e-Journal of Nondestructive Testing - ISSN 1435-4934 - www.ndt.net

14th International Conference on Industrial Computed Tomography - February 4-7, 2025 (Antwerp, Belgium)

Mitigation of human factor in tomographic post processing of additive manufactured critical parts for aviation application

Author: Stefano Benuzzi[1], Davide Borghi[1]
Co-Author: Maria Grazia Righi[1], Natanaele Galavotti[1] , Fabio Esposito[1]
[1]TEC Eurolab srl, Viale Europa 40, Italy, e-mail: benuzzi@tec-eurolab.com, borghi@tec-eurolab.com, m.righi@tec-eurolab.com, galavotti@tec-eurolab.com, esposito@tec-eurolab.com

Abstract

Over the past decade, the development of the additive manufacturing process resulted in the manufacture of parts with increasingly complex geometries. The design freedom that Additive Manufacturing allows, enables the designer to develop increasingly optimized parts, capable of joining different geometries (lattice structures, thick walls, geometries optimized for heat dissipation) on a scale that can vary significantly depending on the required application.
Combining such different features, however, introduces new challenges during inspection; in fact, traditional non-destructive testing suffers from significant limitations that make it not completely suitable for 100% inspection of the sample:

- FPI (Fluorescent Penetrant Inspection: Applicable to limited areas depending on the roughness of the surface
- RT-2D (Radiographic Testing Film e Non-Film): difficulty in positioning the detector with respect to the source, need for positioning of the source-detector system in an orientation favourable to the interception of manufacturing discontinuities
- UT (Ultrasonic Testing): Limitations caused by the parallelism of the area to be inspected and the surface condition of the component

Inspection by Industrial Computed Tomography (ICT), thanks to the ability to inspect the reconstructed volume using arbitrarily sliding planes (optimized according to the manufacturing strategy) combined with the complete scanning of the specimen, removes many of the limitations of traditional NDT, becoming the typically required control for inspection of components produced by Additive Manufacturing in aerospace.
Simultaneously to the development of AM fabrication, tomographic systems have also adapted to meet the needs of application-dependent inspection: from micro-focus and nano-focus systems for finding micrometre-sized discontinuities, to linear accelerators for inspecting large components built in high-density alloys, the current range of machinery allows for traversing and inspecting current production by filling the gap generated by the manufacturing paradigm shift.
However, it is critical to analyse the effort that is required to the technical personnel responsible for analysing tomographic data for NDT applications. In fact, unlike other inspection modes, the amount of data that must be analysed to deliberate an aviation component and the inspection methods themselves produce a high level of stress that can generate human factor phenomena, which is particularly critical for the aviation industry.
The purpose of this presentation is to analyse some ways to mitigate the human factor in the post processing of tomographic data for NDT applications in the aviation industry and, ultimately, focus the attention to who is responsible for defining whether a component is fit for service or not.

Keywords: Human Factor, NDT, Additive Manufacturing, interpretation

1 Introduction

Industrial computed tomography (ICT) is nowadays widely used as an inspection method for aerospace components produced via additive manufacturing. Aerospace AM parts, in fact, are well suited for this inspection method as they are generally produced by complex designs (such as heat exchangers), which would be almost impossible to inspect with other NDT methods.
The ability to clearly inspect the intricate internal features of these components extends both to metrology and to defect analysis. However, while the metrology aspect can be automated almost completely (by relying on measurement routines that run on STL files obtained from the CT scans) the defect analysis still relies mainly on human interpretation.
This is a crucial aspect of the complete control chain, which is often overlooked in favor of scan/reconstruction techniques and data post processing, while it should have at least the same relevance. Of course, data quality is a fundamental aspect also for the human performance in defect analysis, as human interpretation is greatly aided if the amount of artifacts and noise is reduced (and therefore the application of the main standards (ASTM E3375, ASTM E1695, ASTM E1817) available for CT image quality is required). That stated, it is worth noticing that literature is still lacking the needed amount of material when it comes to the study of the human factor applied to the interpretation of CT images of additively manufactured aerospace components. This part of the process is in fact analogous to the work performed by radiologists that interpret radiographic, CT, MRI, and mammography images in the healthcare field, with the substantial difference that in the biomedical field the human aspect in the interpretation of radiology results is well studied and documented. However, this parallelism is a good starting point to assess the current situation of the analogous task in CT imaging of aeronautical parts. With the aim to give an introductory overview of the common aspects between medical image interpretation and NDT image analysis, refer to Table 1.

https://doi.org/10.58286/30729

	Medical Image Interpretation	**Aeronautical Parts Image Interpretation**
Purpose	Diagnose diseases or injuries (e.g., tumors, fractures)	Identify structural defects (e.g., cracks, voids)
Complexity	Identifying subtle abnormalities in tissues	Detecting minute flaws in materials
Consequences of Misinterpretation	Incorrect diagnosis, delayed treatment, patient harm	Missed defects, potential component failure, safety risks
Role of Human Expertise	Requires training and experience to identify pathologies	Requires specialized knowledge to assess structural integrity
Potential for Error	False positives/negatives due to fatigue or bias	False positives/negatives due to fatigue or bias
Subjectivity	Interpretation varies based on the radiologist's experience	Varies based on inspector's experience and judgment
Technological Assistance	AI tools assist in anomaly detection and diagnosis	AI tools assist in flaw detection and analysis (still in development)
Standardization Needs	Guidelines for consistent diagnosis (e.g., protocols)	Inspection standards (e.g., ISO or ASTM standards)
Collaboration	Often involves consulting with other specialists	May involve teamwork with engineers or materials scientists
Continuous Learning	Ongoing education to stay updated on new methods	Ongoing training on new inspection techniques
Impact of Interpretation	Affects patient care and treatment outcomes	Affects aircraft safety and operational integrity

