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# A New Computational Imaging Method for the Remote Detection and Quantification of Hidden Corrosion

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## Introduction

Corrosion in aluminium structures is largely calendar driven and is an increasing problem in our ageing air transport fleet where a structure weakened by metal loss in a pressurised cabin situation, could potentially threaten the safety of the aircraft. Currently there are aircraft in regular service that are over thirty years old. An example of this is the US fleet of KC135 Tanker aircraft, which are actually the old Boeing 707's with a future service life projected to be another 35 years. Corrosion occurs in a variety of places in aircraft particularly with lap joints that run the length of the fuselage. In passenger aircraft the galley and lavatory areas are an additional problem.

Methods for detection of hidden corrosion do exist or are currently being developed. However, these systems can be both slow and lack the ability to quantify the total metal losses in a joint. Many of these are based upon high frequency ultrasound and pulsed eddy current which only detects to the first layer[1]. Other optically based methods include D-Sight which relies upon the presence of jacking in order to detect the defect[2]. Quantification does present problems. A well-published method undergoing development is Thermal Wave Imaging, which does hold considerable hope for a solution to the question of quantification. In a laboratory based experiment it has quantified corrosion at a 2.5% level of metal loss but this was achieved on a single layer of metal. Additionally, as disclosed in the Spring 1998 ASNT[3] Conference, it is necessary to coat the region undergoing inspection with black paint. At the other end of the technology spectrum, neutron radiography has been successfully applied as a detection tool, however, the presence of hydrogenous material such as paint, sealant, or adhesive would result in false measurment[4]. It is an expensive technique and impractical for normal in-service applications Additionally a high level of shielding is also required.

Reliable detection and quantification of metal losses under field conditions does present a difficult situation. Currently, no reliable and practical method exists, although there are considerable efforts now directed towards a solution. This paper presents promising early results in detection and quantification of corrosion in lap joint situations using our Remote Acoustic Impact Doppler (RAID) technology.

## The Remote Acoustic/Doppler Technology

In summary, the RAID[5] technique is based upon the production of a remotely located high intensity air coupled acoustic impulse of extremely short duration which excites the object undergoing NDT. This could be considered analogous to a tap on the surface, except the excitation is now over a large area compared to a localised tap. The resulting relaxation frequencies at the surface are interrogated by a scanning laser Doppler velocimeter on a point by point basis covering the area to be inspected. The time domain signal which results is subsequently processed to a Fast Fourier Transform (FFT) and stored for subsequent analysis. At the analysis stage, the FFT information at each data point is processed by a specially designed in house software package. The resulting data is used to produce a velocity based image which reveals the location and extent of any local changes in the frequency response present in the material under inspection which can be interpreted as a defect or other anomaly[6].

## Application of the RAID technology to corrosion measurement

The RAID technology has been developed under a contract for the Defence Advanced Research Projects Agency (DARPA) and is now at a Phase III level. The original objective of this contract was for a remote large area scan system for the detection of defects in composite materials. Recently, modification of this technology has been demonstrated to have the potential to detect corrosion in lap joints.

In brief, the system operates very much as it does in the field of composites. The effect of the presence of corrosion will affect the local relaxation frequencies. A rather over simplified analogy is a drum surface: The frequency produced by the drum will be the sum total of the boundary conditions, the skin thickness and the tension of the skin. In the case of hidden corrosion the metal skin thickness is a function of the metal losses due to corrosion, the boundary condition will be the extent of the corrosion whilst the tension is a function of the corrosion by product. Aluminium oxide has a lower density and a larger volume than the original metal, thus causing a tension on the surface. The situation is complicated by the fact that corrosion is irregular in area and depth, thus a series of frequencies would cover a typical corroded area. These would be apparent as measurable antinodes in different region of the recorded frequency spectrum. However, in the future design it is intended that measurement of these using a purpose designed software package will eventually provide some form of three dimensional profile of the corroded region.

## Experimental Results

As an initial test, a lap joint corrosion sample, removed from a KC-135 lap joint section, was supplied to us by Tinker Air Logistics Command. Figure 1(a) shows the corroded region after the joint had been destructively tested. Figure 1(b) shows the RAID NDT result when scanned from the front or outside of the panel (Note: all our original results are in colour; different colour representing different velocities). It was a first attempt but does show a very fair representation of the corroded region, where up to 20% metal losses were present. Note: Figure 1(a) has been graphically inverted for ease of comparison with Figure 1(b).

Subsequently, a further complete lap joint was supplied as a blind test in which the system detected corrosion and this was later confirmed by a destructive test. No attempt was made to quantify at this stage of our work. As a result of this test, we made up a lap joint in the laboratory and simulated metal by the removal of metal: 5%, 10%, and 15% respectively. Our in-house developed software analysis program provides what we have termed a "Normalised Selective RMS" function. The algorithm for this software selects only the few recorded FFT frequencies which actually contain data relating to a defect condition and rejects the remainder. This method reduces noise which would otherwise swamp the defect information. The result is illustrated in Figure 2. This result clearly shows all three regions of simulated corrosion spots overlaid on a CCD record of the lap joint sample.

