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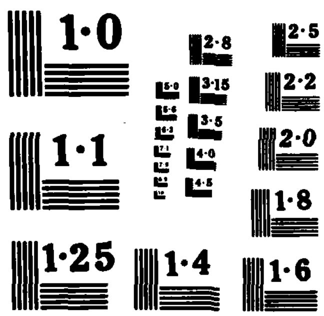
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REPORT ON AN OVE

by

DR C.M. SC

SUMMARY

A report is given on an overse the U.S.A., U.K. and Switzerland for a p departing Australia on 7 July 1984. Th visit were to:

[i] attend and present a paper at the Quantitative NDE held at the Univ San Diego;

[ii] undertake updating visits to labo U.K. to review current research i (NDE) and to determine useful dir research;

[iii] coordinate progress (in both the the DSTO contract with Battelle P to monitor fatigue crack growth i acoustic emission (AE).

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1. INTRODUCTION

An overseas visit was made to the U.S.A., U.K. and Switzerland for a period of thirty-two days departing from Australia on 7 July 1984. The principal purposes of the visit were to:

(i) attend and present a paper at the Review of Progress in Quantitative NDE held at the University of California, San Diego;

(ii) undertake updating visits to laboratories in the U.S.A. and U.K. to review current research in nondestructive evaluation (NDE) and to determine useful directions for future NDE research;

(iii) coordinate progress (in both the U.S.A. and Switzerland) on the DSTO contract with Battelle Pacific Northwest Laboratories to monitor fatigue crack growth in a Mirage aircraft using acoustic emission (AE).

2. REVIEW OF PROGRESS IN QUANTITATIVE NDE

The Review of Progress in Quantitative NDE is a highly prestigious conference attended by many of the outstanding NDE researchers worldwide. It provides a valuable forum for detailed interdisciplinary interchange and the opportunity for a rapid overview of current NDE research. The 1984 Review was sponsored by the Centre for Advanced Nondestructive Evaluation (Ames Laboratory, Iowa State University), U.S. Air Force Wright Aeronautical Laboratories, U.S. Naval Sea Systems Command and the Office of Basic Energy Sciences of the U.S. Department of Energy. The conference was held from 8-13 July 1984 and comprised 183 papers, presented in parallel sessions. A research paper was presented at the conference entitled "An analysis of acoustic emission detected during fatigue testing of an aircraft" by C.M. Scala, R.A. Coyle and S.J. Bowles; the paper will appear in the conference proceedings.

2.1 Acoustic Emission

Presently there is a R and D program in Structure of Materials Group at Aeronautical Research Laboratories (ARL) to develop the AE technique as an airworthiness indicator for RAAF aircraft. Hence, the AE session at the Review of Progress in Quantitative NDE was of particular interest.

Papers on "Defect characterization and monitoring by acoustic emission" by C.B. Scruby (AERE Harwell) and on "Acoustic emission characterization of the effect of temperature and overaging on inclusion fracture in 7075 aluminium alloys" by S.L. McBride and J.L. Harvey (Royal Military College, Canada) were of considerable relevance, given the proposed collaboration on AE in aluminium alloys between ARL, AERE Harwell and Royal Military College, Canada under TTCP PTP-5 (see 2.3). Dr McBride reported on AE monitoring of crack growth at temperatures in the range -40 to 120 degrees Celsius in 7075-T6 aluminium alloy and an overaged alloy. These results were interpreted in terms of the influence of local plasticity and misfit stress on the fracture of Mg/Si inclusions during crack growth. Interpretation of the results obtained at low temperatures is continuing. The study should ultimately provide a better understanding of the AE behaviour of commercial aluminium alloys for the wide range of temperature conditions encountered by aircraft in service. Dr Scruby presented results of an experimental study of fatigue crack growth in an aluminium alloy, in which a multichannel recording system was used to obtain the coordinates of each emission event to an accuracy of ± 1 mm.

Using this system, Dr Scruby was able to discriminate between the events (believed to be inclusion fracture) occurring close to the crack tip and events due to gripping noise. AE from crack face rubbing was also detected under some loading conditions. Emissions attributed to crack face rubbing were detected at various positions on the load cycle, including close to the maximum load. Further studies on crack face rubbing are planned (see 2.3).

Dr W. Sachse (Cornell University) also described the successful use of a multichannel AE system which was applied to indentation studies. His paper was entitled "Studies of AE from point and extended sources". Indentation techniques are finding increasing application for the generation of simulated and controlled AE signals in brittle materials (such as glass), in commercial aluminium alloys and in metal-matrix composites.

An interesting and controversial presentation on the theory of AE was made by Prof. J.D. Achenbach (Northwestern University) in a paper entitled "Amplification of acoustic emission from a microcrack due to the presence of a macrocrack". Achenbach's work is presently restricted to the case of AE during nucleation of a microcrack in the plane of a macrocrack. The theory predicts that the emission resulting from the macrocrack and microcrack would be much larger than would emanate from a solitary nucleating microcrack. Consideration will have to be given to extending the theory to incorporate the more realistic out-of-plane case but there are already implications for quantitative AE measurements, particularly in the case of a large macrocrack.

Various codes presently allow the use of AE for certification of composite aerial lift devices, pressure vessels, etc. However, it was interesting to note in the presentation by G.F. Hawkins (The Aerospace Corp.), and in discussions with other conference delegates, that a need for further basic research related to the codes has been identified. Hawkins' paper entitled "Studies of acoustic emissions when an applied stress is reduced" reported on a relationship between strength degradation in carbon-carbon composites and AE from crack face rubbing during unloading. The other presentations in the two AE sessions illustrated the diversity of possible applications of the AE technique. Topics included monitoring of martensitic phase transformations, AE studies during electron beam melting and rapid solidification of aluminium alloys, and on-line reactor monitoring.

