17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

An Quantitative Evaluation of the Canadian Forces New Radiology Inspection Systems for the Detection of Water Ingress in CF188 Flight Control Surfaces

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Abstract

Canadian Forces (CF) CF188 Hornet aircraft have been plagued with water ingress and related damage in their composite flight control surfaces (FCS). Water ingress can cause structural degradation including corrosion, delamination and disbond.

Two different radiology inspection systems were recently acquired by the CF. A new Neutron Radioscopy system and an X-ray Computed Radiography (CR) system underwent evaluation for detecting water ingress in the composite FCS of the CF188.

A Probability of Detection (POD) study revealed that the new neutron radioscopy system has an $a_{90/95}$ value of 4.65 μL for water detection. Furthermore, the X-ray CR system demonstrated sensitivity similar to conventional X-ray film radiography; its $a_{90/95}$ value for water detection is 20.55 μL. The image plate from the CR system was also used in conjunction with a conversion screen for neutron radiography and was able to identify water defects in the FCS.

Keywords: Neutron Radioscopy, Computed Radiography, Probability of Detection, Canada

1. Introduction

Water ingress is considered to be the origin of damages such as corrosion, delamination and disbond in the omposite flight control surfaces (FCS), and has been found in the CF188; hence, water ingress detection is of foremost importance to aircraft structural integrity.

The CF possesses different Non-Destructive Testing (NDT) inspections such as neutron radiology[1] (which includes neutron radiography and neutron radioscopy), X-radiography, Infrared (IR) thermography and Ultrasonic testing for water damage detection. These techniques have indicated various types and stages of failure in the graphite/epoxy skin and aluminum honeycomb core of the flight controls. Some of these systems had been evaluated for their Probability of Detection (POD) of water ingress.

Two new NDT inspection systems were recently acquired by the CF. A new Neutron Radioscopy system was installed at the Royal Military College (RMC) of Canada and a Computed Radiography (CR) system was purchased by the Aerospace and Telecommunication Engineering Support Squadron (ATESS). A methodical study of the two new systems was carried out using the "R" program which is associated with the Nondestructive Evaluation System Reliability Assessment Handbook (MIL-HDBK-1823). The purpose of this study was to generate POD data to assess the systems reliabilities for detecting water ingress in flight control surfaces. Furthermore, a first attempt at using CR with Neutron Radiography was carried out.

2. Neutron Radiology

The CF Neutron Radiology Facility (NRF) at RMC carries out both neutron radiography (film-based) and neutron radioscopy (Charged Coupled Device (CCD)). Neutron radiology is considered to be a complementary NDT technique to conventional X-radiography. Unlike X-radiography, which interacts mainly with orbital electrons of atoms, neutron matter interaction occurs with the atomic nuclei. While X-radiography attenuation increases uniformly with mass numbers and densities, neutron attenuation does not follow any fixed pattern. Certain light elements, i.e. hydrogen or boron attenuate neutrons very well.

The NRF uses a Safe LOw Power c(K)ritical Experiment (SLOWPOKE-2) nuclear reactor to generate a neutron flux of 2 to 3 x 10^4 n cm^{-2} s^{-1} at the image plane[2]. A conversion screen is required for radiography and a scintillation screen for radioscopy. The conversion screen absorbs neutrons and emits a conversion electron which exposes the film for radiography. For radioscopy, a scintillation screen converts ionizing radiation directly into light and a CCD camera is used for image acquisition.

The new radioscopy system[3] was installed to replace the old system with an Apogee AP7 CCD. This system utilizes a new scintillation screen, enhanced CCD, lens and imaging software. The new scintillation screen has a 2:1 mixture of ZnS/Li^6F that is 0.1mm thick x 400mm x 400mm. The new camera is an ANDOR 436-BV, back-illuminated CCD capable of performing real time image capture in low light environments. Table 1 compares the new and existing systems.

