# EFFECT OF CRACK PRESENCE ON IN-FLIGHT AIRFRAME NOISES IN A WING ATTACHMENT COMPONENT

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## ABSTRACT

The relation of the occurrence of airframe acoustic emissions to aircraft manoeuvre are reported for Avro CF-100 upper forward wing trunnions. Periods of excessive noise are found when the airframe load is changing during entry to and exit from sustained-G manoeuvres. During constant-G periods, the airframe noise level is reduced by a factor of more than one hundred. These quiet periods provide a suitable signal-to-noise level for the in-flight detection and monitoring of slow, stable crack growth in common airframe materials, even in a noisy load transfer component such as the wing trunnion studied here. Simultaneous in-flight acoustic emission measurements in symmetrically-located airframe components are also reported. The ratio of the number of recorded event counts in a cracked component to that in an uncracked component during the same flight is found to increase linearly with the crack face area for through crack lengths in the range 0-5 mm.

## INTRODUCTION

Acoustic emission provides a potential method for monitoring cracks within large volumes of a component using a passive sensing system. This aspect makes it attractive for in-flight monitoring of airframe components, particularly for bolt or fastener holes and components which require considerable disassembly before performing conventional NDT inspections. In-flight acoustic emission monitoring has already received considerable attention (Day, 1968; McBride and Hutchison, 1975; Pless and Bailey, 1975; Mizell and Lundy, 1976; Bailey, 1976; Bailey and Pless, 1976; McBride, 1978;

Pless, Bailey and Hamilton, 1978; Rodgers, 1979, 1982; Martin, 1980; Hutton et al, 1981; Scott, 1981 and Black, 1981).

We have previously reported (McBride & Maclachlan, 1982) that in-flight airframe noises such as the rubbing and fretting of bolted structures are likely to be considerably more frequent and of higher amplitude than signals due to slow stable crack growth in airframe materials. In the component studied here, it was found that many hundreds of airframe noise signals per flying hour are likely while Bailey and Pless (1981) suggest that in the order of only one signal per flying hour would be expected from slow, stable crack advance. We reported that not only are there many more airframe noises than crack growth signals but that the airframe noises can be larger than the crack growth signals by more than an order of magnitude. In this paper we investigate the relation of the occurrence of airframe noises to aircraft manoeuvres to determine the extent to which it is possible to separate out crack growth signals from airframe noises using an external parameter such as the output of a strain gauge, load cell or accelerometer. The particular component studied is the CF-100 upper forward wing trunnion. This component is expected to be very noisy due to its function as a load transfer point (Bailey and Pless, 1981).

This paper will present two main results. One involves the relation of airframe noises to some specific flight manoeuvres of the CF-100 aircraft. It will be shown that even in the noisy component studied here, there can be quiet periods during flight. These quiet periods are found during steady and sustained loading of the airframe. This will lead us to the conclusion that accelerometer or strain gauge outputs could be used to isolate noise-free regions during which slow, stable crack growth would be detectable, should it occur.

The other main result is the direct determination of crack size via crack face rubbing or fretting noises. This is accomplished using two sensors, each located symmetrically on the airframe. A new parameter (Nc/Nuc) is introduced. It is defined to be the ratio of the number of events detected above threshold in the cracked component, (Nc), to the number of events detected above the same threshold in the symmetrically-located, uncracked, "control" component, (Nuc), as measured on the same aircraft and during the same flight. A linear relationship is found between Nc/Nuc and crack face area. The interpretation of this result is based on the premise that symmetric locations in an airframe have sufficiently similar in-flight noise behaviour and that an additional noise contribution occurs in a cracked component due to crack face rubbing or fretting. We will show that for the case studied here, Nc/Nuc determined during a flight lasting no more than one hour can provide an estimate of crack size in the cracked component.

EXPERIMENTAL

The apparatus used to record the acoustic emission data is a dual-channel version of that previously described (McBride and Maclachlan, 1982). Here, however, the main body of the equipment was mounted on a removable rocket bay cover. The preamplifiers were attached inside the wings and bolted to wing access panels. The transducers were acoustically coupled to the port and starboard upper forward wing trunnions (Fig. 1).

