4aEAa6. Detection of defects in aerostructures using non-contact ultrasonic transducers

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This paper describes an investigation into the possibility of using non-contact ultrasonic transducers for detecting defects in aerostructures. Our study deals with an ultrasonic method that underscores the recent advances in non-contact and analytical methodologies. Ultrasonic waves are generated by a transducer connected to a Sonatest DryScan 410D using through-transmission mode. In this investigation, ultrasonic through-transmission signals passing through the aerostructures are analyzed with respect to their amplitudes. We treat this problem experimentally. Various aspects of our approach are presented. The observations reported in this paper deal with defects in aluminium, composite and re-inforced plastic with wood layer structures. Results obtained using non-contact ultrasonic sensors are compared with those obtained by using the Eddy current testing method. The results obtained by both methods are in good agreement, indicating that these techniques can be considered as quantitative nondestructive tools for detecting defects in aerostructures. Results are presented and discussed.
INTRODUCTION

There is always a climate change in the sky which is observed when aircrafts travel. This may lead to some parts of the aircraft being dysfunctional which may later cause disasters and calamities. To overcome such disasters, the components must be periodically inspected for defects. Nondestructive testing (NDT) is one of the most important means to detect, verify and to authenticate the quality of items. When applied during all stages of a product’s life-cycle from design to operation, NDT has always been a central part of quality assurance. Reliable and accurate testing as well as confidence to the test results must be provided by NDT techniques.

With increasing use of composite materials in critical structural applications, it is essential to independently assure structural integrity. Complexity of the advanced composite materials including layered and bonded structures represents challenges in the development of optimized ultrasonic testing techniques. Conventional ultrasonic NDT methods are sometimes inappropriate and may mislead when applied to anisotropic and non-homogeneous composite materials. In advanced technology applications such as aerospace, it is critical to develop robust and practical NDT methods.

Most aircraft parts cannot be inspected using conventional ultrasonic testing techniques as they use a coupling medium which may penetrate the part and influence its purpose. To overcome this limitation, non-contact ultrasonic testing offers new possibilities. Examples of non-contact testing include the use of EMAT’s, laser and air-coupled transducers. The non-contact techniques were proposed decades ago but were not practiced as a result of inadequate equipment. Today, improved transducer design and electronics allow non-contact measurements to be made with sufficient signal-to-noise-ratio.

Non-contact ultrasonic testing has advanced from being laboratory work and became applicable in situ. This technique is now in a stage where it is applicable during manufacturing. Enormous efforts have been made by ultrasonic testing equipment manufacturers to improve the quality of transducers so that they become sensitive enough to transmit ultrasound without any contact. The new devices are classical piezo-transducers in which a combination of transitional layers and final matching layer is applied on the piezo-electric element in order to improve the transfer of energy. As there is no couplant to damp the surface vibrations, non-contact (air coupled) testing may result in the production of Lamb or Plate waves when the transducers are placed on the same side of the curved material under test.

Applications of this technique include wood, re-inforced plastic, aluminium, composites, foams and missile propellants. A variety of frequencies (less that 1 MHz) may be employed resulting in better resolution and penetration as with conventional ultrasonic testing techniques. With appropriate equipment, sensitive inspections for defects may be performed.

DRYSCAN TECHNIQUE

When sound passes across an interface between two materials, a portion of the sound is transmitted into the second material while the rest of the sound is reflected. The amount of energy transmitted depends on how close the acoustic impedance of the materials matches. If sound has to propagate between air and a test piece, less amount of energy will be transmitted because air has very low acoustic impedance.

In non-contact ultrasonic testing, probe movements can be tolerated without coupling the transmitter. One way of achieving this is through the use of the Dryscan 410D. This is also known as the shadow technique. The system is highly reliable for flaw detection and geometric considerations applied to traditional ultrasonic tests can now be ignored. The software in this flaw detector is very user-friendly in such a way that one can operate without being trained on it, as long as the operator is familiar with the concept of non-contact ultrasound.

The shadow technique is mainly used for inspection of high technology materials that are used in the aviation and aerospace industries. These materials are not suitable for inspection by conventional NDT methods. Shadow technique may be employed in the through-transmission mode where the signal passes directly through the material from the transmitter to the receiver. Through-transmission is a technique that utilises two transducers. One transducer acts as a transmitter and the other as a receiver. These transducers are placed on opposite sides of the component and should be aligned. The technique is also known as the obscuration technique because it measures total attenuation within the material as a result of imperfections that obscure the beam. The transmission ratio of the incident wave on the interface of two media is given by

\[
T = \frac{2\rho_2 c_2}{\rho_1 c_1 + \rho_2 c_2} = \frac{2\eta_2}{\eta_1 + \eta_2}
\]
where $\rho_1$ and $\rho_2$ are densities of media 1 and 2 respectively, $c_1$ and $c_2$ are the velocities in media 1 and 2 respectively and $\eta$ is the acoustic impedance.

The ultrasonic energy is coupled between the transducers and the material under inspection through the use of special plastic pads on the transducers, eliminating the need for a coupling medium. Roller type transducers for continuous pass scanning may be used. These transducers result in an improved near-surface resolution.

