Migrating from traditional to Digital Radiography in Aerospace

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Abstract

The aerospace sector with its high and demanding quality standards is a heavy user of non-destructive testing (NDT) and especially X-ray inspection. Increasing production volumes and higher quality standards require efficient and reproducible inspection processes. Digital Radiography (DR) allows to achieve both targets but poses many new challenges. A main focus will be the different quality metrics of the X-ray setup like spatial resolution (SR), Signal to Noise Ratio (SNR), Contrast Sensitivity (CS), focal spot analysis and long-term stability evaluation of Digital Detector Arrays (DDA). Additionally, the spotlight will be on the industry standards like ASTM 2737 and ASTM 2597, DICONDE, process requirements like NADCAP and specific company standards like the Boeing BSS7044 or Airbus AITM.

During the introduction, the most relevant use cases of DR in Aerospace and its specific challenges will be presented and analyzed. A special focus will be on weld inspection and honeycomb structures with very unique requirements. Another spotlight will be on efficient system design and automation using modern robot handling or manipulation systems.

A side note will evaluate the changes of Computed Radiography (CR) as a transfer technology to a completely digitized process. This includes the need for traceability and inclusion to MES or production management systems (Industry 4.0).

1. Introduction

The aerospace sector is the industry with the strictest quality standards and most sophisticated non-destructive testing (NDT) processes. For a good reason: Part failures can have fatal consequences and have to be prevented at all costs. Over the years the industry and most OEMs have generated extensive guidelines for every method. This paper will focus on X-ray inspection and will discuss especially the transition from analogue film to digital detector arrays (DDA). This process requires some changes to the inspection procedures and personnel qualification. The following sections will briefly introduce the technology, summarize the industry standards and give suggestion on the implementation.

2. Implementation of DR in the aerospace

2.1 Digital X-ray technology

This paper does not focus on the explanation of DDA technology. For the sake of understandability, a brief overview is still given: DDAs consist of an array of photo-diodes and a scintillator. X-ray photons attenuate the scintillator and the generated light is captured by the photo-diodes. This signal is directly transferred to the image processing software and post-processed with calibration data. The software is also capable of performing image enhancements, measurements and archiving of the image data. Fast read-out speeds above 25 frames per second (fps) allow a real-time view of the inspected part. Computed Tomography (CT) is a process that collects a big number of images (projections) and reconstructs a 3D view of the inspected part.

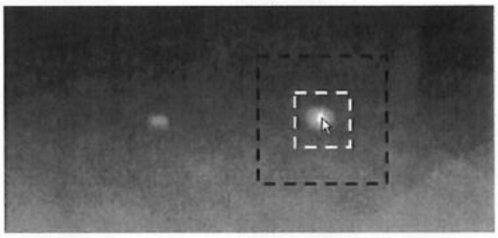
2.2 System performance parameters

A digital system has many parameters defining the system quality, which are explained in the following sections. When transitioning from film operators are used to take into account the film grade and the contrast. This is not sufficient for digital systems.

2.2.1 Contrast Sensitivity (CNR)

Contrast can be measured through single wire IQIs or through hole type IQIs. The second option is the by far favoured technique in the aerospace industry and will be explained here. The Contrast to Noise Ratio is measured to determine the contrast sensitivity, which determines the minimum defect depth to be resolved in comparison to the material thickness.

To perform this the mean grey value inside the 4T hole has to be subtracted to the mean grey value on the IQI. This value has to be normalized by standard deviation. Image 1 explains this process more detailed.



$$CNR = \frac{GV_{median}[hole] - GV_{mean}[beside\ squares]}{Sigma[beside\ squares]}$$

$$CS\ [\%] = \frac{GBV}{CNR} * \frac{MT_{IQI}}{MT_{total}} * 100$$

Known Parameter:

$MT_{step} = 50mm$; $MT_{IQI} = 0.5mm$

$GBV = 2.5$

Measured Parameter:	Calculation:
GV_{median} [hole] = 4800	$MT_{total} = 50.5mm$
GV_{mean} [beside squares] = 4600	CNR = 4800 - 4600 / 50 = 4
Sigma [beside squares] = 50	CS [%] = 2.5 / 4 * 0.5mm/50.5mm * 100
	CS [%] = 0.6188%

Figure 1. Calculation of CNR values with a hole type IQI

2.2.2 Spatial resolution (SRb)

Spatial resolution was not required when using film but becomes crucial with DDAs. Due to the fact that the detectors digitize the analogue signal with a certain sampling rate (pixel pitch) and magnification is used to increase resolution, it is required to measure the resolution at the object. To do this a duplex wire IQI is used. The gaps between each wire pair have exactly the same size as the wire itself. Now the resolution can be determined looking for the first “unsharp” wire with a dip of less than 20%. Figure 2 describes the principle. SR describes the minimum defect area that can be detected.