Briefly, the operation of the data recording apparatus is as follows. When an acoustic emission signal larger in amplitude than a preselected threshold occurs at the transient recorder input, it is digitally recorded at 0.2 microseconds per point and outputted once at a rate of 20 microseconds per point. The 6 bit, 256 word transient recorder then rearms. Hence, each acoustic emission signal in the frequency range 0.1-1 MHz can be recorded on audio tape in the frequency range 0-10 kHz at a maximum rate of up to 190 signals per second.

Calibration of the system was carried out as described in our previous paper. Amplitude and frequency calibration of the electronics was produced in terms of a sine wave inserted at the preamplifier input. Overall system calibration was accomplished using the helium jet (McBride and Hutchison, 1976, 1978; Acquaviva et al, 1980). The sensors used were the D9202A transducers developed by the Dunegan/Endevco Corporation for in-flight acoustic emission use in the Lockheed C-5A study (Bailey, 1976). This transducer type is insensitive below a frequency of about 300 kHz and has a relatively flat response throughout the frequency range 300 kHz to 1 MHz as determined by the spark bar calibration method. Fig. 2 shows the

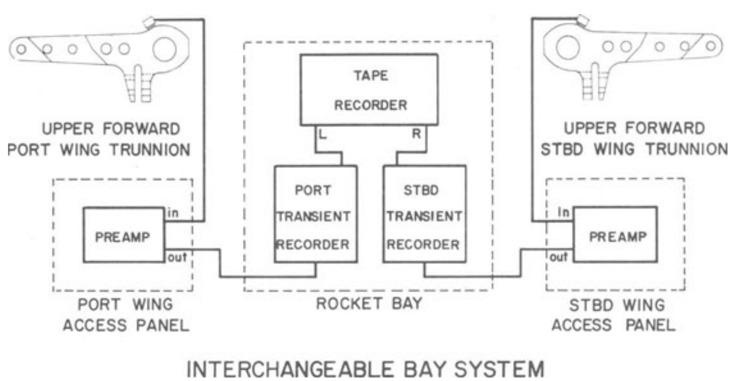


Fig. 1 The dual-channel data collection system used to record in-flight acoustic emission signals from two symmetric locations in the same aircraft (upper forward wing trunnions).

helium jet system calibration for this transducer attached to a CF-100 upper forward wing trunnion excited at the location of the crack by the helium jet. This calibration shows a substantial frequency dependence due to the effect of the component and the non-uniform but highly reproducible frequency-dependence of the helium jet (Acquaviva et al, 1980).

In-depth analysis was carried out using the microprocessor-based apparatus described elsewhere by Pollard (1981) and shown schematically in Fig. 3(a). The AE signal recorded on cassette tape was amplified, envelope-followed and captured in a transient recorder. Samples of the signal were taken by the microprocessor and this data recorded on disk along with the time of occurrence of the signal. The data disks were then examined using a data analysis system (Fig. 3(b)) which allowed a variety of graphs including peak amplitude versus time, event number versus time and peak amplitude distribution to be plotted on a high resolution graphics terminal and printed out on a line printer.

The rationale for the dual channel system was to increase the amount of data which could be recorded during each flight and to permit comparison of data on two trunnions during the same flight