2.2 In-flight AE Monitoring

Attendance at the 1984 Review of Progress in Quantitative NDE provided the opportunity for discussions with various delegates involved in the recent upsurge in research on AE monitoring of aircraft. Dr F. Chang (General Dynamics) discussed a proposal by General Dynamics to install AE sensors in the F-16 aircraft. W. Jeffrey Rowe (Lockheed Georgia Co.) briefly described AE studies at Lockheed. Dr Stuart McBride (Royal Military College, Canada) commented on the complexity of the ARL Mirage AE program and discussed the simpler in-flight AE applications in which he was involved. Randall R. Sands (Naval Air Development Centre (NADC)) also requested further details on AE monitoring of Mirage. In discussions he outlined the current status of the DARPA/NADC AE program in which ARL participated under project arrangement 79/704. The final report of the program has been submitted to NADC for approval, with DARPA approving a minor extension for further analysis of AE calibration data by Rockwell. The next proposed stage in the program is for NADC to seek U.S. Naval funding for AE instrumentation of a P-3 aircraft.

2.3 Collaboration Between ARL, AERE Harwell and Royal Military College, Canada

A collaboration under TTCP PTP-5 had been discussed in correspondence between Dr Scala (ARL), Dr Scruby (AERE Harwell) and Dr McBride (Royal Military College, Canada), on their complementary research programs on AE in aluminium alloys. Attendance at the 1984 Review by Dr Scala, Dr Scruby and Dr McBride provided the opportunity for direct discussions on the proposed collaboration. The following joint activities were recommended: (i) ARL would provide specimens of 2024-T351 aluminium alloy to Royal Military College to allow further quantification of the relationship between inclusion size distribution and AE during fatigue crack growth in aluminium alloys; (ii) AERE Harwell and Royal Military College would test laboratory alloys containing inclusions of selected size (these alloys would be produced by RAE); (iii) ARL and AERE Harwell would consult on their studies of AE from crack face rubbing. The consultation with Harwell would be valuable given the considerable relevance of the fretting problem to the AE monitoring of Mirage project (see 4). In particular, some years ago ARL identified the need for multi-channel AE equipment in order to distinguish between AE from fretting and from other damage-related sources - such equipment is still not available at ARL but a suitable system has recently been commissioned for AE monitoring at Harwell.

2.4 Other NDE Fields

The 1984 Review of Progress in Quantitative NDE comprised papers in a wide range of NDE fields besides the AE papers already discussed. The keynote address was delivered by Dr G. Glover (General Electric Medical Systems Group) on the subject "Magnetic resonance imaging in medicine: Quantitative tissue characterization". Dr Glover provided a description of NMR imaging techniques, summarized results obtained in medical studies and discussed potential applications of NMR imaging to NDE problems. Other sessions in the conference were on NDE of composite materials, eddy current fundamentals, inversion and imaging, NDE of ferromagnetic materials, fatigue cracks and interfacial stress, ultrasonic inversion techniques and applications, acoustoelasticity and stress, materials processing and properties, transducers, optical and thermal techniques, and error analyses.

As in previous years, the largest number of papers (approximately half those presented) were on the ultrasonic technique with various theoretical papers on inverse scattering, papers discussing the size of defects (e.g. surface cracks, sub-surface cracks, porosity, elliptical cracks, cavities, rough surfaces), attenuation and velocity measurements in various materials, signal processing (including colour display) and reliability of ultrasonic inspection. There appeared to be no outstanding developments in the ultrasonics area, although the extensive effort being directed to ultrasonic residual stress measurement was noteworthy. Some researchers (for example, K. Salama (University of Houston)) were studying the combined influences of temperature and stress on the ultrasonic velocity in metals. Several authors discussed the use of birefringence measurements. In the useful paper "Evaluation of the absolute acoustoelastic stress measurement technique" by S.S. Lee, J.F. Smith and R.B. Thompson (Ames Laboratory), the effects of misorientation so that waves did not propagate along pure mode directions (e.g. texture axes) were considered.

Papers presented in the eddy current field dealt principally with applications or comparison of experiments with previously published theories. B.A. Auld (Stanford University), who has been an outstanding researcher in NDE for many years, presented several papers on eddy currents at the conference, including a paper entitled "Improved probe-flaw interaction modelling, inversion processing, and surface roughness clutter" by B.A. Auld, M. Riaziat and S. Jeffries. In this paper, he presented encouraging results showing good agreement between experimental results on a slot and theoretical results presented at the 1983 Review; amplitude measurements differed from theory by 30% and phase by 10 to 20%.

One feature evident in much of the work presented at the 1984 Review was the rapidly increasing role of lasers in NDE research. Lasers are now commonly used in AE and ultrasonic applications for the reproducible non-contact generation of various wave types. (The ARL proposal to use lasers in these areas has yet to be funded). Laser interferometry is also being successfully used in various laboratories for the detection of elastic waves. A different application for lasers was suggested in the paper by R. Mehrabian (University of California) entitled "Needs for process control in advanced materials processing". Mehrabian envisaged the use of lasers in the automation of ceramic and metal powder processing, fabrication of fibre-reinforced expoxy composites, surface modification by various techniques and other applications. The use of lasers was also discussed in a diversity of papers involving methods for the thermal detection of cracks, debonding, etc.

3. LABORATORY VISITS

One day visits were undertaken to six research laboratories to discuss recent advances in NDE. The establishments visited, the researchers with whom discussions were held, and the major topics discussed are summarised in Table 1. Some topics for which the state-of-the-art has been summarized in part 2 of this report (e.g. AE in aluminium alloys, laser generation of elastic waves) will not be dealt with further. However, further details on other topics of particular interest will now be given.