From the data contained in the rich data set on the computer record of the scan, we extracted the FFT spectrum of each data point of the primary antinodes in each of the fault regions. What is to be noted here is that the peak response for each of the different defects is in an entirely different region of the vibration spectrum and relates directly to the metal thinning in that region. Figure 3a shows a normal (non-corroded) response and b and c shows two of the FFT spectra clearly illustrating the peaks due to the corrosion.

Figure 4 is a plot of the metal loss condition against the resulting frequency. It conforms to the equation for membrane resonant frequency, $w_n$, given by[7]:

$$w_n = B\sqrt{\frac{Et^2}{r\,a^4(1-v^2)}}$$

where $B$ is a variable dependent upon the shape of flaw and edge conditions, $E$ is the Young's modulus, $t$ is the thickness of plate, $r$ is the mass density, $a$ is the dimension of plate, and $v$ is the Poisson's ratio.

This various aspects of this work and the RAID technology work is also describe in patents granted[8,9,&10] and others pending.

## Conclusion

In the application of this technology to detection of corrosion and the quantification of the resulting metal losses, the situation is complicated by the make –up of various types of lab joint. Some contain resign bonding together with the normal three lines of rivets. In some cases where the metal has not been originally drilled true, there are benign conditions where one layer of the skin is not in absolute contact with the other skin. A further complication is the skin stress generated of the presence of the corrosion product. These will all effect the resulting relaxation frequencies exhibited by the skin surface. However, these can be used to identify the subsurface condition. One objective of this research will be to ensure that the computational algorithm must account for these situations.

Although these are preliminary results, we feel that there is sufficient evidence to warrant sponsoring further investigation and research. We suggest that this new technology does offer the possibility of a rapid computational method of quantifying corrosion as well as defining the corrosion profile using the secondary antinode information contained in the rich data set recorded. Furthermore this system requires no physical contact with the surface undergoing test; in fact it has been demonstrated to operate at a stand off distance of several meters [5].

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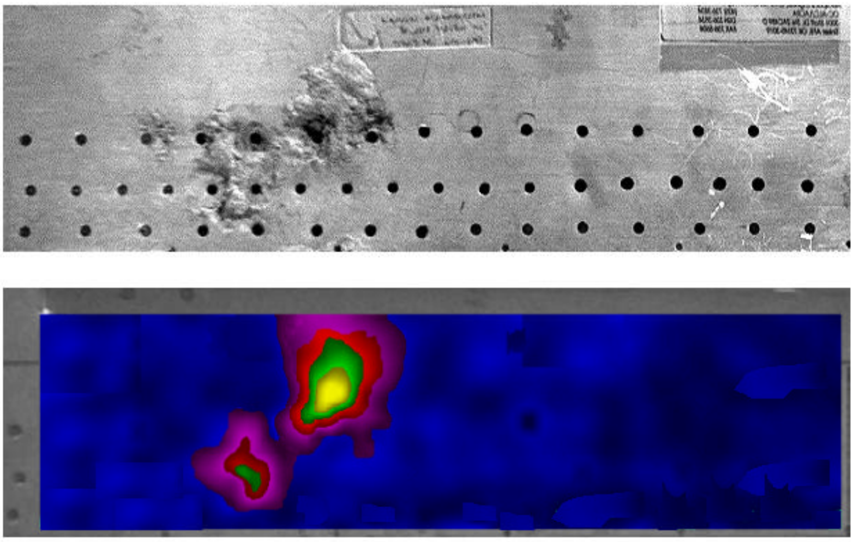

**Figure 1: (a) Record of the corroded region, captured from a lap joint panel after destructive inspection. This image was then inverted for ease of comparison with the NDT result. (b) Result of the RAID Doppler scan performed on the exterior of the panel.**

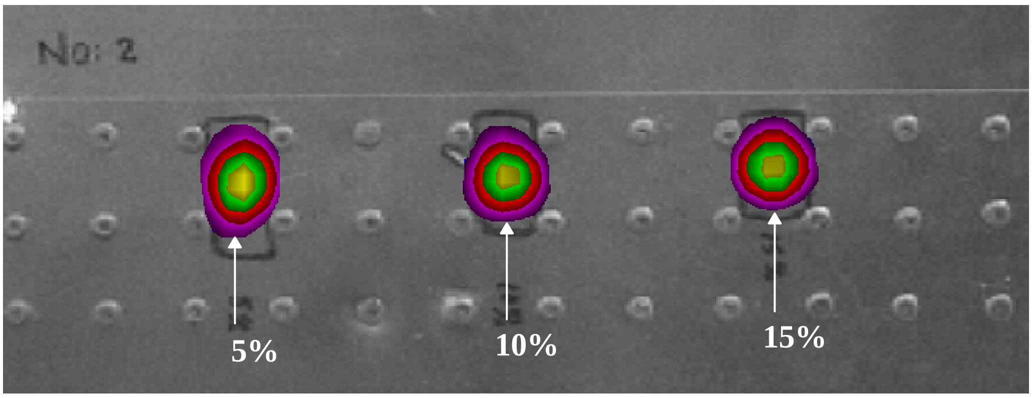


**Figure 2: Lab joint panel manufactured with 5%, 10% and 15% metal thinning. Note: all three regions are clearly revealed.**