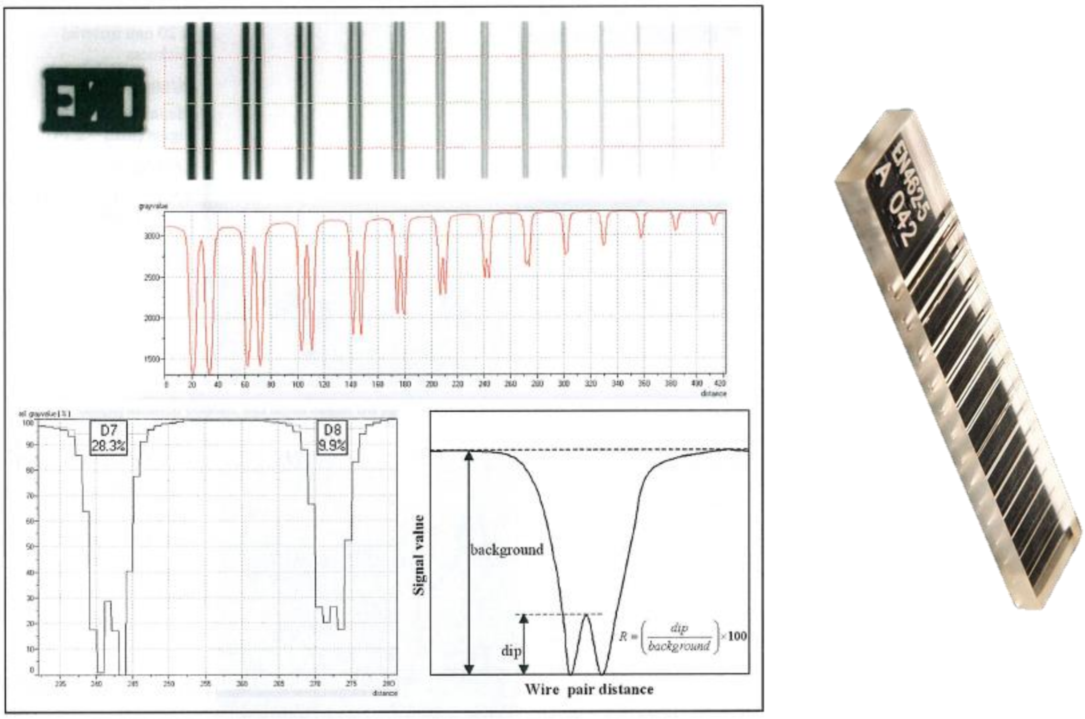


Figure 2. Calculation of Spatial Resolution (SRb) with a Duplex Wire IQI

2.2.3 Signal to Noise Ratio (SNR)

The signal to noise ratio describes the distance of the noise level to the real system signal. The signal to noise ratio is measured as the mean grey value inside a 25 x 25 px windows divided through its standard deviation. Typically, this value has to be normalized by the spatial resolutions to receive the normalized Signal to Noise Ratio (SNR_N). Generally, a high SNR is desired as it greatly improves the detectability of details.

2.2.4 Detector calibration and dead pixel correction

Detectors need to be regularly tested and qualified to check if all photo-diodes are still responding correctly and uniformly. Therefore, a dead pixel test has to be performed. Bad pixels can be categorized in dead pixels, overresponding pixels, under-responding pixels, non-linear pixels and lagging pixels. Defect or wrong-responding pixels can be corrected by taking the mean value of its surrounding pixels if the pixel has five or more good neighbours. If that is not the case the pixel is called a Cluster Kernel Pixel (CPK) and cannot be corrected. The only options are replacement of the detector, masking the field of view (if located at the side) or projection of the pixel into the inspection image so operators are aware of this cluster.

Calibration has to be done regularly as well and typically consists of a gain and offset calibration, which linearizes the detector response and reduces the electronic noise by a big amount. This process shall not be described in this paper.