3.1 NDE of Advanced Aircraft Materials

In recent years, an exciting range of new materials have emerged for use in aircraft applications or are currently under development. These new materials pose challenging problems to the NDE researcher.

(i) Fibre-reinforced epoxy composites

Considerable research is in progress in various laboratories on NDE of fibre-reinforced epoxy composites. Concentration is being placed on the further development of ultrasonic techniques which appear suitable for the detection of the majority of defects occurring in these materials. Several laboratories are continuing to examine the relationships between attenuation, measured velocity of ultrasound and materials properties. An approach which is used in various laboratories to monitor damage in epoxy-composite panels/components is to undertake comparative ultrasonic scans at set inspection intervals, resulting in the need for large-scale computer storage of data. A different approach is being examined at NRL whereby only defect-related information would be stored.

The use of thermography has long been suggested for use in NDE of materials such as fibre-reinforced composites. However, there have been various practical problems in the implementation of the technique. Some of these problems have recently been overcome at AERE Harwell where transient thermography has been successfully applied to epoxy-composites and to bond testing. Harwell use a recently developed commercial television camera sensitive to thermal infrared radiation and operating at normal video rates. It is claimed that the use of the camera provides a particularly convenient method for observation of surface temperature distributions with a good (20 ms) time resolution. The camera therefore appears well-suited to methods of transient thermography in which the source of heat is in the form of a short (<20 ms) pulse applied over a wide area of the surface.

(ii) Metal-matrix composites - Collaboration under TTCP PTP-5

A minor research program on the mechanical properties of B/Al fibre-reinforced composites has recently commenced in Materials Division, ARL - it is planned to use AE as a laboratory technique in this study. In addition, a collaborative program on NDE of metal-matrix composites has been proposed between Naval Surface Weapons Centre (NSWC) and ARL under TTCP PTP-5. Thus, an objective in understanding several of the laboratory visits was to overview research on NDE of metal-matrix composites and to have direct discussions with NSWC on the proposed collaboration in this area.

Considerable research has been undertaken on ultrasonic testing of B/Al composites but only limited AE studies have been carried out. However, current research at NBS suggests that AE will be useful in monitoring impact damage in these materials. Studies at NSWC have concentrated on SiC/Al and graphite/Al fibre-reforced composites. Materials development is on-going and a wide variety of NDE techniques (e.g. ultrasonic C-scan, eddy current and dye penetrant testing) are being combined to assess the presence of defects/damage. The detection of porosity is particularly important. Although NSWC has wide experience in many NDE techniques, they do not have the expertise of ARL in AE monitoring. Hence, the two laboratories plan to collaborate on testing of SiC/Al composites at a future date (NSWC has already supplied some material to ARL for this purpose).

(iii) Powder metallurgy alloys

NDE of powder metallurgy alloys and ceramics usually requires the detection of very small defects. Research on this problem at University College London has yielded promising results. A new series of ultrasonics techniques based on mode-conversion phenomena which occur at such defects has been developed. This work has recently been extended to an immersion testing scheme based on leaky Rayleigh wave generation.

(iv) Materials subjected to surface modification

Directed high energy sources (lasers and electron beams) are currently being evaluated for rapid surface melting and resolidification of a range of engineering alloys. Ion implantation is also being used to modify surface layers. The purpose of such procedures is to produce materials with surfaces with enhanced wear and corrosion resistance. NBS has pioneered research on NDE of such materials during processing. Some promising results have been obtained using both ultrasonic and acoustic emission testing but further research is required. Studies are also being carried out to evaluate final surface condition using eddy current methods.

3.2 Transducers

There were few new design concepts in ultrasonics or AE transducers. The NBS conical sensor (for measurement of out-of-plane surface displacement) and the pinducer have been used for some time at ARL for AE measurements and are now being more widely used overseas for ultrasonics and AE applications (including AE source location). NBS has a new transducer under development for measurement of in-plane surface displacement. The transducer features a trapezoidal shaped pzt active element with a large matched pzt backing. The combined use of the in-plane and out-of-plane transducers should ultimately allow more complete characterization of AE sources.

NRL has not pursued the development of focussed annular arrays comprising pzt active elements but is developing arrays with polyvinyl fluoride elements. The advantage of such an array is ease of coupling but sensitivity is a problem. Electromagnetic acoustic transducers (EMATs) also have low sensitivity but are finding increasing applications in ultrasonic residual stress measurements - the non-contact EMATs allow more accurate measurement of ultrasonic wave velocities than conventional transducers.

3.3 Residual Stress Measurements

The accurate determination of the residual stress present in materials/components is important in many applications. X-ray methods are widely used overseas (and at ARL) for this purpose, but problems can arise due to the lack of portability of X-ray equipment and to the time necessary for inspection of large components. Thus, considerable effort has been devoted to the development of complementary techniques, particularly ultrasonics (see 2.4). Ultrasonic testing offers the promise of rapid inspection of large components, where an average, rather than a localized, stress is all that is required. Several of the laboratories visited were carrying out research in this area. Problems still exist in dealing with texture effects in other than 'slightly' anisotropic material unless a suitable unstressed sample of the material is available for testing or the type of texture is known. (AERE Harwell have successfully used longitudinal wave time delay in addition to the time delays of the two shear waves used in the birefringence technique to measure residual stress in steels with known texture). A standard for absolute stress measurement is also needed - NBS are investigating the use of a ring-plug shrink-fit specimen for this purpose.

