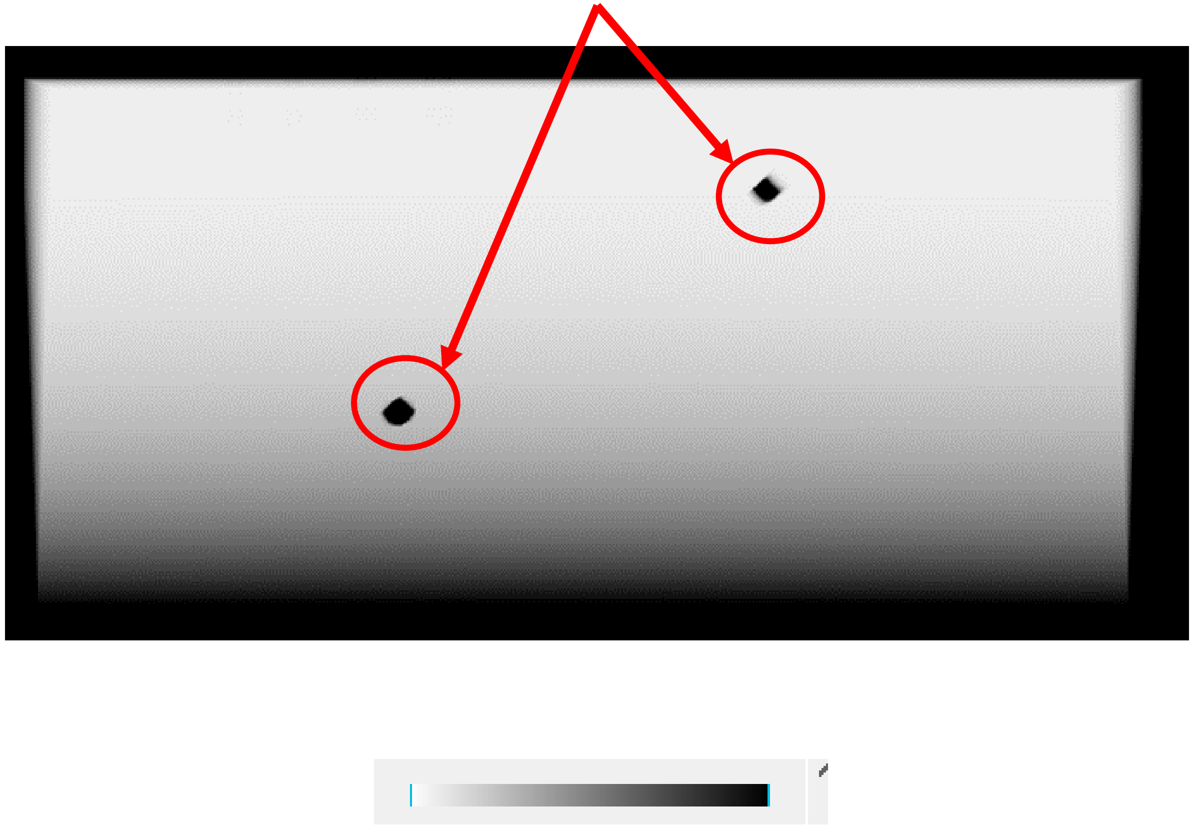


X-Ray Result – Angle 0°

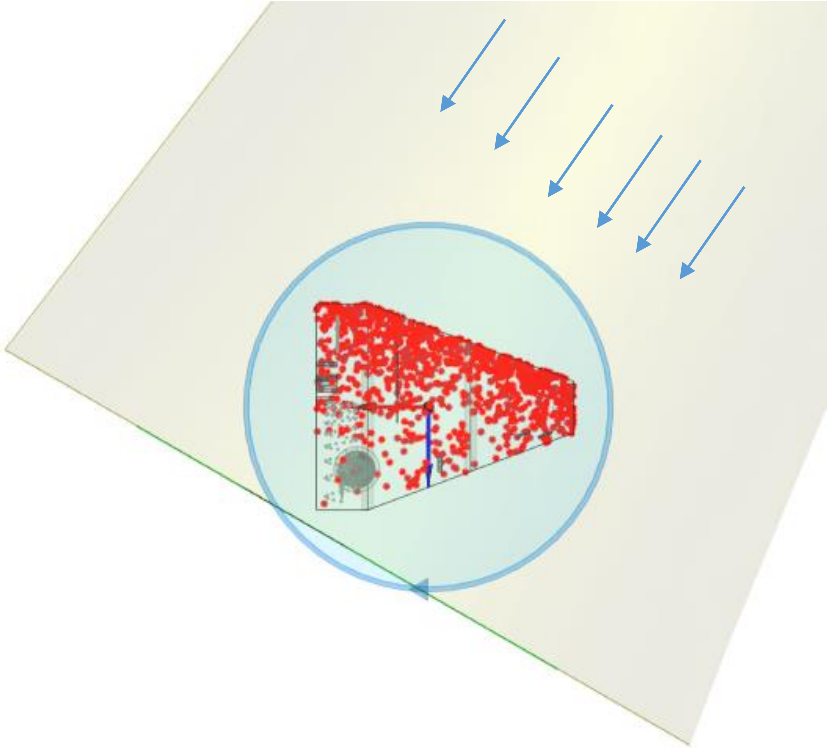


Photon beam penetration

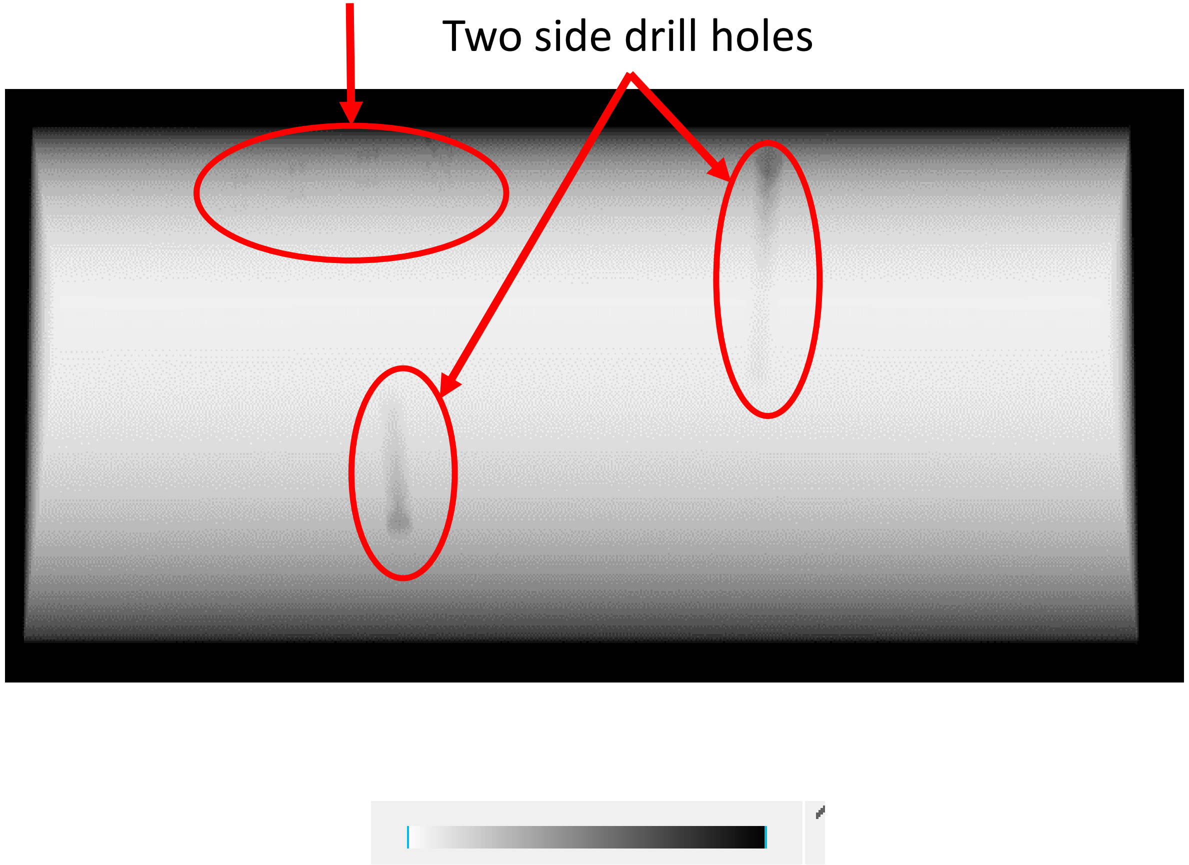
Two side drill holes



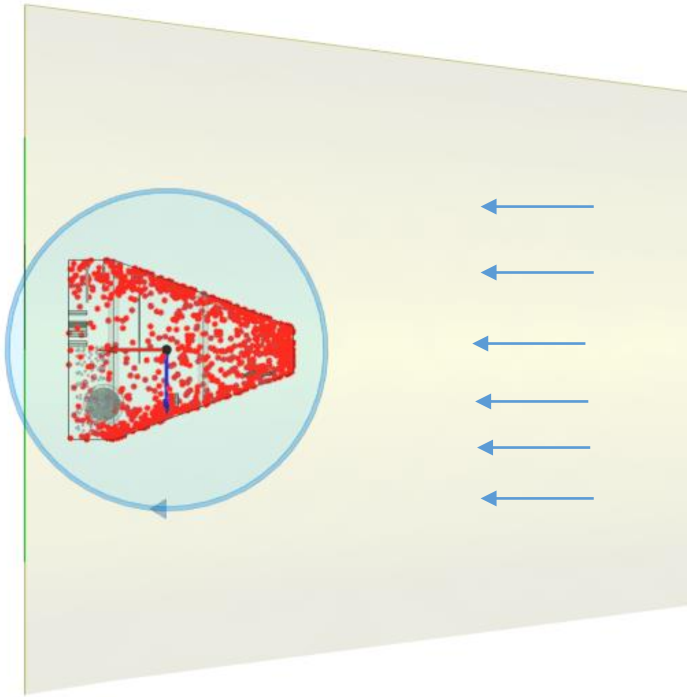
X-Ray Result – Angle 30°



Photon beam penetration

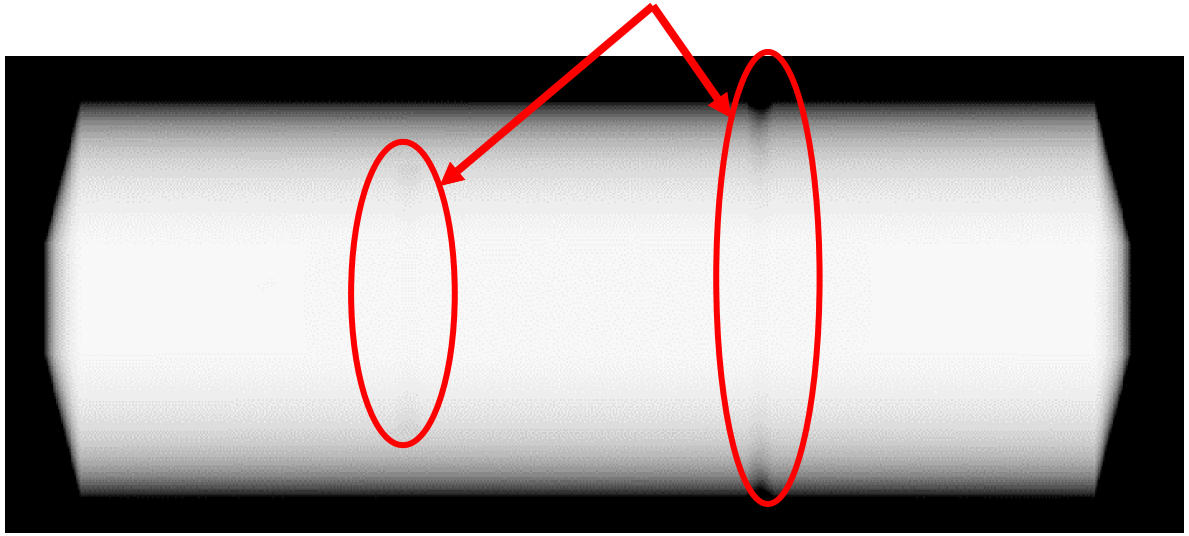


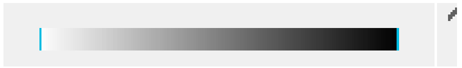
X-Ray Result – Angle 90°



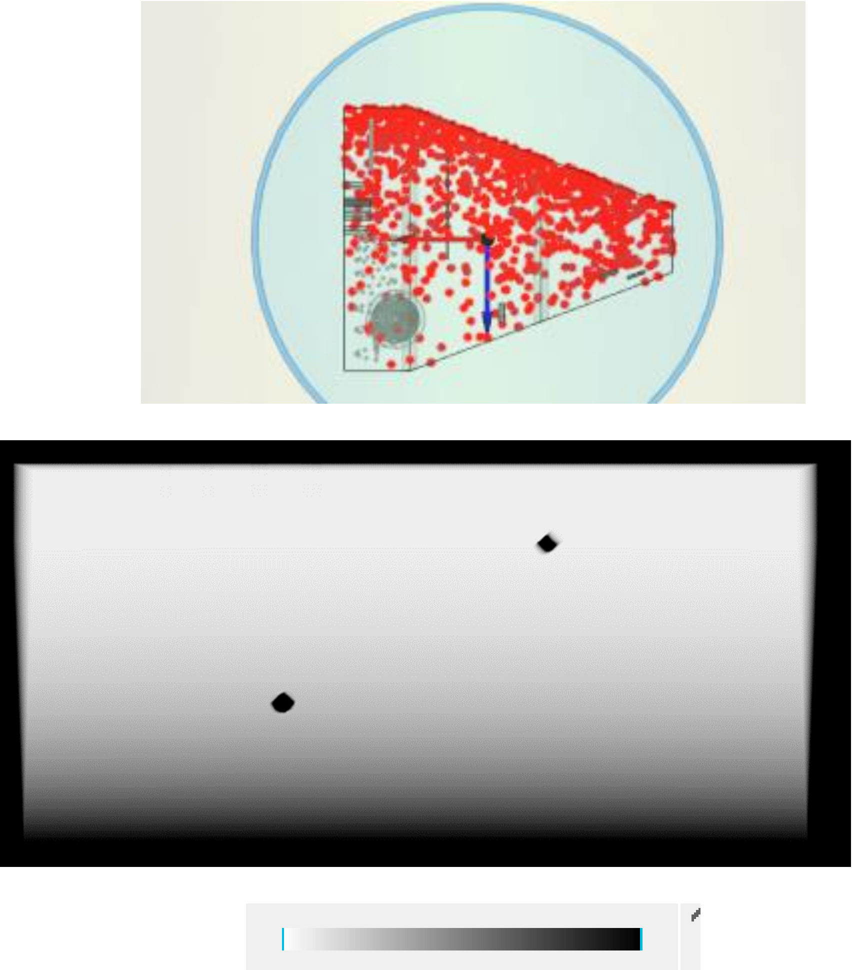
Photon beam penetration

Two side drill holes different sizes

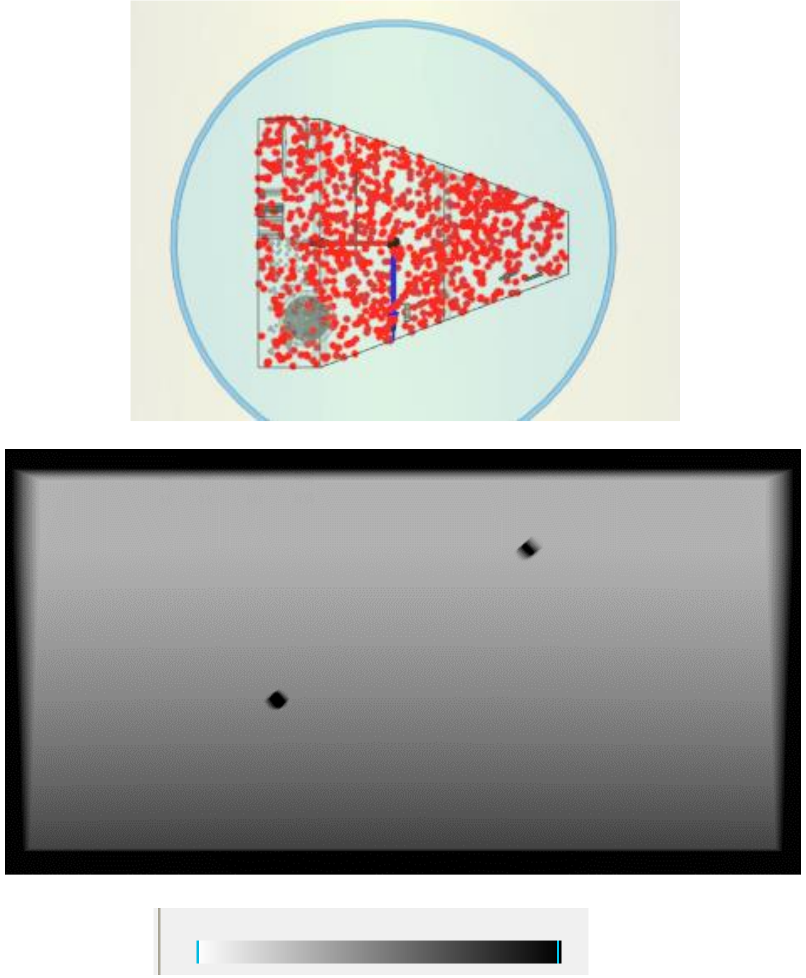