CHARACTERISTICS	ANDOR 436-BV	Apogee AP7
Active Pixels	2048 x 2048	512 x 512
Pixel Size (μm)	13.5 x 13.5	24 x 24
Pixel Well Depth (electrons)	100,000	296,000
Peak Quantum Efficiency	95%	95%
Min Operating Temp, Thermoelectric (TE) Cooling	- 60°C	-30°C
Dark Current @ - 60°C (Andor) / -33°C (Apogee) (electrons/pixel/second)	0.0005	0.8

Table 1: RMC Neutron Radioscopy System Cameras Comparison.

The ANDOR 436-BV has a smaller pixel size which provides enhanced resolution. The image area is larger which is preferred given our application involves imaging large components. The most significant advantage of this CCD is that it can be cooled down much lower than the old system, which helps to decrease dark current. Dark current, measured in (electrons/pixel/sec), is a measure of the current that accumulates on a pixel in the absence of light; it is. The ANDOR camera achieves low temperature cooling through the use of a thermoelectric three-stage Peltier cooler. Although the camera specifications indicate that a minimum temperature of -75^0C can be achieved, this level of cooling is not always possible depending on room temperature. Therefore, a minimum operating temperature of -60^0C was chosen for practical reasons for all image acquisitions. Furthermore, the new system has a Nikkor 50 mm f1.4 lens with a Tamron 70 mm f1.4 converter. The f1.4 lens is one of the brightest models available on the market, which is advantageous since it reduces exposure times. The image acquisition software is the "SOLIS I", developed by ANDOR; image processing was performed using "Image J".

3. Computed Radiography

Computer Radiography (CR) differs from conventional radiography in that CR uses a flexible, reusable, photostimulable phosphorous image plate (IP) instead of film to capture an image. The use of CR eliminates the need for film, processor, developer, hazmat disposal and dark room. The Kodak Industrex ACR-2000i was used for this study. It is considered to be a mobile system with full DICONDE compliance. DICONDE is the ASTM E2339 standard which facilitates the interoperability of NDE imaging and data acquisition equipment by specifying the image data file format. This system uses the Kodak Industrex Flex HR or GP IP. The IP is comprised of the phosphor, overcoat and backing layers.

4. Experimental Design

The POD study requires a coupon with known defect sizes (1/2" thick x 12" x 7" aluminum honeycomb with a removable top surface). The aluminum honeycomb coupon used was manufactured to represent the CF188 FCS. Water of various amounts was pipetted into individual honeycomb cells to simulate water ingress. In order to select appropriate defect sizes for the POD trials, the sensitivity of the systems had to be known first. Thus, sensitivity tests were carried out to determine the detectable limits and to allow system parameters settings. Subsequently, appropriate defect sizes were used to generate POD data. For each trial, a total of at least 60 defects and at least three times as many non-defect locations were used.

4.1 New Neutron Radioscopy System

For Neutron Radioscopy, a bellows was used to produce a light tight area between the scintillation screen and CCD camera. The exposure time was determined by varying the time for optimal resolution and contrast. Once the inspection parameters and approximate sensitivities were determined, water defect volumes were chosen for the POD trial.

4.2 X-ray Computed Radiography

The Kodak Industrex Flex GP image plate[1] was used. Previous X-ray evaluation on composites[4] were carried out with approximate settings of 60kV, 5mA, and 60s exposure. It is known that the use of CR reduces exposure time; thus the first tests were conducted to determine the inspection settings for CR. Once the X-ray system parameters were optimized, the POD assessments were carried out with appropriate defect sizes.

4.3 Computed Neutron Radiography

Lastly, a combination of the two systems was evaluated, Computed Neutron Radiography. The direct (short half-life) conversion was coupled with the CR Image Plate (IP). A simple test was carried out to examine the feasibility of coupling the conversion screen with the IP to acquire an image. For this trial, a different coupon, 12" x 12" x 2" honeycomb (Fig.1), with known defects was used. Two exposures, 5 and 20 min, were carried out with neutron radiography.