3.4 Advances In Data Acquisition and Processing

The increasing availability of high-speed, low-cost transient recorders is having an impact on both ultrasonic and AE testing. In ultrasonic testing, systems have conventionally displayed rectified, filtered signals. However, the increasing use of transient recorders is placing a greater emphasis on waveform recording and more sophisticated data processing. In the AE area, the availability of such recorders is enabling more meaningful characterization of AE sources using multichannel systems (see also 2.1).

An example of an advanced approach to data processing may be found in the work of General Research Corporation, who have extensive experience in pattern recognition analysis. They use features such as signal risetime, power spectra, skewness, kurtosis and standard deviation in their ultrasonic and eddy current data analysis. They are also increasingly using calibration data in the development of adaptive learning networks.

The deconvolution of AE waveforms to yield propagation-independent source information is an important problem in AE data analysis. Hence, NBS, NRL and AERE Harwell have all undertaken/funded considerable research in this area in recent years. The case of a transducer at the epicentre in a half-space or plate now seems to be well understood, but research on a more general solution for an arbitrary transducer location in a plate has highlighted the complexity of the problem.

4. AE MONITORING OF A MIRAGE AIRCRAFT

This section contains detailed technical information, related to AE monitoring of a Mirage aircraft during full-scale fatigue testing, which is intended for use mainly by analysts of data from the Mirage test and by the Australian project manager for the AE testing.

4.1 Background Information

In 1980, ARL contracted Battelle Pacific Northwest Laboratories (BNW) to develop the AE technique to detect fatigue crack growth in fastener and rivet holes in the main wing-spar of a Mirage aircraft undergoing fatigue testing at Eidgenossisches Flugzeugwerk (F+W), Emmen, Switzerland. Analysis of the test data was undertaken by S.J. Bowles, R.A. Coyle and C.M. Scala (ARL) and related laboratory studies were also carried out. ARL made a number of recommendations to Battelle as a result of these studies - important modifications to the AE measurement system were suggested and a series of specialist experiments devised. A visit to BNW was arranged in order to have in-depth discussions on the proposed recommendations and to coordinate progress on the DSTO contract. A visit to F+W enabled direct collaboration between ARL and BNW personnel, which was essential for the specialist experiments. Further details on the need for these experiments, on the terminology used in this section and on the systems used for data acquisition in the Mirage test, may be found in Refs. 1-3.

4.2 Discussions at BNW

4.2.1 Mirage Testing

The two-day visit to BNW commenced with a detailed presentation entitled "AE during fatigue testing of a Mirage aircraft", in which AE research at ARL related to the Mirage test was described. In the presentation, emphasis was placed on the analysis of AE waveforms (recorded on magnetic tape) and peak height/peak time data (recorded on cassette) from the full-scale fatigue test. The research program which is being carried out at ARL to establish a basis for this analysis was also outlined. (The program includes the determination of possible AE sources in the spar material (a commercial aluminium alloy), selection of suitable sensors, and development of a capability for distinguishing between AE sources associated with fatigue crack growth and extraneous sources encountered in a full-scale ground test or in flight). Consideration was also given to the effectiveness of the AE sensor array used to spatially locate AE waveforms in the fatigue test and to an evaluation of parameters (e.g. risetime, duration and autocorrelation lags) extracted from the waveforms for distinguishing between AE from fatigue crack growth and from extraneous sources in the Mirage test.

The presentation was attended not only by BNW staff directly involved in the Mirage project (P.H. Hutton, BNW project manager for Mirage, Dr D.K. Lemon and J.R. Scorpik) but by various other staff involved in the DARPA and EPRI funded AE programs at BNW. Among comments on the presentation were those made by Dr D. Daley on the usefulness of some of the advanced analysis concepts used. He was particularly interested in the incorporation of calibration data in the analysis.

Discussions were then held with P.H. Hutton, D.K. Lemon and J.R. Scorpik on the modifications required by ARL to the AE equipment at F+W. Amendments made by BNW were as follows:

(i) BNW had modified the equipment to ensure that clipped signals were not recorded on magnetic tape.

(ii) A problem with load data on the magnetic tapes had been corrected. Battelle had also arranged for data from four strain gauges (Nos. 8, 353, 370 and 467) to be recorded on magnetic tape.

(iii) At BNW it had not been possible to duplicate a problem at F+W in recording time data on the cassettes.

(iv) Header information recorded on magnetic tape had been checked and found to be correctly recorded.

(v) The facility to record only data above a certain strain level had been incorporated in the equipment.

(vi) Amplifiers had been obtained to allow the measurement of both cassette and magnetic tape data at variable gain.

The modifications made met the ARL requirements, although there was clearly a need to check the AE monitoring system (including amendments) on its return to F+W. The additional modification made by BNW to increase the number of strain gauges monitored from one to four was undertaken to assess load variations on the spar. However, it is unclear whether any of the numerous unidirectional gauges on the spar accurately reflects the load history within a given fastener hole.

The next stage in the coordination of the Mirage project was to review the proposed plan for testing at F+W. In order to assist in the interpretation of presently available data from the Mirage test (and to ensure the collection of future data in a suitable form), the following test plan was agreed upon:

(a) Tests would be conducted at F+W during which AE waveforms would be obtained at various gains. Vital information about the high level (almost certainly extraneous) signals and the low level (damage-related signals) could then be obtained.

(b) The gains of the cassette and magnetic tape data collection systems would be temporarily brought closer together in order to allow more direct comparison of data from the two systems.

(c) The existing BNW sensor used for waveform acquisition would be replaced by a wider band sensor (a pinducer) supplied by Dr Scala and the measurements in (a) and (b) repeated.