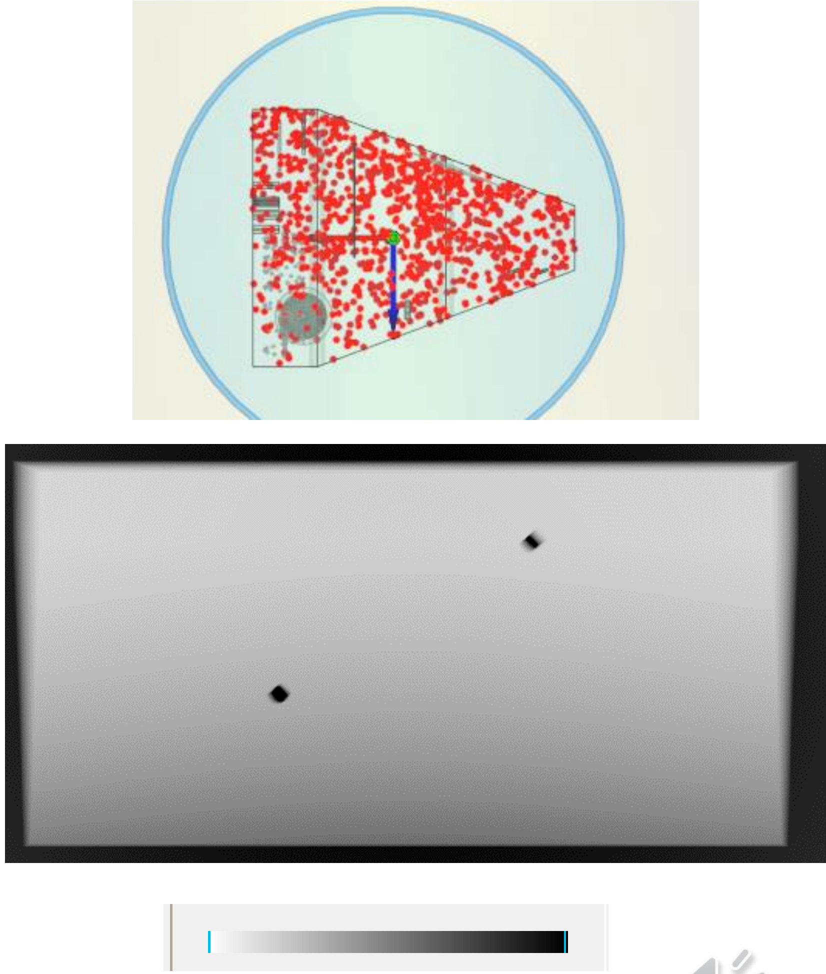
X-Ray



Gamma



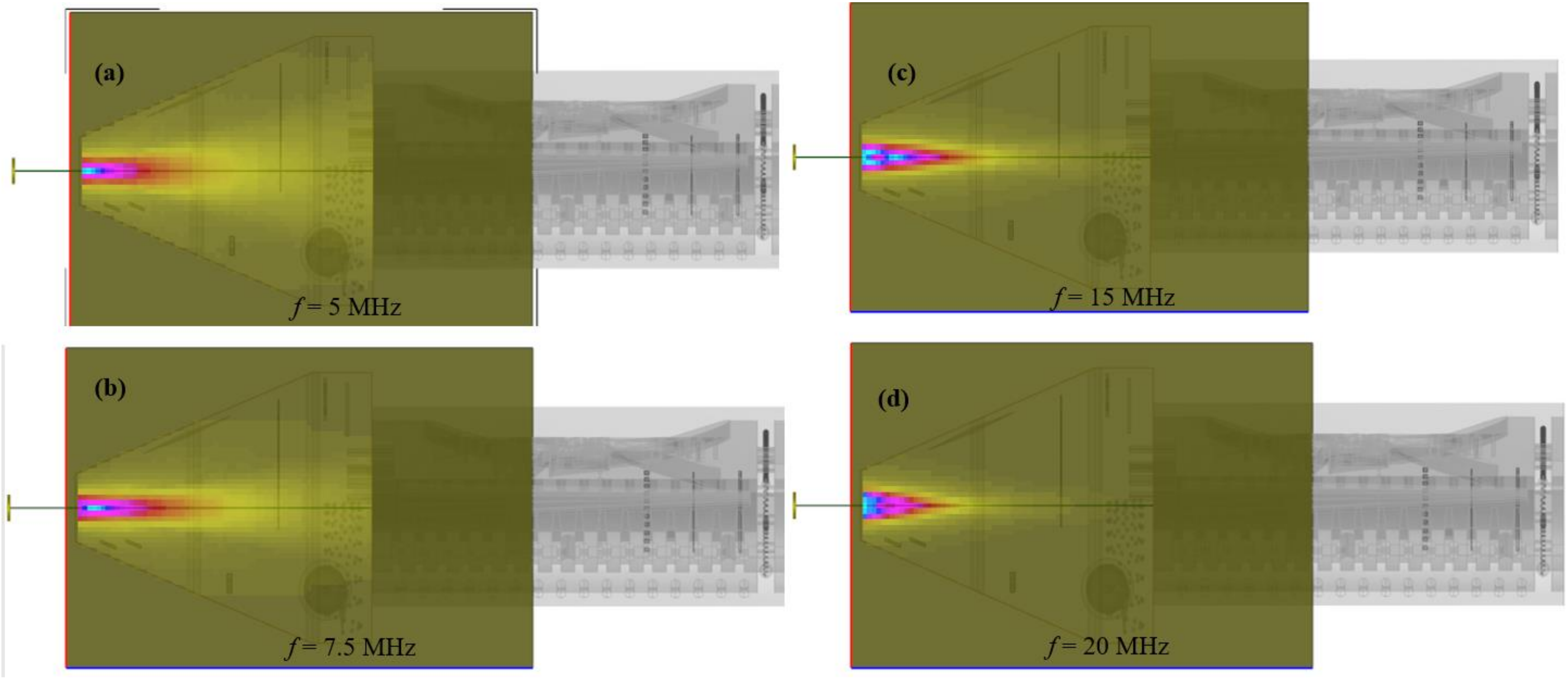
High Energy



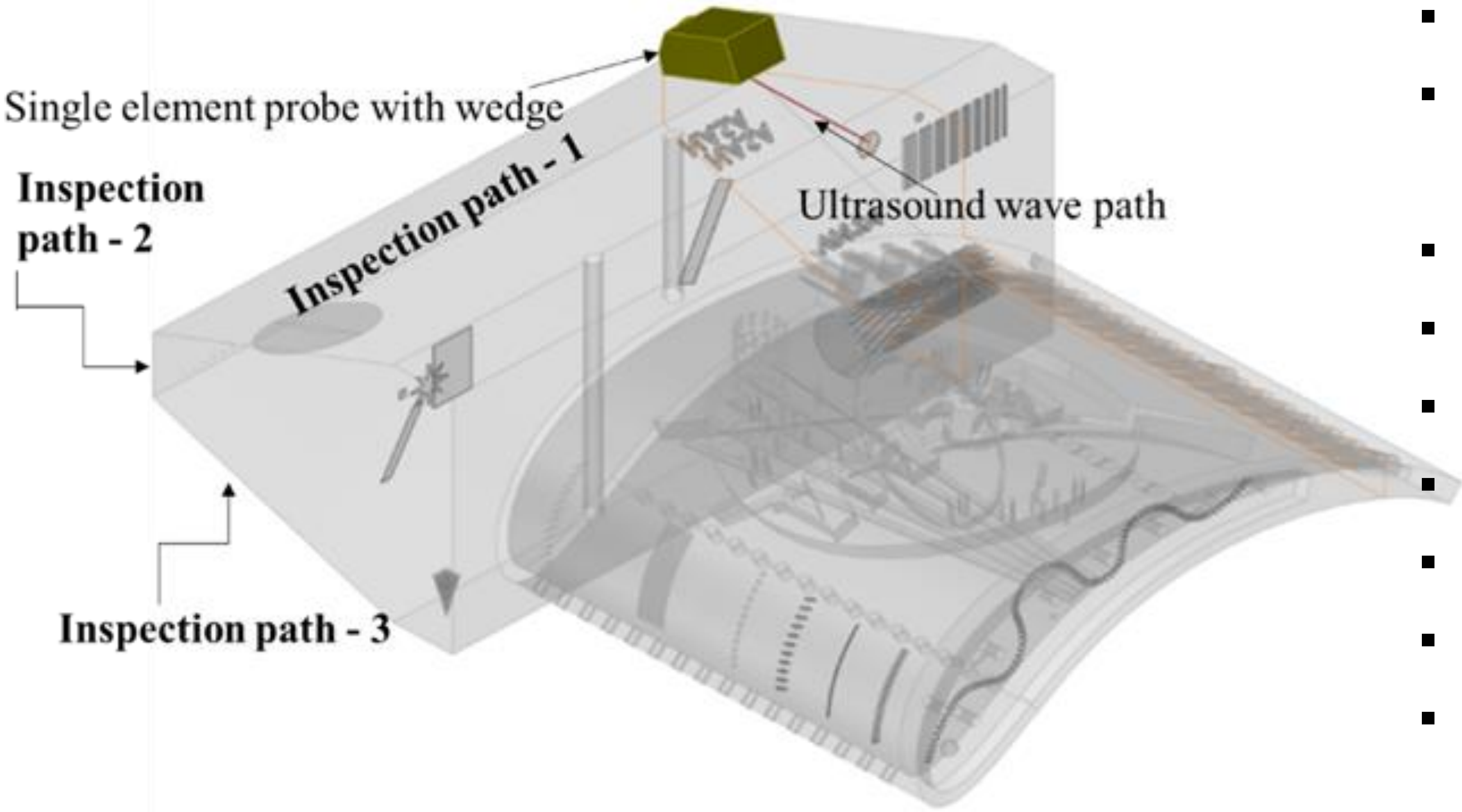
Ultrasonic Inspection – Whole sample

Ultrasonic Inspection – Whole sample

Dovetail – Beam inspection

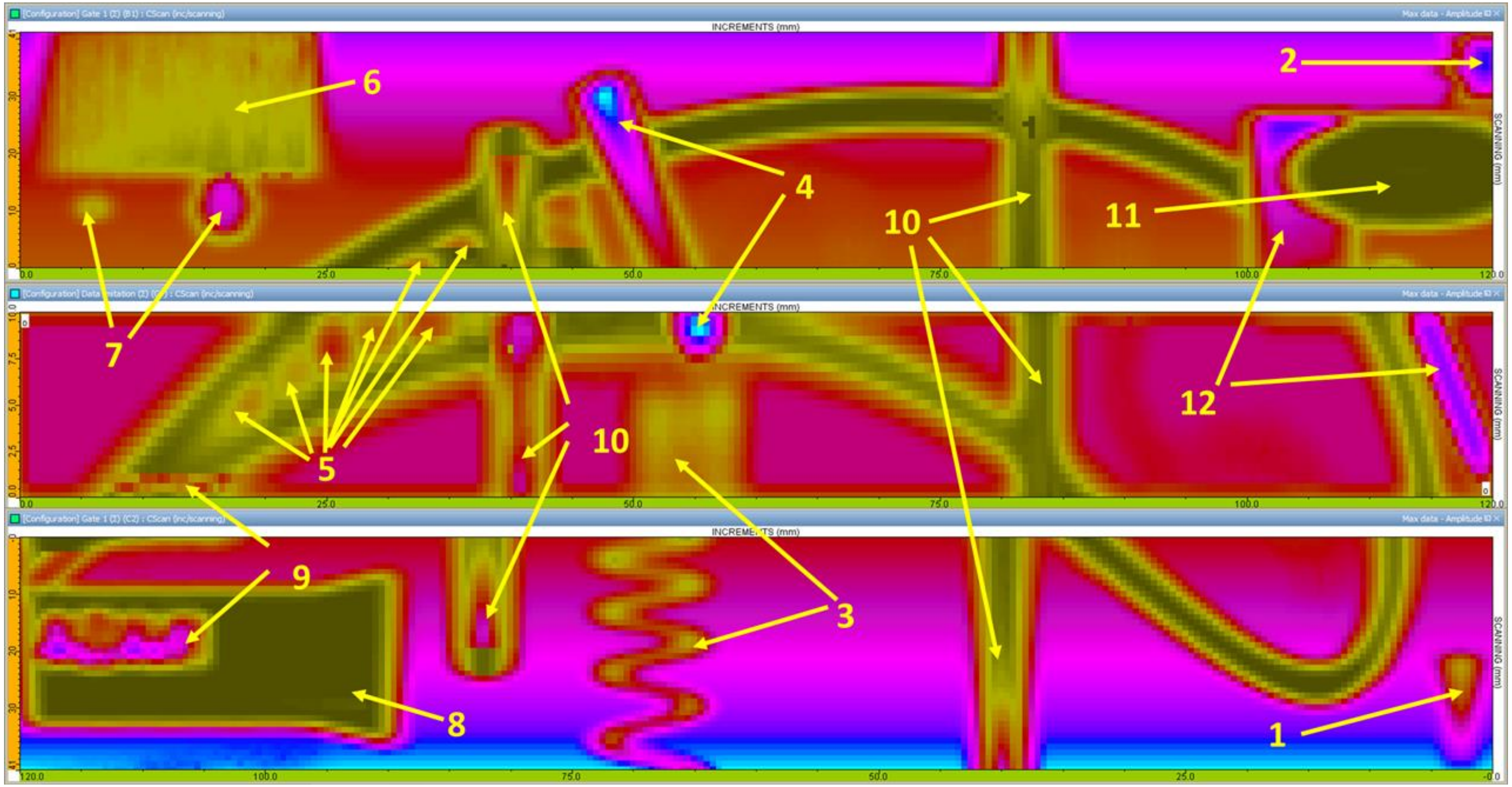


Dovetail - Contact inspection

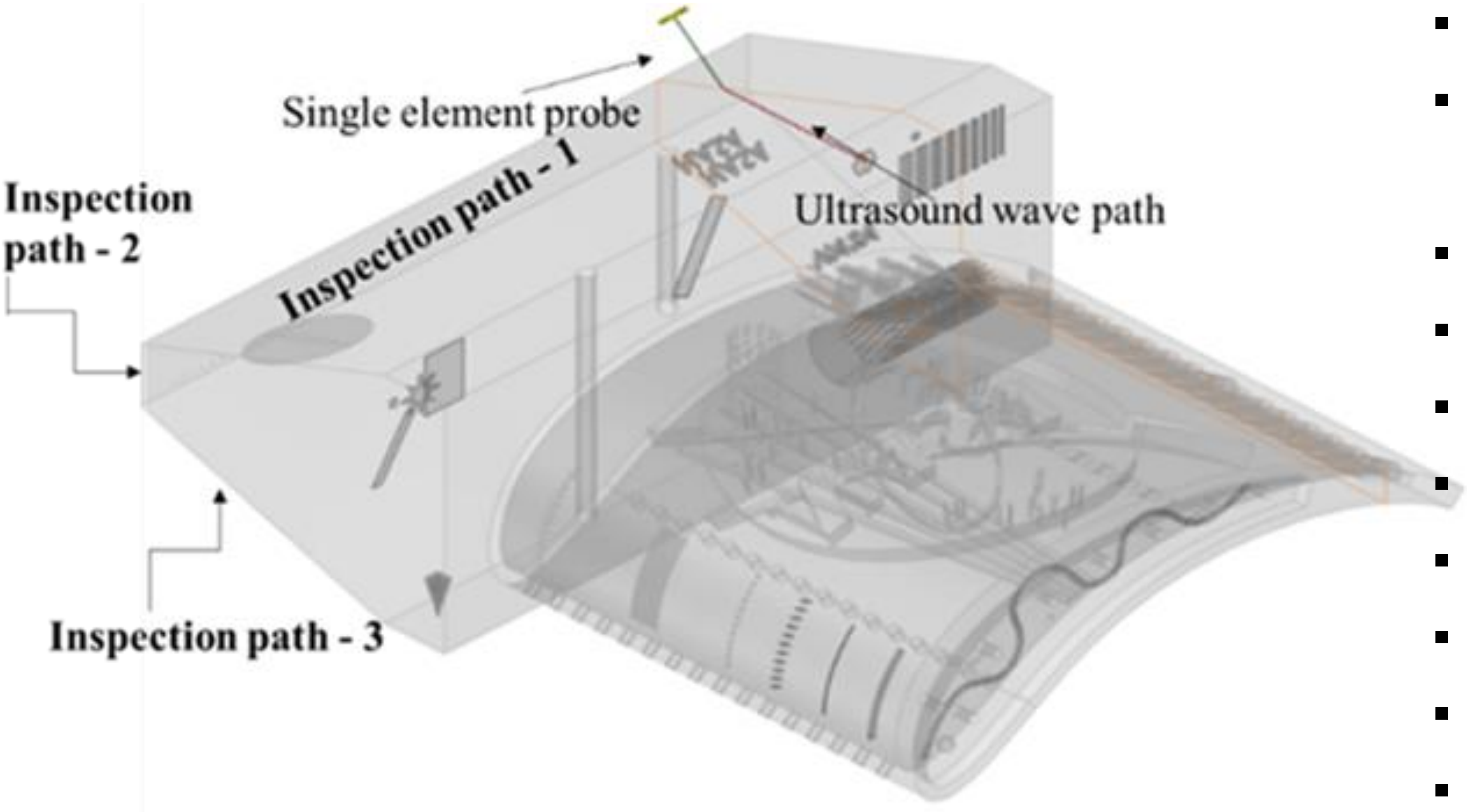


- **Wave type** – Shear wave
- **Probe type** – Single element w/wo wedge
- **Probe shape** – Circle
- **Probe diameter** – 5 mm
- **Wedge material** – Plexiglass
- **Wedge angle** – 54°
- **Frequency** – 7.5 MHz
