APPLICATION OF ACOUSTIC EMISSION FOR AVIATION INDUSTRY - PROBLEMS AND APPROACHES

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Abstract□Descriptions have been given on the application of acoustic emission (AE) in aviation industry. Special attention has been paid to the condition monitoring of aircraft structures and some special problems to be solved. Roles of AE in the evaluation of calendar damage of aircraft are presented and some achievements in this field by using AE technique are also presented in the paper.

Key Words: Non-destructive testing(NDT) , Acoustic emission□AE□, Damage Tolerance, Aviation Industry

1 Introduction: Acoustic emission (AE) testing is an important branch of non-destructive testing(NDT). The study of AE for its application in aviation industry needs first to understand the role of NDT technique in the same industrial sectors, and hence to understand the role played by AE. It is known that NDT is an essential factor for the damage tolerance design and plays important role in guaranteeing air safety and life extension of aircraft. In Fig.1 is shown such a role played by NDT[1]. It can be seen that through NDT the life of an aircraft is extended much longer than that originally designed without using NDT.

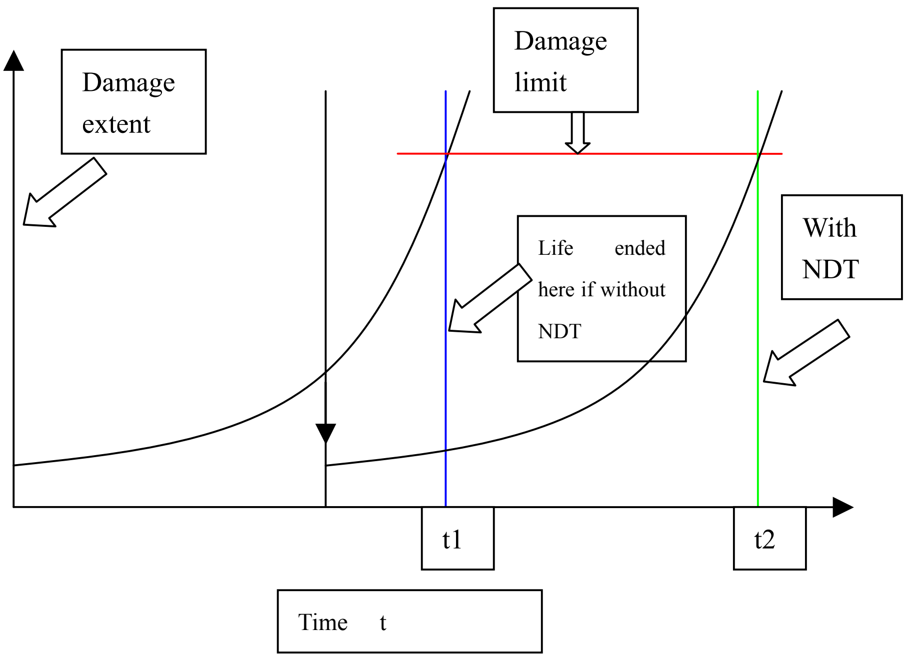

Fig.1 Aircraft life was prolonged with the help of NDT technique□from t1 to t2□

NDT can play its role in two aspects: (1□to enhance detecting capability and hence to decrease the initial size of defect, equivalent to the increase of useful life; □2□to detect and rebuild crack-like defect during each life-cycle, enabling the extended crack size being returned to the initial one and equivalent also to extending the useful life. The AE technique can play role in the first aspect because it can detect defect in much earlier time compared with other conventional NDT means. As for the second aspect, AE technique can play major role in those inaccessible region or regions being difficult to access if using other conventional NDT means.

2 Detecting and Monitoring of Fatigue Crack Initiation and Growth: The condition monitoring and life prediction of aircraft main structures have received great concern because it has significance in maintaining high flight safety. The early detection of fatigue crack initiation and growth is in general beyond the capability of various conventional NDT means, AE however is more suitable to undertake the task. The main advantage of AE is in two folds: the first one is that AE is a dynamic method capable of continuously and in-situ monitoring without disturbing the object under supervision. The second is that AE is a passive means without the need of injecting signals from outside to the object, thus causing less disturbance to the object. The main disadvantage of AE, on the other hand, is the noise, or background noise interferences, and the other one is the difficulty in realizing quantitative evaluation of the defect.