(d) A second wide-band sensor would be coupled to the spar near the sensor used for cassette measurements. This wide-band sensor would be connected to the waveform system and the measurements in (b) repeated. (Rather than undertaking experiment (d), ARL had orginally proposed that the waveform sensor be temporarily re-routed to the cassette system to allow simultaneous recording of signals from the same sensor on cassette and magnetic tape. However, BNW believed that the zone location system would not function correctly under these conditions).

(e) A series of calibration experiments would be undertaken at various locations on the spar using pencil lead fracture as a simulated AE source.

The final topic discussed at BNW on the Mirage project was a consideration of methods of coupling the pinducer to the wing-spar and of matching the sensor to the Battelle pre-amplifier. BNW agreed to check possible attachment methods and suggested that they modify the inductive tuning in their pre-amplifier for use with the pinducer.

4.2.2 Other NDE Expertise

BNW have considerable expertise in the development of advanced equipment not only for AE but also for ultrasonic and eddy current testing. Hence, this visit to BNW also provided the opportunity for brief discussions on some of the ultrasonic and eddy current projects at BNW and on AE projects other than the Mirage test. BNW has pioneered the field application of synthetic aperture focussing techniques (SAFT). In a joint project, Dr S. Crawford and Dr S. Doctor have developed algorithms suitable for various SAFT applications, e.g. the detection of thermal cracking and the examination of material with very large grain size. Colour graphics are used in data presentation, a common feature in many modern ultrasonic systems. Another interesting project at BNW involves the development of automated equipment for the inspection of nuclear reactor fuel element rods. Dr G. Spanner described this equipment which features eddy current probes operating at 50 kHz and 5 MHz to check rod diameter and an ultrasonic probe operating at 5 MHz to check the bonding between rod and fuel element. In the AE field, BNW have been funded for many years to develop the technique for continuous surveillance of nuclear reactor vessels. In an initial phase of the project, technology was developed to identify AE from crack growth in reactor materials and to utilize the AE information to estimate flaw severity. The second phase in the project was concerned with evaluating and finalizing the technology by testing an intermediate scale test vessel. Presently AE is being monitored during a hot functional test of an operating reactor. Promising results have been obtained using a waveguide AE sensor to monitor the reactor under operating coolant flow conditions.

4.3 Visit to F+W

The principal objective in visiting F+W from 31-7-84 to 3-8-84 was to collaborate with BNW staff on the AE monitoring of the Mirage full-scale fatigue test. Hence, four days were spent at F+W with Dr D.K. Lemon and J.R. Scorpik (BNW) undertaking the AE experiments outlined in 4.2.1. During this time, the opportunity was taken to gain more familiarity with the Mirage fatigue test rig and with the AE monitoring equipment. This opportunity was particularly valuable because none of the ARL analysts of AE data from the Mirage test had previously had any first-hand experience with the test.

Discussions with Dr H. Boesch (F+W) on the fatigue test were informative. He discussed in detail various aspects of the loading sequences used in the test (including the variable rate at which a given sequence could be applied), and described some of the problems associated with monitoring defects in several areas of the Mirage aircraft presently under test at F+W. He also discussed some limitations in the usefulness of the strain gauge measurements being made.

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An examination of the results in Table 6 shows that the zone location system was more accurate for pencil lead events occurring towards the mid-point of sensors A and B (Fig. 1). Pencil lead fracture events on the wing skin areas covering the AE zones on the spar (Fig. 1) were validated by the sensor array, but events occurring at other locations on the wing-skins (e.g. near the fuel tank drain plug) were rejected.

Further evaluation of the calibration data and a detailed analysis of the results of the experiments outlined in Tables 2-5 will be undertaken as soon as the magnetic tapes, cassette tapes, load charts and other data from the collaborative AE monitoring of Mirage are received at ARL.

The final task undertaken at F+W was the training of new F+W staff in the operation of the cassette data acquisition system for future AE monitoring of the test.

5. SUMMARY

Attendance at the Review of Progress in Quantitative NDE and updating visits to several research laboratories in the U.S.A. and U.K. provided valuable opportunities for detailed interdisciplinary interchange with many world leaders in the NDE field. Discussions on in-flight AE monitoring and NDE of advanced aircraft materials were particularly worthwhile. Among the emerging trends in NDE were an increasing use of lasers for a variety of applications and a growing reliance on both advanced instrumentation and sophisticated data analysis.

A highlight of this overseas visit was the first opportunity for discussions on two proposed collaborative projects under TTCP PTP-5: (i) a collaboration between AERE Harwell, Royal Military College Kingston and ARL on their complementary research on AE in aluminium alloys; (ii) a collaboration between NSWC and ARL on NDE of metal-matrix composite materials.

Visits were made to BNW in U.S.A. and F+W in Switzerland to assess progress in the DSTO contract with BNW to monitor fatigue crack growth in a Mirage aircraft using AE. Modifications requested by ARL to the AE monitoring equipment had been carried out at BNW. A proposed program for future testing was reviewed at BNW and then successfully carried out at F+W despite the limited time available for the specialist experiments. Analysis of the testing data will be undertaken on its arrival at ARL.

Two formal presentations were made during this visit. A paper entitled "An analysis of acoustic emission during fatigue testing of an aircraft" by C.M. Scala, R.A. Coyle and S.J. Bowles was presented at the Review of Progress in Quantitative NDE and a talk entitled "AE during fatigue testing of a Mirage aircraft" was presented at BNW.

REFERENCES

1. L.G. Scott, "Monitoring crack growth during fatigue testing of aircraft by means of acoustic emission", Proc. 4th Pan Pacific Conf. on Nondestructive Testing, Paper AE4, Sydney (1983).