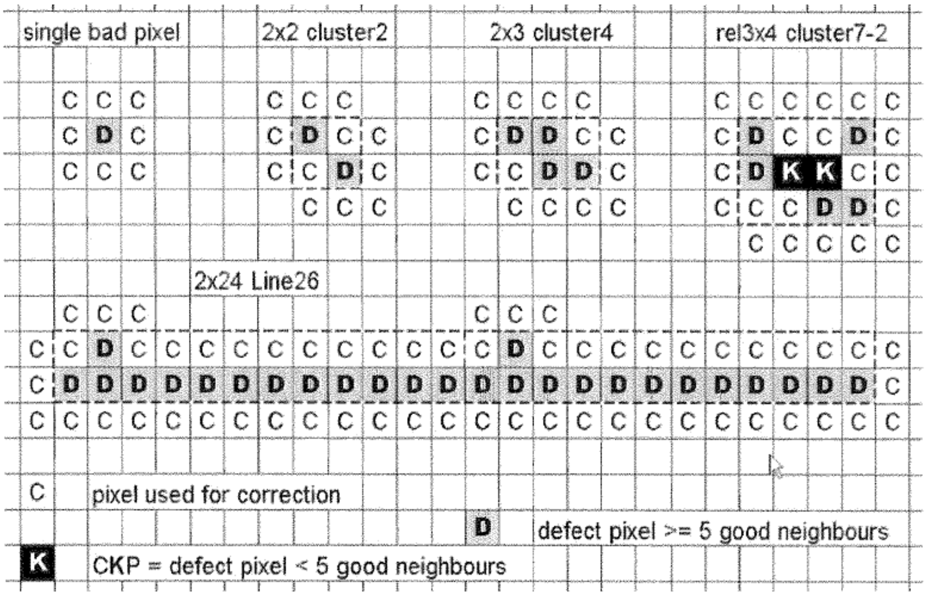


Figure 3. Definition of kernel pixels and bad pixel types.

2.3 Evaluation of system performance

The system performance can be evaluated through standardized phantoms consisting of standardized IQIs. Figure 4 shows some common options used in the aerospace industry. The most commonly used device is the ASTM phantom being defined in the ASTM 2737. It consists of a two-step wedge, where the thin part has to represent the thinnest wall thickness of the inspected part and the thick section the thickest. Two-hole type IQIs are places – one on each section and a duplex wire IQI on the thin section. Such a setup allows a reproducible evaluation of the system performance. Figure 5 shows the evaluation of the phantom in a digital system. All tests and calculations can be performed automatically.

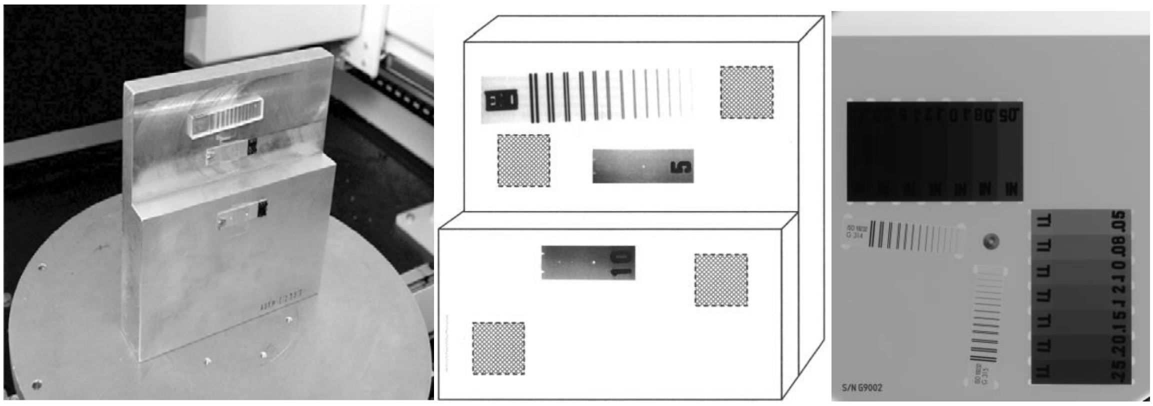


Figure 4. From the left: Picture of the ASTM phantom, drawing of the ASTM phantom, X-ray image of a TAM phantom