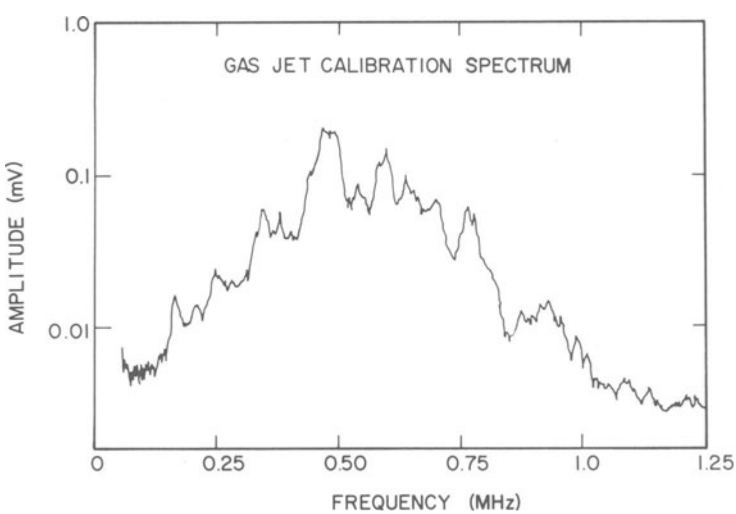


Fig. 2 The helium gas jet calibration for the D9202/trunnion/instrumentation system as measured in the laboratory.

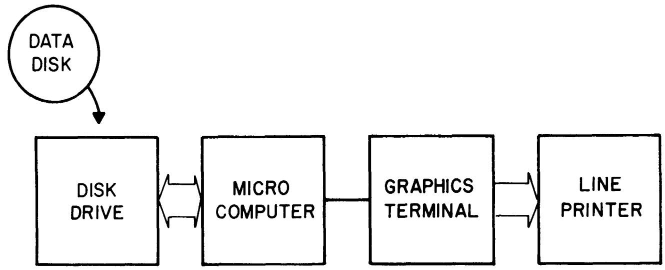


Fig. 3(a) Schematic diagram of the system used to measure the characteristic parameters of the signals on tape and store them on disk prior to analysis.

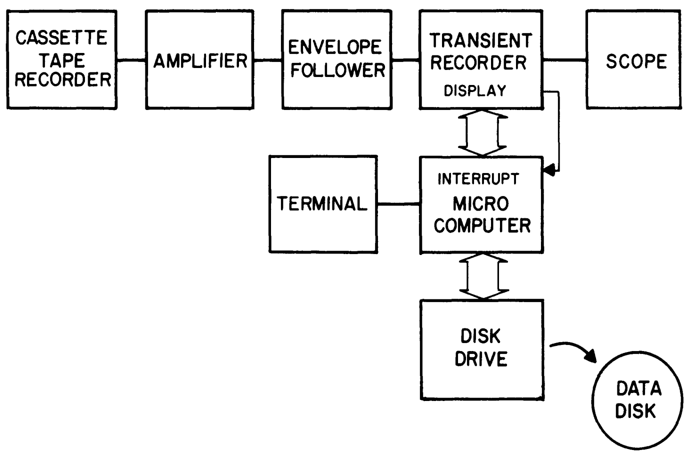


Fig. 3(b) Schematic diagram of the system used to analyze the data on disk. Hard copies of the plots produced on the graphics terminal were obtained using a line printer.

profile. With it we were able to record data from seven pairs of upper forward wing trunnions, each pair located in each of seven different aircraft. Fig. 4 shows the upper forward wing trunnion and illustrates the position of the indicator crack. Some of these trunnions had indicator through-crack lengths ranging up to 5 mm while others were uncracked. In all cases, only one trunnion in each pair was cracked in a given airframe. The data set thus provides a range of crack lengths in a variety of trunnions, each with an uncracked "control trunnion" in a symmetric location in the airframe.

Based on some preliminary flights, a specific flight pattern was selected to investigate the relation of the occurrence of airframe noises to flight manoeuvres. This test flight consisted of a climb to 4000 feet followed by a sequence of +2G, +3G and +4G right and left turns, each sustained for about 1 minute. The total

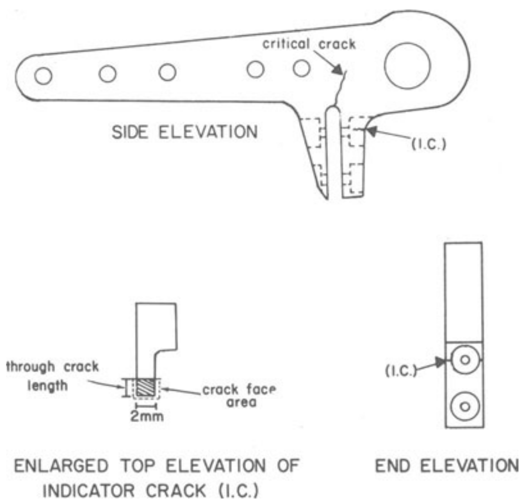


Fig. 4 Schematic diagram of the CF-100 upper forward wing trunnion. Also shown is the indicator crack under investigation here and the position of a potentially-critical crack which was not present in any of the airframes studied.