- **Wavelength shear** – 0.4 mm
- **Mesh size** – 0.001 mm

Dovetail – Contact result

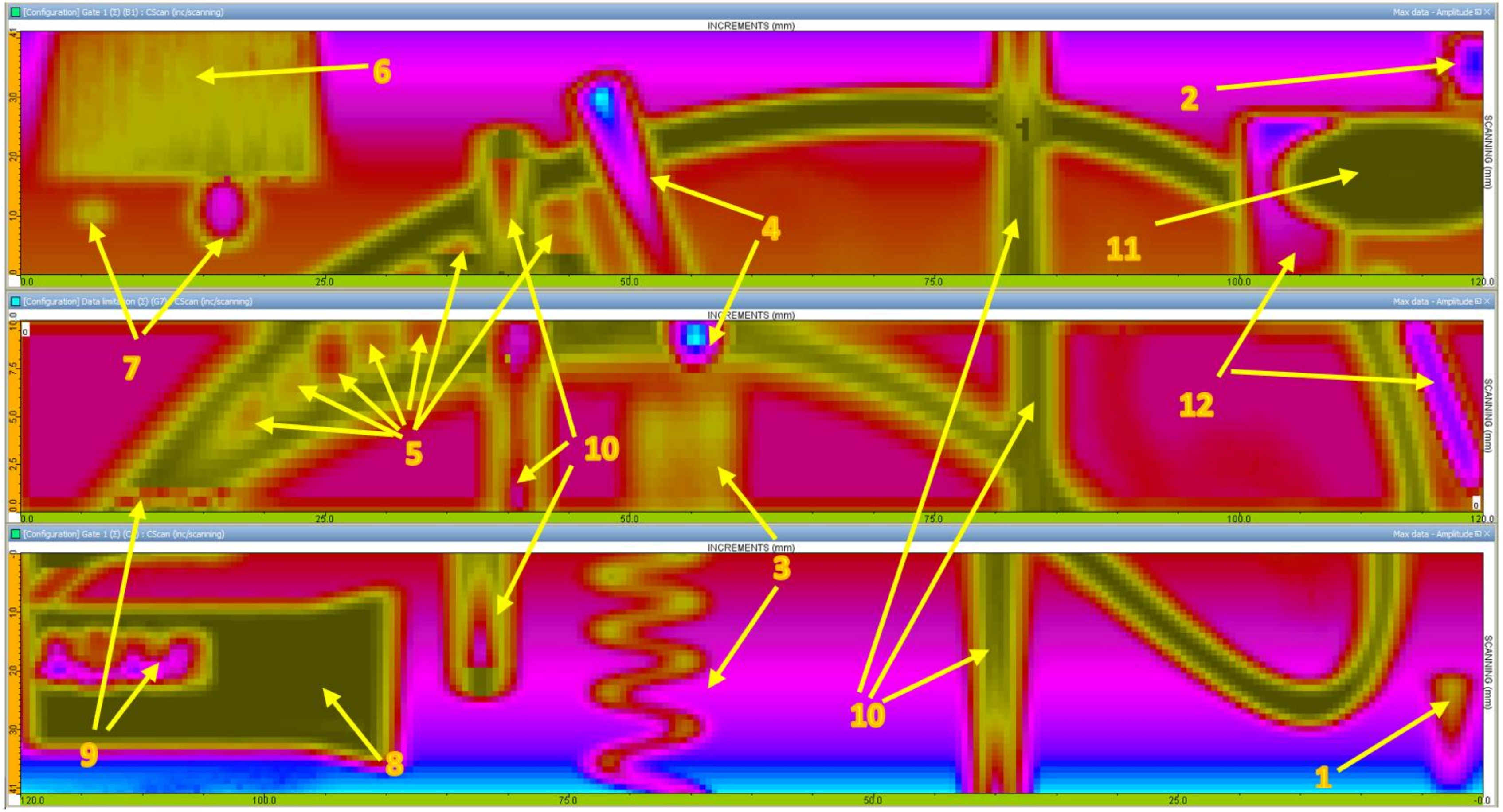


Dovetail - Immersion technique

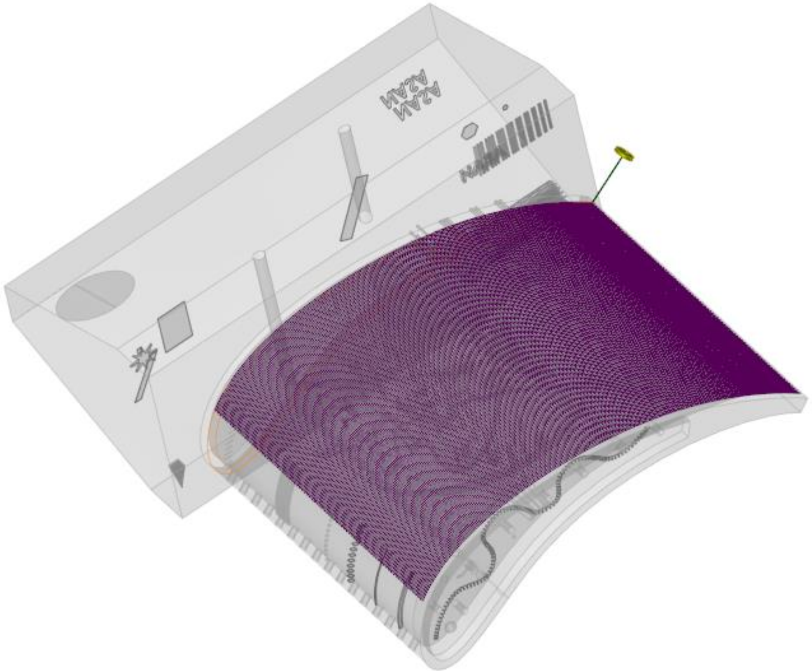


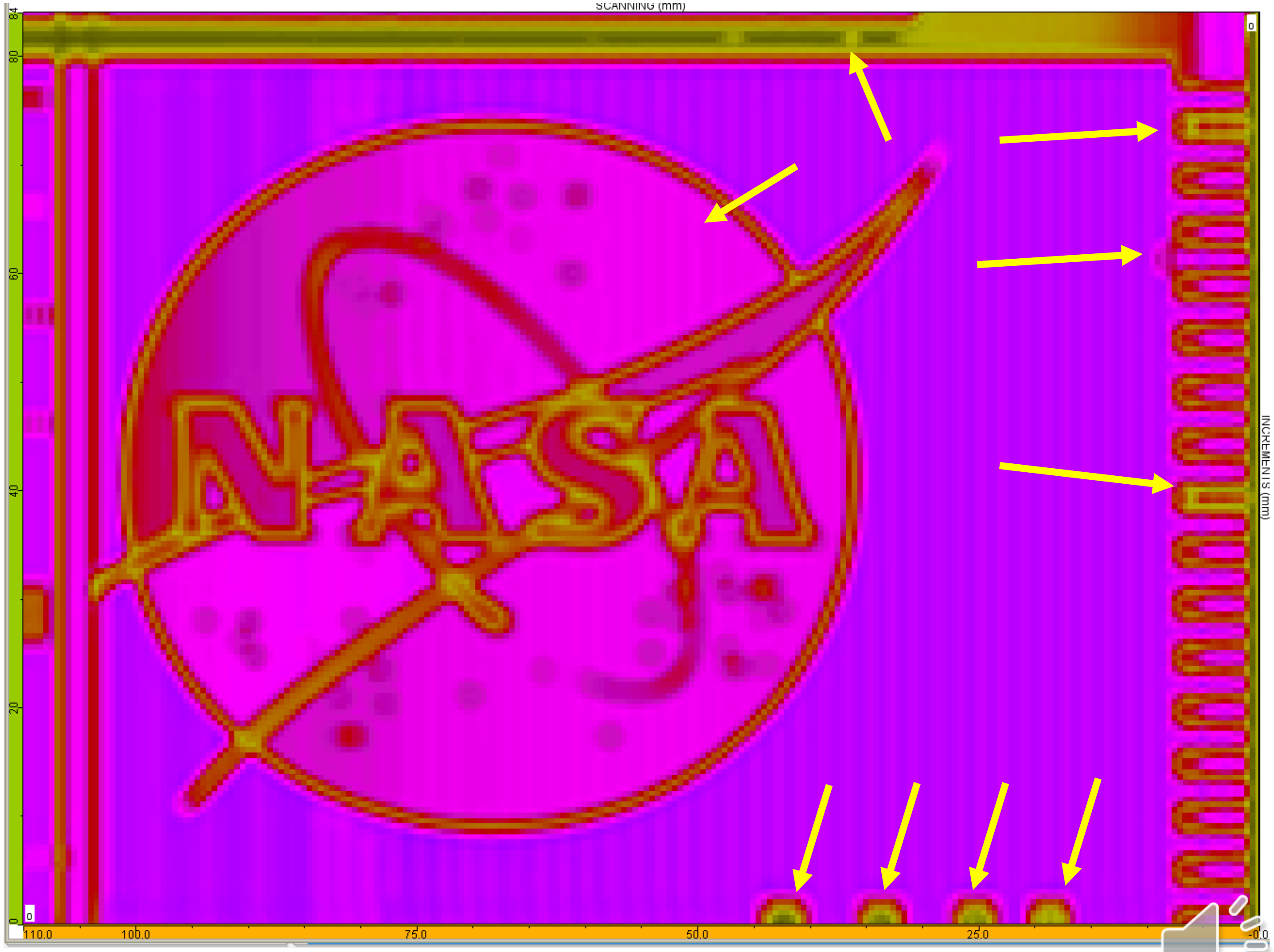
- **Wave type** – Longitudinal wave
- **Probe type** – Single element immersed
- **Probe shape** – Circle
- **Probe diameter** – 5mm
- **Incidence angle –** 26°
- **Frequency** – 7.5 MHz
- **Wavelength longitudinal** – 0.8 mm
- **Wavelength shear** – 0.4 mm
- **Mesh size** – 0.001 mm
- **Water path** – 14 mm