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[1] Kodak Industrex Flex GP serial number SO-170 2319004026CI9977

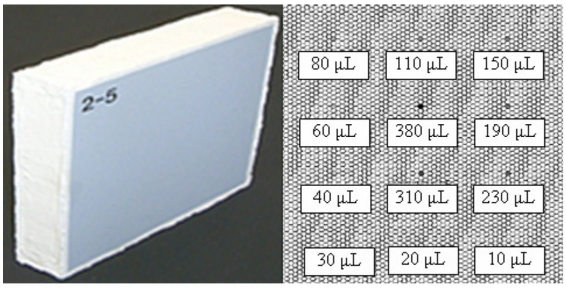

Figure 1: Coupon used for Computed Neutron Radiography trials.

5. Experimental Results and Discussions

Once the images were generated, the inspector used a binary code to display results in which a "Hit" – defect found, is represented by 1 and "Miss" – not found, was denoted 0. The Hit/Miss data was then imported into the "R" program. The Logit model was applied to the Hit/Miss data, and the Loglikelihood Ratio method was used to construct confidence bounds.

5.1 New Neutron Radioscopy System

The "R" program generated an $a_{90/95}$ value of 4.65µL for the new neutron radioscopy system. The exposure time was reduced to two minutes or half of the previous system for similar image quality. Moreover, the number of false calls was one fifth that of the previous system.

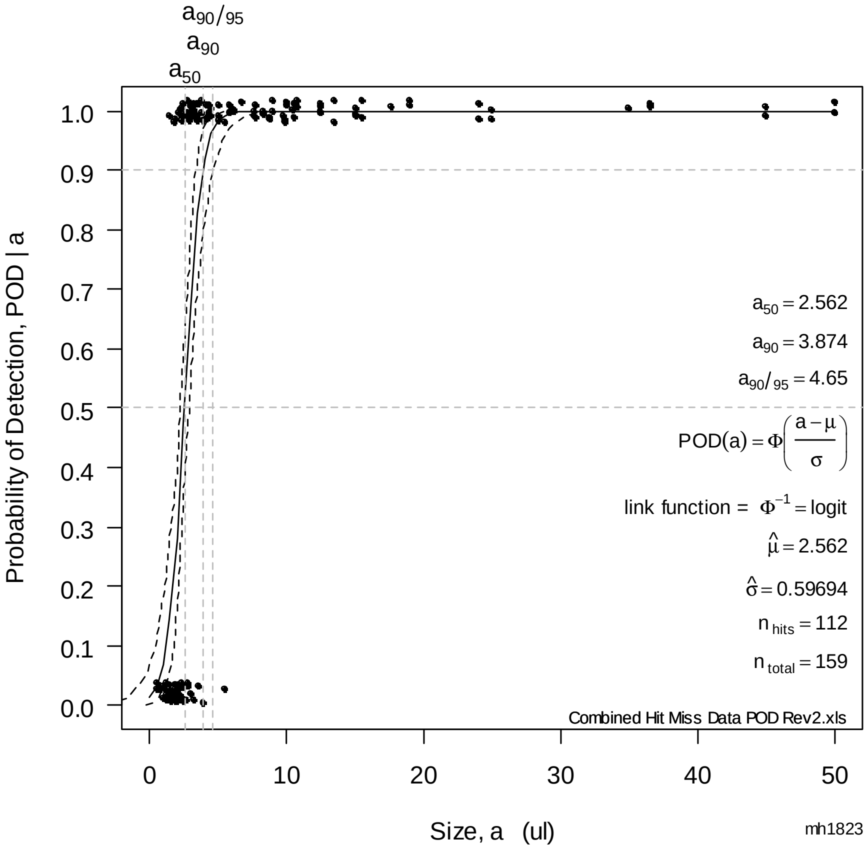

Figure 2: POD curve generated from "R" for the new Neutron Radioscopy system for water ingress detection in flight control surfaces.