Table 1 - Introductory overview of the similarities between medical image interpretation and aeronautical parts image interpretation

TEC Eurolab, being involved, among other tasks, in the defect analysis of aeronautical and aerospace critical parts, has developed through the years several strategies to compensate for the variability in the interpretation of CT images obtained from high density AM components that is intrinsic in defect analysis performed by humans.
These methods include: extensive training of the new operators, standardization and periodical check of inspection rooms (including screen performance and ambient light checks using SMPTE RP133 **[1]**), periodical operators eye exam, masking of certain areas of complex AM parts of focus the eye attention on specific areas, usage of AI aided defect recognition to reduce the impact of the analysis on the operator, dual-operator check of the same parts, and knowledge sharing on the running tasks. These methods and others, greatly help to control the human effect of the CT images interpretation, and will be used as a starting point for future development in this field.

2 Materials and Methods

The aim of the first part of this work is to assess the current methods implied in defect detection performed by human operators of critical aerospace AM parts, highlighting the aspects already considered as "relevant" and that are already studied in the healthcare field, and the ones that still do not get the required attention. The parallelism with the medical field will be helpful as a reference point. The second part of the work will focus on various methods that can be applied to overcome these challenges, and some current ways to implement them.

2.1 Factors that affect human interpretation of images in the healthcare field

When it comes to evaluating the ability of an operator to correctly interpret a radiographic image / CT slice, it becomes necessary to start from all the possible sources of interpretation errors, that are well documented by Waite et al. **[2]**. The main sources of interpretative error can be subdivided into internal and external sources, as shown in Figure 1:

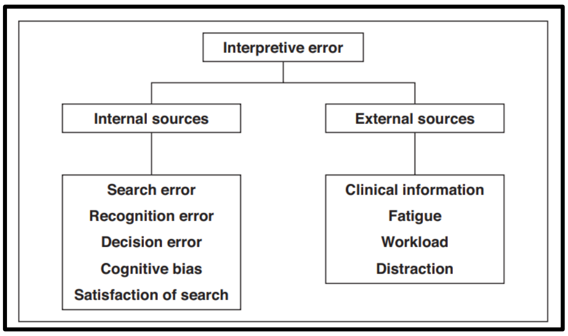


Figure 1 - Factors influencing diagnostic interpretative error [3]

Internal sources comprise:

- **Omission Errors**: these are referred to what was found to be critical in the medical field using eye-tracking technology during image interpretation: search error, recognition error, decision making error. The Search error is due to the observer never fixating on the point of interest to allow processing. The Recognition error is due to a too short fixation time on the area of interest, which was found to be at least 500ms – 1000ms by Krupinski et al **[3]**. The decision making error occurs when the inspector actually fixates the defect for more than one second but fails to recognize it.
- **Attention and perception**: Humans are unable to process all the information in their visual field. As a result, the human visual system manages this limitation through various strategies, one of which is restricting "high-resolution" vision to the fovea. The fovea covers just a few degrees of the visual field, while the areas immediately surrounding it experience a significant drop in visual acuity. **[4]** Therefore, a selection of items to focus this narrow cone of high resolution vision is needed. The attention is in fact focused on objects that have specific features. The choice of these "objects" depends on the target that the operator has in his mind, and by his understanding of the scene contents and layout. Therefore learning, memory, attention and expectation all play a role in this process. It was demonstrated that observer can fail to note even obvious features if he is not actively paying attention to them. This phenomenon is called "inattentional blindness" and it is accepted to be a limit of the human brain to perform "search tasks", as it cannot be entirely prevented. **[4]**
- **Cognitive Biases:** This category of errors is more related to logic mistakes caused by nonanalytic reflexive thinking **[5]** and can be subdivided into four main groups:
    - **Anchoring:** The failure to revise an initial impression when faced with conflicting information. This bias is linked to confirmation bias, where clinicians interpret new findings in a way that supports their initial hypothesis.
    - **Framing:** Diagnostic decisions are influenced by how a problem is presented or framed. The wording of a referral can narrow the range of diagnoses considered.
    - **Availability:** The tendency to favor diagnoses that are easily recalled or come to mind quickly. This bias is more likely to occur after a recent diagnostic error or similar case.
    - **Alliterative:** When radiologists' interpretations are swayed by previous diagnoses, either their own or those of colleagues. This influence can affect how they interpret current images.
- **Satisfaction of search:** This bias occurs when a visual search is prematurely ended after identifying an initial abnormality, leading the searcher to feel "satisfied" with the image's interpretation. Satisfaction of search (SOS) can affect the interpretation of various imaging modalities, potentially causing other abnormalities to be missed.
- **Prevalence effect:** The prevalence effect refers to the relationship between the prevalence of a particular abnormality and observer performance.

External factors comprise:

- **Clinical history**: having previous clinical history for the patient is generally considered beneficial to the success of the interpretation, as it focusses perception on an area of interest, or it changes the level of interpretive suspicion. Although some studies have shown that no difference in interpretative performance was observed with or without prior history, there are no proofs that it decreases interpretation accuracy. Therefore, it is currently considered beneficial.
- **Fatigue and error:** Krupinski et al. **[6]** found increased subjective fatigue and decreased accuracy on both conventional radiography and CT interpretation after a day of reading. Moreover, the work in shifts with circadian misalignments can result in sleepiness and chronic fatigue, which negatively affect performance. **[7]**
- **Workload, Interpretative Speed and Error:** a sustained artificially high interpretative rate can result in additional interpretative errors from both general and oculomotor fatigue. **[6]**

- **Distractions and error:** as it was studied by Balint et al **[8]** multitasking can generate distractions that could introduce errors when interpreting images, with an increased error rate of 12% when the interpreter receives a phone call in the hour before the interpretation activity.