Dovetail - Immersion result



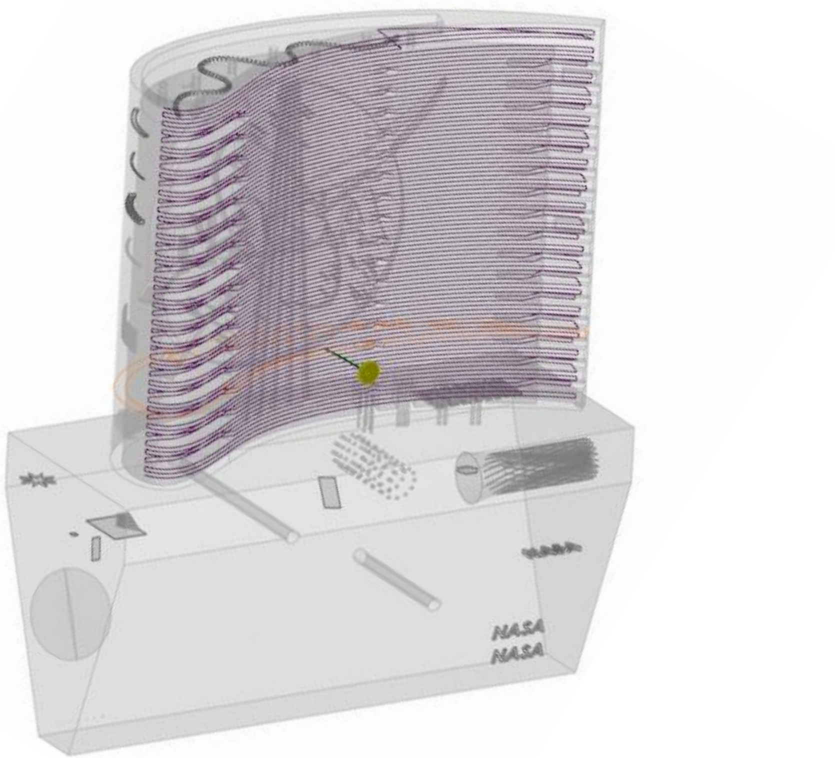
Airfoil – Immersion technique



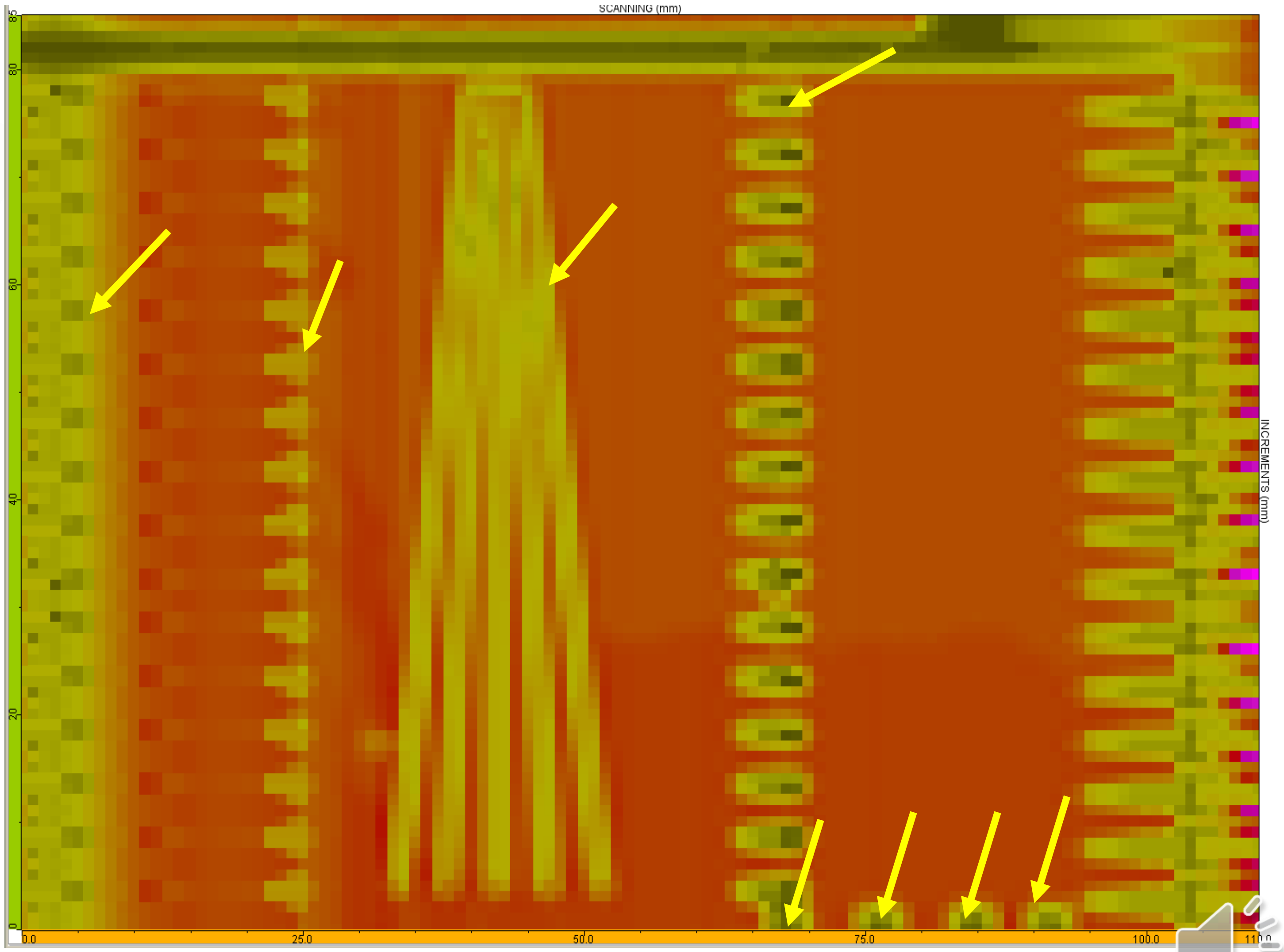


- **Wave type** – Longitudinal wave
- **Probe type** – Single element immersed
- **Incidence angle –** 0°
- **Frequency** – 7.5 MHz

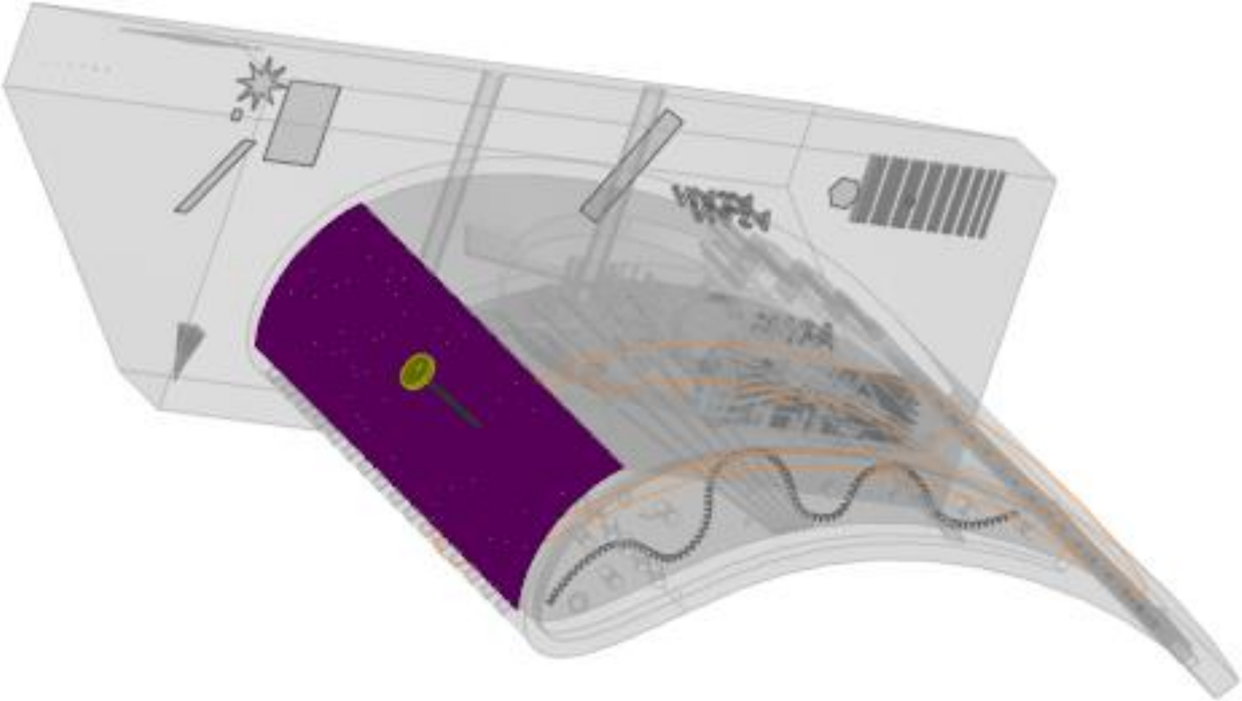
Immersion inspection on rear side of airfoil

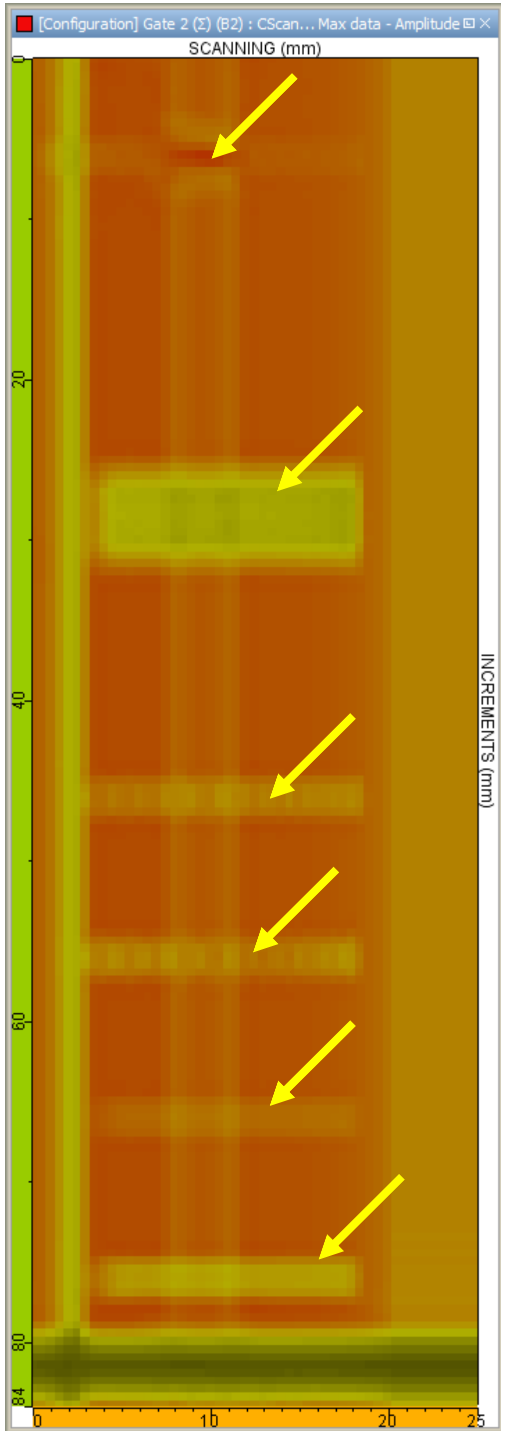


- **Wave type** – Longitudinal wave
- **Probe type** – Single element immersed
- **Incidence angle –** 0°
- **Frequency** – 7.5 MHz



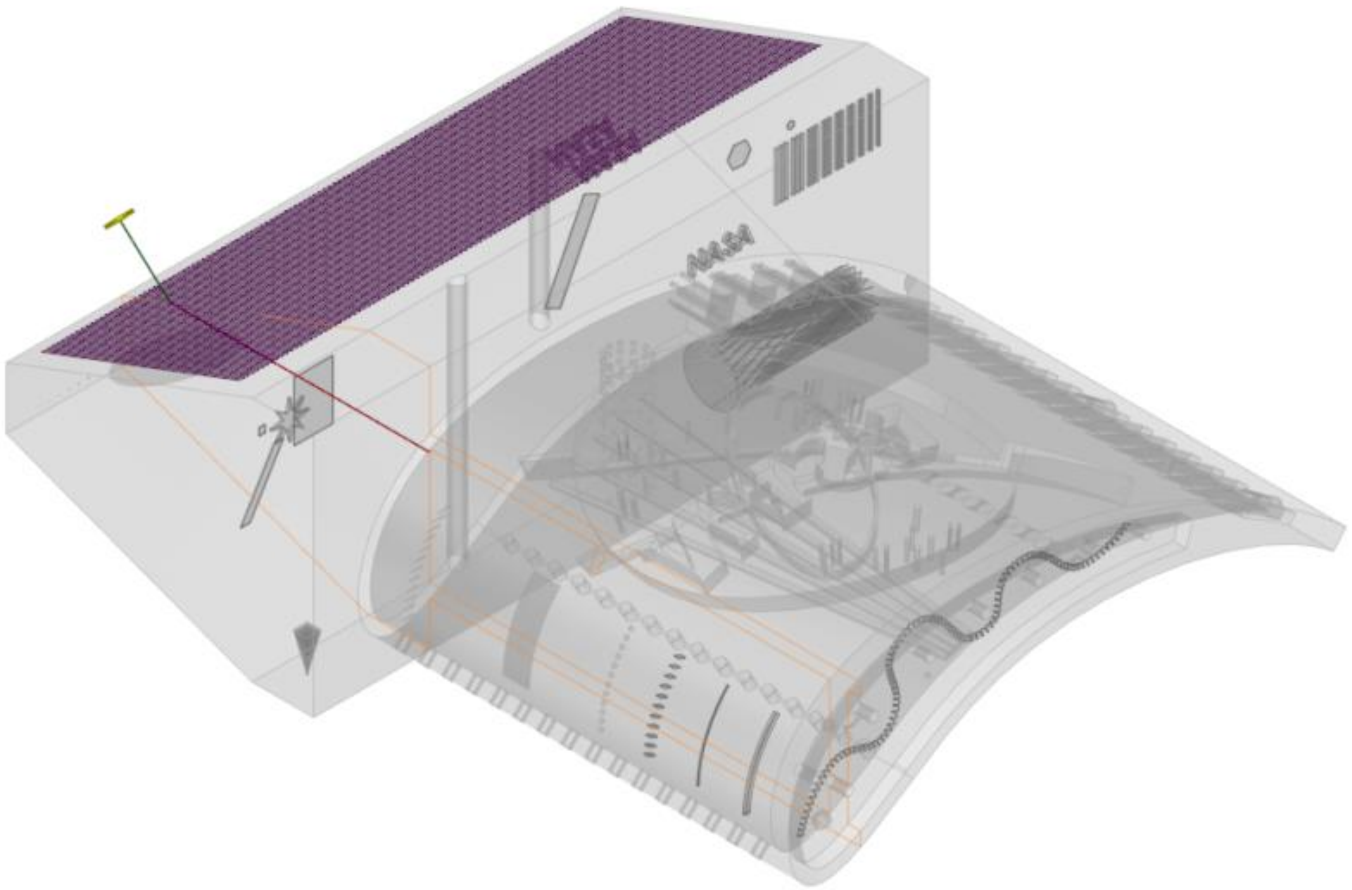
Airfoil leading edge



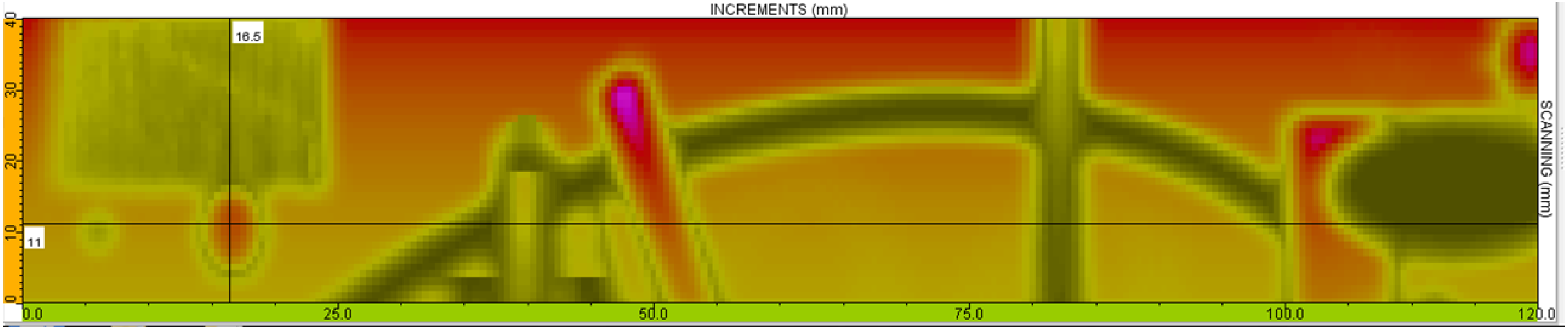


- **Wave type** – Longitudinal wave
- **Probe type** – Single element immersed
- **Incidence angle –** 0°
- **Frequency** – 7.5 MHz