As early as in the 70's of 20th century, Lockheed Corpration carried studies on monitoring of fatigue crack growth in wings of a C-5 cargo plane during fatigue test. From Dec. 1987 to Sept. 1990, The Wright Laboratory and McDonnell-Douglas had a jointed program in monitoring fatigue cracks in F-15 fighter during full-scale wing fatigue test, aiming at the application of AE in some critical area of aircraft for in-flight monitorings[2]. In the early 90's of last century, Digital Wave□DW□of USA proposed to use modal acoustic emission (MAE) in the monitoring of fatigue cracks in aircraft structures. According to MAE, the growth of fatigue crack shall produce mainly the lowest symmetric plate wave, i.e. the extensional waves, having higher frequency contents[3]. The author of present paper carried the same studies in this field at nearly the same time. During the full-scale fatigue test of an aircraft, the author used AE to monitor the crack initiation and growth in some critical areas, such as wing spar bolt holes, bolt of bulkhead, and he was successful in the prediction of some critical cracks formed during the fatigue test[4]. In Fig.2 is shown the testing site and equipment used by the author and his colleagues.

Fig.2 AE test during full-size body fatigue test of a trainer aircraft

Some special AE data processing methods were taken during the fatigue test. It was suggested to use trend analysis first to observe any abnormalities in the collected AE data during fatigue test. Changes in the value of AE parameter were accompanied by the changes of aircraft structure, and that any AE parameter would show no abrupt increment during the test, as long as the structure underwent no sudden changes. It was therefore proposed to use the trend of one or several AE parameters with time during the course of fatigue test as an indicator of structural conditions. In a period of time, any parameters, such as hit, events, count, energy, rise time and duration etc would certainly undergo large fluctuations, if being properly processed however, they could still show a distinctive trend to vary. One was then able to relate this trend with the structural condition.

A full-size fatigue test can last more than one calendar year and 10,000 flight hour experimental time. In order to avoid short time fluctuation effect, proposition was postulated to use "statistically averaged" parameter instead of the real time one. For every 50-100 flight hour test, one divided the time as several periods with each one involving long enough duration say 18-20 minutes. After obtaining AE data in each duration and having a sequence of data, one then was in the position to average these data and to name it as the one in a specific flight hour, and so on.

In order to identify fatigue crack initiation and growth more effectively, multi-parameter and correlation analysis needed to be used. The word "correlation" here refers to the statistic AE parameters between different measuring channels. It is therefore different from the commonly accepted conceptions. Although noises are non-correlated each other, their statistic parameters such as mean value or standard variance, are strongly correlated, provided signals are steady random noise or averaged over a long enough time period. In theory, when the received signals were produced by the same source, different channels would show stronger correlation than signals being from different sources. If there is no crack initiation or crack growth, sensors of each group will receive noise only. Over a period, when a sensor near to crack source receives crack-related signals, other sensors in the same group may receive relatively weak signal due to the high attenuation of sound wave in the path. The correlation coefficient between channels of the group shall be declined. It is therefore possible to identify crack-related signal by observing correlation changes.

Multi-parameter identification is a process similar to thinking activity of human brain and is used to decrease diagnostic errors caused by insufficient data. The author had decided to use AE hits, events, energy, rise time, duration, amplitude distribution of density type - f(A),and cumulative AE amplitude distribution - F(A) to form an 8-dimentional vector for an integrated identification of received signals. Some success was achieved.

A typical and successful case of application of the above-mentioned method was the prediction of cracks of No.2 bolt hole in the left wing spar at 3600 and 4800 flight hour, respectively, during the fatigue test. In Fig.3 is shown the AE hit against flight hours, in which sharp increases or fluctuations of AE hits at 3600 and 4800 were obvious. The amplitude distribution analysis also showed the large amplitude predominance at the two instances(figures no shown here). This prediction was proved by disintegrated testing(magnetic particle- silicon rubber forming).