The major causes of interpretation errors (applied to the specific case of mammography images interpretation) were also studied by Clerkin et. al. **[9]**. They found, in the category of the external influence factors, some common topics with the work of Waite et al., among which: fatigue, workload, interpretative speed, availability of prior images (clinical history). However, Clerkin et. Al. also included the effect of Social Networking, and the volume of reporting as influencing factors on the interpretative error rate. Moreover, experience and training (as internal factors) also play an important role.

Here follows a brief description of the three additional external and internal factors:

- The study on the **volume of reporting** effect, focuses on the relation between the number of mammographic screening inspected and the interpretation performance score, showing that this factor is one of the most important.
- In addition to the number of "reads per year", it was studied that the interpretation performance is also affected by the **experience level and education**. In fact, studies have demonstrated that with increasing years of experience and continuous professional development, readers may reduce the number benign recalls (false-positive rates) while maintaining high cancer detection rates **[10]**.
- **Social Networking:** A study investigating the social dynamics of a group of breast radiologists, outlined a strong association between social and professional interactions with optimum performance. The study outlined how radiologists with a wide circle of peers had a positive correlation with improved image interpretation. **[11]**

The paper by Clerkin et. al., also points out that, in addition to the effect of night shifts on detection performance that was also studied by Waite et al. **[2]**, also the time of the day has a measurable influence on the detection score. In fact, interpretations performed in different hours during a standard work day (eg. 9 to 5) produces different detection scores, with the highest ones being in the 2PM-4PM range and the lowest ones being in the 4pm-6pm range. **[12]**

This short summary will serve as a reference starting point for the comparison of the current challenges when inspecting aerospace components.

2.2 Parallelism between image interpretation in the medical field and in the aerospace field

Once established the main sources of interpretation failure that have been recognized until now in the medical field, it is necessary to progress by finding similar situation when it comes to the inspection of images in the NDT field (specifically CT slices). In fact, although the subject of the analyzed images is quite different, many similar situations and mechanisms are also present when inspecting aerospace components. The following list will try to summarize the main ones:

- **Omission Errors**: similarly to the types of omission errors that could arise when inspecting a chest CT scan, also during the inspection of a, e.g., heat exchanger, the operator may miss a relevant indication as the consequence of not fixing the point of interest for long enough, or by completely missing the indication as the result of a decision-making error.
- **Attention and perception**: additively manufactured heat exchangers can show quite complex geometries. When scrolling through their internal features in a CT reconstruction, the eye and the attention mechanism of the brain will adopt several strategies to process this huge amount of information. Similarly to the observation of a chest radiography, the small cone of "high resolution vision" of the fovea will focus on a few "critical spots". The position of these spots will depend on several factors, among which the geometry of the part itself, the experience of the user, his memory, attention and expectation. This implies that also factors like cognitive biases, user experience, number of working hours, etc. play an important role in the output of the analysis.
- **Cognitive Biases:** in analogy to the types of bias that can affect the interpretation of an (e.g.) head CT scan, many cases of non-analytic reflexive thinking could also affect NDT analyses:
    - **Anchoring:** failing to adjust initial impression in light of contrary information. This type of bias could show when a certain component on which it was expected to find some kind of defect (e.g. after customer explicit request), actually does not present any. The operator may still "detect" some indications by mistakenly reporting noisier zones or artifacts as possible indications.
    - **Framing:** Operators are influenced by the way a problem is worded or framed. The request for a "void analysis" may lead the operator to only focus his attentions to voids in the material, and by omitting other kinds of potential defects that were not explicitly requested (e.g. trapped powder, geometrical deformation, positive indications, foreign material in ducts, etc.). Note that when explicit acceptance criteria are present in the drawing, the reporting of non-relevant defect is not requested. However, it is good practice to report them anyway in a different category (e.g. named "other indications") which is not subject to acceptability judgement.
    - **Availability:** This bias may be considered dependant on previous analyses on the same component that showed a specific "trend" in the typology of detected defects. This may as well be caused by previous known issues

with that component (e.g. a part that is inspected after a failure related to a specific internal feature). The operator could in fact be more “ready” to find a specific kid of defects as he is more willing to find them.

  - **Alliterative:** Results from the influence that different operators have on each other. If one operator reads a report or talks to another one before inspecting the same P/N, he may be more inclined to search for the same kind of defects that the first operator found in the first place.

- **Satisfaction of search:** when inspecting a P/N, the operator could become “satisfied” after detecting a major defect that makes the part nonacceptable. He may consequently lower his attention level on “smaller” defects that may be non-acceptable as well.
- **“Clinical history” → P/N previous inspections:** when inspecting different S/N of the same component, the operator becomes aware of the recurring typologies of indications that the P/N most frequently has. He will be therefore more prone to search for them, creating the risk to pay less attention to non-recurring defects, which may as well be non-acceptable.
- **Fatigue and error:** all the studies and the consideration made by Krupinski et al. **[6]** are still valid when inspecting aeronautical components. In fact, when the operator is requested to perform several consecutive full days of defect analyses, his attention level, his ability to focus, and his awareness of potential biases become less effective.
- **Workload, Interpretative Speed and Error:** as stated for the medical field, a sustained artificially high interpretative rate can result in additional interpretative errors from both general and oculomotor fatigue. **[6]**
- **Distractions and error:** analogously to what happens in an hospital environment, several interruptions can also occur for the activity of the operator who is performing a defect analysis. He may, in fact, be involved also in the scanning and post processing of the volume that he will later inspect, causing his interpretation activity to be often interrupted by these different operative tasks.
- **Volume of reporting**: performing a defect analysis on multiple SN belonging to the same PN with a constant pace, keeps the operator’s mind ready and makes it easier and faster to perform the analysis, as the geometry and scan characteristics (e.g. noise characteristics, specific artifacts, etc.) are well known to him.
- **Experience level and education**: It is common knowledge that higher experience level is the base for better defects recognition. This is true for the experience on the analysis on the same PN, as the user learned to recognize “how the defect are represented” in that specific scan (which has specific noise characteristics and artifacts). However this experience can then be applied also to scans of different PN with different characteristics, (e.g. when the user reaches a high enough level of understanding of how artifacts affect the image to be able to discriminate them from real indication).
- **Social Networking:** As it was studied by **[11]** it is also true for the NDT field that sharing experiences and talking about the different analyses can help to gain a broader view of the analyses possibilities, integrating the personal view of the operator with the experience and the interpretation of other colleagues.