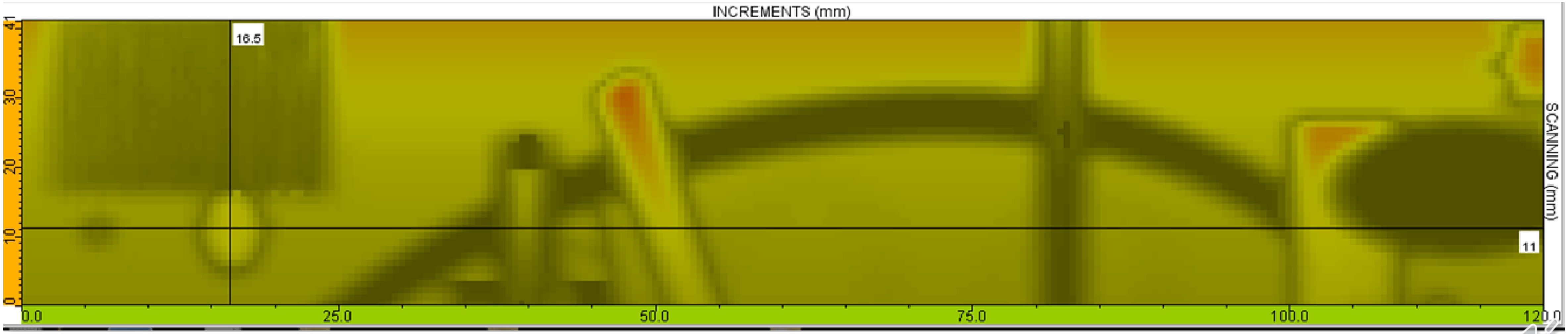
Calibration results in scanning path 1 with contact and immersion techniques



Calibration



Contact



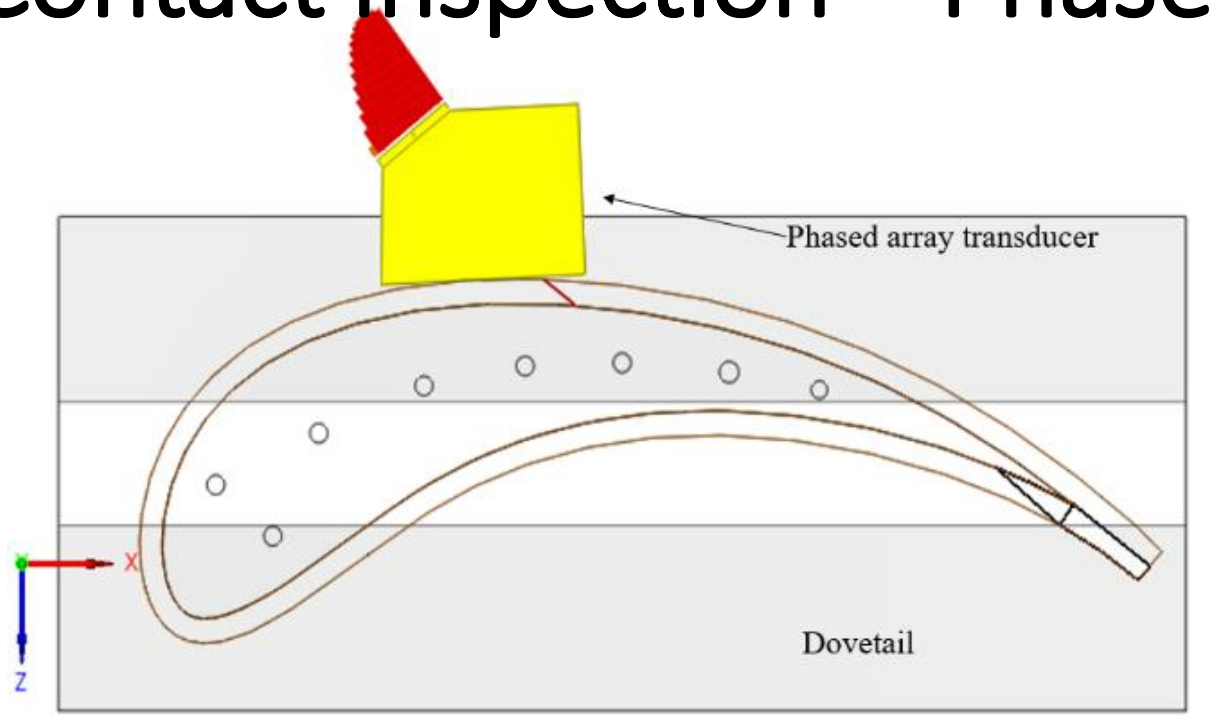
Immersion

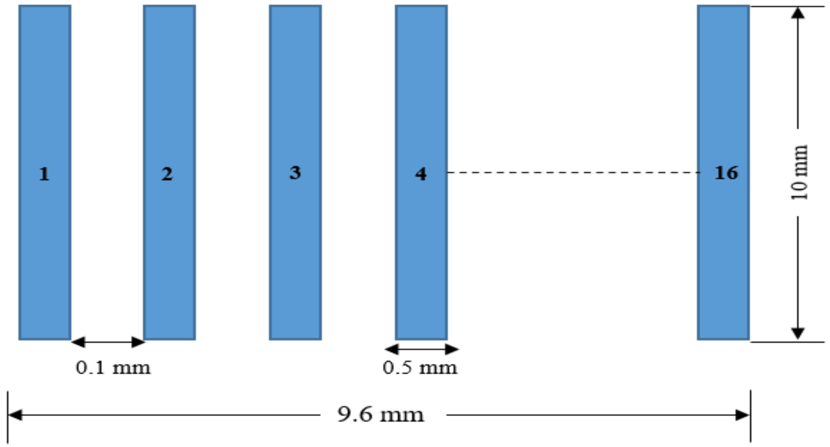
Ultrasonic Inspection – particular defects in airfoil side of the blade

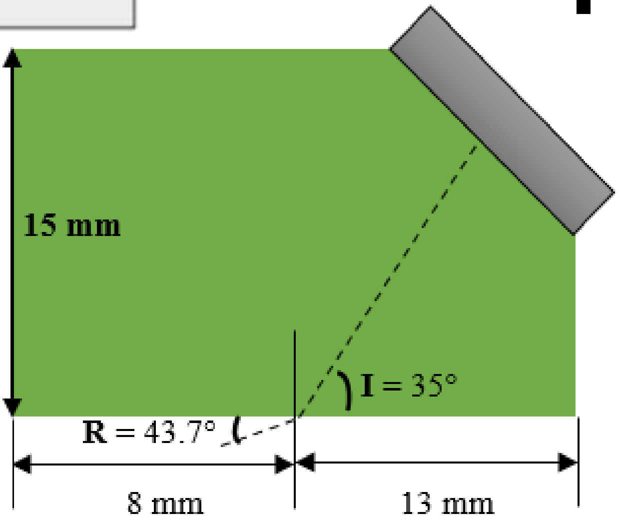
Content

- Inspection of Aerofoil on jet engine turbine blade
  - Beam Computation
  - Inspection of SDH with Contact and Immersion testing
  - Inspection of FBH with Contact and immersion testing
  - Inspection of Spherical holes using contact and immersion testing

Contact inspection – Phased array

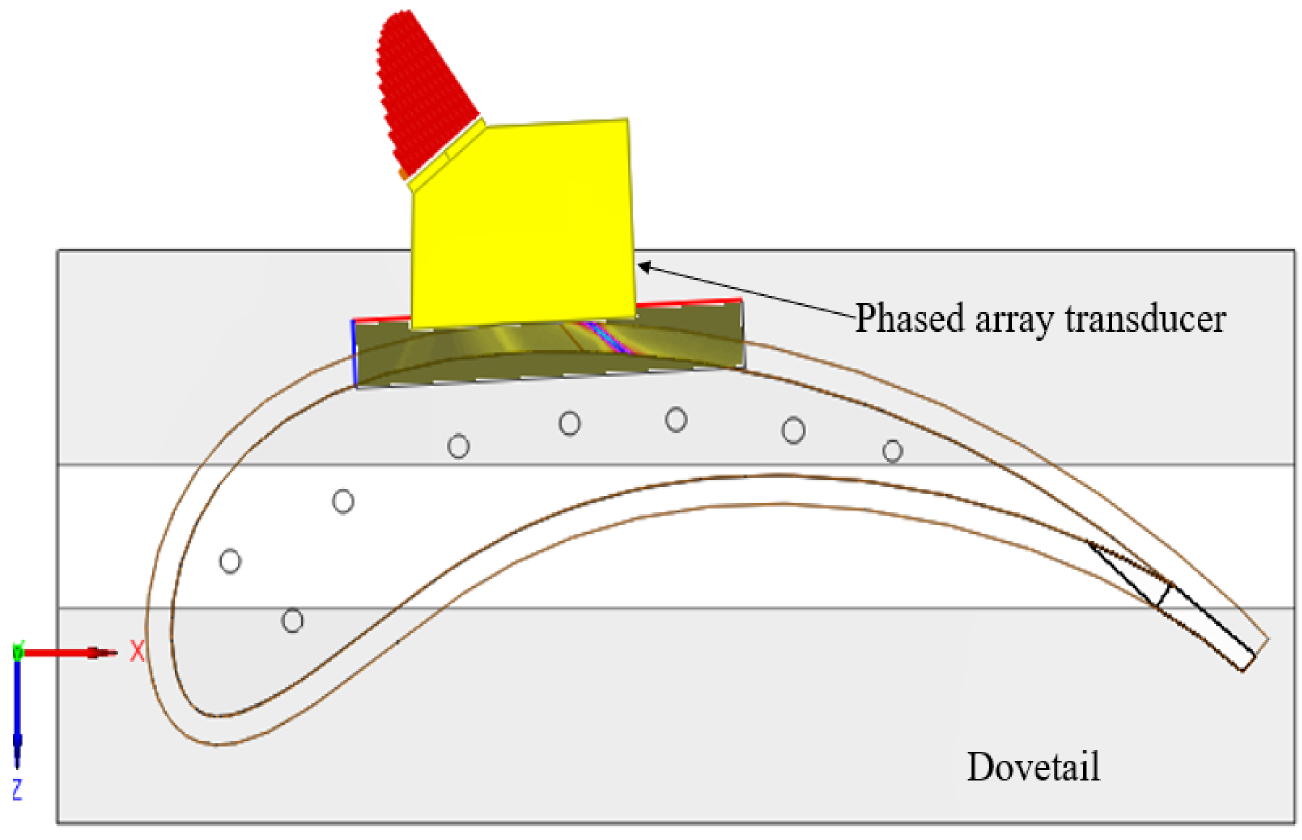


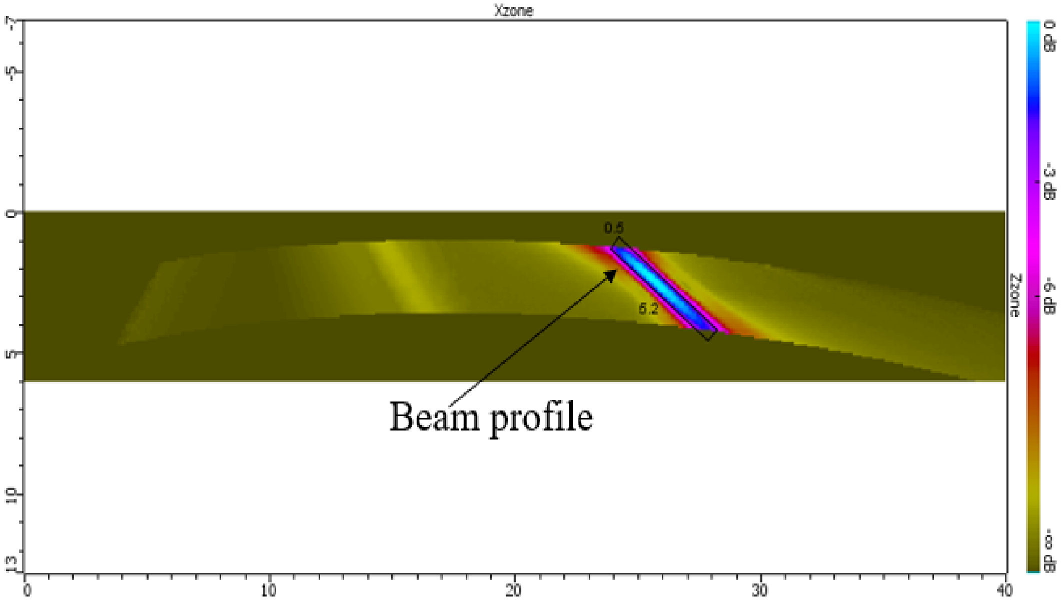




- **Wave type** – Shear wave
- **Probe type** – Phased array (16 elements)
- **Wedge angle** – 35°
- **Focused type** – Multi-focusing
- **Frequency** – 10 MHz
- **Wavelength** – 0.3 mm
- **Mesh size** – 0.01 mm