2. S.J. Bowles, "The use of acoustic emission for detection of fatigue crack growth", Proc. 4th Pan Pacific Conf. on Nondestructive Testing, Paper AE3, Sydney (1984).

3. C.M. Scala, R.A. Coyle and S.J. Bowles, "An analysis of acoustic emission detected during fatigue testing of an aircraft", Review of Progress in Quantitative NDE, Vol. 4, Plenum (in press, 1984).

TABLE 1 - Laboratory Visits

	Establishment	Researcher	Topic Discussed
1.	Naval Research Lab, Washington, D.C.	Dr H. Chaskelis (Group Leader, NDE Section)	Overview of NDE research at NRL on ultrasonic transducer modelling, ultrasonic testing of epoxy-composites, ultrasonic measurement of residual stress, AE deconvolution.
		Dr N. Batra	Ultrasonic detection of small defects, ultrasonic testing of fibreglass.
		Dr K. Simmonds	Automated ultrasonic inspection of composites.
		Dr R. Mignogna	Ultrasonic measurement of residual stress.
2. (a)	Ultrasonic Standards Group, National Bureau of Standards, Washington, D.C.	Dr D. Eitzen (Group Leader)	Overview of Ultrasonic Standards Group's research on AE and ultrasonic transducer calibration (including medical applications, AE deconvolution, visualization of elastic waves in transparent material).
		Dr N. Hsu	AE source location; simulated AE sources.
		Dr G. Blessing	Standards for ultrasonic residual stress measurement; ultrasonic testing of metal-matrix composites.
		Dr T. Proctor	Development of transducers to measure in- and out-of-plane surface displacement.
		Dr F. Breckenridge	Transducer calibration.

TABLE 1 (cont.)

(b)	Metallurgy Div. National Bureau of Standards	Dr H. Wadley (Group Leader)	Overview of activities on AE and ultrasonic testing of rapidly solidified layers, eddy current testing, AE in metal-matrix composites.
		Dr R. Clough/ Dr J. Simmons	AE deconvolution procedures, AE during electron beam melting; laser generation of elastic waves.
3.	Naval Surface Weapons Centre, White Oak Lab, MD	Dr C. Anderson (Group Leader, Materials Evaluation Branch)	Summary of NDI research on SiC/Al and graphite/Al composites involving ultrasonic testing, neutron radiography, eddy current testing dye penetrant examination.
		Dr J. Liu	Wave propagation in SiC/Al composite including temperature dependence; collaboration under TTCP PTP-5; transducer development.
		S. Vernon	Eddy current testing of composites.
		Dr P. Gammell	Ultrasonic signal processing.
4.	General Research Corp., McLean, VA	Dr M. Whalen/ Dr G. Germana	Recent advances in adaptive learning hardware and software.
5.	Dept of Electronic & Electrical Engineering, University College London	Dr L. Bond	Ultrasonic elastic wave model studies; mode conversion ultrasonic testing, transducers, laser elastic wave generation and detection.
		P. French	Eddy current testing
		M. Nikoonahad	Acoustic microscopy

TABLE 1 (cont.)

6.	AERE Harwell	Dr C. Scruby	AE in aluminium alloys (see 2.3); laser generation and detection of ultrasonic waves; transducers.
		Dr A. Hughes (Head, Materials Physics and Metallurgy Div.)	Overview of NDE in Materials Physics and Metallurgy Division.
		Dr W. Reynolds	Thermographic testing of composites.
		Dr W. Allen	Ultrasonic residual stress measurement.

TABLE 2 - Preliminary Testing by BNW

Date	Cassette No.	Waveform Tape No.	Cassette Gain (dB)*	Waveform Gain (dB)+	Waveform Sensor		Load Sequence				Comments
					Location	Type	T(s)	Period	Flight No.	Current Load	
30-7-84	301A	301	86	60	W	BNW	-				No load sequence data
30-7-84	301B	302	86	42	W	BNW	-				No load sequence data

* BNW cassette sensor at location A

\+ Biomation range 5V unless specified otherwise.

TABLE 3 - Tests (a) and (b) in 4.2.1

Date	Cassette No.	Waveform Tape No.	Cassette Gain (dB)*	Waveform Gain (dB)+	Waveform Sensor		Load Sequence				Comments
					Location	Type	T(s)	Period	Flight No.	Current Load	
31-7-84	302A	303	86	42	W	BNW	0	83	119	0(?)	
31-7-84	302B	304	86	42	W	BNW	0	83	131	38	
31-7-84	303A	305	86	42	W	BNW	0	83	147	139	Started with 20dB on waveform - nothing recorded; 7.5g at waveform no. 200.
31-7-84	303B	306	60#	62	W	BNW	0	83	157	1	At waveform 42, cassette threshold changed to 0.1V for subsequent testing at 60 dB cassette gain.
1-8-84	304A	307	60#	62	W	BNW	0	84	1	1	

+ Biomation range 5V unless specified otherwise.
# 60 dB used with sensors A and B.
* BNW cassette sensor at location A.

TABLE 4 - Test (c) in 4.2.1

Date	Cassette No.	Waveform Tape No.	Cassette Gain (dB)*	Waveform Gain (dB)+	Waveform Sensor		Load Sequence				Comments
					Location	Type	T(s)	Period	Flight No.	Current Load	
1-8-84	304A	308	60#	62	W'	Pin2	7970	84	22	1	
2-8-84	304A	309	60#	62	W'	Pin2	14515	84	40	1	
2-8-84	304B	310	86	42	W'	Pin2	0	84	65	65	
2-8-84	304B	311	86	42	W'	Pin2		84	75	47	
2-8-84	305B	314	86	62	W'	Pin2	0	84	122	106	
2-8-84	305B	315	86	62**			2880	84	132	1	**Biomation range 0.5V; hence effective gain 82dB
					W'	Pin2					Waveforms 1 - 119
					W	BNW					Waveforms 120 - 258
					W'	Pin2					Waveforms 259 -

TABLE 4 - (cont.)