test flight time was about 1 hour. During each flight, data was recorded simultaneously from the symmetrically-positioned sensors on the port and starboard upper forward wing trunnions. The data thus obtained was analyzed to obtain cumulative events and signal peak amplitude as a function of time. A time record of the flight was provided by the navigator to allow us to relate the acoustic emission behaviour to specific in-flight manoeuvres.

## RESULTS AND DISCUSSION

The cumulative event-time behaviour produced by our test flight is shown in Figs. 5(a), (b) and (c) for three different aircraft. These data exhibit a characteristic step-like pattern during the periods of controlled-G manoeuvres regardless of the presence or absence of a crack. The similarity of the general form of the cumulative event-time behaviour of cracked and uncracked trunnions is further illustrated in the normalized cumulative plot shown in Fig. 6 for the data of Fig. 5(b). A difference does exist in the total number of signals from each of the two trunnions, the cracked trunnion always generating the larger number of signals. This result suggests that a procedure of comparing the actual number of acoustic emissions greater than a selected threshold from a cracked and from an uncracked component in symmetric locations in the same aircraft and during the same flight could take into account the effect of flight profile on the occurrence of airframe noise. Fig. 7 shows a plot of the ratio (Nc/Nuc) as a function of

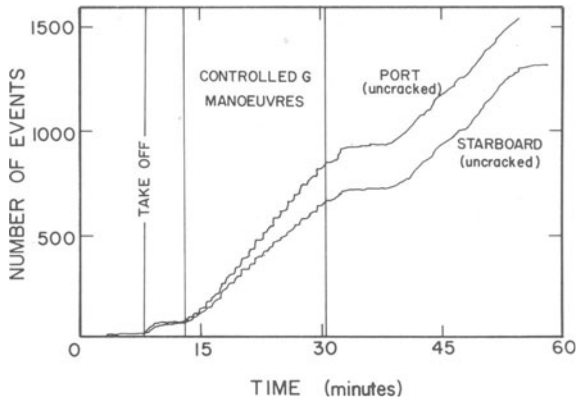


Fig. 5(a) The in-flight recorded acoustic emission cumulative event-time plot for two symmetrically-located uncracked upper forward wing trunnions on the same airframe during the same flight.

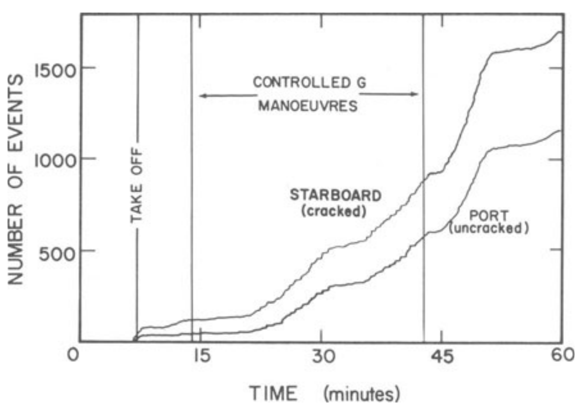


Fig. 5(b) The in-flight recorded acoustic emission cumulative event-time plot for two symmetrically-located upper forward wing trunnions on the same airframe during the same flight. The port trunnion is uncracked and the starboard trunnion contains a crack with a crack face area of 3.30 $mm^2$.