5.2 X-ray Computed Radiography

The X-ray CR was carried out at 5mA, 40kV, 20s instead of 60kV and 70s. The use of CR shortened the exposure time which is a great advantage especially in a medical capacity. Overall, the "R" program (Fig.3) generated an $a_{90/95}$ value of 20.55 μL for X-ray with the Kodak system. Furthermore, 1 false call was reported. A comparison of the two systems is illustrated in Fig.4.

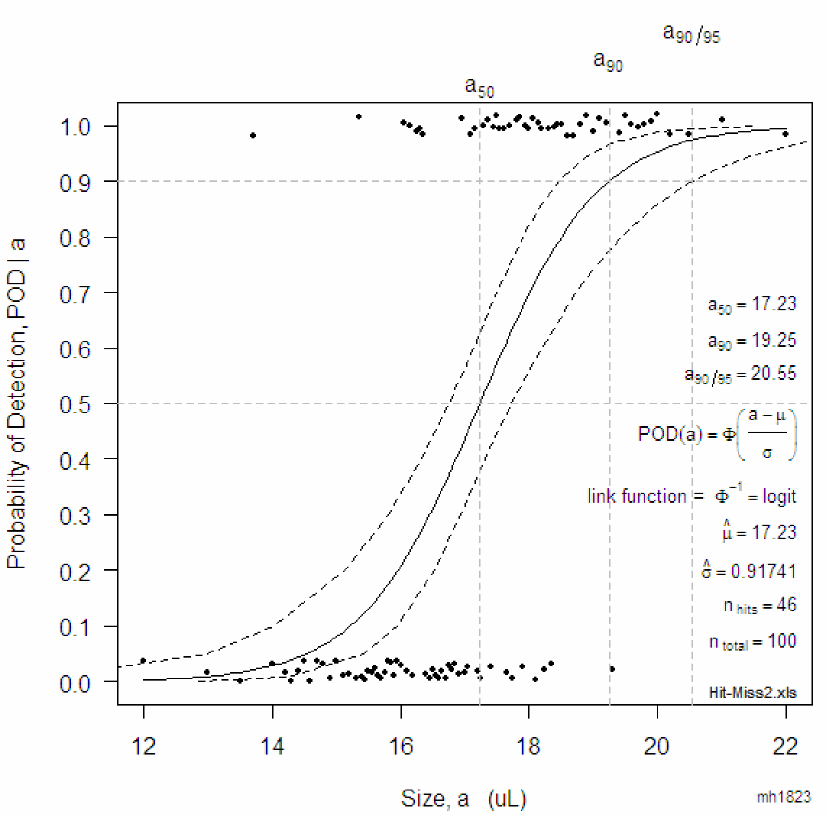

Figure 3: POD curve generated from "R" for the X-ray inspection with Computed Radiography system for water ingress detection in flight control surfaces.