The transmitted ultrasonic pulse is a short burst, wideband signal with very little damping creating a characteristic signal envelope. The received signals in this technique produce a typical pattern in which the first group contains from 7-10 cycles and must reach full scale with a specified dB value for the structure to be good. In this way, the waveform patterns look normal. If there is a sudden change in intensity or amplitude between adjacent cycles, it is an indication of defective parts. Defects normal to the direction of sound transmission will interrupt resulting in very low levels of transmitted sound.

When the material is good, the sound passes through with minimal attenuation. Defects in alignment with the direction of sound will not interrupt the sound very much resulting in very little sound interruption or no attenuation of the received sound. Good area gives a high level of sound transmission.

**AEROSPACE STRUCTURES**

Most aircraft structures are unidirectional and made of light materials. This means that one dimension, being the length, is much longer than the others, that is, width or height. Unidirectional materials consist of thin, relatively flexible long fibres which are very strong in tension. Such materials include wood, re-inforced plastic, aluminium and composites. These materials are considered because of their lightness and toughness. The lighter the aircraft is, the less power is needed for it to take off the ground. Besides the properties of these materials, their cost also plays a significant role.

Below are figures of the aircraft parts that will be inspected.

![Aircraft Part](image1)

(a)

![Aircraft Part](image2)

(b)

**FIGURE 1.** (a) Glass fibre re-inforced plastic with (b) a wooden layer
EXPERIMENTAL SETUP

Three aircraft components made of aluminium, composite and re-inforced plastic with wood are inspected for defects. Two roller probes are connected to the Sonatest Dryscan 410D flaw detector to make the mode of operation to be through-transmission. The manipulation system is manual and the probes are setup for continuous pass scanning. The probes are placed on opposite sides of the components under test as shown in Figure 3. The operating frequency of the system is 280 kHz.
Ultrasound is transmitted into the component by the transmitter. The sound propagates through the component and is received at the other side by the receiving transducer. The amount of energy received depends on whether the component is homogeneous or has imperfections. This experiment is done on all the three aircraft components shown in Figures 1, 2 and 3.

The probes are first scanned on a homogeneous region of the component. The amplitude of the resulting signal on the screen of the flaw detector is noted. The probes are then moved over to where there is an imperfection. As they approach the imperfection, we also take note of what is appearing on the screen of the flaw detector. When the probes are completely over the imperfection, the results are also noted. This procedure is carried out on all components.

RESULTS AND DISCUSSION

Wheel Axle (Aluminium)

The wheel axle is tested first and only one defect is detected. The figures below show the results obtained when scanning the wheel axle.
As the probes are moved over a homogeneous region of the component, there is little attenuation taking place in the component. This results in signals of high amplitude observed on the screen of the flaw detector. As the probes start to approach an imperfect region, we notice that the amplitude of the received signal starts to reduce. When the probes are completely over the region with imperfections, the amplitude of the received signal reduces further. The reduction in amplitude of the signals is due to a lot of energy being absorbed by the imperfection.

**Re-inforced plastic with wood layer component**

The plastic-wood component is also tested. Two defects are located and only one is presented. When the probes are moved over an area without imperfections, less energy is absorbed. As a result, signals with high amplitudes are obtained on the screen of the flaw detector. Greater attenuation occurs when the probes are scanned over areas with imperfections. This is proven by the reduction in amplitude of the signal obtained. Below are the figures that show the results obtained when scanning the re-inforced plastic/wood component.
When testing the composite structure, three defects were found but only one is presented. The figures below are of the results obtained.

**Composite**

FIGURE 7. (a) Signal obtained when the probes are over a homogeneous region and (b) signal obtained when probes are over an imperfection.

FIGURE 8. (a) Signal obtained when the probes are over a homogeneous region and (b) signal obtained when probes are over an imperfection.
When the probes are on a defect free area, the amplitudes of the signals recorded are high as shown in Figure 8. This amplitude starts to decrease as the probes are approaching a region with defects. Further reduction in signal amplitude occurs when the probes are directly over a defect.

Upon comparison of the results among the three components, the highest level of signal amplitude is that of the composite. Aluminium has the second largest amplitudes of signals while the plastic/wood structure has the lowest. This is so because much attenuation takes place in re-inforced plastic/wood than in composite and aluminium as the grain structures are not closer to each other. The amplitudes of the signals resulting from the defects are further influenced by how large the imperfection is in the component.

CONCLUSION

The objective of this paper is to investigate the possibility of using non-contact ultrasonic transducers for detecting defects in aerostructures. It is very crucial to choose a suitable inspection technique that does not impair the usefulness of a structure under test. It has been observed that as probes are on a homogeneous region, the amplitudes of the signals are high and the other way round when the probes are over defective areas. The results obtained in this investigation correlate well with the known results we obtained by using the Eddy current Testing. This proves that the use of non-contact through-transmission shadow technique can be considered as a quantitative nondestructive tool for detecting defects in aerostructures where traditional ultrasonic techniques are inappropriate. This technique may be employed during manufacturing and also when the components are in-service.

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