2.3 Peculiarities of image interpretation in NDT with respect to the medical field

In addition to the several similarities listed in the previous paragraph, some differences can also be pointed out when it comes to the analysis of Aeronautical Components. The main ones being:

- **Complete and complex scans:** CT scans of aeronautical parts often include the complete component, with its high geometrical complexity. This means that the user faces the task to inspect a large and complex image, composed by several features. In the medical field, on the other hand, CT scans are often focused on specific body areas which are under investigation.
- **Higher slices number:** CT scans of aeronautical parts, when possible, are performed with a higher resolution with respect to medical images, generating large datasets. In fact, when a CT scan is performed on a human being, the ALARA principle must be applied, therefore the scan resolution and the number of slices will be limited by that. On the other hand, when scanning non-living objects, the ALARA principle is less stringent and longer scan times and higher resolution can be achieved. This implies that the operator often has the task to “scroll” through several thousands of slices, to complete the analysis of a single component, generating a higher level of fatigue.

  As an example to clarify the meaning of the above statements, let’s consider an example of a typical component to be analyzed through CT scan: a heat exchanger. The part has the following characteristics:

  - Geometry: Inconel 718 lattice structure
  - Size: 7,85 [In] x 5,90 [In] x 5,90 [In]
  - Min. Interpretable: 0.020 [In]
  - Chosen slice Step Width for inspection: 0.002 [In] (1/10 of the min. interpretable)

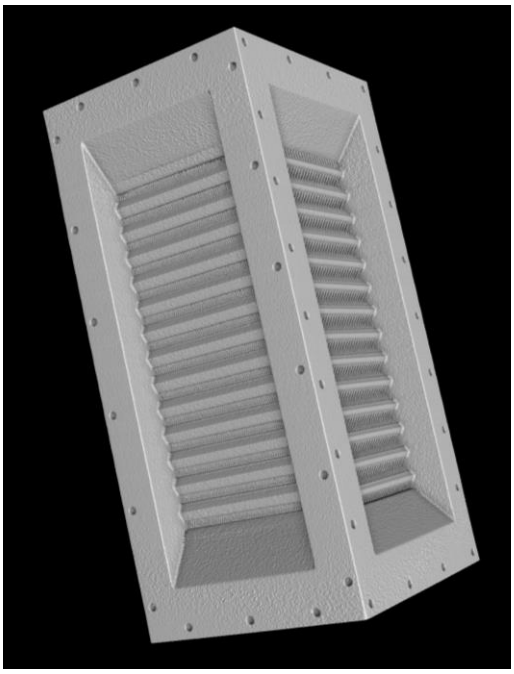
  Aside from the possible artifacts that may arise from an Inconel 718 lattice structure (being composed by several interlacing thick and thin walls), and only based on the size of the reconstructed volume, assuming to perform the inspection in two different planes (parallel and perpendicular to the printing direction) the operator would face a total of around 7000 slices to inspect.
- **Non-stop inspection**: if the operator is not involved in other tasks (such as managing the scan of the parts of their post processing) he may find himself forced to perform full consecutive days of defect analysis, leading to fatigue and to the risk of higher interpretative error. On the other hand, not having several interruptions during the analysis can reduce the “distraction kind” source of error. Consequently, a balance of consecutive interpretation hours and of planned pauses is recommended. Note that planned pauses are different from the interruptions caused by external unexpected events, as pauses are directly planned by the operator himself, and therefore the is not suddenly interrupted with loss of concentration.
- **Artifact presence**: while CT reconstruction artefacts are present in the medical field too (e.g. generated by metallic prosthesis), when it comes to the scans of components with intricate geometries with several thickness variations and simultaneously made by high density alloys, the presence of artefacts can be stronger, which requires a greater ability to distinguish between them and real defects. Moreover, CT artifacts could also mask some areas containing defects, making it harder for the operator to detect them. With high density materials, it is often required to use high energy sources (such as Linacs) which can introduce additional scattering artefacts and a higher level of blur in the image. Generally, the level of complexity that the operator has to face can be subdivided into four groups, as shown in Table 2.

		Material	
		Al, Ti, TiAl	Super Alloys
Geometry	Uniform (e.g. Blades)		
	Complex (e.g. Heat exchanger)		

Table 2 - Difficulty in the interpretation of CT images of aeronautical components based on the combination of material and geometrical complexity. Green: easy, Yellow: medium, Red: hard

2.4 Possible strategies to mitigate the human factor

To better understand the possible strategies to mitigate the human factor on image analysis, let's consider a typical component as an example. Again, we will be taking into consideration a high-density alloy heat exchanger, as it offers the harder combination of intricate geometries and high attenuating materials, which is the hardest condition to face due to the artifacts that may arise.