Phased array - Beam computation

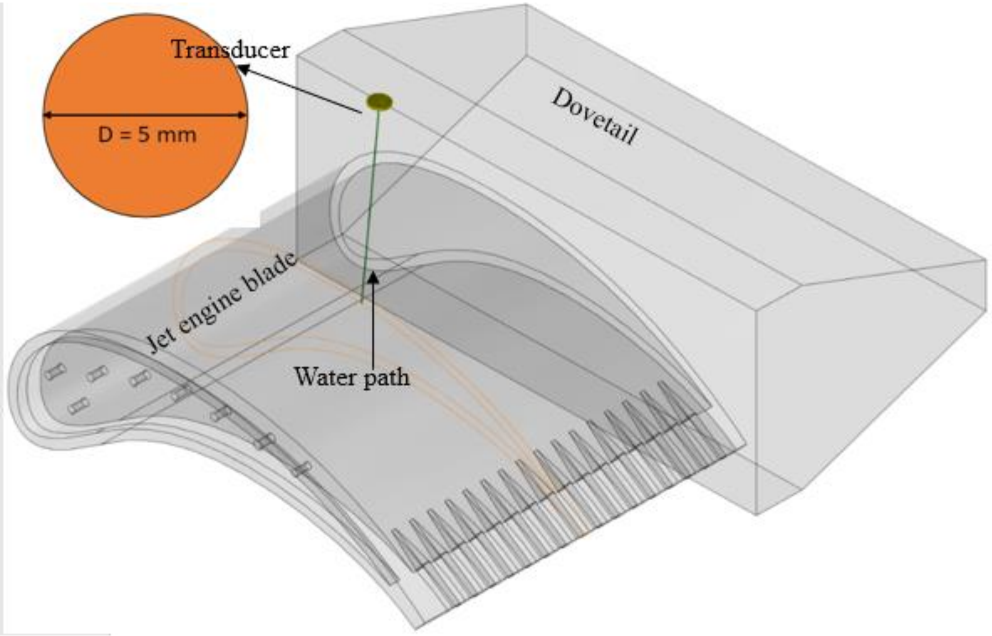


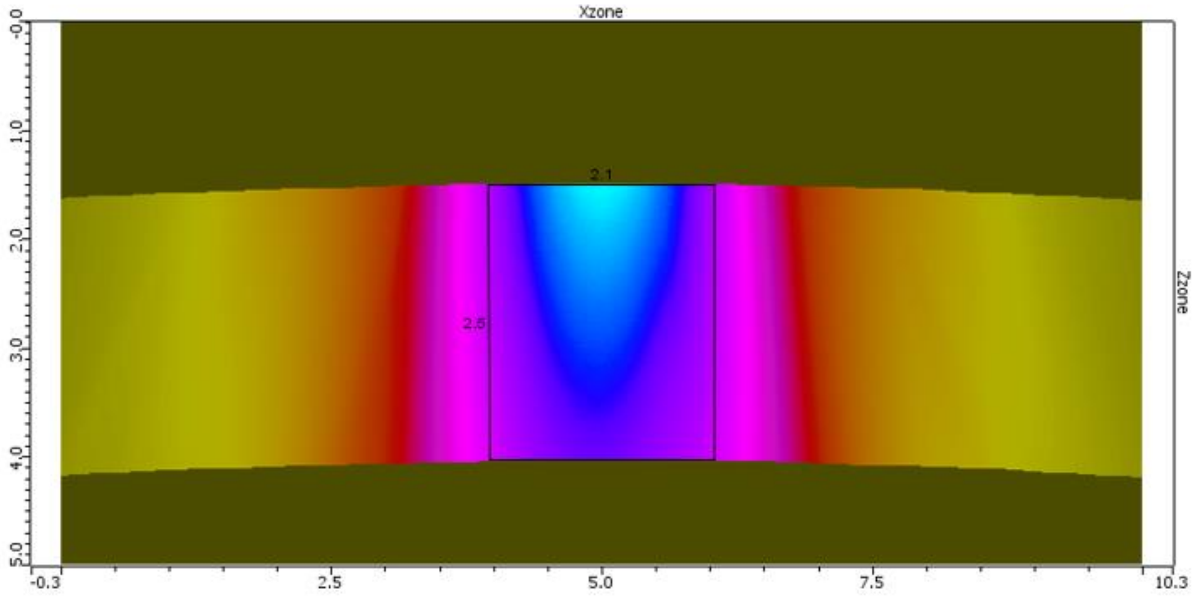


Immersion technique – Beam computation

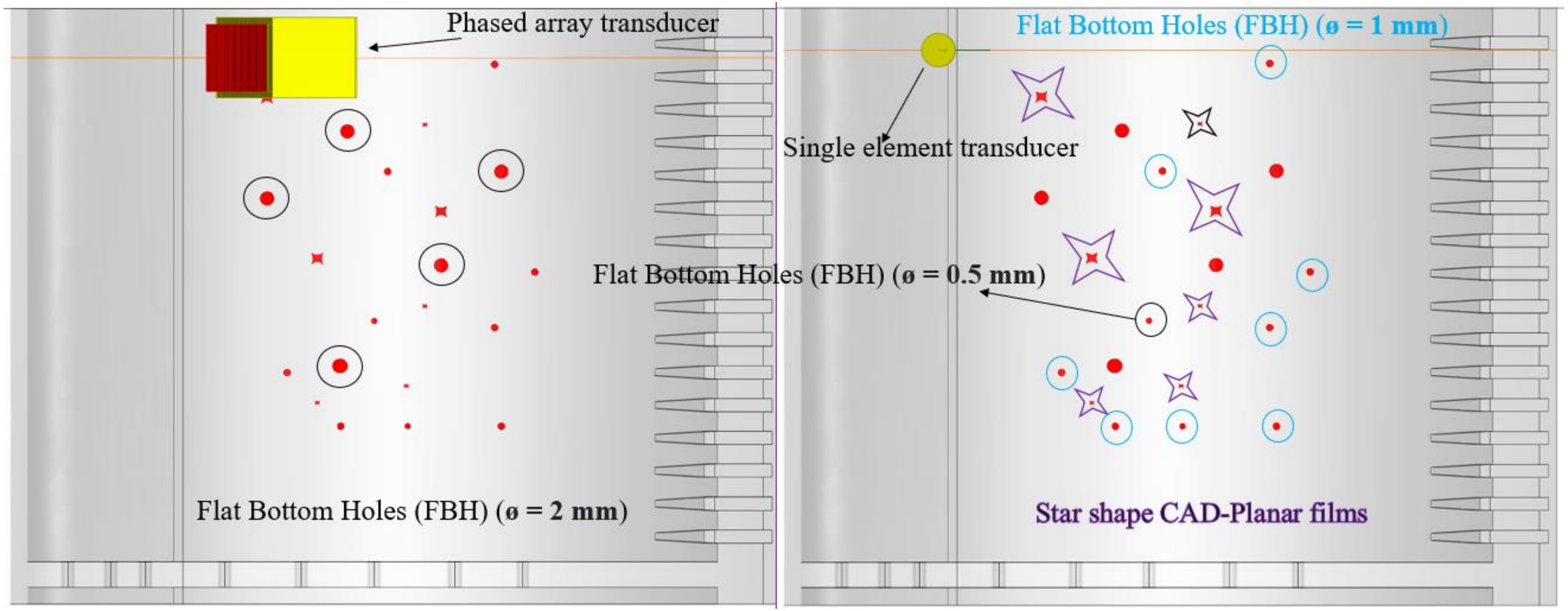
- **Wave type** – Longitudinal wave
- **Probe type** – Single element
- **Focused type** – Flat
- **Transducer type**: GE-0069141-MWB2PA16 from CIVA library

- **Frequency** – 20 MHz
- **Wavelength** – 0.3 mm
- **Mesh size** – 0.01 mm





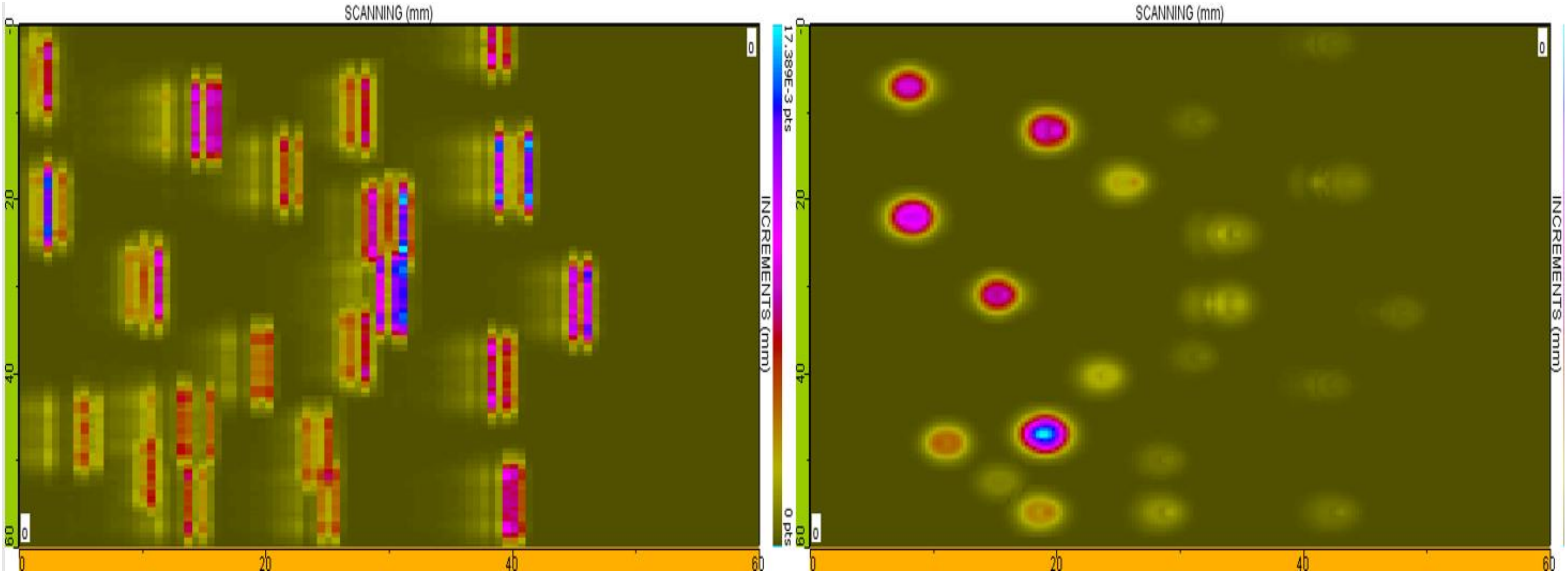
Contact and immersion inspection



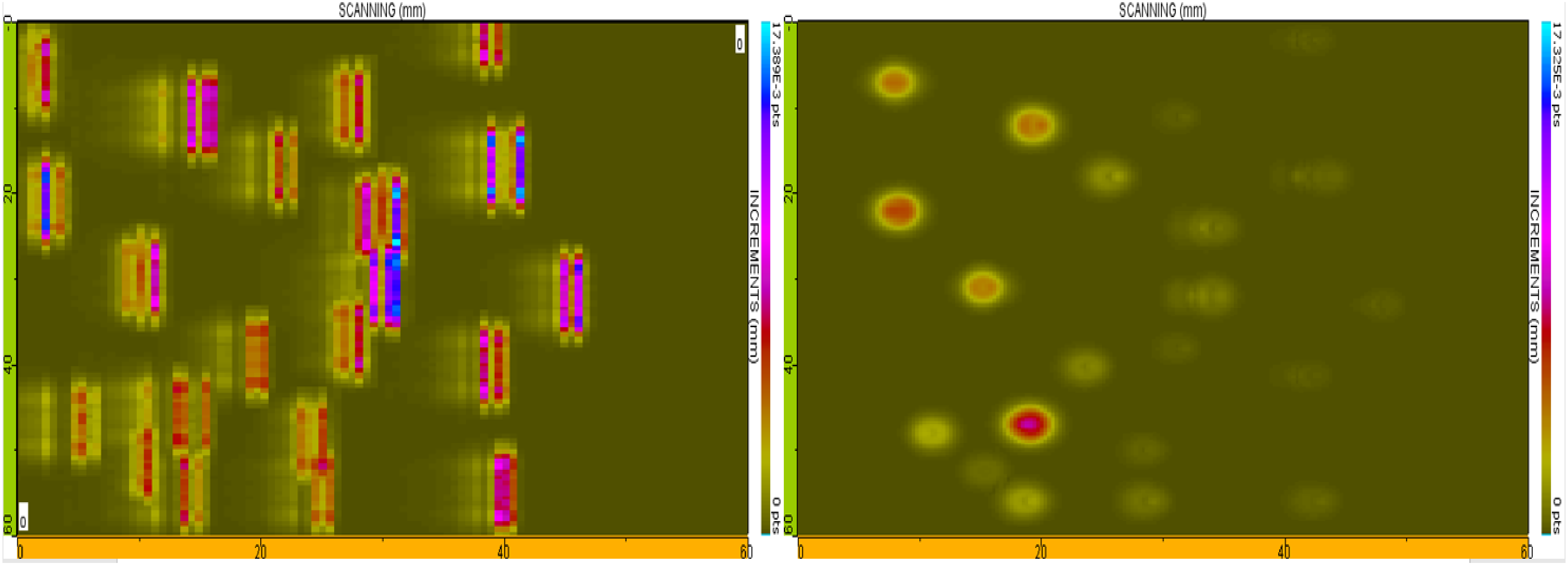
Central frequency: 10 MHz
Shear wave for inspection
Contact phased array transducer

Central frequency: 20 MHz
Longitudinal wave for inspection
Single-element flat transducer