It was possible to use AE to detect the incorrectly mounting condition, for example, at 5600 flight hour of the test, AE signal near NO.2 left spar wing bolt hole showed an unusual increment(Fig.4). At that time, the bolt hole had just been re-finished(at 5200 flight hour). The possibility of occurrence of new fatigue crack was unlikely, and a report of possible incorrectly assembling state was issued to the chief engineer who was in charge of the fatigue test. The test was temporarily stopped and the bolt condition was checked. A loose bolt was found and tightened, and afterwards, AE signals were back to normal, also see Fig.4.

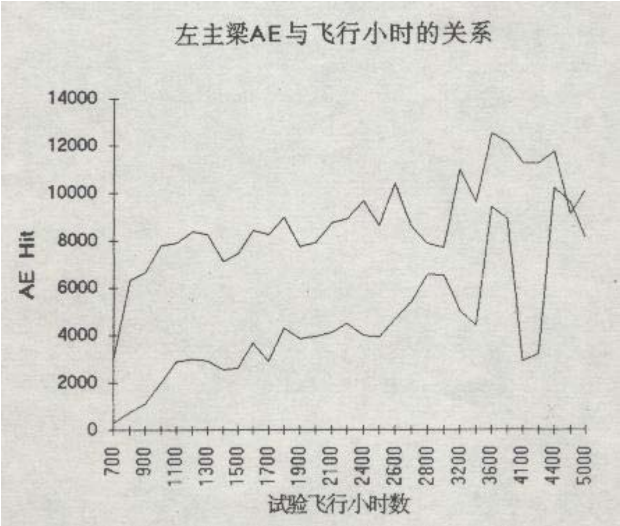

Fig.3 AE near NO.2 spar wing hole against flight hours

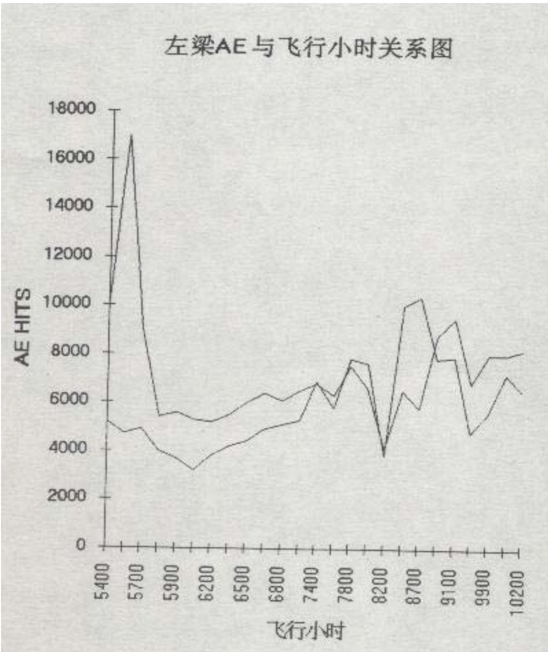

Fig.4 Forecasting the unfitness of bolt mounting by using AE

3 Application of MAE in Aviation Industry: In essence, MAE is a method based on waveform analysis and on the classical Lamb wave theory under the assumption of the plate thickness being much smaller than that of wave length. If, as in most cases, the thickness of the specimen is much less than the wavelength of sound wave, then the predominant modes excited in the plate shall be the lowest two modes, i.e. the lowest symmetric mode S_0(extensional wave) and lowest asymmetric mode A_0(flexural wave), and that whichever is dominant depends on the way how the force is applied. The phase velocities of the two modes are as follows[3]:

$$C_e = [E/\rho(1-\nu^2)]^{1/2} \qquad (1)$$

$$C_f = [E/3\rho(1-\nu^2)]^{1/4}(\omega d)^{1/2} \qquad (2)$$

Where, E is Young’s modulus, ν Poisson ratio, ω angular frequency, ρ mass density and d half thickness of the plate. It can be seen that the flexural wave shows frequency dispersion effect and its phase velocity increases with the increase of frequency. Through analyzing the possible AE source, especially the force model related with AE, one can predict the main wave modes, and hence to identify useful AE signals from background noise based on the understanding of the source mechanism. For example, there are different sources to produce AE while a composite is under stress. Things become easier to differentiate AE signals produced by different source, like fiber breakage, delamination□matrix cracking and disbonding etc. The fiber breakage normally takes place inside the plane and is to produce an in-plane force, and therefore it is normally to produce extensional wave predominant AE signals. On the other hand, the delaminations normally take place between different fiber layers and produce out-of-plane force, and therefore are to produce flexural wave predominant AE signals. The fatigue crack has the same characteristics with the fiber crack from the point of view of plate wave theory because it occurs inside the plane. According to our studies, fatigue crack-produced AE signals are characteristic of the followings[5.6]:

□1□ typical extensional wave with high frequecy being extended over 1000 kHz and without dispersion effect□

□2□ There is a distinct time difference for AE wave to reach the two transducers. Noises have no such features.

□3□ AE occurs at high level of loading stress, showing the existence of Kaiser effect.

In Fig.5 is shown a practical measuring system for fatigue crack, where HF is a band pass filter with higher central frequency, whereas LF is a band pass filter with lower central frequency. The trigger signal is to guarantee the same AE event being processed by two or more channels of the system.

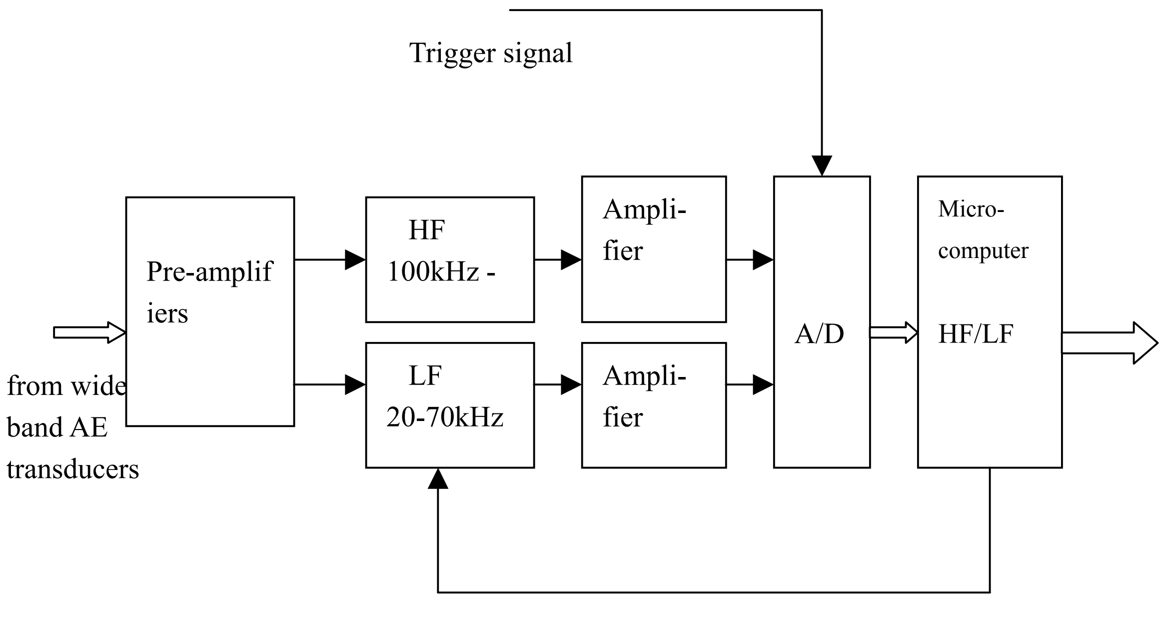

Fig.5 schematic block diagram of the filtering circuit

4 Role of AE in Evaluating Calendar Damages: There are two different aspects of life for aircrafts, one is the fatigue life and the other is calendar life. Method for determining fatigue life is available and has become mature, on the other hand however, means for determining and evaluating the calendar life of an aircraft is still mostly based on experience and is lack of systematic and scientific foundation. In order to study the calendar life, the calendar damage, which is mainly caused by corrosion, must be first investigated. Hence, monitoring and investigation of corrosion damages of aircraft aluminum structures, such as bulkhead, fastener holes, wing skin and fuel-tank baffle etc are of significance. The work can supply scientific basis for determining calendar life.