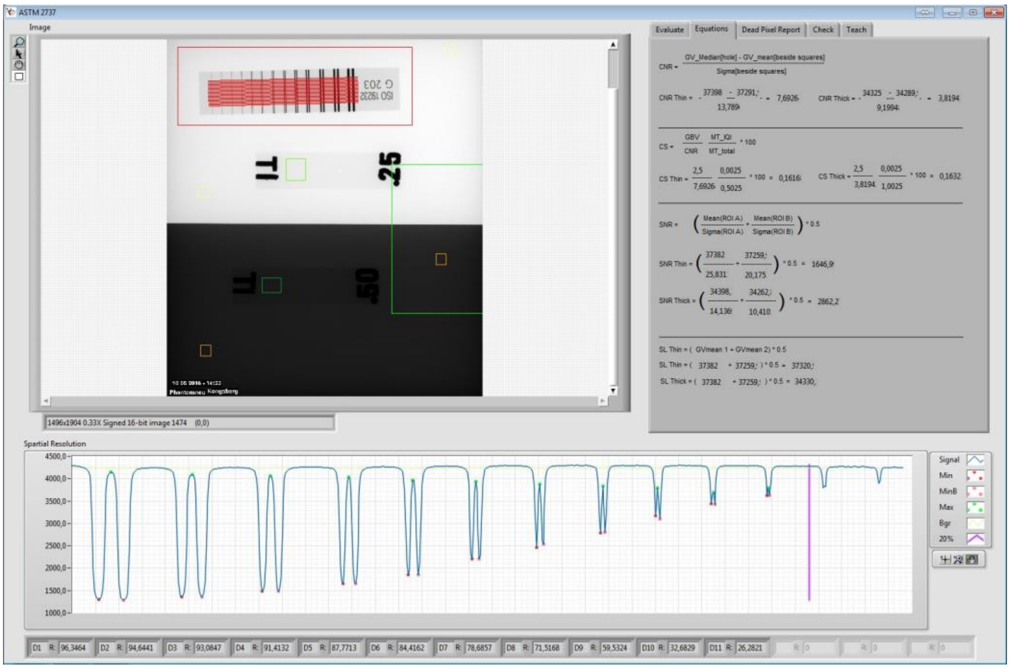


Figure 5. Automatic evaluation of all system performance parameters through the VisiConsult evaluation module.

2.4 Report generation and archiving

Compliant archiving of performance checks and inspection results is of highest importance in the aerospace industry. Figure 6 shows the standard report format for ASTM 2737 system performance checks. These reports have to be saved including all acquired images like dead pixel map, phantom etc. X-ray images need to be archived in a way that they cannot be altered and access is provided for up to 30 years. This can be achieved by using the DICONDE data format and PACS server. This principle is adapted from the medical industry (DICOM) and ensures vendor-neutral archiving and system communication.

DDA System		voltage	kV	
Construction Year		tube current	mA	
Last Service		pre filter (material and thickness)		
Detector Settings		focus detector distance	mm	
Software		object detector distance	mm	
Software Version		total exposure time per image	s	

Test	☐ Acceptance Test	Used IQIs	☐ 5-Groove-Wedge	Material of the used IQIs	☐ Aluminium
	☐ Test after Repair or new Software		☐ Duplex Plate Phantom		☐ Titanium
	☐ Longterm Stability (short version)		☐ Duplex Wire IQI (EN 462-5)		☐ CRES
	☐ Longterm Stability (long version)		☐ Hole IQI		
			☐ Wire IQI (EN 462-1)		
			☐ no IQI required		

Tests		Unit	Result (new)		Limit		Result		Remark
			thin	thick	thin	thick	thin	thick	
Spatial Resolution	SR	µm							
Contrast Sensitivity	CS	%							
Material Thickness Range	MTR	mm							
Signal-to-Noise Ratio	SNR								
Signal Level	SL								
Image Lag	Lag	%							
Burn In	BI	%							
Offset Level	OL								
Bad Pixel Distribution									

Date of Tests	
Conclusion	
Operator	

Figure 6. Inspection report according to ASTM 2737

2.5 System design

Aerospace applications require typically very specialized inspections procedures. Therefore, available standard cabinets are not suitable for many tasks. Customized X-ray systems lead to highest process safety, shortest cycle times and safest part handling. The presentation will focus on different system types from roof mounted gantry systems all the way to automated in-line inspection solutions. Figure 7 shows some examples.

Figure 7. From the left to the right: A top-loader cabinet, a roof-mounted gantry system and a tower based high-accuracy system

2.6 Training and certification

Due to the fact that DR systems require fundamentally different skills and knowledge than RT systems all operators need to be trained and certified for the usage of digital X-ray. Typically, basic operators of the systems have to be minimum level 1, while operators performing image enhancement have to be minimum level 2.

3. Conclusions

This paper explained the basic parameters that need to be taken into account. Additionally, it discussed ways to automatically evaluate the system performance through standardized phantoms. During the presentation, there will be a comprehensive discussion of system and manipulation concepts and their advantage on the inspection and process safety. These assumptions will be proven through real applications and references.

The transformation from film to digital is clearly speeding up throughout the last years. All major OEMs like Boeing, Airbus and others have implemented guidelines (e.g. BSS, AITM etc.) for DR inspection. The major drivers of this development are cost pressure, lack of skilled personnel and cycle time requirements.