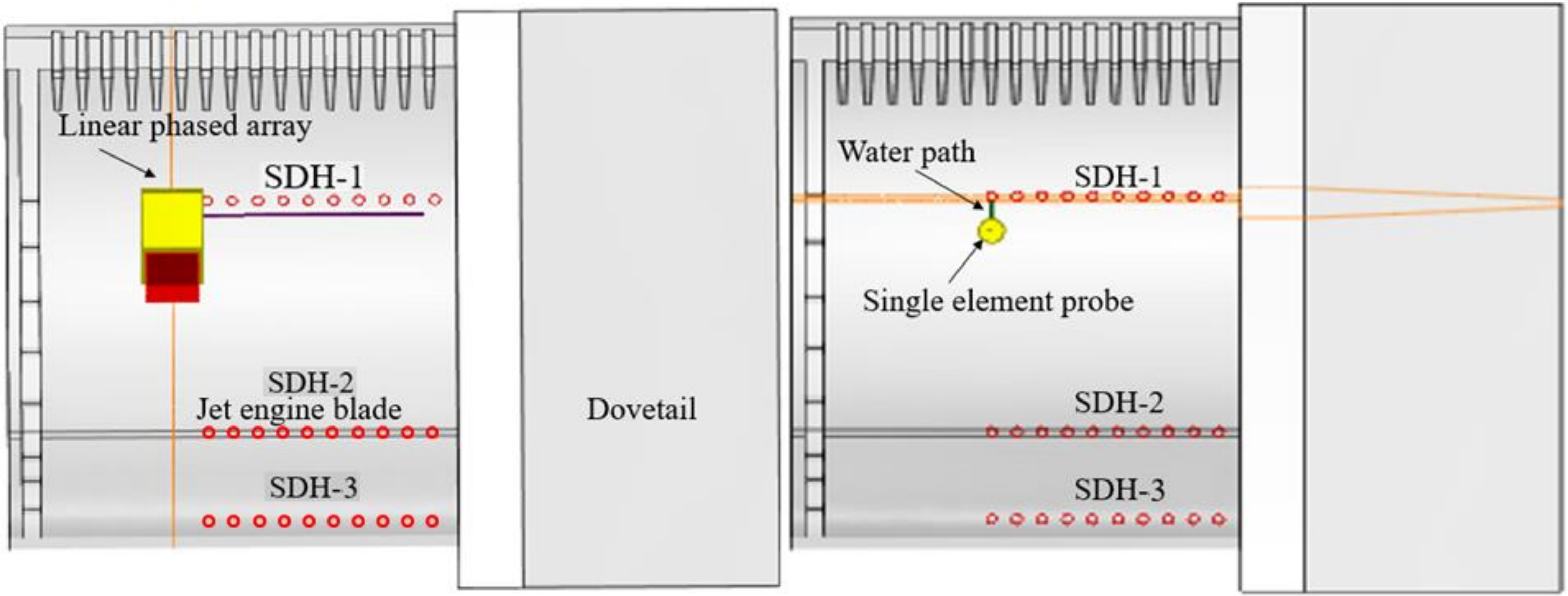
Contact and immersion inspection result



Calibration



Inspection of SDH with Contact and Immersion Technique

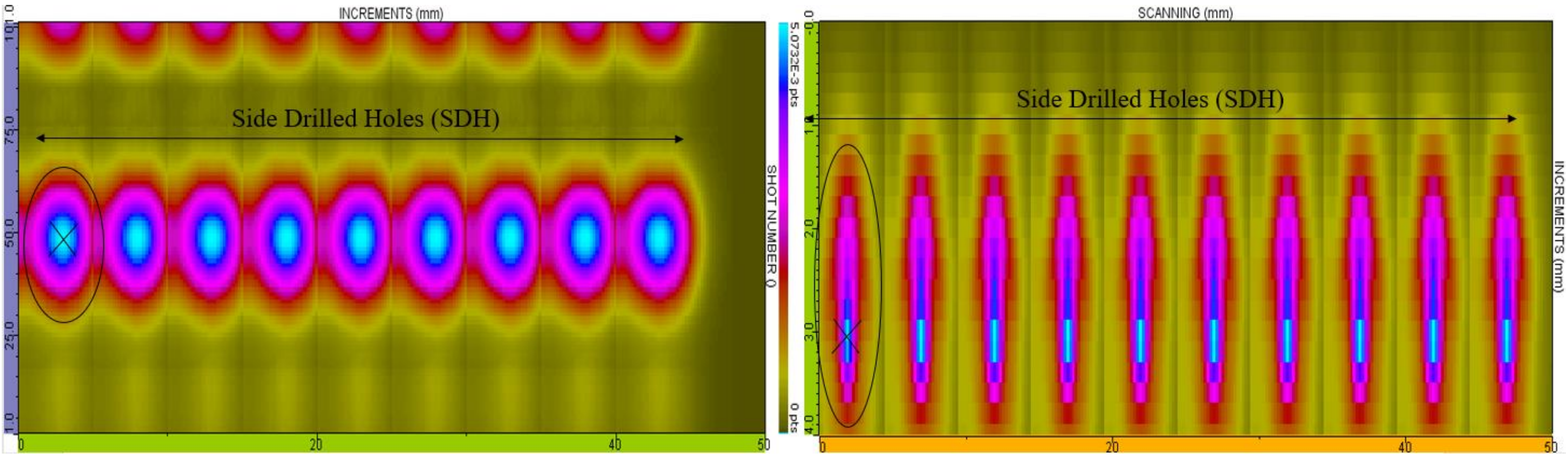


Central frequency: 10 MHz
Shear wave for inspection
Contact phased array transducer

Central frequency: 20 MHz
Longitudinal wave for inspection
Single-element flat transducer

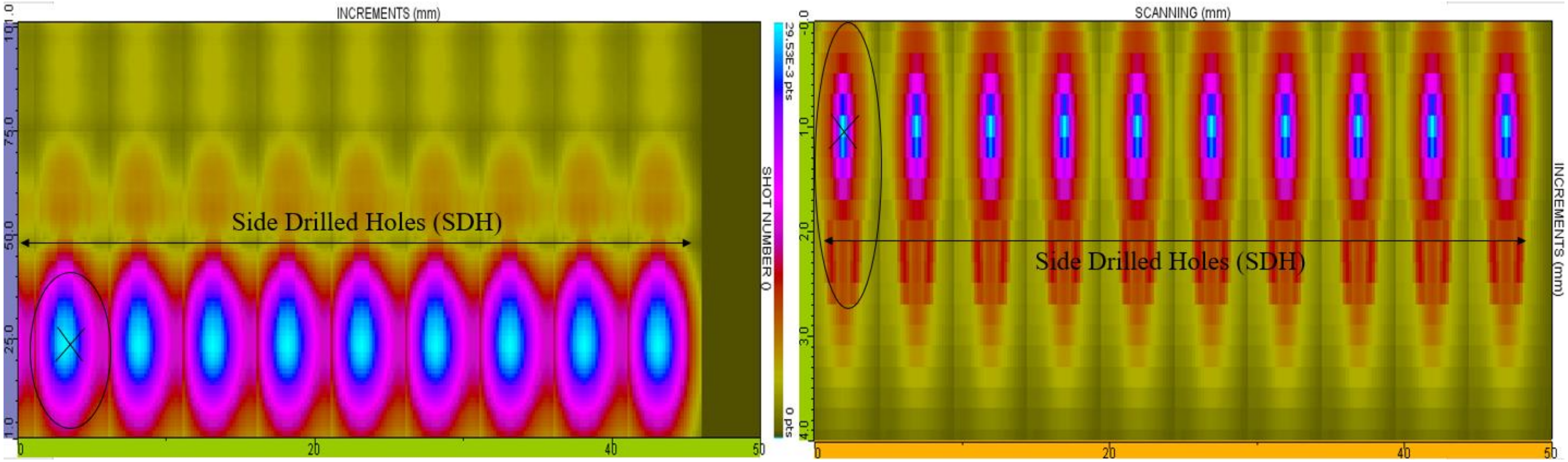
Inspection of SDH with Contact and Immersion Technique - Result

SDH location - 1



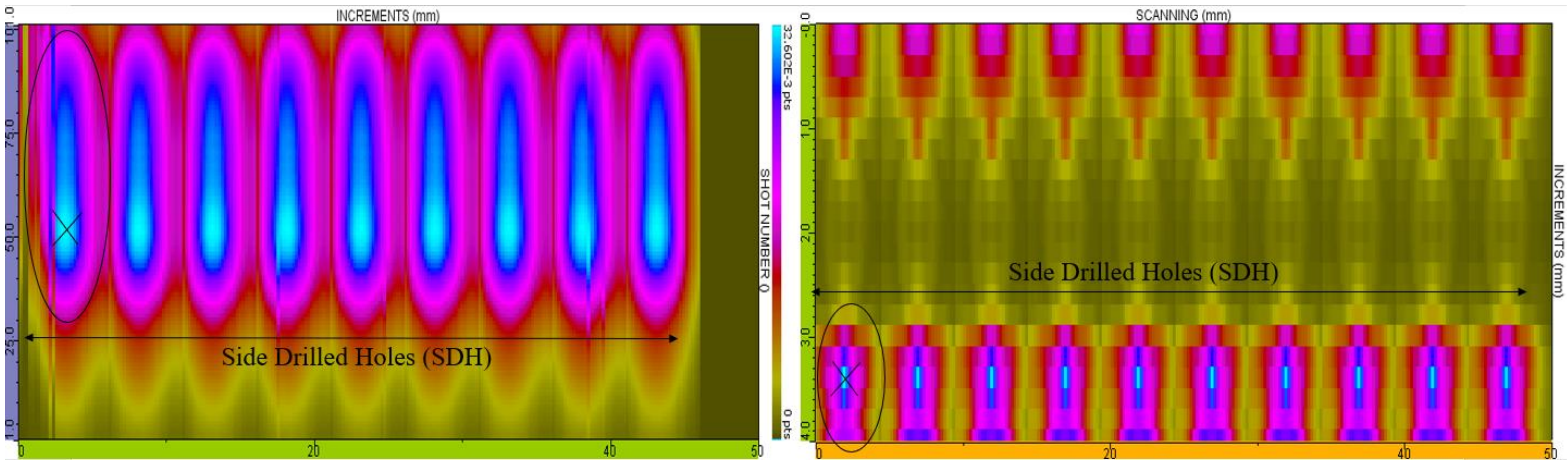
Inspection of SDH with Contact and Immersion Technique - Result

SDH location - 2



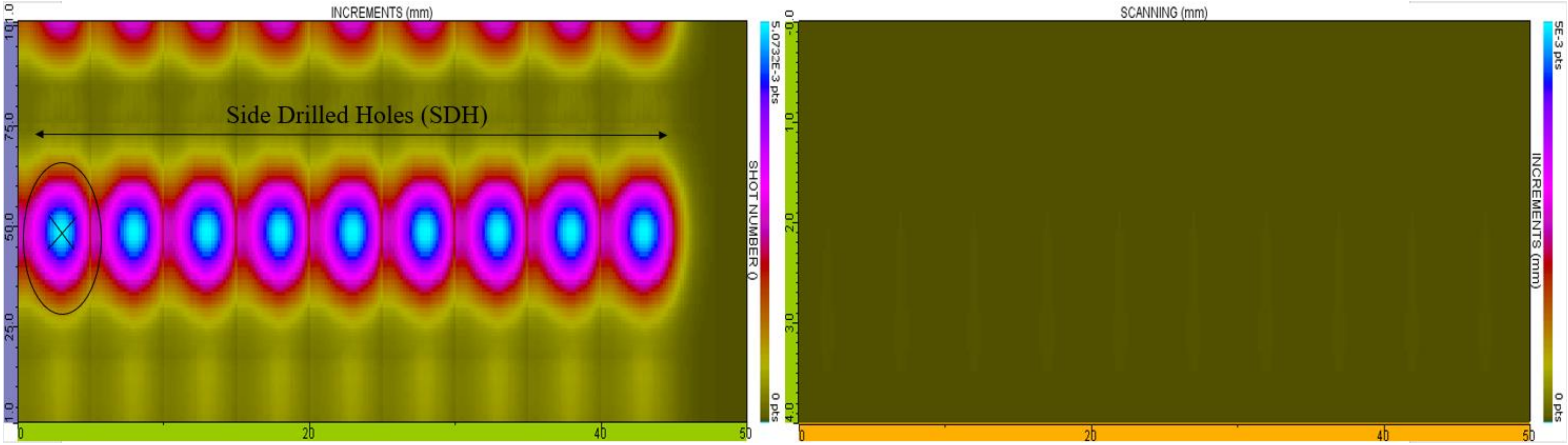
Inspection of SDH with Contact and Immersion Technique - Result

SDH location - 3

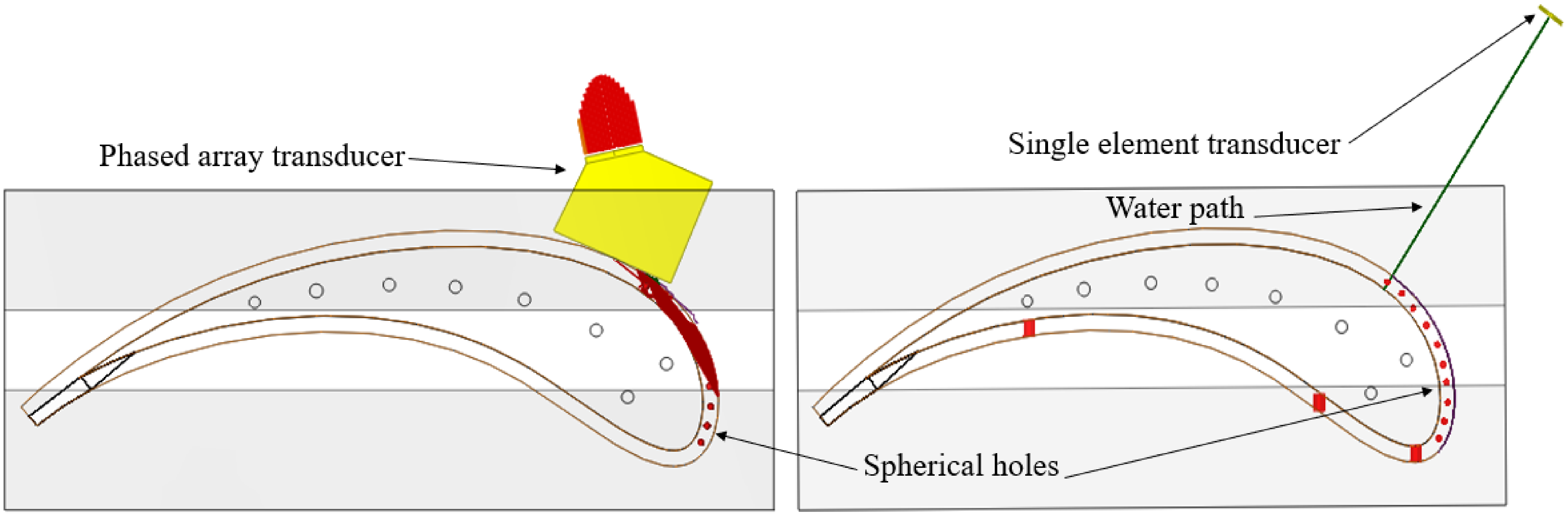


Calibration

SDH location - 1



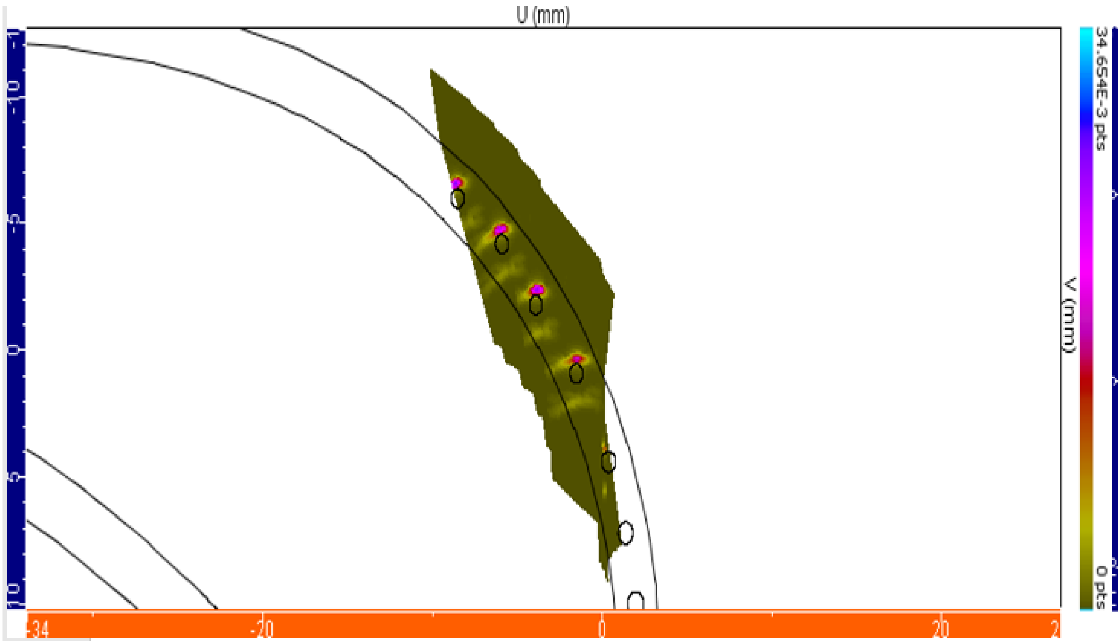
Inspection of Spherical holes

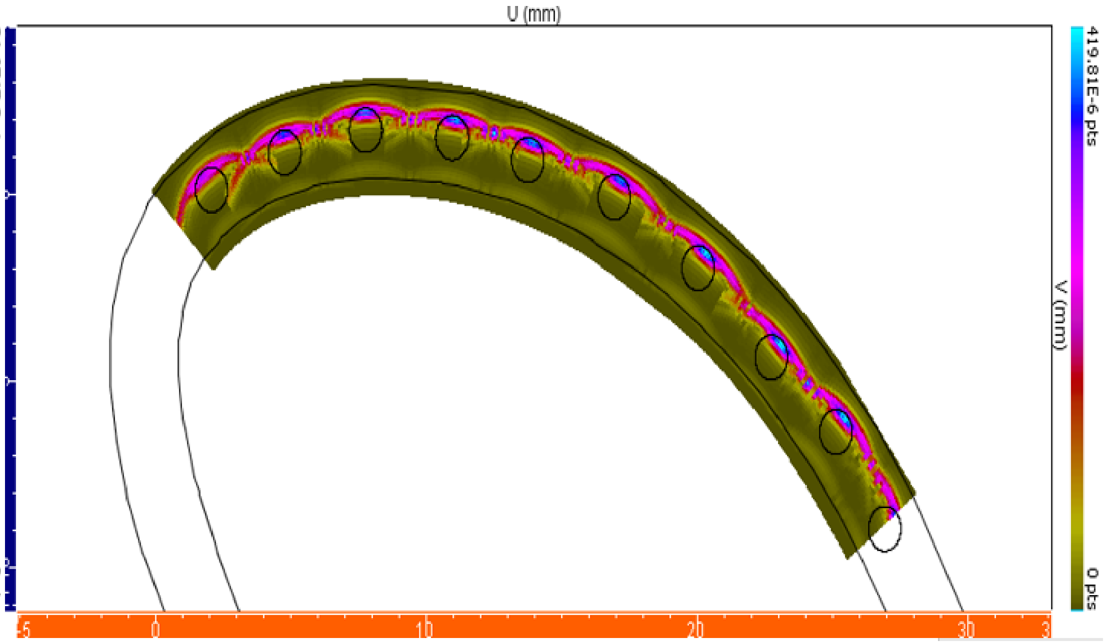


Central frequency: 10 MHz
Shear wave for inspection
Contact phased array transducer

