INSPECTION OF THE LOWER HALF OF WING LAP JOINTS WITH EMATS

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ABSTRACT

Detection of fatigue cracks at the fastener holes in the lower portion of the C5A wing lap joint is complicated by lack of a direct line of access, and by the presence of fasteners and sealant material. Furthermore, any successful detection procedure must take into account the wide variation in the geometrical features of the joint. In this work, periodic permanent magnet EMATs (electromagnetic-acoustic transducers) have been employed to excite the n=0 horizontally polarized shear mode of the skin at 200 kHz and 250 kHz. These modes are partially transmitted into the overlap region joined by the fastener. Spectral analysis of suitably time gated and apodized portions of the reflected waveform have allowed simulated cracks growing out of fastener holes to be detected, and preliminary sizing algorithms have been developed.

SUMMARY

A major problem in aircraft maintenance is the detection of cracks growing from fastener holes in wing lap joints. As shown in Fig. 1, the problem is particularly difficult in the lower half of the joint, where direct measurement is obscured by intervening metallic and sealant layers. The former is opaque to all but low frequency eddy currents, whereas the latter has a variable, and often high, attenuation for ultrasonic waves in the MHz frequency range.

**Fig. 1** The problem: to detect cracks in lower plate of wing lap joint.

The work described herein, funded by AFML and DARPA, includes a completed study performed in 1978 (Ref. 1) and a new study in progress. The 1978 study was done largely with an unassembled mockup of the lower half of the joint. It contained 18 fastener holes, 12 of which were usable for experimental purposes. Four of the holes had a 0.010" wide saw slot of lengths 0.030", 0.11", 0.20", and 0.26", emanating from the hole perpendicular to the lap joint towards the edge of member B of Fig. 1.

Figure 2 illustrates the approach. The waves were injected into the lap joint region by a coupling free, EMAT (electromagnetic-acoustic transducer) operating at 250 kHz and placed on the right hand exposed portion of the lower half of the joint. The energy propagated around the discontinuities, interrogated the fastener region, and returned to a receiving EMAT probe. An analog-based Fourier transform signal processor analyzed the experimental data. Horizontal shear waves were chosen in order to minimize loss in received ultrasonic energy due to mode conversion.

**Fig. 2** Approach: Detection of cracks under fasteners with EMATS

Figure 3a shows actual transducer positions on the mockup and the received and analyzed waveforms. The initial pulse centered at about 15 μs in Fig. 3b is the result of rf leakage from the

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transmitter to the receiver. In effect, the receiver acts as a radio antenna. This leakage has been found to be quite useful since it provides a measure of the true zero of time for measurement of acoustic delays. The signal centered near 60 μs is the reflection from the first step encountered in the wing lap joint. This merges with the reflection from the extreme plate edge, which is centered at approximately 60 μs. At 110 μs, the reflection from the end of the stiffening rib (member C) is just beginning.

Figure 3c shows the signal after the Hanning apodization function is used to gate out all but the flaw information. Figure 3d is the Fourier transform of the waveform shown in Fig. 3c.

Note that Fig. 3a shows two paths for an acoustic beam to travel: L1 and L2. The concept used to guide the analysis here is that uncracked holes yield a signal which is a sum of the signals from both paths L1 and L2. That sum will show, at some angle ϑ, an interference null in the Fourier spectrum. The size of the signal due to the path L2 will decrease as the crack or slot increases in length and therefore the depth of the interference null will correspondingly decrease. A theoretical model of the wing lap joint was constructed based on a single mode equivalent circuit. When combined with measurements of the geometry of the mock-up, the calculation of the structure transfer function for this model affirmed the presence of this interference null within the bandwidth of the EMAT transfer function (Fig. 4b). Figure 4c shows the results when an experiment with ϑ = 45° was performed on the wing mock-up. Indeed, there is an interference null, and its depth does decrease as the saw slot length increases. This allows a measurement of the length of the slot based on this null only.

The effort in Ref. 1 also included experiments on a real wing lap joint supplied by AFML into which a 0.100" saw slot was inserted. Both reflection and transmission data was collected and analyzed. Figure 5 shows the experimental setup and the results. With the bolt removed, the 0.100" saw slot definitely decreased the depth of the interference null. Furthermore, the data in transmission indicate that the acoustic energy transmitted through the lap joint was also affected by the presence of the saw slot. Hence, this 1978 work demonstrated the feasibility of using EMATs and horizontally polarized shear waves to detect fatigue cracks growing from fastener holes in the lower half of the joint. Saw slots originating in the fastener holes were successfully detected and the ultrasonic response quantified in terms of slot length. However, the primary limitations of that study included a high noise level, the lack of an opportunity to study

**PROCESSED WAVEFORMS**

![Fig. 3 Signal processing](image-url)
CRACK DESTROYS INTERFERENCE NULL BY ELIMINATING ONE WAVE PATH

(a)

THEORETICAL MODEL

(b)

DATA

(c)

Fig. 4 Data on mock-up sample

LABORATORY SYSTEM

REFLECTION DATA

NO. 19 BOLT REMOVED

NO. 19 BOLT REM 0.10 IN. CUT

TRANSMISSION DATA

NO HOLE

0.10 IN. CUT

Fig. 5 Data on real wing lap joint
real fatigue cracks in assembled wing joints, and
the lack of an opportunity to explore procedures
which were adaptable to changes in part geometry.

The new study, in progress now, has as its
objectives:

1. to achieve refinement of the system de­
veloped in Ref. 1 and to establish procedures
to distinguish flaw responses from sample­
geometry-determined changes in the ultra­
sonic response;

2. to prepare, and use in experiments, a mini­
imum of three wing joint specimens, two of
which would contain laboratory grown in­
terior layer corner fatigue cracks;

3. to develop a preliminary configuration de­
sign of an EMAT system suitable for field
inspection of wing lap joints for such

In order to achieve objective 1., the 250 kHz
EMATs were replaced with 200 kHz devices in order
to avoid all but the n=0 mode of acoustic propaga­
tion. The power supplies for the amplifying elec­
tronics were replaced. Finally and most important
of all, the analog signal processor was replaced
by a minicomputer-based data acquisition and
analysis system. The computer is used to acquire,
gate, and Fourier transform the time waveforms. A
few of the resulting advantages are:

1. Averaging of up to 250 signals can be used
to improve the signal-to-noise ratio.
2. Data can be collected once, and then the
location of the gate and the type of
apodization used can be varied for the same
data. This allows accurate comparison of
the effects of these different parameters.

3. The graphical display capabilities of the
computer can be employed for comparison
purposes.

Figure 6 shows the results of the first
experiments on the original mock-up, unassembled.
Here $\theta$ was varied over 5 angles from 40° to 50°.
Notice that the curves generated by the Fourier
transform for the hole with no slot are all very
similar in shape. However, the same angles for a
slotted hole yield curves very dissimilar in
shape. This kind of comparison could be easily
quantified with appropriate software in the
computer for a yes/no decision on whether a crack
was present. Furthermore, this technique may
prove to be less geometry dependent than the use
of data at just one $\theta$.

The current directions of the new study
include:

1. detailed mapping of the acoustic energy
field in the region of the fastener hole
with a special, small area, EMAT probe;
2. preparation of 2 fully assembled specimens
with laboratory-induced fatigue cracks;
3. investigations of the effects of the seal­
ant and other geometrical variables;
4. selection of the design parameters of a
fieldable instrument.

REFERENCE

1. "Detection of Cracks in the Inaccessible
Lower Half of Wing Lap Joints Using EMATs,"
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