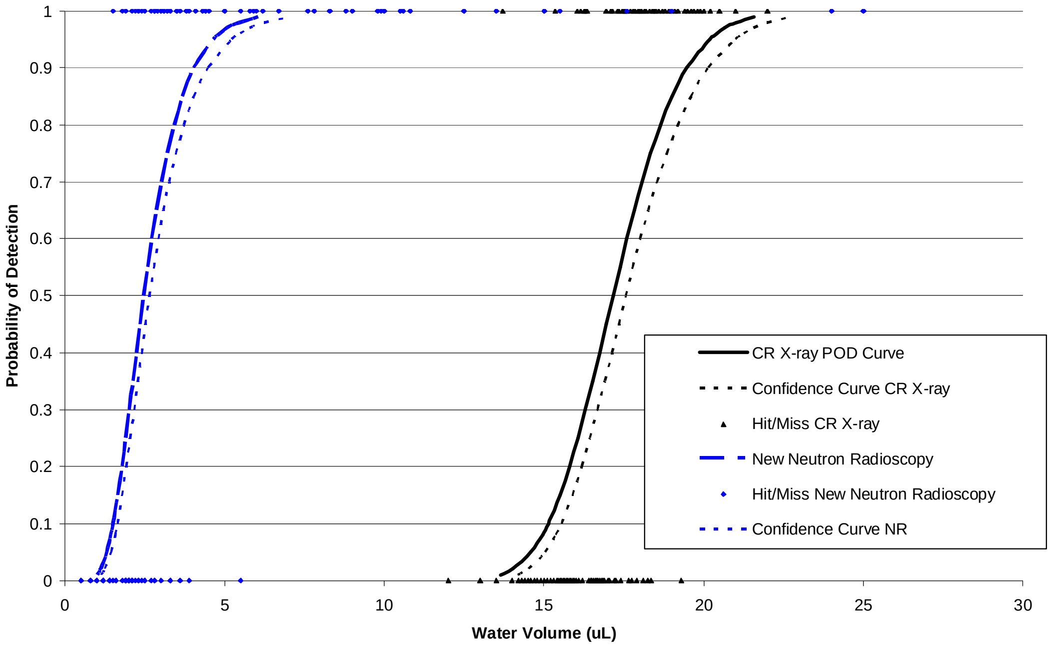

Figure 4: POD curves comparison of the new Neutron Radioscopy system and the CR system with X-ray.

Fig.4 can be used to qualitatively compare the new Neutron Radioscopy system and X-ray CR. Since the "R" program is unable to generate multiple curves on the same graph, a different program which provided very similar $a_{90/95}$ values was used; however, only $a_{90/95}$ generated from "R" are considered statistically accurate. The new Neutron Radioscopy system displayed a steeper POD curve which suggests that the detectability threshold is more defined. And in comparison, the reliability is far better than that of X-ray CR. The X-ray CR POD curve is more gradual which suggests that detection threshold is ambiguous.

5.3 Computed Neutron Radiography

The coupling of the conversion screen and the IP was able to locate water defects images using neutron radiography very effectively. Fig.5 shows that water defect as low as 30µL were detected when using the IP with neutrons. However, previous study[4] had shown that Neutron Radiography was able to detect amounts as low as 20µL. Two trials of 5 and 25 min were carried out and it showed that longer exposure time did not provide a better image.

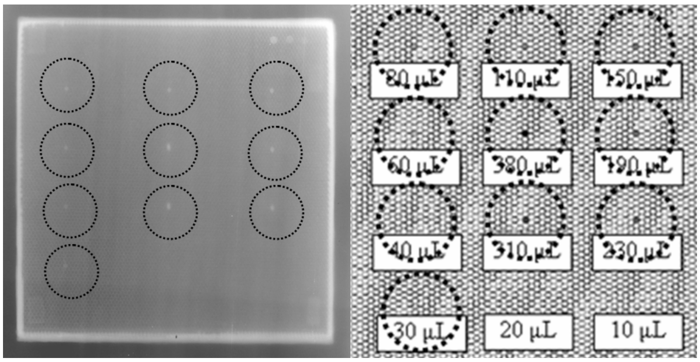

Figure 5: Computed Neutron Radiography. Water amount of 30µL was detected.

6. Conclusion

The new Neutron Radioscopy system at RMC was determined to be superior for water ingress detection than the existing system with an $a_{90/95}$ of 4.65µL which was almost as reliable as the Penn State neutron radioscopy system, and was better than the CF NRF Neutron Radiography.

The X-ray Computed Radiography tests showed that the exposure time required was much less than that of conventional X-ray. Furthermore, the POD tests revealed that the CR system had an $a_{90/95}$ of 20.55µL, slight improvement over conventional radiography, for water ingress detection in flight control surfaces.

Lastly, by coupling the conversion screen and phosphorous IP, it was demonstrated that Computed Neutron Radiography was possible for the detection of water ingress; and that it exhibited similar sensitivity and required a much shorter exposure than neutron radiography. However, more analysis is required to determine the exact sensitivity and exposure requirement.

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