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# Hybrid inspection method using 3 dimensional scanning, lock-in thermography and laser shearography

**H.P. Jansen[1]*, D.J. Platenkamp[2] and J.S Hwang[3]**

[1]AVTH, Royal Netherlands Aerospace Centre, Marknesse, Netherlands; patrick.jansen@nlr.nl
[2]AVTH, Royal Netherlands Aerospace Centre, Marknesse, Netherlands ; jacco.platenkamp@nlr.nl
[3]AVIL, Royal Netherlands Aerospace Centre, Marknesse, Netherlands ; jason.hwang@nlr.nl
*Contact: patrick.jansen@nlr.nl

**Abstract**
The proportion of composite materials (such as CFRP) to the metal used on the modern aircrafts is rising, imposing different kind of failure modes. Since the composite structures are known to be sensitive to the impact loading, there is need for means to assess the sub-surface damage in the structure rapidly. Royal Netherlands Aerospace Centre NLR has an extensive track record on contactless non-destructive inspection (NDI) methods based on optical sensors, such as 3D surface scanning, lock-in thermography and laser shearography. The combination of these methods (multi-domain inspection) enables us to assess the structural integrity of an aircraft outer surface in a short time, reducing inspection costs and the "down time" of the aircraft. Recently, NLR is working towards a 3D oriented mesh environment of an object, enhanced with NDI data, providing sub-surface damage information. By automatically stitching the 3D object images, it is possible to expand this method for a complete scan of an aircraft surface. Furthermore, the thermographic and shearography imaging information has been integrated into the 3D surface accounting for the image distortion from the different measurement angles. In this paper, the results from the various studies will be presented involving integration of the 2D measurements with the 3D scan mesh.
**Keywords:** Thermography, Shearography, 3D scanning, Data fusion

## 1. Introduction

The use of composites in military primary aircraft and helicopter structures has increased significantly in the last ten years due to the opportunities they present for weight saving. In addition to their high specific stiffness and strength, other advantages include their superior fatigue performance. These materials are typically anisotropic leading to high mechanical complexity of damages caused by, for example, impacts. The impact damages are typically difficult to detect visually.

Non-Destructive Inspection (NDI) can be used to detect the barely visible impact damage. There are numerous NDI techniques in use today to detect barely visible impact damage, each with pros and cons. For Carbon/Glass Fibre Reinforced (CFRP/GFRP) panels, used in aerospace, ultrasonic testing is the primary inspection method. However, this technique can be costly to apply (labour intensive) and needs a couplant and mechanical contact with the part to be inspected. Using thermography and shearography these defects can also be detected. Characteristics of the techniques are: fast inspection, large Field Of View (FOV) and contactless inspection. An added benefit of using more than one NDI technique is that it allows for better defect detectability and classification as well as data fusion[1][2]. This paper will show data fusion using the mesh obtained by 3D optical scanning as the backbone to project thermography and shearography data on.

## 2. Principles and methods

Three different systems are used for experiments: a 3D optical light scanner, thermography and shearography. For each system a small description will be given in the text below.

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The ATOS5 system is a blue light optical stereo camera which scans three-dimensional objects and converts images to high density point clouds[3]. This allows accurate measurement and capture of the shape and size of the external surface of 3D objects. The resolution and accuracy of the mesh depends on the lenses that are used in the system. Reference markers are put on the object to be able to stitch individual scans together. The same reference markers are visible in the NDI results, allowing the data to be mapped on top of the 3D surface mesh.

Infrared thermography (IRT) is a non-contact NDI method that monitors the heat radiation pattern on the surface of a test part. The IR camera that is used for experiments is a FLIRSC7600 (Cooled MWIR, 640x512 pixels, Noise equivalent temperature difference (NETD) < 25mK, 25 mm lens, 3.4-4.9 µm wavelength). Excitation is done using the Edevis OTVIS 4000 Thermography system (Lock-in) which uses two halogen lamps for optical excitation with a combined power of 4kW. Data analysis is done in the DisplayIMG 7 software[4].

Shearography is an optical method, based on speckle interferometry, for the non-contact measurement of out-of-plane deformations of a material surface. For the experiments the excitation is done using the halogen lamps of the Edevis OTVIS 4000 thermography system. The camera that is used is the ISI-SYS SE2 sensor (2452x2056 pixels, Tamron f=10-24 mm lens, 12 Hz framerate). In total 4 100mW LDA-100-5 laser arrays are used for generating a speckle pattern on the surface.