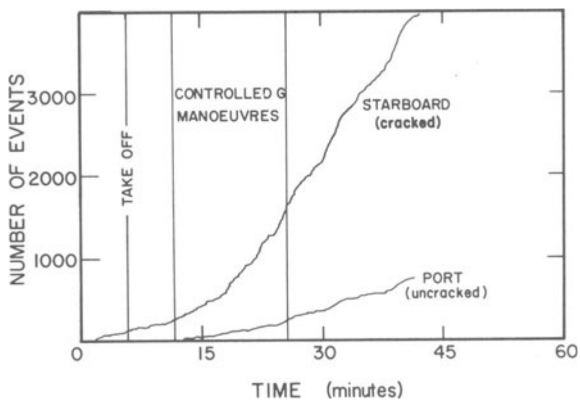


Fig. 5(c) The in-flight recorded acoustic emission cumulative event-time plot for two symmetrically-located upper forward wing trunnions on the same airframe during the same flight. The port trunnion is uncracked and the starboard trunnion contains a crack with a crack face area greater than 9 $mm^2$.

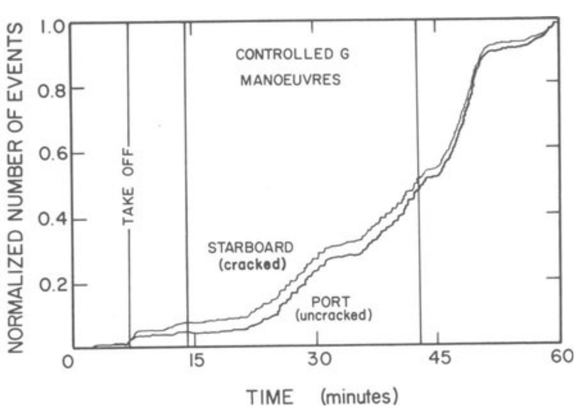


Fig. 6 The in-flight recorded normalized acoustic emission cumulative event-time plot for two upper forward wing trunnions (one cracked, one uncracked) on the same airframe during the same flight. This plot is derived from the data of Fig. 5(b).

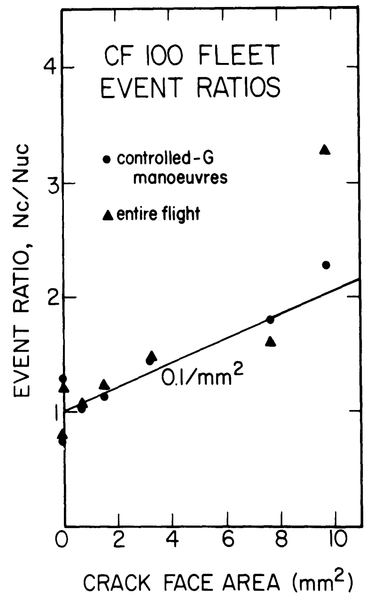


Fig. 7 The ratio of Nc/Nuc of the number of in-flight recorded acoustic emission signals from symmetrically-located cracked and uncracked upper forward wing trunnions (during the same flight) versus the crack face area in the cracked trunnion. Each data point is for a different airframe. The ● gives the ratio while the ▲ gives the ratio for the entire flight.

crack face area. Here Nc is the number of signals occurring on a cracked trunnion and Nuc is the number from the uncracked trunnion for one test flight. For this group of aircraft, six contained a crack in one trunnion but not on the other symmetrically-located trunnion. It is interesting to note the approximate linear relation between Nc/Nuc and crack face area for the range of 0-9 $mm^2$ of crack face area (Fig. 7). One aircraft which contained a trunnion with a crack greater than 9 $mm^2$ showed a considerable positive deviation from the linear behaviour observed for smaller cracks.

While there is not sufficient data to state categorically that the increase in ratio with crack size is due entirely to crack size, the available data strongly suggests that it is so. Hence, the possibility exists for estimating crack size on the basis of Nc/Nuc using data accumulated during a test flight lasting no more than one hour. This present result assumes, of course, that only one component of the selected pair of symmetric locations is cracked. More data would be required before addressing the problem of estimating crack size via Nc/Nuc for two symmetric locations both containing cracks. In addition, the validity of this scheme for in-flight crack size estimation will require extension to other components in other aircraft. These studies are currently underway. Nevertheless, it is widely known that crack face rubbing and fretting can produce acoustic emissions. The only questions that remain are whether these are sufficient to significantly increase the total trunnion noise and whether airframe noises are sufficiently symmetric within the airframe.