- Heat exchanger - AM Inconel 718
- Size: 250 mm x 180 mm x 130 mm
- Combination of features with high and low thickness (< 1 mm)
- High energy scan required to perform dimensional and defect analysis

Figure 2 - 3D rendering and sample characteristics of an Inconel 718 heat exchanger

2.4.1 Artifacts recognition

This kind of part, due to its combination of shape and material, generally requires a high energy scan to be performed. While this could be the only way to obtain a usable reconstruction when the part has these characteristics, it also has the downside to introduce scattering artifacts and generally a higher level of blur in the image. While there are ways to compensate for scattered radiation, it generally involves increasing the scan time by several orders of magnitude, while "scatter reduction software filters" often reduce scatter at the expense of SNR and CNR, which is not suited for defect analysis. On possible way to reduce geometry derived artifacts is to scan the part with different orientations, and inspect the volumes separately or merge them together with a Boolean operation. However, this may not always be possible for time or costs constrains. Consequently, some amount of artefacts is generally present in the image, as shown in Figure 3.

When dealing with "unremovable" artifacts in the context of defect analysis, one possible strategy that the operator can adopt is to observe the same area on different slice planes, to assess if the local gray value variation is due to a defect or to an artifact judging by its shape, its contrast and its position. In the image above we can see that the darkening highlighted in the yellow ellipse is present on all four edges of the part, and it is always in correspondence of an interception of thick and thin walls. Additionally, when inspecting the volume from a perpendicular view, it is possible to notice that this darkening is still in correspondence of the four edges and it starts with high contrast next to the edge of the material but degrades gradually moving away from it, as visible in Figure 4.

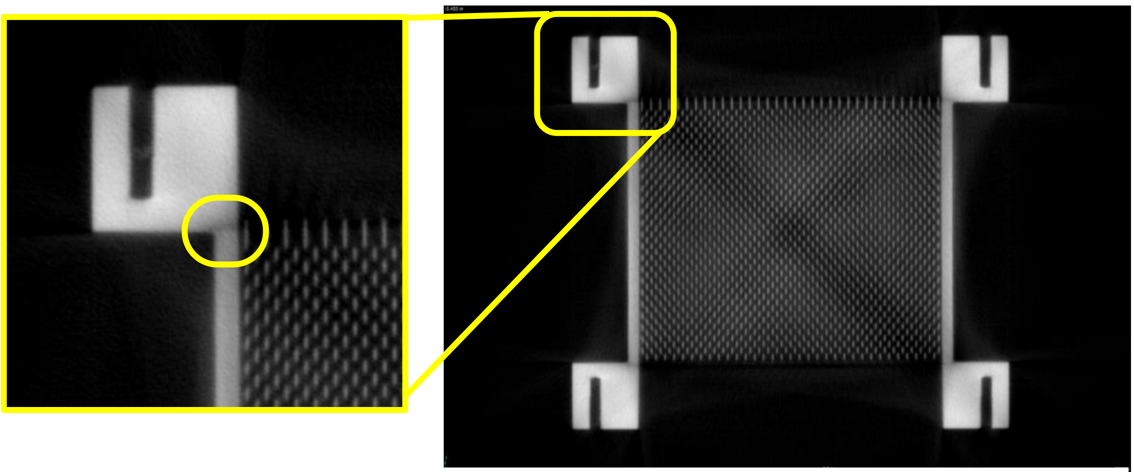


Figure 3 - Example of streaking artifact in the area where thin and thick walls intersect

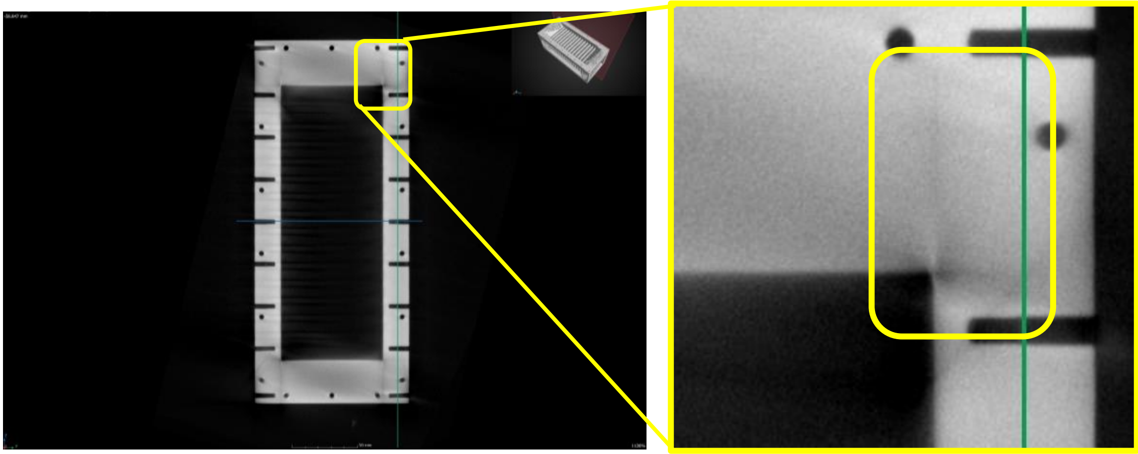


Figure 4 - Edge artifact as it appears when viewed from a plane perpendicular to the one used in Figure 3

2.4.2 Viewing parameters

Often, acceptability criteria require to check both negative and positive indication, such as voids/cracks and foreign material relatively, that could be present in internal cavities. These types of indications may not be clearly visible with one set of viewing parameters (namely Level and Window, which correspond to brightness and contrast in the image). Consequently, it may be necessary to adapt two or three sets of different viewing parameters, one for each type of indication. In the following image, the effect of the application of two different W/L parameters is shown when looking for negative and positive indications.