## 3. Results and discussion

**Radome**

The three aforementioned NDI techniques are applied on a radome of an aircraft. The aircraft flew through a hail storm, resulting into impact damage on the part of the radome. The radome is made of a GFRP external skin with a 1.1 mm thickness and GFRP internal skin of 0.8 mm thickness, in between a Nomex honeycomb core with cell size of about 3 mm and a height of 6.3 mm. The specimen has a size of approximately 450x665x22 mm. First the entire radome is scanned using the ATOS5 scanner with a measuring volume of 320x240x240 mm, resulting in a point spacing of 0.068 mm and an accuracy of about 0.02 mm. The reference markers placed on top of the radome have a size of respectively 3 mm and 6 mm. A total of 61 3D measurements were done to capture the entire specimen, if only the front side is needed a total of 14 scans would be sufficient. Scanning can also be performed with a larger measuring volume of 1000x750x750 mm, requiring only a single scan of a couple of seconds with the consequence of losing point spacing and accuracy (0.20 mm point spacing and accuracy of about 0.05mm) The resulting surface mesh is shown in Fig. 1(A), showing dents on the surface. For better visibility of the dents a surface defect map can be constructed as shown in Fig. 1(B). Scaling starts at green at 0.0 mm, dark blue regions have a dent depth of 0.07 mm or above. A total of 11 dents can be seen on the surface.

External data, represented by images, can be mapped on the 3D surface mesh as long as the reference markers are present in the data. In each individual data set 5 markers need to be visible which corresponds to the markers on the 3D model. As a first example 4 standard optical photographs are taken from the radome, each covering ¼ of the area with some overlap. The images can be mapped on top of the 3D mesh, resulting in RGB values for each vertices (x,y,z) as shown in Fig. 1(C). The colour of the radome and the reference markers can now easily be identified.

Only external geometric effects are captured by the 3D scanner, and no information on the damage inside of the skin, skin-honeycomb interface and honeycomb can be extracted from the data. Therefore thermographic and shearographic inspections are also performed on the front side of this specimen, which is the side that would be accessible in a Maintenance Repair and Overhaul (MRO) environment. For the thermographic inspection, the front side of the panel is divided into 4 areas. The FOV of the infrared camera is 365 x 300 mm, resulting in a resolution of 0.58 mm/ pixel. The inspections were done at four different lock-in frequencies: 0.50, 0.20, 0.10 and 0.05 Hz. Fig. 1(D) shows the mapped thermographic phase images at 0.10 Hz. Small difference in greyscale values between the separate images can be seen as straight bands on the model. The reference markers are visible as white spots on the thermographic images which have been used for the mapping of data. Damage in the GFRP skin can be seen as black spots on the image. Not all dents that have been found using 3D scanning show damage inside of the skin. The damage found with the thermography inspection is the cracking of the skin and not all dent locations show this cracking. Cracking of the skin can result in water ingress of the radome and it is therefore an important defect that needs to be found.

Shearographic inspection has also been performed in a similar manner as the thermographic inspection, resulting in roughly the same FOV but with a higher resolution of 0.15 mm/pixel. The unwrapped phase information of the shearographic measurement is exported to an image and the results can be mapped on the surface as shown in Fig. 1(E). For an undamaged radome, a uniform image is expected. This is not the case and multiple damages can be seen on the radome, corresponding to the locations where a dent is visible from the 3D scan. Using shearography the gradient of the out-of-plane deformation under stress induced by the halogen lamps can be detected. This difference in out-of-plane movement is caused by defects that alter the stiffness of the panel. In this case it is probably caused by damage inside of the honeycomb, or a debond between the GFRP skin and the honeycomb.