Figs. 8-10 illustrate in more detail the relation of the occurrence of airframe noise to flight manoeuvre. Fig. 8 shows the cumulative event-time plot obtained for a +2G, +3G, +4G flight sequence. For one flight, the acoustic emission amplitude recording range was 2 to 20 mV (Fig. 8(a) while for the other the recording range was lowered by 20 dB to 0.2 to 2 mV (Fig. 8(b)). The general behaviour exhibited is that when the airframe is being loaded (roll-in) or unloaded (roll-out), excessive noise is emitted by the airframe and detected at the trunnion locations by the acoustic emission sensors. During sustained-G manoeuvres the trunnion location becomes relatively quiet. This effect is most marked for the highest constant load. Indeed, for sustained 4G manoeuvres, hardly any noise signals are detected. Those which were detected, occurred almost simultaneously with a signal from the other symmetrically-located trunnion. We believe that the small number of rogue signals observed during sustained 4 C manoeuvres were produced by buffetting, and hence, were the result of instantaneous variations in G. Instrumented recording of G (or some other suitable parameter such as a strain gauge output) would be required to resolve this matter.

Fig. 9 shows a typical amplitude-time plot for acoustic emission events occurring during a 4G turn in one airframe. Each data point indicates the occurrence of an event with the peak amplitude shown. From Fig. 9, it can be seen that signals occur over a wide amplitude range during roll-in and roll-out, while the trunnion is virtually silent throughout the entire recorded amplitude range during the constant 4 G region. This result is typical of both cracked and uncracked trunnions. Thus, even when a crack is present in an airframe, the noises emitted are minimal for constant high-G manoeuvres. This observation was extended to lower amplitudes in two airframes. There it was discovered that the quietening persisted to a trigger level which was a factor of 10 below that used

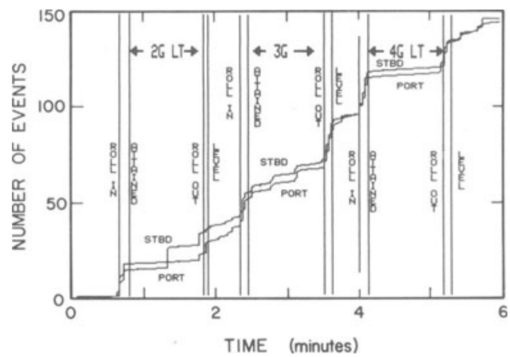


Fig. 8(a) Number of in-flight recorded acoustic emission events vs. time during a series of left turns (acoustic emission range 2 to 20 mV). The starboard trunnion is uncracked while the port trunnion contains a crack with a crack face area of 1.50 $mm^2$.

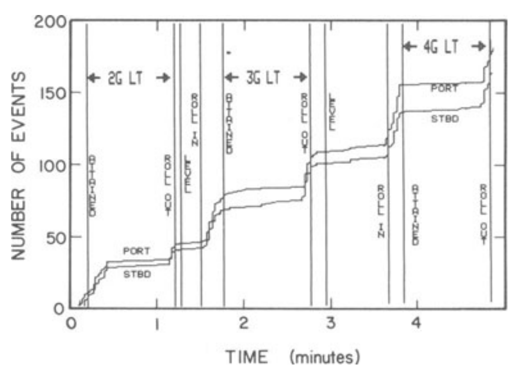


Fig. 8(b) Number of in-flight acoustic emission events vs. time during a series of left turns (amplitude range 0.2 to 2.0 mV). The starboard trunnion is uncracked while the port trunnion contains a crack with crack face area of 1.50 $mm^2$.

to obtain the result in Fig. 9. We conclude that by confining the recording of data to constant high-G conditions, the signal-to-noise ratio for in-flight detection of crack growth is improved by a factor of more than 100 compared to that obtained for an arbitrary flight profile.