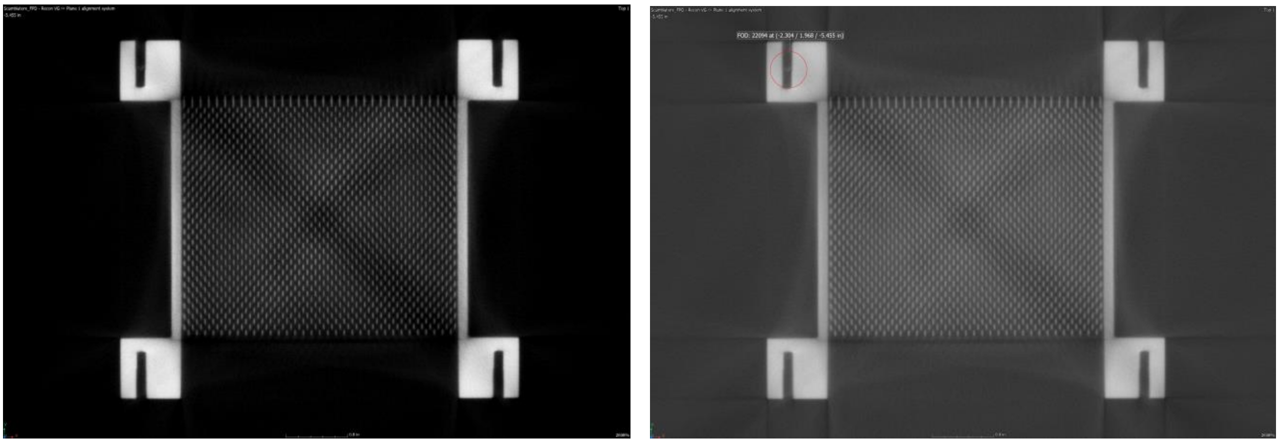


Figure 5 - Two sets of W/L values for negative indications (left) and for positive indications (right)

In the image on the right, it can be noted that the foreign material has better visibility with respect to the darker and more contrasted visualization on the left. The W/L parameters on the left, on the other hand, may be more useful when looking for internal voids thanks to the higher contrast.

2.4.3 Choice of slices orientation (knowledge of the production process)

Because additively manufactured parts have a specific growth direction, it is common knowledge that defects have higher probability to form with a shape parallel to the growth plane. Knowing the growth direction, helps the operator to check on specific planes that are parallel and perpendicular to the growth direction. While it is not advised to only inspect the part on two planes that are both parallel or both perpendicular to the growth direction, as shown in Figure 6.

Figure 6 - Example of correct planes orientations: on the left two parallel and perpendicular planes relative to the growth direction (correct), on the right two planes both perpendicular to the growth direction (not advised).

2.4.4 Choice of the slice step width

One of the most used ways to scroll through CT slices when performing defect analysis is by the use of the mouse wheel. This means that each "step" of the wheel rotation will correspond to a certain distance in terms of voxels or fractions of millimeters traveled inside the CT volume. The two main factors that may influence the choice of the slice step width are:

- The size of the "minimum interpretable indication" defined by the acceptance criteria
- The complexity of the geometry of the area of the part the is being inspected. This also generally affects the quality of the volume in terms of artefacts.

It can be assumed that a general conservative choice for the slice step width is to be at least smaller than 1/5 of the minimum interpretable size for "uniform" and low complexity areas, and 1/10 of the minimum interpretable size for areas with highly complex geometry. As an example see Figure 7.

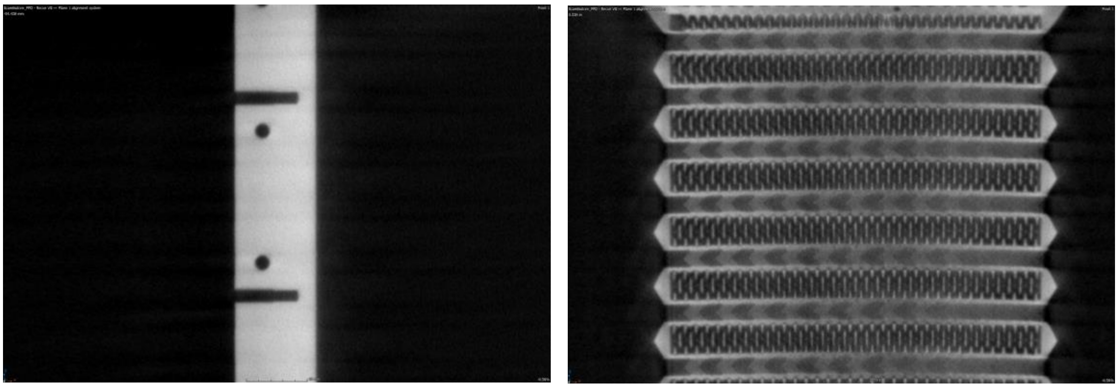


Figure 7 - Example of two geometries with different complexities: on the left a "simple" uniform wall, on the right a comples pattern of lamellae inside the heat exchanger

2.4.5 Masking of areas that are not under inspection

Another possible way to deal with intricate geometries is to subdivide them into simpler sub-sections, so that the attention of the inspector is not constantly threatened by features in the surroundings of the area of interest. It is in fact possible to choose several sub-sections of the component under inspection in function of their geometry. Take as an example the subdivision performed in Figure 8.