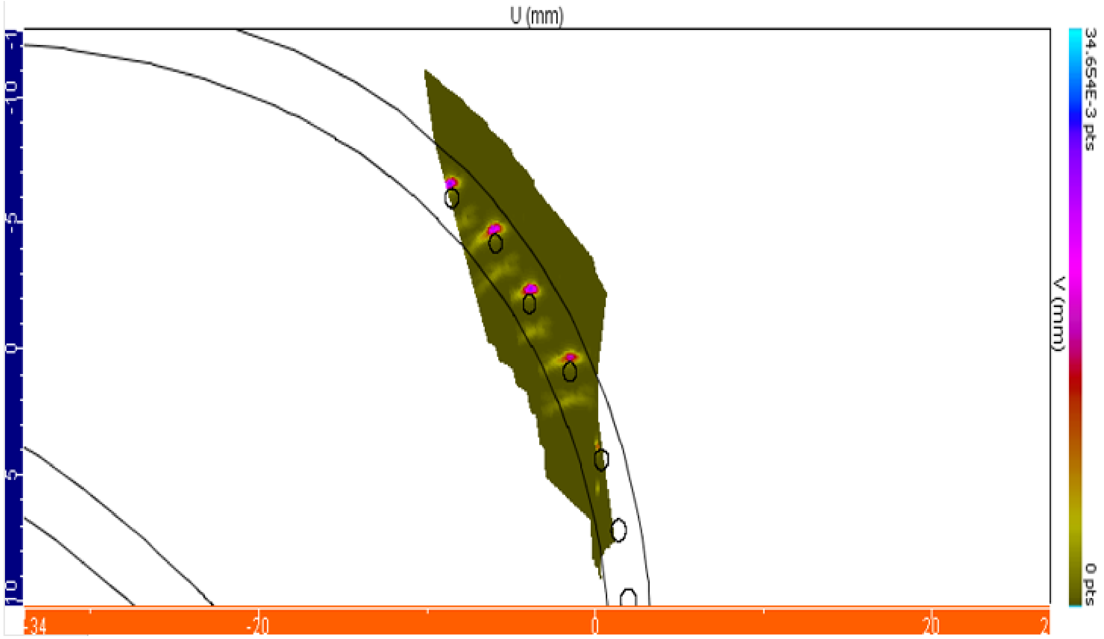
Central frequency: 20 MHz
Longitudinal wave for inspection
Single-element flat transducer

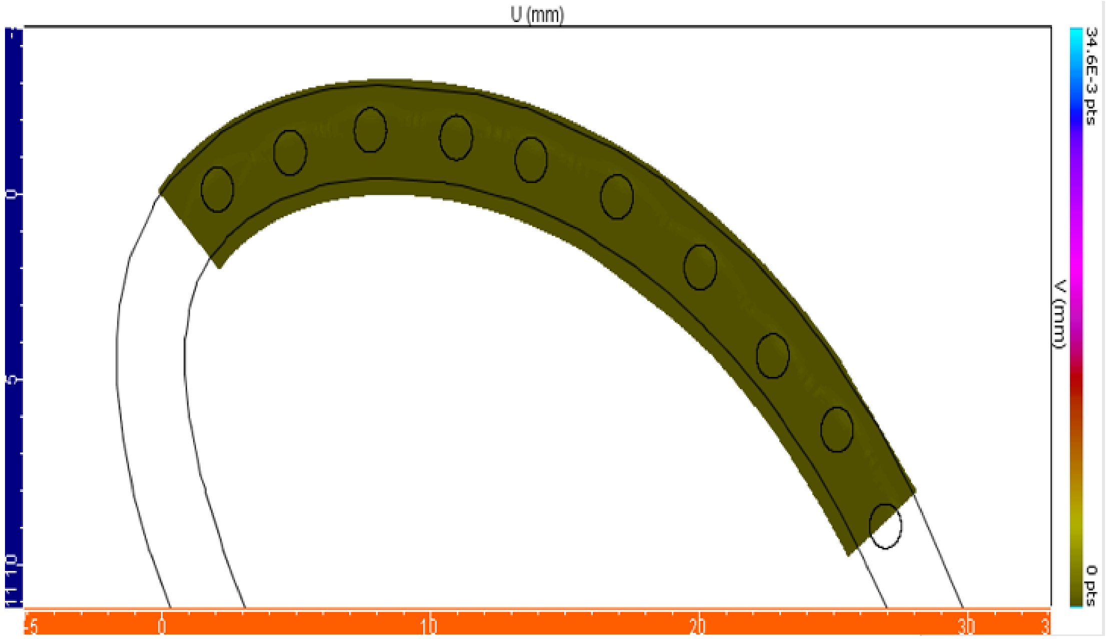
Inspection of Spherical holes - Result



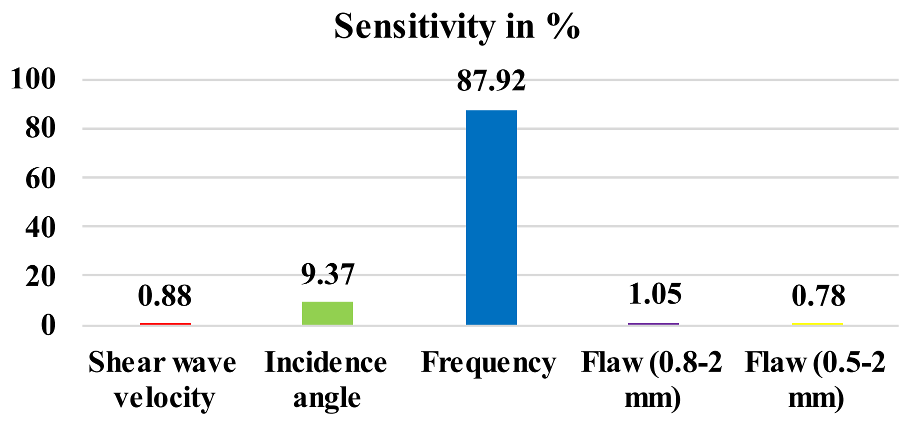


Calibration

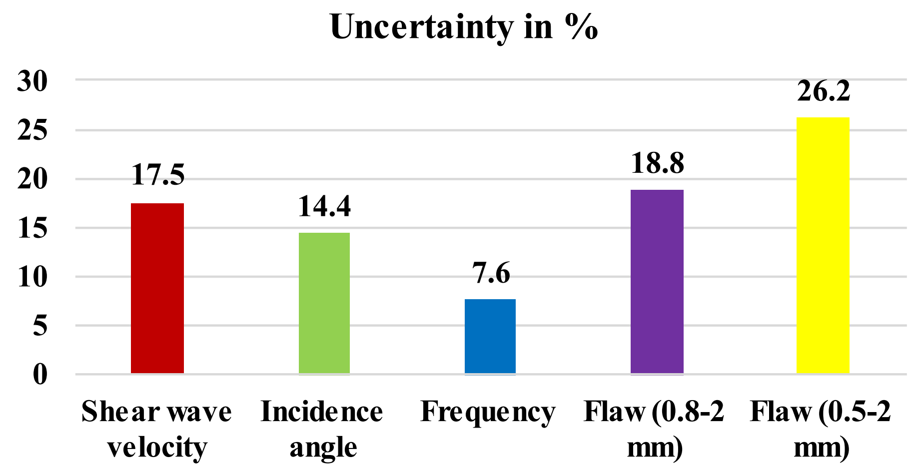




Sensitivity analysis

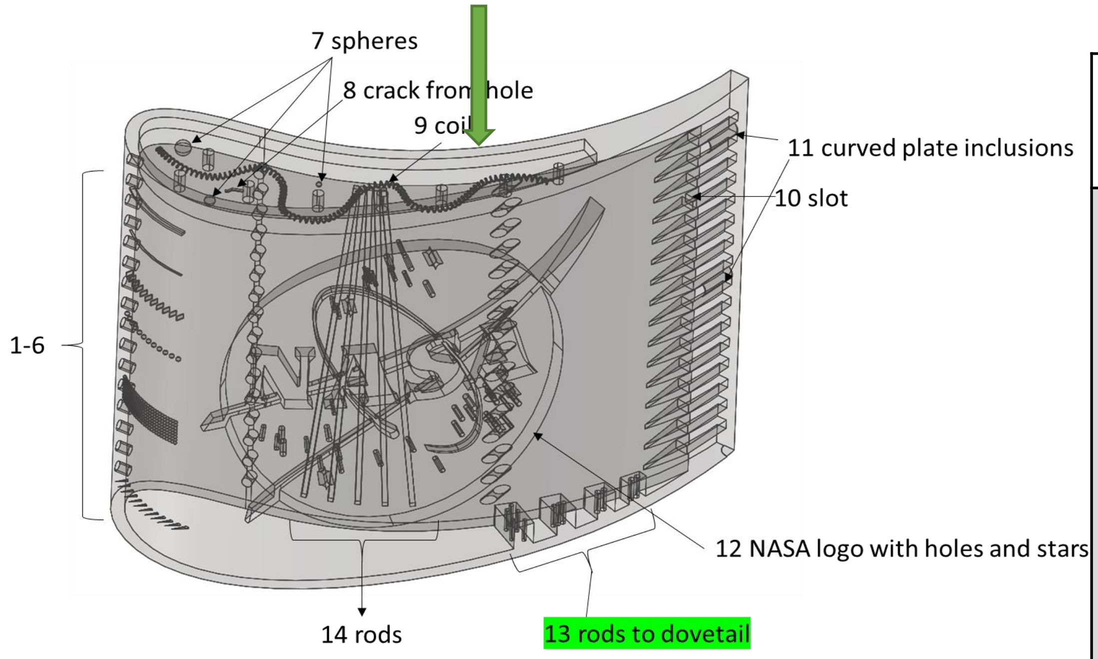


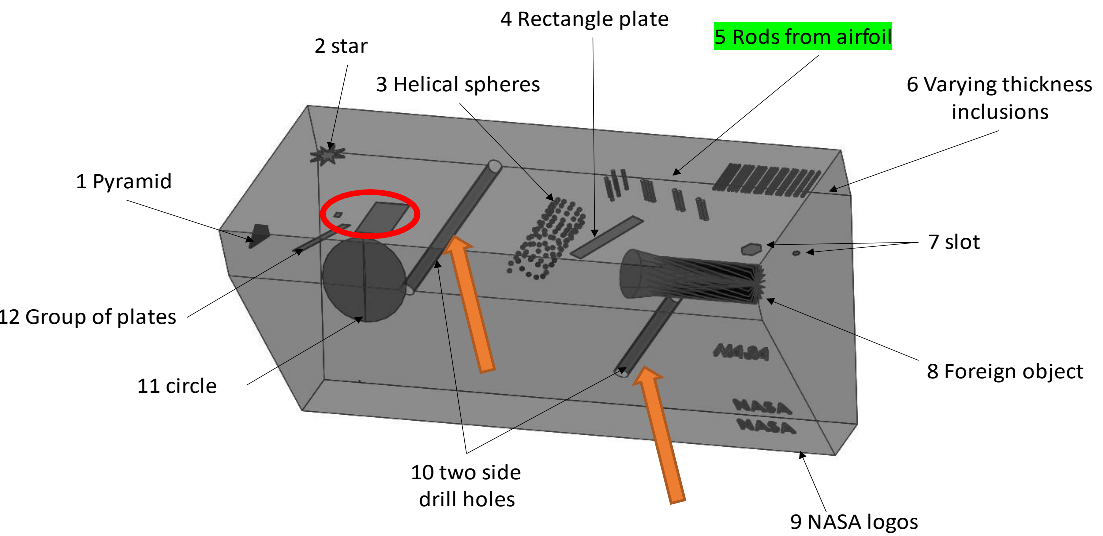
(a)



(b)

Comparison of NDT techniques





Defect location	Defect Type	Radiography	Contact UT	Immersion UT
Dovetail	1-11 (leading edge, Spherical pores, hole and crack)	✓	✗	✓
	12 (NASA logo with stars)	✓	✓	✓
	13,14 (rods)	✓	✓	✓
Airfoil	10 (SDH)	✓	✓	✓
	1-9,11,12	✗	✓	✓

Conclusions

- In this study, radiography and ultrasonic inspection techniques were used to inspect the jet turbine blade model using CIVA in order to identify a variety of defects.
- Using radiography technique, it was possible to identify the defects in airfoil side of the blade with good contrast but not in the dovetail part due to the high thickness.
- Using ultrasonic technique,
  - The whole component was inspected and most of the defects were identified
  - Then specific defects were inspected for obtaining detailed information. It was found that with specific configuration of the transducers, all the defects can be identified.

Recommendation

- Due to feasibility and ability to inspect the structure in-situ, contact inspection is recommended because no specialized setup necessary
- Inspection using immersion technique is recommended only when high resolution of the defect is required. Also, the inspection with immersion technique can be made with one type of transducer on the complex object.
- With radiography technique, most of the defects in the airfoil side of the defect was identified but it would be difficult in the dovetail part due to the large thickness and losses due to scattering.

NDT in Aerospace

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