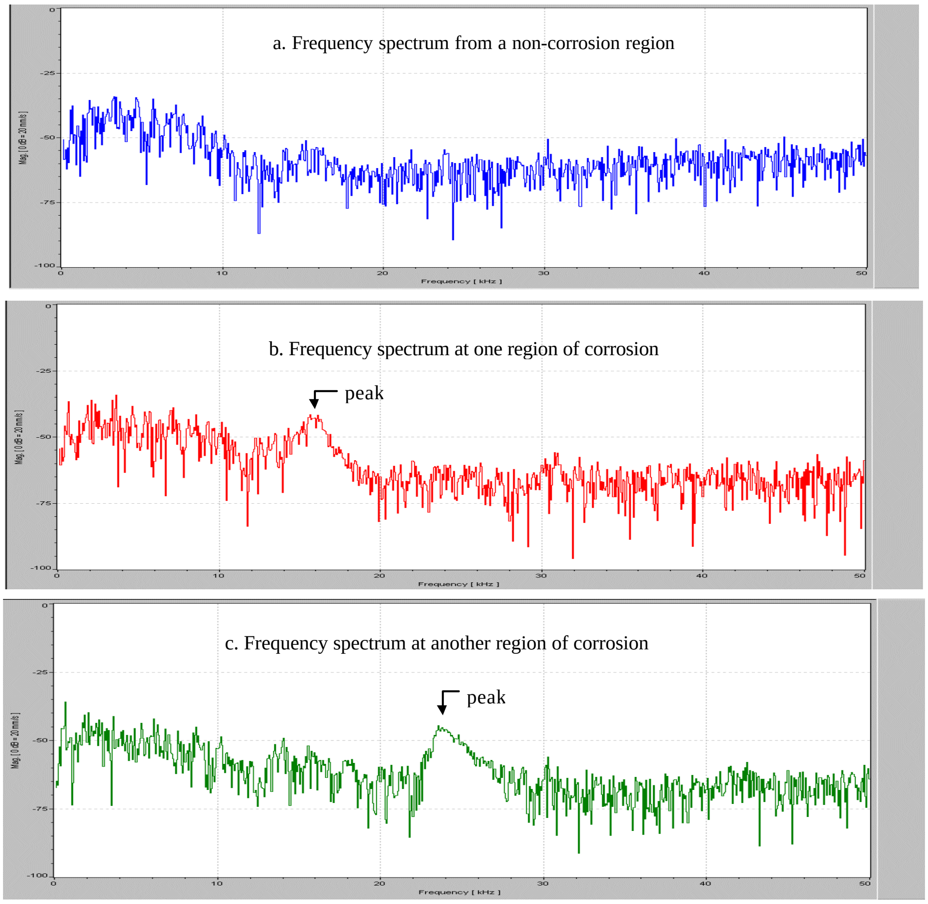


**Figure 3: Comparison of frequency spectrums at corrosion and non-corrosion regions**

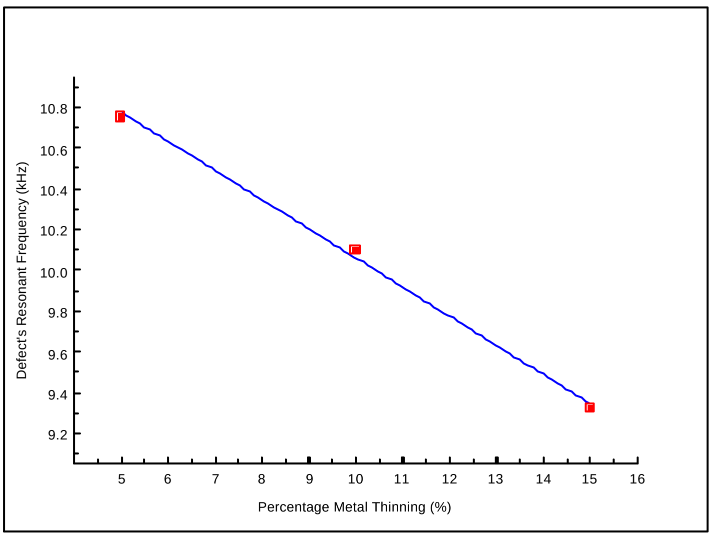


**Figure 4: Graph of metal thinning against resonant frequency for the results in figure 2**