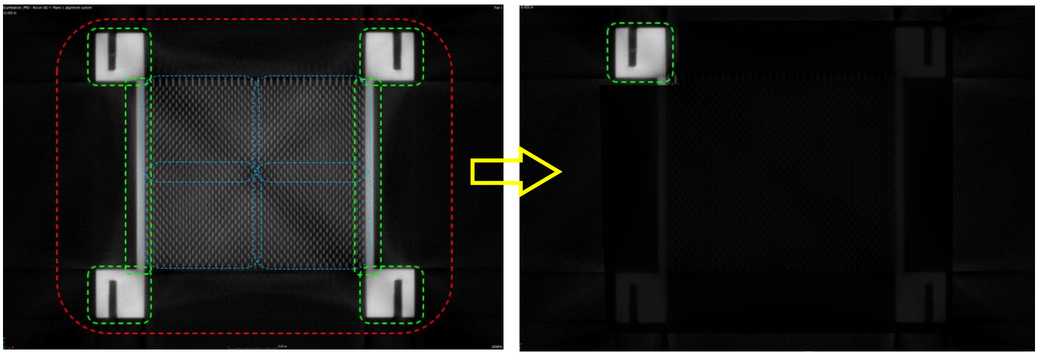


Figure 8 - The highlighted areas could be inspected separately by masking the adjacent ones

Here we can observe that the different areas of the sample walls were subdivided based on their shape and on their complexity and position:

- The two vertical thin walls: to be inspected separately with at least one slice plane parallel to the flat part of the wall.
- Four bulk square edges: to be inspected separately due to their position (they are distant one from the other in the image)
- Central heat exchanging area with lamellae: even though it is concentrated in the same area of the image, its complexity makes it necessary do divide it into four sub-sections.

Finally, it is worth mentioning that, despite the masking of surrounding areas may help to concentrate the high resolution view of the small fovea area of the eye (as documented by Wolfe et al. [4]) only on the area of interest, an initial general overview of the complete component may also be helpful to gather the general knowledge of its status. This can be achieved by a preparative fast scrolling of the volume, to assess the most evident indications and to try to avoid certain cognitive biases by having, before ~~the actual deep inspection starts, a more realistic knowledge of what could be expected in the defect analysis which is~~ about to begin. In addition to the masking of certain areas, the inspection software could be further customized with predefined checklist that guide less experienced operators during the complete inspection. These further controls could also include more constraints on the scrolling speed and reporting of the W/L used during the inspection.

2.4.6 Non-planar views

It is worth adding that another instrument which is available to the operator that uses the main visualizations software available on the market, is to create “nonplanar” views that can follow more precisely the geometry of axisymmetric components, or parts with freeform surfaces that develop in the tridimensional space.

It is, in fact, possible to “unroll” those cylindrical, spherical, or freeform surfaces (in this last case the CAD of the part will help the creation of the freeform surface) onto a plane, to have an easier and more complete view of the part. The user may also define “custom paths” using a line drawn “by hand” on the CT slices, or obtained by the intersection of geometrical elements, as the path for a specific slice plane.

However, it is worth noting that using these kinds of views, especially for freeform ones, may lead to artifacts in the unrolled view itself, if the starting geometry element is not fitted correctly to the surface. These instruments must consequently be used with caution.

2.4.7 Dynamic inspection

Visual defect detection performed on CT slices is different with respect to the analyses performed on “standard” radiographies. In CT, in fact, the operator has the possibility to inspect the part “dynamically”, with the ability to observe the “development” of indications that could be hard to see if observed statically.

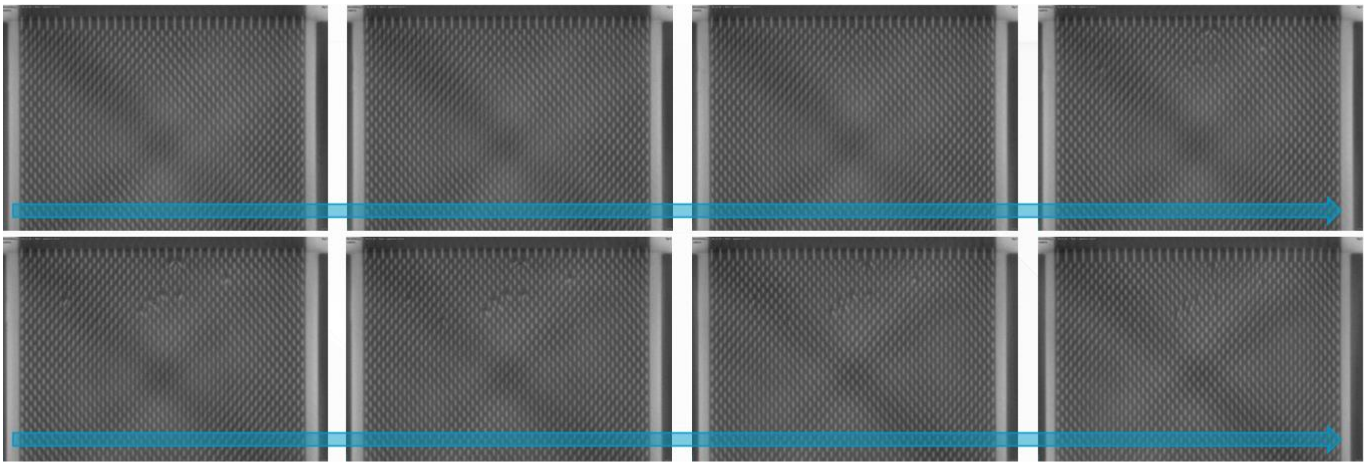


Figure 9 - Development of an indication of misplaced lamellae in the heat-exchanging area.

In Figure 9, we can see that scrolling through the slices containing the visible defects (bent fins in the reported example) we gain knowledge of the development of this deformation. This gives the operator a higher level of information on the indication, and is able to recognize it more confidently.

2.4.8 Use of AI aid to perform automated defect detection

Despite the implementation of several methods to compensate for the possible sources of error when it comes to image interpretation performed by human operators, there will always be some remaining error risk associated with that. Therefore, one possible strategy is to have a non-human operator to perform the analysis. With this target in mind, TEC Eurolab developed a tailored software that, after exporting the reconstructed CT volumes into stacks of RAW images, performs an automated analysis based on the use of artificial intelligence, and generates a report containing all the anomalies that it detects. **[13]**

An example image of the obtainable output is shown in Figure 10.