3-8-84	306B	317	86	62**	W'	Pin2	0	84	140	1	**Biomation range 0.5V; hence effective gain 82dB
3-8-84	306B	318	86	62**	W'	Pin2	4500	84	147	14	**Biomation range 0.5V; hence effective gain 82dB
					W'	Pin2	5895	84	149	1	Waveforms 1-175; recording stopped for flight 148 Waveforms 176-461 (on flight 150, 7.5g at waveform no.418)
3-8-84	306B	319	86	20	W'	Pin2	-7270	84	-155		Waveforms 1-13 in 1728s; Biomation 2V for waveforms 3-5.

+ Biomation range 5V unless specified otherwise
# 60 dB used with both sensors A and B
* BNW cassette sensor at location A

TABLE 5 - Test (d) in 4.2.1

Date	Cassette No.	Waveform Tape No.	Cassette Gain (dB)*	Waveform Gain(dB)+	Waveform Sensor		Load Sequence				Comments
					Location	Type	T(s)	Period	Flight No.	Current Load	
2-8-84	305A	312	60	62	A'	Pin3	0	84	86	45	
2-8-84	305A	313	60	62	A'	Pin3	~7860	84	108	17	Test stopped for NDI at waveform 115, restarted at T=106311 on flight 111, current load 2.

+ Biomation range 5V unless specified otherwise.

* BNW cassette sensor at location A.

TABLE 6 - Test (e) in 4.2.1

Date 3-8-1984, Cassette No. 306A (Cassette Gain 86 dB), Waveform tape No. 316

Waveform No.		Waveform Sensor		Waveform Gain (dB)	Input Range (V)	Break Location Notes	Zone No.
Start	Finish	Type	Location				
1	5	PIN2	W'	42	5	Midway between bolts 2 and 3, as close as possible to centre of spar.	8,9,9,9,9
6	10	PIN3	A'	42	5	" " " "	9,9,9,9,9
11	15	BNW	W	42	5	" " " "	9,9,9,9,9
16	20	BNW	A	42	10	" " " "	
21	25	PIN2	W'	42	1	Rear slan rivet (on forward side)	7,7,7,7,7
26	30	PIN2	W'	42	1	Forward slan rivet (on forward side)	7,7,9,7,9
31	35	PIN2	W'	42	1	Forward slan rivet (on rear side)	9,9,9,9,7
36	40	PIN2	W'	42	1	Rear slan rivet (on rear side)	9,9,9,9,9
41	45	PIN2	W'	62	1	Bolt hole 1 (on forward side)	5,5,5,5,5
46	50	PIN2	W'	62	1	Bolt hole 1 (on rear side)	5,5,5,5,5
51	55	PIN2	W'	62	1	Bolt hole 2 (on forward side)	7,5,7,7,7,

TABLE 6 - (cont.)

56	60	PIN2	W'	62	1	Bolt hole 2 (on rear side)	7,5,7,7,7
61	65	PIN2	W'	62	1	Bolt hole 3 (on forward side)	9,9,9,9,9
66	70	PIN2	W'	62	1	Bolt hole 3 (on rear side)	7,9,7,9,9
71	71	PIN2	W'	62	1	Bolt hole 4 (on forward side)	9,
72	75	PIN2	W'	62	2	Bolt hole 4 (on forward side)	11,11,11,11
76	80	PIN2	W'	62	2	Bolt hole 4 (on rear side)	9,11,11,9,9
81	85	PIN2	W'	62	2	Bolt hole 5 (on forward side)	13,13,13,13,13
86	90	PIN2	W'	62	2	Bolt hole 5 (on rear side)	15,13,13,13,13
91	95	PIN2	W'	62	2	Bolt hole 6 (on forward side)	15,15,15,15,15
96	100	PIN2	W'	62	2	Bolt hole 6 (on rear side)	15,15,15,15,15
101	105	PIN2	W'	62	1	Bolt hole 7 (on front side)	19,17,19,17,17
106	110	PIN2	W'	62	1	Bolt hole 7 (on rear side)	17,17,17,17,17
111	112	PIN2	W'	62	1	Bolt hole 8 (in centre, Philips head recess)	17,17
113	115	PIN2	W'	62	2	" " " "	17,15,17
116	120	PIN2	W'	62	2	Bolt hole 9 (in centre, Philips head recess)	17,19,19,17,19

TABLE 6 - (cont.)