Through proposing AE mechanism and with the help of corrosion and accelerating corrosion test on aluminum structures from aircraft, the relationship between AE and calendar damages were obtained. Corrosion damages can be divided into three stages. The first stage is the initially rapid developing stage in which corrosion damage develops very rapidly, and correspondingly, corrosion AE is to increase rapidly. The second one is the stable stage, in which corrosion rate is to decrease and corrosion develops slowly. Correspondingly, corrosion AE in this stage is to increase slowly. It is recommended that early prevention measures against corrosion can shorten first stage and prolong the second stage, and hence to prolong the life of the structure under discussion. The third stage is that corrosion again increases rapidly and the same for corrosion produced AE signal, which means that the calendar life of the material is about to end. The above-mentioned findings and conclusions can help us to realize the importance of early detection of corrosion.

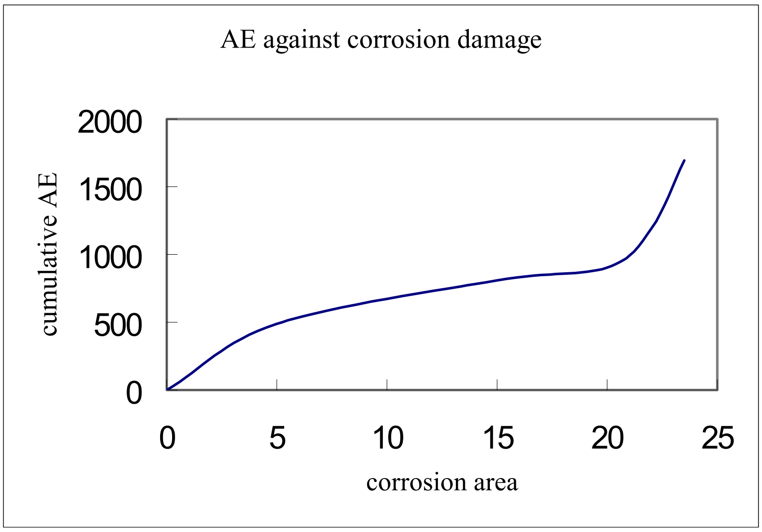

Fig.6 AE against corrosion damages

5 **Problems and Challenges:** The real challenge of application of AE in aviation industy is in the in-flight monitoring of aircraft structure. Much effort has been spent on this respect, less success has, however, been achieved so far. Main challenge comes still from the backgroud noise. Such as mechanical noise (vibration-induced noise), noise by air flow, EM interference, trnsient noise. The fretting of fasteners and the rubbing noise between bolt and bolt hole are other sources of strong noises. Studies have shown that the rubbing noise between bolt and bolt hole is almost to have the same characteristics with the fatigue-related AE, which

makes it difficult to defferentiate the two. The other difficulty in developing the in-flight monitoring system lies in the limitation of space available for mounting the AE facility. The requirement for the facility to meet the environmental(temperature, humidity, vibration and shock etc) conditions forms another challenge. All these make the task a real challenge for researchers working in this field.

There are comparatively less codes and standards of AE testing in aviation area as compared with other NDT means. The large scale application of AE in wide area of aviation still need time, and it is reasonable to image that there is a long way to go before the AE can become a more popular NDT means in aviation industry.

6 Conclusions: AE technique is of significance in safeguarding air safety. Due to the lack of quatitative appraisal of defect and of the standard and code, its application in aviation is limited to very narrow areas. Traditional AE parameter analysis supplies a rapid, simple and cost-effective means of inspecting and monitoring structure deffect and failure for aviation industry, it however, due to the lack of understanding of AE source mechanism or the failing to grasping the physical essence of AE source, is not able to meet practical demands in many cases. Modal acoustic emission is close to the source mechanism, it however needs more advanced instrument and higher cost, and moreover, it needs large memory space for the instrument and is time consuming. A real time AE instrument for health monitoring of aircraft structure, if is not impossible, is difficult to realize to a great extent. With the help of the combination of modal AE and parameter analysis, AE still can play important role in new aviation material studies, in health monitoring of aircraft structures. The design of calendar damage monitor and detector is attracting more attention at present and it should become a key area to develop.

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