We believe that the improvement in signal-to-noise ratio which can be achieved under constant high loading conditions is sufficient to permit the in-flight detection of crack growth in common airframe alloys. This deduction invokes the data presented in a previous paper (McBride and Maclachlan, 1982) which reports typical CF-100 upper forward wing trunnion noises and examples of acoustic emission signals which result from slow crack growth. There it is seen that at a frequency of 500 kHz, the in-flight noises have amplitudes no greater than about 50 times the amplitude of the helium jet calibration signal. In 7075-T6 Al, crack growth acoustic emission events extended up to about the helium jet amplitude during slow, stable crack growth and near specimen failure could be at least 100 times larger. In the trunnion material, the acoustic emission signals reached about 0.3 times the helium jet calibration signal for slow crack growth and 20 times larger near specimen failure. Hence, the decrease by a factor of greater than 100 in airframe noise level during constant high-G manoeuvres is sufficient to make the in-flight detection of crack advance feasible even in the event of slow, stable crack advance. This result is particularly important since it suggests that acoustic emission can be used, under special data-gating conditions, to detect crack advance at a rate of less than one micron per load cycle even in a noisy load transfer joint such as the wing trunnion. This could provide an in-flight acoustic emission system capable of detecting crack advance with a resolution similar to that normally attributed to static NDT measurements.

The results described above are characteristic of the behaviour of 13 trunnions with through-crack lengths ranging up to about 4 mm. The one exception was a trunnion containing a through-crack of length 5 mm. Fig. 10 shows that this trunnion exhibits a reduction in the signal amplitudes during a constant 4G manoeuvre. This reduction in amplitude is not sufficient to permit the detection of crack advance. No detailed explanation of this exceptional behaviour is possible from the available information. However, the unusually long crack in this component terminates at the inside surface of the bolt hole and this could produce the acoustic activity observed under nominally constant loading conditions. Should this explanation be correct, it heralds the emergence of the symmetric measuring technique suggested here as a possible solution to the important problem of the detection of cracks inside bolt or fastener holes.

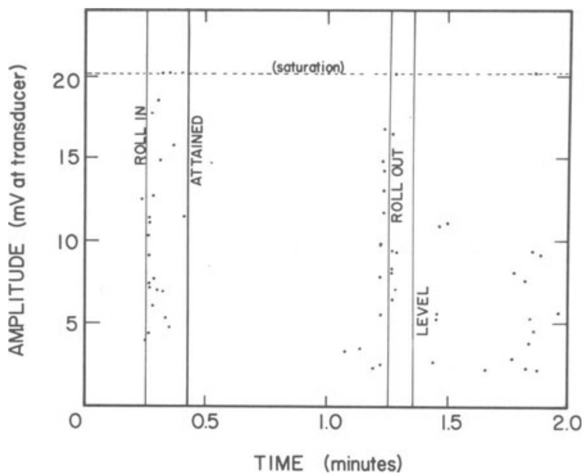


Fig. 9 Amplitude vs. time plot for in-flight recorded acoustic emission events occurring during a 4G turn in an uncracked upper forward wing trunnion.

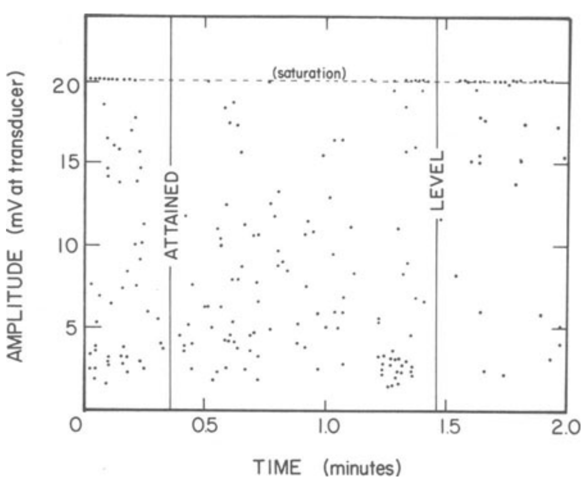


Fig. 10 Amplitude vs. time plot for acoustic emission events occurring during a 4G turn from an upper forward wing trunnion with a crack face area greater than 9 $mm^2$.

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