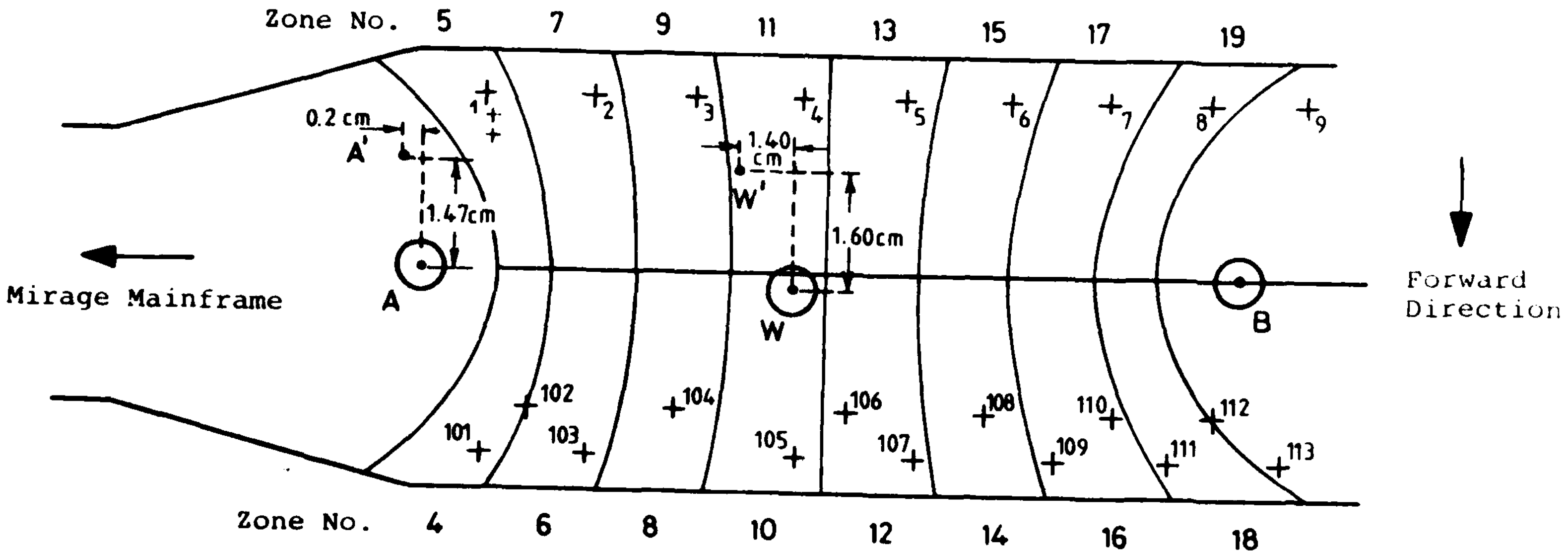
121	125	PIN2	W'	62	2	Rivet hole 101 (rear edge)	6,4,4,4,4
126	130	PIN2	W'	62	5	Rivet hole 102 (rear)	4,6,6,6,6
131	135	PIN2	W'	62	2	Rivet hole 103 (rear)	6,6,6,6,6
136	140	PIN2	W'	62	5	Rivet hole 104 (front)	8,8,8,8,8
141	145	PIN2	W'	62	5	Rivet hole 104 (rear)	8,8,8,8,8
146	150	PIN2	W'	62	5	Rivet hole 105 (front)	10,10,10,10,10
151	155	PIN2	W'	62	5	Rivet hole 105 (rear)	10,10,10,10,10
156	160	PIN2	W'	62	5	Rivet hole 106 (front)	10,10,10,10,10
161	165	PIN2	W'	62	2	Rivet hole 106 (rear)	10,10,10,10,10
166	170	PIN2	W'	62	2	Rivet hole 107 (forward)	12,12,12,12,12
171	175	PIN2	W'	62	2	Rivet hole 107 (rear)	12,12,12,12,12
176	176	PIN2	W'	62	5	Rivet hole 108 (forward)	12, (incorrect)
177	180	PIN2	W'	62	5	Rivet hole 108 (forward)	14,12,12,12
181	185	PIN2	W'	62	2	Rivet holc 109 (forward)	14,14,14,14,14
186	190	PIN2	W'	62	5	Rivet hole 110 (forward)	14,14,14,14,14

TABLE 6 - (cont.)

191	195	PIN2	W'	62	5	Rivet hole 111 (forward)	14,14,14,16,14

TABLE 6 - (cont.)

261	265	PIN3	A'	62	2	Rivet 104 (forward)	8,8,8,8,8
266	270	PIN3	A'	62	2	Rivet 106 (forward)	10,10,10,10,10
271	275	PIN3	A'	62	2	Rivet 108 (forward)	12,12,14,14,12
276	280	PIN3	A'	62	5	Rivet 110 (forward)	14,14,14,14,14
281	285	PIN3	A'	62	2	Rivet 112 (forward)	16,16,16,16,16
		PIN2	W'			Near drain plug	Not validated
286	290	PIN2	W'	62	2	On skin, mid-way between bolt holes 1 and 2	7,7,7,7,7
291	295	PIN2	W'	62	2	On skin, mid-way between bolt holes 3 and 4	9,9,9,9,9
296	300	PIN2	W'	62	1	On skin, mid-way between bolt holes 7 and 8	19,19,19,17,17
301	305	PIN2	W'	62	2	On skin, just forward of rivet 102 (on support skin)	6,6,4,6,4
306	310	PIN2	W'	62	5	On skin, rear of rivet 105	10,10,10,10,10
311	315	PIN2	W'	62	5	On skin, rear of rivet 109	14,14,14,14,14



+ Location of fastener/rivet holes

• Location of sensors A, A', W, W' and B on lower surface of bottom flange of Mirage spar

FIG. 1.

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16. Abstract

A report is given on an overseas visit by Dr. C. M. Scala to the U.S.A., U.K. and Switzerland for a period of thirty-two days departing Australia on 7 July 1984. The principal purposes of the visit were to:

(i) attend and present a paper at the Review of Progress in Quantitative NDE held at the University of California, San Diego;

(ii) undertake updating visits to laboratories in the U.S.A and U.K. to review current research in nondestructive evaluation (NDE) and to determine

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16. Abstract (Contd)

useful directions for future NDE research;

(iii) coordinate progress (in both the U.S.A. and Switzerland) on the DSTO contract with Battelle Pacific Northwest Laboratories to monitor fatigue crack growth in a Mirage aircraft using acoustic emission (AE).

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