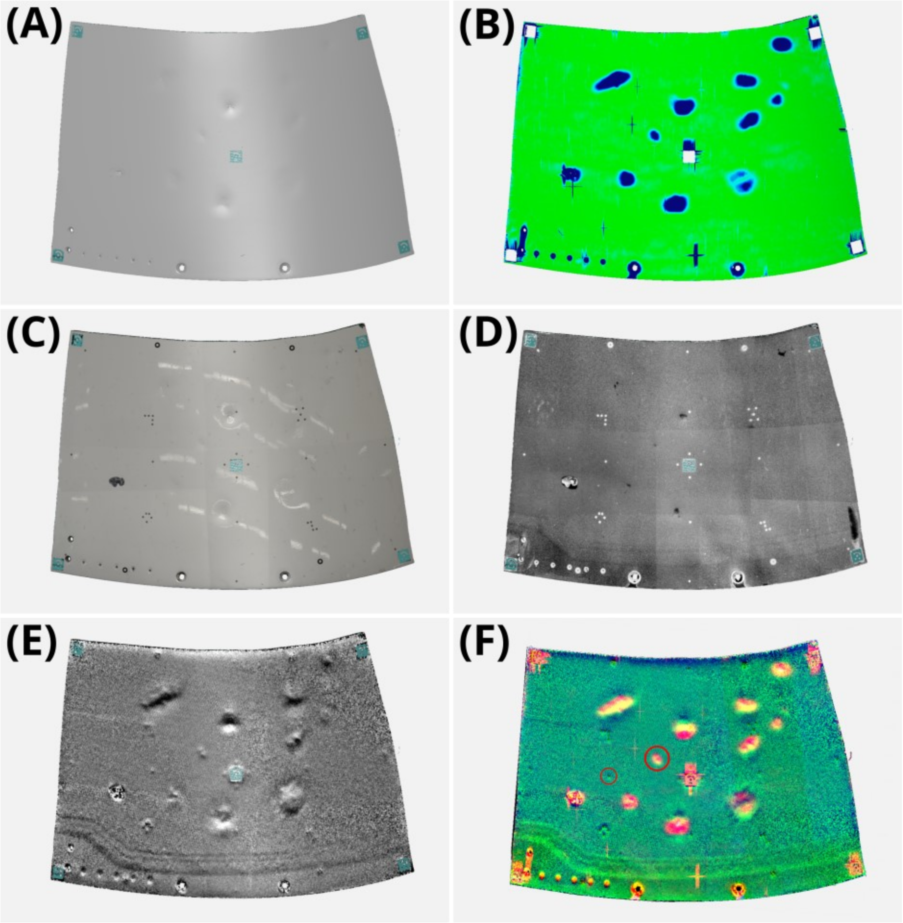

**Fig. 1 Results of the radome (A) Surface mesh, (B) Dent map, (C) Mapped photographs, (D) IRT 0.200 Hz, (E) Shearography, (F) Fusion of data, red channel dent map, green channel shearography, blue channel IRT 0.200 Hz**

A major advantage of mapping the data on the 3D mesh is that the results of the different NDI methods can be easily compared. For example, the depth and location of a dent can be extracted from the 3D scan, while damage inside of the skin can be detected using thermography. Shearography can then be used to detect damage in the skin, skin to honeycomb core disbond as well as damage inside of the honeycomb. If there is no indication in the thermographic data, but there is an indication in the shearography data, damage in the skin can be excluded. This shows the strength of having the same data at the same location.

All NDI data is mapped on the same surface mesh allowing for data fusion and a compiled image. Fig. 1(F) shows the data in a compiled image, where the surface dent map is expressed in the red channel, shearographic data in the green channel and the thermographic data at 0.20 Hz in the blue channel. When there is a defect in all data types the area will be white. This can be seen in some of the dents in the centre, where there is also damage in the skin which is detected by thermography. Areas that are yellow contain a defect in both the surface defect map and the shearographic data.

Using images produced by data fusion for NDI makes the classification of defects easier as certain indications will be visible in one technique and invisible in another. For example, using this technique the reference markers that produce a signal in the thermographic and shearographic inspection can be filtered out since they do not appear in the defect map. And, while the response in the shearographic data between a small dent and a reference marker can be difficult to distinguish. In the fused image, the reference marker is immediately identifiable as it appears green while the small dents appear red and yellow (see red circles in the image),

**Flap 747-400**

To demonstrate the same procedure on a larger scale a flap of 747-400 was scanned with the aforementioned NDI techniques. The right hand inboard aft flap is used measuring about 8.6 m by 1 m by 0.21 m. This is larger than 3 standard measuring volumes of the ATOS 5 with the measuring volume of 1000 mm, so photogrammetry is necessary to capture the reference markers beforehand to enable the accuracy of 0.05 mm for the entire flap. The reference markers are placed on the flap in such a way that the pattern can be used for the thermographic and shearographic inspections.

3D scanning was done manually by moving the camera on a tripod. A total of 206 scans were necessary to capture the entire flap including all the hinges that are present. Scanning of the hinges requires a lot of measurements due to the structure of a hinges. When looking at the hinges from a specific direction only a small part can be scanned, requiring a lot of scans. If only the front and the backside of the flap needs to be scanned this can be done in about 70 measurements.