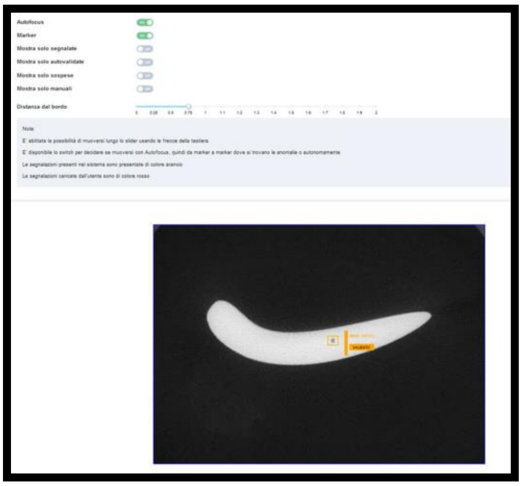


Figure 10 - Example image of the AI tool dashboard with a detected defect

While this kind of instrument is not still usable as a substitute for the human activity in the final accept / reject decision, it can be used as a support for the operator, to help him detect eventual false negative outputs. In fact, having an additional help and a further element of comparison for the detected indications could be beneficial for several reasons:

- It can reduce the strain on the operator, decreasing the possible errors due to fatigue.
- Not being subject to human biases (as long as it was properly trained from a large dataset obtained from a large group of different operators), it can be used as a neutral comparison for indications detected by operators that could be affected each one by its own biases.
- It is not affected by the distraction error, concentration error, attention error, omission errors and all mistakes that were detailed in the previous section.

3 Conclusion

A parallelism between the human factor effect in the medical field radiographic examination and the human factor in the NDT field was carried out. It was assessed that extensive research has been performed in the medical field, while still just a few studies are present for the NDT one. The two fields share the main sources of error such as omission errors, perception errors, biases, workload related errors, operator experience, fatigue errors, among others. However, despite having many similarities which can be used by the operator who has the task to inspect aeronautical parts to transfer the medical field knowledge to his work, also several peculiarities are present too. The main ones being the need to inspect complete components with high geometrical complexity and with a high slice number, with the addition of CT artifacts when inspecting high density parts.

Some possible strategies were proposed with the aim to reduce the human errors, among which the correct choice of multiple sets of viewing parameters (W/L), the correct choice of slices orientation with respect to the growing direction, the choice of an appropriate slice step width, the isolation of “non-interest” areas, the use of “non planar views”, taking advantage of the “dynamism” of the CT inspection technique, and finally, the use of AI defect recognition as an aid to the operator. On this last topic TEC Eurolab developed a tailored software for defect recognition based on a previously trained AI, that showed encouraging results when compared to the human performance **[13]**.

Despite numerous precautions that are currently actuated and that are still in development, the effect of human factor on the interpretation of images obtained from CT scans of additively manufactured aerospace parts is still a topic that deserves further study, as its output is critical to aerospace parts validation.

References

[1] L. Yenumula, R. V. Acharya, U. Kumar and A. Dash, *Performance Evaluation of Industrial Computed Radiography Image Display System,* Bhabha Atomic Research Centre, Mumbai – 400085, India: Industrial Tomography and Instrumentation Section, Isotope Production and Applications Division, 2016.

[2] S. Waite, J. Scott, B. Gale, T. Fuchs, S. Kolla and D. Reede, Interpretive Error in Radiology, American Roentgen Ray Society, 2017.

[3] E. A. Krupinski, Current perspectives in medical image perception, Tucson, Arizona.

[4] J. M. Wolfe and T. S. Horowitz, What attributes guide the deployment of visual attention and how do they do it?, Nature Publishing Group, 2004.

[5] E. A. Krupinski, Current perspectives in medical image perception, Tucson, Arizona: The Psychonomic Society, Inc, 2010.

[6] E. A. Krupinski, K. S. Berbaum, R. T. Caldwell, K. M. Schartz and J. Kim, Long Radiology Workdays Reduce Detection and Accommodation Accuracy, American College of Radiology, 2010.

[7] S. Rohatg, T. N. Hanna, C. W. Sliker, R. M. Abbott and R. Nicola, After-hours radiology: Challenges and Strategies for the Radiologist, AJR, 2015.

[8] B. J. Balint, S. D. Steenburg, H. Lin, C. Shen, J. L. Steele and R. B. Gunderman, Do telephone call interruptions have an impact on radiology resident diagnostic accuracy?, CrossMark, 2014.

[9] N. Clerkin, C. Ski, P. Brennan and R. Strudwick, Identification of factors associated with diagnostic performance variation in reporting of mammograms: A review, Elsevier, 2023.

[10] D. L. Miglioretti, C. C. Gard, P. A. Carney, T. L. Onega, D. S. M. Buist, E. A. Sickles, K. Kerlikowske, R. D. Rosenberg, B. C. Yankaskas, B. M. Geller and J. G. Elmore, When Radiologists Perform Best: The Learning Curve in Screening Mammogram Interpretation, Radiology, 2009.

[11] S. Tavakoli Taba, L. Hossain, R. Heard, P. Brennan, W. Lee and S. Lewis, Personal and Network Dynamics in Performance of Knowledge Workers: A Study of Australian Breast Radiologists, CrossMark, 2016.

[12] A. Alshabibi, M. Suleiman, K. Tapia and P. Brennan, Effects of time of day on radiological interpretation, Elsevier, 2020.

[13] D. Borghi, F. Esposito, S. Benuzzi and L. Gay, "High Energy Computed Tomography of high-density alloys using a 6 MeV Linear Accelerator: detectability and use of Artificial Intelligence," 2024. [Online]. Available: https://www.ndt.net/search/docs.php3?id=29238.