After 3D scanning of the flap visual photographs are taken with a normal camera to be able to visualise the paint system and possible contamination. The FOV of the visual photographs were taken larger than the inspection for thermography and shearography. A total of 18 visual photographs were taken.

The IRT inspections were done on multiple frequencies, to be able to capture all details of the flap. A total of 9 different frequencies were used: 0.005, 0.010, 0.050, 0.100, 0.200, 0.300, 0.500, 1.000 and 1.500 Hz. The highest frequencies have the least amount of penetration power, resulting in information from the sub-surface. At lower frequencies details of the underlying structure can be observed. The FOV of the inspection are is 825 x 660 mm, resulting in a resolution of 1.29 mm/pixel. A total of 58 scans (29 for each side) where done to capture the entire flap, resulting in 522 thermographic phase images.
The shearographic inspection were done at two different shear directions, one vertical and one horizontal giving information about the gradient of surface deformation in both directions. A total of 50 measurement areas were taken at both shear vectors, resulting in 100 images for the shearography measurement.

Additionally, a part of the flap was also scanned by traditional ultrasonic C-scanning in squirter pulse-echo mode using a single transducer of 19 mm with a nominal frequency of 5 MHz. All data from all experiments have been mapped on top of the 3D mesh, resulting in a single file containing all the inspection data. Results from the bottom side of the flap are partially shown in Fig. 2.

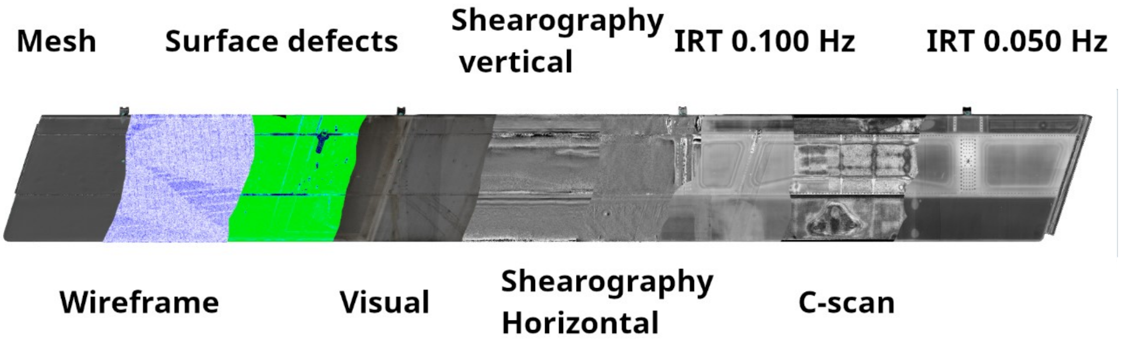

*Fig. 2 Results of the mapped data of the 747-400 flap showing the bottom side. From left to right, mesh, wireframe, surface defects, visual images, shearography vertical, shearography horizontal, IRT 0.100 Hz, C-scan and IRT 0.050Hz*

The data shown in Fig. 2 is ideally suited for a digital twin in which all data of a component can be stored. More details on the mapping procedure and the results will be published in a technical report[5].

## 4. Conclusions

Using 3D optical scanning, thermography and shearography a part of radome containing hail damage has been investigated. Using reference markers the data from the thermography and shearography inspections can be mapped on the 3D mesh, allowing for better defect classification using data fusion. Besides thermography and shearography, most NDI techniques can be mapped on top of the surface, as long as the reference markers are present within the data. To show scalability of the process, results are also shown of a 747-400 inboard aft flap.

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## References

[1] BCF de Oliveira, P Nienheysen, CR Baldo, AA Conçalves Jr, RH Schmitt, "Improved impact damage characterisaiton in CFRP samples using the fusion of optical lock-in thermography and optical square-pulse shearography images", NDT&E International 111 (2020) 102215

[2] D Balageas, X Maldague, D Burleigh, VP Vavilov, B Oswald-Tranta, JM Roche, C Pradere, GM Carlomagno," Thermal (IR) and Other NDT Techniques for Improved Material Inspection", J Nondestruct Eval 35:18, 2016

[3] https://www.gom.com/en/products/high-precision-3d-metrology/atos-5, 06-02-2023

[4] https://www.edevis.com/en/, 06-02-2023

[5] HP Jansen, AF Bosch, DJ Platenkamp," Multi-domain contactless NDI approach: Data fusion of structural light scanning with thermography and shearography", NLR-TP-2022-021, The NLR Reports Repository, https://reports.nlr.nl